THE EUROPE WE WANT

17th European Roundtable on Sustainable Consumption and Production
Research | Experience | Development
14.-16. October 2014 | Portorož | Slovenia

ERSCP 2014
14-16 October 2014
Portorož, Slovenia

Conference Proceedings

www.erscp2014.eu

17th European Roundtable on Sustainable Consumption and Production
14.-16. October 2014, Portorož, Slovenia

Conference Proceedings

Proceedings Editor:
- Rebeka Kovačič Lukman
- Peter Glavič
- Damijan Koletnik
- Peter Virtič
- Boris Horvat

Organizers: Nigrad d.d., Maribor
University of Primorska, Institute Andrej Marušič, Koper

Published by: Nigrad d.d., Maribor, 2014
Copies: 200- only for participants

CIP - Katažni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

502.131.1(082)(0.034.2)

EUROPEAN Roundtable on Sustainable Consumption and Production (17 ; 2014 ; Portorož)
Conference proceedings [Elektronski vir] / 17th European Roundtable on Sustainable Consumption and Production - ERSCP 2014, 14-16 October 2014, Portorož, Slovenia ; [organizers Nigred Maribor, University of Primorska, Institute Andrej Marušič Koper ; editors Rebeka Kovačič Lukman ... et al.]. - El. knjiga. - Maribor : Nigrad, 2014

Način dostopa (URL): http://www.erscp.eu

ISBN 978-961-93738-1-1 (pdf)
1. Kovačič Lukman, Rebeka 2. Nigred (Maribor) 3. Univerza na Primorskem. Inštitut Andrej Marušič (Koper)
276357632

INTERNATIONAL SCIENTIFIC COMMITTEE

Nigrad d.d, a utility company

Address	Zagrebška cesta 30 2000 Maribor, Slovenia
Phone	+ 386 2 4500 300
Fax	+ 386 2 4500 362
E-mail	info@nigrad.si
Website	www.nigrad.si
The principal activity	Sewerage
Year of establishment	Since 1857

University of Primorska

Address	Titov trg 4 6000 Koper, Slovenia
Phone	+ 386 5 611 75 00
Fax	+ 386 5 611 75 30
E-mail	info@upr.si
Website	www.upr.si
The principal activity	Education, Research
Year of establishment	Since 2003

UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

switchmed

ZRS Bistra
PTUJ

ELEKTRO MARIBOR

Skupina hse
dem
dravske elektrarne maribor

CROATIAN CLEANER PRODUCTION CENTRE

Zanesljivo vsepovsod
POŠTA SLOVENIJE

ABELIUM
Research & Development

Snaga
Za lepše okolje!

PIVOVARNA
LAŠKO
1825

MOJA NALOŽBA

PREPARE

ECO SCP MED

Med
L'Europe en Méditerranée
Europe in the Mediterranean

Projet cofinancé par le Fonds Européen de Développement Régional (FEDER)

Project cofinanced by the European Regional Development Fund (ERDF)

MED CAP

Is the EMAS cluster-based voluntary approach an effective way to improve corporate performance? The case of the industrial paper production cluster of Lucca (Italy)

Tiberio Daddi[1*], Fabio Iraldo[1,2], Francesco Testa[1]

[1]*Sant'Anna School of Advanced Studies e Institute of Management, Piazza Martiri della Libertà 33, 56127 Pisa, Italy*
[2]*IEFE e Institute for Environmental and Energy Policy and Economics, Bocconi University, Milan, Italy*

* corresponding author: tiberio.daddi@sssup.it, tel. 050 883971

Keywords:
Environmental performance, industrial clusters, Environmental Management Systems, paper industry, SMEs

Abstract
This paper aims to assess the effectiveness of the so-called "EMAS cluster approach" when applied to environmental policies, by focusing on the case history of the industrial paper production cluster located in the Province of Lucca (Italy). The Lucca cluster represents approximately 20% of Italian paper production, and Italy is the fourth leading paper producer in Europe. In the last 10 years, environmental policies have been developed under the common "umbrella" of a strong public and private partnership based on stakeholder networking within the application of the EU EMAS Regulation. This article evaluates the outcome of such an approach, by comparing the environmental performance indicators for the Lucca's paper industry using data collected from more than 40 plants before and after the adoption of this voluntary tool. The results show considerable improvements for many environmental performance indicators, consistently with the implementation of the cluster approach.

1. Introduction

An increasing amount of research indicates that the proximity of economic activities enables higher levels of productivity and innovativeness (Smith, 1994; Bathelt, 1998; Porter, 1998; Bengtsson and Soelvell, 2004).
In recent years, there has been a growing recognition of the idea that clusters of proximate firms play a key-role in supporting innovation and wealth creation. For example, some authors (Schmitz and Nadvi, 1999) concluded that clustering helps firms to "overcome growth constraints and compete in distant markets". For some scholars, high performing clusters are underpinned by the economic efficiencies they confer on constituent firms, including increased specialization, reduced transaction costs and enhanced reputation (Aharonson et al., 2007). From this perspective, spatial proximity, in particular, allows firms to take advantage of economies of scale and positive

externalities such as an abundance of highly skilled labor, specialized subcontractors and rapid flows of information (Hirschman, 1958; Rosenthal and Strange, 2003).
One may wonder if the higher capability of resilience demonstrated by firms operating in clusters is a limited or negligible phenomenon considering the economy as a whole. This is certainly not the case with the EU: the Cluster Observatory of the European Commission carried out a quantitative analysis of EU-based clusters grounded on a fully comparable methodology. This study shows that clusters are a crucial part of the Union economy: according to this analysis, it can be assumed that roughly 38% of all European employees work in enterprises that form a part of a cluster. Other studies show that in some regions this share reaches over 50%, while in others it drops to 25% (MERIT, 2006).
A peculiarity of the clusters is that the companies in this kind of territorial contexts are mostly Small and Medium Enterprises (SMEs). Quite interestingly, a part of the literature focusing on clusters, in the most recent years has emphasized how this co-operative approach is leading SMEs to gain new competitive edges, thanks to the ability of these territorial aggregations to tackle environmental, social and ethical issues linked to industrial production. In particular, the environmental problem has become, especially for SMEs, a key factor affecting their ability to comply with the law and to respond to consumers' and customers' demand, thus to survive on the market.
There are many studies in the literature that attempt to provide insights into the environmental problems caused (and faced) by SMEs (Peters and Turner, 2004). The ECAP – Environmental Compliance Assistance Programme, by the European Commission, for example, reports that SMEs contribute up to 70% of the industrial pollution in the EU. Other studies concentrate on specific environmental aspects. A survey carried out in France (ADEME, 2007), for instance, showed that SMEs are to be held responsible for 40-45% of all industrial air emissions, water consumption and energy consumption, as well as for 60-70% of industrial waste production. The Institute of Directors (2006) carried out a survey reporting that SME members involved in sectors such as construction, mining, transport or manufacturing are 'heavily exposed' to environmental regulation.
In light of this empirical evidence, one of the main emerging research questions concerning clusters regards their possible role to support proximate SMEs in managing environmental issues. In other words, the question is: can an SME participating in a cluster rely, for environmental management and innovation, on the same peculiar co-operative dynamics and locally-based resources that have traditionally supported its competition, growth and resilience to economic downturns?
According to empirical evidence and several research studies, networking between SMEs is one of the most important factors to foster environmental management and eco-innovation. Many authors (Hillary, 1999; Biondi et al., 2000; Steger 2000; Rizzi et al., 2012) emphasize that working together with other "fellow companies" is a useful and efficient way of adopting eco-innovation, particularly for SMEs, which often suffer from a lack of human, technical and economic resources needed for the application of eco-innovative solutions (Kassinis, 2001). This happens to be particularly effective between organizations operating in the same sector and between organizations operating in the same territorial area.
Moreover, consistently with the marshallian theory of the "industrial atmosphere", the high degree of co-operation, engagement and, sometimes, even strategic integration that takes place in the cluster between the SMEs and their social-institutional context, proves

to be very effective in promoting eco-innovation, as confirmed by many studies (Alshuwaikhat and Abubakar, 2007).
The European Commission has underlined the key-role of networking for overcoming the barriers to the adoption of eco-management and innovation practices among SMEs (European Commission, 2007). According to this perspective, SMEs operating in a cluster can exploit synergies and gain benefits in several ways: e.g. by identifying and tackling the same environmental aspects (because these originate from similar production processes and technologies), by developing common technological and operational solutions that can be applied to similar production processes and products, as well as by defining collective "organizational structures" (e.g.: cluster organisations) that are suitable for the same kinds of managerial needs and business models. Moreover, there can be synergies both in improving the environmental impacts on the same ecosystem (e.g.: using the waste produced by a "fellow SME" as a secondary raw material, as it happens in industrial ecology), and in interacting and communicating with the same stakeholders (local population, authorities, etc.) (Daddi et al., 2010).
There are cases in which a specific environmental policy has stimulated co-operative behavior, and even network creation, among SMEs within a cluster, in order to support information exchange and skill sharing and to define and apply common solutions to similar environmental, technical and/or organizational problems, or to share environmental management resources. This has happened particularly with the set of voluntary policy instruments introduced since the early 90's by the European Commission: the EMAS Regulation, the EU Ecolabel, covenants and voluntary agreements, etc.. The EMAS implementation has been strongly enhanced and empowered by way of co-operative formal or informal networks of SMEs, often taking place within the supply-chain, e.g. with a larger customer willing to stimulate and support small suppliers in applying, and eventually registering in this scheme (Andreas et al., 2010).

1.1 The "EMAS cluster approach"

On the basis of these premises, a new model for supporting the adoption of voluntary management tools (known as the "EMAS Cluster Approach") has been developed in the last years (Battaglia et al., 2010; Von Weltzien and Shankar, 2011).
This "territorial" approach to Environmental Management originated in the European context at the end of the 1990s (Battaglia et al., 2008). The first cluster-oriented EMAS experiments revealed the possibility of a new way of applying the scheme requirements (according to Reg. EC/761/2001, modified in Reg. EC/1221/2009) to spatial aggregations of many similar SMEs, strongly innovating what had been, until then, the process of implementing an environmental management system only to a single organization or site. At the beginning, this approach led to the EMAS registration of a productive areas and industrial parks (i.e.: groups of companies located in a limited and constrainable area), but it was not applicable, as such, to wider territorial clusters (Frey and Iraldo, 2007). Only at a later stage, at the end of the 1990s, the EMAS Cluster approach was extended and upgraded to be applicable also to wider contexts, such as industrial districts or even local and regional supply-chains.
This approach fosters a cooperative and integrated environmental management at the cluster level, based on the relations existing between territorial environmental performance and the proximity between firms and other local actors and stakeholders. The methodology underpinning the approach encompasses the implementation of

exactly the same steps foreseen by the EMAS Regulation (European Commission, 2009) for single companies, but reinterpreted at the cluster level, i.e. by exploiting the “co-opetition” attitude (i.e.: cooperation between firms which also compete) and the potential collaboration between private companies and the other economic and institutional actors.

This wider applicability of EMAS provides the possibility to consider the EU scheme as a new policy tool that is capable of pursuing together and in synergy two goals at different levels: on one hand, fulfilling the environmental managerial needs of the smaller companies and, on the other, responding to the interests of Local Governments to improve the environmental performance of companies under their jurisdiction (Amadei et al., 1998; Hillary, 1999; Del Brio and Junquera, 2003; Lepoutre and Heene, 2006).

The first need emerges from the fact that, despite their constraints in terms of human, technical and economic resources, the adoption of EMAS represents a relevant opportunity for SMEs facing the competitive challenges induced by the globalization process and the increased (and increasing) social and market attention on environmental performance (Steger, 2000; Rennings et al., 2005; Barla, 2007; Iraldo et al., 2009; Daddi et al. 2011). The second need, for a new and more effective approach to territorial environmental management, stems from the considerable limits of the traditional policy tools available to Local Governments, such as the Agenda 21 Local processes (Baldizzone, 2000). The EMAS cluster approach can be an answer to this twofold need felt by both the private and the public actors operating in an industrial district, a technological park or any other form of territorial agglomeration.

This approach relies on the possibility that, since the SMEs in a cluster are similar and face the same environmental problems, they can develop and share solutions at the territorial level. For instance, when tackling the key-steps of an environmental management system implementation process, the SMEs located in a cluster could take advantage from defining shared environmental “targets” and common improvement plans, from identifying the same relevant environmental aspects, as well as by responding to the needs of the same environmental stakeholders, given the same social and institutional “fabric” with which they interact.

Moreover, the SMEs belonging to a cluster must presumably comply with the same local and sectoral legislation, make business with the same players in the supply-chain (e.g.: the raw material suppliers or the technology providers) and face the same environmentally-relevant emergency situations. In addition, there are several scale-economies that can result from joint environmental management of the equipment and services shared by the SMEs in the cluster (e.g. water purification systems). Finally, in a cluster there are positive effects resulting from interacting with the citizens as environmental stakeholders, due to the almost total coincidence of companies’ personnel with the local community of the cluster.

According to this perspective, a “territorial” approach based on EMAS has been considered in many EU Member States as an opportunity to integrate industrial, territorial and environmental policies in industrial clusters (Battaglia et al., 2008; Daddi et al., 2010).

This approach has been tested and developed especially in the Member States where EMAS has had greater success: Germany (with the so-called “Konvoi” approach), Italy (for with the APO “Ambiti Produttivi Omogenei” scheme, i.e.: homogeneous

productive contexts), Spain (co-operation in the supply chain, especially in the tourism sector) and Nordic Countries (especially in Denmark and Sweden).
A study by IEFE Bocconi (2006), carried out on behalf of the European Commission to support the revision of EMAS, confirmed the importance of networking. The results of 200 interviews with EMAS registered organisations and other stakeholders showed that:

- EMAS is positively affecting environmental management within the supply chains, e.g. 77% of the EMAS registered organisations are supporting their suppliers in the adoption of measures and initiatives for environmental improvement, and 72% declare that the environmental management system influences their products performance in the supply chain;
- 54% of the interviewees believe that a simplified access to registration for micro enterprises and SMEs, also based on co-operative and networking initiatives, would be a fairly or very important support for EMAS development (another 17% believe that that this would be "somewhat important"). This percentage is higher if we consider the sub-sample of the small companies (less than 50 employees);
- 31% believe that it would be (very or fairly) important to use a 'cluster approach' as a potentially effective support for the diffusion of EMAS among SMEs (an additional 23% think it would be "somewhat important").

Similarities can be also identified between the EMAS Cluster approach and the Regional Environmental Management Systems (REMS). In the literature, some papers describe REMS application experiences (Welford, 1996; Niutanen and Korhonen, 2003; Welford, 2004). To apply the "REMS model", there is no specific fixed criterion established as a standard. Despite this, the model works through some principles that can be linked to the requirements of the EMAS cluster approach. For example, the model foresees a wide public-private partnership and the identification of shared local, regional, and state priorities, relevant to the partnering organizations (V-REMS, 2012).
Finally a recent paper describes the capacity of EMAS cluster approach to spread the tool not only among industrial companies: the experience involved a cluster of 33 small municipalities (Botta and Comoglio, 2013). The authors observe that "the cluster approach allowed to analyze in a uniform and comprehensive way the environmental issues of the territory both at cluster and at single municipality level, sharing knowledge and resources among cluster members, creating scale-economies that led to a significant costs reduction and enforcing the position of the municipalities in the relationships with relevant stakeholders"
Grounding on these experiences, several studies have been performed in the past on co-operative environmental management and voluntary policy instruments adopted in industrial clusters, but very few assessed the effectiveness of these approach. In this article, we aim to evaluate if and how the EMAS cluster approach has been fully effective in improving the environmental performance of companies operating in a cluster. To achieve this goal, we use the evidence collected in the case-study of the Lucca paper industry cluster located in the Region of Tuscany in Central Italy.

2. Method and research questions

The method used in the paper is the case study analysis. By analyzing the case history of one of the most advanced application of the so-called "EMAS cluster", we intend to identify and emphasize the outcomes to which this approach can lead and the dynamics

by which the activities and tools foreseen by the EMAS cluster can foster and support the creation of opportunities for environmental improvement.
The Lucca cluster represents the most advanced experience in the application of the EMAS cluster approach in Italy. The EMAS process began in 2002 and, since then, this cluster has achieved important awards and national recognitions for the environmental initiatives promoted and managed in the framework of EMAS (Cariani, 2009; Daddi et al., 2012).
Although in the literature we can find several studies related to cluster policies and to the application of the EMAS cluster approach, only few of them aim to assess the effectiveness of those policies. So the first research question to test is the following: have almost ten years of applying the EMAS cluster approach facilitated the achievement of environmental improvements? In order to answer to this question, in the next section we compare the main environmental indicators of a representative sample of paper production companies in Lucca. The indicators are related to the year 2003 (the beginning of application of the EMAS Cluster Approach) and 2010.
A second research question relates to the identification of the "building blocks" of the EMAS cluster approach that can be effectively implemented by the single SMEs to support and accompany their environmental management and, consequently, performance improvement.

3. Case study profile

3.1 Lucca paper industry cluster

According to the statistics of the Confederation of European Paper Industries (CEPI, 2011a) the European paper production in the year 2011 amounted to 94,976 kilo tons. With a production of around 9,100 kilo tons in 2011, Italy represents the fourth most prominent paper producing country in Europe.

Paper production by Country in 2011	
Germany	23,9%
Finland	11,9%
Sweden	11,9%
Italy	9,6%
France	9%
Spain	6,5%
Austria	5,2%
UK	4,6%
Other Countries	17,4%

Table 1. Paper production in Europe by Country (Source: CEPI, 2011a)

By analyzing the main features of the European paper industry provided by the EU cluster observatory (www.clusterobservatory.eu), we can determine some important aspects related to the structure of this sector. The data on the number of employees is compatible with the ranking shown in the Table 1. On the contrary, verifying the number of installations, Italy surpasses the first three Countries (Germany, Finland and Sweden). According to this data, in the first three Countries the paper production is

undoubtedly more concentrated in big companies with integrated processes. On the opposite, the Italian paper industry structure is characterized by a high number of companies with few employees. Considering the literature definition of an industrial cluster as a group of independent companies (mainly SMEs) that are geographically concentrated in one or several regions, we can affirm that Italy is one of the most important Countries for paper industry clusters.
The Lucca paper "cluster area", in particular, extends over a geographical surface of 750 km^2, including the territories governed by 12 Municipalities with a population of 121,000 inhabitants.

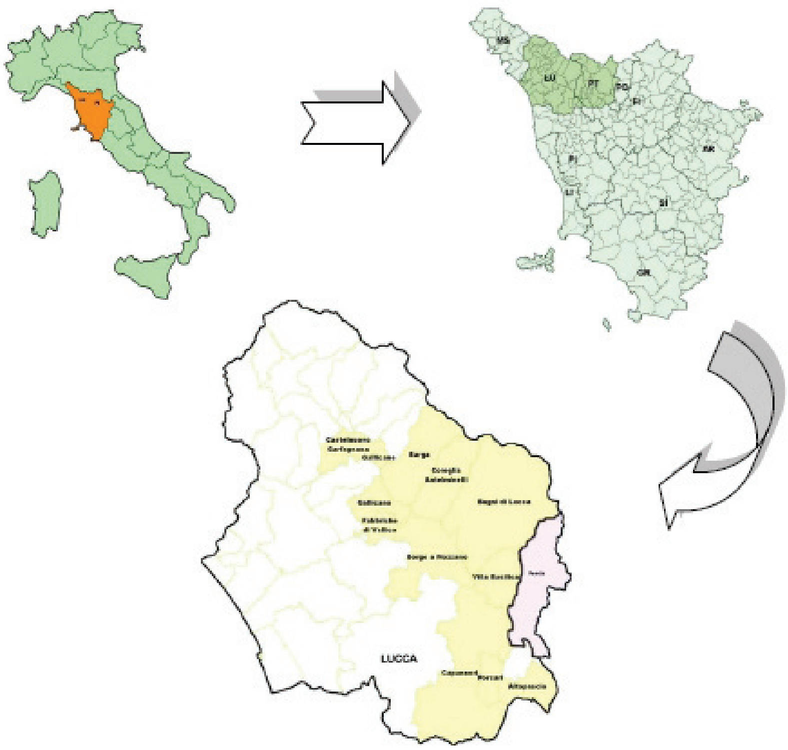


Figure 1. Location of Lucca cluster in Tuscany Region and in the Province of Lucca

More than 130 paper producing or processing firms (most of which are SMEs) are located in the area, with a high level of aggregation, a considerable density per km^2, and an occupational capability of more than 5,800 workers, all employed in the paper sector. The companies located in the Lucca cluster manufacture around 20% of total Italian paper production. In this area, the industrial activities are deeply rooted in the social and institutional local context, and the production sites are mixed and integrated with many other services, as well as with civil, commercial, logistic and administrative activities. This is the typical structure of a cluster, which is known as the marshallian "industrial district," in the United Kingdom and in Italy. In the case of Lucca, the clustering of paper producers is due to (and originated from) the considerable local availability of water, a vital input for this sector. The concentration of a huge number of firms operating in the same sector causes relevant environmental impacts and, simultaneously, offers some opportunities for co-operation to minimize those impacts. This holds true for all the territorial areas bearing the characteristics of a cluster, even if not located in a particular, well-defined territorial area (e.g. a supply chain).

3.2 The application of the EMAS approach in the Lucca cluster

Since 2002, the Lucca cluster has been applying the EMAS Cluster Approach thanks to the EU co-funded Life PIONEER project. This EMAS Cluster Approach has created a common basis for all the individual organizations intending to use collective resources and a cooperative approach to achieve the individual EMAS Registration. For this purpose, the project provided a territorial initial environmental review, a local policy, a programme for the sustainable development of the cluster, a sort of "Cluster Environmental Management System" (composed of various resources and procedures that are available for the individual organizations, e.g. training, auditing, monitoring and communication activities) and, finally, a cluster "environmental statement." These elements were used by the involved organizations to facilitate their own management activities and environmental improvements.

The initial step was the set-up of the "EMAS Promotion Committee" for the whole Lucca cluster. This Committee is a true "yardstick" for PPP (public-private partnership) applied to EMAS, as it brings together the public bodies (e.g. Province of Lucca) and the manufacturers (e.g. Industrial Association of Lucca) of the cluster and is in charge of defining the strategic guidelines for the cluster environmental policies and providing some "common resources," in order to guarantee a co-ordinated and integrated management of the environmental issues within the cluster.

The second step was the Initial Environmental Review with reference to the whole cluster. This review enabled the identification of the most significant (and sometimes critical) environmental aspects for the cluster. The aim of the Environmental Review of the Cluster was to support the involved organizations in identifying and assessing their own environmental aspects, according to EMAS.

As a third step, the Promotion Committee defined and shared a cluster environmental Policy that became a reference for the EMAS policies of all the organizations involved in the cluster. The Environmental Policy for the Lucca cluster sets the guiding principles and general priorities based on the most significant environmental aspects and impacts resulting from the previous review. The Environmental Policy was officially approved by the Promotion Committee and communicated to all the interested parties in the cluster.

A collective and cooperative Environmental Programme and related common improvement objectives and targets stemmed from the cluster policy, pursuing the principle of continuous improvement. This improvement is pursued in the Lucca cluster also by setting the objective of a continuous increase in the number of individual EMAS registrations and/or in the number of licenses for the EU Eco-Label in the area. The cluster programme includes some very practical and measurable commitments for carrying out strategic and high-priority actions and measures for the whole cluster.

By means of a sort of "Cluster Environmental Management System", the Promotion Committee also provides the local SMEs with many resources and activities that can be shared and collectively exploited at the cluster level. All these actions are aimed at supporting the development of EMAS on an individual basis by the interested organizations located in the cluster. Among these activities and resources, the Lucca Promotion Committee implemented the following: searching for common technical, organizational or managerial solutions for solving the environmental problems of the local SMEs; providing assistance to paper producing SMEs in the identification and assessment of the indirect environmental aspects, with particular reference to product life cycle-related issues; planning and carrying out environmental training activities, aimed at improving the awareness, competence and skills of managers, employees and technical staff of the organizations operating in the cluster; creating a common "audit team", qualified to perform audits in the cluster in favorable conditions, etc.

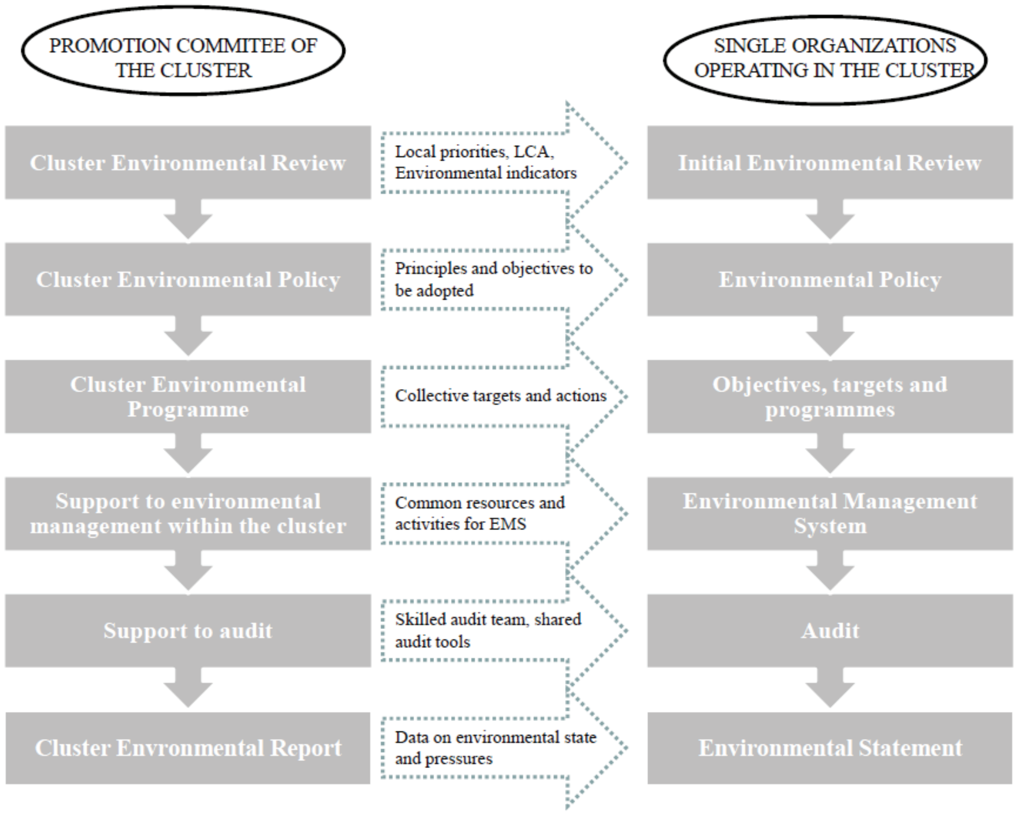


Figure 2. Methodological steps of the EMAS cluster approach in Lucca

In the year 2008, the application of the EMAS Cluster Approach in the Lucca cluster obtained an important recognition from the Italian EMAS Competent Body. In Italy, districts that apply the EMAS Cluster Approach can achieve this goal after they are positively assessed by an environmental third-party accredited auditor. Although the European EMAS Regulation n. 1221/2009, in its current version, includes a specific article entitled "Cluster and step-by-step approach," this sort of cluster certification is still not regulated at the EU level.

3.3 The benefits of the approach at firm level

Most of the benefits emerging from the adoption of a cluster approach are related to resource savings and to the possibility of relying on a shared set of tools and competences for the application of EMAS. The following are just few examples on how the companies located in Lucca and involved in the cluster approach, benefited from cluster-based common resources, made available by the Promotion Committee.

Kartocell (former Kartogroup, now Wepa group) a tissue-paper producer, found it very useful to perform an assessment of its most significant environmental aspects by strongly relying on the "cluster" environmental initial review, carried out during the project. This company used the results of the cluster initial review to identify the most relevant direct aspects, and defined an assessment methodology based on the relevance that each aspect had for the whole cluster, the capability of influencing the local environment (indicators provided by the cluster review) and the level of importance of each aspect according to the local communities sensitiveness (information provided by the same cluster review, basing on the "in-field" survey). These were simply adopted as assessment criteria by Kartocell.

Delicarta, another tissue-paper producer, carried out the review and assessment of its environmental indirect aspects relying on the LCA that had been carried out on the locally manufactured products. This LCA was performed with a "streamlined" approach by the Promotion Committee, on both tissue paper and corrugated board (which are the two most important products of the cluster). The data and information deriving from the LCA were included in the cluster environmental review, in such a way to be easily adopted by any interested paper producer to identify and assess its product-related indirect aspects.

Cartiera Lucchese, the first company to obtain the EU Eco-Label in Italy, also relied on the cluster approach to identify and assess its environmental indirect aspects. In this case, the most useful tool has been a scheme for identifying and measuring indicators relating to the most relevant indirect aspects for the tissue-paper local industry. This tool has been prepared by the Promotion Committee and diffused to the interested companies.

SCA Packaging (SCA group), a corrugated board producer, particularly relied on another cluster-based tool, that was made available to the local producers: a common audit team. This activity was judged as very effective by the company, especially because it provided a relevant opportunity to rely on external competence and to compare its experience in environmental management with other approaches.

Not only paper producers were able to take advantage of the cluster approach: two interesting examples refer to a connected supplier-sector: the manufacturing of paper-producing machinery. The paper-machinery manufacturer Fosber strongly relied on the environmental training initiatives carried out at the cluster level, in order to replace the training activities that the companies should have carried out on their own. Among many other involved companies, Fosber took part in some courses that were organized and managed by the Promotion Committee on: environmental management, external communication, environmental auditing, etc. A second example is that of Toscotec, another machinery producer, that strongly relied on an effective managerial tool that was diffused to all the organizations involved in the project. The Toscote*c* environmental management system, in fact, was build on the basis of some "model" and easy-to-adapt procedures referring to the main EMAS elements: identification and assessment of environmental aspects, Non Compliances and Corrective and Preventive actions, Audit, Management Review, Training and Information of personnel, etc.

It has to be noted that, besides the abovementioned "direct" benefits for the organizations operating in the cluster, some "indirect" benefits are produced for the whole institutional and social contexts of the interested territorial area, such as:

- a higher level of knowledge sharing and networking between the EMAS organizations operating in the cluster;
- a significant "multiplier" effect on all the other organizations of the cluster (higher sensitiveness, involvement in improvement actions, stakeholder pressure on the laggards, etc.);
- a wide availability of common resources and tools for environmental management, that can be made available to any interested organization;

Finally, the application of cluster approach has allowed to better inform the targeted policy makers and local institutions about the specific characteristics and environmental priorities for the local industrial system.

4. Results and discussion

Besides the benefits and advantages obtained by the single companies from the EMAS cluster approach under the managerial, operational and technical points of view, it has to be determined if this approach has been able to achieve its main aim, i.e.: yield a better environmental performance of the whole paper productive system in the cluster.
In order to answer the main research question of our work, in this section we will analyze the most important environmental indicators of the paper industry located in the Lucca cluster. We will compare the performance of two different years, 2003 and 2010. In 2003 the data was collected by a specific questionnaire prepared by the authors of this paper in the framework of the Life PIONEER project activities. For the year 2010 we used official data communicated by the companies to the Province of Lucca. In fact, most paper production companies are in the scope of the IPPC (Integrated Pollution Prevention and Control) regulation. According to this EU Directive and to its transposition into the Italian legislative context, every year the companies must communicate all environmental data and indicators to the Competent Authorities. The table below shows the characteristics of the sample used to calculate the environmental indicators.

Years	Number of paper production companies	Paper production (tons)
2003	18	1,274,187
2010	21	1,441,134

Table 2. Sample used in the elaboration of environmental indicators

Considering the Lucca cluster's total production of around 1,900,000 tons in both years, this production represents more than 60% of total cluster production. In addition, considering Italian paper production as a whole in 2010 (9,100,000 tons), the sample used to calculate the indicators in this paper represents approximately 15% of the national production.
When calculating the indicators, we took into account a technical and a geographical issue. From the technical point of view, the indicators were calculated after subdividing them according to the different productive processes and product categories in the cluster. One group of performance indicators is related to the companies that produce tissue paper, and another group is related to the paper packaging production companies. The reason for this is connected with the different environmental impacts of the companies. Plants that produce tissue paper mainly use virgin cellulose as their raw material, consume less water in the process and produce little waste. On the other hand, companies that produce packaging paper characteristically use recycled paper as their fiber source, and can therefore have different environmental performance with relation, for example, to waste production (e.g. sludge from the re-pulping of recovered paper).
The second subdivision depends on the geographical location of the companies. The Lucca cluster is characterized by two main areas. The "Garfagnana" is a mountain area

rich in surface and ground water. The companies located in this area do not have any problem related to water availability. The other area is close to Lucca, in a plain area, where during the last year the scarce availability of groundwater has become a territorial environmental problem. Therefore, separate environmental performance indicators for the two areas were calculated.
Many of the improvements observed in the environmental indicators can be easily linked to the actions applied at cluster or firm level during the application of the EMAS Cluster approach. In the next paragraph, discussing the trends in the indicators, we will point out the main links between these two aspects.

4.1 Resource efficiency indicators

The paper industry has historically been considered a major consumer of natural resources (including water) and energy (fossil fuels, electricity) and a significant contributor to pollutant emissions in the environment. In the pulp and paper industry a large number of chemicals are used, depending on the grade of paper produced, the process design and operation and the product qualities to be achieved. Chemical additives are used to give paper various characteristics while chemical auxiliaries are used to increase efficiency and reduce disruption of the production process.
Water is an essential element in the production of paper. It is used in large quantities throughout the pulping and papermaking process, inevitably picking up effluents along the way.
Energy efficiency is seen as the core of good paper mill performance. In the Lucca cluster cogeneration is widely adopted, a system that produces electrical and thermal energy at the same time, saving energy and reducing emissions.
The following table shows some key-performance indicators linked with resource efficiency issues for the companies operating in the Lucca cluster. All the indicators are calculated as an average among all the available company data, based on the tons of paper produced by the companies included in the sample. As mentioned in the previous section, the data of our sample are classified according both to their different productive process (tissue and packaging productive processes) and to the geographical area (Lucca plains and Garfagnana). In the last column, we point out the variation of each indicator in the two reference years, expressed as a delta in percentage.

Environmental performance indicators in "Lucca plain" of Lucca cluster							
Environmental aspect	***Performance indicator***	***Tissue paper***			***Packaging paper***		
		2003	*2010*	*Var. %*	*2003*	*2010*	*Var. %*
Chemical consumption	kg chemicals/t	19.3	23.5	21.8	23.5	50.5	114.9
Water consumption	m^3/t	7.4	5.7	**-23.0**	6.8	4.7	**-30.9**
Energy consumption	m^3 methane/t	303.1	311.9	2.9	179.1	151.1	**-15.6**
	kwh/t	988.5	975.7	**-1.3**	401.7	439.0	9.3
Environmental performance indicators in "Garfagnana area" of Lucca cluster							

Environmental aspect	Performance indicator	Tissue paper			Packaging paper		
		2003	2010	Var. %	2003	2010	Var. %
Chemical consumption	kg chemicals/t	20.1	23.1	14.9	39.8	57.0	43.2
Water consumption	m^3/t	25.9	17.5	**-32.4**	11.6	8.4	**-27.6**
Energy consumption	m^3 methane/t	187.4	178.2	**-4.9**	203.5	162.8	**-20.0**
	kwh/t	1043.4	944.2	**-9.5**	486.6	383.3	**-21.2**

Table 3. Environmental performance indicators of chemical consumption, water consumption, energy consumption

The analysis of the data related to the use of chemicals shows a generalized worsening of the performance for the analyzed period. All the increases in the use of chemicals are of more than 10% and in the case of packaging paper of the Lucca plains the increase is quite substantial.
The opposite situation can be observed in water consumption performance. All the indicators show a relevant improvement with all percentages well above 20%. We can observe that the paper sites located in the Lucca plains had better performance than the plants located in the Garfagnana. This aspect depends on the scarcity of groundwater availability in the area near the city of Lucca, that functions as a leverage to reduce water consumption. On this issue, the Promotion Committee created, within the application of the EMAS cluster approach, a specific Scientific Committee to analyse and assess possible technological and management solutions linked with the water consumption. The Scientific Committee identified the most suitable BAT (Best Available Techniques) for the Lucca's paper mills and started to boost their adoption by the cluster companies. As a consequence of these actions, in the last years there was a great incentive to close up water circuits in paper mills, in order to reduce water consumption. In a parallel way, the Promotion Committee during the Life Pioneer project fostered the development and adoption of innovative management options to reduce the odour emissions (as a cross media effect derived by the fresh water consumption reduction), that were identified and implemented in the paper factories.
Regarding energy consumption, the data shows a general improvement. Only the electric energy consumption of packaging paper producing companies and methane consumption of tissue paper producing companies in the Lucca plains worsens in the analyzed period. The other eight indicators show considerable improvements. These improvements may seem unexpected considering the economic situation. In the past years, the industry has decreased its production due to the economic downturn. The key challenge of these critical economic phase has been the utilization of rolls and converting machines at a lower capacity, with consequent reductions in efficiency per ton of product produced. Paper companies of the Lucca cluster have found ways to overcome this aspect of the crisis, by maintaining efficiency, in spite of their lower capacity utilization.

4.2 Waste water, air emissions and waste production performance

Emissions to water and solid waste generation are relevant environmental topics for the paper industry.

Atmospheric emissions are mainly related to energy generation by combustion of fossil fuels in power plants. Waste water effluents from pulp and paper mills contain mainly solids, nutrients (nitrogen and phosphorus) and organic substances. The concentration of organic substances in effluent water is expressed as the amount of oxygen it takes to degrade these substances through either biological processes (biological oxygen demand - BOD) or chemical reactions (chemical oxygen demand - COD).
The waste produced is different in the two production processes. In the Lucca cluster all producers of packaging paper obtain the cellulosic fibers from recycled paper and not from virgin cellulose. Although this issue represents the important environmental topic of re-using waste paper and reducing the consumption of wood, it causes the production of huge amounts of sludge derived from the first processes applied to the recycled paper. For this reason, as we can observe in the table below, the environmental performance related to waste generation is completely different in the two processes.

Environmental performance indicators in "Lucca plain" of Lucca cluster							
Environmental aspect	***Performance indicator***	***Tissue paper***			***Packaging paper***		
		2003	*2010*	*Var. %*	*2003*	*2010*	*Var. %*
Waste water	kg BOD/t	0.64	n.a.	/	0.39	0.09	**-76.9**
	kg COD/t	1.06	1.07	0.9	1.38	0.91	**-34.1**
	kg TSS/t	0.82	0.32	**-61.0**	0.30	0.15	**-50.0**
Air emissions	kg NOx/t	1.35	0.87	**-35.6**	0.43	0.18	**-58.1**
	kg CO/t	0.27	0.35	29.6	0.05	0.05	0.0
Waste production	kg waste/t	9.94	11.84	19.1	96.59	90.69	**-6.1**
Environmental performance indicators in "Garfagnana area" of Lucca cluster							
Environmental aspect	***Performance indicator***	***Tissue paper***			***Packaging paper***		
		2003	*2010*	*Var. %*	*2003*	*2010*	*Var. %*
Waste water	kg BOD/t	0.44	0.49	11.36	1.29	n.a.	/
	kg COD/t	1.29	1.58	22.5	2.83	0.74	**-73.9**
	kg TSS/t	0.30	0.22	**-26.7**	0.36	0.14	**-61.1**
Air emissions	kg NOx/t	0.39	0.42	7.7	0.74	0.16	**-78.4**
	kg CO/t	0.87	0.17	**-80.5**	0.09	0.02	**-77.8**
Waste production	kg waste/t	17.4	8.7	**-50.0**	144.30	124.49	**-13.7**

Table 4. Environmental performance indicators of waste water, air emissions and waste production

The performance showed by all the 24 indicators elaborated in this section may be summarized as follows: 15 indicators improved, 6 indicators worsened, 1 indicator remained stable and 2 indicators were not available. In many cases the percentage values of the improvements are higher than those of the worsening situations.
Regarding waste water we collected data related to three pollutants—BOD, COD, and Total Suspended Solids (TSS). In some cases data related to BOD was not available. In the Lucca plains, we observe a relevant improvement in performance. The indicators related to the total suspended solids show improvements in both processes and both areas. In this case the actions of the Cluster approach has influenced mainly the factories located in the Lucca Plain. The companies of that area are connected to a common wastewater treatment plant. This plant is a consortium composed of private (industrial associations) and public (municipalities and Province) bodies. These bodies are the same components of the Promotion Committee and they found the periodical meeting of the Committee as the natural context to dialogue and find solutions in order to improve the water emissions. The solution implemented was the adoption of a mix of policy instruments: command and control and economic instruments. In particular, they set stricter emission limits for the wastewater discharged in the sewer and, at the same time, imposed a higher fee to pay (proportionally to the pollutants load discharged) in the sewer Regulation. This action in the last years has stimulated the adoption actions (e.g. identifying more environmental friendly chemicals) that lead to the improvement of the performance indicators showed in the table.
The fact that specific emissions per ton of product have increased only in two cases is an important result. In fact, every observer expected a worsening in the environmental performance as direct cause of the sector economic crisis.
Only the tissue companies of the Lucca plains worsened their performance related to waste production. The other three indicators show improvements. As mentioned, the packaging companies exhibit a higher indicator due to the sludge produced by the use of recycled paper as the source of fibers. The main components of the waste produced by paper companies are not dangerous and they are sent to a recovery system instead of the landfill.
Finally, in order to better assess the performance trends of the Lucca cluster, in this last table we aim to compare the main environmental indicators monitored in the section above with relevant international references. In fact, if the Lucca cluster indicators display better performance than the international benchmark values, we can affirm that even a slight improvement in performance represents a relevant result. In this way we could better interpret the results shown in the previous sections. The benchmarking activities will be referred not only to the performance but it also aims to compare the trend of the improvements. A higher improvement trend of Lucca cluster compared to the international benchmark values will strength the usability of the results to justify a positive effect of the EMAS cluster approach in the Lucca area.
As a benchmark we used the Sustainability Report 2005 and 2011 of the Confederation of European Paper Industries (CEPI, 2005; CEPI, 2011b). CEPI is a non-profit organization based in Brussels and represents about 520 pulp, paper and board producing companies across Europe and about 95% of the European pulp and paper industry in terms of production. The following table shows the performance indicators published by CEPI and the performance of the Lucca Cluster. CEPI does not classify tissue and packaging producing companies separately as we did in the previous tables. As in the case of the Lucca cluster, the data from CEPI are related to the performance

during 2010. Regarding the Lucca cluster we selected for this table the indicators with the highest improvement between the data of the two reference areas (Lucca plain and Garfagnana).

Environmental aspect	Performance indicator	Lucca cluster performance (2003-2010)					
		Tissue paper		%	Packaging paper		%
		2003	2010		2003	2010	
Electricity consumption	kwh/t	1043.4	944.2	**-9.5**	486.6	383.3	**-21.2**
Air emissions	kg NO_X/t	1.35	0.87	**-35.6**	0.74	0.16	**-78.4**
Waste water	kg BOD/t	0.44	0.49	11.36	0.39	0.09	**-76.9**
	kg COD/t	1.06	1.07	0.9	2.83	0.74	**-73.9**

Environmental aspect	Performance indicator	CEPI (2004-2010)		
		2004	2010	%
Electricity consumption	kwh/t	990	1,050	6,07
Air emissions	kg NO_X/t	0.81	0.85	4,9
Waste water	kg BOD/t	1,2	0.89	**-25,8**
	kg COD/t	6.8	6.26	**-7,9**

Table 5. Comparison between LUCCA Cluster performance and CEPI indicators

From the table above we can appreciate the improvement trends registered at European and Lucca level. CEPI doesn't publish the data referred to the year 2003 so we selected the year 2004.
The benchmarking confirms the relevance of the improvements observed in the performance of the Lucca cluster. Looking at the indicators of the year 2010 the data reveals how all the indicators of the Lucca cluster are lower than the European references. Moreover considering the improvement trend we observe that Lucca cluster has had a highest improvement in all the benchmarked performance indicators for the packaging production and in 2 performance indicators for the tissue production.

5. Conclusions

The results of our analysis should be evaluated taking into account some specific elements that strengthen our research.
First of all, the representativeness of our sample should be emphasized. As we have seen in the previous sections, the Lucca cluster is an industrial district with particular relevance in the framework of the Italian and European paper industry, and our sample represents approximately 60% of total cluster production. Secondly, the sources of data for the year 2010 are official communications sent by the companies according to a

specific European legislation. For this reason, the data can be considered especially reliable. Finally, the representation of the data according to the different productive processes and geographical areas allows the reader to assess the performance trends more in depth.
Having said this, we can draw some general conclusions from the results of our analysis.
The trends in the reported indicators show that the application of the EMAS cluster approach to the Lucca paper industry, in most cases, leads to relatively positive effects on performance concerning the investigated environmental aspects. Considering the 40 elaborated indicators we observe the following: in 25 cases the indicator presents an improvement in the period considered, 1 indicator is stable, 2 indicators have been not calculated due to the unavailability of data and only 12 indicators declined from 2003 to 2010.
The relevance of the positive results is increased when one takes into account two additional issues. The environmental indicators of the year 2010 are related to a period of economic downturn. In that period the firms could not achieve the full operational capacity utilization of their machines. Consequently, there was a reduction in the efficiency of the machines of the paper plants. For this reason, in that period, one should have expected a worsening of indicators calculated per ton of product.
Secondly, the last section of the paper related to the benchmarking of Lucca's performance demonstrates that Lucca's indicators are generally lower and with a more positive trend than the indicators of the paper industry published at the EU level. This aspect highlights the relevance of the improvements of Lucca's indicators.
Despite these positive aspects we can identify some limitations of the paper. The first is connected to the link between the application of the EMAS cluster approach and the improvements in performance. Surely the policies developed through the EMAS cluster approach have facilitated the companies' movements towards performance improvements. Despite this, we should consider additional drivers as well, such as the economic savings achievable through increased energy efficiency. Another limitation can be linked with the data related to air emissions. Many paper producers have continuous monitoring systems, but some companies of the sample do not, and the data provided were related to one single audit carried out throughout the year. Finally, the fact that at the EU level environmental indicators are not available subdivided into tissue and packaging paper producing companies reduces the reliability of the benchmarking carried out in the last section.
The authors will continue to monitor the trends of the Lucca paper industry in the coming years. Future research should aim to verify if the environmental improvements of the companies have contributed to an improvement of the environmental conditions of the whole territorial area.

References

ADEME, 2007. L'environnement et la maîtrise de l'énergie dans les PME. Paris: French Agency for the Environment and Energy.

Aharonson, B.S., Baum, J.A. and Feldman, M.P., 2007. Desperately seeking spillovers? Increasing returns, industrial organization and the location of new entrants in geographic and technological space. Ind and Corpor Chan, 16, 89–130.

Amadei, P., Croci, E. and Pesaro, G. 1998. Nuovi strumenti di politica ambientale – Gli accordi volontari. Milano: Franco Angeli.

Andreas, B. Eisingerich, S., Bell, J., and Tracey, P., 2010. How can clusters sustain performance? The role of network strength, network openness, and environmental uncertainty. Res Policy, 39, 239-253.

Alshuwaikhat, H. M. and Abubakar, I., 2007. Towards a Sustainable Urban Environmental Management Approach (SUEMA): Incorporating environmental management with Strategic Environmental Assessment (SEA). J of Environ Plan and Manag, 50, 257-270.

Baldizzone, G., 2000. L'Agenda 21 come strumento cardine delle politiche di sviluppo sostenibile. Ambiente e Sviluppo, 5, 6-18.

Barla, P., 2007. ISO certification and environmental performance in Quebec's pulp and paper industry. J of Environ Econ and Manag, 53, 291–306.

Bathelt, H., 1998. Regionales Wachstum in vernetzten Strukturen: Konzeptioneller Überblick und kritische Bewertung des Phänomens, Drittes Italien. Die Erde, 129, 247-271.

Battaglia M., Daddi, T. and Ridolfi, R., 2008. Environmental Territorial Management: A New Approach for Industrial Clusters, in Robert H. Theobald (Eds.), Environ Manag: 105-120. New York: Nova Publisher.

Battaglia, M., Bianchi, L., Frey, M. and Iraldo, F., 2010. An innovative model to promote CSR among SMEs operating in industrial clusters: evidence from an EU project. Corpor Soc Responsib and Environ Manag, 17, 133-141.

Bengtsson, M. and Soelvell, O., 2004. Climate of competition, clusters and innovative performance. Scandin J of Manag, 20, 225-244.

Biondi, V., Frey, M. and Iraldo, F,. 2000. Environmental Management Systems and SMEs. Gree Manag Internat 29, 55–69.

Botta, S., Comoglio, C., 2013 Implementing environmental management systems in a cluster of municipalities: a case study. Amer J of Environ Sc 9: 410-423.

Cariani, R. 2009. Ecodistretti-Made “Green” in Italy: le politiche ambientali dei sistemi produttivi locali e dei distretti industriali. Milano: Franco Angeli.

CEPI, 2005. Sustainability Report 2005. Brussels: CEPI.

CEPI, 2011a. European Pulp and Paper Industry – Key Statistics. Brussels: CEPI.

CEPI, 2011b. Sustainability Report 2011. Brussels: CEPI.

Daddi T., Testa F. and Iraldo F., 2010. A cluster-based approach as an effective way to implement the ECAP (Environmental Compliance Action Program): evidence from some good practices. Loc Environ, 15, 73–82.

Daddi T., Magistrelli M., Frey M. and Iraldo F., 2011. Do Environmental Management Systems improve environmental performance? Empirical evidence from Italian companies. Environ, Develop and Sustain, 13, 845–862.

Daddi T., Tessitore S. and Frey M., 2012. Eco-innovation and competitiveness in industrial clusters. Intern J of Tech Manag, 58, 49–63.

Del Brío, J.A. and Junquera, B., 2003. A review of the literature on environmental innovation management in SMEs: implications for public policies. Technov, 23, 939-948.

European Commission, 2007. Communication from the Commission to the Council, the European Parliament, the European economic and social Committee and the Committee of Regions “Small clean and competitive - A programme to help small and medium-sized enterprises comply with environmental legislation, COM (2007)379 final**.** Brussels: European Commission.

Frey, M.; Iraldo, F. A cluster-based approach for the application of EMAS. *IEFE Working Paper Series* 2007, 3, 1-15.

Hillary, R. 1999. Evaluation of Study Reports on the Barriers, Opportunities and Drivers for Small and Medium Sized Enterprises in the Adoption of Environmental Management System**s**. London: Routledge.

Hirschman, A.O., 1958. The Strategy of Economic Development. New Haven: Yale University Press.

Kassinis, G., I., 2001. Location, Networks and Firm Environmental Management Practices. J of Environ Plan and Manag, 44, 815-832.

IEFE Bocconi, Adelphi Consult, IOEW, SPRU, and Valor & Tinge, 2006. EVER: evaluation of eco-label and EMAS for their revision – research findings [online]. Final Report to the European Commission – Part I. Brussels: DG, Environment European

Community. Available from: www.europa.eu.int/comm/environment/emas [Accessed 10 June 2009]

Institute of Directors. 2006. The Business of the Environment: Policy and Opportunities. London: IOD.

Iraldo, F., Testa, F. and Frey, M., 2009. Is an environmental management system able to influence environmental and competitive performance? The case of the eco-management and audit scheme (EMAS) in the European union. J. Clean. Prod., 17, 1444–1452.

Lepoutre, J., and Heene, A., 2006. Investigating the impact of firm size on Small Business Social Responsibility: A critical review. J of Bus Eth, 67, 257-273.

MERIT – Maastricht Economic and social Research and training centre on Innovation and Technology, 2006. 2006 European Regional Innovation Scoreboard. Maastricht: MERIT.

Niutanen, V. and Korhonen, J., 2003. Towards a regional management system - waste management scenarios in the Satakunta Region, Finland. Intern J of Environ Techn and Manag, 3, 131-156.

Peters, M. and Turner, R. K., 2004. SME environmental attitudes and participation in local scale voluntary initiatives: some practical applications. J of Environ Plan and Manag, 47, 449-473.

Porter, M.E., 1998. On Competition. Boston: Harvard Business School Press.

Rennings, K., Ziegler, A., Ankele, K. and Hoffmann, E., 2005. The Influence of Different Characteristics of the EU Environmental Management and Auditing Scheme on Technical Environmental Innovations and Economic Performance. Ecolog Econ, 57 , 45- 59.

Rizzi, F., Bartolozzi, I., Borghini, A., and Frey, M., 2012. Environmental Management of End of Life Products: Nine Factors of Sustainability in Collaborative Networks. Bus Strat and the Environ, DOI: 10.1002/bse.1766

Rosenthal, S.S. and Strange, W.C., 2003. Geography, industrial organization, and agglomeration. Review of Econ and Statist, 85, 377–393.

Schmitz, H. and Nadvi, K. 1999. Clustering and industrialization: introduction. World Development, 29, 1885-1903.

Smith, R. and Van de Ven, A., 1994. Developmental processes of cooperative interorganisational relationships. Acad of Manag Rev, 19, 90–118.

Steger, U. 2000. Environmental Management Systems: Empirical Evidence and Further Perspectives. Europ Manag J, 18, 23-37.

Studer S., Tsang S., Welford, R. and Hills P., 2008. SMEs and voluntary environmental initiatives: a study of stakeholders' perspectives in Hong Kong. J of Environ Plan and Manag, 51, 285-301.

Von Weltzien Høivik, H. and Shankar, D., 2011. How Can SMEs in a Cluster Respond to Global Demands for Corporate Responsibility? J of Bus Eth, 101, 175–195.

V-REMS. 2012. Virginia Regional Environmental Management System (V-REMS): A model for successful implementation of a regional approach in Virginia. Accessed April 2013. http://www.peercenter.net/ewebeditpro/items/O73F8455.pdf.

Welford, R., 1996. Regional development and environmental management: new opportunities for cooperation. Scandin J of Manag, 12, 347–57.

Welford, R., 2004. Commentary: regional environmental management systems: lessons and challenges for industrial ecology research. Progr in ind ecol, an Internat J, 1, 286-291.

Food consumption and GHGs: insights from Lithuania

Renata Dagiliūtė*, Rita Juozėnaitė, Genovaitė Liobikienė

Vytautas Magnus University, Vileikos 8, Kaunas, Lt 44404, Lithuania
**Corresponding author email r.dagiliute@gmf.vdu.lt*

Abstract. Consumption, especially food, patterns are those contributing significantly to environmental burden. As the food related greenhouse gases (GHGs) emissions are attributed to all its life cycle stages, from agriculture to waste disposal, it is important to estimate food consumption related GHGs and foresee policy options for food related GHGs emission reduction.

Paper gives an overview of the Lithuanian food consumption in 1990-2010 and possible GHGs reduction scenarios, implying dietary changes, meat reduction and reduction of food waste. Results indicate that food consumption decreased by 9% (kg/per capita) during this period, but even some growth is registered for the period 2002–2010. Overall food related GHGs during 2002–2010 decreased by 5%, but per capita emissions slightly increased reaching 1123.8 CO_2 eq. kg/cap in 2010. Pork, dairy products and vegetable consumption were the main contributors to food related GHGs, though milk and grain products and potatoes dominated in overall food consumption structure in Lithuania. Analysis of three different food consumption scenarios showed that lower meat and meat products consumption and food waste reduction are the solutions towards more sustainable food consumption and GHGs reduction. Only healthier diets would not benefit sustainability in terms of GHGs. Therefore policy review and education and information provision are the tasks to be address in order to induce changes in food consumption patterns, which may affect not only GHGs decline, but also a positive effect on overall health and quality of life.

Keywords: climate change, greenhouse gases, food, sustainable consumption, Lithuania

1. Introduction

Food and beverages consumption is gaining more and more attention, especially in the light of environmental issues. Approximately one third of households' total environmental impact is related to food and drink consumption (EEA, 2005). Food and beverages account up to 20–30% environmental impacts reaching some 60% in separate impact categories like eutrophication (EIPRO, 2006). In all impact categories, food products are among top 35 products with highest environmental impacts. Within food and beverages, meat and meat products are the most important, followed by dairy products. The main environmental impacts from food system include soil degradation, water and energy consumption, eutrophication and water pollution, biodiversity loss, the introduction of hazardous chemicals, cultivation of a genetically modified organism, air pollution, and waste disposal.

Food production and consumption also significantly contributes to the greenhouse gas (GHGs) emissions. GHGs are generated in all stages of the food life cycle (agricultural production, food processing/manufacturing, distribution, public catering/retail, home cooking, consumption, waste disposal), and between stages (transportation) (Sabaté and Soret, 2014). Every stage of food life cycle is encountered with methane, nitrous oxide and carbon dioxide emissions. Therefore, it is important to achieve maximum efficiency using the resources by planning all stages of food production and consumption. One of the important tasks is population changes in food consumption patterns, which may affect not only GHGs decline, but also have a positive effect on overall health and quality of life.

Agriculture is associated with some 10-12% of global GHGs emissions (Smith et al. (2007). Great part of the contribution (40%) is related to soil management (especially use of fertilizers), some 27% is related to cattle and other livestock digestive processes, 10% of the emissions are associated with the cultivation of rice in wetlands, 9% - the use of energy from fossil fuels and the use of electricity, 7% - manure management. The biggest part of the issue (46%) consists of nitrous oxide gas, as well as methane (45%) gas. CO_2 emissions from agriculture account for only 9% of the total emissions (Baumert et al., 2005). Garnett (2011) also highlights 91% emissions "to the farm gate" (excluding land use change) to be emissions of methane and nitrous oxide gas. Emissions "from the farm gate" for the largest part are of carbon dioxide, produced mainly on fossil fuels, to a lesser extent the issue is related to the refrigeration products related emissions. During the life cycle of food products (excluding land use change) 40% of the GHG emissions are related to agriculture, 12% - transportation, 12% - food production, 9% - cooking at home, 7% packaging and retail trade, up to 6% - catering, 5% - fertilizer, 2% - waste disposal as represented in UK case (Garnett, 2011).

Different products have distinct carbon footprint; hence contributing differently to the GHGs. Within global warming potential meat accounts up to 5.5%, poultry 3.9%, sausages and prepared meat products 2.5%, milk, 2.4%, cheese 2.1% of all consumption input to the climate change (EIPRO, 2006). Some other studies (Garnett, 2011) also indicate meat and dairy products as ones mostly contributing to climate change. Other food products and their consumption patterns contribute relatively less, but still are of importance.

Different food consumption patterns and their possibilities for climate change mitigation have gained attention by many scholars (eg. Biesbroek et al. 2014; Pairoti et al. 2014; Sabaté and Soret, 2014 and others). It is estimated that reduction of all meat and dairy products by half could contribute to significant GHGs (25 - 40%), nitrogen emission (40%), land use (up to 23% per capita) reduction (Westhoek et al. 2014). Overall, dietary choices could lead up to 25% reduction of GHGs with significant benefits for the health (Berners-Lee et al., 2012).

To this end, the paper analyses food consumption peculiarities (1990–2010) and food associated GHGs emissions (2002–2010) of the Lithuanian population. In addition, it looks for scenarios of food consumption likely to reduce such emissions.

2. Methodology

The analysis of food consumption and food consumption trends is based on the data of Lithuanian Department of Statistics. There is estimated annual total, as well as product groups per capita food consumption in kilograms. The total food intake includes 9 product groups: cereals (kg), potatoes (kg), meat and meat products (kg), fish and fishery products (kg), vegetables (kg), fruits (kg), milk and milk products (kg), sugar (kg) and eggs (pcs.). Egg units converted to kilograms assuming that 1 egg weighs 50 grams. Food consumption analysis covers 1990-2010 period.

Since detailed data on the consumption of meat products in accordance with the type of meat (beef, pork, and veal) is only available from 2002, rough GHGs emission estimation and analysis is done only for the 2002-2010 period. Based on data on food consumption per capita, individual product groups as well as total food-associated greenhouse gas emissions were estimated. For the calculations, mainly data on GHGs emissions of single products from Stockholm city guide for residents on environmental issues (2009) was used: GHGs associated with grain products, vegetables, potatoes, pork, beef, poultry, fish and fish products. Data on fruit, milk and dairy products, egg consumption related emissions were used from Fredén (2010) study. When calculating the total food consumption related GHG emissions, sugar was not included into calculations. Plassmann et al. (2010) suggests that with 1 kg of sugar is linked from 0.34 to 0.87 kg of greenhouse gas emissions. As annual per capita sugar consumption is about 28 kg in Lithuania, it can be argued that the exclusion of sugar above does not affect significantly the outcome of the investigation.

The assessment of the contribution of fruits to total GHGs emissions is based on the assumption that 50% of the Lithuanian population intake of fruits is apples, 50% - citrus fruits, as Lithuanian residents mostly consume these fruits (Martinez-Palou and Rohner-Thielen, 2008). Apple-related emissions are 0.246 kg CO_2-eq./kg, citrus fruit – 0.567 kg CO_2 eq./kg (Fredén, 2010). The highest GHG emissions per kilogram are related to the beef and veal (14 kg CO_2 eq./kg), pork (5 kg CO_2 eq./kg), vegetables, and fish and fish products in use (4 kg CO_2 eq/kg). The lowest emissions per kilogram of product related to the potatoes (0.2 kg CO_2-eq./kg), fruit (0.246, 0.567 kg CO_2 eq./kg), grain products (0.5 kg CO_2 eq./kg).

Neither the analysis of food consumption nor related GHGs analysis included beverage consumption. CO_2 eq. values were multiplied by mass of each food group consumed (CO_2 eq. used for estimations is presented in Table 2.1).

2.1 Table. Used GHGs emissions calculation factors

Product or product group	GHG emission per product unit, kg CO_2 eq./kg(l)
Cereals	0.5
Vegetables	4

Potatoes	0.2
Fruits and berries	0.246; 0.567
Eggs	1.4
Pork	5
Beef and veal	14
Poultry	3
Milk and milk products	1.1
Fish and fish products	4

To offer the potential Lithuanian population food consumption scenario, in which the food-associated greenhouse gas emission could be reduced, 3 scenarios on possible food consumption patterns were the simulated:

Scenario 1. The first scenario assumes that all Lithuanian residents' nutrition is based on the recommendations for a healthy diet provided by the Lithuanian Health Education and Disease Prevention Center (SMLPC, 2010) associated to the Ministry of Health of the Republic of Lithuania. These recommendations propose nutrition of different product groups based on the number of portions. Minimum total number of portions (14) is proposed for older, passive, over weighted people, the maximum (26 portions) – for younger, more active people who do not have overweight. Healthy eating in this scenario is considered the food consumption in proper ratio, while total food intake does not change (considered average for 2002-2010 is 783.23 kg per inhabitant per year). Scenario simulated 2 cases: *a* case of a minimum number of portions, *b* - maximum. Data used for calculations is presented in Table 2.2.

Table 2.2. Data for the 1st scenario calculations

Product or product group	Recommended number of portions (a; b)	Share in daily ration (a; b), %
Cereals and potatoes	5; 11	36%; 42%
Vegetables	3; 5	21%; 19%
Fuits and berries	2; 4	14%; 15%
Milk and milk products	2; 3	14%; 12%
Meat, fish, eggs	2; 3	14%; 12%

Usual diet consists of 51% plant-origin products and 49% animal-origin products. Replacing the usual diet with healthy eating in the case *a*, plant-origin food products would represent 72%, animal-origin - 28% of the diet. In the case *b,* plant-origin products should consist of 76%, animal-origin products - 24% of the diet (Figure 2.1.). This leads to the pronounced dairy products reduction.

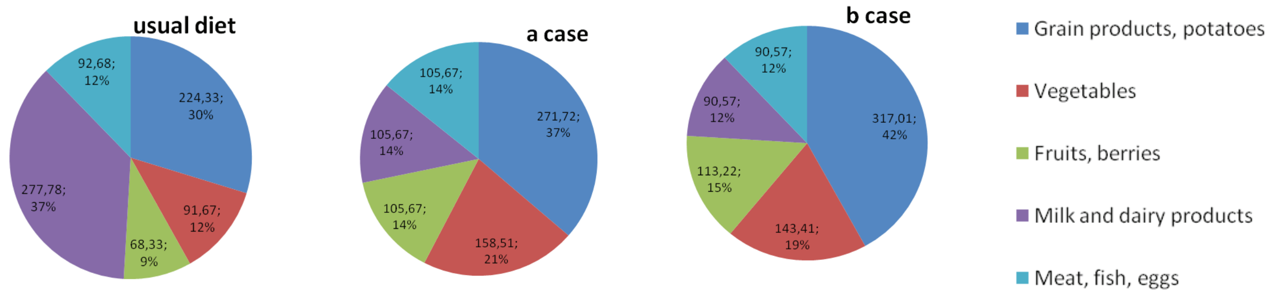


Fig. 1. Composition of ration in the of 1st scenario cases *a* and *b*.

Scenario 2. In the second scenario, it was assumed that food consumption is reduced by 30% in all categories. According to FAO (2013) 31–39% of food is wasted at consumption level in developed regions. As other study (Ventour, 2008) on British households indicates, 61% of wasted food could be consumed if it would be better handled. Hence, elimination of food wasted would reduce related GHGs emissions of all food groups.

Scenario 3. In the third scenario, based on the recommendations of nutrition experts to reduce the consumption of animal products, it was assumed that the consumption of food of animal origin (milk and milk products, fish and fish products, eggs, pork, beef, veal, poultry) is reduced by 30% compared to 2002-2010 average, while the intake of vegetable products remains unchanged. %). According Westhoek et al. (2014), even with reduced intake of all animal-based foods by 50%, the average protein intake will be more than required in EU.

3. Results

3.1. Food consumption in Lithuania in 1990-2010

Over 1990-2001 period a statistical Lithuanian resident consumed on average of 784.2 kg of basic food products per year, during 2002-2010 period - 783.23 kg on average annually. Maximum food intake was recorded in 1990 and 1991 (respectively 1015.5 and 859 kg per person), mainly due to the high consumption of milk and dairy products. Since 1991 food consumption per capita fell by 9% (see Fig. 2).

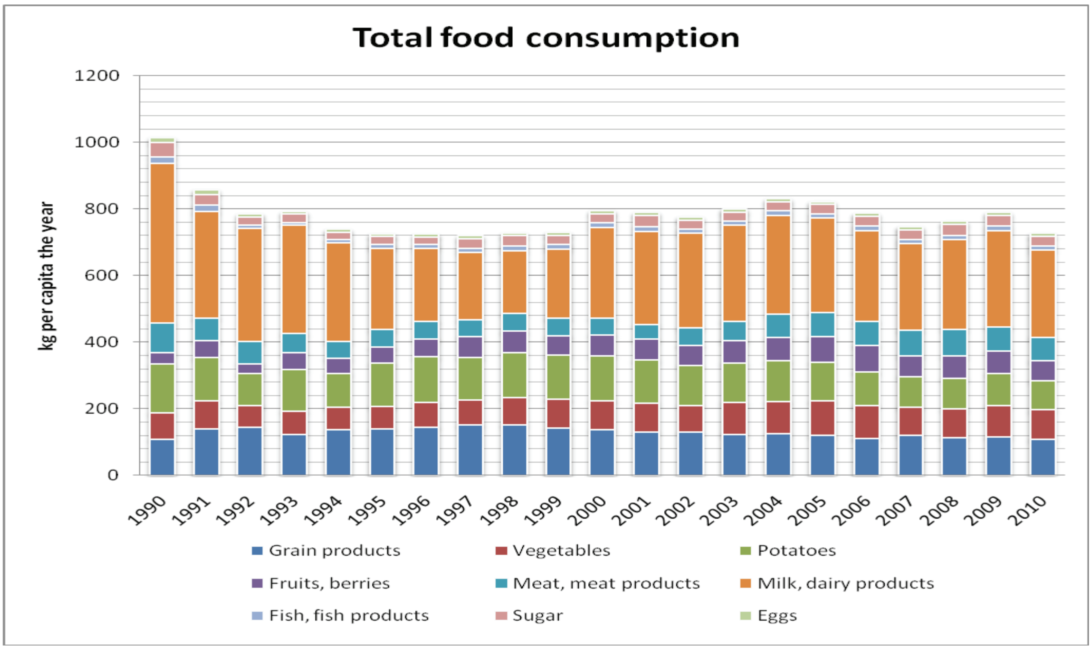


Fig 2. Food consumption in Lithuania in 1990-2010

More than a third of the per capita consumption of food comprises milk and dairy products. During 1990-2001 their consumption accounted for 36%, since 2001 - 35% of the total food intake on average. Other most-consumed group of products - cereal products, followed by – potatoes (Fig. 3). During the period under analysis, consumption of vegetables, fruit, meat and meat products, and sugar consumption increased. Meanwhile fish and fish products and eggs in the total consumption remained unchanged and accounted for 2 and 1% in the total ration. During 1990-2010 milk and dairy products, grain products, and potato consumption decreased (Fig. 3).

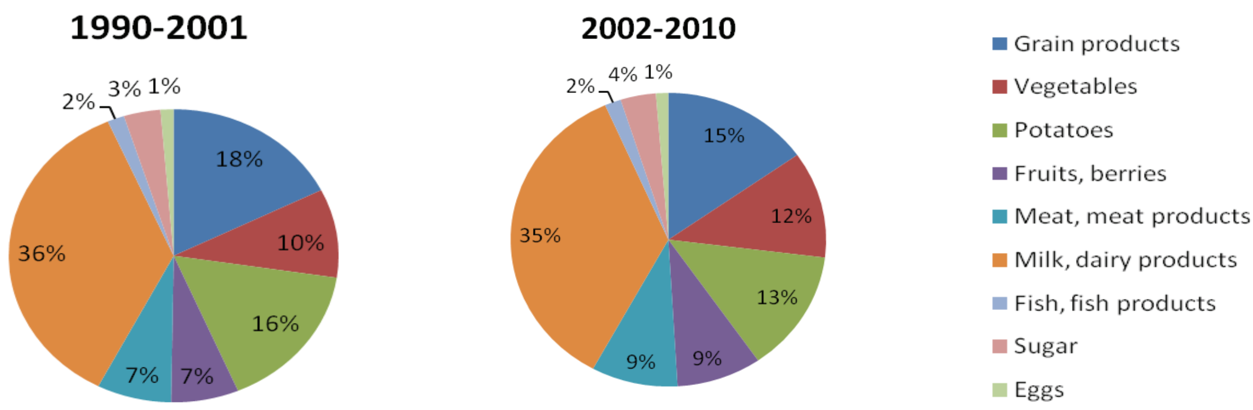


Fig. 3. Composition of the diet of 1990-2010.

For 2002-2010 period, almost 1.4 times increase in meat consumption is registered. Change in meat consumption by type is also notable: 1.6-fold increase in pork and 1.8 - poultry consumption, but even the 2.5 drop in beef and veal (making the largest contribution - 14 kg CO_2-

eq./kg - to GHG emissions). In 2010 beaf and veal consumption amounted to only 6% of the total of meat consumed.

3.2. Food-associated GHGs emissions during 2002-2010 in Lithuania

Food consumption related GHGs emissions during 2002-2010 period ranged from 3.69 to 4.41 Mt. Overal food related GHGs emmisions decrease of 5% is observed during the period (Fig. 4). While the annual population decreases on average was about 23 000 persons per year, a statistically significant correlation between the annual Lithuanian population and food-related GHGs was not detected. If it were assumed that all Lithuanian residents consumed food is produced in Lithuania, these emissions would ammount on average to 18.25% of the total GHGs national emissions (reference national emmisions EEA, 2011).

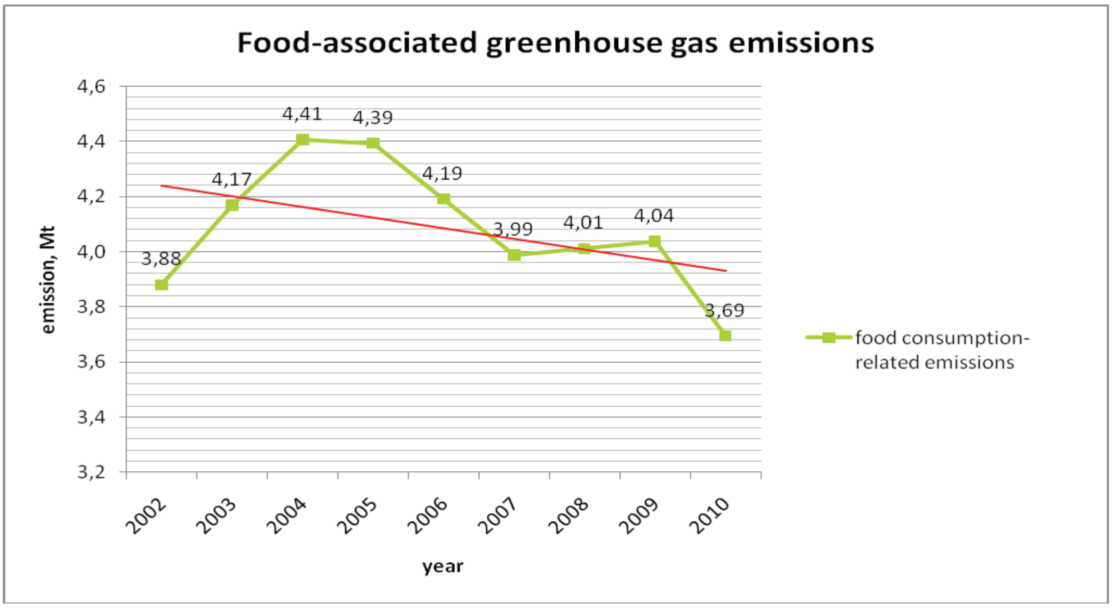


Fig 4. Food-associated greenhouse gas emissions (Mt CO_2 eq.) 2002-2010.

2002-2010 Lithuanian consumed on average 783.23 kg of food products and this was related to 1204.19 kg GHGs emmisions. In 2002 per capita consumption of 777.3 kg of food led to 1118.42 kg of GHG emissions per capita (Fig. 5). In 2010 food (727.06 kg) related GHGs emissions accounted for 1.123.8 kg per capita. Although food consumption slightly decreased per capita GHGs emissions increased. In the beginning of period 39.2% emisions were related to plant-based food products, 60.8% with animal based products. In 2010 the share of plant-based products sligtly increased – 39.6% of the GHGs were related to plant-based food consumption, the remaining - 60.4% - to the animal-origin food consumption.

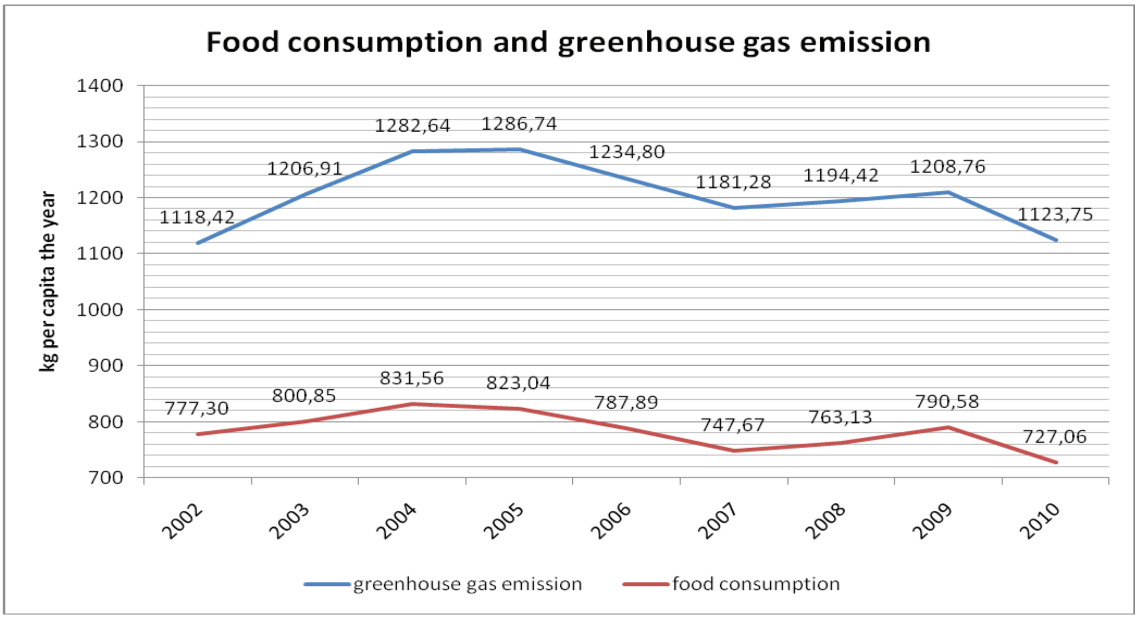


Fig 5. Total food consumption and the associated greenhouse gas emissions per capita during 2002-2010.

Over the period of 2002-2010 the largest part of the GHGs (31%) was associated with the consumption of vegetables (Fig.6). 25% of the emissions were associated with milk and milk products consumption. Pork also significantly contributed to GHGs emissions (16%). Although the average beef consumption amounts only to 7.6 kg annually, it contributes significantly to the GHGs emissions (9%). Altogether, meat accounts up to 30% of total GHGs emissions.

During this period the increase in vegetables, fish and meat products, pork, poultry and decreased grain products, potatoes, milk and dairy products, beef's relative contribution to the total emissions associated with food is observed.

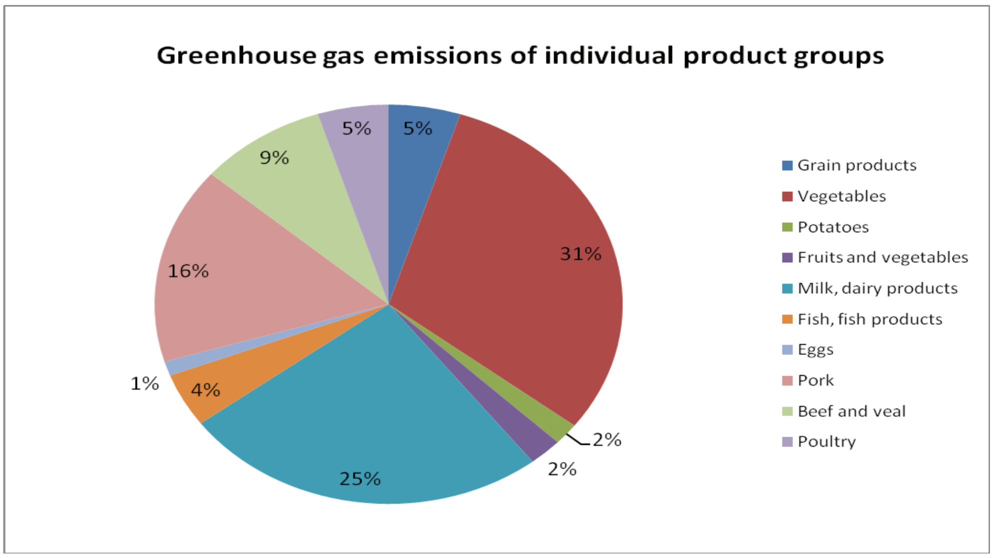


Fig. 6. The contribution of the different groups of products to the food-related GHG emissions on average (%) over 2002-2010.

3.3. GHGs reduction scenarios

Scenario I

Replacing the usual diet with the minimum number of servings of healthy eating in the case *a*, plant–origin food products would represent 72%, of animal–origin - 28% of the diet. Although plant products would account a higher proportion of the diet compared to a usual diet, in the case of the minimum number of servings food-related emissions per capita would even increase by 16% and reach 1394.1 kg CO_2 eq. per person per year. Vegetable consumption related emissions would increase 1.7 times (would account half of all food-related GHGs). A slight increase in the fruit, pork-related emissions and 2.6-fold reduction in the milk and milk-related products GHGs would be observed (Fig. 7).

In the case *b* with the maximum number of servings plant-origin products should consist of 76%, animal-origin products - 24% of the diet. In this case, the annual GHGs food-related emissions would 1264.57 kg per capita, i.e. it would be 5% higher than the actual average of 2002-2010 period (Fig. 7). Compared with the period 2002-2010 data, in the case of *b* scenario vegetable contribution to the emissions would be 1.6 times, grain products - 1.4 times, fruits - 1.7 times bigger. Nevertheless 3-fold reduction of milk and dairy products contribution as well as a slight reduction beef and veal input to food related GHGs could be expected (Fig. 7).

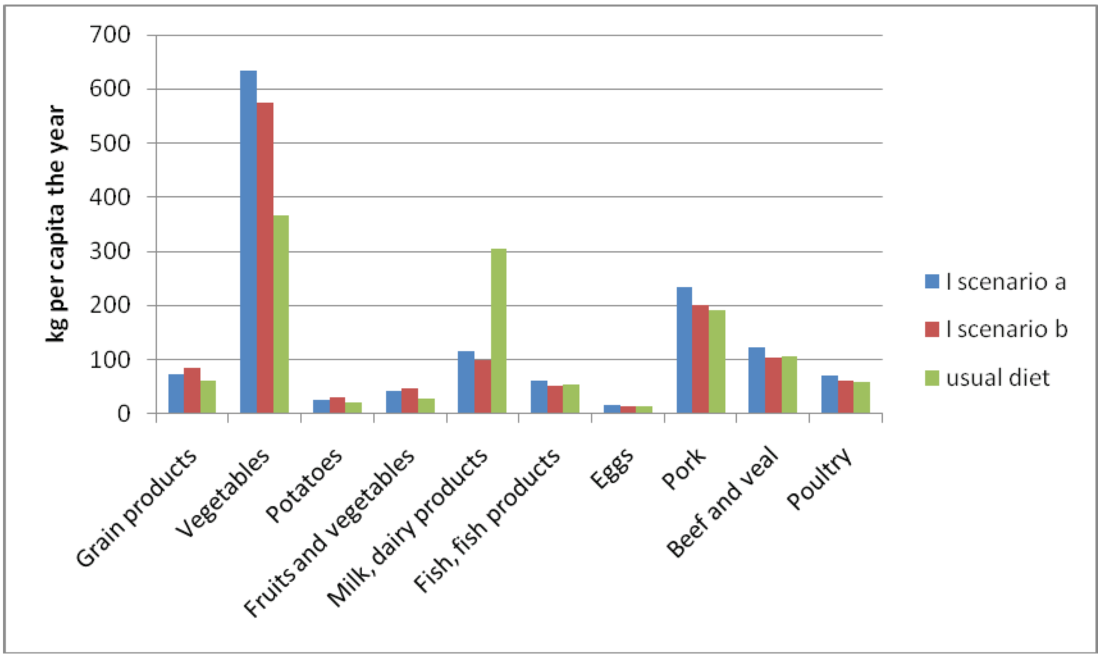


Fig. 7. GHG emissions in *scenario I* and usual food consumption cases

Scenario I *b* case has some advantage over a case *a* in terms of lower GHGs emissions. It contains a higher proportion of cereals, potatoes, fruits and berries, which are associated with relatively lower GHGs emissions. Also share of vegetables, meat, fish, eggs, milk and dairy products (i.e. products with relatively high GHGs levels) would be lower. Despite this advantage, GHG emissions compared to the current situation, would not be lower.

Scenario II

In the second scenario, the food shares in the total ration remain the same, only the amount of food consumed is reduced by 30% compared with 2002-2010 average, i.e., to 548.26 kg per person per year. Food-related emissions would be also reduced by 30% and reach 842.93 kg per person per year. As in the case of the usual diet, the greatest contribution to the GHGs emission would come from vegetables, milk and dairy products, pork consumption.

Scenario III

Reducing the consumption of animal - origin products by 30% compared with 2002-2010 average, plant – origin food in the total ration would compose 62%, animal-origin products - 38%. Food intake would be reduced only by 14% compared with conventional consumption and food-related GHGs emissions capita per year would account to 985.47 CO_2 eq.kg. This is 18.2% lower compared with the estimated average of 2002-2010 emissions per capita (Fig. 8). Nevertheless, the largest contribution to the total emissions would be the same as in the case of usual diet – related to vegetables, milk and dairy products, pork consumption.

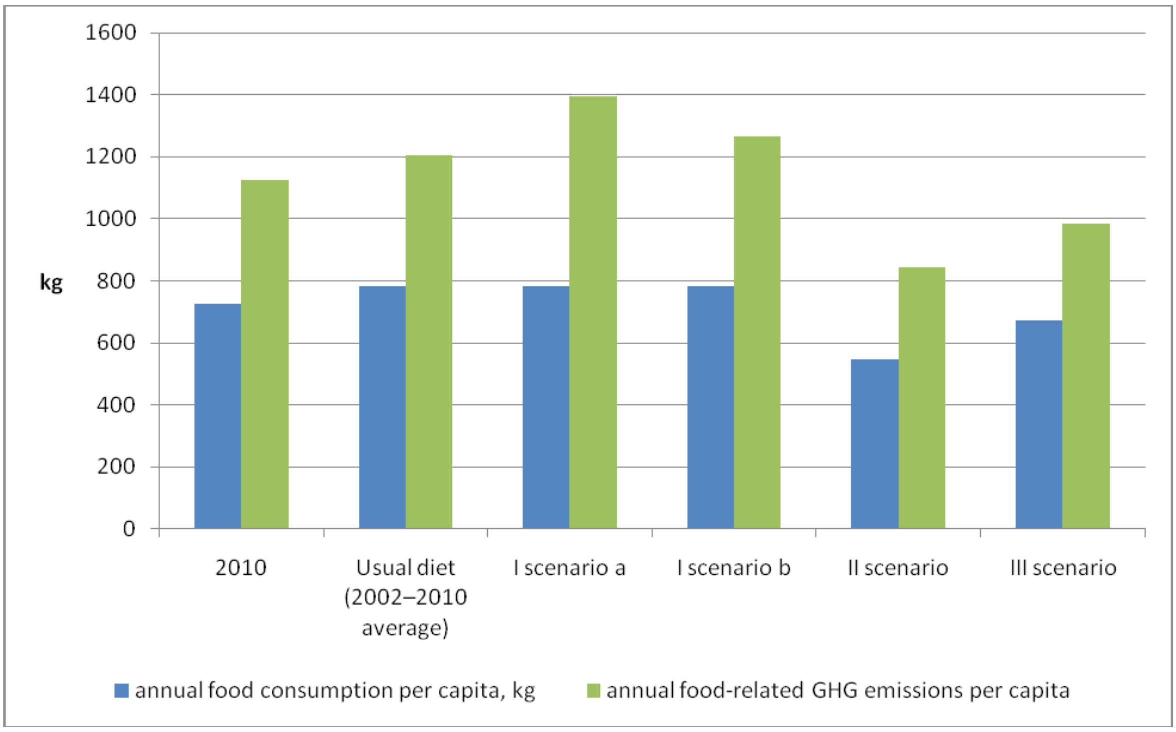


Fig. 8. Comparison of food consumption and related GHGs emissions scenarios

4. Discussion and conclusions

The largest food-associated emission of GHGs is most likely to be in the scenario I *a* and *b* cases. In the *a* case it would be 16%, in the case *b* - 5% higher than the average of 2002-2010 emissions. In the both II and III scenario, GHGs emission per capita would be much less to compare to the average of the 2002-2010 period. Second scenario would result in emission reductions by 30%, third - 18.2% compared to the average of 2002-2010 emissions.

In the case of scenario I, redistribution of ratio of different groups of food consumption without reducing the total amount of food consumed would not bring positive results in terms of reduction of the food-related GHGs emissions. In *b* case scenario emissions only slightly differs from the average of 2002-2010, but animal – origin foods in this case is just up 24%, while in 2010 accounts for 49% of the diet. So this might have if not environmental, but health implications.

Scenario II is quite challenging i.e. brings to a one-third reduction in overall food consumption and the best result: the food-associated emission reductions by 30% compared to the 2002-2010 average. It is 361 kg of CO_2 eq. per person per year. Such reduction could be expected by cutting food waste generation at households. However, some food waste is unavoidable. Still this scenario might be an option, even with slighter reductions. It is more feasible as could bring also financial benefits for consumers and might be more acceptable. If pre- and post- purchasing food waste is eliminated even more significant results might be achieved. A UK case (Berners-Lee et al., 2012) indicates up to annual 0.94 t CO_2 eq. per capita reduction of food waste related GHGs emissions if pre- and post- purchasing food waste is avoided.

Scenario III would be most beneficial in to two aspects: only one group of products has to be addressed (and only 14% reduction of food intake) and reduction of food-associated GHGs emission is quite effective (18.2%). As Westhoek et al. (2014) state, even with reduced all animal-origin foods intake by 50%, the average EU protein intake will be more than required. Of cause, even relatively reduction of meat products might be a challenging task. Some studies indicate that people are reluctant refuse or reduce meat in their ration (Tobler et al., 2011; Vanhonacker et al., 2013) though it might significantly reduce their carbon footprint. It is estimated that reduction of all meat and dairy products by half could contribute to significant GHGs (25-40%) reduction and contribute to other environmental problems (reducing nitrogen emission (40%), land use (up to 23%) per capita) (Westhoek et al. 2014) with significant benefits for the health (Biesbroek et al. 2014). Vegetarian or vegan diets are seen as most promising ones, even compared with Mediterranean diet (Pairotti et al., 2014). Some researchers (Sabaté and Soret, 2014) argue that radical reduction of meat and dairy products is unavoidable achieving sustainability goals.

To achieve significant results in GHGs mitigation, not only reduction of animal based food consumption, but also promotion of local plant based nutrition and food waste reduction (Meier et al. 2014), reduction of luxury food consumption, i.e. combination of several nutritional adjustments is needed (Jungbluth et at. 2012). This is probably the most probable option as transition to more sustainable diets is rather challengeable. Eating is not only about health and environment, but also about culture and pleasure (Macdiarmid, 2014). This might be the reason why promotion of healthier diets gives no significant results, as most people might not be interested in healthy eating. Nevertheless, adding environmental aspects might reach even those not concerned about health; create new cultural phenomena, new expectations from more sustainable food etc. Other (Tobler et al., 2011) suggest that particularly health and taste aspects should be combined to achieve diets that are more sustainable. Summing up, obstacles like taste preferences, culinary traditions, social norms have to be taken into account (Sabaté and Soret, 2014) while achieving shift to plant-based diets.

In general, consumers play an important role, even taking into account that consumers' choices depend a lot on the systems providing products and services (Akenji, 2014). Food chains today more than ever are long and complex. For consumer it is important to realize that the simpler and shorter the food chain have less impact on the environment, as well as bringing more benefits to both the manufacturer and the same consumer. In general, informational campaigns are needed, as consumers still lack knowledge of food consumption related environmental impacts (Tobler et al. 2011). Producers do not know, who is the purchaser, and the purchaser do not know, where and how was the product grown and/or produced (CORPUS, 2010). Continuous innovation, large different evaluations of risk, related with food, contradictory and short-lived nutrition information in the media, information overload has led to consumer confusion (Bergmann, 2002; Hawkes, 2004). Many consumers are overwhelmed and rather stick to their habitual choices (Mick et al., 2004). Here, Laestadius et al. (2013) stress the continued need of NGOs engagement with educational campaigns in the issue (eg. the case of meat reduction and climate change).

To the consumer Garnett (2011) offers to reduce meat and dairy consumption, as well as the overall food consumption (eat no more than is necessary to maintain a healthy body weight). Also to avoid food waste and handle properly unavoidable waste, more often choose seasonal foods, prepare food for more than one person, and not for one day, consume less products with lower nutritional value (alcohol, tea, coffee, chocolate and so on.), choose environmentally friendly travel shopping way.

In the case of Lithuania, food consumption related environmental impacts are not addressed on policy level, only some NGOs projects on awareness rising were implemented. Hence, there is no sufficient information, nor policy, which would induce changes in this area. Main sustainable development document – National sustainable development strategy (2009), do not refer to concrete consumption targets, and only aims at consumption policy creation and implementation (Dagiliute, article accepted for publication). Food as an area, which could be addressed, is still forgotten. Yet, this is not only the case of Lithuania. Reisch et al. (2013) indicate that so far strategies for sustainable food consumption are uncommon, existing regulations concentrates mostly on food safety and are limited with information provision. Nevertheless, results are not the ones desired. Although consumer‘s knowledge about healthy nutrition, healthy food, food storing and cooking has increased, competencies in nutrition as well as in cooking and food storing have decreased at the same time (CORPUS, 2010). Consumption of fast food and out of home consumption is increasing; also, time spent on eating and cooking has decreased significantly over the past few years (Hamermesh, 2007). In some cases initiatives on sustainable food consumption patterns (eg. local food promotion) is even seen as a contradiction to EU law (Reisch et al., 2013). Hence, policies still need to be reviewed and supplemented even on EU level. As indicated by Girod et al. (2014), policies regarding climate change mitigation have to be improved and extended to all consumption categories.

Coming back to Lithuanian case, bottom up initiatives and consumer awareness rising still is the primary option in the case of Lithuania. Policy initiation and implementation regarding sustainable consumption especially for the consumer side are not likely to be prompt, unless EU will initiate these changes. National Strategy for Climate Change Management Policy (2012) focuses mainly on energy efficiency and renewable energy. Consumption patterns, especially those not directly related with energy are omitted. Regarding food, only some objectives address agriculture as such for GHG emission mitigation.

More detailed analysis on food consumption patterns, related GHGs emissions, possible reductions targets, obstacles and benefits are needed before policy formation and implementation in Lithuanian case.

References

Akenji, L., (2014), Consumer scapegoatism and limits to green consumerism, *Journal of Cleaner Production* 63, 13–23.

Baumert, K. A., Herzog, T., Pershing, J. 2005. Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. *World Resources Institute Report.* USA. p 122.

Bergmann, K. 2002. *Dealing with consumer uncertainty: public relations in the food sector.* Berlin: Springer. p 215.

Berners-Lee, M., Hoolohan, C., Cammack, H., Hewitt, C.N. 2012. The relative greenhouse gas impacts of realistic dietary choices. *Energy Policy* 43, 184–190

Biesbroek, S., Bueno-de-Mesquita, H. B., Peeters, P. H.M., Verschuren, W.M. M., van der Schouw, Y.T., Kramer, G.F.H., Tyszler, M., Temme, E., H.M. 2014. Reducing our environmental footprint and improving our health: greenhouse gas emission and land use of usual diet and mortality in EPIC-NL: a prospective cohort study. *Environmental Health*, 13:27, 1-9.

CORPUS. 2010. Reisch, L. A., Scholl, G., Eberle, U. CORPUS Discussion Paper 1 on Sustainable Food Consumption. p 25. URL: http://www.scp-knowledge.eu/sites/default/files/Food_Discussion_Paper_1.pdf

EEA. 2005. *Household consumption and the environment*. European Environment Agency report No 11/2005. Luxembourg: Office for Official Publications of the European Communities. P. 68.

EEA. 2011. *Greenhouse gas emission trends and projections in Europe 2011*. European Environment Agency report No 4/2011. Luxembourg: Publications Office of the European Union, p. 147.

Environmental Impact of Products (EIPRO). 2006. *Analysis of the life cycle environmental impacts related to the final consumption of the EU-25*. European Commission, Joint Research Centre (DG JRC), Institute for Prospective Technological Studies. Technical Report EUR 22284 EN. p. 139

FAO. 2013. Food wastage footprint. Impacts on natural resources. Summary report. FAO, p. 63. URL: http://www.fao.org/docrep/018/i3347e/i3347e.pdf

Fredén, J. 2010. Analys och beräkning av emissions faktorer för växthusgaser. Magisteruppsats. 85 p.

Garnett, T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food policy.* 36,. S23–S32.

Girod, B., van Vuuren, D. P., Hertwich, E.G. 2014. Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions. *Global Environmental Change* 25, (2014) 5–15

Hamermesh, S. D. 2007. Time to eat: household production under increasing income inequality. *American Journal of Agricultural Economics.* 89 (4),. 852–863 p.

Hawkes, C. 2004. *Nutrition labels and health claims: the global regulatory environment.* Geneva: WHO. P. 74.

Jungbluth, N., Itten, R., Schori, S. 2012. Environmental impacts of food consumption and its reduction potentials. *8th International Conference on Life Cycle Assessment in the Agri-Food Sector* (Ed. M. S. Corson, H. M.G. van der Werf), 100-105

Klimatsmart i hemmet. 2009. Stockholms stad miljöförvaltningen. Stockholm. p 35.

Laestadius, L.I., Neff, R.A., Barry, C.L., Frattaroli, Sh. 2013. Meat consumption and climate change: the roleof non-governmental organizations. *Climatic Change* 120:25–38

Macdiarmid, J. I. 2014. Seasonality and dietary requirements: will eating seasonal food contribute to health and environmental sustainability? *Proceedings of the Nutrition Society* 73, 368–375

Martinez-Palou, A., Rohner-Thielen. 2008. Fruit and vegetables: fresh and healthy on European tables. *Eurostat.* Statistics in focus. p 8.

Meier, T., Christen, O., Semler, E., Jahreis, G., Voget-Kleschin, L., Schrode, A., Artmann, M. 2014. Balancing virtual land imports by a shift in the diet. Using a land balance approach to assess the sustainability of food consumption. Germany as an example. *Appetite* 74, 20–34

Mick, D. G., Broniarczyk, S. M., Haidt, J. 2004. Choose, choose, choose, choose, choose, choose, choose: emerging and prospective research on the deleterious effects of living in consumer hyperchoice. *Journal of Business Ethics,* 52, 207–211

NSSD, (2009), National strategy for sustainable development, approved by Resolution No 1160 of the Government of the Republic of Lithuania of 11 September 2003 (as amended by Resolution No 1247 of the Government of the Republic of Lithuania of 16 September 2009).

Pairotti, M. B., Cerutti, A. K., Martini, F., Vesce, E., Padovan, D., Beltramo, R. 2014. Energy consumption and GHG emission of the Mediterranean diet: a systemic assessment using a hybrid LCA-IO method. *Journal of Cleaner Production*. Article in Press.

Plassman, K., Norton, A., Attarzedeh, N., Jensen, M. P., Brenton, P., Edwards-Jones, G. 2010. Methodological complexities of product carbon footprinting: a sensitivity analysis of key variables in a developing country context. *Environmental Science & Policy.* doi:10.1016/j.envsci.2010.03.013.

Reisch, L., Eberle, U., Lorek, S. 2013. Sustainable food consumption: an overview of contemporary issues and policines. *Sustainability: Science, Practice, & Policy*, Volume 9|Issue 2, 7 -25

Sabate´, J., Soret, S. 2014. Sustainability of plant-based diets: back to the future. *The American Journal of Clinical Nutrition*, 100(suppl):476S–82S.

Seimas of Republic of Lithuania. 2012. National Strategy for Climate Change Management Policy. Decision No. XI-2375, p 78.

Smith P., Martino D. et al. 2007. Agriculture. Climate Change 2007: Mitigation. *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* New York: Cambridge University Press,p. 851.

SMLPC. 2010. Sveikos mitybos rekomendacijos [Recommendations for a healthy diet]. Metodinės rekomendacijos. Vilnius: Sveikatos mokymo ir ligų prevencijos centras, p. 38.

Tobler, Ch., Visschers, V.H.M., Siegrist M. 2011. Eating green. Consumers' willingness to adopt ecological food consumption behaviors. *Appetite* 57, 674–682

Vanhonacker, F., Van Loo, E.J., Gellynck, X., Verbeke, W. 2013. Flemish consumer attitudes towards more sustainable food choices. *Appetite* 62, 7–16

Ventour, L. 2008. *The food we waste.* Banbury/Oxon: WRAP. 236 p. URL: http://wrap.s3.amazonaws.com/the-food-we-waste.pdf

Westhoek, H., Lesschen, J. P., Rood, T., Wagner, S., De Marco, A., Murphy-Bokern, D., Leip, A., van Grinsven, H.,. Sutton, M. A., Oenema, O. 2014. Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change* 26, 196–205

R&D and LCA across the supply chain: Choice of Unsaturated Polyester Resins for cc-GRP Pipe Systems

Marcin Pazdro [a], Thomas Simoner [b], Victor Vladimirov [c, *]

[a] REICHHOLD AS, P.Boks 2061, N-3202 Sandefjord, Norway
[b,c] HOBAS Engineering GmbH, Pischeldorfer Str. 128, AT-9020 Klagenfurt, Austria

Abstract

In today's economy efforts are taken towards re-using of available resources and using of resources which are re-generable, thus reducing the impact on the environment. For the polymer industry the development of alternative and renewable raw materials represents an essential task. The study evaluates the different choices of unsaturated polyester resins (UPR) for production of centrifugally-cast glass reinforced pipe (cc-GRP) systems.

The environmental impacts of three types of resin were evaluated and compared. The resins are: UPR standard, UPR containing recycled PET material (rPET-UPR) and UPR containing bio-sourced material (BIO-UPR).

The analysis focuses on comparing the variations in environmental indicators caused by resin selection for three increasingly complex product layers (Base plate of cc-GRP shaft, cc-GRP Shaft and 1km cc-GRP Pipe-system).

The study equally provides an insight onto R&D and LCA collaboration across the supply-chain. One of the main challenges in LCA today is using specific data from the suppliers instead of generic data. The paper indicates how LCA tools and established R&D processes can be employed to transfer LCA calculations across the supply-chain.

The use of specific BIO-UPR resin selected for evaluation results in higher environmental indicators than for the standard product (i.e. “total renewable energy”, “net use of fresh water” or “depletion of abiotic resources”). On the other hand, the bio-based component is just one of many production components. Particularly, high share of styrene and propylene glycol (PG) tend to increase values (i.e. CO2-eq emissions calculated for PG or Styrene are twice as high as for the bio-component used in production). Knowing this, it is possible to design new bio-based resins having more favorable sustainability footprints than those in-use today.

The use of rPET-UPR results in better environmental indicators for the final product, especially as the quantity of material increases (i.e. for 1km pipe system).

BIO-UPR and rPET-UPR are alternatives which are realistic in terms of costs and which ensure the required quality for the manufactured products. rPET-UPR can be used for production of complete pipe systems, with positive environmental indicators. Mechanical proprieties of BIO-UPR restrict its usability and use of this resin presents similarities with the debate regarding use of bio-diesel.

Key words: R&D, supply-chain, polymers, GRP, BIO resin, recycled PET resin

*Corresponding author, Tel. +43 463 482424

REICHHOLD HOBAS® Make things happen.

E-mail addresses: marcin.pazdro@reichhold.com
(M. Pazdro), thomas.simoner@hobas.com (T. Simoner), victor.vladimirov@hobas.com (V. Vladimirov)

1. Introduction

Companies today are expected to work toward achieving environmental responsibility across the supply chain in order to evaluate the life-cycle environmental impacts of products. Products manufactured within the supply chain should be evaluated from an environmental point of view regarding their design, distribution, use, disposal and recycling. One of the main challenges is the reduction of the use of non-regenerable materials. In other words, efforts need to be maximized to re-using available resources or to using resources which are re-generable, thus reducing the impact these products have on the environment. Many companies however do not have a coherent and systematic approach for incorporating sustainability in their business relationships. Even though internal reports and improvements may be pursued, deeper cooperation across the value chain is often reduced to data transfer or exchange of readily available information without necessarily involving common work or joint R&D processes.

The analysis of environmental impacts of products has been gaining attention due to increasing refinement of life cycle analysis methods (LCA). The ability to innovate and to jointly assess the market viability of products through R&D processes as well as the environmental imprint of products is the direction that HOBAS and REICHHOLD jointly established.

Inclusion of environmental assessment in material evaluation was possible on basis of the long-term close collaboration of the R&D departments of both companies. Regarding life cycle assessment, the first step was to perform an initial LCA analysis of a generic cc-GRP pipe in order to identify the key material and energy flows for the determination of environmental impacts. For instance, the Global Warming Potential (GWP) 100a expressed in CO2-eq. was considered.

As shown in the Fig. 1 below, the main inputs are determined by resin and glass fibre, followed by production and transport activities.

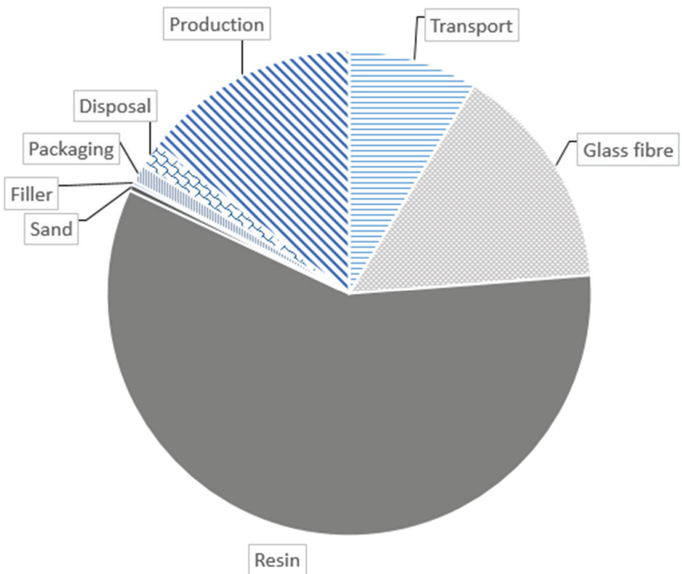


Fig. 1. Generic Impact of Material and Energy Flows for cc-GRP Pipes (GWP 100a)

HOBAS® Make things happen.

According to ISO 14044:2006 "Environmental management -- Life cycle assessment -- Requirements and guidelines", "specific data should be used for those processes that contribute the majority of the mass and energy flows in the system". The Technical Report CEN/TR 15941:2010 "Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data" indicates that "specific data for a certain product or process should be used".

"Often, however, such specific data are not available and the practitioner has to identify information from other sources; generic data then replaces specific data". According to the technical report, "generic data should never replace specific data if specific data are available". Furthermore, EN 15804:2012 "Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products" states that, "as a general rule, specific data derived from specific production processes or average data derived from specific production processes shall be the first choice" as a basis for calculation. The LCA normative references cited only indicate that using specific data (data from direct suppliers) is literally good practice when it comes to life cycle assessment. This is at the same time one of the greatest challenges, as a limited number of companies today have readily available datasets.

The present study evaluates the different choices of unsaturated polyester resins (UPR) for cc-GRP pipe systems, from a LCA perspective. To this purpose the environmental impacts of three types of resin were evaluated and compared. The resins are: Standard UPR, UPR resin containing recycled PET material (denoted rPET-UPR) and UPR resin containing bio-sourced material (denoted BIO-UPR).

An important step in using new resins is to determine the possible applications and to ensure that final product properties shall be maintained. In addition the choice of the new resin should also prove its economic functionality, so that products can be manufactured and be made available to market at reasonable costs. Some of the essential questions which needed to be answered included: For which applications can rPET-UPR, respectively BIO-UPR be used? Will the final product quality be the same as for the standard resin? How do environmental impacts of products manufactured with Recycled and BIO-UPR differentiate from standard resin? Answers to these questions have been gradually identified and represent the core of this study.

rPET-UPR can be successfully employed to manufacture cc-GRP pipe systems. One possible application, as presented in this study, is sewage systems. Some of the raw materials used in polyester resin production process can be derived from polyethylene terephthalate bottles. REICHHOLD has developed an innovative technology to substitute up to 30 w-% of typical raw materials with recycled post-consumer or post-industrial PET material. The rPET-UPR concept can be used for the production of the entire structure of the GRP pipe, thus contributing to the essential short- and long term properties of the products. Testing results have proven that pipes produced with the new resin meet all normative requirements. The values are comparable to existing data derived from pipes made with standard resin types.

BIO-UPR is a medium reactivity orthophthalic resin which is produced with addition of renewable resources originated from soybean oil. In recent years there has been increasing interest in the development of thermosetting resins using bio-based products that can reduce or potentially eliminate the usage of petroleum based hydrocarbons. The BIO-UPR resin was tested in the HOBAS laboratory to determine possible applications. Based on product tests and manufacturing trials it was determined that BIO-UPR resin can be successfully employed in production of GRP Shafts, namely for the production of the Shaft Base Plate

REICHHOLD HOBAS® Make things happen.

(environmental impact indicators are further presented in this study). The Shaft Base Plate was produced based on vacuum production process. This design eases the way of manufacturing and improves the repeatability and is at the same time a very lean production technology.

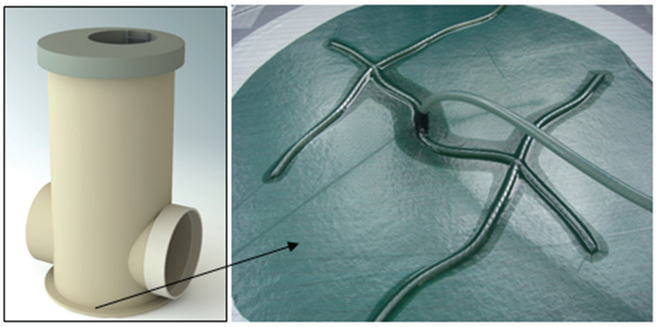


Fig. 2. Base Plate (part of Shaft) manufactured with BIO-UPR by vacuum infusion

2. Method

The goal of this study is to compare the environmental impacts of standard UPR resin (reference) with rPET-UPR resin and BIO-UPR resin, as employed in HOBAS products. Based on product and manufacturing trials, BIO-UPR can be employed for the production of the Base Plate of GRP Shafts. In order to make the comparisons more relevant two declared units (cradle to gate) and one functional unit (cradle to cradle) were defined: one typical unit Base Plate of GRP Shaft DN 1000 mm and one typical unit GRP Shaft DN 1000 mm. The functional unit was defined as 1000 meters typical buried sewage non-pressure cc-GRP Pipe system of pipes DN 400 mm with couplings and Shafts DN 1000 mm, with a reference service life of 100 years. The different levels of calculation are depicted in Fig. 3 below.

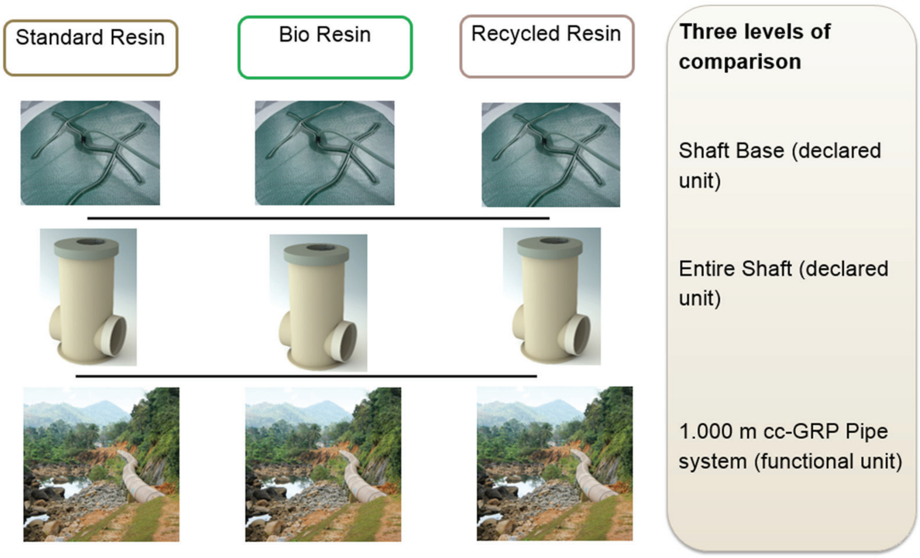


Fig. 3. Levels of comparison (declared and functional units)

System boundaries were defined in accord with ISO 14040-44 and EN 15804. Details about each stage is presented in the Table 1 below:

Table 1 System boundaries for the functional and declared units

Stage	Detail	Level
Raw material supply (A1)	Included. Main raw materials are: unsaturated polyester resin, fibre glass, sand and filler. To these additives are added. Inclusive packaging of main raw materials.	Functional and declared unit

Transportation – product stage (A2)	Included.	Functional and declared unit
Manufacturing (A3)	Included. Inclusive use of ancillary products for manufacturing, energy flows (electricity, natural gas and diesel), water consumption and packaging of products.	Functional and declared unit
Transportation – construction / installation stage (A4)	Included. Installation of the pipe system was calculated according to ÖNORM EN 1610 Verlegung und Prüfung von Abwasserleitugnen und –kanälen. The installation phase includes materials and activities connected to installation of the piping systems at location, excavating a trench of 1000 m, placing the components according to requirements and backfilling of the trench. This includes use of machines and lifting equipment, consumption of machinery, re-filling material (gravel), transportation of products / transportation of wastes from the installation site / transportation of gravel from the mine to the installation site/ transportation of local mass to the landfill and waste management from the installation site.	Functional unit
Use stage (B1 – B5)	The use stage is calculated for 1.000 meters of GRP pipe system during 100 years. Energy required to transport water in the piping system (i.e. pumps) is excluded from the LCA as the piping system is based on gravity. Flushing or cleaning activities of the pipes during the operation stage are excluded from the analysis, as the activity is assumed to have minor impact on the total results. It is assumed that no hazardous or toxic materials are used for cleaning. It is assumed that maintenance activities, replacements or repairs of pipes not will be necessary during the course of 100 years.	Functional unit
End of life stage (C1 – C4)	It is assumed that the most likely end of life scenario will be that the pipes are left in the ground after use.	Functional unit
Issues beyond the system boundary.	Not included.	Functional and declared unit

3. Calculation background and supply-chain collaboration

3.1 Calculation background

The LCA calculations account for 99,9% product mass. For some materials (i.e. additives and ancillary) specific LCA datasets were not readily available at the time of the calculation and these were replaced with generic datasets. Sensitivity analysis was performed in order to evaluate the influence of these materials on the results. Input material and energy flows comprising more than 1% of the total mass or contributing more than 1% to primary energy consumption are considered. The production inputs and process-specific waste and process emissions were considered. Input material flows below 1% mass were also included; however, packaging of additives and ancillary materials (material flows under 1%) was not included. Capital goods were included.

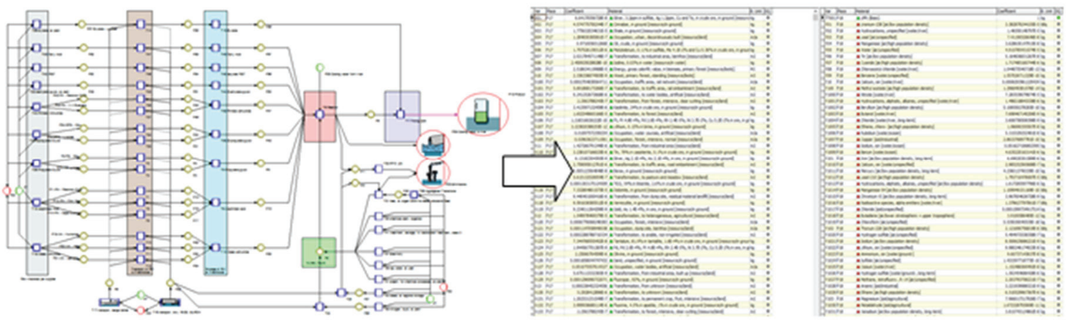
The geographical scope of the study is in Europe. Pipes are produced at the HOBAS European factories in Germany, Poland, Austria and Romania. Pipe DN 400 mm with coupling is calculated as an average European pipe (all locations), Shaft (including Base Plate) are calculated for the Austrian factory. The period is that of year 2012; data from production facilities was collected from the year 2012. Generic data are from the Ecoinvent Database (Version 2.2). Site-specific data have been collected in order to characterize the production processes and their related physical flows. Data collected from suppliers (LCA data sets) includes resin and glass-fibre.

3.2 Supply-chain LCA collaboration

Calculations for HOBAS and REICHHOLD models were performed with Umberto for LCA developed by ifu Hamburg. The software represents the collaborative tool for LCA modeling between the two companies in the value chain (input material, resins = REICHHOLD and end-product, cc-GRP pipe systems = HOBAS). Using the same calculation tool enabled data exchange easily either in Umberto or Ecospold formats. Visualization, valuation of results and easy exchange of datasets constituted key advantages in joining efforts between two companies and especially in the field of R&D. Calculated datasets (products) were exported and, equally, the environmental impacts were readily obtained with the valuation function. The same function was equally used to verify received datasets, in order to validate the received information. Adopting a LCA collaborative tool and internalizing it constitutes sound premises for long term sustainability assessment. The association of the LCA tool with R&D departments allows evaluating the environmental impacts and benefits of products from the very first phases of product development.

Another key aspect of collaboration is the sharing of proprietary data. Concerns may be issued that if LCA product models are shared, then proprietary data may be thus also transmitted. Even if confidentiality agreements are in place, there is always caution to sharing data and models that are specific and part of the core competence of a company.

The advantage with a LCA collaborative tool is that while models may be discussed together, data which is actually transmitted across the supply-chain and used by the next company in the calculation of its own products can be exported as a typical life cycle inventory (LCI) balance sheet. Within the balance sheet all required material flows for the LCA calculations are included; however it is not possible to identify the structure and the specific proprietary data in the initial calculation model. Thus, confidential internal data remains with the producer, which is an important aspect that needs to be addressed. Deeper collaboration on



the other hand is equally possible and permits reviewing of the models in detail, if producers in the supply chain agree to proceed so.

Fig. 4. REICHHOLD UPR LCA proprietary model (left) is exported as a typical LCI balance sheet (right) for confidentiality purposes

Finally, scenario development emphasizes connection with R&D and technical departments, new products and raw materials can be tested and new data integrated in already existing models. Variation of multiple parameters as well as calculation of various types of sensitivity analysis were performed. Thus, environmental impacts can be assessed readily and early in the development stage. These possibilities were unavailable just a few years ago.

4. Results

As previously mentioned, BIO-UPR can so far be used for the Base Plate of the Shaft. Therefore a first analysis at this level is most relevant for this resin. rPET-UPR and standard UPR resin can be used for all types of products (Base Plate, Shaft and Pipe System). In a second step, the Base Plate is integrated in the Shaft. At this level, differences in environmental impact assessment caused by the BIO-UPR are noticeable in a lesser extent as Base Plate becomes part of a bigger element, the Shaft. Finally, impact of the BIO-UPR can be detected at the System level, albeit in an even lesser extent as pipes with couplings are added to the calculation. The results are compared against standard UPR resin, thus allowing to position the rPET-UPR and the BIO-UPR as possible alternatives.

The Fig. 5 below indicates the mass proportion of BIO-UPR in the Base Plate, Shaft and 1000m System.

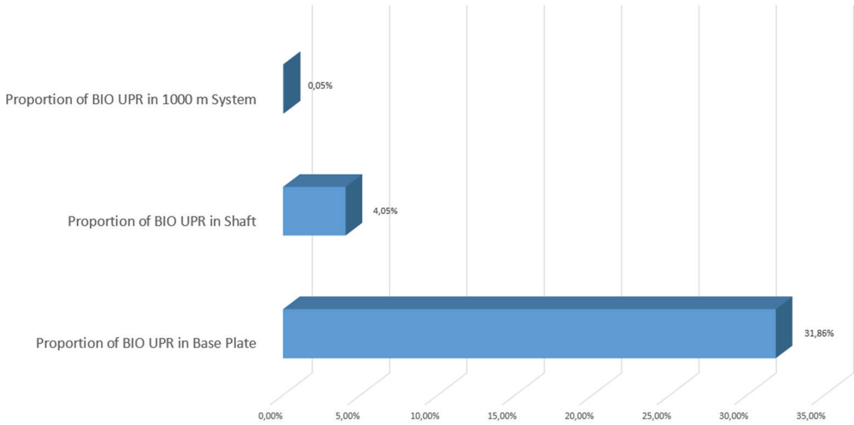


Fig. 5. Mass proportion of BIO-UPR at different calculation levels

The results at Base Plate level clearly indicate differences in the environmental impacts of the Base Plate manufactured with BIO-UPR, as compared with standard UPR and rPET-UPR. If results for the latter two resins are quite close, results for the Base Plate with BIO-UPR present interesting variations. For instance CO2-eq. emissions are similar but indicators such as “total renewable energy”, “net use of fresh water”, “depletion of abiotic resources”, “stratospheric ozone depletion” and “photochemical ozone creation (POCP)” vary considerably in case of BIO-UPR.

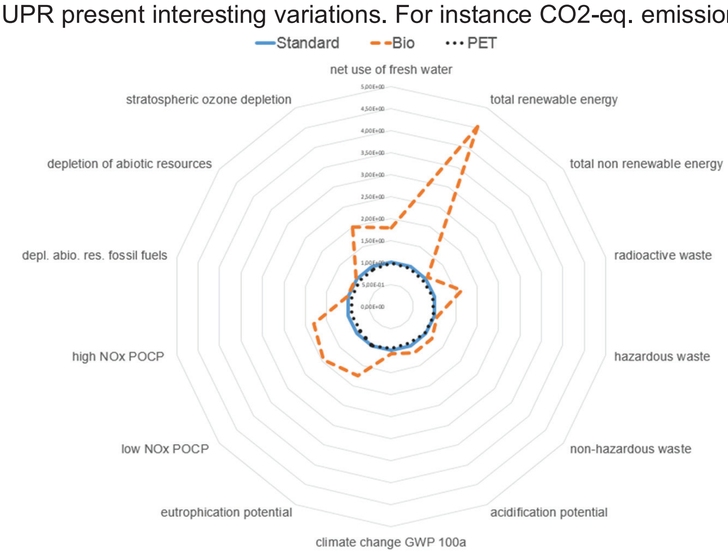


Fig. 6. Base Plate Level comparison

The results of the comparison for the Shaft product are presented in the Fig. 7 below.

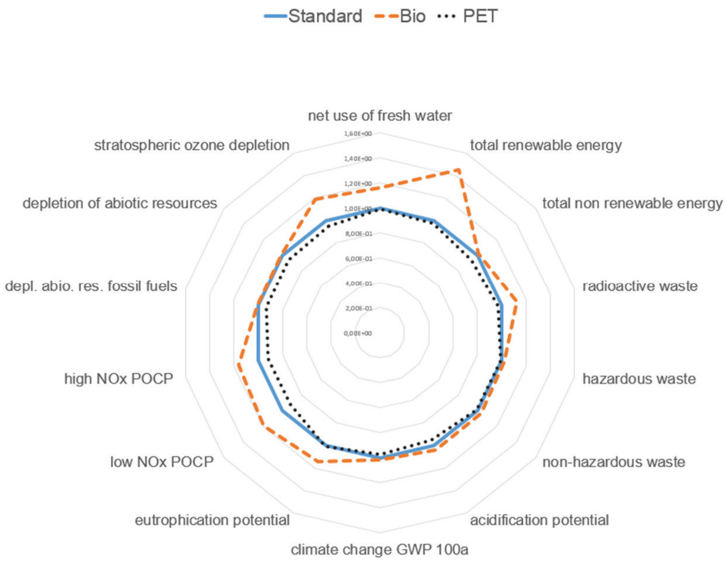


Fig. 7. Shaft Level Comparison

By comparing the three products it can be noticed that results are similar to the Base Plate level but subdued as the BIO-UPR Base Plate becomes a part of the Shaft. Environmental results for the Shaft produced with rPET-UPR are similar and slightly better with the standard UPR Shaft.

Environmental impacts for the 1000m Pipe System are determined for three scenarios: Pipe System produced with standard UPR resin, Pipe system produced with standard UPR while the Base Plate for Shafts is produced with BIO-UPR and, finally, Pipe system produced with rPET-UPR including the Base Plate. The results of the comparison are presented in the Fig. 8 below.

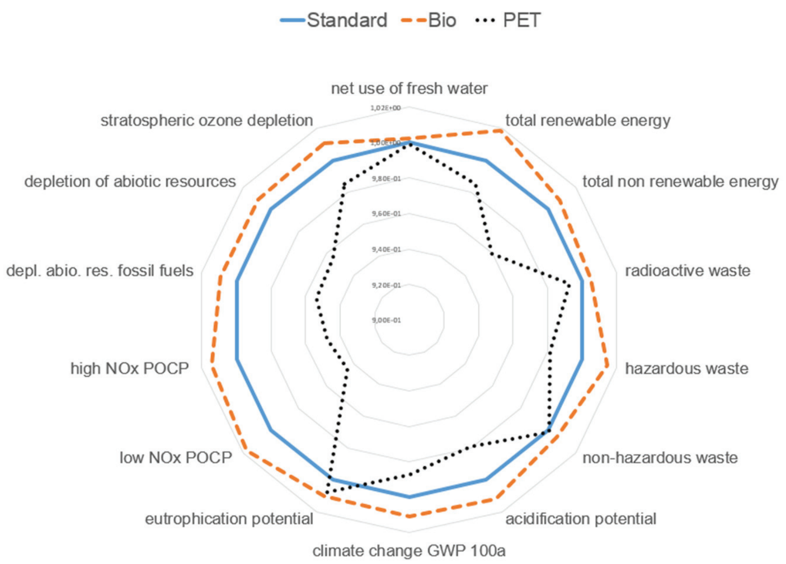


Fig. 8. Pipe System Level Comparison

By comparing the three systems it can be noticed that results are within the same trend as previously analyzed regarding use of BIO-UPR (several increases of environmental indicators) and of rPET-UPR (several decreases of environmental indicators).

4. Discussion

By using BIO-UPR, the environmental impact indicators for the Base Plate increase. It is important to keep in mind that BIO-based component is just one of many components used to produce the BIO-UPR resin. As further analysis has showed, it is not the BIO component but other ingredients of the resin which are negatively affecting some of environmental indicators. Particularly, high share of Styrene and Propylene Glycol (PG) in this resin tend to increase some values (i.e. Global Warming Potential –GWP- calculated for PG or Styrene is twice as high as for bio-component used in production). This aspect is detailed in Table 2 below, presenting the impact of selected raw materials on GWP 100a values. Knowing this, it is possible to design new bio-based resins in the future having a much more favorable sustainability footprint than today.

Table 2 Normalized %-contributions of selected raw materials to GWP 100a [kg CO2-eq.] for BIO-UPR resin.

Raw material	GWP 100a for specific raw materials in 1 kg of BIO-UPR	%-contribution for GWP 100a for 1 kg resin	Weight %	Normalized %contribution
Styrene Monomer (SM)	1,31	36,13	30,14	1,20
Propylene Glycol (PG)	1,11	30,41	24,65	1,23
Fatty acids	0,28	7,59	12,12	0,63

At a second look, the indicator with most variation is "total renewable energy". This indicator varies with 450% as compared with the Base Plate produced with Standard resin. Consumption of renewable energy is however today increasingly prioritized. According to statistics, "in 2011 energy from renewable sources was estimated to have contributed 13.0% of gross final energy consumption in the EU27, compared with 7.9% in 2004 and 12.1% in 2010". Furthermore, "the share of renewables in gross final energy consumption is one of the headline indicators of the Europe 2020 strategy. The target for the EU27 to be reached by 2020 is a share of 20% renewable energy use in gross final energy consumption" (Urhausen, 2013). It may be argued that, on one hand with use of BIO-UPR the consumption of renewable energy increases but on the other hand renewable energy provides definite advantages (it does not consume limited and more polluting resources such as fossil fuels). Therefore, the question: if renewable energy is a priority and is preferable to conventional energy sources, is it then a better choice to consume more renewable energy than conventional fossil fuels in order to obtain the same product?

Another aspect, equally interesting, is the increase in water consumption for the product with BIO-UPR. This is not a surprise as the BIO-UPR is obtained through vegetable mass. The question here may be not only the consumption of water but also what happens with the water. If water is part of the agricultural cycle and returns to nature, to which degree does increased consumption of water raises an issue? On one hand, increasing biofuels production may "impact water quality due to the use of agro-chemicals and through harmful substances produced in feedstock processing and conversion" (Ajanovic, 2010). On the other hand, in order to reduce water consumption and competition with food production, "biofuel feedstock under irrigated conditions could be discouraged and feedstock appropriate for rain-fed cultivation could be used" (Fischer et al., 2009).

Increase of the indicator "depletion of abiotic resources" is equally interesting as abiotic resources include crude oil, metals ores (i.e. gold, iron, copper, silver, etc.) and mineral compounds. Another indicator with a relevant increase is "photochemical ozone creation" (POCP). Generally, the main source of emissions for this indicator is fuel combustion followed by VOCs (volatile organic compounds). VOCs are commonly emitted from solvents, which is in this case related to current technology in production of BIO-UPR. Values for the "stratospheric ozone depletion" indicator likely also relate to this issue.

Considering the use of BIO-UPR as an alternative may also connect to the biofuels controversy. The increase of biofuels consumption takes place within the present "unsustainable pattern of energy use, which is characterized by a profligate (mis-)use of abundant and cheap fossil fuels" (Sachs, 2007). The unsustainability of the present energy consumption trends can be analyzed in the Reference Scenario of global energy demand to 2030. The demand is expected to increase by just over a half between 2007 and 2030 – an average annual rate of 1.6 per cent. Fossil fuels will likely remain the dominant source of energy, accounting for 83 per cent of the overall increase in energy demand between 2004 and 2030. The share of biomass will decrease a little, accounting for 10 per cent of total primary energy demand in 2030, since the traditional forms of biomass use will decrease, offsetting the growing use of biofuels and biomass-based electrical power. The share of all other renewable energy technologies will likely increase from 0.5 per cent today to only 1.7 per cent in 2030" (Birol and Mandil, 2007). Use of biofuels raises the dilemma of diverting farmland or crops for fuels production to the detriment of the food supply (the issue was increasingly debated during the 2006 - 2008 commodity price boom).

On the other hand, biofuels may also represent an opportunity, "an important tool with which to combat hunger and poverty" (Graziano da Silva, 2007) with an "enormous potential for accelerating growth in many of the world's poorest countries, fostering agriculture and providing modern energy to one third of the world's population" (Diouf, 2007). For example, a study of the World Bank concluded that "the effect of biofuels on food prices [in the 2006 – 2008 period] has not been as large as originally thought" (Baffes and Haniotis, 2010).

One in-depth approach to the issue of BIO-UPR is to globally assess the results, considering all environmental impacts. For example, impacts on climate change are similar for Standard resin and BIO-UPR but indicators such as "renewable energy" consumption, "depletion of abiotic resources", "photochemical ozone creation" and "eutrophication" (the latter due to the use of fertilizers) are higher for BIO-UPR. In addition, normalized results indicate further that among considered indicators, "depletion of abiotic resources" may be one of the key values even if the variation of this indicator is not as significant as of the other indicators mentioned above.

Regarding the Shaft, the indicators which vary most for the Shaft with BIO-UPR are "total renewable energy", "photochemical ozone creation" (POCP), "net use of fresh water" and "eutrophication potential". These indicators have been discussed in regard with the BIO-UPR for the Base Plate. The indicators which vary most for the Shaft with rPET-UPR, in the sense that environmental impacts are in this case reduced, are "total renewable energy", "photochemical ozone creation" (POCP), "depletion of abiotic resources" and "depletion of abiotic resources fossil fuels". In general, environmental results for the Shaft produced with rPET-UPR are similar, slightly better as compared with the standard UPR resin Shaft. Again, use of rPET-UPR for the product seems to be the environmentally friendly choice.

For the Pipe System level, where the Shafts include Base Plates produced with BIO-UPR there is increased consumption notably for the "total renewable energy" indicator. However, it can be noticed that, for one km pipe system, the variation of impacts when BIO-UPR is used for manufacturing is less significant due to the small mass proportion of the BIO component in the entire system.

The Pipe System produced with rPET-UPR presents altogether good values, with environmental impacts below those of the System manufactured with standard UPR. Most variation, in the positive sense of reduced environmental indicators, is noted for "photochemical ozone creation" (POCP), "total renewable energy", "depletion of abiotic resources" and "depletion of abiotic resources fossil fuels".

5. Conclusions

Choice of BIO-UPR seems to be a more complex choice and can hardly be reduced to the simple question of, for example, which resin generates more or less CO2-eq emissions for the product. In a first step, increased consumption of "renewable energy", "water consumption", "stratospheric ozone depletion" and "photochemical ozone creation" are noticed from the calculation. This places the use of BIO-UPR in the mainstream concern of sustainability today, associated with biofuels, where such alternatives need to be thoroughly assessed for their benefits as well as for their possible disadvantages. However, the exploration of alternatives to limited (fossil) resources and the common efforts to identify and provide applicable and cost-effective solutions to existing raw materials is a fruitful and necessary step. Regarding use of BIO-UPR for the Shaft and 1000m Pipe system, it can be noticed that variation amplitude is lower as compared with the Base Plate.

It can be observed that the use of rPET-UPR constitutes an interesting alternative, which may definitively be a valid choice from an environmental perspective. rPET-UPR has an overall excellent behavior in terms of mechanical and environmental performance. BIO-UPR, while in its incipient stage in finding applications in the GRP Pipe Systems poses more challenges and may constitute a possible choice, given that its environmental impacts are pondered at different levels (Shaft Base, Shafts, and Pipe System).

Identification and evaluation of environmental alternatives is especially significant for the constructed space as it intertwines with the nature around us. Enhancing R&D with LCA assessment capabilities across the supply chain is one of the best choices which can be met today in ensuring sustainability. This may not necessarily point out to just comparisons about products in terms of environmental impact categories but to a more profound and aware analysis as well as identification of long-term solutions that provide most functionality while respecting the surrounding environment.

References

Ajanovic, A., 2010. Biofuels versus food production: Does biofuels production increase food prices?, Energy, 5

Baffes, J., Haniotis T., 2010. Placing the 2006/08 Commodity Price Boom into Perspective, Policy Research Working Paper 5371, World Bank, documents.worldbank.org/curated/en/home, 2

Birol F., Mandil C., 2007. IEA scenarios, what role for biofuels in the global energy scene? Revue des Ingénieurs, 12–14

BS EN 15804, 2012. Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products, British Standards Institute, London, 26

CEN/TR 15941, 2010. Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data, European Committee for Standardization (CEN), 7

Diouf J., 2007. Biofuels should benefit the poor, not the rich. Financial Time.

Fischer G. et al., 2009. Biofuels and food security, OFID Pamphlet Series 39, International Institute for Applied system Analysis (IIASA)

ISO 14044, 2006. Environmental management -- Life cycle assessment -- Requirements and guidelines, International Organization for Standardization, Geneva, 10.

Sachs I., 2007. The Biofuels Controversy, United Nations Conference on Trade and Development, DITC - International Trade: Trade, Environment and Development, UNCTAD, 3-7.

Graziano da Silva J., 2007. Biocombustiveis para os pobres. Ecodebate, www.ecodebate.com.br

NPCR 019, 2012. Piping systems for use for sewage and storm water (under gravity). Norwegian EPD Foundation, www.epd-norge.no/category.php?categoryID=642

Urhausen J., 2013. Renewable energy - Share of renewable energy up to 13% of energy consumption in the EU27 in 2011, Eurostat Press Office, europa.eu/rapid/press-release_STAT-13-65_en.htm, 2

The role of values, environmental risk perception, awareness of consequences and willingness to assume responsibility for environmentally friendly behaviour: Lithuanian case

Genovaitė Liobikienė[a], Justina Mandravickaitė[b], Romualdas Juknys[a]

a Vytautas Magnus University, Vileikos g. 8, LT-44404 Kaunas, Lithuania
[b] Baltic Institute of Advanced Technology, Sauletekio av. 15, 10224 Vilnius, Lithuania

Abstract:

Applying the Values-Beliefs-Norms model the impact of values on environmentally friendly behaviour was based on the Goal Framing theory approach. According to the Lithuanian representative survey conducted in 2011 and applying factor analysis two different value orientations: self-transcendence and self-enhancement were identified. The results showed that people with stronger self-transcendence value orientation, which are guided by normative goals, are more perceptive of environmental problems, assuming responsibility and behaving in a more environmentally friendly way. After applying the causal model to the data it was found that the most important direct determinants of environmental behaviour were self-transcendence value orientation, environmental problem perception and the assumption of responsibility. However, a gap between awareness of behavioural consequences and real behaviour was observed. These findings could be important for policy implications which seek to promote more environmentally friendly behaviour.

Keywords: values, environmental friendly behaviour, Goal Framing theory, Values-Belief-Norms, gap

1. Introduction

Over the last decade great efforts have been put into policies and programmess aimed at the production processes. However, in recent decades the importance of the consumption perspective has been highlighted as high levels of consumption threaten the quality of the environment and the sustainable development processes (Tukker, Jansen, 2006; Chitnis, Hunt, 2012, Tukker et al, 2010, Liu et al., 2010). While seeking sustainable consumption, which aims to achieve that the growth of goods and services consumption should not worsen environmental quality, the most important element is to promote more environmentally friendly behaviour.

The study of environmentally friendly behaviour and its determinants is well documented. Moreover, the Values-Beliefs-Norms (VBN) model is the most popular one for the investigation of environmental behaviour determinants. This model was described by P. Stern (2000). The researcher proposed that behavioural friendliness towards the environment depends on values, which influence attitudes towards the environment. It influences the awareness of behavioural consequences, the ascription of responsibility and, thereby, pro-environmental actions. However, in this study through using the Goal Framing model is a new approach.

Firstly, in this research the analysis of values impact on environmentally friendly behaviour was based on Goal Framing theory. Moreover, regarding the perception of values influence and environmental problems (Steg et al, 2014), which in general is partially analysed, this study encompasses the impact of this variable on behaviour and how it is related to the awareness of consequences and the assumption of responsibility as well. Additionally, in this study through analysing the determinants of environmentally friendly behaviour contrary to VBN theory, the path model was not applied but the general causal model instead. It included socio-demographic variables, values orientations, environmental problem perception, and the awareness of behavioural consequences and the assumption of responsibility. Applying this model in which man as a whole unit was considered, all factors such as values, perception of environmental problems and behaviour are related; the determinants which influence environmentally friendly behaviour directly were evaluated.

Therefore, this paper is organized as follows: section 2 briefly reviews the literature on Goal Framing theory, impacts of values, environmental problem perception, the awareness of behavioural consequences and the assumption of responsibility for environmental behaviour, as well as environmental friendly behaviour barriers. Section 3 explains survey methods, questionnaire scales and the proposed model. The results are presented in section 4. The discussion and policy implications are to be found in section 5. And section 6 produces the main conclusions.

2. Literature review

2.1 Goal Framing theory and impact of values on environmentally friendly behaviour

The concept of values is not new to the field of environmental psychology, as most studies have been conducted referring to VBN theory. According to this theory, a majority of research work declared that values, particularly biospheric, determined environmental attitude (Hansla et al., 2008, Stern et al, 1993, 1995, Lee, 2011, Lopez-Mosquera, Sancher, 2012, Papagiannakis, Lioukas, 2012, van Riper, Kyle, 2014). Thus values help to shape the judgments people make about the world around them. Also, values organize the guiding principles in life and determinants of attitudes. Thereby values mostly influence behaviour via behaviour-specific beliefs, attitudes, and norms (De Groot, Steg, Dicke, 2008; Gärling et al., 2003; Jakovcevic & Steg, 2013; Nilsson et al., 2004; Poortinga, Steg, Vlek, 2004; Lee, 2011, Stern, Dietz,1994; Stern et al.,1995, Ives, Kendal, 2014; Steg, De Groot, 2012, van der Werff et al, 2013) However, other authors have declared that values have direct effects on behaviour (Stern et al, 1995). Moreover, values act as filters or amplifiers with regard to information about threats to objects of value (Slimak, Dietz, 2006; Brunso et al, 2004).

Furthermore, value orientation is mostly related to Goal Framing theory, which stated that behaviour is determined by prevailing goals (or motivations) (Lindenberg, Steg, 2007, Lindenberg, Steg, 2013, Steg et al, 2014). Other authors also defined values as desirable goals that serve as guiding principles in one's life (Brunso et al, 2004, Schwartz, 1992; van der Werff et al, 2013). Additionally, values reflect overarching goals which people find the most important in life in general. Meanwhile goals per se reflect what motivates people in a given situation, which depends not only on their values but also on situational cues (Lindenberg, Steg, 2007, Lindenberg, Steg, 2013, Steg et al, 2014). .

Goal Framing theory states that there are three different types of goals, which govern environmental behaviour in a given situation: hedonic goals, gain goals, and normative goals. Hedonic goals lead individuals to focus on ways to improve their feelings of pleasure or seeking excitement, alongside avoiding any effort. Thereby, people with hedonic goals may be motivated to engage in environmental friendly behaviour, because it is enjoyable and pleasurable. Gain goals mainly prompt the seeking of material benefit, for example, to save money. Normative goals lead people to behave on the appropriateness of actions and it makes them especially sensitive to what people think they ought to do. In other words, people may be motivated to engage in environmental friendly behaviour because they think protecting the environment is the right thing to do (Lindenberg, Steg, 2007, Lindenberg, Steg, 2013; Steg et al, 2014).

Meanwhile, according to the greatly used three value orientations (egoist, altruist and biospheric) in the research work of environmental psychology (Stern et al., 1999; Stern, De Groot & Steg, 2007, 2008; Steg, De Groot, Dreijerink, Abrahamse, & Siero, 2011; Steg et al., 2005; Steg et al 2014), egoistic values influence the chronic accessibility of gain goals and make a person focus on safeguarding or increasing his or her resources. Altruistic values reflect a key concern with the welfare of others and biospheric values follow a key concern with nature and the environment for its own sake (De Groot & Steg, 2007, 2008; Steg, De Groot, Dreijerink, Abrahamse, & Siero, 2011; Steg et al., 2005; Stern et al, 2014, Hurst et al, 2013). Both latter groups of values affect the chronic accessibility of normative goals in a given situation

Taking into account that researchers have found strong links between biopheric and altruistic environmental values, (De Groot, Steg, 2007; Nordlund, Garvill, 2002; Stern & Dietz, 1994; Swami et al 2010; Hurst et al, 2013) past empirical findings have supported a two-dimensional structure of values. In this light, biospheric-altruistic values fall into a higher order category of self transcendence values, reflecting a key concern with collective interests (Dietz, Fitzgerald, &

Shwom, 2005; Steg & De Groot, 2012, Steg et al, 2014). Meanwhile, egoistic values are encompassed by a broader category of self-enhancement values, reflecting a key concern with one's individual interests. Thus people with self-enhancement values are guided by hedonic and gain goals, while people who are characterized with self-transcendence values are led more by normative goals (Steg, Perlaviciute, Van derWerff, Lurvink, 2014, Steg et al, 2014).

L. Steg and colleagues (2014) stated that the most important element in seeking pro-environmental behaviour is to strengthen normative goals. Moreover, other authors have also found that normative considerations, which are related with self-transcendence values, promote pro-environmental actions (Aquino et al, 2009; Lindenberg, Steg, 2007; Schultz & Zelezny, 1998; Thogersen, Olande, 2002). Brown and Kasser (2005) also argue that people who hold that family and community are very important are also likely to engage in less harmful environmental behaviour.

However, researchers have found that individuals can strongly value nature and the environment, but do not see themselves as people who act pro-environmentally (Gössling et al., 2009, Lorenzoni et al., 2007; Miller et al., 2010, Juvan, Dolnicae, 2014, Van der Werff et al., 2013). This gap could occur because people do not acknowledge environmental problems (Gössling et al., 2009; Lorenzoni et al., 2007, Juvan, Dolnicae, 2014) or because they do not believe that these problems could or should be mitigated via individual actions (Van der Werff et al., 2013, Juvan, Dolnicae, 2014), and thus deny or displace individual responsibility (Gössling et al., 2009, Lorenzoni et al., 2007; Miller et al., 2010, Juvan, Dolnicae, 2014). Therefore, it is very important to evaluate the impact of environmental problem perception, the awareness of consequences and willingness to assume responsibility as the main determinants of environmentally friendly behaviour. Moreover, analysing values researchers found that values affect the strength of goals in a particular situation, thereby influencing the perceived importance of environmental issues, the different consequences of behavioural options as well as the perceived likelihood of these consequences (De Groot et al., 2013; Verplanken, Holland, 2002, Steg et al, 2014).

2.2 Impact of environmental problem perception, awareness of behavioural consequences and willingness to assume responsibility on environmentally friendly behaviour

In the vastly used VBN theory most studies of environmentally friendly behaviour determinants encompassed the environmental concern variable, which has been defined as environmental attitude, and measured referring to the New Environmental Paradigm (NEP) scale (Dunlap et al., 2000). Inherent to the idea of NEP are consumers' recognition of their role in relation to nature, reciprocal threats from environmental deterioration, ecological limits, imbalances in nature, and ecological catastrophes (Abdul-Muhmin, 2007; Dunlap et al, 2000; Fernández-

Manzanal et al., 2007; Robinot & Giannelloni, 2009; Martin, Bateman, 2014, van Riper, Kyle, 2014, van der Werff et al, 2013, Slimak, Dietz, 2006).

These researchers revealed that individuals who demonstrate strong environmental concern are more likely to undertake waste recycling, green purchasing behaviour and lower energy consumption (Lin, Huang, 2012, Baumann et al., 2002; Tseng, Hung, 2013, Sapci, Considine, 2014). The justification for this is that consumers who support this aspect of environmental concern are willing to behave in a more environmentally friendly way in order to help environmental protection (Roberts, Bacon, 1997). However, other reviews of the literature on the relationship between concerns and behaviour illustrated a weak relationship (Mostafa, 2007, Zhao, 2014, Alwitt and Pitts, 1996; Bamberg, 2003; Tseng, Hung, 2013).

However, it is proposed that, instead of environmental concern, or environmental knowledge and consciousness about important environmental issues which may lead to environmentally responsible behaviour (Casey & Scott, 2006; Fraj & Martinez, 2006; Martin, Bateman, 2014, Kollmuss, Agyeman, 2002; Bamberg, Möser, 2007 Zsoka et al, 2013), the environmental problem perception variable is included, which in the environmental psychology literature is only partially analysed. Thereby the latter determinants precisely reflect environmental threats, which are determined by people's behaviour. Thus environmental problem perception could motivate people to behave in a more environmentally friendly way in order to contribute to the mitigation or reduction of environmental problems. However, a gap can occur between environmental problem perception and behaviour because some people believe that technological solutions will solve environmental problems (van der Werff et al, 2013, Gössling, et al, 2009; Lorenzoni et al., 2007, Juvan, Dolnicae, 2014, Zsoka et al, 2013). Therefore, the awareness of behavioural consequences and the assumption of responsibility are very important.

The awareness of consequences, according to VBN theory, is a necessary prerequisite for the assumption of responsibility (De Groot, Steg, 2007; Poortinga et al., 2004; Hansla et al., 2008, Steng et al., 2014). Moreover, higher problem awareness is also associated with higher outcome efficacy (De Groot & Steg, 2009; Gärling et al., 2003; Steg & De Groot, 2010; Steg et al., 2005). Additionally, growth of the responsibility perception significantly increases people's readiness to more environmentally friendly behaviour (Liu et al., 2010, Wang et al, 2014, Lopez-Mosquera, Sanchez, 2012). Therefore people for whom environmental problems are very important, who relate them to their behaviour and take responsibility to solve these problems, should behave in a more environmentally friendly way.

2.3 Environmentally friendly behaviour barriers

When analysing the determinants of environmentally friendly behaviour, it is very important to consider barriers, which can be an obstacle to certain behaviour and cause a gap between attitude and behaviour. One of these barriers is ingrained habits which are very difficult to change (Wang et al, 2014, Wolters, 2013). Therefore, much of the prior environmental research on the theory of reasoned action and planned behaviour shows that there is a gap between environmental beliefs and actions which is caused by the great difficulty of changing habits (Ozaki, 2011, Gadenne et al, 2011, Pickett-Baker, Ozaki, 2008; Zhao, 2014)

Furthermore, economic reasons, particularly for green purchases, are very important. Those people whose incomes are rather low cannot afford to buy these products. Therefore income, in general, tends to play a decisive role (Lopez-Mosquera, Sanchez, 2012). Thereby initial cost have been identified as an environmental barrier in a number of studies (Gardner, Stern, 2008; Jager, 2006; Lane, Potter, 2007; Niemeyer, 2010; Ozaki, 2011; Vermillion, Peart, 2010; Gadenne et al, 2011, Lukman, 2013; Zhao, 2014). Moreover, pro-environmental values do not match up with the green behaviour of consumers because many green products in the marketplace do not meet their expectations (Rex and Baumann, 2007, Tseng, Hung, 2013) or have poor brand image (Lane and Potter, 2007, Gadenne et al, 2011)

Also, in order to behave in a more environmentally friendly way it is important to have the abilities to do so, for example, to have access to a green product supply (Sapci, Considine, 2014, Wang et al, 2014; Wolters, 2013, Juvan, Dolnicae, 2014). Moreover, other authors found that people do not save energy, water, or change behaviour because they are busy and have no time to put any concrete efforts into acting in a more environmentally friendly way (Valkila, Saari, 2013, Wolters, 2013, Niemeyer, 2010, Gadenne et al, 2011, Lorenzoni et al., 2007, Juvan, Dolnicae, 2014). Additionally, it is very important to have enough knowledge and information about environmental problems, behavioural consequences and modes on how to behave in a more environmentally friendly way (Kollmuss, Agyeman, 2002; Bamberg, Möser, 2007; Zsoka et al, 2013; Salmela, Varho, 2006, Young et al., 2010, Gadenne et al, 2011, Juvan, Dolnicae, 2014, Sapci, Considine, 2014, Mostafa, 2007; Haron et al., 2005; Zhao, 2014, Flamm, 2009; Tanner, Kast, 2003; Tseng, Hung, 2013).

3. Method

3.1. Survey samples characteristics

In order to ascertain the impact of Lithuanian citizens' values, environmental problem perception, the awareness of behavioural consequences and the assumption of responsibility on environmentally friendly behaviour, a representative survey was conducted between 8th and 17th April 2011. During the survey 1011 citizens of Lithuania were questioned face-to-face. Citizens between 15-74 years old were chosen as the target group. Interviewees were selected using the quota sampling method based on gender and age in proportion to the size of Lithuanian population. 47% of respondents were males and 53% females. Regarding the age structure, 22% of respondents were 15-24 years old, 17% - 25-34 years old, 17% - 35-44 years old, 13% - 55-64 years old and 14% - 65-74 years old. The sample size included a sampling error of 3% at the significance level of 95%. Answers to questions consisted of a quadric-score system ranging from 1 (absolutely irrelevant, do not agree absolutely) to 4 (very important, agree absolutely).

3.2. Questionnaire scales

S. H. Schwastz (1992a) factor analysis for value classification was applied in this study, which helped to simplify the inter-relationship complexity among variables when identifying common factors. Thus it allowed a deeper view into the fundamental data structure, where two-dimensional structure of values are separated and named as self-transcendence and self-enhancement. The modified (rotated) weights (correlations) of dependant factors' items are presented in Table 1. the first factor (self enhancement value) explained 30 % of variance and this internal consistency of scale is rather large (Cronbach's α = 0.72). Meanwhile, the second factor (self-transcendence value) explained 16 % of variance with Cronbach's α equal to 0.68.

Table 1 Values rotated component matrix

Values	Component	
	1 (Self-enhancement)	2 (Self-Transcendence)
Public recognition	**0.632**	0.210
Material wealth	**0.4**	0.212
Authority	**0.778**	0.005
Career	**0.817**	-0.038
Individual work	**0.605**	0.158
Varied and exciting life	**0.637**	0.175
Tradition	0.048	**0.584**
Clean environment	0.068	**0.767**
Wealth of all people	0.181	**0.671**
Family wealth	0.174	**0.555**
Thrift	0.005	**0.652**

The second scale of this survey reveals the perception of environmental problems (Fig. 1). This scale encompasses local environmental problems such as, water or air pollution; and global ones such as, resource depletion or climate change.

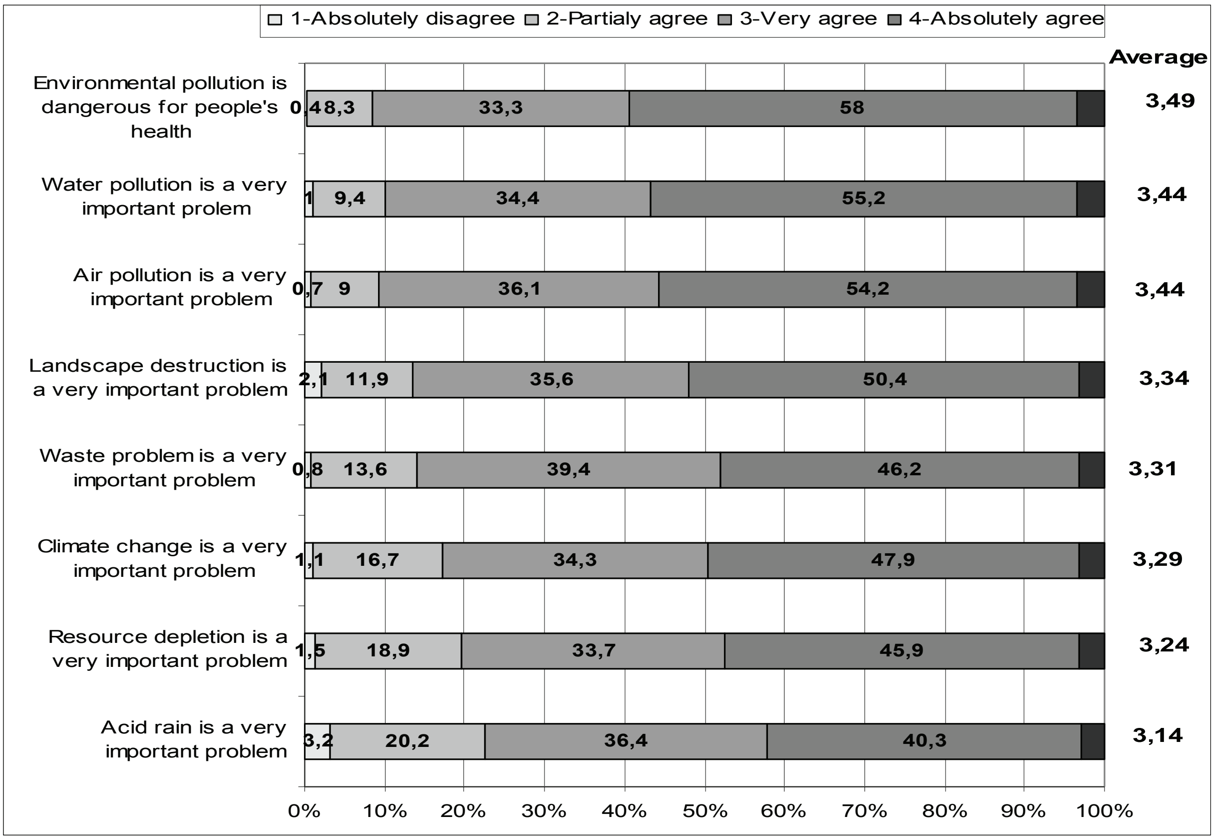


Figure 1. *The importance of the main environmental problems*

Note: (Cronbach's α = 0.91)

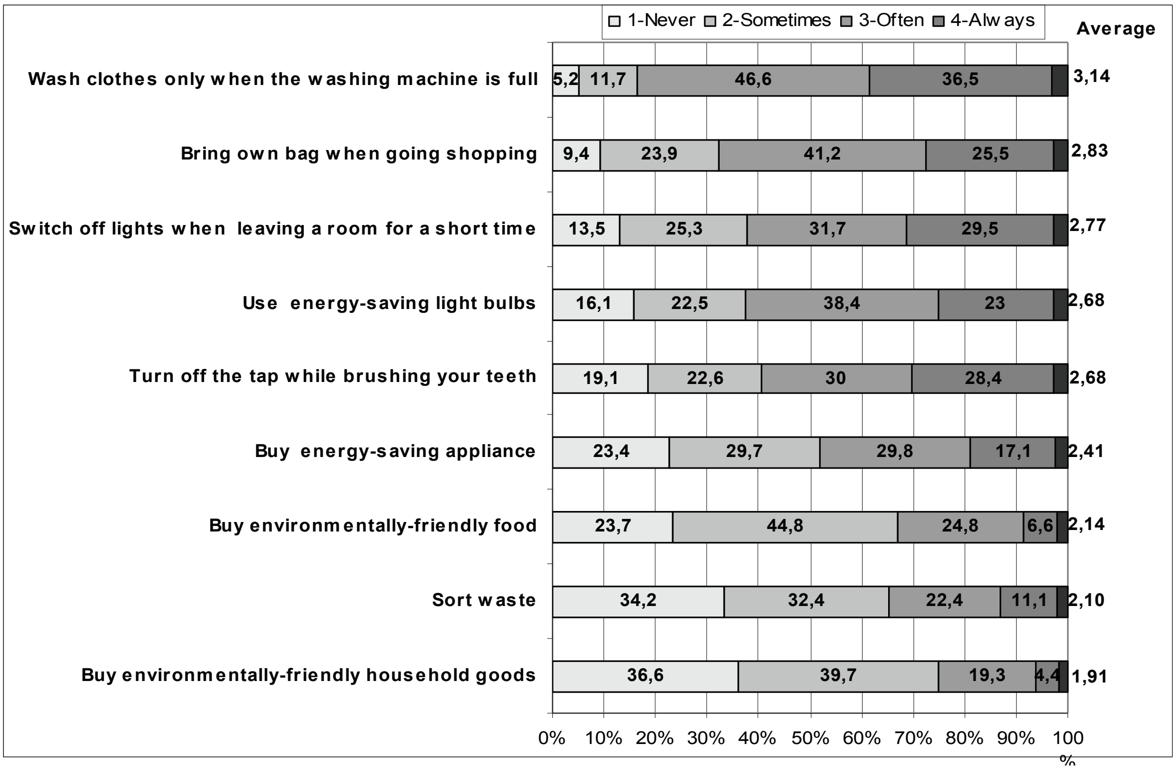


Figure 2. *The frequency of environmental friendly behaviour*

Note: (Cronbach's α = 0.77)

The third scale of this survey reveals the level of environmentally friendly behaviour. This scale was constituted regarding environmentally friendly habits, purchasing decisions and recycling behaviour. The full scale of environmentally friendly behaviour is presented in Figure 2.

3.3. Proposed model of statistical analysis

In order to evaluate determinants of environmental behaviour, in the causal model of environmentally friendly behaviour socio-demographic variables (gender, age education, and income), values, environmental problem perception, the awareness of behavioural consequences and the assumption of responsibility are included. The model was estimated using ordinary least squares regression. This method helped to evaluate variables which influence environmental behaviour directly.

Probability plots of regression residuals were used to test the normality and VIF statistics - to check for colinearity. These diagnostics did not reveal any problems with the suitability of the model. Thus unstandardized regression coefficients (B) and t values showed which factors determine environmentally friendly behaviour directly and which have the greatest influence.

4. Results:

4.1. Descriptive analysis

While analysing the environmentally friendly behaviour of Lithuanian citizens, at first personal values were assessed. As the results revealed (Figure 3), citizens hold family wealth in the first place by value of importance (the average of replies was 3.89). Material wealth (reply average 3.68) and clean environment (reply average 3.64) were attributed to the most important values as well. 70.4% of respondents stated that a clean environment is very important, 24.1% - moderately important, 4.6% - of less importance, 1% - not important.

Therefore, these results reveal that a clean environment is one of the most important values for Lithuanian citizens. Applying correlation analysis (Kendalls' tau_b ((τb) regarding other values, it was assessed that a clean environment was more important to those respondents to whom the wealth of all people ($\tau b=0.44$, $p<0.05$), family wealth ($\tau b=0.3$, $p<0.05$), and thrift ($\tau b=0.27$, $p<0.05$) were also important. These results displayed that people to whom other people are important perceived a clean environment as also important as it is one of the conditions to secure other people's wellbeing.

Meanwhile, our survey revealed that thrift, traditionalism, wealth of all people, individual work and a varied and exciting life was moderately important for the respondents. Finally, public recognition and career were the least important in respondents' replies, and authority took the last position of all these values (Fig. 3).

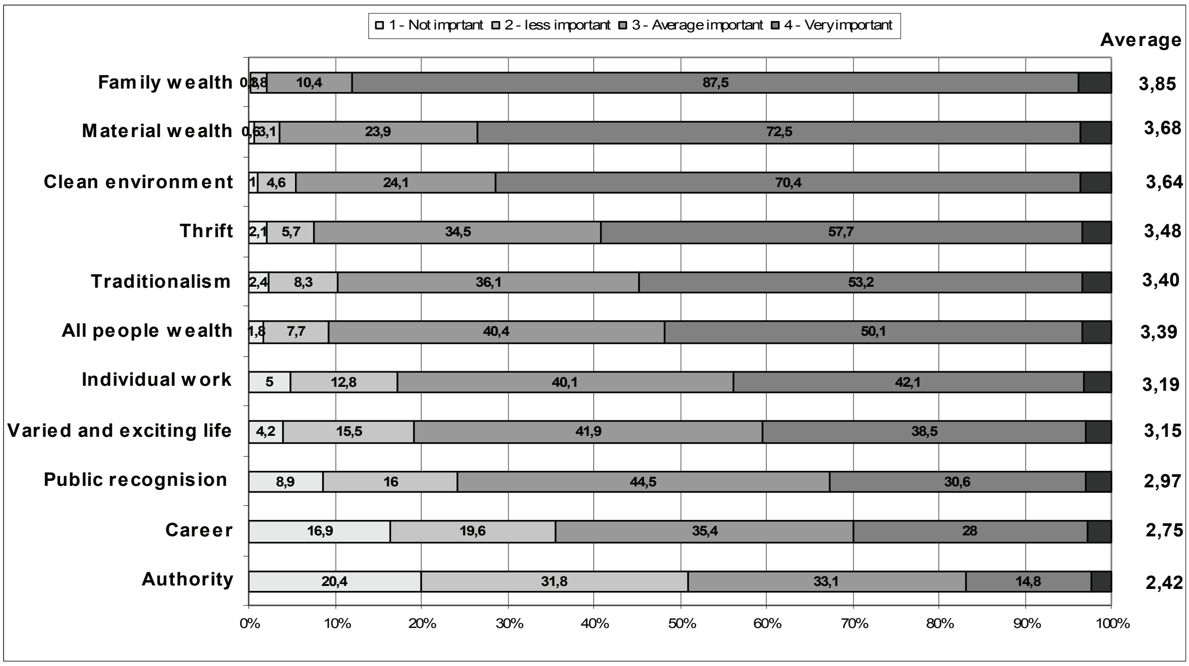


Figure 3. *The importance of the main values of Lithuanian citizens*

According to these personal values, when applying factor analysis, there was a separate two-dimensional structure of values. It consisted of self-transcendence values, which reflected a key concern with collective interests and self-enhancement values following a key concern with one's individual interests (Dietz, Fitzgerald, Shwom, 2005; Steg & De Groot, 2012, Steg et al, 2014). As seen in table 2, self-transcendence values are the most prevailing rather than self-enhancement for the Lithuanian population. Moreover, younger, richer and males had more attributes of self-enhancement values, while older and less rich females were more attributed to self-transcendence values.

Table 2. *The means and std deviation of main structures of values*

	Mean	Std. Deviation
Self-transcendence	3.55	0.43
Self-enhancement	3.03	0.58

While analysing citizens' evaluation of environmental problems, Fig. 2 reveals that the majority of consumers agreed with the statement that environmental pollution is the most dangerous for people's health and that water and air pollution problems are also very important ((M=3.4). Almost two thirds of respondents agreed with the latter statements. However, landscape destruction, waste disposal, climate change, resource depletion and acid rain problems were perceived as the least important ones by the respondents. Other authors have also found that regional and global problems were comprehended as less important (Nistor, 2008, Szoka et al. 2013).

Furthermore, the analysis shows that Lithuanian citizens are less aware of behavioural consequences (M=2.41, S.D = 0.89). Only 13.7% of respondents absolutely agreed with the statement that their behaviour contributes to environmental problems. So, these results reveal that people were still not sufficiently aware that their behaviour influences the environment. Referring to these results, it is evident that in Lithuania there is lack of information about the causalities of environmental problems.

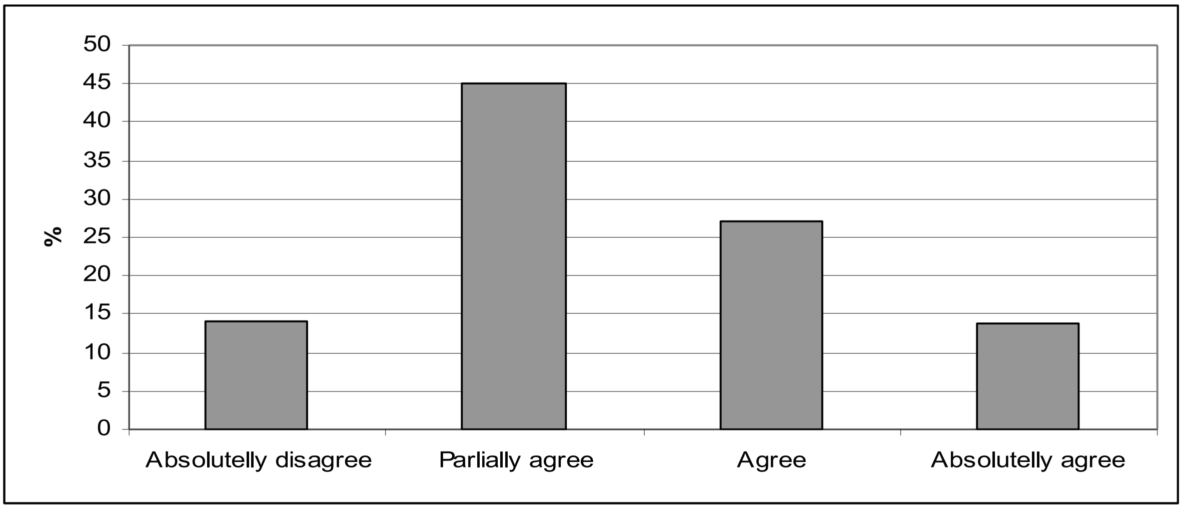


Figure 4. *Agreement with* behaviour contributes to environmental problems

Moreover, analysing to whom people attribute responsibility for solutions of environmental problems, Fig. 5 shows that solutions for the above mentioned problems were mostly inclined to attribute to industry and governmental institutions by consumers. However, only less than one third of respondents (27.2%) agreed absolutely with the statement that they themselves should solve environmental problems. Also, these results revealed that those citizens who think that their behaviour contributes to environmental problems were more inclined to attribute solutions of environmental problems to themselves (τb=0.34, $p <0.05$) than to governmental institutions (τb= 0.18, $p<0.05$) or industry (τb= 0.07, $p<0.05$).

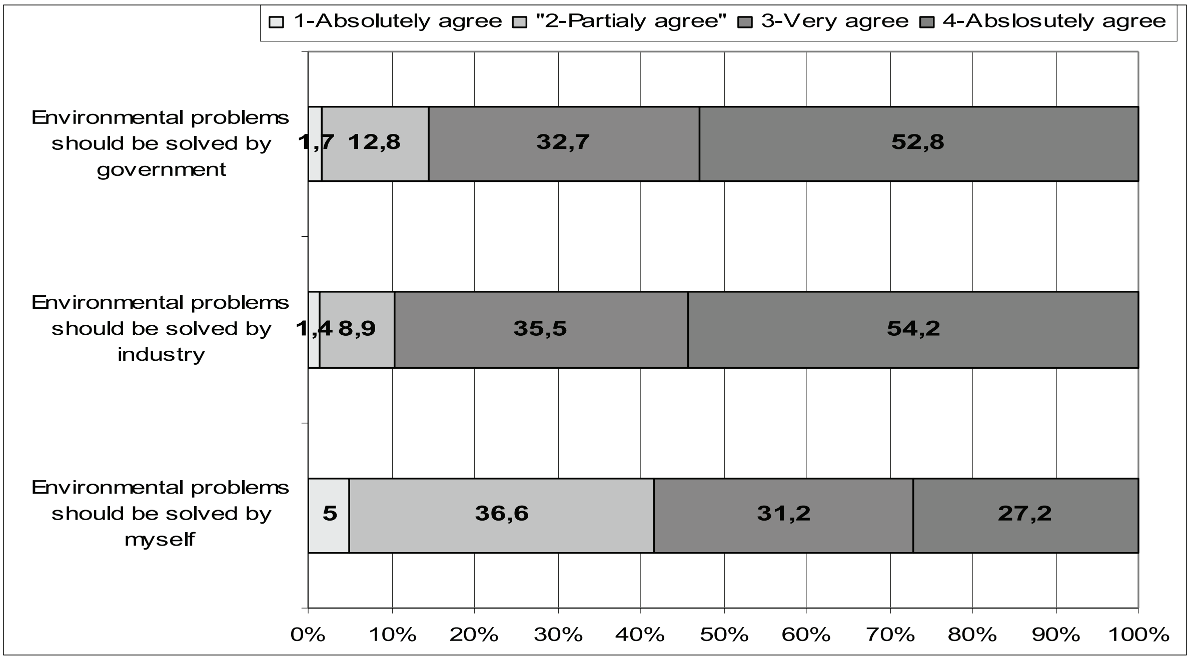


Figure 5. *The attribution the responsibility for solutions of environmental problems*

Performing analysis on people's behaviour further, Fig. 2 presents results that revealed that Lithuanian citizens were frequently inclined to save water as well as rather often to switch off lights when leaving a room and use energy-saving light bulbs. Meanwhile the most problematic is the consumption of environmentally friendly food and other household goods which are rather expensive and the supply is rather low in Lithuania. Finally, evaluating Lithuanians' environmental behaviour frequency, we estimated that the mean score was 2.52 (S.D. = 0.54). This means that behaviour of Lithuanian citizens is moderately environmentally friendly.

4.2. Impact of values on environmentally friendly behaviour

Considering that different values guide people by different goals, according to the literature it is considered that people with self-enhancement values are guided by hedonic and gain goals, meanwhile people for whom self-transcendence values are attributed follow normative goals (Steg, Perlaviciute, Van der Werff, Lurvink, 2014, Stern et al, 2014). Therefore analysing these values impact on environmentally friendly behaviour it was found that self-transcendence value orientation influences all environmentally friendly behaviour (correlation is positive and significant). Thereby people who hold that others and the environment are important and theoretically are guided by normative goals, behave in a more environmentally friendly way. Particularly the largest coefficient of correlation was observed between self-transcendence values and the behaviour of "use energy saving light bulbs", "bring own bag when going shopping" and "sort waste".

Table 3. *Correlation between value orientations and environmentally friendly behaviour*

	Wash clothes only when the washing machine is full	Bring own bag when going shopping	Switch off lights when leaving a room for a short time	Use energy-saving light bulbs	Turn off the tap while brushing your teeth	Buy energy-saving appliance	Buy environmen-tally friendly food	Sort waste	Buy environmenta-lly friendly household goods
Self-transcendence	0.123*	0.23*	0.14*	0.27*	0.1*	0.2*	0.15*	0.21*	0.1*
Self-enhancement	0.008	-0.17*	-0.13*	0.17*	0.002	0.18*	0.22*	0.07*	0.2*

* $p<0.005$

Meanwhile, analysing the correlation between self-enhancement value orientation and environmental friendly behaviour, insignificant correlation was observed for “wash clothes only when the washing machine is full“ and “turn off the tap while brushing your teeth“. Moreover the negative coefficient of correlation was found for “bring own bag when going shopping“, and “switch off lights when leaving a room for a short time”. Therefore people who are self-enhancement and guided by more hedonistic goals do not behave to save environmental resources. However, they are more inclined to buy environmentally friendly food and household goods than people with more self-transcendence value orientation.

Additionally, considering that values affect the strength of goals that not only guide attention but also affect how individuals evaluate the likelihood of different consequences of behavioral options (De Groot et al., 2013; Verplanken, Holland, 2002, Steg et al, 2014), people with stronger self-transcendence value orientation care about environmental problems, intend to take responsibility and behave in an environmentally friendly way more than people attributed to self-enhancement value orientation. At the same time self-enhancement value orientation was more related to the awareness of consequences (Table 4).

4.3. Determinants of environmentally friendly behaviour

Analysing the main determinants of environmental friendly behaviour and considering the correlation matrix, it was evaluated that a correlation exists between all the variables, which means that all determinants are related, except for the awareness of behaviour consequences and environmental friendly behaviour. Therefore a gap between awareness of behavioural consequences and behaviour was observed. This gap conveys that respondents do not give particular behaviour, such as, to sort waste or turn off the tap while brushing your teeth, prominence and did not understand or could not afford to behave in a more environmentally friendly way. Meanwhile the largest correlation coefficient was observed between the awareness of behavioural consequences and the assumption of responsibility.

Table 4. *Correlation matrix*

	Environmental problem perception	Awareness of behaviour consequences	Assumption of responsibility	Environmental friendly behaviour
Self-enhancement	0.23*	0.12*	0.16*	0.1*
Self-transcendence	0.39*	0.08*	0.19*	0.28*
Environmental problem perception		0.26*	0.32*	0.28*
Awareness of behaviour consequences			0.38*	0.06
Assumption of responsibility				0.17*

In order to evaluate the main determinants of environmentally friendly behaviour multiple regression analysis was used. The model encompasses all socio-demographic variables (income, education, gender and age), also environmental problem perception, the awareness of behaviour consequences, the assumption of responsibility and both value orientations (self-enhancement and self-transcendence values), considering that those two value orientations at a different level exist in people. Therefore this model takes into account a person as a general unit. According to the model's summary, model explanatory variables account for 16.8 % of the variance.

As indicated by the regression analysis of environmentally friendly behaviour (Table 5), the most important determinant was observed as self-transcendence value orientation. Meanwhile, self-enhancement value orientation in this model has an insignificant influence. Environmental problem perception is the second determinant, which contributes to more environmentally friendly behaviour. Furthermore, the weakest impact on environmentally friendly behaviour was observed in the assumption of responsibility. Only the awareness of behavioural consequences had an insignificant impact in this model, which means that the latter variable does not have a direct impact on environmentally friendly behaviour.

Table 5. *Regression results of environmental friendly behaviour*

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.579	0.156		3.704	0.000
Self-transcendence	0.200	0.045	0.159	4.473	0.000
Self-enhancement	0.038	0.034	0.041	1.118	0.264
Environmental problem perception	0.174	0.031	0.189	5.558	0.000
Awareness of behavioural consequences	-0.026	0.020	-0.043	-1.326	0.185
Assumption of responsibility	0.062	0.020	0.102	3.092	0.002
Education	0.036	0.011	0.097	3.187	0.001
Income	0.000	0.000	-0.017	-0.573	0.566
Gender	0.091	0.032	0.084	2.804	0.005
Age	0.043	0.011	0.135	3.927	0.000

According to socio-demographic variables, the most import variable is gender. Therefore these results confirmed again that women are more environmentally friendly (Stern, Dietz, 1993, Gilg et al. 2005, Gilg, Barr, 2006, Zhao, et al, 2014). Moreover, it was evaluated that more educated and older people are more environmentally friendly. These results were also confirmed by A. Gilg et al. (2005), A. Gilg and S. Barr (2006), L. Nistor (2008), H-h Zhao, (2014). In this model among socio-demographic variables only income had an insignificant influence.

5. Discussion and policy recommendations

Analysing the impact of values on environmental behaviour this study tries to explicitly reveal value orientations, which are related to particular goals, and their impact on separate environmentally friendly behaviour. This study shows that self-transcendence value orientation influences all environmentally friendly behaviour and according to Goal Framing theory it can be related to the fact that people are motivated to behave in an environmentally friendly way because they think that protecting the environment is the right thing to do (Lindenberg, Steg, 2007, Lindenberg, Steg, 2013; Steg et al, 2014). Furthermore, our study reveals that people with more self-transcendence value orientation, for which other peoples' wellbeing is the most important, are more sensitive to environmental problems and more responsible for their own actions, rather than people with stronger self-enhancement value orientation.

Meanwhile people characterized by self-enhancement value orientation, for whom authority, career, a varied life and material wellbeing are of the greatest importance do not behave in order to save environmental resources, perhaps because it is inconvenient and unpleasant. However, they are more inclined to buy environmentally friendly goods. This is related to the fact that these people are richer and can afford to buy green products. Moreover, buying environmental friendly products can enhance their status, which means that this environmental friendly behaviour supports gain goals (Lindenberg, Steg, 2007, Lindenberg, Steg, 2013; Steg et al, 2014).

Additionally, considering that people are the whole unit whose actions make all the value orientations and applying the causal model it was evaluated that self-transcendence value orientation determines general environmentally friendly behaviour directly and among all included variables latter variable influence environmental behaviour the most. Meanwhile, self-enhancement value orientation has an insignificant influence on general environmentally friendly behaviour.

Therefore, considering to these findings, in order to promote environmentally friendly behaviour the most important element is to promote self-transcendent value orientation, when people engage in environmentally friendly behaviour because they are following the normative goal. However, many authors have suggested promoting environmental friendly behaviour by increasing the costs of environmentally-harmful actions via taxes or by making pro-environmental actions fun or convenient (e.g., by increasing the availability of trash cans), or by making environmentally-harmful options less pleasurable (e.g., by implementing speed humps) (Bolderdijk, Lehman, Geller, 2012; Steg, Vlek, 2009), by spreading information that environmental friendly behaviour is appealing and beneficial (De Groot & Steg, 2010; Green-Demers, Pelletier, Ménard, 1997; Koestner, Houlfort, Paquet, Knight, 2001; Steg et al, 2014) and it is very suitable for people whose main value orientation is self-enhancement and thus they are guided by hedonistic or gain goals. Meanwhile to promote environmentally friendly behaviour considering that the normative goal is the most related, is more difficult and requires more efforts to enhance the interest of the other people's wellbeing or to spread information that a clean environment is humankind's guarantee of welfare.

Furthermore these results show that the environmental problem perception is the second most important determinant and that the weakest impact on environmentally friendly behaviour was observed for the assumption of responsibility. However, an insignificant impact of the awareness of behavioural consequences was observed, which means that there is a gap between the awareness of behavioural consequences and real behaviour. This gap could occur because of inner obstacles, such as lack of information and/or knowledge about the real behavioural impact on the environmental, abilities: money, time, power and ingrained habits, or outer obstacles, such as lack of supply, prices, social norms and advertising, which give an incentive to consume instead of choosing an environmentally friendly lifestyle (Gardner, Stern, 2008; Jager, 2006; Lane, Potter, 2007; Niemeyer, 2010; Ozaki, 2011; Vermillion, Peart, 2010; Gadenne et al, 2011, Lukman, 2013; Zhao, 2014; Refsgaard, Magnussen, 2009). Nevertheless, for future research it is important to analyse the determinants of this gap in more detail.

Therefore, resumptive suggestions for policy, considering that environmental problem perception is strongly related to environmentally friendly behaviour,are: (a) it is very important to provide more information how particular behaviour contributes to environmental problems; (b) it is necessary to change deep-rooted habits. Moreover, considering that Lithuanian citizens are more inclined to attribute responsibility for solutions of environmental problems to industry and governmental institutions than to themselves, it is very important to spread information that people are able to solve environmental problems themselves. Also, it should follow that governments or industry should also make a reasonable input, but most of the responsibility regarding nature should stay with the people themselves.

6. Conclusion

Analyzing the impact of values on environmentally friendly behaviour based on Goal Framing theory, it was evaluated that people with stronger self-transcendence value orientation, who are guided more by normative goals behave in a more environmentally friendly way. It could be related to the fact that they think protecting the environment is the right thing to do. People with stronger self-enhancement value orientation, who are guided by hedonic and gain goals, do not behave in order to save environmental resources, perhaps because it is inconvenient and unpleasant. However they are more incline to purchaser behaviour - buying environmentally friendly food and household goods, which can be related to fact that they can afford more expensive goods which enhance their status. Moreover, self-transcendence value orientation is more related to care about environmental problems and the assumption of responsibility, which means that while seeking other people’s wellbeing the same people are more sensitive to environmental problems and more responsible for their own actions.

According to the causal model, the most important for environmental behaviour is self-transcendence value orientation, environmental problem perception and the assumption of responsibility. However, it was observed that the awareness of behavioural consequences does not have a direct impact on behaviour. Therefore it is very important to provide more information about that personal behaviour contributes to the environmental problems and that it is necessary to change ingrained daily habits. Finally, it is very important to stress that people are able to solve a large part of the environmental problems themselves.

Reference:

Abdul-Muhmin, A. G. (2007). Explaining consumers' willingness to be environmentally friendly. International Journal of Consumer Studies, 31(3), 237–247.

Alwitt, L.F., Pitts, R.E., 1996. Predicting purchase intentions for an environmentally sensitive product. Journal of Consumer Psychology 5 (1), 49-64.

Aquino, K., Freeman, D., Reed, A. I., Lim, V. K. G., & Felps,W. (2009). Testing a social cognitive model of moral behavior: The interactive influence of situations and moral identity centrality. Journal of Personality and Social Psychology, 97,123-141.

Bamberg, S., 2003. How does environmental concern influence specific environmentally related behaviors? A new answer to an old question. Journal of Environmental Psychology 23 (1), 21-32.

Bamberg, S., Möser, G., 2007. Twenty years after Hines, Hungerford, and Tomera: a new meta-analysis of psycho-social determinants of pro-environmental behavior. Journal of Environmental Psychology 27, 14-25.

Baumann, H., Boons, F., Bragd, A., 2002. Mapping the green product development field: engineering, policy and business perspectives. Journal of Cleaner Production 10 (5), 409-425

Bolderdijk, J. W., Lehman, P. K., & Geller, E. S. (2012). Encouraging pro-environmental behaviour with rewards and penalties. In L. Steg, A. E. van den Berg, & J. I. M. de Groot (Eds.), Environmental psychology: An introduction (pp. 233-242). Oxford, UK: John Wiley & Sons.

Brown, K. W., & Kasser, T. (2005). Are psychological and ecological well-being compatible? The role of values, mindfulness, and lifestyle. Social Indicators Research, 74, 349-368.

Brunso, K., Scholderer, J., Grunert, K. G. 2004. Closing the gap between values and behavior—a means–end theory of lifestyle. Journal of Business Research 57, 665– 670.

Casey, P., & Scott, K. (2006). Environmental concern and behaviour in Australian sample within an ecocentric–anthropocentric framework. Australian Journal of Psychology, 58(2), 57–67.

Chitnis M., Hunt L. C. 2012. What drives the change in UK household energy expenditure and associated CO2 emissions? Implication and forecast to 2020. *Applied Energy,* 94, p. 202-214.

De Groot, J. I. M., & Steg, L. (2009). Mean or green: Which values can promote stable pro-environmental behavior? Conservation Letters, 2, 61-66.

De Groot, J. I. M., Steg, L., & Dicke, M. (2008). Transportation trends from a moral perspective: Value orientations, norms and reducing car use. In F. N. Gustavsson (Ed.), New transportation research progress. Hauppauge, NY: Nova Science Publishers

De Groot, J. I. M., Steg, L., & Poortinga, W. (2013). Values, perceived risks and benefits, and acceptability of nuclear energy. Risk Analysis, 33(2), 307-317.

De Groot, J., & Steg, L. (2007). Value orientations and environmental beliefs in five countries: Validity of an instrument to measure egoistic, altruistic and biospheric value orientations. Journal of Cross-cultural Psychology, 38(3), 318-332.

Dietz, T., Fitzgerald, A., & Shwom, R. (2005). Environmental values. Annual Review of Environmental Resources, 30, 355-372.

Duplan, R. E. Van Liere, K. D., Mertig, A. G., Jones, R. E. 2000. Measuring endorsement of the New Ecological Paradigm: A revised NEP scale. Journal of Social Issues, 56 (3), p. 425-442.

Fernández-Manzanal, R., Rodríguez-Barreiro, L., & Carrasquer, J. (2007). Evaluation of environmental attitudes: Analysis and results of a scale applied to university students. Science Education, 91(6), 988–1009

Flamm, B., 2009. The impacts of environmental knowledge and attitudes on vehicle ownership and use. Transportation Research Part D 14 (4), 272-279.

Fraj, E., &Martinez, E. (2006). Environmental values and lifestyles as determining factors of ecological consumer behaviour: An empirical analysis. Journal of Consumer Marketing, 23(3), 133–144.

Gadenne, D., Sharma, B., Kerr, D., Smith, T. 2011. The influence of consumers' environmental beliefs and attitudes on energy saving behaviours. Energy Policy 39, 7684–7694

Gardner, G., Stern, P., 2008. The short list: the most effective actions U.S. households can take to curb climate change. Environment 50 (5), 12.

Gärling, T., Fujii, S., Gärling, A., & Jakobsson, C. (2003). Moderating effects of social value orientation on determinants of pro-environmental intention. Journal of Environmental Psychology, 23, 1-9.

Gilg A., Barr S. 2006. Behavioural attitudes towards water saving? Evidence from a study of environmantal actions. *Ecological Economics,* 57, p. 400-414.

Gilg A., Barr S., Ford N. 2005. Green conumption or sustainable lifestyles? Identifying the sustainable consumer. *Futures,* 37, p. 481-504.

Gössling, S., Haglund, L., Kallgren, H., Revahl, M., & Hultman, J. (2009). Swedish air travellers and voluntary carbon offsets: Towards the co-creation of environmental value? Current Issues in Tourism, 12(1), 1–19.

Green-Demers, I., Pelletier, L. G., & Ménard, S. (1997). The impact of behavioural difficulty on the saliency of the association between self-determined motivation and environmental behaviours. Canadian Journal of Behavioural Science, 29(3), 157-166.

Gronho, A., Thogersen, J. 2009. Like father, like son? Intergenerational transmission of values, attitudes, and behaviours in the environmental domain. Journal of Environmental Psychology 29, 414–421.

Hansla, A., Gamble, A., Juliusson, A., Gärling, T., 2008. The relationships between awareness of consequences, environmental concern, and value orientations. Journal of Environmental Psychology 28, 1-9.

Haron, S.A., Paim, L., Yahaya, N., 2005. Towards sustainable consumption: an examination of environmental knowledge among Malaysians. International Journal of Consumer Studies 29 (5), 426-436.

Hurst, M., Dittmar, H., Bond, R., Kasser, T. 2013. The relationship between materialistic values and environmental attitudes and behaviors: A meta-analysis. Journal of Environmental Psychology 36 , 257-269.

Ives, C. D., Kendal, D. 2014. The role of social values in the management of ecological systems. Journal of Environmental Management 144, 67-72.

Jager, W., 2006. Stimulating the diffusion of photovoltaic systems: a behavioural perspective. Energy Policy 34 (14), 1935–1943.

Jakovcevic, A., & Steg, L. (2013). The effects of normative considerations on car use in Argentina. Transportation Research F, 20, 70-79.

Juvan, E., Dolnicar, S. 2014. The attitude–behaviour gap in sustainable tourism. Annals of Tourism Research 48 , 76–95.

Klockner, C. A. 2013. A comprehensive model of the psychology of environmental behaviour—A meta-analysis. Global Environmental Change 23 ,1028–1038.

Koestner, R., Houlfort, N., Paquet, S., & Knight, C. (2001). On the risks of recycling because of guilt: An examination of the consequences of introjection. Journal of Applied Social Psychology, 31, 2545-2560.

Kollmuss, A., Agyeman, J., 2002. Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research 8, 239-260.

Lane, B., Potter, S., 2007. The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. Journal of Cleaner Production 15 (11–12), 1085–1092.

Lee, K. 2011. The role of media exposure, social exposure and biospheric value orientation in the environmental attitude-intention-behavior model in adolescents. Journal of Environmental Psychology 31, 301-308.

Lin, P.C., Huang, Y.H., 2012. The influence factors on choice behavior regarding green products based on the theory of consumption values. Journal of Cleaner Production 22 (1), 11-18.

Lindenberg, S., & Steg, L. (2007). Normative, gain and hedonic goal-frames guiding environmental behavior. Journal of Social Issues, 63(1), 117e137.

Lindenberg, S., & Steg, L. (2013a). Goal-framing theory and norm-guided environmental behavior. In H. C. M. van Trijp (Ed.), Encouraging sustainable behaviour (pp. 37e54). New York: Psychology Press

Liu J., Wang R., Yang J., Shi Y. 2010. The relationship between consumption and production system ant its implications for sustainable development of China. *Ecological Complexity*, 7, p. 212-216.

Lopez-Mosquera, N., Sanchez, M. 2012. Theory of Planned Behavior and the Value-Belief-Norm Theory explaining willingness to pay for a suburban park. Journal of Environmental Management 113, 251-262.

Lorenzoni, I., Nicholson-Cole, S., & Withmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. Global Environmental Change, 17(3/4), 445.

Lukman, R., Lozano, R., Vamberger, T., Krajnc, M. 2013. Addressing the attitudinal gap towards improving the environment: a case study from a primary school in Slovenia. Journal of Cleaner Production 48, 93-100.

Martin, W. C., Bateman, C. R. 2014. Consumer religious commitment's influence on ecocentric attitudes and behavior. Journal of Business Research 67, 5–11.

Miller, G., Rathouse, K., Scarles, C., Holmes, K., & Tribe, J. (2010). Public understanding of sustainable tourism. Annals of Tourism Research, 37(3), 627–645.

Mostafa, M.M., 2007. A hierarchical analysis of the green consciousness of the Egyptian consumer. Psychology and Marketing 24 (5), 445-473.

Niemeyer, S., 2010. Consumer voices: adoption of residential energy-efficient practices. International Journal of Consumer Studies 34 (2), 140–145.

Nilsson, A., Von Borgstede, C., & Biel, A. (2004). Willingness to accept climate change policy measures: The effect of values and norms. Journal of Environmental Psychology, 24, 267-277.

Nistor L. 2008. Rootless and clustered environmentally significant consumption. Sustainable Consumption 2008 Conference; Corvinus University of Budapest, Hungary; October 8, 2008: Academic conference proceedings, p. 101-118.

Nordlund, A. M., & Garvill, J. (2002). Value structures behind pro-environmental behavior. Environment and Behavior, 34, 740-756.

Ozaki, R., 2011. Adopting sustainable innovation: what makes consumers sign up to green electricity? Business Strategy and the Environment 20 (1), 1-17.

Papagiannakis, G., Lioukas, S. 2012. Values, attitudes and perceptions of managers as predictors of corporate environmental responsiveness. Journal of Environmental Management 100, 41-51.

Pickett-Baker, J., Ozaki, R., 2008. Pro-environmental products: marketing influence on consumer purchase decision. The Journal of Consumer Marketing 25 (5), 281-293.

Poortinga, W., Steg, L., & Vlek, C. (2004). Values, environmental concern and environmental behavior: A study into household energy use. Environment and Behavior, 36(1), 70-93.

Refsgaard K., Magnussen K. 2009. Household behaviour and attitudes with respect to recycling food waste – experience from focus groups. *Journal of Environmental Management*, 90, p. 760-771.

Rex, E., Baumann, H., 2007. Beyond ecolabels: what green marketing can learn from conventional marketing. Journal of Cleaner Production 15 (6), 567-576.

Roberts, J.A., Bacon, D.R., 1997. Exploring the subtle relationships between environmental concern and ecologically consumer behavior. Journal of Business Research 40 (1), 79-89.

Robinot, E., & Giannelloni, J. (2009). Attitude toward environmentally friendly hospitality management: A measurement scale. Recherche et Applications en Marketing (English Edition), 24(2), 29–50.

Rodríguez-Barreiro, L. M., Fernandez-Manzanal, R., Serra, L. M., Carrasquer, J., Murillo, M. B., Morales, M. J., Calvo, J. M., Valle, D. 2013. Approach to a causal model between attitudes and environmental behaviour. A graduate case study. Journal of Cleaner Production 48, 116-125.

Salmela, S., Varho, V., 2006. Consumers in the green electricity market in Finland. Energy Policy 34 (18), 3669–3683.

Sapci, O., Considine, T. 2014. The Link Between Environmental Attitudes and Energy Consumption Behavior. Journal of Behavioural and Experimental Economics, article in press.

Schultz, P. W., & Zelezny, L. C. (1998). Values and pro-environmental behaviour. A five-country study. Journal of Cross-cultural Psychology, 29(4), 540-558.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In M. P. Zanna, & M. P. Zanna (Eds.), Advances in experimental social psychology (pp. 1-65). San Diego, CA US: Academic Press

Slimak M. W., Dietz T. 2006. Personal values, beliefs, and ecological risk perception. *Risk Analysis,* 26(6), p. 1689-1705.

Steg, L., & De Groot, J. I. M. (2010). Explaining prosocial intentions: Testing causal relationships in the Norm Activation Model. British Journal of Social Psychology, 49, 725-743.

Steg, L., & De Groot, J. I. M. (2012). Environmental values. In S. Clayton (Ed.), The handbook of environmental and conservation psychology (pp. 81-92). New York: Oxford University Press.

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. Journal of Environmental Psychology, 29, 309-317.

Steg, L., Bolderdijk, J. W., Keizer, K., Perlaviciute, G. 2014. An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. Journal of Environmental Psychology 38 , 104-115.

Steg, L., De Groot, J. I. M., Dreijerink, L., Abrahamse, W., & Siero, F. (2011). General antecedents of personal norms, policy acceptability, and intentions: The role of values, worldviews, and environmental concern. Society and Natural Resources, 24(4), 349-367.

Steg, L., Dreijerink, L., & Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: Testing VBN theory. Journal of Environmental Psychology, 25(4), 415-425.

Steg, L., Perlaviciute,G., Van derWerff, E.,&Lurvink, J. (2014). The significance of hedonic values for environmentally-relevant attitudes, preferences and actions. Environment and Behavior, 46(2), 163-192.

Stern P. 2000. Toward a coherent theory of environmentally significant behaviour. *Journal of Social Issues*, 56 (3), p. 407-424.

Stern, P. C., & Dietz, T. (1994). The value basis of environmental concern. Journal of Social Issues, 50, 65-84.

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A value belief norm theory of support for social movements: The case of environmentalism. Human Ecology Review, 6, 81-95.

Stern, P. C., Dietz, T., Kalof, L. 1993. Value orientations, gender, and environmental concern. Environment and Behavior, 322-348.

Stern, P. C., Dietz, T., Kalof, L., Guagnano, G. A. 1995. Values, beliefs, and proenvironmental action: Attitude formation toward emergent attitude objects. *Journal of Applied Social Psychology,25 (*18) 161 1-1 636.

Stern, P.C., Dietz, T., 1994. The value basis of environmental concern. J. Soc. Issues 50, 65-84.

Swami, V., Chamorro-Premuzic, T., Snelgar, R., & Furnham, A. (2010). Egoistic, altruistic, and biospheric environmental concerns: A path analytic investigation of their determinants. Scandinavian Journal of Psychology, 51, 139-145.

Tanner,C.,Kast, S.W.,2003. Promoting sustainable consumption: determinants of green purchases by Swiss consumers. Psychology & Marketing 22 (10), 883-902.

Thogersen J., Olander F. 2002. Human values and the emergence of a sustainable consumption pattern: A panel study. *Journal of Economic Psychology*, 23, p. 605-630.

Tseng, c-S., Hung, S-W. 2013. A framework identifying the gaps between customers' expectations and their perceptions in green products. Journal of Cleaner Production 59 ,174-184

Tukker A., Cohen M. J., Hubacek K., Mont O. 2010. Sustainable consumption and production. *Journal of Industrial Ecology*, 14 (1), p. 1-3.

Tukker A., Jansen B. 2006. Environmental impacts of products. A detailed review of studies. *Journal of Industrial Ecology,* 10 (3), p. 159-182.

Valkila, N. Saari, A. 2013. Attitude–behaviour gap in energy issues: Case study of three different Finnish residential areas. Energy for Sustainable Development 17 , 24–34.

van der Werff, E., Steg, L., Keizer, K. 2013. The value of environmental self-identity: The relationship between biospheric values, environmental self-identity and environmental preferences, intentions and behaviour. Journal of Environmental Psychology 34 , 55-63

van Riper, C. J., Kyle, G. T. 2014. Understanding the internal processes of behavioral engagement in a national park: A latent variable path analysis of the value-belief-norm theory. Journal of Environmental Psychology 38, 288-297.

Vermillion, L.J., Peart, J., 2010. Green Marketing: making sense of the situation, paper presented to Allied Academies International Conference. In: Proceedings of the Academy of Marketing Studies, New Orleans, LA, April 14–16.

Verplanken, B., Holland, R. W. (2002). Motivated decision making: Effects of activation and self-centrality of values on choices and behaviour. Journal of Personality and Social Psychology, 82, 434-447.

Wang, P., Liu, Q., Qi, Y. 2014. Factors influencing sustainable consumption behaviors: a survey of the rural residents in China. Journal of Cleaner Production 63 , 152-165.

Wolters, E., A. 2013. Attitude–behavior consistency in household water consumption. The Social Science Journal, article in press.

Young, W., Hwang, K., McDonald, S., Oates, C.J., 2010. Sustainable consumption: green consumer behaviour when purchasing products. Sustainable Development 18 (1), 20–31.

Zhao, H-H., Gao, Q., Wu, Y-P., Wang, Y., Zhu, X-D. 2014. What affects green consumer behavior in China? A case study from Qingdao. Journal of Cleaner Production 63, 143-151.

Zsoka, A., , Szerenyi, Z. M., Szechy, A., Kocsis, T. 2013. Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. Journal of Cleaner Production 48 , 126-138

Macro-economic and development indexes and ISO14001 certificates: a cross national analysis

Tiberio Daddi[1], Marco Frey[1], Maria Rosa De Giacomo[1], Francesco Testa[1], Fabio Iraldo[1,2]*

[1]*Sant'Anna School of Advanced Studies e Institute of Management, Piazza Martiri della Libertà 33, 56127 Pisa, Italy*
[2]*IEFE e Institute for Environmental and Energy Policy and Economics, Bocconi University, Milan, Italy*

Abstract

Environmental Management Systems (EMSs) implemented according to the ISO14001 standard have been examined by many authors, especially focusing on its impact at the firm level. However only a few papers have investigated the impact of ISO14001 from a country perspective. This paper aims to contribute to bridging this gap. The aim is to study the relation between ISO14001 growth and the trend in selected macro-economic and development indexes. By applying the Growth Mixture Model to a panel of 73 countries for the period 1999-2012, we assess the following hypotheses: (a) the increase in numbers of ISO14001 certifications corresponds to an increase in economic indexes; (b) the increase in ISO14001 corresponds to an increase in development indexes; (c) the trends of ISO14001 adoption and macro-economic indexes confirm the relationship described by the Environmental Kuznets Curve.
The results confirm a positive relation among the trends of some variables such as ISO14001 and GDP, ISO14001 and industry value added. In addition, using the industry added value as the variable to measure economic development, our results support the theory of the Environmental Kuznets Curve.

Keywords: Environmental Management Systems, ISO14001, Environmental Kuznets Curve, time series analysis, economic development

1. Introduction

Environmental voluntary instruments and particularly environmental certifications are important tools for public policies as well as business strategies. The key concept is the voluntary decision of firms to improve their environmental performance in order to achieve an official recognition (certification) through the adoption of an Environmental Management System (EMS).
Environmental certifications are one of the three broad categories of environmental policy instruments that have evolved over the past thirty years, which can be generally defined as (Barde, 1995):

- ✓ regulatory instruments (e.g., emission standards), also called command and control instruments, public authorities impose emission limits for firms and monitor their compliance regarding these limits;
- ✓ economic instruments (e.g., taxes, tradable permits, refund systems), whereby firms or consumers are given financial incentives to reduce environmental damage;
- ✓ voluntary instruments (e.g., environmental certifications, ecolabelling schemes), firms commit to improve their environmental performance beyond the legal requirements.

In the face of the limitations of government regulations and economic incentives, policymakers have attempted to encourage facilities to take voluntary action. The voluntary approach is recognized as being more flexible, effective, and less costly than traditional approaches (Arimura et al., 2007). Over the last few decades, an increasing number of "voluntary approaches" have been implemented in the environmental policies of many countries. Usually, they have been introduced as supplements to existing “command and control” regulations, as part of policy packages also involving– for example – environmentally related taxes or emissions trading, or they have represented the first steps in regulating a particular environmental issue. Voluntary actions and environmental certifications introduced by firms to improve environmental performance have been welcomed by several policy makers and there is a considerable amount of literature indicating that firms can profit from taking such voluntary action.

Well functioning EMSs can be an advantage for certified organizations in terms of: performance and resource efficiency (Turk, 2009; Daddi et al., 2011, Martín-Peña et al., 2014), market opportunities (Ann et al., 2006), competitiveness (Iraldo et al., 2009; management of environmental issues such as emergency and legal compliance (Milieu Ltd and RPA Ltd, 2009), reputation (Studer et al., 2008), labour productivity (Delmas and Pekovic, 2012), and administrative simplifications (Daddi et al., 2014).

Despite the numerous papers that analyse the effects of EMSs at the firm level, only a few papers have investigated the ISO14001 phenomena from a country perspective (Potoski and Prakash, 2013). This paper aims to contribute to the existing literature in the field of EMSs by attempting to bridge the aforementioned gap. By considering the trend of key macro-economic and development indexes, the paper studies the relation of these trends with the trend of ISO14001 certifications in a panel of 73 countries.

The aim of the paper is to examine whether the positive effects of EMSs on performance, market position, reputation of the firm are related at a country level to economic indexes (such GDP and industry added value indexes) and/or development indexes (such as public spending on education, research and development expenditure, unemployment) . In addition we investigate whether our study confirms the Environmental Kuznets Curve (EKC). Considering the ISO14001 numbers as a proxy of the level of pollution in a country (with a negative relation), we will study whether the relation between ISO14001 certificates and macro-economic indexes change, considering countries with industrial or post-industrial economies.

The paper is structured as follows. In the next section, by identifying the key research hypothesis, we describe the relationship between pollution and economic development at a country level and the effects of ISO14001on performance and competitiveness. We then outline the empirical analysis providing specifications on the data used and the statistical model applied. We then present the results, followed by a concluding section where the results are discussed and future research opportunities identified.

2. Theoretical background and hypothesis

2.1 Economic development and pollution at a country level

The debate on the link between economic development and the environmental pollution at a country level is still open and many authors have presented controversial results. The topic is particularly wide with the most discussed approach being is the graphical representation described by Kuznets (Environmental Kuznets Curve - EKC). According to this hypothesis, when a typical economy is in a pre-industrial stage and is based on agriculture, the pollution level is increasing with economy but slowly. When the economy is based on the industrial sector, pollution and economy increase very fast till a tipping point where they start to decrease. When the economy then passes to a post-industrial stage, technological development, the sensitivity of consumers, (and several other variables) offset the increase in the pollution caused by the growth of the economy as in the previous industrial stage. In this phase there is a positive relationship between economic growth and the quality of the environment, and the curve shows that economy increases and pollution decreases.

Many empirical studies on the relationship between economic growth and environmental degradation support the EKC hypothesis, while other authors are more sceptical.

Firstly, let us look at the studies that for the most part confirm the EKC. Orobu and Omotor (2011) investigated the relationship between per capita income and environmental degradation in Africa. The study found the existence of EKC for suspended particulate matter but there were no clear results for organic water pollutants.

Grossman and Krueger (1991) focused on the potential environmental impacts of NAFTA (North American Free Trade Agreement). They found evidence in support of an inverted U-shaped relationship between economic growth (measured by increases in per capita income) and various indicators of environmental quality.

The focus on the BRICS and NAFTA countries is very critical due to their rising importance in the last few years. Goldman Sachs (2003) also confirmed the significance of the BRICS economies in the world.

Xuemei et al. (2011) investigated the relationship between economic development and environmental pollution using the EKC. They confirmed the Kuznets curve in terms of emissions of sulphur dioxide and GDP per capita referring to Shandong province, however this was not the case for waste water and industrial waste.

Honglei et al. (2011) outlined the relationship between economic growth, foreign trade, FDI and environmental degradation in China. They found that an export-oriented economy is good in terms of reducing industrial emissions. The EKC hypothesis was also confirmed for emissions of solid waste, smoke dust and COD.

Ozturk and Acaravci (2013) supported the validity of the EKC hypothesis in Turkey. They explored the causal relationship between financial development, trade, economic growth, energy consumption and carbon emissions in Turkey in the period 1960-2007. The authors found that an increase in the foreign trade to GDP ratio results in an increase in per capita carbon emissions, and that in the long run financial development has no effect on per capita carbon emissions.

There are also some studies that do not support the EKC theory. For example, Saboori and Sulaiman (2013) explored the relationship between economic growth, carbon dioxide emissions and energy consumption, by focusing on aggregated and disaggregated energy consumption data in Malaysia. The inverted U-shaped relationship was supported only with disaggregated data (based on many energy sources). Other studies have not found a positive relationship between GDP and improved environmental quality. For example, Boopen and Vinesh (2011) explored the link between GDP and carbon dioxide emissions for Mauritius in the period 1975-2007. They found that GDP had a negative effect on these emissions. With the increase in GDP, the economic and human activities had a negative environmental impact in the country.

Zhai and Song (2013) investigated the causal relationship in China between economic growth, energy structure, R&D investments, and carbon emissions. They found that the impact of economic growth and R&D investments on carbon emissions was insignificant both in the long and short term. Tharakan et al. (2001) also showed a negative relationship between the industrial development of Asian countries and the environmental impacts. They found that economic growth did not alleviate the environmental problems.

Other studies have affirmed a bidirectional causality between income and environment. Apergis and Payne (2011) found a bidirectional causality between renewable energy and economic growth for some central American countries. Yang (2000) also found a bidirectional causality between energy consumption and GDP income in Taiwan between 1954-1997.

In summary, the relationship between economic growth and the environment at a country level is thus not very clear. Country studies show varying results on the validity of EKC and the casual relationship between economic development and environmental degradation.

2.2 ISO14001 and its economic effectiveness at the firm level

ISO 14001 is an international standard issued by the International Organisation for Standardisation (ISO). Together with the European Management and Audit Scheme (EMAS) they represent the most common references to implement an EMS and to obtain an environmental certification.

The first version of ISO14001 was issued in 1996 and the current version was revised in 2004. A new version is due to be published in the next few months. At year end 2012, 285,844 organisations had obtained ISO14001 certificates, highlighting a growth of 9% (+ 23 887). ISO14001 was issued in 167 countries in 2012, nine more than in the previous year. The top three countries out of the total number of certificates issued were China, Japan and Italy, while the top three in terms of growth in the number of certificates in 2012 were China, Spain and Italy (ISO, 2012).

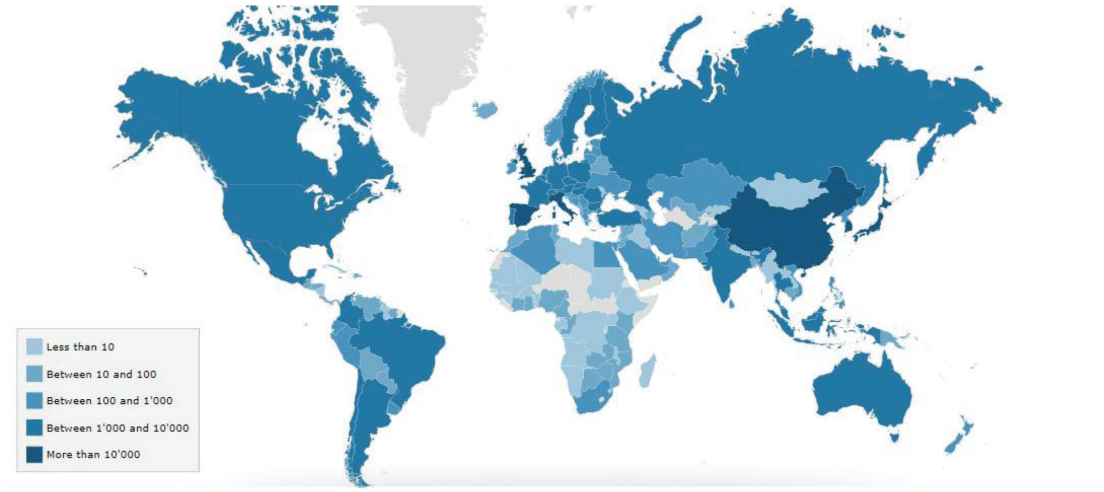


Figure 1. World distribution of ISO14001 certificates in 2012 (ISO, 2012).

The “indirect” contribution of EMSs to the economic development of a country is linked to the effects of these instruments on the competitiveness at the firm level. The relationship between environmental goals and industrial competitiveness has usually been thought of as involving a trade-off between social benefits and private costs. The issue was how to balance society’s desire for environmental protection with the economic burden on industry.

Indicators of competitiveness can refer to many aspects, such as, higher level of productivity, improvement of economic or market performance, better and improved relationship with the supply chain, and the better use of resources.

The empirical studies addressing the relation between environmental performance and competitiveness in ISO14001 facilities focused, mainly, on economic performance at the firm level. One of the milestones in this field is the theory published by Porter in 1995 (Porter and Van der Linde, 1995). In their study they define pollution as the “incomplete use of resources” and “signs of inefficiency”. According to this theory, EMSs (as ISO14001 is), which are based on the principle of pollution prevention, lead to the reduction in these productive inefficiencies, thus increasing the competitiveness of firms (King et al. 2005, Daddi et al. 2011, Testa et al., 2014).

The scientific literature provides different perspectives on the relationship between ISO14001, performance, resource efficiency and competitive performance. The debate in the last fifteen years over a wide range of theoretical questions investigates under what circumstances and exactly how environmental issues are related to competitiveness.

Several authors have focused on how ISO14001 effects on performance, exports, resource efficiency and thus indirectly the capacity to reduce costs.

De Oliveira et al. (2010) carried out a questionnaire in 2008 with Brazilian ISO14001 certified companies. The main benefits identified were related to the development of preventive environmental actions, and the reduction in the consumption of power, water, gas and fuel oil. Heras and Arana (2010) also found that for ISO14001 surveyed companies and for other Ekoscan certified organisations, one benefit is the improvement in resource efficiency.

Yasuhumi and Eric (2008) investigated the determinants of ISO certification in facilities and tried to reveal how ISO14001 certification affects various environmental and managerial outcomes in Japan. Data refer to 2001 and to more than 1700 industrial organisations in four sectors: electronics, electrical power, electric machinery and chemical manufacturing. Results showed that ISO certified facilities are larger and report higher levels of environmental management. In addition, early certifiers are more likely to have established voluntary environmental agreements and are more active in international trade and business.
Other studies pointed out the weak influence of ISO14001 on resource efficiency. For instance, Wagner (2002) analyzed a sample of 306 German manufacturing firms and found no significant differences in energy efficiency between firms with and without EMS (EMAS and ISO14001), both for 2001 and for the period 1991–2001. Hertin et al. (2004) performed regressions and times series analyses on European industrial companies and production sites with different EMS policies. Their main finding was that the link between a company's EMS and environmental performance (measured with eco-efficiency indicators) was weak and ambiguous.

2.3 ISO14001 effectiveness at the country level

It seems clear that the relationship between ISO14001 and economic and competitive performance at the firm level has been thoroughly investigated, however the same cannot be said if we broaden the focus taking into consideration the country perspective. There are very few studies that analyse the relationship between the number of ISO14001 certificates issued in a country and the macro-economic and development indexes within the same territorial context. Others studies have simply analysed the trend of ISO14001 adoption without a cross comparison with other indexes (Delmas, 2002; To and Lee, 2014)
One of the first studies in this field was carried out by two American scholars using a panel of 108 countries over seven years to investigate whether international trade encourages firms to adopt ISO14001 (Prakash and Potoski, 2006). The study looked at the effect of international trade on countries' ISO14001 adoption rates, examining both countries' structural dependence on exports and how often their main trading partners have high rates of ISO certification. They found that international trade influences ISO 14001 adoption through bilateral trade but not through structural trade. Countries whose export destinations have higher levels of ISO 14001 certifications have higher certification levels themselves.
Nishitani (2010) analyzed how the environmental preferences and pressures of customers in environmentally conscious markets influences the number of ISO 14001 adoptions in a country. The research was carried out over eight years using a sample of 155 countries. The findings show that the environmental preferences and pressures of customers in, for example, Finland, Japan, Germany and Denmark are more likely to encourage both domestic and foreign suppliers to adopt ISO14001.
Moon and DeLeon (2005) explored the relation between institutional interactions and ISO14001 adoption at the country level. Their sample covered 34 countries analyzing three types of interactions: inter-business interactions; government–business interactions; and government interactions. They observed that the successful tradition of cooperative government–business interactions at the country level led to a higher number of ISO14001 adoptions in the country. Similarly, Blanco and Borsky (2013) deal with the institutional determinants of the implementation rate of EMAS. Focusing on differences between countries' environmental regulatory stringency and institutional quality, found observed that a stricter environmental regulation decreases the number of EMAS certificates.
Lim and Prakash (2014) investigated the relation between the numbers of ISO14001 and eco-innovation examining a panel of 79 countries for the period 1996–2009. Their key explanatory variable was the annual ISO14001 participation levels (logged) observed at the country level. The authors showed that the country numbers of ISO14001 certificates can be considered as a predictor of a country's environmental patent applications.

Finally, Potoski and Prakash (2013) studied the relation between ISO14001 numbers and the pollution at the country level. Using a sample composed of a panel of 138 countries for the period 1995-2005, they found a statistical significant positive relation between the numbers of ISO14001 and SO2 reduction, while no similar relation was observed considering water pollution (COD emissions).
Our aim is thus to investigate the following hypothesis.

Hypothesis 1: The increase in ISO14001 certificates issued at the country level in recent years corresponds to an increase in macro-economic indexes (i.e. GDP per capita; industry added value).

Hypothesis 2: Countries' ISO14001 positive adoption levels are associated with a positive trend in development indexes (i.e. public spending on education; research and development expenditure; unemployment).

Hypothesis 3: the relation between the trend in ISO14001 adoption levels and the trend in macro-economic indexes observed in industrial and post-industrial economies confirms the theories based on the environmental Kuznets curve.

3. Empirical analysis

3.1 Data description

In order to test the above hypotheses, we collected time series data referring to the numbers of ISO14001 certificates issued at the country level and the macro-economic and development indexes for the same period and the same countries.
The source of data on ISO14001 numbers was www.iso.org and the periodic publications issued by the ISO (ISO, 2012). The panel of data used refers to the period 1999 – 2012. In order to have a variation in numbers of certificates across years we selected only those countries that in 2012 had at least one hundred ISO14001 certificates issued. This enabled us to select a panel of 73 countries distributed as follows in each continent: 33 European countries, 12 countries in North and South America, 4 countries in Africa, 26 countries in Asia and Oceania.
The source of data on macro-economic and development indexes at the country level was the World Bank and its periodic publications on World Development Indicators (World Bank, 2014). The time series covered the same period as the ISO14001 data from 1999 to 2012 and referred to the same countries. The data used was the following:

- GDP per capita (current US$)
- industry, value added (% of GDP)
- public spending on education, total (% of GDP)
- research and development expenditure (% of GDP)
- unemployment, total (% of total labor force)

GDP per capita was selected for its international recognition in measuring the growth of a country. The industry added value is an indicator strictly connected with ISO14001 numbers. Although international certifications can be applied to organisations belonging to all productive sectors, manufacturing is the sector where it is adopted the most (ISO, 2012).
The development indicators are all linked with the theme of education. They show the investments of a country in education and assess the effects of these investments (unemployment variable).

3.2 Model specifications

We used the growth-mixture modeling (GMM) method to test our hypotheses . Recent studies have highlighted the significant limitations of conventional latent-growth modeling (LGM) (mainly related to latent trajectories of unobserved populations) in many applied-research situations focused on the analysis of longitudinal trajectories. To overcome these limitations, GMM can be considered as a good method for handling longitudinal data (Wang and Bodner, 2007).
In order to test the relationships between the changes over time, and between the variables in the analysis, we performed latent cluster analysis (LCA) through Mplus 6.1 (Muthen and Muthen, 2010). This analysis identifies trajectories of the variables, which correspond to an intercept (baseline level of a variable) and the slope (the mean change over time). For each variable analyzed, we obtained a linear trajectory, namely the baseline level of the variable (at time 0) and the mean change over the years. With Mplus 6.1 several different variables/trajectories can be included at the same time, which can be tested against each other. That is, the trajectories (specifically their intercepts and slopes) can be correlated with each other, and also regressed on each other. For the intercepts (or baseline level of the variables), a positive correlation suggests that both variables start at the same level. A negative correlation suggests that if one variable starts lower, the other starts at a higher level.

(1) $y_{ti}=\eta_{0i}+ \eta_{1i}x_t+ \varepsilon_{ti}$

Equation 1 (which is a common standard regression) summarizes the GMM we used, where y is our outcome, t is the time-point, i is the individual level (in our study, each country), x is the time score. η_0 is the latent factor intercept, whereas $\eta_1$is the latent factor slope and ε corresponds to the residuals. Intercept and slop are random, since they can vary across individuals (the *I* in the equation).

(2) $\eta_{0i} = \alpha_0 + \gamma_0 w_i + \zeta_{0i}$

(3) $\eta_{1i} = \alpha_1 + \gamma_1 w_i + \zeta_{1i}$

The two *ηs* are latent variables and can be used as outcomes, i.e. they can be regressed on independent variables, see equations 2 and 3. The equations refer to standard regressions, where α is the intercept, γ is the slope, w is a time-invariant covariate and ζ is the residual variance. Unlike equation 1, in equation 2 and 3 we do not have random effects but rather fixed effects (that is, they do not vary across individuals).

4. Results and discussion

The variables analyzed followed a diverse scale and range, and because this difference could influence the results of the analysis, the variable were recorded in their quintiles. All the variables analyzed thus resulted in five levels. The range of each single variable over the years, i.e. the maximum and the minimum of each variable were considered over all the waves (instead of at each time point). The quintiles were then obtained by considering the overall range of the variables.
The results of the correlation/regression (the change trend over time) of slopes should be interpreted as follows. A positive coefficient between two slopes indicates that if one variables increases over time, the other variable also increases. A negative coefficient, suggests that if a variable increases, the other variable decreases.
A positive relation between intercept and slopes suggests that if the variable starts (baseline) low, the change over time is positive (the variable increases). If the coefficient is negative, then this should be interpreted as if a variable has a lower baseline, the changes over time correspond to a decrease in the variables. A multiple process analysis was conducted, where the trajectories of

different variables were correlated against each other. The multiple analysis identifies intercept and slopes for each of the variables' trajectories. An initial analysis was conducted on the overall sample, in order to test the co-variation (correlation) of intercepts and slopes.

4.1 The trajectories of ISO14001 certificates compared with macro-economic and development indexes

The results of the correlations between the trajectories tested with the latent cluster analysis are reported in Table 1. Of the six processes tested (ISO14001 certificates, GDP per capita, industry, value added, public spending on education, research and development expenditure, unemployment), we reported the correlation between the trajectory intercepts (I) and slopes (S). Using a multiple group analysis, the trajectories (intercepts and slopes) of GDP, IND, SPEN, RD, and UNEM were tested as predictors of the ISO' slope (the intercept was used as a predictor). Each variable's trajectory (intercepts and slopes) was tested in a separate analysis, since the inclusion of several processes can increase the model's complexity.

		I1	S1	I2	S2	I3	S3	I4	S4	I5	S5	I6
ISO	I1											
	S1	-.54***										
GDP	I2	.59***	-.54***									
	S2	-.17	**.33****	-.21								
IND	I3	-.13	.12	-.24*	.16							
	S3	-.31**	**.43*****	-.39***	.11	-.19						
SPEN	I4	.27*	-.20	.46***	.00	-.07	-.19					
	S4	.02	-.06	-.22	-.01	-.02	-.01	-.58				
RD	I5	.69***	-.36**	.62***	.02	-.20	-.35***	.46***	.01			
	S5	.10	.19	.04	-.05	-.22*	-.02	.01	-.05	-.19		
UNEM	I6	-.35***	.24**	-.43***	.09	-.08	.22	-.28*	.23	-.26*	.11	
	S6	.23*	-.08	.22*	.14	-.05	-.40	.34	-.05	.23*	19	-.59***

** p< .05, ** p < .01, *** p < .001*

Table 1 Correlations of intercepts and slopes of ISO, GDP, IND, SPEN, RD, UNEM.

The results in Table 1 provide answers to hypotheses 1 and 2. The first value marked in the table indicates a positive correlation between the slope of ISO14001 certificates with the slope of GDP (value 0.33). This value indicates that an increase in GDP corresponds to an increase in ISO14001 certificates in the countries of the sample. Similarly, a significant and positive relation can be observed between the ISO14001 slope and the variable "industry added value". This shows that an increase in ISO14001 certificates correlates to an increase in industry added value with a higher value than in the case of GDP: 0.43.
These results confirm our first hypothesis: the increase in ISO14001 certificates issued at the country level in recent years corresponds to an increase in the selected macro-economic indexes. Despite this, according to the model applied, it is not possible to observe whether the increase in ISO14001 certificates influences the increase in the selected macro-economic indexes or vice versa. Focusing on the intercept values, a significant and negative correlation can be seen between the ISO slope and the intercept of GDP. The reason for this may be that a lower baseline level of GDP corresponded to a greater increase in ISO, i.e. countries with a low level of GDP in 1999 saw a fast increase in ISO14001 certificates. This result may be influenced by the fact that these countries started in 1999 from a very low number of ISO14001 certificates which is why the increase in environmental certificates seems very high. This is confirmed by the negative and significant correlations between ISO intercept (I1) and ISO slope (S1). Similarly, the positive correlation

between the GDP intercept and ISO intercept (value 0.59) indicates that the country with a high GDP at the starting point of the time series (year 1999) also had a high number of ISO14001 certificates.
To test our second hypothesis, the results of the correlations between the slope of ISO (S1) and the slopes of the selected development indexes (S4, S5, S6) should be considered. In all cases no significant relations were found. The growth of ISO14001 in the sample countries can never be significantly associated with the growth (or reduction) in public spending on education, R&D expenditure, and unemployment. The significant values of intercepts of these variables with the intercept of ISO indicate that the higher public spending, development expenditure and employment (negative correlation of unemployment) are in the first year of the time series, the higher the number of ISO14001 certificates issued. Despite this, no significant results were found when observing the trajectories of the different variables, and thus the second hypothesis cannot be confirmed: the ISO14001 positive trend is not associated with positive trends in development indexes.

4.2 ISO14001 trends and the Environmental Kuznets Curve (EKC)

The EKC hypothesis postulates an inverted-U-shaped relationship between different pollutants and the stage of economic development (mainly measured by GDP per capita). As discussed in Section 2.1, this topic has been widely debated. We wanted to test our third hypothesis in order to verify whether the trend in ISO14001 compared with the macro-economic variables (GDP and IND) can confirm this the EKC.

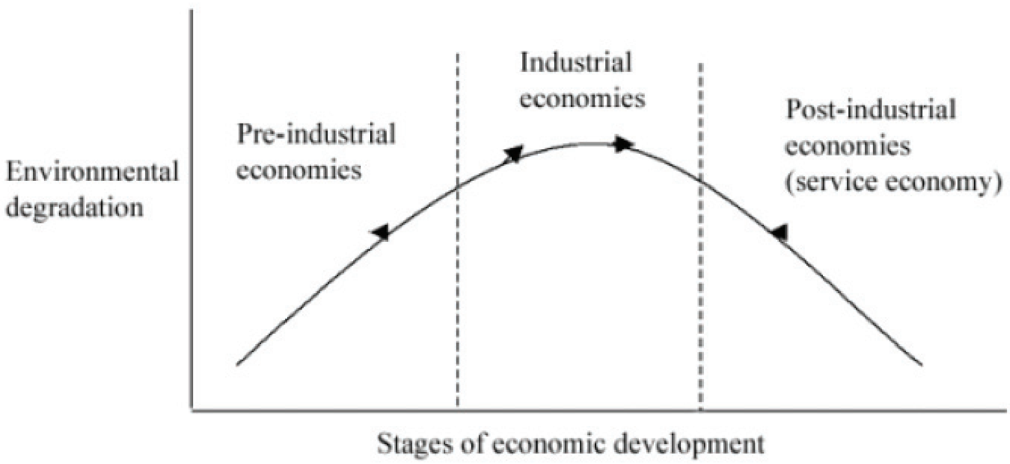


Figure 1. Environmental Kuznets Curve

To proceed with the testing of our hypothesis several assumptions are needed. First, in our case environmental degradation (often in other representations also indicated simply as pollution) is (inversely) measured by the trend in ISO14001 certificates in the different countries. To support this assumption, we refer to previous studies that have demonstrated the capacity of ISO14001to improve the environmental quality at the firm level (De Oliveira et al., 2010; Testa et al., 2014) as well as the country level (Potoski and Prakash, 2013). Second, in our study the stages of economic development are measured by both GDP per capita as well as industry added value. In other studies on EKC the horizontal axis of the figure is sometimes represented by GDP per capita. In our case, as ISO14001 is mainly applied to manufacturing facilities, we believe that the variable "industry added value" also helps to test our hypothesis.

As explained Figure 1, the EKC describes different relations between pollution and countries in different stages of economic development. Thus the first task was to split the initial sample of 73 countries into groups to represent the different stages of economic development.
To represent industrial economies, we selected Brazil, Russia, India, China and South Africa (i.e. BRICS). These countries are considered to be the fastest growing economies in the world and in our sample they all had more than 100 ISO14001 certificates issued in 2012. The other remaining countries in the sample were classified as non-industrial economies in order to compare them to the industrial economies. Tables 2 and 3 show the results of the application of GMM model on these countries.

	S_{ISO}	
	Industrial economies	**Other countries**
I_{GDP}	-0.353^{NS}	-0.286^{*}
S_{GDP}	0.022^{NS}	0.192

**p <.05, ** p < .01, *** p < .001*

Table 2. Growth coefficient of ISO regressed on GDP intercept and slope

	S_{ISO}	
	Industrial economies	**Other countries**
I_{IND}	0.039	0.114
S_{IND}	0.304	0.314^{**}

**p <.05, ** p < .01, *** p < .001*

Table 3. Growth coefficient of ISO regressed on IND intercept and slope

The tables show that the ISO slopes regressed with the GDP and IND slopes do not show a significant relation in industrial economies. This means that in the BRICS countries, there is no indication of a significant simultaneous increase in ISO14001 certificates in relation to the macro-economic indexes selected to measure the economic development. On the contrary in Table 3, as in Table 1, the relation between the increase in ISO14001 and industry added value maintains its significant and positive relation. No significant relations were observed considering GDP and the variable used to measure economic development.
According to the results shown and considering the industry added value as a parameter to measure economic development, the results appear to support our third hypothesis. This study shows that in BRICS countries, although the economic indicators are increasing, the number of ISO14001 certificates is not increasing (or at least not at the same speed). We can thus locate these economies in the first half of the section of the Kuznets Curve related to industrial economies, where the economy is growing together with pollution.
To test our third hypothesis in advanced economies (post industrial economies) we selected countries according to the 2014 IMF (International Monetary Fund) list (IMF, 2014), which identifies 36 countries with an "advanced economy". In our regression we considered 30 of these 36 countries, eliminating the countries with advanced economies but with less than 100 ISO14001 certificates in 2012 (Cyprus, Iceland, Luxembourg, Malta, San Marino and Taiwan). Table 4 shows the results after applying the model to the post-industrial economies.

	Slope - ISO Post-industrial economies
I_{GDP}	-.016
S_{GDP}	.020

I_{IND}	.087
S_{IND}	.185*

*$p < .05$, ** $p < .01$, *** $p < .001$*

Table 4. Growth coefficient of ISO in post-industrial economies regressed on GDP and IND intercepts and slopes

Considering the industry added value as the variable to measure economic development, our results confirm the EKC theory. The positive and significant relation between the slopes of ISO and IND indicates that in the post-industrial economies, there is a positive relation between the growth in the number of ISO14001 certificates and the added value produced by the industrial sector. These results confirm the negative inclination of the Kuznets curve for the post-industrial economies where the economy is growing and pollution is decreasing (in our case ISO14001 is increasing).
We did not test our method on pre-industrial economies, since our sample referred to countries with more than a hundred ISO14001 certificates. Nevertheless, even for developing countries we can still make some remarks. Analysing the countries with economic growth, however slow, (e.g. Ethiopia, Congo, Chad, Zambia) less than ten ISO14001 certificates have been issued, and the trend is not growing, some developing countries not having yet obtained their first certificate. This thus suggests that also for the first part of the EKC, our hypothesis works.

5. Conclusions

We applied a statistical model to investigate the relations between ISO14001 and macro-economic and development index trends at the country level. The results show a positive relation between the growth of ISO14001 and the selected economic indexes, while no significant relation was observed in terms of the development indexes. In addition we used our data to test the EKC theory , considering ISO14001 certificates as a variable to measure (inversely) pollution. Using the growth of industry added value to measure economic development, our analysis confirms the inverted-U-shaped relationship between pollution and economic development.
The main limitation of the study is the impossibility, according to our model, of identifying whether the growth of an economy boosts the number of ISO14001 or on the contrary, whether the widespread adoption of ISO14001 has a positive influence on economic indexes at the country level. Future research should analyse this further.
As shown in the previous sections, no significant relations were observed between the environmental certificates and development indexes. Future studies could consider the number of international standards more focused on social issues (e.g. SA8000, Global Compact) at the country level in order to investigate the relationship with these kinds of indexes. We believe that our work contributes to a new research agenda in the field of EMS studies, and we invite other scholars to investigate and assess the adoption of EMSs from a country perspective.

Acknowledgements
I wish to thank Andrea Norcini Pala for his great support.

References

Ann, G.E., Zailani, S., Wahid, N.A., 2006: A study on the impact of environmental management system certification towards firms' performance in Malaysia. Manag of Environ Qual 17, 73–93.

Apergis, N., Payne, J., 2011. The renewable energy consumption-growth. Nexus in Central America. Appl Energ 88, 343–347.

Arimura, H., Hibiki, A., Katayama. H., 2008. Is a Voluntary Approach an Effective Environmental Policy Instrument? A case for environmental management systems. J Environ Econ Manag. 55, 281–295.

Barde, J.-Ph., 1995. Environmental Policy and Instruments, in: Folmer, H., Gabel, L.H., Opschoor, H. (Eds.), Principles of Environmental and Resource Economics, Edward Elgar, London, 201–227.

Blanco, E., Borsky, S., 2013. Setting one voluntary standard in a heterogeneous Europe - EMAS, environmental taxes and institutional quality. Available at: http://www.webmeets.com/files/papers/EAERE/2013/850/EAERE%20updated.pdf (accessed September 2014).

Boopen, S., Vinesh, S., 2011. On the relationship between CO2 emissions and economic growth: the Mauritian experience. EDiA Paper No. 776. Available at: http://www.csae.ox.ac.uk/conferences/2011-EDiA/papers/776-Seetanah.pdf (accessed September 2014).

Daddi, T., Magistrelli, M., Frey, M., Iraldo, F., 2011. Do environmental management systems improve environmental performance? Empirical evidence from Italian companies. Environ. Dev. Sustain. 13, 845–862.

Daddi, T., Testa, F., Iraldo, F., Frey, M., 2014. Removing and simplifying administrative costs and burdens for EMAS and ISO 14001 certified organizations: evidences from Italy. Environ Engin and Managem J. 13, 689–698.

Delmas, M. A., 2002. The diffusion of environmental management standards in Europe and in the United States: An institutional perspective. Policy Sci. 35: 91-119.

Delmas, M.A., Pekovic, S., 2012. Environmental standards and labour productivity: Understanding the mechanisms that sustain sustainability. J. Organiz. Behav. 34, 230–252.

De Oliveira, O.J., Serra, J.R., Salgado, M.H., 2010. Does ISO 14001 work in Brazil? J. Clean. Prod. 18, 1797–1806.

Goldman Sachs, 2003. Dreaming with BRICs: the path to 2050. Global Economics, Paper no. 99

Grossman, G., Krueger, A., 1991. Environmental impacts of a North American Free Trade Agreement. NBER Working Paper Series, No. 3914.

Heras, I., Arana, G., 2010. Alternative models for environmental management in SMEs: the case of Ekoscan vs. ISO 14001. J. Clean. Prod. 18, 726–735.

Hertin, J., Berkhout, F., Wagner, M., Tyteca, D., 2004. Are 'soft' policy instruments effective? The link between environmental management systems and the environmental performance of companies. SPRU Electronic Working Papers Series. Available at: http://www.sussex.ac.uk/spru/research/sewps (accessed September 2014).

Honglei, C., Xiaoriong, Z., Qiufeng, C., 2011. Export-oriented economy and environmental pollution in China: the empirical study by simultaneous equation model. Energy Procedia 5, 884–889.

IMF, 2014. World Economic and Financial Surveys. World Economic Outlook (WEO). Recovery strengthens, remains uneven.

Iraldo, F., Testa, F., Frey, M., 2009. Is an environmental management system able to influence environmental and competitive? The case of the ecomanagement and audit scheme (EMAS) in the European union. J. Clean. Prod. 17, 1444-1452.

ISO, 2012. The ISO Survey of Management System Standard Certifications. Available at: http://www.iso.org/iso/home/standards/certification/iso-survey (accessed September 2014).

King, A., Lenox, M., Terlaak, A., 2005. The strategic use of decentralized institutions: exploring certification with the ISO 14001 management standard. Acad Manage J. 48, 1091–1106.

Lim, S., Prakash, A. 2014. Voluntary regulation and innovation: the case of ISO 14001. Publ Adminn Rev 74, 233–244.

Martín-Peña, M.L., Díaz-Garrido, E., Sánchez-López, J.M., 2014. Analysis of benefits and difficulties associated with firms' environmental management systems: the case of the Spanish automotive industry. J. Clean. Prod. 70, 220–230.

Milieu Ltd. and Risk and Policy Analysis Ltd. 2009: Study on the Costs and Benefits of EMAS to Registered Organisations. Final Report for DG Environment of the European Commission under Study Contract No. 07.0307/2008/517800/ETU/G.2.

Moon, S., DeLeon, P., 2005. The patterns of institutional interaction and ISO 14001 adoptions. Corpor Techn Transr and Soc 3, 35–57.

Muthen, B. and Muthen, L., 1998-2010. Mplus User's Guide. Sixth Edition. Los Angeles, CA: Muthen &Muthen

Nishitani, K., 2010. Demand for ISO 14001 adoption in the global supply chain: an empirical analysis focusing on environmentally conscious markets. Resource and Energ Econ. 32(3), 395–407.

Orobu, C.O., Omotor, D.G., 2011. Environmental quality and economic growth: searching for environmental Kuznets curves for air and water pollutants in Africa. Energ Policy 39, 4178–4188.

Ozturk, I., Acaravci, A., 2013. The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energ Econ. 36, 262–267.

Porter, M.E., van der Linde, C., 1995. Toward a new conception of the environment competitiveness relationship. J Econ Perspect. 9, 97–118.

Potoski, M., Prakash, A., 2013. Do Voluntary Programs Reduce Pollution? Examining ISO 14001's Effectiveness across Countries. Policy Stud J. 41, 273–294.

Prakash, A., Potoski, M., 2006. Racing the bottom? Trade, environmental governance, and ISO 14001. Am. J. Polit. Sci. 50, 350–364.

Saboori, B., Sulaiman, J., 2013. Environmental degradation, economic growth and energy consumption: evidence of the environmental Kuznets curve in Malaysia. Energ Policy 60, 892–905.

Studer, S., Tsang, S., Welford, R., Hills, P., 2008. SMEs and voluntary environmental initiatives: a study of stakeholders' perspectives in Hong Kong. J of Environm Plann and Manag, 51 (2), 285–301.

Testa, F., Rizzi, F., Daddi, T., Gusmerotti, N.M., Frey, M., Iraldo, F. 2014. EMAS and ISO 14001: the differences in effectively improving environmental performance. J. Clean. Prod. 68, 165–173.

Tharakan, P., Kroeger, T., Hall, C.A.S., 2001. Twenty five years of industrial development: a study of resource use rates and macro-efficiency indicators for five Asian countries. Environ Sci and Policy 4, 319–332.

To, W.M., Lee, P.K.C., 2014. Diffusion of ISO 14001 environmental management system: global, regional and country-level analyses. J. Clean. Prod. 66, 489–498.

Turk, A.M., 2009. The benefits associated with ISO 14001 certification for construction firms: Turkish case. J. Clean. Prod. 17, 559-569.

Wagner, M., 2002. The Relationship between environmental and economic performance of firms and the influence of ISO 14001 and EMAS: An empirical analysis and implications for government policy. Paper presented at the 5th Environmental Management Accounting Network Europe (EMAN-Europe) Annual Conference, University of Gloucestershire, Cheltenham, UK, pp. 11–12.

Wang, M., Bodner, T.E., 2007. Growth Mixture Modeling. Identifying and Predicting Unobserved Subpopulations With Longitudinal Data. Organis Research Meth 10, 635–656.

World Bank, 2014. World Development Indicators. Available at: http://data.worldbank.org/data-catalog/world-development-indicators (accessed September 2014).

Xuemei, H., Mingliang, Z., Su, L., 2011. Research on the relationship of economic growth and environmental pollution in Shandong province based on environmental Kuznets curve. Energy Procedia 5, 508–512.

Yang, H.Y., 2000. A note on the casual relationship between energy and GDP in Taiwan. Energ Econ. 22, 309–317.

Yasuhumi, M., Eric, W.W., 2008. The ISO 14001 environmental management standard in Japan: results from a national survey of facilities in four industries. J of Environm Plann and Manag 51, 421–445.

Zhai, S., Song, G., 2013. Exploring carbon missions, economic growth, energy and R&D Investment in China by ARDL approach. Geoinformatics, 21st International Conference, page 1-6,

DOI:10.1109/Geoinformatics.2013.6626205. Available at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6626205 (accessed September 2014).

Non-public bulk consumers as drivers of eco-innovations and demand side related innovation policy

Frieder Rubik[1]*, Ria Müller[2]

[1] *Institute for Ecological Economy Research (IÖW), Bergstraße 7, D-69120 Heidelberg/Germany*

[2] *Institute for Ecological Economy Research (IÖW), Potsdamer Straße 105, D-10785 Berlin/Germany*

* *Corresponding author: Emal frieder.rubik@ioew.de; phone ++49-6221-649166*

Topic: Results of Sustainability Innovations Research and Development

Abstract

Innovation policy is oriented towards the supply side. However, the demand side is an important driver of innovation, and this has received more attention in recent years. The role and potential of public procurement ("Green Public Procurement") has been especially highlighted in a couple of empirical examples and in literature. In this paper, we focus on the role of bulk consumers as drivers of eco-innovations.

We present the background of the paper and the applied research methods, work on hypotheses and the conceptual framework. A definition of bulk consumers is given and relevant markets in the German context clarified. Some empirical insights based on expert interviews, analyses of cases and three workshops are followed by potential policy strategies and some conclusions.

Keywords: Innovation, eco-innovation, demand side policy, market diffusion, consumption

1 Introduction

The orientation of innovation towards sustainability has become a systematic policy strategy in Europe ever since the Lisbon Strategy together with the EU Sustainable Development Strategy was put into place in 2004. Accordingly, this step is of high importance for the stimulation of eco-innovations. Hence, eco-innovations have been assigned an important role in reducing environmental pollution and – in this way – creating a more sustainable production and consumption patterns. It is expected that eco-innovations could generate synergies by decoupling environmental impacts and economic growth. As a result, the development and diffusion of eco-innovations are crucial elements for a transformation of production and consumption patterns.

From a welfare-theory perspective, there exists a twofold justification for innovation policy promotion of eco-innovations, due to their positive effects on both innovation and the environment (Rennings 2000; COWI 2009).

By "tradition", innovation policy is oriented towards the supply side. However, the demand side is an important driver of innovation, and this has received more attention in recent years. Edler (2007) analysed the German case of how government might trigger public and private demand to stimulate innovations. An overview of demand-side policy measures has been presented by Izsak/Edler (2011). The role and potential of public procurement ("Green Public Procurement") has been especially highlighted in a couple of empirical examples and in literature (e.g. Edler/Georghiou 2007; Knopf et al. 2010; OECD 2011). In this paper, we focus on the role of bulk consumers as drivers of eco-innovations.

This paper is organised as follows: **Chapter 2** presents the background of the paper and the applied research methods. **Chapter 3** is focussed on hypotheses and the conceptual framework. **Chapter 4** outlines our definition of bulk consumers and relevant markets in the German context. Empirical insights are presented in **Chapter 5**, whereas potential policy strategies are outlined in **Chapter 6** and some conclusions presented in the final **Chapter 7**.

2 Objectives and methods applied

In a research project on behalf of the German Federal Environment Agency (UBA), the role of greening demand by bulk consumers has been analysed[1]. Bulk consumers act on the demand side; with their purchases, they are able to influence the suppliers by making specific inquiries about environmental innovations and thereby contribute to their diffusion – that is the basic idea of the research topic.

First, the still running project determined the relevant markets on which bulk consumers play a crucial role. After doing so, 30 eco-innovations have been collected which have a promising environmental potential. These innovations have been prioritized. To collect empirical evidence on the interests, strategies and mobilisation potential, three national (German) workshops were held, along with the German Federal Environment Agency, in autumn 2013 and summer 2014 directly addressing bulk consumers for one specific eco-innovation each. As eco-innovations CO_2 air-conditioning systems in cars, energy-efficient commercial tumble dryers, and cotton made by recycled fibers or by bio-cotton were selected. After the workshops, policy strategies and measures were analysed to activate bulk consumers. To enlarge our focus and knowledge, experiences from innovation-oriented

1 The project runs from September 2012 until October 2014, its final publication is expected for early 2015.

public procurement, as well as from discussions on environmental and sustainability innovations drawn upon interviews with 19 international experts, have been added.

The main objective of the German Federal Environmental Agency is to assess the potential of bulk consumers to transform markets, and their relative importance and influence in contract, to private consumption and to public procurement.

3 Conceptual framework

The basic idea and hypotheses behind demand side eco-innovation appear simple: in a given market, a plethora of products with different environmental features co-exist, competition urges market actors to innovate to generate market leadership and to realise benefits. But, distinguishing features are not limited to technical ones. Environmental features will also be heterogeneous. Eco-innovations might be confronted with different handicaps in the market, like higher prices, less customers, market access hurdles etc. But if they are more environmentally benign, their market barriers prevent considerable positive environmental impacts[2]. Therefore, an earlier and broader introduction and diffusion of eco-innovative products might substitute the current portfolio of "dirty" products and realise a double dividend: reductions in environmental burdens and externalities.

Altogether, a demand-side related innovation policy focuses on the demand side to stimulate development, market introduction and diffusion of eco-innovations: "Demand side policies [...] define a need, or support the ability and willingness of potential buyers to demand an innovation or co-produce it with suppliers" (Edler 2013: p. 5).

4 Definition of bulk consumers and relevant markets

4.1 Definition

Based on an analysis of literature, we define as non-public bulk consumers by the following characteristics:

- commercial as well as non-profit-making,
- non-public organisations,
- which operate on the market as purchasers/ users either in the format of an independent organizational unit, or
- as one partner in a joint procurement activity,
- holding a significant share in the relevant market regarding the quantity of purchase or turnover per product group or service.

This definition is based on two assumptions:

- Due to the large volume of their procurement budget, bulk consumers are able to accelerate market introduction and penetration of eco-innovations independent of public funding.
- The reason for acquisition does not influence the market power of bulk consumers. This means that it has no impact whether or not procurement is done in order to address the institution's very own requirements, or goods and services are purchased, used and traded by this organization functioning as a service provider or reseller. Additionally, it is

2 Economists would say: ceteris paribus, but considering rebound effects the picture has to be enlarged.

immaterial how procurement is organised – independently, or as part of a buyers' group (so-called joint procurement).

3.2 High-priority markets of environmentally relevant goods and services

To focus on the – environmentally – most important markets of bulk consumers, we identified markets with high priority to bulk consumers and high environmental impact at the same time. Based on a literature review, several product groups were identified comprising application of the following environmentally relevant goods and services:

- Electric motors/electrical drives/generators/transformers,
- indoor lighting,
- textiles,
- cleaning products,
- hard floor coverings,
- IT/ICT-devices, specifically:
    - Desktop-PCs and
    - LCD-Monitors/flat screens.

Major environmental pollution and a high level of consumption or application accompany each of these product groups, and, therefore, considerable reduction in environmental impact is expected from bulk consumers purchasing eco-innovations.

5 Empirical evidence

As mentioned, we carried out literature analysis, expert interviews and three workshops with non-public bulk consumers. Examples like the greenfreeze campaign (cp. Härlin 1994), fairphone (Pett 2014) or energy+ (cp. Ostertag/Dreher 2002) demonstrate the opportunities, challenges and restrictions of a mobilization of consumers (some of them bulk consumers, some of them private consumers) and some as drivers for eco-innovation.

We identified a couple of key factors influencing support or hindrance for this approach. Altogether six clusters[3] could be distinguished:

- *Innovation-related key factors:* Quality and reliability, visibility and recognition, complexity and compatibility of innovation.
- *Supplier-related key factors:* Availability of innovation, adaptation costs, reputation of supplier, branch-related key factors, system management, configuration of the branch, business associations, lock in dependencies.
- *Demand side-related factors:* liability of purchasing intention, supply channels and routines, uncertainties as to qualities, position of supplying departments, change agents, rationalities, company culture and objectives, demand side fragmentation, benefits for bulk consumer, knowledge of innovation developments.
- *Context-related factors:* Standards, public interest, promotors, problem awareness/minimum level of attention, setting of actors.
- *Policy-related factors:* Policy framework, lead markets, antitrust law.

[3] The structure of the clusters follows Fichter/Clausen (2013, p. 96ff.).

This list hints to a considerable number of factors which influence – positively or negatively – the market introduction and dissemination of eco-innovations in the context of non-public bulk consumers as purchasers.

If we take these factors as relevant, we might also ask for the setting of actors in the whole "game". Bulk consumers as purchasers are a part of the story. By their purchasing decisions they influence the suppliers and their chains. Beside the supply chain and the bulk consumers, other – external actors – like policy/government, NGOs, media, networks and lobbyists affect the involved players, see Figure 1.

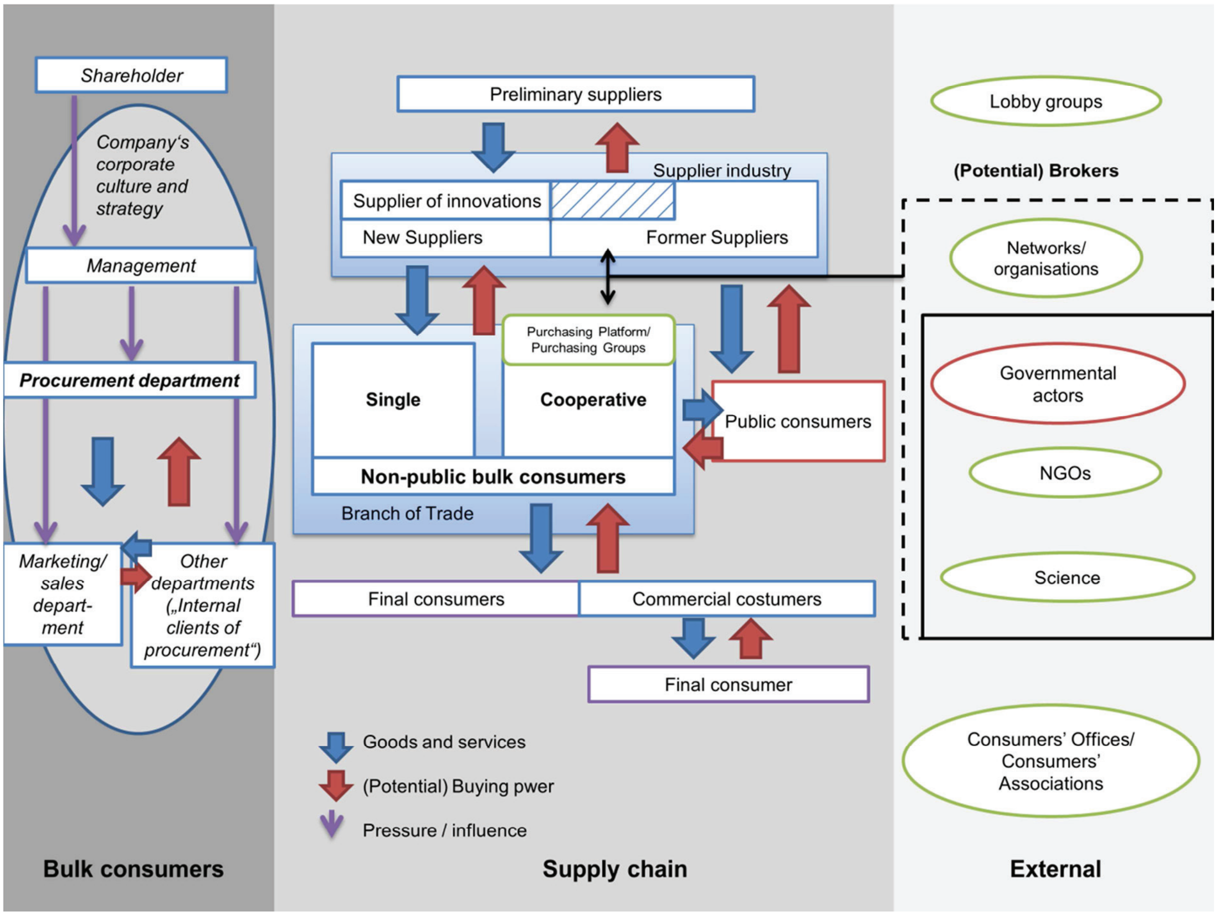


Figure 1: Configuration of actors purchasing eco-innovative products by non-public bulk consumers

Based on these insights, we brought together some key lessons learnt:

- *Pre-study for market targeting:* A strong market targeting is needed, so far, analysed activities are based on experiences of promoters and their intuitive feeling.
- *Mediators and brokers:* Evidence shows that different institutions might act as mediator in the market, e.g. NGOs, scientific organisations. The bundling of different purchasers in an organised market demand requests professional acting and bargaining. Among heterogeneous actors, specialized and respected entities are needed to fill in this gap. Environmental or consumer NGOs might be involved to increase credibility.
- *Roles in innovation process:* Bulk consumers could perform in different roles, namely as triggers for innovations, as co-producers or as "early adopters".

- *Realisation of theoretical market power in real demand:* Declared demand is not a real demand; it is not a strong signal. Binding demand has to be generated. Aside from that, purchasing is often decentralised, linked to the restricted “implementation power“ of management and rare embedment of the purchasing department in the strategic management level.
- *Business application context:* Purchasers have to “catch up“. This might be easier if the purchasers have a certain willingness to act (“Change agents”) and if they are allowed to take risks. To deal with these risks, eco-innovations have to be promoted credibly, long-term and comprehensive cost thinking has to be developed (“Life Cycle Costing“). People have to be trained. Also, differentiated risk sharing between suppliers and bulk consumers has to be promoted. Companies acting intrinsically or which have a sustainability management system are easier to involve than other companies.
- *Pooling of purchasers:* The aggregation of the demand of several purchasers increases their market power. But there are a couple of barriers, e.g. the competition situation in case of horizontal cooperation (cp. Hieronimus/Alf 2004, p. 6). A cooperation among public and commercial companies has to consider prescriptions of public tendering and competition laws.
- *Public awareness and problem awareness:* Attention towards environmental challenges, e.g. by actions of environmental NGOs, sensitises the general public, among them private households, public procurements or commercial procurement. The degree of the perception of problems might be an economic risk for vendors. Their products might be connected to these problems. This might stimulate incentives to take up eco-innovations. Especially “focal“ companies gain a lot of public attention and that of NGOs (cp. Seuring/Müller 2004, p. 144; Seuring/Müller 2008, p. 1699).
- *Political support and and “background music“:* The political system could act/react on a multi-governance system at the international and national level and send strong (regulative) and weaker (policy objectives, long term visions) signals of policy requests to emphasize specific future requests. Thereby, business and their associations receive hints for acting and are able to actively configure their own risk management.
- *Monitoring:* The observation of innovation related purchasing might document successes and failures. Monitoring supports companies to document and transfer their experiences as well as to report them. Also a dynamic snowball-effect might arise.

6 Specific eco-political strategies and possibilities for activating bulk consumers

Environmental innovations can be supported by policy in many ways. Summary overviews are to be found in Edler (2013), Horbach et al. (2003), Lehr/Löbbe (1999) or Rennings et al. (2008). Based on these and the insights from our research, we think that different levels of actions and actors are requested: Policy, bulk consumers and suppliers. The development and marketing of eco-innovation and the realisation of market potential is a risky path for suppliers, but these risks might not be too different from those for “classical” innovations. The forming of markets is a not trivial process, and it requires co-operation with clients (i.e. the purchasing companies).

In the following, we will focus on the policy level and chances to improve the framework to develop and diffuse eco-innovations. Specific eco-political strategies and possibilities for activating bulk consumers as drivers for eco-innovations are subdivided into several clusters of actions (cp. Figure 2):

- *Regulatory measures*: Previous experiences demonstrate the potential of regulatory measures like strict threshold limits or prohibition. Such measures are able to contribute to a phasing out of products and services and to an introduction of eco-innovative ones. Also liability rules or mandatory information are suitable actions.
- *Economic measures:* They intend to change the incentive structure and to strengthen demand for eco-innovations. Economic incentives (e.g. fiscal incentives, subventions) deal with the higher prices of innovative products and services in the first market phase and should arrange incentive for purchasers. Also, innovation funds or the link of subsidies with accompanying advisory services, are other approaches. Also co-operation of commercial and public procurement as well as the bundling of procurers will generate, on the one side, sale guarantees and on the other side generate economies of scale. To reduce risks of early adopters, risk insurance systems might support the early market adoption.
- *Informative and communicative measures:* Eco-innovative products might be supported by publicly credible labelling programmes (e.g. EU Flower, Blue Angel) which should act as early as possible to take eco-innovative product groups / requirements for eco-innovative solutions into their portfolio. Training and qualification of public and commercial purchasers is suitable to influence the demand side. Also, demonstration projects, innovation data banks and highlighting good/best practices could promote eco-innovations. Campaigns by NGOs or public entities could hint at environmental challenges and innovations to overcome them. Innovation or sustainability awards might also accentuate eco-innovations.
- *Reflexive and discursive measures:* Eco-innovations are often not very “visible” in the market. An exchange of experiences, fora, experience platforms etc. might contribute to a better reflection of experiences and to learning by actors involved. Evaluation studies and boards might help.
- *Co-operative measures:* Cooperation between business and public entities is a suitable approach to start dialogue among actors of a specific chain (horizontal, vertical networking). Also, co-production/user involvement in the innovation process might be used in this context. A broader approach is the elaboration and implementation of road maps / action plans indicating agreed measures among participants to support eco-innovations.
- *Lead market initiatives:* Such initiatives could focus national/international efforts towards specific challenges and focus corresponding activities towards them. The intention is to develop “test” markets, to contribute to the realization of economies of scale and to disseminate products afterwards on the global level.
- *Assessment measures:* The different measures intended to support eco-innovations need to be monitored in order to know more about their success and failure. Linked to that, evaluative work is requested to learn more about the stories behind the monitored numbers.

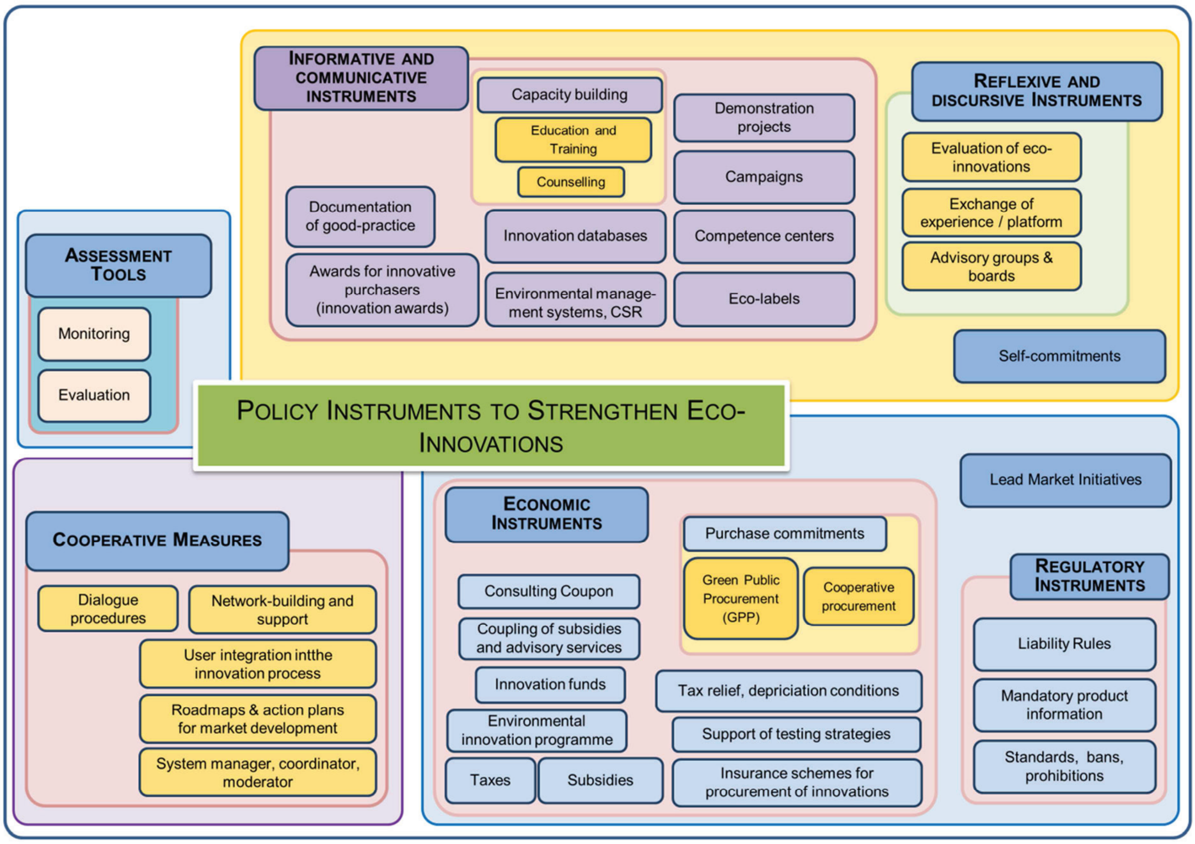


Figure 2: Overview on potential demand side policy measures to strengthen eco-innovations

This short overview on measures to support market access and diffusion of eco-innovation by demand-side policy measures demonstrates the diversity of measures.

7 Conclusions

The strategic mobilisation of the demand side to strengthen eco-innovations and to stimulate sustainable consumption and production patterns is an important cornerstone of environmental policy. The demand side consists of several main clusters of actors, namely private consumers, retailers, public procurement and commercial/non profit procurement of business. The latter is a heterogenous group. Among them are bulk consumers, which have an important market share.

The concept of using their market power to support development, market entrance and market diffusion of eco-innovations seems to be a promising approach. However, details must be considered. There are key influencing factors which have been highlighted in this paper. An appropriate constellation of actors – suppliers, market brokers, purchasers – is important to choose the appropriate “line up” of actors together with policy.

Policy might support eco-innovations focusing on the demand-side. A couple of approaches have been suggested. Naturally, these have to be adapted to the concrete context. Policy activities are able to generate welfare gains by cost reduction and improvement of environmental burdens.

References

COWI (2009): Bridging the Valley of Death. Public Support for Commercialisation of Eco-innovation. Final Report.

Edler, J. Review of policy measures to stimulate private demand for innovations. Nesta Working Paper 13/13, Manchester.

Edler, J., 2007. Bedürfnisse als Innovationsmotor. Konzepte und Instrumente nachfrageorientierte Innovationspolitik. Sigma, Berlin.

Edler, J., Uyarra, E., 2013. Public procurement of innovation, in: Osborne, S., Brown, L. (Eds.), Handbook of Innovation in Public Services. Edward Elgar Publishing, pp. 224–237.

Fichter, K., Clausen, J., 2012. Erfolg und Scheitern "grüner" Innovationen. Metropolis, Marburg.

Härlin, B., 1994. Die "Greenfreeze"-Erfahrung, in: Hellenbrandt, S., Rubik, F. (Eds.), Produkt und Umwelt. Anforderungen, Instrumente und Ziele einer ökologischen Produktpolitik. Metropolis, Marburg, pp. 222–232.

Hieronimus, M., Ahlf, N., 2004. Beschaffungskooperationen. RECO, Göttingen.

Horbach, J. (Ed.), 2003. Nachhaltigkeit und Innovation. Rahmenbedingungen für Umweltinnovationen. Ökom, München.

Izsak, K., Edler, J., 2011. Trends and Challenges in Demand-Side Innovation Policies in Europe. Thematic Report 2011 under Specific Contract for the Integration of INNO Policy TrendChart with ERAWATCH (2011-2012) Contract number x07.

Knopf, J., Kahlenborn, W., Weiß, D., Pechan, A., Khuchua, N., Jacob, K., Bär, H., Grubbe, M., Münch, L., 2010. Innovationspotentiale der umweltfreundlichen öffentlichen Beschaffung. UBA-Texte 54/2011.

Lehr, U., Löbbe, K., 1999. Umweltinnovationen - Anreize und Hemmnisse: Ein Überblick über die innovativen umweltpolitischen Instrumente. Ökologisches Wirtschaften 1999, 13–15.

OECD, 2011. Demand-side innovation policies. OECD, Paris.

Ostertag, K., Dreher, C. Cooperative procurement: market transformation for energy efficient products, pp. 314–332.

Pett, S., 2014. Meet Fairphone: A phone company turning protest into a disruptive product. http://www.theglobeandmail.com/technology/tech-news/meet-fairphone-a-phone-company-turning-protest-into-a-disruptive-product/article16901664/. Accessed March 5, 2014.

Rennings, K., 2000. Redefining innovation — eco-innovation research and the contribution from ecological economics. Ecological Economics 32, 319–332.

Rennings, K., Rammer, C., Oberndorfer, U., Jacob, K., Boie, G., Brucksch, S., Eisgruber, J., Haum, R., Mußler, P., Schossig, C., Vagt, H., 2008. nstrumente zur Förderung von Umweltinnovationen. Bestandsaufnahme, Bewertung und Defizitanalyse. Umwelt, Innovation, Beschäftigung 2008.

Seuring, S., Müller, M., 2004. Beschaffungsmanagement & Nachhaltigkeit — eine Literaturübersicht, in: Hülsmann, M., Müller-Christ, G., Haasis, H.-D. (Eds.), Betriebswirtschaftslehre und Nachhaltigkeit. Deutscher Universitätsverlag, Wiesbaden, pp. 117–170.

Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production 16, 1699–1710.

The ISO 26000 standard as a driver for systemic Design for Sustainability

Cristina Rocha(1), Kirsten Schmidt(2)

(1) LNEG – Estrada Paço do Lumiar, 22 – 1649-038 LISBOA – Portugal
cristina.rocha@lneg.pt
(2) Aalborg University, Denmark

Abstract

Sustainable product development is considered a key factor for sustainable development. Products are placed in the interface between production and consumption, therefore the consideration of sustainability criteria early in their development phase, to improve them throughout the life cycle, opens up for innovations that contribute to tackle major sustainability problems in the context of a globalized economy.

Design for sustainability (DfS) is distinguished from ecodesign in terms of sustainability topics covered (not only environmental and economic, but also social) and in terms on the focus on finding new ways to satisfy customers and client needs and make business sense while respecting the physical limits of the planet in providing resources and absorbing pollution.

Given these perspectives and conceptual consensus amongst sustainability experts, efforts have been made to operationalize DfS; some authors have focused on high level models that guide companies in establishing a vision and concepts for (more) sustainable products; other, more instrumental approaches, offer methods and tools dedicated to different phases of typical product development stages.

The state of the art is that tools and methods are available for product innovation including environmental, economic and social criteria; nevertheless, it is recognized that social criteria are still poorly established, except in specific design approaches such as social design, which then overlook the environmental dimension. In other words, full integration in order to find a sustainability optimum, rooted in stakeholder dialogue and validated by life cycle assessment (environmental, social and economic), is far from accomplished. As for more radical sustainable product innovations, despite of the existence of several encouraging and inspiring examples, limitations in methods for sustainability assessment and in the availability of workable design criteria are acknowledged. Another drawback is the lack of coordination between many strategies and practices already used by organizations for tackling environment, quality, health and safety, sustainability communication, reporting and assessment, life cycle management, etc., and product development.

One possible contribution to progress towards a model for sustainable product development on what concerns improved rooting in companies' sustainability management practices, stakeholder engagement and a more robust integration of social aspects, can be derived from social responsibility. Organizational social responsibility has registered a remarkable progress in the last decade, culminating in the development of a comprehensive guidance document for the systematic management of organization's impacts on society and the environment: the ISO 26000 standard on social responsibility from 2010. Although products and life cycle thinking are conceptually part of the activities that organizations following the standard are

supposed to manage in a responsible way, this has not been accomplished yet. Furthermore, the social responsibility cardinal principle of stakeholder engagement is also a window of opportunity for companies to understand stakeholder's and society's expectations regarding their products and find innovative solutions to respond to them.

The development of a framework for DfS building upon previous work in the field of sustainable design management and bringing the novel element of establishing the link to social responsibility principles and practices is a very ambitious task. According to ISO 26000, organizations should address organizational governance, human rights, labour practices, the environment, fair operating practices, consumer issues and community involvement and development in order to reduce their negative impacts and increase their positive impacts on society and the environment. Of course, the implications of products in the context of the system where they are manufactured, transported, used, disposed-off and recycled vis-à-vis all these subjects vary immensely with the product's value chain and characteristics.

Key words: design for sustainability, sustainable development, social responsibility, ISO 26000

1 Introduction

The integration of environmental considerations into product development with the objective of reducing products' environmental impacts along their life cycle (ecodesign, also known as life cycle design, design for the environment or green product development) has been subject of research (for instance, van Hemel, 1998; Myrdal, 2010), tools and methods development (Brezet and van Hemel, 1997; Behrendt et al., 1997; Tischner et al., 2000) and implementation in companies since the 1990's (for instance, Klostermann and Tukker, 1998; Stevels, n.d.).

Key characteristics of ecodesign include the life cycle perspective (i.e. considering the environmental aspects – inputs and outputs – and associated impacts at each life cycle stage, such as climate change, resources depletion, toxicity, air, water and soil pollution, etc.), and early integration (i.e., addressing environmental considerations at the earliest possible stage of product development (Thrane and Eagan, 2007), when there is more room for introducing changes to the product concept and achieve optimum outcomes).

In order to deal with the challenges that underlie the sustainable development concept, companies have to drastically change the way they address product development and its management. The ecodesign concept has evolved to a broader one described as design for sustainability, which includes more radical innovations in the product, questioning its function and thus influencing the existing patterns of consumption which are expected to give a far bigger contribution to sustainable development (Brezet and Rocha, 2001). Unlike in ecodesign, not only environmental concerns are taken into account, but also social and economic ones, in accordance to the so-called "three pillars of sustainable development".

Some definitions of ecodesign, derived to distinguish it from mainstream design, go beyond incremental gains. However, these definitions were made in the absence of DfS as an additional category (Spangenberg et al., 2010). These authors highlight that DfS broadens the horizon by including long-term and global assessments and challenges established practices around the understanding of the needs and functionality of the product. By that, it creates an additional level of complexity and makes solutions less clear-cut, and therefore more risky.

Another understanding of DfS comes from the European Commission that in 2009 launched their definition of DfS as a driver of user-centered innovation stating that DfS is the holistic approach to problem solving, allowing for factors that include functionality, ergonomics, usability, accessibility, safety, sustainability, cost, and intangibles such as brand and culture (EU Commission, 2009). In the Wuppertal Institute Designguide the definition of DfS is "…all about establishing or maintaining the individual's quality of life without limiting the potential well-being of other people or future generations…", and with that purpose "…includes the promotion of a sustainable use of environmental space…" and "…needs to provide social-technical solutions that didactically foster appropriate transition processes". Furthermore, the DfS approach in a consistent and comprehensive way needs to consider that (a)"…we are individuals who are organized into social groups and work in organizations that follow certain economic…" and social rationales; and (b) "…needs and desires are satisfied by materialized products and are incorporated into preferences for social justice or meaningful work which are themselves the results of social norms and values (Liedtke et al., 2013).

In their understanding of DfS, Crul and Diehl (2010) point at the need of working with DfS in both systemic and systematic ways including, among other things, consumer needs and the need for sustainability oriented interventions. In the same line of thought, Vezzoli and Manzini (2008) argue that a design approach seeking to effectively tackle radical innovation and sustainable consumption should operate on a system innovation level. They identify two dimensions in a system design approach to sustainability: eco-efficient (product-service) system design and design for social equity and cohesion, and highlight the need to promote and facilitate new configurations (of partnerships and interaction) between different stakeholders to find innovative solutions able to lead to a convergence of economic, environmental and social interests. This calls for the ability to operate or facilitate a participatory design process among entrepreneurs, users, non-governmental organizations, institutions and so on. The agenda of social design is inspired by, among others, Victor Papanek's idea that designers and creative professionals have a responsibility and are able to cause real change in the world through good design. Already in the 1970's he wrote about his ideas for ecologically sound design and designs to serve the poor, the disabled, the elderly and other minority social groups (Papanek, 1971).

Spangenberg et al. (2010 p. 1492) concur to this: *Design for Sustainability must be able to draw on the detailed knowledge of science (and produce its own), but must go beyond it to provide comprehensive solutions by involving actors, stakeholders and consumers in the process. Selective, decontextualised perception of tasks and challenges is not future proofed, as the objects of design cut across all spheres of life and all components of eco-efficiency. Thus design(ers) need a vision of a better life in tomorrow's society and a clear understanding of their role, their possible contribution to and responsibilities in the transition towards sustainable development.*

Building upon the several contributions to understanding the concept of DfS, in this paper the following definition is adopted:

DfS is a holistic design approach to problem solving and to societal well-being that enables to integrate and assess the sustainability dimensions in different stages of the product development process towards the required scale of incremental and/or radical innovations. DfS thus encompasses the dimensions of sustainability performance and stakeholder engagement, and the organizational processes to support them.

When it comes to operationalizing the concept of DfS or sustainable product development, literature is relatively scarce; there are few tools and methods developed to orient the system design process towards socio-ethically sustainable solutions (Vezzoli and Manzini, 2008; Tischner, 2008).

One landmark is the publishing of UNEP's manual "Design for Sustainability – A Step by Step Approach" (Tischner et al., 2009), a joint publication with Delft University of Technology. This manual proposes three approaches: (i) DfS redesign, aiming at incremental product innovation and (ii) new product development and (iii) product-service systems, aiming at radical product innovation. Being a guide, it is very practical and implementation orientated, targeting companies of all sizes and degree of acquaintance with DfS concepts, supported by a theoretical framework and examples of applications. Social aspects are of course included in the manual, but the level of detail in which they are organized and addressed varies in the different approaches and tools it provides. The same happens with stakeholder engagement. The part of the manual dedicated to product-service systems is the one where social aspects are more developed; as for stakeholders involvement, more guidance is provided on the chapter dedicated to user-oriented scenarios.

Byggeth et al. (2007) developed a method for sustainable product development (MSPD) based on backcasting from The Natural Step sustainability principles. It was quite conceptual and overarching. In a further attempt to support moving product categories towards sustainability, Ny et al. (2008) proposed templates that can be used in combination with the method for sustainable product development (MSPD), but these focus on the early stages of product development.

The Natural Step sustainability principles were also the foundation for Waage's work (2007) to propose a roadmap for sustainable product design; by using a model for product development based on four phases (understand the problem/need/desire; explore possible solutions; define and refine the best solution; and implement the solution), this author discussed environmental and social implications in all stages of the product development (therefore going beyond the needs analysis and conceptual design). Here, social aspects concern enforced human rights policies (for both company and suppliers), such as safe and healthy working conditions, freedom of association, non-discrimination in personnel practices and prohibition of forced or child labour, but the relationship of these concerns with product and service development is not clear.

Therefore, the lack of integration of social/ethical aspects in both DfS practice and research is still observed and there are multiple methods and levels of approach that denote the need for a systematic and scientifically grounded work in this field. Similarly, as Tischner observed for PSS development in the above mentioned UNEP Manual (Tischner et al., 2009), it is still missing the multi-stakeholder and -actors approach that is necessary to (re-)design the whole production and consumption systems, as well new forms of co-operation and methods to organize these, which take the different stakeholders' motivations and interest into account and are able to deal with possible conflicts. Her work in the field is one contribution to overcome such gap.

Even if there is no common definition of DfS, the concept of DfS has to be understood from both a performance approach including all aspects of sustainable development and a process approach continuously involving the whole organization, the value chain and the stakeholders as opposed to an ad hoc based integration of DfS issues in design or innovation projects. Design management then becomes a part of DfS as it encompasses the ongoing processes, business decisions, and strategies that enable innovation by linking design, innovation, technology, management and customers to provide competitive advantage across the triple bottom line: economic, social/cultural, and environmental factors (Design Management Institute, 2014).

Design management is not a standard model to be applied by every organization, and companies work with design management at many levels from a project or function based level to a fully integrated level where design management is a part of the organizational culture (Kootstra, 2009).

Spangenberg at al. (2010) reflect on the ethical point from the DfS perspective stating that “although re-introducing values into science and design (…) contradicts the self-perception and habits of scientific/academic thinking, it brings design closer to end users: moral and ethics are an indispensable element of any social fabric” (p. 1491).

While the existing tools and approaches to DfS point at the need to include both environmental, social and economic issues; to ground decision making on ethical principles; to implement DfS on all organizational levels; to understand DfS as an ongoing dynamic process and to involve stakeholders in this process – none of these approaches seems to cover all the elements.

The publication of the ISO 26000 standard on Social Responsibility in 2010 brought a new framework for addressing the impacts of organizations’ decisions and activities on society and the environment – including innovation for sustainability. ISO 26000 was developed in a 6 year multi-stakeholder and consensus based process involving more than 500 experts from 99 countries and thus offers a systematic and up to date overview of what can be considered as social responsibility with the aim of promoting sustainable development. As the current DfS frameworks and practices overlook social aspects and stakeholder engagement or deal with these aspects based on an ad hoc list of topics, ISO 26000 potentially offers a new and systematic approach. This paper takes a closer look at ISO 26000 with the purpose of analyzing how the standard can contribute to DfS to overcome these gaps.

It is recognised that management system standards like ISO 14001 and ISO 9001 support companies in managing environmental or quality related risks and, to a certain extent, in meeting societal expectations. This is also the case with ISO 26000, but this guidance standard has an even stronger focus on stakeholder engagement, which may open for dynamic innovation processes in the organization.

Even if ISO 26000 is not a management system standard, it provides a management framework for stakeholder engagement as an integrated part of responsible and sustainable business development. As such, ISO 26000 has the potential to move the DfS agenda from a project based to a holistic design for sustainability approach, systematically taking social, environmental and economic considerations into account.

2 The ISO 26000 standard on social responsibility

2.1 Overview

The development of ISO 26000 on social responsibility was triggered by a multitude of previous initiatives in the field of social responsibility or corporate social responsibility, with varied sustainability focuses (often with an unbalanced orientation towards environmental aspects or specific social aspects such as working conditions, human rights or corruption), being targeted to different types of organizations (mostly enterprises, in some cases of large size) and having different objectives (reporting, management systems, stakeholder engagement, etc.); in this landscape, the concept of social responsibility was (and, for some, is, see for instance Schwarz and Tilling, 2009) loosing focus and becoming a buzz-word. There was a need to move forward in terms of conceptual framework and harmonizing terminology, given the fact that organizations are subject to greater scrutiny by their various stakeholders (ISO, 2010).

According to this standard, organizations are urged to adopt a transparent and ethical behaviour that:

- Contributes to sustainable development, including health and welfare of society;
- Takes into account the expectations of stakeholders;
- Is in compliance with applicable law and consistent with international norms of behaviour; and
- Is integrated throughout the organization and practiced in its relationships (i.e., the organization’s activities within its sphere of influence).

The essential characteristic of social responsibility is the willingness of an organization to incorporate social and environmental considerations in its decision making and be accountable for the impacts of its decisions and activities on society and the environment.

The principles, practices and core subjects described in the standard form the basis for an organization’s practical implementation of social responsibility and its contribution to sustainable development (ISO, 2010). The consistency with international norms of behaviour (derived from customary international law, generally accepted principles, treaties and conventions that are universally – or nearly – recognized) brings an ethical dimension to organization’s activities that may not be expressed in the law it is subject to. “Ethical behaviour” is also a fundamental principle of social responsibility in ISO 26000.

Social responsibility applies to the daily operations of an organization and to its strategic decisions regarding new products, services or even business models. Managing social responsibility in line with the standard builds upon many strategies and practices already used by organizations for tackling environment, quality, health and safety, sustainability communication, reporting and assessment, life cycle management, etc.

ISO 26000 proposes that an organization may recognize and manage its social responsibility in an effective way by considering seven core subjects (each of them detailed in different issues, see next chapter):

- Organizational governance;
- Human rights;
- Labour practices;
- The environment;
- Fair operating practices;
- Consumer issues;
- Community involvement and development.

Figure 1 provides an overview of ISO 26000.

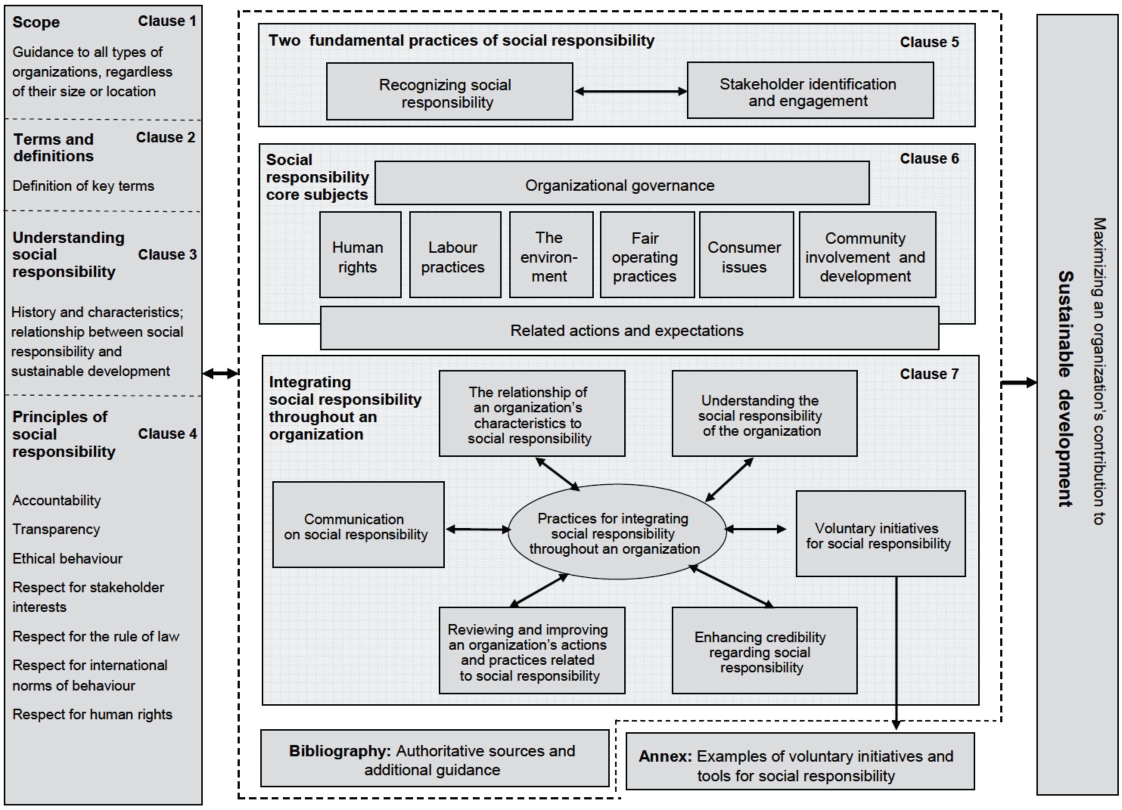


Figure 1 – Schematic overview of ISO 26000

Source: ISO 26000:2010.

The standard provides the following explanation of the figure (ISO, 2010):

— After considering the characteristics of social responsibility and its relationship with sustainable development (Clause 3), the organization should review the principles of social responsibility described in Clause 4. According to the standard, these are fundamental principles the organization according to which the organization, along with the principles specific to each core subject (Clause 6).

— Before analysing the core subjects and issues of social responsibility, as well as each of the related actions and expectations (Clause 6), an organization should consider two fundamental practices of social responsibility: recognizing its social responsibility within its sphere of influence, and identifying and engaging with its stakeholders (Clause 5).

— Once the principles have been understood, and the core subjects and relevant and significant issues of social responsibility have been identified, an organization should seek to integrate social responsibility throughout its decisions and activities following guidance provided in Clause 7.

2.2 Stakeholder engagement in ISO 26000

Identification of- and engagement with- stakeholders are fundamental to social responsibility.

The standard defines stakeholder as “individual or group that has an interest in any decision or activity of an organization” (definition 2.20). It further explains that in this context, ‘interest’ refers to the actual or potential basis of a claim, that is, to demand something that is owed or to demand respect for a right. This may involve financial demands or legal rights, or can simply be the right to be heard. In determining which stakeholder interests to recognize, the organization should consider the lawfulness of those interests, their consistency with international norms and their relationship to sustainable development. This is of major importance because stakeholders’ interests are not always aligned with the broader expectations of society, including – but not limited to – legal compliance. The standard refers to international norms of behavior such as those reflected in the Universal Declaration of Human Rights, the Johannesburg Declaration on Sustainable Development and other instruments.

In other words, the organization should understand and recognize how its decisions and activities impact on society and the environment and understand society's expectations of responsible behavior concerning these impacts. The standard provides guidance to this, primarily by addressing the core subjects and issues. A matter may be relevant to the social responsibility of an organization even if not specifically identified by the stakeholders it consults.

Therefore, organizations are expected to understand the relationship between the stakeholders' interests that are affected by the organization, on the one hand, and the expectations of society on the other.

Understanding how individuals or groups are or can be affected by an organization's decisions and activities will make it possible to identify the interests that establish a relationship with the organization. Therefore, the organization's determination of the impacts of its decisions and activities will facilitate identification of its most important stakeholders. The standard recommends that to identify stakeholders an organization should ask itself the following questions:

- To whom does the organization have legal obligations?
- Who might be positively or negatively affected by the organization's decisions or activities?
- Who is likely to express concerns about the decisions and activities of the organization?
- Who has been involved in the past when similar concerns needed to be addressed?
- Who can help the organization address specific impacts?
- Who can affect the organization's ability to meet its responsibilities?
- Who would be disadvantaged if excluded from the engagement?
- Who in the value chain is affected?

Another key concept in the standard is that of sphere of influence, understood as the “range/extent of political, contractual, economic or other relationships through which an organization has the ability to affect the decisions or activities of individuals or organizations” (definition 2.19). Thus, these ‘individuals or organizations’ “within and beyond the value chain” (ISO, 2010, p.16) can be understood as a subset of the organization’s overall stakeholders towards whose the organization has specific responsibilities. The standard recommends that organizations exercise their influence with others either to enhance positive impacts on sustainable development, or to minimize negative impacts, or both, beyond those impacts organizations are directly responsible for (formally or de facto). This concept is not new; it has been described and practiced in environmental management systems (ISO 14001:2004, paragraph

4.3.1) and Life Cycle Management (UNEP guide on Life Cycle Management, Remmen et al. 2007), for instance.

It follows that engagement with stakeholders and exercising influence in the sphere of influence are two important practices in social responsibility. ISO 26000 addresses them in different ways: while stakeholder engagement concerns activities undertaken to create opportunities for dialogue with stakeholders with the aim of providing an informed basis for the organization's decisions, exercising influence concerns assessing the sphere of influence and determining the organization's responsibilities to promote socially responsible practices in others.

Methods of exercising influence include (ISO, 2010):

- Setting contractual provisions or incentives;
- Public statements by the organization;
- Engaging with the community, political leaders and other stakeholders;
- Making investment decisions;
- Sharing knowledge and information;
- Conducting joint projects;
- Undertaking responsible lobbying and using media relations;
- Promoting good practices; and
- Forming partnerships with sector associations, organizations and others.

In the standard it is recognized that elements of the sphere of influence (concretely suppliers and contractors) can have an impact on the social responsibility of the organization (ISO 2010, p. 71), but in general the emphasis is vice-versa.

Stakeholder engagement is widely addressed in the standard and is of primordial importance in practicing social responsibility, in accordance to the principle of respect for stakeholder interests.

According to ISO 26000, stakeholder engagement can take many forms. It can take place in either informal or formal meetings and can follow a wide variety of formats such as individual meetings, conferences, workshops, public hearings, round-table discussions, advisory committees, regular and structured information and consultation procedures, collective bargaining and web-based forums. Stakeholder engagement should be interactive and is intended to provide opportunities for stakeholders' views to be heard. Its essential feature is that it involves two-way communication.

The purpose of stakeholder engagement in the standard can be summarized as follows:

- Recognizing and determining the relevant issues of social responsibility of the organization;
- Assisting the organization in establishing priorities for action on core subjects and issues and translating them into manageable objectives;
- Enhancing the organization's credibility regarding social responsibility, through the verification of its claims and reports, and through resolving disagreements;
- Providing inputs to review and improve performance;

This relates primarily to the stakeholders' role in supporting the organization in managing and continually improving its social responsibility. Furthermore, the standard highlights other uses to stakeholder engagement (ISO, 2010):

- Providing the organization with the benefits of obtaining diverse perspectives;
- Increasing transparency of the organization's decisions and activities;

— Forming partnerships to achieve mutually beneficial objectives.

Figure 2 presents in a schematic manner the main elements described in this section in regards to how the organization relates its stakeholders according to ISO 26000, in the context of the ultimate goal of contributing to sustainable development.

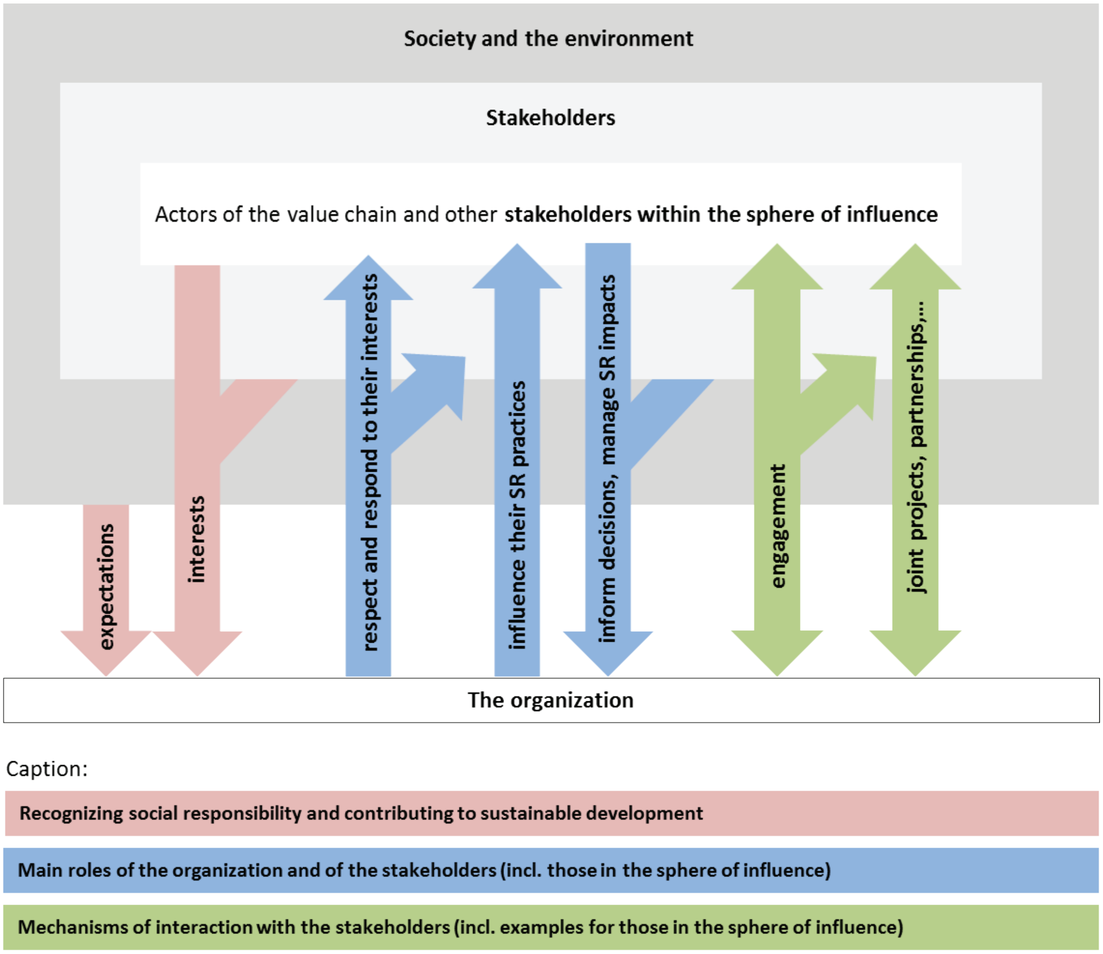


Figure 2
An interpretation of the relationships of the organization, the society & environment and the stakeholders (including those within the sphere of influence) according to ISO 26000

3 ISO 26000 as a framework for DfS

3.1 A comprehensive list of social aspects to address in DfS

According to the standard, the seven core subjects mentioned above cover economic, environmental and social impacts that are most likely to occur during business activities, including products, services and processes, and should therefore be addressed by organizations aiming at contributing to sustainable development by minimizing their negative impacts and maximizing their positive ones on society and the environment.

Each core subject includes a range of issues of social responsibility. To be noted that economic aspects are not a separate core issue, but rather dealt with throughout the subjects. As for organizational governance, the standard states that its nature is somewhat different from the other core subjects, because this subject concerns practices that enable organizations to take action in the other core subjects and to implement the social responsibility principles. In this sense, organizational governance is a “means” to achieve the “ends” (improving performance in relation to the other six core subjects).

The standard calls for a holistic approach – as opposed to a ‘single issue’ approach – to the core subjects and highlights that they are interdependent.

In this chapter, an analysis of the ISO 26000 core subjects and issues is carried out in order to identify those that are in the range of product-service design and against which sustainability performance could be assessed (either with quantitative or qualitative methods). The aim is to produce a comprehensive list of aspects grounded on the robustness of ISO 26000 as argued in the introduction.

The core subject ‘organizational governance’ is excluded from this analysis because it consists of management mechanisms for organizations to make and implement decisions in pursuit of their objectives; governance is very important to support and enable sustainable design management, but it is not a feature of the product or service. It should be noted that, according to ISO 26000, economic aspects are interwoven in the core subjects and issues.

When identifying social aspects that are relevant for DfS, a distinction must be made between (1) those aspects that can be influenced by product/service design and (2) those questions that relate to the choice of suppliers (because this may influence the product/service development process). Moreover, involvement of stakeholders and communities may be regarded as socially responsible in its own right, but this aspect is not included in the assessment of the ISO 26000 issues’ relevance for DfS because it is addressed in the next chapter.

Table 1 gives an overview of the issues in ISO 26000 relevant for DfS and the type of DfS related strategies that are relevant for the issue. The full list of all ISO 26000 issues and their DfS relevance is included in Annex A.

Table 1 – Identification of SR core subjects and issues that are relevant for DfS, and of related design strategies

Core subjects and issues	DfS related practices
Core subject: Human rights	
Issue 5: Discrimination and vulnerable groups	DfS can contribute to fight discrimination e.g. through inclusive design to provide products and services which are accessible to, and useable by, as many people as reasonably possible without the need for special adaptation or specialized design.
Issue 7: Economic, social and cultural rights	Examples of action include adapting goods or services to the purchasing ability of poor people, such as design for the bottom of the pyramid. This may be in the range of DfS, if it fits the company’s market strategy.
Core subject: Labour practices	
Issue 4: Health and safety at work	Avoiding the use of toxic substances and dangerous equipment is within the range of DfS and is closely related to the ecodesign strategy on reducing the environmental impact of production.
Core subject: The Environment	
Issue 1: Prevention of pollution	Prevention of pollution by minimizing emissions, managing waste and handling and disposal of toxic and hazardous substances are recognized as key issues in

	ecodesign and is part of DfS.
Issue 2: Sustainable resource use	Optimizing resource use of energy, water, materials is an integrated part of eco-design and cradle-to-cradle design and should also be included in DfS.
Issue 3: Climate change mitigation and adaptation	Preventing climate changes and, where needed, adapting to climate changes are integrated in eco-design and requires global and local solutions as a part of DfS. Biomimetic design can be used here.
Issue 4: Protection of the environment, biodiversity and restoration of natural habitats	Valuing and protecting biodiversity and ecosystem services, using land and natural resourcing sustainably, and advancing environmentally sound urban and rural development is inside the range of DfS as part of ecodesign, design for biodiversity or cradle2cradle design.
Core subject: Fair operating practices	
Issue 4: Promoting social responsibility in the value chain	Proper documentation and information on sustainability issues in the value chain are within the range of DfS.
Issue 5: Respect for property rights	Respecting property rights are important in any design process and could be dealt with by designers by following codes of ethics for design professionals.
Core subject: Consumer issues	
Issue 1: Fair marketing, factual and unbiased information and fair contractual practices	Responsible marketing and disclosure of life cycle based information like LCA, sLCA, LCC, EPD, ecolabels and other sustainability-related labels to allow consumers to make informed chaices is within the range of DfS.
Issue 2: Protecting consumers' health and safety	Design for consumer's health and safety is inside the range of DfS by using the precautionary principle.
Issue 3: Sustainable consumption	Strategies related to increasing product durability; PSS; design for sustainable consumer behavior; responsible marketing, disclosure of life cycle based information; eco-labels and other sustainability-related labels are within the range of DfS.
Issue 4: Consumer service, support, and complaint and dispute resolution	Increased product durability and support for easy repair and maintenance is part of ecodesign and inside the range of DfS.
Issue 5: Consumer data protection and privacy	Gathering of information on any design process is expected to be based on ethical strategies for market studies and analysis.
Issue 6: Access to essential services	Inside the range of DfS if the company's market strategy supports it.
Issue 7: Education and awareness	Inside the range of DfS by disclosure of life cycle based information, eco-labels and other sustainability-related labels.
Core subject: Community involvement and development	
Issue 1: Community involvement	Involving local people in design processes may lead to more sustainable solutions, e.g. in Product-Service Systems.
Issue 2: Education and culture	Supporting the local education and culture, by empowering disadvantaged groups Is inside the range of DfS for example by integrating local skills, materials and technologies.
Issue 3: Employment creation and skills development	Through the choice of technologies and partnership with local communities, DfS can support the development of local skills and creation of jobs.
Issue 4: Technology development and access	Through the choice of technology and by integrating traditional knowledge, DfS can assist in addressing this issue.
Issue 5: Wealth and income creation	Integrating local skills, materials and technologies and by giving preference to local suppliers is within the range of DfS.
Issue 6: Health	The design of products or services to help combat health risks like obesity, for instance, by inviting to more physical activities when using the product is a way for a company to promote health and is inside the range of DfS
Issue 7: Social investment	DfS can improve social aspects of community life by

	integrating local skills, materials and technologies, by giving preference to local suppliers and by involving the community in generating ideas for sustainable and responsible solutions.

Going through the ISO 26000 revealed that the core subjects and many of the issues conceptually are part of DfS and that it was possible to identify design strategies that are already being practiced to address most of the relevant issues.

The use of ISO 26000 opens up for a very broad range of design strategies (when compared to those in ecodesign, for instance) which is positive in the sense that is comprehensive and complete, if one takes the premise that ISO 26000 is a sound basis for integrating societal expectations in DfS. On the other hand, the large range of potential design strategies makes the process very complex and demanding as regards the know how within the design team, the functions involved in the product service development process and the engagement of stakeholders. From a governance perspective, it will also require complex methodologies and supporting procedures to assure improvements in the sustainability performance and a systematic and documented outcome of the design process.

3.2 Stakeholder engagement and DfS

As Driessen and Hillebrand (2013) note, stakeholder theory is largely silent on how information about stakeholders affects new product development. But the practice of collective creativity in design has been around for nearly 40 years, going under the name ‘participatory design’ (Sanders and Stappers, 2008). Co-design, which was brought to the business community in 2004 by C.K. Prahalad and V. Ramswamy’s book “The Future of Competition: Co-creating Unique Value with Customers”, differs from participatory design and user-centered design in that it does not assume that any stakeholder a priory is more important than any other (Pelle, 1990).

Co-design refers, for some people, to the collective creativity of collaborating designers. Sanders and Stappers (2008) use co-design in a broader sense to refer to the creativity of designers and people not trained in design working together in the design development process. This is the understanding that matters in this paper in relation to stakeholder engagement in DfS.

Thorpe and Gamman (2011) suggest that equitable arrangements between stakeholders are essential to ensure the successful delivery of design for the social change in the real world and argue that, in this sense, socially *responsive* design is ‘good enough’, because designers, rather than being *responsible* for societal changes should look to leverage available resources to work *with* social actors to meet societal goals.

A study on integrating multiple stakeholders’ issues in ‘green’ new product development brought light into some important managerial challenges that result from such complex process where conflicting interests arise (Driessen and Hillebrand, 2013):

- Firstly, a distinction needs to be made between market stakeholders (those directly involved in exchanges taking place in the product markets of the organization, such as customers, competitors, suppliers and retailers) and non-market stakeholders (those that are not involved in those exchanges, such as regulators, special interest groups and – to a lesser degree – employees). The study showed that environmental concerns are much more likely to be brought forward by non-market stakeholders, which leads to tensions or conflicts of interests; these happen also inside a category of stakeholders.

- The process of identifying stakeholders and their issues is important because it will determine the tensions the organization will have to manage. Acknowledging such tensions is a first step towards reaching consensus within the team.
- It is necessary to have coordination mechanisms to keep the 'green' issues in the agenda. Coordination mechanisms range from formal (procedures to include environmental concerns in the innovation process or quantified objectives in a product profile, for example) to informal (that stimulate communication and create a culture where green issues are regularly discussed in new product development meetings). The results showed that using multiple coordination mechanisms in conjunction is important to ensure that a minimum level of coordination issues is safeguarded and no important one is ignored.
- Prioritization principles are necessary and some organizations performed better than others in prioritizing green issues in the decision-making process. New product development projects that address many non-market stakeholders issues use several prioritization principles in conjunction.

Driessen and Hillebrand conclude that stakeholder integration in new product development is a capability which consists of (1) stakeholder issue identification techniques, (2) coordination mechanisms and (3) prioritization principles, and that such capability is developed when the three components are incorporated into the fabric of the organization. This is the result of a learning process which does not happen overnight; furthermore, the features of the organizations matter: those that follow a proactive environmental strategy and are characterized by a high environmental impact are more likely to develop stakeholder issues identification techniques.

The implications of considering all the above when looking at the potential of ISO 26000 to support DfS are manifold:

- ISO 26000 urges organizations to proactively adopt an ethical behaviour and set up social responsibility strategies as a contribution to sustainable development. The standard is in line with the notions of identifying a multitude of stakeholders (and not only the market stakeholders) and of SR issues (regarding which stakeholders have a saying), and the standard explicitly states that all core subjects need to be addressed; this applies to all organizational activities and processes, including new product and service development;

- The purpose of stakeholder engagement includes supporting the organization in defining priorities for action on core subjects and issues and translating them into manageable objectives; no guidance is provided, however, on how to tackle conflicts of interests or wicked problems which is a challenge as the study by Driessen and Hillebrand (2013) pointed out; by extending the scope from environmental management to social responsibility management, this question becomes even more complex;

- The link between the standard and the development of innovations through co-design is less immediate. An adaptation of stakeholder engagement concept, as it is presented in ISO 26000, to the field of design for sustainability would be: to create opportunities for dialogue between in the organization (and specifically the design team) with its stakeholders, with the aim of providing and informed basis for the organization's decisions regarding sustainable product-service development. The stakeholder engagement methods are very broad and If a company wants to pursue co-design, it needs to develop the capabilities, methods and processes for that. In other words, as seen in figure 2 stakeholder engagement and exercising influence according to ISO 26000 do not emphasize the concept of *working together*, although there are examples of activities in the standard that go beyond dialogue and influence, such as the development of joint projects and partnerships with stakeholders.

— ISO 26000 is silent on what concerns distinguishing the interests of market stakeholders and non-market stakeholders; considering that some market stakeholders such as suppliers, clients and end-users are often in the sphere of influence of the organization, the standard's approach to managing the sphere of influence (i.e., focusing on positively influencing their social responsibility practices) should not distract companies from the opportunities of developing partnerships with them for co-design.

4 Conclusion

From the academic sources it can be concluded that on a general level there are some common understanding of Design for Sustainability, but no common definition. Moreover, the different understandings of DfS specify different aspects to be included on the conceptual as well as on the operational level. In this paper, the following definition of DfS was used: *DfS is a holistic design approach to problem solving and to societal well-being that enables to integrate and assess the sustainability dimensions in different stages of the product development process towards the required scale of incremental and/or radical innovations. DfS thus encompasses the dimensions of sustainability performance and stakeholder engagement, and the organizational processes to support them.*

As the current DfS frameworks and practices overlook social aspects and stakeholder engagement or deal with these aspects based on an ad hoc list of topics, the ISO 26000 standard on Social Responsibility potentially offers a new and systematic approach both as regards the social issues to be included in DfS and in managing the stakeholder engagement.

Going through the ISO 26000 revealed that all the core subjects and 22 of the 37 related issues conceptually are part of DfS and that it was possible to identify a broad range of design strategies that are already being practiced in, for example, ecodesign or in supply chain management to address most of the relevant issues.

ISO 26000 thus seems to offer a rather comprehensive and complete basis for including social issues in DfS. On the other hand, the large range of potential design strategies makes the process very complex and demanding as regards the know-how within the design team, the functions involved in the product service development process and the engagement of stakeholders.

Further research and empirical work is needed in developing knowledge and experiences to comprehensively covering social issues in DfS based on ISO 26000; in literature, the only publication we could find refers to a very preliminary experience with the furniture industry in Portugal (Vicente et al., 2010), in which an expert meeting was organized and the concept was well received by the designers' community, academics and industry representatives.

Stakeholder engagement is established as a fundamental principle in ISO 26000 and it is widely addressed in the standard with primordial importance in practicing social responsibility. As concluded by Driessen and Hillebrand, stakeholder integration in new product development is a capability which consists of (1) stakeholder issue identification techniques, (2) coordination mechanisms and (3) prioritization principles, and that such capability is developed when the three components are incorporated into the fabric of the organization. In relation to using ISO 26000 as a framework for DfS, it has a number of implications.

ISO 2600 urges organizations to proactively adopt an ethical behaviour and to engage with a multitude of stakeholders as a part of identifying and prioritizing relevant issues. However, no guidance is provided in the standard on how to tackle conflicts of interest among stakeholders or among the organization and its stakeholders, for example related to market priorities versus social enforcement of local communities.

The ISO 26000 standard was not developed with the specific purpose of supporting innovation and design processes. While the standard does encourage stakeholder engagement and gives recommendations on how to structure this process, it does not emphasize the concept of working together, although there are examples of going beyond a stakeholder dialogue by developing joint projects and partnerships. The eventual use of the standard as a framework for DfS is left open for interpretation by the individual organization and its stakeholders.

From a governance perspective, it will require complex methodologies and supporting procedures to assure improvements in the sustainability performance and a systematic and documented outcome of the design process as stakeholder engagement should be closely related to improvements on relevant social and environmental issues to promote sustainable development.

To deal with the growing complexity in DfS, the designers – or project managers in design teams – will need knowledge and competences to bridge the complexity and become facilitators for the changes that designing for sustainability requires. For example, competences related to communication, change management, and relations building while at the same time being able to assess the relevance, validity and usefulness of the inputs for the design process. Such skills and competences are not specified in ISO 26000 and are for the time being not, or very limited, a part of the curriculum for design engineers. Recent projects as the Leonardo da Vinci DEEDS project (Design Education and Sustainability, 2009) developed a number of principles that need to be considered in DfS, among others related to developing skills, creating change agents and learning together.

Another important aspect to be explored is how to balance the use of scientific methods (e.g. Life Cycle Assessments, social Life Cycle Assessments or Life Cycle Costing) with a stakeholder based approach in evaluating the sustainability profile of a product or service.

An on-going project, SInnDesign (Sustainability and Innovation through Design, funded by the Leonardo da Vinci subprogramme of the EU Lifelong Learning Programme) specifically focuses on integrating DfS in the curriculae for design professionals in the habitat cluster and demonstrating how this can be of use in working with selected companies. In this project the linkage between DfS and ISO 26000 is being experimented in order to bring light into the practical application of this approach of DfS in three sectors of the habitat domain: home textiles, furniture and construction materials.

References

Behrendt, S.; Jasch, C.; Peneda, M.C.; van Weenen, H. (1997): *Life Cycle Design, A Manual for Small and Medium-sized Enterprises*. Springer, Berlin.

Blincoe K.; Fuad-Luke, A.; Spangenberg, J. Thomson, M.; Holmgren, D.; Jaschke, K.; Ainsworth, T.; Tylka, K. (2009): *DEEDS: a teaching and learning resource to help mainstream sustainability into everyday design teaching and professional practice.* Int. J. Innovation and Sustainable Development, 4 (1), 1-23.

Brezet, H. and van Hemel, C. (1997): *EcoDesign: A promising approach to sustainable production and consumption.* UNEP, Paris.

Brezet, H. and Rocha, C., (2001): *Towards a Model for Product Oriented Environmental Management Systems (POEMS)*. In Sustainable Solutions: Developing Products and Services for the Future, Ed. Charter & Tischner, Greenleaf Publishing.

Byggeth, S.H.; Broman, G.I.; Robèrt, K.H. (2007): *A method for sustainable product development based on a modular system of guiding questions*. Journal of Cleaner Production, 15, 1-11.

CEN ISO 14001:2004 (2004): *Environmental Management Systems.* Requirements with guidance for use.

Crul, M. and Diehl, J.C. (2010): *Design for sustainability: Moving from incremental towards radical design approaches*. “Transitions to Sustainability” NZSSES Conference 2010, Auckland.

Design Management Institute: https://dmi.site-ym.com/?What_is_Design_Manag, retrieved on September 19th, 2014.

Driessen, P.H. and Hillebrand, B. (2013): *Integrating Multiple Stakeholder Issues in New Product Development: An Exploration.* Journal of Product Innovation Management, 30 (2), 364-379.

EU Commission (2009): *Design as a driver of user-centered innovation* (http://ec.europa.eu/enterprise/policies/innovation/policy/design-creativity/index_en.htm)

ISO 26000:2010 (2010): *Guidance on social responsibility*. International Organization for Standardization, Geneva.

Klostermann, J.E.M. and Tukker, A. (Eds., 1998): *Product Innovation and Eco-Efficiency: Twenty-three industry efforts to reach the Factor 4.* Kluwer Academic Publishers, Dordrecht.

Kootstra, G. (2009): *The incorporation of design management in today’s business practices*. An analysis of design management practices in Europe, p.12. INHOLLAND University of Applied Sciences.

Liedtke C.; Ameli N.; Buhl J.; Oettershagen P.; Pears T.; Abbis P. (2013): *Wuppertal Institute Designguide*, Wuppertal Spezial 46, Wuppertal Institute for Climate, Environment and Energy.

Ny, H.; Hallstedt, S.; Robèrt, K.H.; Broman, G. (2008): *Introducing templates for sustainable product development: A case study of televisions at Matsushita Electric Group*. Journal of Industrial Ecology, 12 (4), 600-623.

Papanek, V. (1971): *Design for the real world: Human Ecology and Social Change*. New York, Pantheon Books.

Pelle, E. (1990): *Work-oriented design of computer artifacts*. L. Erlbaum Associates Inc. Hillsdale N.J., USA.

Remmen, A.; Jensen, A.A.; Frydendal, J. (2007): *Life Cycle Management. A business Guide to Sustainability*. Paris: United Nations Development Programme (UNEP).

Sanders, E.B.-N. and Stappers, P.J. (2008): *Co-creation and the new landscapes of design*, CoDesign: International Journal of CoCreation in Design and the Arts, 4:1, 5-18.

Schwarz, B. and Tilling, K. (2009): *'ISO-lating' Corporate Social Responsibility in the Organizational Context: A Dissenting interpretation of ISO 26000*. In: Corporate Social Responsibility and Environmental Management. 16, 289–299.

Spangenberg, J.H.; Fuad-Luke, A.; Blincoe, K. (2010): *Design for Sustainability (DfS): the interface of sustainable production and consumption*. Journal of Cleaner Production, 18, 1485–1493.

Stevels, A. (n.d.): *Adventures in eco-design of electronic products 1993-2007. A personal view*. Delft, Delft University of Technology.

Thorpe, A. and Gamman, L. (2011): *Design with society: why socially responsive design is good enough.* CoDesign, 7(3-4), 217-230.

Thrane, M. and Eagan, P. (2007): *EcoDesign*. In Kørnøv et al.: "Tools for Sustainable Development", 267-291. Aalborg, Aalborg Universitetsforlag.

Tischner, U.; Schminke, E.; Rubik, F.; Prösler, M. (2000): *How to do eco-design? A guide for environmental and economically sound design*. Berlin, German Federal Environmental Agency.

Tischner, U. (2008): *Design for (social) sustainability and radical change*: In: System Innovation for Sustainability 1: Perspectives on Radical Changes to Sustainable Consumption and Production, Tukker at al. (eds.). Greenleaf, Sheffield.

Tischner, U.; Ryan, C.; Vezzoli, C. (2009): *Product-service systems. Design for Sustainability (D4S): A Step-By-Step Approach. Modules,* Paris: United Nations Environment Program (UNEP).

Vezzoli, C. and Manzini, E. (2008): *Review: design for sustainable consumption and production systems*. In Tukker et al. (eds.): System Innovation for Sustainability 1:

Perspectives on Radical Changes to Sustainable Consumption and Production, Greenleaf, Sheffield.

Vicente J.; Frazão R.; Rocha C.; Silva, F.M. (2010): *The integration of social criteria in sustainable design for furniture.* Proceedings of the 14th European Roundtable on Sustainable Consumption and Production, Delft, 25-29 October.

Waage, S.A. (2007): *Re-considering product design: a practical "road-map" for integration of sustainability issues*. Journal of Cleaner Production, 15, 638-649.

Annex A

Core subjects and issues	Relevance for DfS
Core subject: Human rights	
Issue 1: Due diligence	This is a process to identify, prevent and address actual or potential human rights impacts resulting from the organization's activities. It's a management process outside the range of DfS.
Issue 2: Human rights risk situations	Organizations should take particular care when dealing with these situations. Outside the range of DfS.
Issue 3: Avoidance of complicity	Actions to avoid complicity include seeking for information about the social and environmental conditions in which purchased goods and services are produced. Outside the range of DfS.
Issue 4: Resolving grievances	This is about remedy having remedy mechanisms to protect human rights. It's a managerial activity outside the range of DfS.
Issue 5: Discrimination and vulnerable groups	Discrimination involves any distinction, exclusion or preference that has the effect of nullifying equality of treatment or opportunity. DfS can contribute to fight discrimination through the provision of products and services which are inclusive.
Issue 6: Civil and political rights	Absolute rights such as the right to life, the right to a life with dignity, the right to freedom from torture, the right to security of person, the right to own property, liberty and integrity of the person, and the right to due process of law and a fair hearing when facing criminal charges. Too vast of an issue to be identified as within DfS range.
Issue 7: Economic, social and cultural rights	Examples of action include adapting goods or services to the purchasing ability of poor people, such as design for the bottom of the pyramid. This may be in the range of DfS, if it fits the company's market strategy.
Issue 8: Fundamental principles and rights at work	This has to do with the relationship between the organization and workers (freedom of association and right to collective bargaining; the elimination of all forms of forced or compulsory labour; the abolition of child labour). Outside the range of DfS.
Core subject: Labour practices	
Issue 1: Employment and employment relationships	This is about freedom of association, collective bargaining, and elimination of forced labour, child labour and discrimination as specified in the ILO conventions. Outside the range of DfS.
Issue 2: Conditions of work and social protection	Includes wages, working time, disciplinary and dismissal practices, maternity protection, welfare matters and access to medical services. Outside the range of DfS.
Issue 3: Social dialogue	This includes negotiation, consultation or exchange of information between governments, employers and workers. Outside the range of DfS.
Issue 4: Health and safety at work	This issue concerns the physical, mental and social well-being of workers and prevention of harm to health caused by working conditions. Design solutions to avoid the use of toxic substances and dangerous equipment is within the range of DfS.
Issue 5: Human development and training in the workplace	This is about expanding human capabilities and functioning enabling people to live healthy lives, be knowledgeable and have a decent standard of living. It also includes access to being creative and productive at work. Outside the range of DfS.
Core subject: The Environment	
Issue 1: Prevention of pollution	Prevention of pollution by minimizing emissions, managing waste and handling and disposal of toxic and hazardous substances are recognized as key issues in ecodesign and is part of DfS.
Issue 2: Sustainable resource use	Optimizing resource use of energy, water, materials is an integrated part of ecodesign and is part of DfS.
Issue 3: Climate change mitigation and	This is about preventing climate changes and, where

adaptation	needed, to adapt to climate changes. The preventive aspects are integrated in ecodesign but require global and local solutions as a part of DfS.
Issue 4: Protection of the environment, biodiversity and restoration of natural habitats	Includes valuing and protecting biodiversity and ecosystem services, using land and natural resourcing sustainably, and advancing environmentally sound urban and rural development. This is inside the range of DfS as part of ecodesign, design for biodiversity or cradle2cradle design.
Core subject: Fair operating practices	
Issue 1: Anti-corruption	Corruption is the abuse of entrusted power for private gain and anti-corruption concerns the way the organization and its relations are managed. Outside the range of DfS.
Issue 2: Responsible political involvement	It concerns the way the organization and its relations are managed. Outside the range of DfS.
Issue 3: Fair competition	It concerns the way the organization and its relations are managed. Outside the range of DfS.
Issue 4: Promoting social responsibility in the value chain	This is about influencing other organizations in the value chain to support social responsibility. Proper documentation and information on sustainability issues are within the range of DfS.
Issue 5: Respect for property rights	Respecting property rights are important in any design process and could be dealt with by designers by following codes of ethics for design professionals.
Core subject: Consumer issues	
Issue 1: Fair marketing, factual and unbiased information and fair contractual practices	This is to allow consumers to make informed choices and to secure fair market practices. It includes responsible marketing and disclosure of life cycle based information like LCA, sLCA, LCC, EPD, ecolabels and other sustainability-related labels. This is inside the range of DfS.
Issue 2: Protecting consumers' health and safety	This involves the provision of products and services that are safe and that do not carry unacceptable risk of harm when used or consumed, both intentedly and in foreseeable misuse. Design for consumer's health and safety is inside the range of DfS as a precautionary principle.
Issue 3: Sustainable consumption	Is about consuming products and resources at rates consistent with sustainable development. Strategies related to increasing product durability; PSS; design for sustainable consumer behavior; responsible marketing, disclosure of life cycle based information; eco-labels and other sustainability-related labels are within the range of DfS.
Issue 4: Consumer service, support, and complaint and dispute resolution	These are the mechanisms to address the needs of consumers after products and services are bought or provided. Increased product durability and supporting easy repair and maintenance is part of ecodesign and inside the range of DfS.
Issue 5: Consumer data protection and privacy	This is intended to safeguard consumers' rights of privacy by limiting the types of information gathered and the ways in which such information is obtained, used and secured. Gathering of information for any design process should be based on ethical strategies for market studies and analysis.
Issue 6: Access to essential services	Although the state is responsible for ensuring the access to essential services like water, energy, wastewater services and communication, an organization can contribute to the fulfillment of this right through DfS if the company's market strategy supports it.
Issue 7: Education and awareness	These are initiatives to enable consumers to be well informed and aware of how to consume responsibly. This is inside the range of DfS by disclosure of life cycle based information like LCS, sLCA, LCC, EPD, eco-labels and other sustainability-related labels.

Core subject: Community involvement and development	
Issue 1: Community involvement	This is about how the company is involved in the local community for instance by participating in and supporting civil institutions. Involving local people in design processes may lead to more sustainable solutions, e.g. in product-service systems.
Issue 2: Education and culture	This is about supporting the local education and culture, for example by empowering disadvantaged groups. DfS can support the promotion of the community culture by integrating local skills, materials and technologies.
Issue 3: Employment creation and skills development	Through the choice of technologies and partnership with local communities, DfS can support the development of local skills and creation of jobs.
Issue 4: Technology development and access	Access to information and technologies is key to overcoming the disparities that exist between countries, regions, generations, genders etc. Through the choice of technology and by integrating traditional knowledge, DfS can assist in addressing this issue.
Issue 5: Wealth and income creation	Organizations can support the wealth and income creation through DfS by integrating local skills, materials and technologies and by giving preference to local suppliers.
Issue 6: Health	This is about promoting health and preventing health threats and diseases in the local communities. The design of products or services to help combat health risks like obesity, for instance, by inviting to more physical activities when using the product is a way for a company to promote health and is inside the range of DfS
Issue 7: Social investment	Social investment takes place when organizations invest their resources in initiatives and programmes aimed at improving social aspects of community life. DfS can support this by integrating local skills, materials and technologies, by giving preference to local suppliers and by involving the community in generating ideas for sustainable and responsible solutions.

MULTI-PERSON HOMES – converting detached houses in Austria that no longer match the needs of their inhabitants OR enhanced possibilities of densification

Julia Lindenthal (corresponding author), Gabriele Mraz, Austrian Institute of Ecology

Seidengasse 13/3, A-1070 Vienna, Austria

Phone: +43 -699-15236111

Fax: +43 -1-5235843

lindenthal@ecology.at, mraz@ecology.at

Abstract

Detached and semi-detached houses are among the most popular types of housing in Europe. In Austria, three-quarters of buildings are of this type, accommodating 58% of all Austria's inhabitants. Land consumption is huge, the need for renovating housing stock is high. With migration to cities, and changes in family structures and lifestyles, detached houses increasingly have single person occupancy. This encourages social isolation and often financial problems, heightened by the growing need for building renovations. This situation mostly affects women. Yet the number of new constructions on the outskirts of communities exceeds the number of refurbishments by far. Moreover, in the countryside there is a lack of adequate and affordable housing space offering new forms of communal living, such as flat sharing, start-up apartments, or assisted living.

The problem of excessive land use has encouraged research, initiatives, and incentives. In Austria, Germany and Switzerland, for example, efforts to densify built up areas have been intensified.

Densification is usually defined as trying to bring vacant lots, close to village centres, onto the market for development and /or to create a separate living unit (often as an annex) in order to enable multi-generational living within families. This is where our project starts.

The current ReHABITAT[1] project researches how single family homes can be transformed into multi-person homes, offering different varieties of gender and age-sensitive housing. Furthermore, we investigate the solutions needed to achieve these options at a technical, social and administrative level, and the factors convincing or preventing the relevant stakeholders from deciding in favour of those solutions. The relevant stakeholders are inhabitants of detached houses in need of renovation, planners, energy efficiency consultants, relevant players in the communities, and gender and housing researchers.

After research into the framework requirements and surveys of the needs of the relevant players, during workshops, focus groups and semi-structured interviews, sample technical

[1] The paper is based on the interim results of the ReHABITAT research project. Project Lead: Austrian Institute of Ecology (AIE); Partner: Gugerell KG, Constance Weiser architope; The project is funded by the Austrian Federal Ministry for Transport, Innovation and Technology within the framework of the FEMtech research projects programme, 2013-2015.

and organizational designs have been drawn up. All the information and drawings created during the project are being compiled in a handbook.

The benefits of multi-person housing are multiple and range from the creation of affordable, high-quality living spaces which foster communities and increase social contacts, to reductions in vacancy levels and rural depopulation.

Highlights

- Interest in joint living is growing amongst owners and residents of detached houses
- Public authorities and communities in Lower Austria are showing strong interest in densification through shared residency
- Solutions for social aspects of this form of cohabitation are of the utmost interest
- Networks are needed to reach all those interested in making their detached homes available

Keywords

multi-person homes, detached houses, joint living, re-densification, gender and age, sensitive retrofit

1. Introduction

Housing is a basic need. However, fulfilling this basic need has a significant impact on our environment, depending upon parameters such as house typology, the energy performance of the buildings, the site and, of course, user behaviour.

Residential buildings comprise the biggest segment of the EU´s building stock and are responsible for the majority of the sector´s energy consumption. This is largely the result of around 83% of all European residential buildings having been constructed before 1990, and incorporating few or no energy efficiency measures. Only a small proportion of this building stock has undergone major energy-saving retrofits.

Detached and semi-detached houses are among the most popular residential forms throughout Europe. See Figure 1:

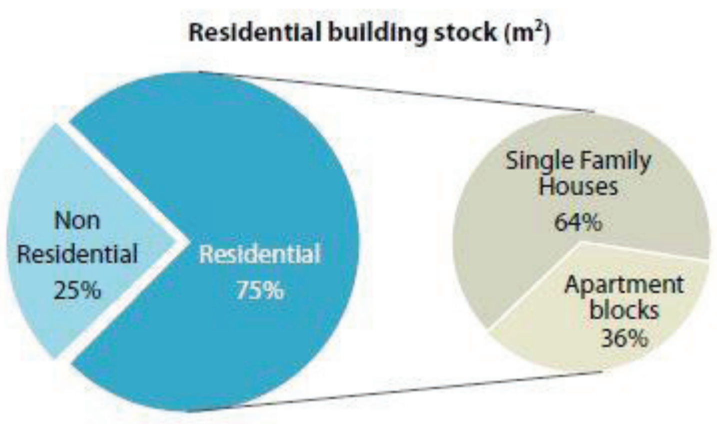


Figure 1: European Buildings (Building Performance Institute Europe - BPIE, 2011)

In Austria, this percentage is even higher. Three-quarters of all residential buildings are single family houses, accommodating 58% of the country's inhabitants.

Single family homes are not only very energy consuming, their land consumption is also enormous: one hectare of land is sufficient to provide housing in the form of either 10 detached houses, 20 terraced houses or 60 flats in apartment blocks. (UBA, 2014a)

Furthermore, with migration into the cities and changes in family structures and lifestyles, detached houses are increasingly being inhabited by only a single person. Austrian statistics from 2011 showed that of a total of 3,649,309 households, 1,324,287 households consisted of only a single person (36.3%) – see Figure 2:

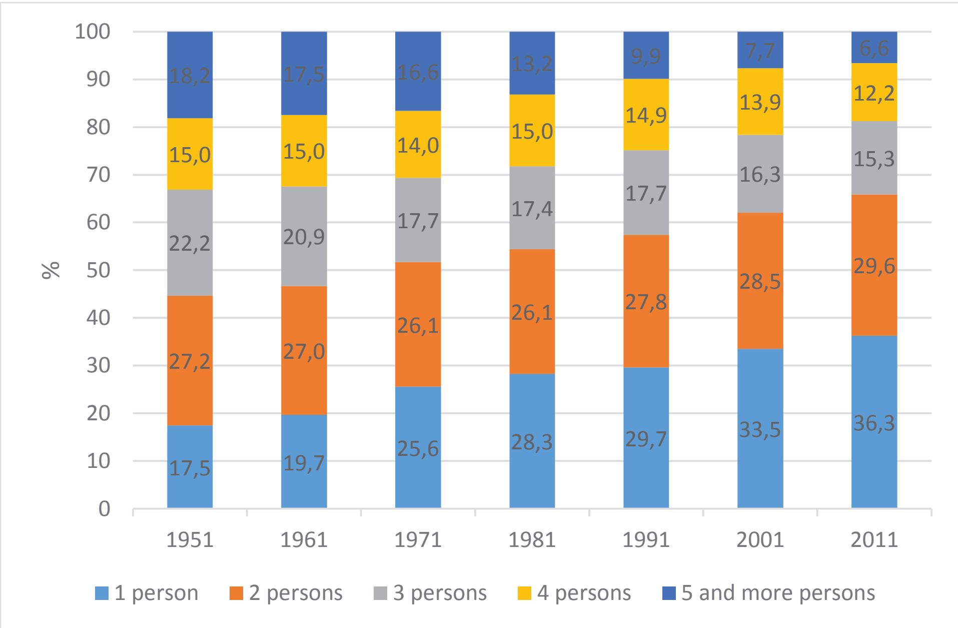


Figure 2: Private households in Austria. (Statistik Austria, 2014a)

By 2030, the number of single occupancy households in Austria will have increased to 1.62 million, with 686,995 of these inhabitants aged 65 and older. (Statistik Austria 2014b)

This encourages social isolation and often leads to financial problems, heightened by the need for building renovations. This affects mostly women – as by 2030, 70% of those living alone will be women aged 65+.

Land-take, the result of expanding residential areas and construction sites, is the main cause of increased urban land coverage at European level. The annual land-take in European countries, as assessed in 2006 by the Corine land cover project (EEA39 excepting Greece), was approximately 108,000 ha/year in 2000-2006. (EEA 2011)

In Austria, around 15 ha/day is used for housing and transport purposes (this number corresponds to approx. 30 soccer pitches.) (UBA 2014b, 2014c) And this land is mostly acquired by rezoning agricultural land. Although there are sufficient building area reserves in Austria for the coming decades, many communities prefer to reallocate agricultural land as building land, rather than building on already development areas. This leads to urban sprawl and land-take which is usually irreversible.

Figure 3 shows an example of a European region with uncontrolled development.

Figure 3: Aerial photograph of southern Germany, north of Stuttgart, Google maps

The number of new constructions on community outskirts exceeds the number of refurbishments. In Austria (excluding Vienna), 76,711 single family homes were erected between 2005 and 2009, with a maximum of 49,000 detached houses having been renovated during the same period.[2] (Statistik Austria 2014c, 2014d).Yet still there is a lack of adequate and affordable housing in the countryside which offers new forms of joint living, such as flat sharing, 'start-up' apartments, or assisted living.

The current research project takes a comprehensive approach, and aims to explore solutions to many of the problems mentioned above. How can detached houses be transformed into 'multi-person homes' (MPHs) which enable joint residential forms above and beyond intra-familial, 2-3 generation living concepts?

Consequently, we have focused on the following key research areas:

- Which options exist for the sensible densification of 4 different detached house typologies (built between the 1950s and 1990s) in order to create more housing units which can be accessed separately and allow different types of residential living above and beyond family groups?
- What solutions are needed to achieve these options at a technical, social and administrative level?
- What convinces and what impedes the relevant target groups (inhabitants of detached houses in need of renovation, planners, energy efficiency consultants, relevant players in communities, gender and housing research) from deciding in favour of these solutions?

[2] Based on Statistik Austria 2014d and an annual renovation rate of 1%

This research has the following objectives:

- Stimulating sustainable forms of housing and settlement developments which are energy-efficient, resource-conserving and liveable, by
  - enabling energy exchange between houses
  - offering improved infrastructure
  - fostering social life and community
- Developing redevelopment options which reflect gender and age requirements, to create better living conditions
- Raising awareness within the target groups of the different problems and solutions
- Fully tapping the potential for densification

This project makes a substantial contribution to supporting the aims of sustainable communities and sustainable settlement developments: protecting ground and soil resources is of the utmost importance. It also provides an excellent example of 'smart communities', offering multiple new forms of sustainable consumption and production, achieved by sharing not only living spaces but also infrastructure, services and tools.

2. Approaches

Three particular approaches are relevant to the question of sustainable living in single family homes. It is not enough to focus only on a single house; we must also consider the community in which this house is located. But what makes a community and its houses sustainable? Can this question be answered by **smart city/smart community** approaches? Or is **re-densification** a better approach than ICT-oriented smart concepts?

Sustainability, as we understand it, is not only a question of ecology and economy. It is also very much a social question. For a long time social aspects of sustainable building have been marginalized in favour of aspects such as energy savings and costs. In regional planning, on the other hand, the relevance of community building is a very important issue, but it does not necessarily extend as far as the single house and its residents. Therefore taking a **gender and age-sensitive approach** to house owners and residents can provide insights at both an individual and community scale.

2.1. Communities: sustainable and/or smart?

In sustainability discourse, the concept of smart cities/communities[3] has been made a new benchmark for planning and building projects. However, there are some important factors which need to be considered urgently.

To date there is no common agreement amongst scientists about how to define a smart city. But the most quoted aspects relate to the use of linked ICT (information and communication technology) and technological infrastructure, the use of social infrastructure and the availability of knowledge transfer in order to increase economic and political efficiency and to enable social, cultural and urban development.

We believe a city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with the wise management of natural resources, through

[3] Usually smart city concepts are also applied to smaller communities as the basic characteristics are independent of actual community size.

participatory governance. (Caragliu et al., 2009, p.50). See also Papa et al. (2013), Giffinger et al. (2007).

In our project we argue the reverse. This mainstream way of thinking leads to a dead end, because it fails to take some fundamental aspects sufficiently into account.

To begin with, **any** economic growth – no matter whether 'traditional' or related to the 'green economy' – has a significant negative impact on our environment. It is an illusion to believe that economic growth can be decoupled from the consumption of resources and environmental damage if only innovative technology is used. Rebound effects and other consequences work against the original objective (Paech 2012).

Secondly, especially from a gender and age-sensitive perspective, it should be taken into consideration that not all people have access to ICT and other infrastructures. Theoretically, however, access is crucial if the system is to work.

Thirdly, we believe that the common Smart City concepts primarily contribute to raising the current level of luxury in which we live. Under the guise of sustainability, many ICT products are promoted to save their users time and make their lives easier. But in reality they only encourage our inherent idleness, and contribute to even greater energy consumption or gas emissions during application and production.

Therefore a more interesting question would be: is it possible to form a community that abstains from high-tech dependence, being smart only by offering short distances to relevant facilities, offering an excellent network of public transport, reducing material flows and interpreting efficiency as a reduction of consumption in general?

We think it is crucial to avoid technological tunnel vision. Technology cannot save us from climate change and environmental problems unless we are willing to simultaneously change our lifestyles. A better approach would be to apply a broad and integrative approach. Resources have to be distributed and – even more importantly – used in a 'smart' way. Technology may play a vital part, but a smart community as defined above only makes sense when social and political solutions for living together in the future are also found. Technologies should serve primarily to reduce energy and resource consumption, and they need to be accepted by the users.

So our research focuses strongly on the social aspects of bringing together people in order to share spaces and tools. The technological aspects (how the buildings are transformed, which energy standard needs to be applied) are a part of the framework conditions. They are not the starting point.

2.2. Re-Densification

The problem of excessive land use has encouraged research, initiatives, and incentives. In Austria, Germany and Switzerland, for example, efforts to densify built up areas have been intensified.

Densification is usually defined as trying to bring vacant lots, close to village centres, onto the market for development and /or to create a separate living unit (often as an annex) in order to enable multi-generational living within families.

The understanding of densification as used in our research approach extends beyond this definition, making it more helpful in tackling the problems.

The potential for densification will be fully tapped by combining three different approaches: avoiding new ground sealing, enabling energy exchange between houses, enhancing infrastructure, and fostering the community, all at the same time.

- 'Internal densification', converting single family houses into multi-person homes, beyond intra-familial 2-3 generation living concepts. The actual square meter per capita is lowered in favour of generous common spaces.
- Including potential open spaces within the grounds for densification, closing gaps between buildings, and configuring public spaces.
- 'Non-materialistic' densification through the common use of building parts, as well as energy supplies and social care organizations beyond property boundaries.

2.3. Gender and age-sensitivity

What could a gender and age-sensitive approach offer for the development of multi-person homes? Gender relations are fundamental to our society and influence all aspects of daily life, including building and living conditions and habits.

When regarding room arrangements, renovation costs and resident resources, gender, especially related to age, is an important factor influencing needs and possibilities.

With changes in family structures and lifestyles and the aging of society, detached houses increasingly have single occupancy. Due to longer life expectancy, this is often an older woman. Necessary house renovations can be a financial challenge, especially for women who still have less disposable income on average than men. Moreover, many women (and some men) do not have the necessary DIY competencies and are unable to deal with technical components in everyday situation. A gender and age-sensitive approach must consider these differences in resources and skills.

In the 1960s, feminist planners started to analyse gender-specific segregation and hierarchies in the spatial arrangements of houses: while the central living room was used for representation/recreation for the male breadwinner, rooms for housework and childcare were the domain of the female housekeeper, smaller and situated less attractively. In many of our research objects, detached houses built between the 1960s and 1980s, these room arrangements still exist: kitchens are small and suitable for only one person, other rooms of relevance for everyday life (washing room, food storage rooms, fuel storage, etc.) are impractically located and designed. This remains the case although traditional gender roles have undergone some shifts in the last decades, and women are no longer solely responsible for domestic work. Therefore, a gender-sensitive approach in a building project must still focus on a building's practicality for everyday domestic work.

3. Materials and methods

Input from two groups of experts was analysed. The first group included planners, politicians, lawyers, and 'experts in everyday life'. The second group included owners and residents of detached houses who demonstrated an interest in converting their houses to turn them into multi-person homes. Future owners and inhabitants were also included in this group.

To date no research has been conducted on the needs, requirements, resources and motives of 'experienced house owners' wishing to open up their houses. Therefore an explorative approach was chosen. From the experiences of Austrian groups such as the initiative for cooperative building and living ("Initiative für gemeinschaftliches Bauen und Wohnen"), we know that many people are interested in communal forms of living, but typically they engage themselves in larger cooperative building and living groups in new-build homes, instead of sharing small houses, many in need of renovation. Therefore we were required to find interview partners amongst house owners and residents using the snowball principle: the only preconditions were a general interest in the idea of converting their single family houses into multi-person homes, and that they lived in Eastern Austria. Starting points for the search were initiatives, networks, organisations and media engaged in sustainable building and common living, as well as experts and the project team members' own contacts. We quickly reached more interested persons than necessary, more women than men, and more older than younger people.

A workshop was conducted with twelve experts from different professional disciplines. Two questions were posed (6-3-5-method) at the beginning in order to get the experts' opinion on multi-person homes. The resulting arguments were clustered in categories.

A focus group was also held with 13 experienced house owners (five men and eight women). Topics not discussed in satisfactory detail during the focus group were subsequently deepened in additional interviews (e.g. focus group interview partners did not have enough rental experience).

Transcripts from the focus group and the interviews were analysed using qualitative content analysis according to Mayring (1999) and Schmidt (2003).

Research on the technical, legal and financial aspects of framework conditions was conducted simultaneously through literature research and a further workshop with experts for alternative financial methods.

The results of the analysis and research have been used to develop options for four different types of residential unit. These options will illustrate the possibilities for converting single dwellings into multi-person homes. Sample drawings and solutions for the technical and organizational designs will be produced.

A concrete example is given for each of the four types of unit: a settlement-house (built in the 1950/60s, 116 m^2 of living space), a bungalow (1970/80s, 166 m^2), a country house (1980/90s, 250 m^2), and a semi-detached house (late 1980s to mid-1990s, 290m^2). They were chosen because of the different building years, cubature and living spaces, and particularly because of their frequency of occurrence in rural regions and small towns in Eastern Austria.

Figures 4-7 show typical examples of the chosen house types:

Figure 4: Settlement-house, 1957, © Norbert Priebe

Figure 5: Bungalow, 1980, © K. Bailer

Figure 6: Country House, 1984, © P. Eichlinger

Figure 7: Semi-detached House, 1994, © K.König

4. Results and discussion

The ReHABITAT research project is ongoing. The results presented in this chapter are based on the research work package on the requirements, needs and motives of owners and residents of detached houses. These results are currently being translated into options for the building types listed above.

Figure 8 shows the relevance of different topics to the experts and the experienced house owners. In their interviews, both experts and experienced house owners considered social topics to be the most important for multi-person homes. This category includes the mix of residents, communication, shared activities and rules of joint living. The second most important topic for the house owners was maintaining their private sphere in a MPH, while the experts regarded this topic as less important, focusing instead on financing and legal questions – questions also highly relevant for the house owners. Assistance and care were not discussed in depth.

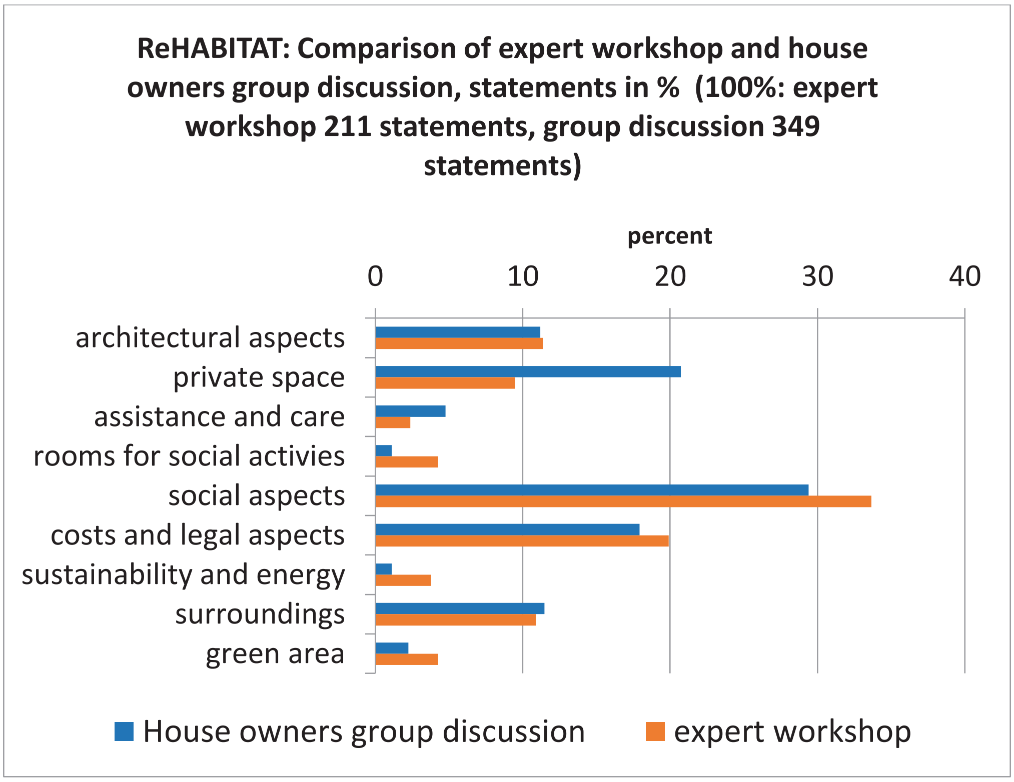


Figure 8: Proportion of topics (%) mentioned for each clustered category, comparison between the expert group and the group discussions of experienced house owners (Austrian Institute of Ecology, 2014)

Selected results from the detailed analysis indicate the topics which are highly relevant for developing multi-person homes:

Emotional attachment towards one´s house is particularly strong if the owners built it themselves or grew up in it; there is less of an attachment if the house was bought.

Are there preferred forms of living? A **broad spectrum is possible, from separate living units to residential communities**. However, everyone needs their own space and privacy, and somewhere to be alone. Only having a shared kitchen is not (yet) acceptable to anyone, shared bathroom and toilets are possible for some. Sharing or splitting a garden or terrace/balcony is considered acceptable, while even outside there is a wish to have space to oneself.

Who would I like to share a residential community with? The discussion followed two tracks:

- Suitable age composition
- Advantages and disadvantage of living together with family members vs. non-family members

While mixed generations living together can take many forms, the combination of 'young-old' is one most people thought of first. Respondents recalled many conflicts experienced living together with family, however, this seems to be still preferable to sharing living space with friends or strangers – but better boundaries with non-family members are expected.

Renting or renting out is the preferred option for house-owners when it comes to establishing a residential community. The exception is for close family members living together, although this is sometimes organized along the lines of formal rental contracts. The interviews demonstrated a limited understanding of tenancy law, and understanding of the rights and responsibilities needs to be improved for both sides involved. This is mirrored in the fear expressed by landlords of being responsible for all repairs around the house.

Mobility: Contrary to the expert discussion group, the respondents did not give public transport and closeness of infrastructure priority. The role of the car as a vital means of transport was not questioned.

Counselling and support – the role of the community: Research showed that counselling, support and services regarding architecture, law and finance would be appreciated. This could be offered by local communities to assist with legal problems, establish a contact point or even mediating contacts between house owners and those looking for a home.

Living together is often regarded as a remedy for loneliness; at the same time **providing care and nursing** a co-resident is not seen as an automatic duty.

From a gender and age perspective, the results show that many aspects must be considered in developing the building options. Topics discussed in the past decades in feminist and gender planning discourse are still relevant, and new topics have emerged. The focus remains on the **optimal organization of household and care work**: when living together in multi-person homes these include the availability of adequate rooms both for communal social activities and sharing daily work in the kitchen, laundry, boiler room, garden shed, etc. These facilities need to be ergonomically designed and attractive. Perceived safety is also important, e.g. when planning lighting solutions.

Costs are a key topic, especially when considering the income of older women. In 2012, the monthly pension received by women in Austria averaged €811, while men enjoyed a pension of €1,433. (BMASK 2013a) 32% of women renting (and 16% of men) who live in one-person households are at risk of poverty. Only single mothers have a higher risk of poverty.

5. Next steps

The requirements, needs and motives of owners and inhabitants of detached houses, as well as the expert opinions discussed above, were analysed in order to translate them into building options.

The framework surveys on technical, legal and financial aspects were also analysed with respect to their impact on building options.

The following approach was chosen for implementing the most important components: variations on each plan will be provided for each of the four building typologies. Possibilities for living together and creating residential communities range from separate apartments with separate entrances, to comprehensive flat sharing. There are also intermediate forms of living in which everybody has their own small space and other spaces are shared amongst all the residents. The floor spaces will be divided accordingly, to allow all forms of joint living.

However, as 'multi-person homes' claim to provide new impulses for their direct environment and local community, they should focus on living forms which offer combinations of living and working, living and arts and crafts, living and public facilities.

It is obvious that the varied sizes and structures of existing buildings will also play a role in determining the possible implementations.

All the designs will be analysed with respect to technical installations and the use of low-tech rather than high-tech solutions, achieving the same results thanks to smart room configurations.

The options will be ready by end of 2014, and a further expert panel will provide quality assurance.

The results of the interviews and the designs will also be used to compile a handbook, providing information and motivation for 'first movers' to convert their detached house into a multi-person home. The concept of multi-person homes could be promoted and spread if several examples of MPHs were built and made accessible to those interested in understanding the concept better.

Therefore anyone interested is invited to get in contact and subscribe to our blog (http://rehabitatprojekt.wordpress.com/). Many interview partners and experts as well as a much wider circle of interested people are already involved in the project and exploring ways of implementing the concept.

6. Conclusions

There is no universal blueprint for designing a multi-person home: each house has its own characteristics, even those belonging to the same typology, and house owners and residents have their own special needs and wishes. Therefore it is vital to bring together people with similar needs and who share the same wishes. Furthermore, advisory support from competent municipality representatives would be very useful. Likewise, the creation of platforms to bring together those looking for somewhere to live and people willing to share their houses would be very helpful. And last but not least, mayors and municipality representatives need to address their citizens personally, as well as via social networks, in order to advertise the opportunities for living in multi-person homes both locally and further afar.

Multi-person homes can offer many benefits at different levels:

- Creates affordable, high-quality living space
- Combines renovated and converted buildings to form optimized residential compounds, maximising the variety of new housing forms and promoting the use of local infrastructure and services.
- Conserves the resources soil, energy, water and materials.
- Reduces vacancies and rural depopulation by revitalising village centres and settlements through functional reorganisation
- Supports communities in development processes
- Fosters communities and increases social contacts
- Strengthens regional economic cycles and boosts economic advantages for communities, the general public and individuals, e.g. by improving their detached houses

The project's interim results are exceptionally promising, and it is becoming evident that, as a new form of densification, multi-person homes are a very simple, efficient, cost effective and robust method of responding to ecological, social and economic challenges.

7. References

BMASK (2013a): Factsheet Pensionen Juli 2013, http://www.bmask.gv.at/cms/site/attachments/6/4/0/CH2325/CMS1354719150788/fact_sheet_20133007_pivot.pdf, accessed 23 Oct 2013.

Building Performance Institute Europe - BPIE (2011): Europe´s buildings under the microscope, A country by country review of the energy performance of buildings.

Caragliu, A, Del Bo, C., Nijkamp, P, (2009): Smart Cities in Europe, In: 3rd Central European Conference in Regional Science – CERS, p. 45 -59.

EEA (2011): Land Take Assessment. Europäische Umweltagentur.

Giffinger, R, Fertner, C., Kramar, H., Kalasek, R. Pichler-Milanović, N., and Meijers, E. (2007): Smart cities -Ranking of European medium-sized cities", Final report (October 2007). On the web: http://www.smartcities.eu/download/smart_cities_final_report.pdf.

Mayring, Philipp (1999): Einführung in die qualitative Sozialforschung. 4. Auflage. Beltz Psychologie Verlags Union Weinheim.

Paech, Niko (2012): Liberation from excess. The road to a post-growth economy. oekom, Munich.

Papa, R, Gargiulo, C, Galderisi, A, (2013): Towards an Urban Planners´Perspective on Smart City, In: TeMA 1 (2013), p. 5-17.

Schmidt, Christiane (2003): Analyse von Leitfadeninterviews. In: Qualitative Sozialforschung. Ein Handbuch Hg. von Uwe Flick, Ernst von Kardoff, Ines Steinke. rowohlts enzyklopädie im Rowohlt Taschenbuchverlag, Reinbek bei Hamburg, p. 447-456.

Statistik Austria (2014a): Haushalte 1951 bis 2011 nach Haushaltstyp bzw. -größe und Bundesländern. Volkszählungen 1951 bis 2001, Registerzählung 2011. Erstellt am 04.11.2013. http://www.statistik.at/web_de/statistiken/bevoelkerung/volkszaehlungen_registerzaehlungen/haushalte/073491.html, accessed 17 Sept. 2014.

Statistik Austria (2014b): Ein- und Mehrpersonenhaushalte 2011 bis 2060. Haushaltsprognose 2013. Erstellt am 14.05.2014. http://www.statistik.at/web_de/statistiken/bevoelkerung/demographische_prognosen/haushalts_und_familienprognosen/023526.html, accessed 17 Sept. 2014.

Statistik Austria (2014c): Österreich ohne Wien neu errichtete Gebäude nach deren Eigenschaft und nach Bundesländern http://www.statistik.at/web_de/statistiken/wohnen_und_gebaeude/errichtung_von_gebaeuden_und_wohnungen/fertigstellungen/index.html, accessed 19 Sept. 2014.

Statistik Austria (2014d): Gebäude 2011 nach überwiegender Gebäudeeigenschaft, Errichtungsjahr und Bundesland, http://www.statistik.at/web_de/statistiken/wohnen_und_gebaeude/bestand_an_gebaeuden_und_wohnungen/Gebaeude/index.htm, accessed 17Sept. 2014.

UBA (2014a): Unsere Wohnformen beeinflussen den Flächenverbrauch. Umweltbundesamt – Environment Agency Austria, http://www.umweltbundesamt.at/umweltsituation/raumordnung/flchen-entw/bauflaeche/wohnen/, accessed 17 Sept 2014.

UBA (2014b): Versiegelung nimmt zu. Umweltbundesamt –Environment Agency Austria, http://www.umweltbundesamt.at/umweltsituation/verkehr/auswirkungen_verkehr/flaechenverbrauch/, accessed 17 Sept. 2014.

UBA (2014c): Flächennutzung in Österreich. Umweltbundesamt –Environment Agency Austria, http://www.umweltbundesamt.at/umweltsituation/raumordnung/flchen-entw/, accessed 17 Sept. 2014.

8. List of figures

Cleaner Production Assessment - Improvement of Energy and Resource Efficiency of Thermal Power Plants in Serbia

Bojana Vukadinović[a], Ivanka Popović[b], Branko Dunjić[a], Miloš Vlajić[c], Dejan Stanković[c], Zoran Bajić[c], Mirjana Kijevčanin[b]
[a]Cleaner Production Centre of Serbia, Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia
[b]Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia
[c]Thermal Power Plants Nikola Tesla, Electric Power Industry of Serbia

ABSTRACT

The Public Enterprise Electric Power Industry of Serbia is facing significant environmental challenges due to the fact that the biggest percent of electricity produced comes from lignite-fired power plants. Cleaner production was recognized as a first and very important step in harmonizing the operation of existing plants with the requirements of the European directives and improvement of technology and optimization of resource consumption that can influence the reduction of internal costs. The results presented here relate to the first phase of the Cleaner production project with four coal thermal power plants of the public company “Thermal Power Plants Nikola Tesla”, which operates within the Electric Power Industry of Serbia. These four power plants with an installed capacity of 3,288 MW, account for 36 % of the total installed capacity in Serbia. The research carried out in Thermal Power Plants, and the application of cleaner production methodology was based on the balance of material and energy flows, best available techniques assessment, selection of the appropriate options, and evaluation of these options in terms of environmental protection, from the technical and economic aspects. The case of one of the thermal power plants, TENT A, was summarized, with the potential of theirs realization, along with the brief technical description.

Keywords: cleaner production, coal thermo-power plants, implemented measures, emissions reduction, cost savings

1. Introduction

Many papers, books and toolkits about resource efficiency and cleaner production indicate the significance and need for research in this area (Fresner and Yacooub, 2006; Henriksson and Söderholm, 2009; Mattsson et al., 2010; Van Berkel, 2007). A trend of increasing energy use, especially in developing countries, and projections according to which the world’s energy consumption shall increase for 33 % from 2010 to 2030 (Abdelaziz et al., 2011) necessitate further reasearch and demonstration of implemented measures (Dobes, 2013; Fresner et al., 2010; Laforest 2013; Olanrewaju and Jimoh, 2014; Tanaka, 2011).
Most works and projects deal with energy efficiency in manufacturing processing, especially on the subject the energy efficiency potentials of energy intensive industries (e.g., chemical and petrochemical, iron and steel, pulp and paper) (Abbaszadeh and Hassim, 2014; Lee, 2013; Saygin et al., 2011a, 2011b; Van Caneghem et al., 2010). However, some studies have shown (Tzolakis et al., 2012; Wang et al., 2013) that the great potential for the reduction of energy consumption exists in manufacturers of energy

themselves, such as plants for the production of electricity, especially thermo power plants.
Most plants for the production of electricity in Serbia are owned by Public Enterprise – Electric Power Industry of Serbia (EPS) whose total capacity for the production of the electricity is 7,124 MW. The biggest share of the electricity is produced in six coal thermal power plants whose total capacity is in the amount of 3,936 MW, while the total capacity of eleven hidro power plants is 2,835 MW. EPS also encompasses power plants TETO, of the total capacity of 353 MW, which use gas for the combined production of electricity, process steam and heat (EPS, 2014). In 2013, 37,433 GWh of electricity has been produced in the power plants of EPS, 70 % of which in coal thermal power plants. Around 28 % of the total electricity produced derives from hydropower plants, whereas an insignificant part, less then 1 %, derives from gas power plants, industrial power plants, wind and solar power plants (MME, 2014).
In terms of energy, Serbia is among 20 most intense countries in the world regarding energy use per GDP. Moreover, Serbia emits relatively large amounts of green house gas emissions (GHG) deriving from the combustion process, measured per unit of GDP by purchasing power parity (SuDES, 2012). Certainly, electricity production represents one of the most significant influences on the environment regarding the amount and quality of the coal used as a raw material in thermal plants (Jovanovic et al., 2011).
Since 2000, EPS, the Serbian Government and international financial institutions (primarily from the European Union) have jointly made considerable efforts to improve environmental protection. The largest funds have been invested in modernization of the existing plants which achieved the total saving of coal in the amount of 4.2 million tons a year and at the same time increased the production of electricity to the power of a new block of 400 MW, and energy efficiency to 12 %. Projects such as the construction of a wastewater treatment plant on one of the thermal power plants and installment of desulphurization units have been initiated for the purpose of the reduction of emissions and their harmonization with the requests of the Large Combustion Plant Directive (EPS, 2009).
The project of implementation of cleaner production in EPS has been initiated in 2010 including 10 plants within EPS (all six coal thermal power plants, three gas thermal power plants - heating plants and one coal heating plant) and it lasted three years.
The results presented here relate to the first phase of the Cleaner production project with four coal thermal power plants of the public company "Thermal Power Plants Nikola Tesla" (TENT), which operates within the Electric Power Industry of Serbia.

2. Implementation of Cleaner Production Concept in TENT

Company "Thermal Power Plants Nikola Tesla" is the largest manufacturer of electricity in Southeast Europe. It has 14 units whose overall installed power is 3,288 MW, which is one third of the installed capacities of the Electric Power Industry of Serbia, and it annually produces more than 50 % of Serbian electricity.
Company TENT consists of 5 organizational parts. They are: TENT A in Obrenovac (6 units of the total power of 1,650 MW), TENT B in Obrenovac (two units, 620 MW each), Thermal Power Plant „Kolubara" in Veliki Crljeni (5 units of the total power of 271 MW), Thermal Power Plant „Morava" in Svilajnac (one unit of 125 MW) and the Rail Transport which annually transports around 28 million tons of lignite from the open pit mines of "Kolubara".
The average age of the units is 30 years and Company TENT has devoted its attention to modernization and activities on the energy efficiency increase over the past few years.

The research carried out in Thermal Power Plants, and the application of cleaner production methodology was based on the material and energy balance analysis, best available techniques assessment, optimization of the existing processes and equipment, selection of the appropriate options, and evaluation of these options in terms of environmental protection, from the technical and economic aspects.

2.1 Heat and material balance

For the purpose of the balance preparation, data were collected for the period of three years (from 2008 to 2010) on the electricity produced (MWh), amounts of the consumed coal (in tons, as well as its calorific value in KJ and MWh), heavy oil, on the consumption of chemicals, oil and lubricants as well as the amounts of the produced waste and emissions. In preparing the energy balance, the electricity on the generator, self-consumption of electricity and the electricity taken form the grid were taken into consideration. The water balance for different types of water – demineralized water, decarbonized water, cooling and sanitary water, was prepared separately.
Based on the analysis of the collected data, performance indicators (UNIDO and UNEP, 2010) were established that would be the most significant for all four thermal power plants. The same indicators, such as kg of coal/kWh produced, kg of ash generated/kWh produced, kJ of coal/kWh produced, % of own electricity consumption, m^3 of demineralized water/GWh produced, kg HCl/m^3 of demineralized water and kg NaOH/m^3 of demineralized water, were calculated for each plant for the period of three years.

2.2 Detected problems

The comparison of the environmental indicators showed not only deviation in some values within the companies, but also different values between the thermal power plants themselves. One of the reasons was the improvement of certain parts of the process in some of the thermal power plants (Stevanovic, 2014), but in some cases those were the losses caused by leaking or discontinuous parameter monitoring. The simultaneous analysis identified mutual problems for all four power plants which influenced the initiation of their joint solution and proposal of cleaner production options.

2.3 Classification of cleaner production options

The cleaner production options have been analyzed form a technical point of view, economic point of view (necessary investments and payback period) and environmental point of view. All of the options of cleaner production which have been identified during the project may be divided into the following groups:

1) Good housekeeping and organizational measures with the payback period less than a year
2) Technological modifications and options analyzed through additional projects
3) Options which does not lead to direct savings, but have positive influence on the environment
4) Mutual options for all thermal power plants

2.4 Overall project results

In all thermal power plants there have been identified 76 options of cleaner production and the overall results of the evaluated options are shown in table 1.

Table 1
Overall project results in company TENT.

Power plant	Potential for reduction					Estimated costs, EUR	Estimated savings, EUR	Pay back, years
	Water m^3/a	Coal t/a	Electricity MWh/a	Waste t/a	CO_2 t/a			
TE Kolubara	601,000	51,995	2,560	303,465	21,696	9,769,000	6,525,700	1.5
TE Morava	11,000	20,296	8,350	3,500	14,860	13,350,000	1,447,500	9.2
TENT A		170,600	2,400	1,014,400	126,500	90,670,000	17,380,000	5.2
TENT B	70,000	85,800	5,758	811,900	62,880	50,133,000	23,622,000	2.1
TOTAL	**682,000**	**328,691**	**19,068**	**2,133,265**	**225,936**	**163,922,000**	**48,975,200**	**3.3**

It should be emphasized that table 1 shows only the saving possibilities of the completely evaluated options. In some thermal power plants there is a series of options which should be analyzed with a huge potential for the improvement of the efficiency of work.
Preliminary results show that with an investment of 164 MEUR it is possible to achieve a reduction in the consumption of coal by 0.33 Mt/a, water by 700,000 m^3/a, electricity by 20 GW h/a, and ash by 2 Mt/a. This investment would lead to a CO_2 emissions reduction of 0.2 Mt/a. The payback period of the investment, by simple calculation, would be approximately slightly more than 3 years. The action plan defined for each thermal power plant sets the year 2015 as the year for the implementation of the proposed options.

3. Case study - cleaner production options in TENT A

The case of one of the thermal power plants, TENT A was summarized, with the potential of theirs realization, along with the brief technical description.
The thermal power plant “Nikola Tesla A“ (TENT A) consists of six units A1 – A6 with total installed power of 1,650 MW. TENT A is built on the right bank of the Sava River, near Obrenovac. At the average, more than 8 billion kilowatt hours are produced per year. Besides electricity, plant also produces steam for district heating - delivered to Obrenovac. Its first 210 MW unit was commissioned on March 7, 1970. Six months later it was joined by unit A2, with the same power. The construction continued five years later, and by the end of 1979, the EPS was empowered by additional 308.5 MW unit's, and TENT A reached the power of the biggest electric power facility in the country.
Production of electrical and heat power and technical steam at TENT A is carrying out by combustion of lignite from the “Kolubara” mine.

3.1 Identified cleaner production options

Table 2 shows selected options evaluated from the technical, economic and environmental point of view. Apart from these options in the table, the measures which are necessary to conduct for the purpose of satisfying the legislations on the emission limit values in the air (monitoring of the content of flue gases, reduction of SOx, NOx, powdery materials etc.) have been processed, as well as the measures related to the future projects which deal with solutions of waste water problems.

Table 2
Identified options in TENT A.

No	Proposed cleaner production option	The potential for reduction	Estimated cost [€]	Estimated savings [€/a]	Payback period
1	Increase the power of units' A3 and A5 by retrofit of the turbine and boiler	Increase in power of the units from 30 – 40 MW	82,500,000	10,500,000	6 - 7 years
2	Use ash in construction (road construction)	Waste reduction: approximately 50 % of the total ash quantity e.g. 1,000,000 t/a	minimal	1,880,000	instantly
3	Installation of on-line measurement of coal quality	Reduction of coal by 55,000 t/a CO_2 reduction of 37,300 t/a	2,000,000	660,000	3 years
4	Install flow meters of cooling water	Condenser monitoring, optimizing cooling pump	50,000	100,000	6 months
5	Monitoring of water losses in the heating system of Obrenovac	Savings of 150 t/day of decarbonised water	200,000	270,000	9 months
6	Optimization of existing soot blowers and installation in units A4 and A6	Automation of the existing blowers by installing the necessary temperature sensors	4,000,000	2,000,000	2 years
7	Repair of insulation of pipelines and fittings	Reduction in coal consumption	200,000	400,000	3 - 6 months
8	Installation of modern sealing systems for rotating heaters in 4 units in order to reduce losses caused by unslealed Ljungstrom air heater (Luvo)	Coal reduction: 80,000 t/a Waste ash reduction: 14,400 t/a CO_2 reduction: 54,300 t/a	1,600,000	1,080,000	1.5 years
9	Improvement of boilers and condensers' tightness	Coal reduction: 32,000 t/a CO_2 reduction: 21,800 t/a	100,000	400,000	3 months
10	Lighting optimization - installation of more efficient lights, sensors and photo cells	Coal reduction: 3,600 t/a Reduction of own electricity consumption by 2,400 MWh/a CO_2 reduction: 2,700 t/a	20,000	90,000	3 - 6 months
11	Education of employees on good housekeeping measures	Minimum 5% of electricity and water consumption	minimal		instantly

3.2 Implemented measures

Within period of 3 years significant efforts were made in implementation of proposed measures, from good housekeeping to big investment such as reconstruction of units. Also projects related to reduction of environmental pollution have been initiated.

3.2.1. Increase in the power of units
This option has been performed on unit A5, while there are ongoing interventions on unit A3. Only brief description of the options will be presented here, without main technical details.

3.2.1.1 Reconstruction of unit A5 - turbine retrofit on unit A5. Basic data on unit A5 are shown in Table 3.

Table 3
Basic data on unit 5.

Nominal power, MWe	308.5
Power plant threshold, MW	280
Year of commissioning	1979
Designed specific consumption, kJ/kWh	11,000
Specific consumption of the heat of a turbo-plant, gross, kJ/kWh	7,825

The works envisaged by these options were preceded by the capital overhaul in 2004 on the turbo-generator plant. Two possible technical solutions have been considered for further works on turbo-plant A5:

1. turbine repair without power increase and
2. turbine retrofit with power increase and lifetime extension.

Investments in the first technical solution, repair of the turbo-plant, are estimated at 16.8 MEUR.

In the second technical solution it is envisaged to increase the gross of the electric power of the unit to 344.5 MW by increasing the mass flow rate of steam for 8.8 %. The analysis conducted for unit A5 has shown that the steam boiler can provide the increased production of steam in this way and that the generator and transformers can transfer the increased electric power without additional investments. The process analysis and calculation of the heat exchange in the condenser has shown that the increase of pressure of condensation from 0.049 bar to 0.054 bar shall happen due to the increase of the flow of steam at the same surface of the condenser, at the cooling water flow and temperature.

Investments in the repair of the turbine in this solution are estimated at 20.23 MEUR (the increase of the investment for 3.434 MEUR in relation to the solution without power increase). The deep analysis has shown that it is justifiable to invest the additional 3.434 MEUR in the turbine retrofit which provides the increase of power of 36 MW gross with a slight increase of the specific heat consumption. In addition, the analysis has shown that annually there is an income deriving form the sale of additionally produced electricity of around 8.6 MEUR along with the costs of fuel, operation and maintenance of around 4.9 MEUR by which the realized annual profit is in the amount of 3.7 MEUR. This further indicates that simple payback period is less than a year.

3.2.1.2 Reconstruction of unit A3 - turbine retrofit on unit A3. The primary goal of implementation of this option is to apply the energy efficiency measures which will lead to the reduction of the specific consumption of the turbo-plant, prolongation of the period between two overhauls, reconstruction of the turbine for the co-generation.

The increase of the power of the unit can be achieved by: increasing the level of the efficiency of a thermodynamic cycle according to which the unit operates (Rajakovic – Ognjanovic et al., 2011); increasing the mass flow of the steam; or by improving operation characteristics of some components, and by combining the aforementioned measures.

By the turbine retrofit following can be obtained: increase of the power of the unit for 22 MW, reduction of the specific consumption of the turbo-plant for around 110 kJ/kWh (from 7,899 to 7,789.5 kJ/kWh), reduction of the specific consumption of the unit for around 4 % (from 9,150 kJ/kWh in relation to the project value of 9,500 kJ/kWh), reduced emission of NOx to a level of 200 mg/m^3, reduction of the specific emission of CO_2 (from 1,073 kg/kWh to 971 kg/kWh).

Investments in the turbo-plant repair in this solution for the specified scope of works are estimated at 83.171 MEUR (payback period is 6 years).

3.2.2 Installment of flow meters

New flow meters of the cooling water have been installed in every unit for the purpose of optimization of the cooling pumps. In addition, the remote data sensing has been introduced and hence it is possible to monitor the consumption of the cooling water at any given time. Better maintenance of the equipment (increased consumption of the cooling water indicates fouling in the condenser) has been provided apart from the optimization of the cooling water consumption and savings of the electricity required for the operation of the pumps. The investment of 50,000 EUR has been regained for 6 months.

3.2.3 Heating system

By the application of various measures, the reduction of water addition in the heating system of Obrenovac has been achieved. One of the measures by which the consumption of water has been reduced, is the change of the water quality used for the heating system (instead of demineralized water which caused corrosion, the decarbonized water was used which reduced the loss from 1,200 t/d to 200 t/d – the amount of water was reduced, and the costs of preparation of the water that is used were reduced to one third).

3.2.4 Good housekeeping

Good housekeeping measures such as monitoring and reporting, as well as regular inspections were introduced in the regular plant maintenance.

During the shift, staff perform inspection of the plant for several times (each unit individually) in order to monitor unit operation and compare readings of local measurements and remote measurement readings in control rooms. Production department staff logs irregularities observed into a log book for each unit, in addition to mechanical and electrical problems there are also logged irregularities related to:

- Worsened sealing of boilers, rotary regenerative air heaters (Ljungstrom),
- Visible insulation damages,
- Visible lining damages,
- Places in which increased heat radiation can be felt

Apart from the above mentioned inspection made by operational staff, maintenance department staff performs daily preventive inspections of facilities and devices. During these visits the staff eliminates minor faults, checks remarks made by production staff and if possible eliminates them during plant operation. Defects observed on sealing, lining and insulation can be repaired immediately (stopping and cooling of devices is not required) or can be repaired during overhaul.

3.2.5 Monitoring system for emissions

Individual analyzers for continuous measurement of particulate matter and gases were successively installed since 2003. In November 2011, the installation of equipment in all units of TENT A and TENT B and unit A5 TE Kolubara was carried out within the CEMS (Continuous Emissions Monitoring System) project. The system monitors the concentration of sulfur and nitrogen oxides and particulate matter, and also the concentration of carbon monoxide, content of carbon dioxide and oxygen by volume, and other essential parameters of flue gas (humidity, pressure, temperature, flow). Reports are made as daily, monthly and annual reports on emissions of pollutants and the state of the system for continuous measurements at each of the units, respectively.

3.2.6 Pollution control measures

Thermal power plant “Nikola Tesla A” burns the coal from the mining basin Kolubara which is characterized by the low inferior calorific value (around 6,700 kJ/kg), relatively high content of moisture (48 %) and ashes (22 %) and the total sulfur content from 0.42 to 0.47 %. Concentrations of SO_2 in the flue gases are within the range from 2,800 to 3,200 mg/m^3, and the specific sulfate emission goes from 9 to 13 kg/MWh.

By introducing the flue gas desulphurization on units A3-A6 on TENT A, the reduction of the total emission of SO_2 is expected and its reduction to a level of 200 mg/m^3. Total investments required for the construction of the flue gas desulphurization plant are 221.7 MEUR.

Another measure, which is to be realized, is reconstruction of units’ precipitators in order to reach the value of 30 mg/Nm^3 (reduced to dry gas and reference O_2 of 6 %). Total investments required for the reconstruction are around 12 MEUR.

4. Conclusion

The energy sector represents the largest source of the green house gas emissions, almost 70% of the total emissions of GHG in the Republic of Serbia. Most of the electricity, which makes 28% of the total energy consumption, is produced in six coal thermal power plants and its production surely represents one of the most significant influences on the environment.

Environmental issues in EPS are always refer to large investment projects, whereas options such as process optimization, monitoring, targeting, and reporting or those options which relate to good housekeeping measures and organizational measures are often being neglected and viewed as less important and something which is not as urgent as other bigger problems. However the project of cleaner production has shown that the reduction of CO_2 emissions, reduction of water consumption and the amounts of waste generated, could be achived with proposed cleaner production measures implementation. In the same time, improvement of technology and optimization of resource consumption might significantly influence the reduction of internal costs and achievement of significant cost savings.

Results have shown that payback period for the 40% of identified measures is less than two years with possible savings of 13.3 MEUR for four power plants. Implementation of all identified measures could bring savings of approximately 49 MEUR and the payback period of the investments would be slightly more than 3 years.

Development of energy sector in Serbia is still based on lignite and it will remain so in the long run. Therefore, the realization of energy efficiency projects is essential in long-term sustainability of the power plants. This paper presents brief overview of the potentials, specially for energy efficiency measures.

References:

Abbaszadeh, S., Hassim, M.H., 2014. Comparison of methods assessing environmental friendliness of petrochemical process design. J. Clean. Prod. 71, 110-117.

Abdelaziz, E.A., Saidur, R., Mekhilef, S., 2011. A review on energy saving strategies in industrial sector. Renew. Sustain. Energy Rev. 15 (1), 150 – 168.

Dobes, V., 2013. New tool for promotion of energy management and cleaner production on no cure, no pay basis. J. Clean. Prod. 39, 255 – 264.

[EPS] Electric Power Industry of Serbia, 2014. Annual report for the year 2013. Available at: http://www.eps.rs (in Serbian).

[EPS] Electric Power Industry of Serbia, 2009. The Green Book of the Electric Power Industry of Serbia. Available at: http://www.eps.rs/Eng/Documents/EPS%20-%20The%20Green%20Book.pdf

Fresner, J., Jantschgi, J., Birkel, S., Barnthaler, J., Krenn, C., 2010. The theory of inventive problem solving (TRIZ) as option generation tool within cleaner production projects. J. Clean. Prod. 18, 128 – 136.

Fresner, J., Yacooub, A., 2006. Half is Enough, ISBN 3-9501636-2-X, Graz.
Henriksson, E., Söderholm, P., 2009. The cost-effectiveness of voluntary energy efficiency programs. Energy Sustain. Dev. 13 (4), 235 – 243.
Jovancic, P., Tanasijevic, M., Ivezic, D., 2011. Serbian energy development based on lignite production. Energy Policy 39, 1191–1199.
Laforest, V., Raymond, G., Piatyszek, É., 2013. Choosing cleaner and safer production practices through a multi-criteria approach. J. Clean. Prod. 47, 490 – 503.
Lee, S., 2013. Existing and anticipated technology strategies for reducing greenhouse gas emissions in Korea's petrochemical and steel industries. J. Clean. Prod. 40, 83-92.
Mattsson, L.T., Read, A.D., Phillips P.S., 2010. A critical review of the largest Resource Efficiency Club Programme in England (2005–2008): Key issues for designing and delivering cost effective policy instruments in the light of Defra's Delivery Landscape Review. Resources, Conservation and Recycling 55 (1), 1 – 10.
[MME] Ministry of Mining and Energy of the Republic of Serbia, 2014. Energy balance of the Republic of Serbia for the year 2013. Available at: http://www.merz.gov.rs (in Serbian).
Olanrewaju, O.A., Jimoh, A.A., 2014. Review of energy models to the development of an efficient industrial energy model. Renew. Sustain. Energy Rev. 30, 661 – 671.
Rajakovic – Ognjanovic, V.N., Zivojinovic, D.Z., Grgur, B.N., Rajakovic, LJ.V., 2011. Improvement of chemical control in the water-steam cycle of thermal power plants. Applied Thermal Engineering 31, 119 – 128.
Saygin, D., Patel, M.K., Worrell, E., Tam, C., Gielen, D.J., 2011. Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. Energy 36, 6661 – 6673.
Saygin, D., Worrell, E., Patel, M.K., Gielen, D.J., 2011. Potential of best practice technology to improve energy efficiency in the global chemical and petrochemical sector. Energy 36, 5779 – 5790.
Stevanovic, V.D., Wala, T., Muszynski, S., Milic, M., Jovanovic, M., 2014. Efficiency and power upgrade by an additional high pressure economizer installation at an aged 620 MWe lignite-fired power plant. Energy 66, 907 – 918.
[SuDES] Sustainable Development in Energy Sector An EU funded Project, 2012. Aspects of Climate Change in the Development of the Energy Sector in Serbia, Final Report. Available at: http://www.merz.gov.rs/lat/dokumenti-list/7/127 (in Serbian).
Tanaka, K., 2011. Review of policies and measures for energy efficiency in industry sector. Energy Policy 39 (10), 6532 – 6550.
Tzolakis, G., Papanikolaou, P., Kolokotronis, D., Samaras, N., Tourlidakis, A., Tomboulides, A., 2012. Simulation of a coal-fired power plant using mathematical programming algorithms in order to optimize its efficiency. Applied Thermal Engineering 48, 256 – 267.
UNIDO and UNEP, November 2010. A Primer for Small and Medium-Sized Enterprises: Enterprise-Level Indicators for Resource Productivity and Pollution Intensity. Available at: http://www.unido.org/en/resources/publications/energy-and-environment/industrial-energy-efficiency/resource-productivity-guide.html
Van Berkel, R., 2007. Cleaner production and eco-efficiency initiatives in Western Australia 1996–2004. J. Clean. Prod. 15 (8-9), 741 – 755.
Van Caneghem, J., Block, C., Van Hooste, H., Vandecasteele, C., 2010. Eco-efficiency trends of the Flemish industry: decoupling of environmental impact from economic growth. J. Clean. Prod. 18, 1349 – 1357.
Wang, Y., Xie, B., Shang, L., Li, W., 2013. Measures to improve the performance of China's thermal power industry in view of cost efficiency. Applied Energy 112, 1078 – 1086.

THE EUROPE WE WANT

17th European Roundtable on Sustainable Consumption and Production
Research | Experience | Development
14.-16. October 2014 | Portorož, Slovenia

TITLE PAGE

Title: Farmland use size and the adoption of agri-environmental measures: Farm-level evidence from Slovenia

The corresponding author:

İlkay UNAY GAILHARD
Leibniz Institute of Agricultural Development in Transition Economies (IAMO)
Theodor Lieser Str.2
D-06120 Halle (Saale)
Germany
Tel: + 49 (0)345 2928 322
Email: unaygailhard@iamo.de

Co-author of the paper:
Štefan BOJNEC
Faculty of Management, University of Primorska, Koper, Slovenia
Tel: + 386 5 610 2046
E-mail: stefan.bojnec@fm-kp.si

Farmland use size and the adoption of agri-environmental measures: Farm-level evidence from Slovenia

Abstract

This paper analyses the determinants of agri-environmental measure (AEM) adoption using the Slovenian Farm Accountancy Data Network (FADN) for the 2004-2010 period. Previous papers did not provide a straightforward relationship of the role of farm size in AEM adoption. By considering explicitly with the dimension of farmland use size, the controversial subject of the role of farm size on AEM adoption is investigated by conducting logit regression analyses. We examined the influence of farm-specific characteristics on farm participation in AEMs using three different farmland use sizes: small, medium, and large farms. The AEM farm subsidies go to medium and larger farms than to smaller farms. The findings strongly suggest that regarding to the farm-utilised agricultural area (UAA), there are differences between the determinant factors of AEM adoption, especially between small and large farms. This conclusion is supported by the variables that describe the farm capital intensity, off-farm income and type of farming as significant determinants for large farm models but not for the small farm models. Furthermore, variables that describe land productivity negatively influence AEM adoption for large farms, whereas this variable positively influences small farms. The results highlight the importance of how previously confirmed influenced factors of AEM adoption differ under the three different farmland use size dimensions.

Keywords: Agri-environmental measures, farm size, land use, farm level data, logit model, Slovenia.

1. Introduction

In recent years, agri-environmental measures (AEMs) of farms have become important elements of rural development (RD) policies, addressing the issues of multifunctionality, biodiversity and eco-efficiency in farm and agricultural development (EC, 2005; Beltrán-Esteve1 et al., 2012). Correspondingly, there are several studies of farmer attitudes to environmental conservation, including the farmers' AEM adoption behaviour. In addition to the debate of the role of farm size on being an environmentally friendly farm, previous studies have investigated the influence of farm size on AEM adoption. However, the findings do no not provide a straightforward relationship between farm size and AEM adoption. Therefore, we aim to investigate the determinants of farmers' participation in AEMs, considering explicitly the role of the farmland use size dimensions. This study contributes to the investigation of the adoption of AEMs in a Slovenia by farm-utilised agricultural area (UAA) size divisions using the Farm Accountancy Data Network (FADN) evidence at the farm level.

RD supports are not uniformly adopted between the European Union (EU) member states. High levels of RD supports are observed in Slovenia, Austria, and Luxembourg, while there is a relatively low level of average RD support in Denmark, Spain, Italy and Greece (EC, 2009). In Slovenia, similar to Austria and Luxembourg, the RD support is greater than the first pillar direct payments. Furthermore, Slovenia has the highest RD support among the new member states (NMS-10) of the EU 2004 enlargement and among most of the old EU-15 member states, including being three-to-four-times higher than in neighbouring Italy.

The AEMs that play an essential role in the RD programme for Slovenia are significant policy tools for addressing multifunctionality in rural and agricultural development. According to the Slovenian FADN, 72% of farms adopted AEM farming practices in 2010. Slovenian farmers receive the highest average AEM payment per hectare (ha) among the NMS-10 because of a relatively high participation rate of farms in the AEM programme and relatively high support per hectare (EC, 2009).

The accession to the EU in 2004 provided a brake to the structural change in the Slovenian farms. Between 2005 and 2010, the total number of farms decreased with an increase in the number of very small farms (less than 1 ha) and large farms (greater than 20 ha) but a substantial decrease in the number of medium-farms (Bojnec and Latruffe, 2013). An increase in the number of small farms could be associated with a transfer of small farms from parents to children, which is as an important issue in the Slovenian semi-subsistence farm life cycle as a social buffer providing food for home consumption and hobby farming. However, an increase in the number of large farms could be interpreted as entry and growth of farms that are operated by younger and more educated farmers, who have increased the farm UAA size by buying and renting land, as these farmers see farming as a career opportunity.

These structural changes in the number and size of farms have produced new decision-making processes for farmers to maintain sustainable rural development. The central point on which our research focuses thus concerns the analysis of the determinants of farmers' AEM adoption behaviour by farm UAA size divisions. The main research question is whether and to what extent do the farm UAA sizes contribute to AEM adoption decision-making among Slovenian farmers? What are determinants of AEM adoption under the farm UAA size categories, which are related to FADN evidence? The answer to this question is important for the assessment of the high participation rate of farms in the AEM programme in Slovenia and will provide insights into the factors that determine whether farm size affects farmers' attitudes towards agri-environmental (AE) farming practices. This study examines the influence of farmland use characteristics; farm inputs, such as family labour and capital intensity; off-farm income; land productivity; and farm types on AEM adoption behaviour. By considering structural changes in Slovenian farms, our model captures the behaviour of three different groups of farms via their UAA sizes: small and medium farms, which are mostly family-owned and operated farmers, and large farms, which represent the growth of larger family-owned farms, new entrances, operated farmers and few commercial farmers.

The remaining of the paper is organised into the following sections. Section 2 provides a literature review of the role of farm size in AEM adoption. Section 3 describes the data source and gives descriptive evidence for the main features of AEM adoption in Slovenia. Section 4 explains the methodological approach of the farm UAA size-specific logit model. Section 5 presents the results and discusses the differences between the determinant factors of AEM adoption regarding the three farm size models. Finally, section 6 concludes with the summary of the results that are important for AEM policy making and recommendations for future research.

2. Controversial subject: role of farm size in AEM participation

Since the early 1990s, with the implementation of programmes under the AEM scheme, the adoption of voluntary AEMs by farmers has stimulated the interest of academic studies. These studies have mainly used theories of diffusion of innovation (Morris and Potter, 1995; Mathijs, 2003), the theory of reasoned action and planned behaviour (Wauters et al., 2010; Grammatikopoulou et al., 2012; Mettepenningen et al., 2013), the micro-economic modelling theory (Ozanne et al., 2001; Polman and Slangen, 2008), the profit maximiser theoretical framework (Bonnieux et al., 1998; Dupraz et al., 2003), the social network approach (Deffuant et al., 2008; Unay Gailhard et al., 2014), and the contract theory (Espinosa-Goded et al., 2013).

For each of the remaining major theoretical approaches, the literature demonstrates that several factors influence the adoption behaviour of AEM, such as attitudes and perceptions towards conservation practices (Black and Reeve, 1993; Defrancesco et al.,2008; Vanslembrouck et al., 2002); financial factors (Morris and Potter, 1995; Wilson and Hart, 2000; Ducos et al., 2009; Sutherland and Darnhofer, 2012); continuance of the farm (Ingram et al., 2013); contract design (Fraser, 2011); information actors (Lowe and Cox, 1990; Warriner and Moul, 1992; Skerratt, 1998; Beedell and Rehman, 2000; Frondel et al., 2012), and farmers' characteristics and farm structure (Crabtree et al.,1998; Wynn et al., 2001; Kristensen et al.,2001).

Among the farm structure variables, the farm size, farm type, and farm labour characteristics are important determinants for AEM adoption. The farm size is often measured by the size of the UAA and has been considered one of the most important determinants in AEM farming practices. Furthermore, in addition to the UAA, studies have investigated the influence of farm size using measures such as the standard gross margin (SGM), European size unit (ESU), and total sales. However, previous studies did not observe a straightforward relationship between the role of farm size and farmer participation in AEMs. These mixed results regarding the impact of farm size on AEM adoption in farming practices can be classify into three groups.

The first group of studies argues for a positive association between farm size and the adoption of AEMs. The study of Wynn et al. (2001) in Scotland demonstrated that large farms (measured as total UAA in ha) are likely to join the schemes in environmentally sensitive areas earlier than are small farms. Damianos and Giannakopoulos (2002) in Greece demonstrated that farm size (in terms of ESU) positively influence both the probability of the adoption of the nitrate reduction measure and the intensity of the adoption of that measure. The study of Vanslembrouck et al. (2002) analysed two types of AEMs (extensification of field margins and farm beautification) in Belgium under the assumption that the adoption behaviour of farmers is not only influenced by farmer and farm characteristics but also by the characteristics of the provided AEMs. The authors found that larger farms (>75 ha) demonstrate a greater acceptance of extensification of field margins than do small (<35 ha) and medium (35-75 ha) farms, controlling for other explanatory variables. The broader investigation of Wilson and Hart (2000) with a survey of 1,000 farm households in EU-9 member states (Austria, Denmark, France, Germany, Greece, Portugal, Spain, Sweden, and the United Kingdom) and Switzerland suggests that AEM adoption behaviour of farmers are influenced by farm size: farms that are larger than the regional average are often more likely to adopt AEM. In the recent study in Belgium and the USA, according to the model of Mettepenningen (2013), the probability of AEM adoption increases with farm size; here, the authors used the standardised farm size to correct for differences between the different types of farms. In the early years of AEM adoptions, Wilson (1997) discussed this positive relationship between the farm size and the adoption of AEM in farming practices using eligibility criteria (i.e., small farms that are lacking substantial semi-natural habitats). The study of Wilson and Hart (2000) concludes that the reason for this positive relationship is that farms that are larger than the regional average have larger ecologically important habitats on their farms that are eligible for AEM payments.

The second group of studies argues on the non-significant effect of farm size on AEM adoption. Dupraz et al. (2003) in Belgium showed that the participation rate of the two studied AEMs (late mowing and reduced use of farm inputs) does not significantly vary with farm size (measured as total UAA in ha). Wossink and Wenum (2003) focused on both the actual and contingent participation behaviour of biodiversity conservation (BC) by arable farms in the Netherlands. These authors considered the differences in the proportion of labour-intensive crops in large and small farms. By considering that small farms usually grow a larger proportion of labour–intensive, high-returning crops, BC would be less attractive for these farms. However, contrary to expectations, farm size has no effect on the adoption of BC for both actual and contingent participation behaviour typologies. Studies that used both UAA and SGM farm size measures, such as that of Defrancesco et al. (2008) for Italy and that of Polman and Slangen (2008) for the EU-6 member states (Netherlands, Belgium, Czech Republic, Finland, France and Italy) have concluded that farm size does not have an effect on the adoption of AEM in farming practices.

The third group of studies state a negative association between farm size and the adoption of AEM in farming practices. For the Flemish region in Belgium, Vanslembrouck et al. (2002) demonstrated that the largest farms are significantly less likely to adopt farm beautification measures than are the base and middle categories of farm sizes. The authors explain the reason for this bias as the larger farms already having realised plantation around their new buildings or their situation in more woody areas. Recently, in agreement with these authors, the study of Pascucci et al. (2013) in Italy found that small farms (<16 ESU) are more likely to adopt AEM supports. This negative relationship between farm size and the adoption of AEM is explained by the differences between large and small farms in terms of allocating their labour time and assets to implement AEMs; small farms may have higher benefits and lower opportunity costs relative to large farms. Different from the relationship between farm size and adoption behaviour, Mann (2005) investigated the adoption of meadow extensification measures in growing farms in Switzerland and found that farm growth (in terms of increased farm size) negatively affects participation in AEMs. One of the arguments for that negative relationship is given by the economies of scale. Growing farms have great benefits in terms of economies of scale in food production than for the delivery of public goods and services, e.g., the adopting AEM.

Despite the fact that these previous models have incorporated farm size as an independent variable to explain the participation decision in the adoption of AEMs in farming practices, the literature has so far not provided an assessment of the models that increase the predictive quality of adoption behaviour in terms of participation probability transitions at different farm sizes. Therefore, this paper aims to fill this gap in the literature and investigate the determinants of farmers' participation in AEMs, considering explicitly the role of the farm UAA size dimensions.

3. Data

3.1. Slovenian Farm Accountancy Data Network (FADN)

This paper employs the Slovenian FADN survey sample for the years 2004-2010. The FADN is a European system of sample survey of farms that is used as an instrument for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy (CAP) measures in the EU countries (Eurostat, 2012a; 2012b). In our study, secondary farm level data of the Slovenian FADN sample of farms are investigated on the determinants for AEM adoption in farming practices. The studied years are the Slovenian post-EU accession period with co-existence and a shift from national agricultural policies to the CAP of the EU.

The Slovenian FADN includes farms the above two ESUs; one ESU is equivalent to 1,200 Euros of gross margin. All of the nominal aggregates have been deflated by statistical price indices to obtain their real values in 2004 prices over time. The total output in the land productivity ratio was deflated by the producer price index of agricultural products. The total assets were deflated by the agricultural input price index for goods and services contributing to agricultural investment. The source of data for price deflators is the Statistical Office of the Republic of Slovenia. Table 1 describes the used Slovenian FADN dataset.

Table 1
Description of the used Slovenian FADN dataset (2004-2010)

Variables	Description	Unit
Farm UAA size samples	Total UAA in hectares (ha)	
	Size 1, small farms: less than 5 ha	1
	Size 2, medium farms: 5-10 ha	2
	Size 3, large farms: more than 10 ha	3
Depended variable:		
Adoption of agri-environmental measure (AEM)	AEM adopted by farm in the current year	0=no, 1=yes
Independent variables:		
Farmland use characteristics		
Land use		
Woodland areas	Share of woodland area on UAA of holding	Percentage
Cereals	Share of cereals on UAA of holding	Percentage
Forage crops	Share of forage crops on UAA of holding	Percentage
Tenure status		
Rented land	Rented areas as a percentage of the total UAA of holding	Percentage
Land productivity and capital intensity		
Land productivity	Total output to total land (Euros/ha)	Ratio
Total assets to land	Total assets to land (Euros/ha)	Ratio
Family labour and off-farm income		
Family labour	Unpaid family labour input (FWU) to total labour input (AWU)	Percentage
Off-farm income	Share of the off-farm income to total agricultural revenue	Ratio
Adoption of rural development subsidies		
Less favoured area (LFA) payments	LFA measure adopted by farm in the current year	0=no, 1=yes
Other rural development (RD) payments	Other voluntary RD policy measures adopted by farm in the current year	0=no, 1=yes
Farm types	Eight farm types used as a dummy variable. These are field crops, horticulture, wine, other permanent crops, milk, other grazing livestock, granivore, mixed	0=no, 1=yes
Years	Survey years 2004-2010 used as a dummy variables	0=no, 1=yes

Source: *Slovenian FADN dataset*

Note: *Annual work unit (AWU), 1 AWU=1,800 hours of labour per year (Eurostat 2010, p. 432).*
For the purpose of the study, we investigated the determinants for AEM adoption in different farm UAA size samples. Based on the average Slovenian farm UAA size of 6.3 ha in 2010 (Bojnec and Latruffe 2013), we designed three subsamples to meet the concurrent objectives of providing (1) an estimate of small farms with a UAA of less or equal to 5 ha, (2) an estimate for medium farms with a UAA from 5 to 10 ha, and (3) an estimate for large farms with a UAA of greater than 10 ha. The categorisation into small, medium and large farms would change for other regions where the average farm size is different from our study area.

The Slovenian FADN dataset considers three categories of RD subsidies: AEM, less favoured area (LFA) and other RD payments. The AEM payments cover subsidies for environmental restrictions in farming practices. The LFA payments aim to mitigate the risks, such as agricultural land abandonment, desertification and forest fires. Other RD payments have an objective to help farmers adapt to standards, use farm advisory services, and improve the quality of agricultural products, training, afforestation and ecological stability of forests. Due to our study aims assessing the factors that explain farm participation in AEM farming practices, the analysis focus on the AEM payments rather than on other categories of RD subsidies. This study was conducted in three logit regression analyses with small, medium and large farm sizes in which the adoption of AEM in the current year was a dependent variable.

3.2. Descriptive statistics

Table 2 shows the summary statistics of the variables that were used in the empirical analysis on average during the 2004-2010 period.

Table 2
Descriptive statistics (2004-2010)

Variables	Used statistics	Size 1: Small farms less than 5 ha	Size 2: Medium farms from 5-10 ha	Size 3: Large farms greater than 10 ha
Farm UAA size samples	N (%)	N=390 (7.4%)	N=1260 (23.9%)	N=3605 (68.6%)
Farmland use characteristics				
Land use				
Share of woodland areas	Mean % (Std.)	127.42 (28.0)	119.53 (4.0)	73.67 (1.8)
Share of cereals	Mean % (Std.)	13.60 (1.2)	12.62 (0.6)	16.41 (0.4)
Share of forage crops	Mean % (Std.)	40.04 (1.9)	69.40 (1.0)	75.73 (0.5)
Tenure status				
Share of rented land	Mean % (Std.)	15.43 (1.4)	14.22 (0.5)	42.53 (0.4)
Land productivity and capital intensity				
Land productivity (Euros/ha)	Mean (Std.)	3592.86 (202.0)	2221.37 (73.2)	2157.96 (51.1)
Total assets to land (Euros/ha)	Mean (Std.)	26,276.68 (1113.9)	20,736.90 (399.6)	14,997.28 (131.2)
Family labour and off-farm income				
% of family labour	Mean % (Std.)	95.83 (0.5)	96.69 (0.3)	95.93 (0.2)
Off-farm income (Euros)	Mean (Std.)	672.21 (117.9)	1880.16 (150.9)	3839.26 (642.4)
Adoption of rural development subsidies				
AEM payments	% of yes	57.44	76.51	73.29
LFA payments	% of yes	69.49	82.46	77.25
Other RD payments	% of yes	4.62	14.44	10.37

Source: *Slovenian FADN dataset*
Note: *mean and percentage (%) results represent the average of the 2004-2010 period.*

While small farms account for 7.4% of the sample, this subset is composed of 23% medium and 68% large farms, confirming that the FADN sample included more viable farms that are larger than the average Slovenian farm size (6.3 ha).

Regarding the adoption of RD subsidies, the share of participation in AEM is higher for medium (76%) and large farms (73%) than for small farms (57%), confirming that, on average during the study years in Slovenia, more AEM farm subsidies go to medium and large farmers than to smaller ones. Similarly, for the LFA and other RD payments, small farms exhibit lower percentages of participation relative to medium and large farms.

In addition to the results for average of the 2004-2010 period, Table 3 provides the average AEM subsidies adopted amount (Euro/AWU) and the share of adopters (%) by year with farmland use divisions.

Table 3
Agri-environmental measure (AEM) adoption among Slovenian farms by years.

	%	Mean	Std.	Min.	Max.
Size 1: small farms					
2004	63.33	900.86	422.11	252.47	1593.08
2007	55	605.12	390.79	129.69	1471.8
2010	57.77	638.34	295.25	121.10	1310.55
Size 2: medium farms					
2004	72.27	1271.28	897.30	176.47	4131.18
2007	81.91	1247.63	788.02	111.84	3654.13
2010	75	1222.42	716.08	211.07	4333.04
Size 3: large farms					
2004	68.87	4579.02	7202.74	122.67	89,692.48
2007	77.95	4616.95	5684.33	67.66	38,070.49
2010	71.83	5216.3	6033.92	60.55	39,281.14

Source: *Slovenian FADN dataset*
Note: *percentage (%) represents the share of AEM adopters, mean numbers give the average AEM subsidies that are received by farms (Euro/AWU).*

Consistent with the results for the average during the 2004-2010 period, the share of AEM adopters is higher for medium and large farms (approximately 71-81%) relative to small farms (approximately 55-63%) in the studied years (Table 3). For the three farm UAA size models, the share of AEM adopters slightly varies with the study years. As expected, the average amount that was received for the AEM subsidies was higher for large farms than for medium and small farms. Overall, Table 3 provides a dualistic structure of participation behaviour in which the farm UAA size plays an important role, indicating the necessity of investigating the AEM adoption behaviour by the distinction of farm size.

4. Method: farm UAA size-specific logit model

The study hypothesis that the differences in farm UAA sizes lead to different costs and benefits in AEM adoption, and thus determinant factors in the decision-making process in voluntary AEM farming practices, would not be similar for small, medium and large farms. During the decision-making process, the farmer faces two options: sign an AEM contract or not.

To test our hypothesis, as a first step, three subsamples of farm UAA sizes were pooled from the FADN dataset: small, medium, and large farms. It is assumed that in different farm UAA size divisions, AEM adoption has a different impact on farmers' income by changing the output and efforts for respect requirements. We expect that in each farm UAA size sample, the benefits for providing public goods and services relative to farm income present farmers a distinct decision-making process.

For the three farm UAA size samples, choice modelling proceeds in the second stage. Regarding the literature on the applied methodology for voluntary AEM adoption, the studies have mainly used discrete choice models by considering the adoption decision as a dichotomous problem (Crabtree et al., 1998; Wynn et al., 2001; Vanslembrouck et al., 2002; Polman and Slangen, 2008; Hurle and Goded, 2007). Following these studies, we formulated the decisions of farmers as a discrete choice model. Based on the micro-economic modelling theory, Equation (1) shows that willingness to sign an AEM contract depends on the farmers' estimates of the forgone profits.

(1)

During the last stage, we conducted farm UAA size-specific logit regression analyses. The objective of logit models is to predict the effects of multiple explanatory variables, which can be numeric and/or categorical, on the outcome variable. The general logit regression model is as follows:

(2)

This formula is stated in terms of the probability that y=1, which is referred to as. The probability that y=0 is. The symbol of refers to a natural logarithm and, represents the equation for the regression line, where is the regression constant and is the observation.

An empirical study has been conducted with logit models for small, medium and large farm UAA size subsamples, where AEM adoption is a dichotomous dependent variable. We expect comparatively dissimilar dependent and independent variable associations between the three models.

Due to the missing values for the large farm UAA subsample, the number of observations for the logit analysis was reduced from 3605 to 3550. For the comparative analysis, the results from independent logit models, including coefficient estimates, with P>|z| test significance levels and standard errors are presented. The pseudo R^2 measure of goodness of fit is estimated at 0.186 for the small, 0.178 for the medium and 0.242 for the large farm subsamples. This relatively low pseudo R^2 level can be explained by the specificity of the used unbalanced panel dataset, where it is possible and rather common to have low fit numbers.

5. Results and discussions

Table 4 shows the results of logit regression analyses. These findings strongly suggest that, regarding the farm UAA size, there are differences between the determinant factors of AEM adoption, especially between small and large farms.

Table 4
Results of the farm UAA size-specific logit models for adoption of agri-environmental measure (AEM)

	Small farms N=390		Medium farms N=1260		Large farms N=3550	
	Coef.	**Std.**	**Coef.**	**Std.**	**Coef.**	**Std.**
Farmland use characteristics						
Land use						
Share of woodland areas	.001	.001	.003**	.001	.002**	.0007
Share of cereals	-.027**	.007	-.031**	.008	-.080**	.007
Share of forage crop	-.017**	.006	-.033**	.008	-.097**	.007
Tenure status						
Share of rented land	-.004	.005	-.003	.003	.001	.002
Land productivity and capital intensity						
Land productivity	.009**	.004	-.002**	.000	-.006**	.000
Total assets to land	-.000	.009	.000	.006	-.000**	.000
Family labour and off-farm income						
% of family labour	-.0136	.0146	-.0512**	.0211	.0005	.004
% of off-farm income	.000	.000	.000**	.000	.000**	.000
Adoption of other rural development subsidies						
LFA payments	1.247**	.308	1.066**	.231	1.028**	.123
Other RD payments	.504	.594	.143	.271	.623**	.201
Farm types						
Field crops	17.97	815.41	.270	1.219	-.346	.431
Horticulture	16.51	815.41	-.052	1.416		
Wine	17.04	815.41	-.745	1.336	5.371**	1.400
Other permanent crops	18.13	815.41	.443	1.326		
Milk	17.45	815.41	-.596	1.214	.981**	.379
Other grazing livestock	17.37	815.41	-.209	1.210	.886**	.386
Mixed	17.65	815.41	-.116	1.201	.390	.373
Years						
2004	.696	.570	.141	.312	.024	.173
2005	.768	.490	.583**	.287	.292*	.166
2006	-.123	.461	-.720**	.243	-.692**	.154
2007	.109	.480	.730**	.289	.708**	.166
2008	.450	.461	.914**	.283	1.152**	.166
2009	.216	.458	.4912*	.28	.0729	.151
Constant	-16.239	815.412	8.15**	2.60	9.922**	.911
Prob > chi2	0.000		0.000		0.000	
Pseudo R^2	0.186		0.178		0.242	

Source: *Slovenian FADN dataset*
Note: *The coefficient values are given with P>|z| test significance levels of ** p<.05 and *p<0.1. In the model, the variable "granivores" and the year "2010" were used as base (reference) categories for the explanatory variable groups of farm types and years, respectively.*

Farmland use characteristics

For the medium and large farms, the likelihood of AEM adoption increases with the share of existing woodland areas. Such farms are less likely to be situated in flat areas in Slovenia where crop production more often occurs but are more likely to be situated for production in limited hilly and mountain LFAs. This positive relationship between the share of woodland area and AEM adoption contrasts with the results of the variables of share of cereal and forage crops, which negatively affects the likelihood of adoption for the three models. These results indicate that, regardless of the farm UAA size, AEM adoption is less attractive for farms that are under agricultural land use. This negative impact may explain the fact that the AEM intensity in farming practices decreases the production. If we express this decrease in the production as an opportunity cost (Bertoni et al., 2011), one could expect that regardless of the farm size, the opportunity cost is higher for farms in which the share of UAA is high. Our findings for the share of cereal and forage variables agree with those of Wynn et al. (2001) in Scotland and of Defrancesco et al. (2008) in Italy. In Slovenia, farms under agricultural land use are largely situated in flat areas in Central and Northeastern Slovenia. While this model results highlight the important role of the type of land use, it is also vital to consider the farm location.

Land productivity and capital intensity

Land productivity has significantly positive affects the AEM adoption of the small farms, while it is affecting adoption behaviour negatively for the medium and large farms, indicating that the opportunity costs for maintaining environmental farming obligations are positively related to land productivity only for small farms. This positive effect is partly consistent with the findings of Glebe and Salhofer (2007). These authors investigated the influence of economic, environmental, and political factors on the AEM adoption for EU-15 countries. These results suggest that farms that are situated in relatively low productive agricultural lands tend to adopt AEM comparatively more than do farms that are located in highly productive lands. The positive influence of land productivity on the small farms and the negative influence on the medium and large farms can be explained by the differences in the private costs (e.g., the use of request inputs, which is linked to higher production costs and/or a decrease in the production) between the three studied farm UAA size subsamples. In our case, only the medium and large farms with a certain land productivity level fall below the threshold of profitability for scheme participation.

For the large farms, the negative and significant sign for the capital intensity (total assets to land) indicates that AEM adoption decreases with the increasing degree of fixed and current assets to farmland. This result confirms the findings of Pascucci et al. (2013) in Italy. These authors indicate that a high level of capital intensity (measured as horsepower mechanisation per ha) decreases the adoption behaviour of two studied RD measures: support for AE services and support for competitiveness schemes. In the Slovenia, this is particularly true for the large farms, which are also more commercially oriented, while the capital intensity is not a significant determinant for explaining the attitude towards AEM adoption both for small and medium farms.

Family labour

The estimation results indicate that AEM adoption decreases with the increasing share of family labour for medium farms but it is not significant for small and large farms. However, it should be noted that the all of the studied farms are run mainly using family labour (95%) (see Table 2), demonstrating that, although the share of family labour is similar for all of the studied farm UAA sizes, the opportunity cost of AEM adoption is high only for medium farms, which “are too small to be economically efficient, but they are too large to be profitable” (Bojnec and Latruffe, 2013, p.216). The finding that the share of family labour negatively influences the AEM adoption behaviour for medium farms (5-10 ha) is consistent with the study of Defrancesco et al. (2008) in Northern Italy (in the Alpine area where the average farm size is 7.6 ha). Their results indicate that a high level of family labour increases the marginal probability of non-participation in the three studied AEMs; low input measures, grassland conservation in the aquifer recharge belt and grassland conservation in the Alps.

Off-farm income

The share of off-farm income positively influences the AEM adoption behaviour of medium and large farms, while it is not significant for the small farms. This result is explained by the off-farm income support reducing uncertainty regarding the farmers’ income, making the farmer less dependent on the market, thus positively influencing the participating voluntary conservation practices that provide subsidies. However, for small farms, even farm income gains are supported by the off-farm income, which seems to not offset costs of AEM adoption from shifting to environmental farming practices. Thus, gains from AEM adoption do not decrease income uncertainty and could be perceived as barriers to market entry for small farms.

The literature on the role of off-farm income in the AEM adoption provides diverse results depending on the studied AEM scheme and the region. While Pascuci et al. (2013) found that off-farm activities do not lead to significant differences in AEM adoption (such as afforestation and extensification), Wossink and Wenum (2003) demonstrated that off-farm income increases the likelihood of contingent participation, but there is no significant influence on the actual participation. Jongeneel et al. (2008) found a positive relationship that is consistent with the results of our study. These authors investigated the participation in conservation activities in the Netherlands (the average size for arable farms is 103 ha) and found that off-farm income increases the likelihood of adoption. These authors explain the results by the less labour-intensive farming methods. Based on the observation that off-farm employment is often combined with an agricultural system that uses less labour, these more extensive farms can be easily combined with farming practices that are related to nature conservation.

Adoption of other RD subsidies

The adoption of AEM is significantly influenced by the participation to the other two categories of RD subsidies: LFA and other RD payments. The positive signs of the estimates for the LFA payment variable in all of the farm UAA size models confirm that, regardless of farm size, the adoption of LFA payment in the current year increases the likelihood of AEM adoption. Our study result partly corresponds with previous findings by Crabtree et al. (1998) regarding the adoption behaviour of the farm woodland premium scheme in Scotland. This scheme encourages tree planting on farms, and the authors found that farms in the LFAs have a greater likelihood of planting.

The adoption of other RD subsidies (such as payments that help farmers to adapt to environmental standards, to use farm advisory services, and to improve the quality of agricultural products) significantly positively affects AEM adoption for large farms. However, this variable is not significant for small and medium farms. Overall, it seems that large farms that actively participate in two categories of RD subsidies (LFA and other RD payments) also benefit from AEM payments.

Farm types

For large farms, AEM adoption is significantly influenced by farm types, especially for wine, milk and specialised livestock (e.g., sheep, goats and specialist cattle-rearing). This result demonstrates that vineyards and dairy and livestock farms (greater than 10 ha) have lower costs associated with AEM adoption, which can be related to use of less capital intensive and more environmentally friendly production technologies. However, this positive effect is not observed for small and medium farms, which could be explained by the increased opportunity cost of AEM adoption in farm size-specific management. The importance of large farms with dairy and other grazing livestock is also confirmed by the number observed in the FADN sample. For example, there are few small and medium farms for dairy and other grazing livestock relative to large farms. Non-significant results and large standard errors for the small farm model do not allow for any conclusive statements on comparative base. The finding that livestock farms significantly positively impact the large farm adoption corresponds with the previous findings of Hynes and Garvey (2009) for the adoption of the Irish rural environment protection scheme and of Espinosa-Goded et al. (2013) for the introduction of an alternative cropping system in Northern Spain. These authors explained this positive relationship by fewer changes in the farm operations compared to intensive farmers. For livestock farms, introducing an alternative cropping system that is safe for the environment is associated with a lower cost of AEM adoption relative to non-livestock farms. Furthermore, these livestock farms use these introduced cereal crops as animal feed.

6. Conclusion

This study developed and tested the hypothesis that differences in the farm UAA sizes lead to different costs and benefits for farms, playing an important role in the AEM adoption decision-making process. Within this hypothesis, we examined the influence of the characteristics of the farmland use structure, the share of family labour and off-farm income, the adoption of other RD measures and the type of farming on farmers' participation in AEMs in Slovenia. The models of AEM adoption behaviour depending on these determinants were tested separately in the three farm UAA sizes. Thus, the main novelty and contribution of this paper is the investigation of how previously confirmed influenced factors of AEM adoption differ under the three different farm UAA size dimensions.

The results demonstrate that the influence of determinant factors that vary with farm UAA size need to be considered for the participation to RD supports, especially the AEM adoption behaviour of farmers. The predictions of the econometric logit model are consistent with the given conceptual framework, stating that land use, land productivity, capital intensity, family labour, off-farm income, the adoption of other RD subsidies and the type of farming have significantly impact on AEM adoption. The differences between the three farm size models illustrate the findings and confirm that the factors that influence AEM adoption differ regarding the farm UAA size. This conclusion is mainly supported by the variables that describe farm capital intensity, off-farm income and farm type, where we observe a significant influence on the AEM participation for large farms but not for small farms. Furthermore, the variables that describe land productivity negatively influence AEM participation for large farms, whereas these variables are positive determinants for small farms, indicating that land productivity is the only element significantly influencing the adoption behaviour with an adverse impact regarding the farm size.

Derived from micro-economic modelling theory, these differences in the AEM adoption decision-making process can be explained by the profit maximisation and utility function frameworks. Previous studies, such as those of Bonnieux et al. (1998), Vanslembrouck et al. (2002), Dupraz (2003) and Espinosa-Goded et al. (2010), based their adoption model on the assumption that the farmers' utility maximisation depends both on the production of private goods (which bring the farm income) and on the provision of environmental goods and services. The adoption of voluntary AEM as an additional payment depends on the farmers' estimate of the forgone profits. In our case, the effects of the farm UAA structure, land productivity, capital intensity, family labour, adoption of other RD payments and farm type on AEM adoption have varying results in which the farm UAA size leads to farmer divergence for profit maximisation.

In contrast to the observed differences between the three farm size models, the acceptance of AEM is influenced by the share of farmland under agricultural use (e.g., cereal and forage crop) and the adoption of LFA payments for all of the farm UAA sizes. These results lead us to derive land use policy and management implications. Although there are high AEM compensation rates in Slovenia, regardless of the farm size, participation rates can be negatively influenced by the share of agricultural land, which can be related to the land quality and/or steepness of terrain in hilly and mountainous areas. Furthermore, when the farmers are convinced about the utility of the LFA payment adoption decision, AEM adoption will be greater.

Our results suggest that different decision-making processes influenced by the farm UAA size must be considered when designing AEMs following the Slovenian accession to the EU in 2004. If the average agricultural area per farm continues to grow, it is likely that the factors that influence the farmers' AEM adoption decision will change. This effect has not yet been studied by focusing on the farm UAA size growth and AEM participation in Slovenia. The results here and of Mann (2005) in Switzerland provide potential results of structural change effects in Slovenia.

While our study highlights the importance of factors on the AEM adoption without a distinction of measure, it would be interesting to focus on farmers' participation in specific measure(s). This distinction can help to predict calculated costs and benefits in the decision-making process of farmers for specific AEM adoption and compare within the farm UAA sizes. In addition, the influential factors on AEM adoption can be focus on changing the decision-making behaviour by increasing the size of farms in future research.

Acknowledgements

This research used Farm Accountancy Data Network (FADN) for Slovenia. The authors would like to thank Slovenian Ministry of Agriculture and Environment for the provided farm level data.

References

Beedell, J., Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour. Journal of Rural Studies. 16 (1), 117-127.

Beltrán-Esteve1, M., Gómez-Limón, J.A., Picazo-Tadeo, A.J., 2012. Assessing the impact of agri-environmental schemes on the eco-efficiency of rain-fed agriculture. Spanish Journal of Agricultural Research. 10 (4), 911-925.

Bertoni, D., Cavicchioli, D., Pretolani, R., Olper, A., 2011. Agri-environmental measures adoption: New evidence from Lombardy region. In The Common Agricultural Policy After the Fischler Reform: National Implementations, Impact Assessment and the Agenda for Future Reforms (p. 275–294), edited by Sorrentino, A., Severini S., Henke, R., Ashgate Publishing, Surrey, UK.

Black, A.W., Reeve, I., 1993. Participation in Landcare Groups: The Relative Importance of Attitudinal and Situational Factors. Journal of Environmental Management. 39 (1), 51–71.

Bonnieux, F., Rainelli, P., Vermersch, D., 1998. Estimating the Supply of Environmental Benefits by Agriculture: A French Case Study. Environmental and Resource Economics. 11 (2), 135-153.

Bojnec, S., Latruffe, L., 2013. Farm size, agricultural subsidies and farm performance in Slovenia. Land Use Policy. 32, 207– 217.

Crabtree, B., Chalmers, N., Barron, N., 1998. Information for Policy Design: Modelling Participation in a Farm Woodland Incentive Scheme. Journal of Agricultural Economics. 49 (3), 306-320.

Damianos, D., Giannakopoulos, N., 2002. Farmers´ participation in agri-environmental schemes in Greece. British Food Journal. 104 (3/4/5), 261-273.

Deffuant, G., Huet, S., Skerratt, S., 2008. An agent based model of agri-environmental measure diffusion: What for? In Agent based modelling in natural resource management (p. 55-73), edited by INSISOC, Valladolid, Spain.

Defrancesco, E., Gatto, P., Runge, F., Trestini, S., 2008. Factors Affecting Farmers` Participation in Agri-envirionmental Measures: A Northern Italian Perspective. Journal of Agricultural Economics. 59 (1), 114-131.

Ducos, G., Dupraz, P., Bonnieux, F., 2009. Agri-Environment Contract Adoption under Fixed and Variable Compliance Costs. Journal of Environmental Planning and Management. 52 (5), 669–687.

Dupraz, P., Vermersch, D., Henry de Frahan, B., Delvaux, L., 2003. The environmental Supply of Farm Households. A Flexible Willingness to Accept Model. Environmental and Resource Economics. 25 (2), 171-189.

EC, 2005. Agri-environment measures: overview on general principles, types of measures, and application. European Commission Directorate General for Agriculture and Rural Development, Brussels, 25 March.

EC, 2009. Rural development (2000-2006) in EU Farms. European Commission Directorate General for Agriculture and Rural Development, Brussels, 28 July.

Espinosa-Goded, M., Barreiro-Hurlé, J., Ruto, E., 2010. What do farmers want from agri-environmental scheme design? A choice experiment approach. Journal of Agricultural Economics. 61 (2), 259-273.

Espinosa-Goded, M., Barreiro- Hurlé, J., Dupraz, P., 2013. Identifying additional barriers in the adoption of agri-environmental schemes: The role of fixed costs. Land Use Policy. 31, 526-535.

Eurostat, 2010. Europe in figures. Eurostat statistical yearbook 2010. Eurostat, Luxembourg.

Eurostat, 2012a. Farm Accountancy Data Network. European Commission, Luxembourg.

Eurostat, 2012b. Farm Accounting Data Network: an A to Z of methodology. European Commission, Luxembourg.

Fraser, R., 2011. Moral Hazard, Targeting and Contract Duration in Agri-Environmental Policy. Journal of Agricultural Economics. 63 (1), 56–64.

Frondel, M., Lehmann, P., Wätzold, F., 2012. The impact of information on landowners' participation in voluntary conservation programs – Theoretical considerations and empirical evidence from an agri-environment program in Saxony, Germany. Land Use Policy. 29 (2), 388-394.

Glebe, T., Salhofer, K., 2007. EU Agri-environmental Programs and the Restaurant Table Effect. Agricultural Economics. 37, 211-218.

Grammatikopoulou, I., Iho, A., Pouta, E., 2012. Willingness of farmers to participate in agri-environmental auctions in Finland. Food Economics. 9 (4), 215-230.

Barreiro-Hurlé, J., Espinosa-Goded, M., Dupraz, P., 2010. Does intensity of change matter? Factors affecting adoption of agri-environmental schemes in Spain. Journal of Environmental Planning and Management. 53 (7), 891-905.

Hynes, S., Garvey, E., 2009. Modelling Farmers' Participation in an Agri-environmental Scheme using Panel Data: An Application to the Rural Environment Protection Scheme in Ireland. Journal of Agricultural Economics. 60 (3), 546-562.

Ingram, J., Gaskell, P., Mills, J., Short, C., 2013. Incorporating agri-environment schemes into farm development pathways: A temporal analysis of farmer motivations. Land Use Policy. 31, 267-279.

Jongeneel, R., Polman, N., Slangen, L.H.G., 2008. Why are Dutch farmers going multifunctional? Land Use Policy. 25 (1), 81–94.

Kristensen, S.P., Thenail, C., Kristensen, L., 2001. Farmers´ involvement in landscape activities: An analysis of the relationship between farm location, farm characteristics and landscape changes in two study areas in Jutland, Denmark. Journal of Environmental Management. 61 (4), 301-318.

Lowe, P., Cox, P., 1990. Technological Change, Farm Management and Pollution Regulation: The Example of Britain. In Technological Change and the Rural Environment (p.53-80), edited by Lowe P., Marsden, T., Whatmore S., London: David Fulton.

Mann, S., 2005. Farm Size Growth and Participation in Agri-environmental Schemes: A Configural Frequency Analysis of the Swiss Case. Journal of Agricultural Economics 56 (3), 373-384.

Mathijs, E., 2003. Social capital and farmers' willingness to adopt countryside stewardship schemes. Outlook on Agriculture. 32 (1), 13-16.

Mettepenningen, E., Vandermeulen, V., Delaet, K., Van Huylenbroeck, G., Wailes, E.J., 2013. Investigating the influence of the institutional organization of agri-environmental schemes on scheme adoption. Land Use Policy 33, 20-30.

Morris, C., Potter, C., 1995. Recruiting the New Conservationists: Farmers' Adoption of Agri-environmental Schemes in the U.K. Journal of Rural Studies. 11 (1), 51-63.

Ozanne, A., Hogan, T., Colman, D., 2001. Moral hazard, risk aversion and compliance monitoring in agri-environmental policy. European Review of Agricultural Economics 28 (3), 329-347.

Pascucci, S., de-Magistris, T., Dries, L., Adinolfi, F., Capitanio, F., 2013. Participation of Italian farmers in rural development policy. European Review of Agricultural Economics 40 (4), 605-631.

Polman, N.B.P., Slangen, L.H.G., 2008. Institutional design of agri-environmental contracts in the European Union: the role of trust and social capital. Wageningen journal of life sciences 55 (4), 413-430.

Skerratt, S., 1998. Socio-economic evaluation of UK agri-environmental policy: lessons from an ESA case study. In: Jacques Brossier, Barry Dent, dir., Gestion des exploitations et des ressources rurales. Entreprendre, négocier, évaluer (p. 317-331). Etudes et Recherches sur les Systèmes Agraires et le Développement (31). INRA Edition, Versailles, France.

Sutherland, L.A., Darnhofer, I., 2012. Of organic farmers and 'good farmers': Changing habitus in rural England. Journal of Rural Studies 28 (3), 232-240.

Unay Gailhard İ., Bavorová M., Pirscher F., (in press). Adoption of Agri-Environmental Measures by Organic Farmers: The Role of Interpersonal Communication. The Journal of Agricultural Education and Extension.

Vanslembrouck, I., Van Huylenbroeck, G., Verbeke, W., 2002. Determinants of the Willingness of Belgian Farmers to Participate in Agri-environmental Measures. Journal of Agricultural Economics 53 (3), 489-511.

Warriner, G. K., Moul, T. M., 1992. Kinship and Personal Communication Network Influences on the Adoption of Agriculture Conservation Technology. Journal of Rural Studies 8 (3), 279–291.

Wauters, E., Bielders, C., Poesen, J., Govers, G., Mathijs, E., 2010. Adoption of soil conservation practices in Belgium: An examination of the theory of planned behavior in the agri-environmental domain. Land Use Policy 27 (1), 86-94.

Wilson, G.A., 1997. Factors Influencing Farmer Participation in the Environmentally Sensitive Areas Scheme. Journal of Environmental Management 50 (1), 67-93.

Wilson, G.A., Hart, K., 2000. Financial imperative or conservation concern? EU farmers`motivations for participation in voluntary agri-environmental schemes. Environment and Planning 32 (12), 2161-2185.

Wossink, G.A.A., van Wenum, J.H., 2003. Biodiversity conservation by farmers: analysis of actual and contingent participation. European Review of Agricultural Economics 30 (40), 461-485.

Wynn, G., Grabtree, B., Potts, J., 2001. Modelling Farmer Entry into the Environmentally Sensitive Area Schemes in Scotland. Journal of Agricultural Economics 52 (1), 65-82.

Sustainability considerations in the event industry sector: a literature analysis

Sara Toniolo[1], Anna Mazzi[1], Lorianna Lazzarin[1], Chiara Pieretto[1], Antonio Scipioni[1*]

[1] *CESQA University of Padova, Department of Industrial Engineering, Via Marzolo 9, 35131 Padova, Italy*

* Corresponding author: tel.: +390498275539; fax: +390498275785. E-mail address: scipioni@unipd.it

Abstract

In the last years, the sustainable management of events has attracted the attention in the international debates leading the event industry to become more conscious about the impacts associated with its processes. The impact assessment, indeed, should be part of the planning process for any event taking into consideration social responsibility, marketing, public relations and the environment. The recognition of the importance of sustainability in the event industry is also confirmed by the recently published ISO 20121:2012 "Event Sustainability Management Systems - Requirements with guidance for use". Nevertheless, some researchers in the last years highlighted the need of academic research with particular focus on event management and the related impacts.

Thus, in this context, the aim of this study is to investigate how the academic research has investigated the event industry in terms of event sustainability in the period 2009-2013.

The method of investigation is the analysis of the scientific literature using an online information service platform provided by Elsevier (www.sciencedirect.com) as database. The selection of the literature was carried on limiting the investigation to papers published in journals and written in English. Books, book reviews and editorials were not included in the assessment, because outside the scope of the research. Five papers were considered suitable for the conduction of this study and the following key elements were analysed: year of publication, geographical origin of the research groups, type of events analysed (sport events, touristic events), type of research (case study application or theoretical study), components of the sustainability investigated, presence of a reference to ISO 20121 Standard.

Four out of the five papers selected were published between 2009 and 2012 (the year of publication of ISO 20121), two out of the five papers were written by European research groups and the events analysed are mainly sport and touristic events. Three papers present a case study application, whereas two present theoretical issues with an exploration of key elements and challenges. Only two papers take into consideration all of the components of sustainability, whereas the other three are mainly focused on environment and just one of the selected papers contains a reference to ISO 20121 Standard.

This study represents a first step to explore how the issue of event sustainability is investigated in the academic literature and confirms that, in the database used for the analysis, there is a growing need of scientific literature in this topic. A further development of this study will extend the database of the literature analysis, including other scientific platforms to obtain a clearer picture.

Keywords: event sustainability, research agenda in sustainable events, ISO 20121, bibliographical survey

Introduction

The volume of event and festival around the world has reached overwhelming levels (Case, 2013). In Europe, exhibitions and events are considered service activities characterized by a significant economic impact (Núñez et al., 2009). 2181 exhibitions were organized in 2013 involving 625 organizers, a total of 601323 exhibitors, 60.5 million visitors and 22.1 million square metres of rented space (UFI, 2014). In particular, one of the main European countries involved in this sector is Italy, with France, Germany, Poland, Spain and Turkey (UFI, 2012). This sector by definition deals with the production and management of any type of organized events, from scientific or cultural conferences, to major sporting events (ENEA, 2011). One of the main tasks, for example, of exhibitions is to give the opportunity to share information and manufacturing problems by involving companies, visitors and buyers and by organizing pavilions to operate more effectively (Yoon et al., 2012). The visualization of the idea is of primary interest (Demir, 2012), with the business outcomes of participants (Yoon et al., 2012) and the brand concept communication (Camamero et al., 2010).

Several studies have been conducted in the field of event management (Getz, 2008). A study was carried out to identify a list of determinants for the service quality as perceived by attendees such as booth management, content, registration, access, booth layout and function (Chen and Mo, 2012). Other studies supported the key role of events in increasing tourism flows (Della Lucia, 2013) or were focused on the prediction of the daily visitor attendance during festivals (Su et al., 2014). Often the impact of an event is linked to the economic effect that the event itself entails and this is confirmed by the conduction of several studies published for almost forty years (Della Lucia, 2013). In addition, a method has also been developed to classify and quantify the costs of the local government as a consequence of hosting special events (Chirieleison and Montrone, 2013).

However, closer analyses highlighted the need to focus also on social and environmental issues (de Moraes Sarmento Ferreira 2014; Prayag et al., 2013). Indeed, some studies have been conducted to investigate topics such as social integration and the development or preservation of tradition and the effects on residents at local level (Fleischer et al., 2013). Other studies have focused on the production of waste, the utilization of non-reusable stands and the disassembly of temporary structures (Núñez et al., 2009; Vinodh et al., 2012; Ekvall et al., 2007). In addition, operational performance indicators have been calculated for waste management at festivals (Cierjacks et al., 2012) and the carbon footprint of spectator and team travel of small-scale university events has been analysed (Dolf and Teehan, 2014).

Several organizations of the event sector have recognized the importance to consider the consequences of their activities and thus the issue of sustainability is acquiring, on a global scale, more and more importance because of the increased interest and the common awareness towards the consequences of the event itself (ENEA, 2011). Furthermore, the recognition of the importance of sustainability in the event industry was also confirmed by the recently published ISO 20121:2012 "Event Sustainability Management Systems - Requirements with guidance for use". This standard, developed by the event industry working within the ISO project committee ISO/PC 250, Sustainability in event management, specifies the requirements of an event sustainability management system and is applicable to all types and sizes of organizations involved in the design and delivery of events and accommodates (ISO, 2012a,b).

Thus, even if event studies have increased (Getz et al., 2008) and the attention of the event industry on sustainability have grown (ISO, 2012a) some researchers in the last years highlighted the need of academic research with particular focus on event management and the related impacts (Jin et al., 2012). Thereby, as the role of research in sustainable event management is no doubt of interest to the managers of cultural institutions and exhibitions, this study addresses the sustainable event management, with the aim to analyse how the academic research has investigated the event industry in terms of sustainability in the period 2009-2013.

Materials and methods

The method of investigation was the analysis of the scientific literature using an online information service platform provided by Elsevier (www.sciencedirect.com) as database.

This study was structured in four steps as described in Table 1. The first step was a selection of the literature carried out limiting the investigation to academic papers concerning event sustainability published in scientific journals and written in English, namely in the period 2009-2013. Books, book reviews and editorials were not included in the assessment, because outside the scope of the research. The second step was the identification of specific papers about event sustainability. Through these steps five papers were selected and analysed with focus on geographical origin of the research groups, type of events (sport events, touristic events), type of research (case study application or theoretical study), components of the sustainability investigated, presence of a reference to ISO 20121 Standard. The third step was the analysis of application of key research questions related to event sustainability. The research agenda proposed by Getz, 2008 was considered a suitable starting point for this step because it suggested some key research questions embracing personal, social, cultural, economic and environmental issues (Table 2). The selected studies were then analysed investigating how they faced the selected key questions. Thus, finally, the fourth step was the analysis of the selected papers to investigate how the issues identified by ISO 20121:2012 (Table 3) were addressed. ISO 20121 provides a framework for identifying the potentially social, economic and environmental impacts of events with a management system approach similar to other common Standards (ISO, 2012a). The main requirements concern: understanding of the organization and its context; understanding the needs and expectations of interested parties; actions to address risk and opportunities; event sustainability objectives and how to reach them; communication.

Table 1 Method of investigation

Research steps	Database used to conduct the step	Type of analysis	Aim of the research step
I. Selection of recent scientific papers related to event sustainability	Scientific database (www.sciencedirect.com)	Documental survey of papers published in scientific journals during the period 2009-2013	Search of terms “event and/or sustainability” in title, abstract, keywords and text
II. Analysis of recent	All the papers selected in the step	Analysis of title,	Identification of specific papers

scientific papers related to event sustainability	I	abstract, keywords and text	concerning event sustainability, with focus on country, type of event, sustainability component, method of investigation
III. Analysis of application of key research questions related to event sustainability	All the papers identified in the step II and the research agenda proposed by Getz (2008)	Analysis of the text	Investigate the interest in the key research questions of Table 2.
IV. Analysis of application of the issues identified by ISO 20121:2012	All the papers identified in the step II and the issues identified by ISO 20121 (2012)	Analysis of the text	Investigate how the issues presented in ISO 20121 (Table 3) are applied

Table 2 Main key research questions for the investigation of sustainability in the event sector (Getz, 2008)

Key research questions	
1	How do people describe and explain why event tourism experiences are satisfying, memorable or transforming?
2	What are the personal and social consequences of negative event tourism experiences?
3	What performance measures exist and are needed for the social, cultural and environmental policy domains?
4	How does exchange theory influence various stakeholder perceptions of event impacts?
5	How are social representations of events formed?
6	How does the nature and extent of community involvement influence event tourism success and outcomes?
7	How are the benefits and costs of events tourism distributed through the population? What strategies work best for maximizing local economic benefits?
8	Who are the high-yield event tourists, and how should they be attracted?
9	How can events and event tourism be made more sustainable?
10	What are the cumulative impacts of an event and events in general, within a community or ecosystem?

Table 3 Issues identified in ISO 20121 (ISO, 2012b)

Environmental issues	Social issues	Economic issues
Resource utilization	Labour standards	Return on investment
Materials choice	Health and safety	Local economy
Resource conservation	Civil liberties	Market capacity
Emissions reduction	Social justice	Shareholders value
Biodiversity and nature preservation	Local community	Innovation
Releases to land, water and air	Indigenous rights	Direct and indirect economic impact
	Cultural issues	Market presence
	Accessibility	Economic performance
	Equity	Risk
	Heritage	Fair trade
	Religious sensitivities	Profit sharing

Results

The papers considered suitable for the conduction of the research are presented in Table 4 with general elements such as geographical origin of research groups, type of event analysed, sustainability components investigated and method of investigation. Four out of five papers were published between 2009 and 2012. Two out of five papers were written by European research groups and the events analysed were mainly sport events. Furthermore, two papers took into consideration all of the components of sustainability, whereas the other three were mainly focused on environment and just one of the papers selected contained a reference to ISO 20121 Standard. Three papers presented a case study application, whereas two presented theoretical issues with an exploration of key elements and challenges. Collins et al. (2009) estimated the ecological footprint and applied the environmental input-output modelling. Andersson and Lundberg (2013) estimated the direct expenditure and the opportunity cost for the calculation of the economic impact, the option, bequest and existence values for the socio-cultural aspects, the ecological footprint and carbon emissions for the assessment of the environmental issues. Dickson and Arcodia (2010) investigated the role of professional associations gathering information published on websites. Whereas Laing and Frost (2010) considered some of the challenges involved in incorporating green messages into an event theme and Mallen and Chard (2012) framed a vision about sustainability in sport facilities.

Table 4 Selected papers for the conduction of this study

Paper	Journal	Country of the research group	Type of event	Sustainability Component	Method of investigation
Collins et al., 2009	Tourism Manage.	UK	Sport event	Environment	Case study
Laing and Frost, 2010	Int. J. Hosp. Manag.	Australia	Events in general	Environment	Literature analysis
Dickson and Arcodia, 2010	Int. J. Hosp. Manag.	Australia	Events in general	Economy, society, environment	Survey
Mallen and Chard, 2012	Sport Management Review	Canada	Sport events in general	Environment	Literature analysis
Andersson and Lundberg, 2013	Tourism Manage.	Sweden	Music event	Economy, society, environment	Case study

The combination of the research agenda proposed by Getz (2008) and the main topics addressed in the selected papers revealed that the research question about performance measure was investigated with quantitative analyses in two papers. The ecological footprint and the environmental input-output modelling were applied to calculate the impact of two sporting events, highlighting however difficulties in accounting event-related consumption, limitation of the analysis in some cases and difficulties in data collection (Collins et al., 2009). On the other hand, Andersson and Lundberg (2013) calculated the ecological footprint and greenhouse gases emissions associated with a music event, besides the economic and the socio-cultural impact; finally, they measured these impacts in monetary terms, giving an answer also to question about impacts on ecosystem and community. On the other hand question about sustainability suggestions was addressed by three papers. Laing and Frost (2010) explored the participation of key stakeholders and operational issues; Dickson and Arcodia (2010) discussed the role of professional association in promoting sustainability by highlighting the need of accreditation program within the industry, guidelines and policies; whereas Mallen and Chard (2012) presented several goals to reach better environmental performances in sport facilities.

The combination of the issues identified by ISO 20121 and the main elements considered in the selected papers revealed the following considerations. Collins et al. (2009) took into account travel to and from the event of visitors, food and beverage consumed, waste generated and infrastructure for the calculation of the ecological footprint; whereas works needed on roads for the event, energy and water consumption, besides spectators' travel were included in the environmental input-output modelling. However, Andersson and Lundberg (2013) considered the direct expenditure that festival visitors incurred and the opportunity cost related to the amount of money that would have been spent by visitors in the region even if the festival had not taken place. In addition, they took into account social issues measuring residents' perceived value of the opportunity to visit the event, of provision of entertainment for the younger generations and of the effect that the event had on the image of the city. The environmental impacts were assessed considering energy use, transport of visitors, logistic and local transport, waste, consumption of food and lodging and surface used for the festival. On the other hand, in the literature analysis elaborated by Laing and Frost (2010) a number of operational issues were highlighted, such as accessibility to public transport, waste management, availability of green power and carbon offset and more efficient logistic. In the literature analysis of Mallen and Chard (2012), instead, the proposed goals for the improvement of the environmental profile of sport facilities were linked to energy savings, recycling activities, reductions of air and water emissions and biodiversity.

Discussion and conclusion

According to Getz (2008), event studies are still in the early stage of development and there is a great scope of advances even if it has been recognized that environmental and social issues have been neglected in the industry event sector. On the other hand, all of the papers selected for this study deal with environmental issues; whereas only two papers take into consideration the three components of sustainability including social and economic aspects.

The increasing interest of the event industry in sustainability should be supported by a research agenda able to understand the various aspects of this particular sector. In line with this vision, in this study a research agenda of the tourism event sector was identified, namely the research agenda proposed by Getz (2008) and successively it was adopted to investigate how the academic research has investigated the event industry in terms of sustainability. The results obtained show that questions about performance measure, about sustainability suggestions and about impacts on ecosystem and community are mainly investigated in the selected papers. In addition, this study reveals that the questions about the social issues are seldom considered, even if in the literature a specific study was conducted (Prayag et al., 2013). However, even if two out of five researches highlight the need of a research agenda as an important point for the development of these topics, they do not specifically refer to the research questions proposed by Getz (2008).

Furthermore, in this study the sustainability issues presented in the ISO 20121 were taken into consideration and adopted to investigate the selected papers. This analysis reveals that the application of these issues is seldom uniform. Collins et al. (2009) focused on transport, emissions, venue, waste, supply chain, food consumption; Laing and Frost (2010) explore accessibility, energy, waste and transport; Mallen and Chard (2012) propose objectives about energy, recycling, emissions, water and biodiversity. Andersson and Lundberg (2013) investigate economic impact, local community, energy, transport, waste, food, lodging and the surface used for the event.

In conclusion, through this study an investigation was performed about a research agenda for the sustainability in the event sector and about the sustainability issues presented in the ISO 20121. This analysis revealed that there is no uniformity in the investigation of sustainability in the selected papers: there are no common key research questions even if a research agenda have been proposed; and there is seldom a wide identification of sustainability issues.

This study represents a first step to explore how the issue of event sustainability is investigated in the academic literature and confirms that, in the database used for the analysis, there is a growing need of scientific literature in this topic. A further development will extend the database of the literature analysis, including other scientific platforms to obtain a clearer picture.

References

Andersson, T. D., Lundberg, E., 2013. Commensurability and sustainability: Triple impact assessments of a tourism event. Tourism Manage. 37, 99-109.

Camamero, C., Garrido, M.J., Vicente, E., 2010. Components of art exhibition brand equity for internal and external visitors. Tourism Manage. 31, 495 – 504.

de Moraes Sarmento Ferreira, E.M.M., 2014. Book review Events and the Environment, R. Case (Ed.). Routledge, New York, London (2013). Tourism Manage. 42, 341.

Case, R., 2013. Events and the environment, first ed. Routledge, New York, London.

Chen, Y-F., Mo H-e., 2012. Attendees' perspectives on the service quality of an exhibition organizer: A case study of a tourism exhibition. Tourism Management Perspectives 1, 28-33.

Chirieleison, C., Montrone, A., 2013. Evaluating local government costs and revenues: The case of an Italian privately owned for-profit event. Tourism Management Perspectives 8, 90-97.

Cierjacks, A., Behr, F., Kowarik, I., 2012. Operational performance indicators for litter management at festivals in semi-natural landscapes. Ecol. Indic. 13, 328-337.

Collins, A., Jones, C., Munday, M., 2009. Assessing the environmental impacts of mega sporting events: Two options? Tourism Manage. 30, 828-837.

Della Lucia, M., 2013. Economic performance measurement systems for event planning and investment decision making. Tourism Manage. 34, 91-100

Demir, C., 20121. Graphic design for a permanent exhibition: exhibition design of the Museum Mimar Kemaleddin. Procedia – Social and Behavioral Sciences 51, 495 – 500.

Dickson, C., Arcodia, C., 2010. Promoting sustainable event practice: The role of professional associations. Int. J. Hosp. Manag. 29, 236–244.

Dolf, M., Teehan, P., 2014. Reducing the carbon footprint of spectator and team travel at the University of British Columbia's varsity sports events. Sport Management Review http://dx.doi.org/10.1016/ j.smr.2014.06.003

Ekvall, T., Assefa, G., Björklund, A., Eriksson, O., Finnveden, G., 2007. What life-cycle assessment does and does not do in assessments of waste management, Waste Manage. 27, 989-996.

ENEA, 2011. I Green Meeting per la sostenibilità ambientale degli eventi, XVII Rapporto sul turismo italiano, 2010-2011.

Fleischer, M., Fuhrmann, M., Haferburg, C., Krüger, F., 2013. "Festivalisation" of urban governance in South African Cities: framing the urban social sustainability of mega-event driven development from below. Sustainability 5, 5225-5248.

Getz, D., 2008. Event tourism: definition, evolution, and research. Tourism Manage. 29, 403-428.

ISO, 2012a. Sustainable events with ISO 20121. ISO Central Secretariat Genève, Switzerland.

ISO, 2012b. "Event Sustainability Management Systems - Requirements with guidance for use". Genève, Switzerland.

Jin. X., Weber, K., Bauer, T., 2012. Relationship quality between exhibitors and organizers: A perspective from Mainland China's exhibition industry. Int. J. Hosp. Manag. 31, 1222– 1234

Laing, J., Frost, W., 2010. How green was my festival: Exploring challenges and opportunities associated with staging green events. Int. J. Hosp. Manag. 29, 261-267.

Mallen, C., Chard, C., 2012. ''What could be'' in Canadian sport facility environmental sustainability. Sport Management Review 15, 230-243.

Núñez, M., García-Lozano, R., Boquera, P.,, Gabarrell, X., Rieradevall, J., 2009. Temporary structures as a generator of waste in covered trade fairs. Waste Manage. 29, 2011–2017.

Prayag, G., Hosany, S., Nunkoo, R., Alders, T., 2013. London residents' support for the 2012 Olympic Games: The mediating effect of overall attitude. Tourism Manage. 36, 629-640.

Su, A-T., Cheng, C-K., Lin, Y-J., 2014. Modeling daily visits to the 2010 Taipei International Flora Exposition. Urban Forestry & Urban Greening http://dx.doi.org/10.1016/j.ufug.2014.07.001

Vinodh, S., Nachiappan, N., Praveen Kumar, R., 2012. Sustainability through disassembly modeling, planning, and leveling: a case study. Clean Techn. Environ. Policy 14, 55–67.

UFI, The global association of the exhibition industry, 2012. Euro Fair Statistics.

UFI, The global association of the exhibition industry, 2014. Euro Fair Statistics.

Yoon, K-K., Lim S-S., Park M-N., 2012. Impact of Pavillon Quality on Exhibitor Performance at an International Trade Exhibition. Procedia – Social and Behavioral Sciences 40, 681 – 688.

Benefits and limits of the Environmental Management System: the opinion of the Italian Organizations

Anna Mazzi[1], Caterina Vecchiato[1], Filippo Zuliani[1], Sara Toniolo[1], Antonio Scipioni[1*]

[1] *CESQA University of Padova, Department of Industrial Engineering, Via Marzolo 9, 35131 Padova, Italy*

* *Corresponding author: tel.: +390498275539; fax: +390498275785. E-mail address: scipioni@unipd.it*

Abstract

In the last years one of the most fundamental changes affecting policy makers has undoubtedly been the adoption of the concept of sustainable development.

In response to this new tendency, most countries have adopted new regulations and economic instruments, as environmental taxes, rebate schemes and tradable pollution permits, while many organizations have adopted environmental policies and carried out environmental management tools, such as the Environmental Management System (EMS). An EMS is a transparent, systematic process, with the purpose of prescribing and implementing environmental goals, policies and responsibilities, as well as a regular auditing of its elements.

The international standard to develop an environmental management system is the ISO 14001. In scientific literature, the adoption of an ISO 14001 helps companies to reduce their environmental incidents and liabilities, increase efficiency of operations by removing waste from production and distribution process, increase awareness of environmental impacts of operations among all employees, and establish a strong image of corporate social responsibility.

Over the past 10 years, the University of Padua in collaboration with the Italian Competent Body (ACCREDIA, previously SINCERT) conducted a series of surveys of Italian organizations certified ISO 14001, to know their opinion about difficulties and utility in the ISO 14001 requirements application. The survey involved all types of organizations (public and private organizations, from different industrial and services sectors) through an online questionnaire sent by e-mail.

Analysis of the results shows how, over the years, organizations demonstrate a growing awareness about the usefulness and benefits of the ISO 14001 certification. Italian organizations deem the following requirements of ISO 14001: identification of legal requirements, competence, training and awareness, management of operational control, preparation and emergency response, monitoring and measurement, assessment of compliance, management review. At the same time, the organizations consider as most difficult requirements the following: identification of legal requirements, sourcing of resources, competence, training and awareness, management of operational control, assessment of compliance. We analyzed the responses also according to type of organization (SME or large enterprise, public or private organization, and so on): there are no substantial differences.

In conclusion, Italian ISO 14001 certified organizations find it useful to have an EMS, in particular as regards to manage significant environmental aspects, to assess environmental performance management and to assure legal compliance. Italian organizations also recognize that these are also the most complex steps to develop an EMS. These considerations confirm but also enrich what is already know in the literature, going over the results obtained from similar surveys in other countries.

Keywords

Environmental management system, ISO 14001 certification, survey, Italian organizations

1. Introduction

In the last years, the adoption of sustainable development concept has been affecting policy makers and markets. Most countries have adopted new regulations and economic instruments to support environmental sustainability, as environmental taxes, rebate schemes and tradable pollution permits.

At the same time, many organizations have adopted environmental policies and carried out environmental management tools such as the Environmental Management System (EMS).

An EMS can be defined as an aspect of an organisation's overall management function that determines and implements organisation's environmental policy; it is a transparent, systematic process with the purpose of prescribing and implementing environmental goals, policies and responsibilities, as well as a regular auditing of its elements.

ISO14001 is the international standard with requirements and guidelines related to environmental management system. Approved in 1996 and then revised in 2004, it offers a format for developing an environmental policy, identifying environmental aspects, defining environmental objectives and targets, implementing a program to attain a company's environmental goals, monitoring and measuring effectiveness, correcting deficiencies and problems, and reviewing management system to promote continuous improvement of organization's environmental performances (Vivian, 1998; Rondinelli et al, 2000).

Like many ISO standards, ISO14001 is voluntary; there are no legal requirements to certify. All around the world diffusion of ISO 14001 certifications records important achievements, spreading a consistent and continuous increase during the years both in number of certificated organizations and in number of countries that have issued this certification (ISO, 2013). As number of ISO14001 certificates, Italy is the second country in the world and the first in Europe (ISO, 2013).

The success of this standard is due to several factors. ISO 14001 certification helps companies to reduce their environmental incidents and liabilities, increase efficiency of operations by removing waste from production and distribution process, increase awareness of environmental impacts of operations among all employees, and establish a strong image of corporate social responsibility

(Vivian, 1998; Rondinelli et al, 2000; Zutshi and Sohal, 2004-a).

Firms are using ISO14001 requirements for numerous reasons, such as:

- assurance of regulatory compliance (Bansal et al, 2002; Sharfman and Fernando, 2008; Lopez-Gamero et al, 2010);
- improvement of environmental performances (Bansal et al, 2002; Fryxell, 2002; Morrow and Rondinelli, 2002; Raines, 2002; Iraldo et al, 2009);
- support of the strategic business goals (Kitazawa et al, 2000; Zutshi and Sohal, 2004-a; Wagner, 2008);
- increase of market success (Darnall et al, 2010; Pereira-Moliner et al, 2012);
- response to customers and stakeholders pressures (Miles and Covin, 2000);
- increase of innovation processes and products (Ammenberg and Suntin, 2005; Frondel et al, 2008; Wagner, 2008; Iraldo et al, 2009).

However, many authors complain about the difficulty on organizations to understand the critical factors for a successful implementation of ISO14001, as well as the benefits and limits that would be brought to them by ISO14001 (Gavronski et al, 2008; Iraldo et al, 2009; Heras-Saizarbitoria et al, 2011).

This research aims to investigate the awareness of Italian organizations certified to ISO14001 about the benefits and difficulties of adopting an EMS, and to compare the Italian organizations opinion with that in other countries around the world.

3. Research goals and research methodology

The research, conducted in Italy between 2004 and 2013 by the University of Padua in collaboration with the Italian Competent Body (ACCREDIA, previously SINCERT), aims to analyze what is the perception of benefits and difficulties of the EMS of Italian ISO 14001 certified organizations. The research goals are the following:

- Investigate whether the Italian organizations are able to quantify the benefits and limits deriving from their EMS;
- Investigate what are for the Italian organizations the main benefits deriving from an EMS
- Investigate what are for the Italian organizations the main difficulties adopting an EMS
- Investigate if the opinions of Italian organizations are similar to the results emerging from the literature

The research methodology chosen is a periodic survey conducted every two or three years addressed to the Italian ISO 14001 certified organizations (public and private organizations, of different industrial and services sectors) through an online questionnaire sent by e-mail.

The same questionnaire was adopted in the surveys, in order to allow a comparison between the organizations responses over the years. The items investigated by the survey are the following:

a. General information of the organization;

b. Organization's ability to quantify the benefits and limits of its EMS;
c. Main benefits obtained from the EMS;
d. Main limits derived from the EMS.

To investigate these items, ad-hoc multiple-choice questions are formulated, as listed in table 1.

Table 1: Items of the periodic survey and related multiple-choice questions.

Survey item	Questions	Multiple-choice answers
a. General information of the organization	a.1 What are the name and references of your organization?	a.1 Free answer
	a.2 What is the type of your organization?	a.2-1 Public sector a.2-2 Private sector
	a.3 What is the organization's dimension?	a.3-1 Small-medium organization a.3-2 Large organization
b. Organization's ability to quantify the benefits and limits of its EMS	b.1 Is your organization able to quantify benefits and limits due to the ISO14001 certification?	b.1-1 Yes b.1-2 No
c. Main benefits obtained from the EMS	c.1 How much useful are the individual ISO14001 requirements? (*)	c.1-1 Useless c.1-2 Not very useful c.1-3 Quite useful c.1-4 Very useful
d. Main limits derived from the EMS	d.1 How much difficult is to satisfy the individual ISO14001 requirements? (*)	d.1-1 Very difficult d.1-2 Quite difficult d.1-3 Quite easy d.1-4 Very easy

(*) the question is related to the following ISO14001 requirements: Environmental policy (4.2); Environmental aspects (4.3.1), Legal and other requirements (4.3.2), Objectives, targets and programme (4.3.3), Environmental roles and responsibilities (4.4.1), Resources, roles, responsibility and authority (4.4.1), Competence, training and awareness (4.4.2), Communication (4.4.3), Documentation (4.4.4), Control of documents and records (4.4.5 e 4.5.4), Operational control (4.4.6), Emergency preparedness and response (4.4.7), Monitoring and measurement (4.5.1), Evaluation of compliance (4.5.2), Nonconformity, corrective and preventive actions (4.5.3), Internal audit (4.5.5), Management review (4.6)

Results

Five surveys we conducted from 2004 and 2013 within an increasing number of involved organizations, with a growing percentage of respondent organizations.

Table 2 presents the number of organizations involved in the survey during the years and a synthetic description of respondent organizations.

Organization's ability to quantify the benefits and limits of its EMS is growing in the years, as demonstrated in Table 3. It is notable that not only large organizations but also small-medium (SMEs) improve this ability during the years. However, more than half of the organizations is not able to quantify the benefits of its EMS; this difficulty is more evident for public organizations.

Table 2: General information of Italian organizations involved in the periodic surveys

Year of the survey	N° of organizations involved in survey	% of respondent organizations	% of private companies in respondent	% of SME in respondent organizations

			organizations	
2004	627	16.7%	91%	79%
2006	917	8.9%	96%	85%
2008	2109	10.5%	89%	82%
2010	5308	10.3%	84%	84%
2013	5608	15.0%	93%	82%

Table 3: Organization's ability to quantify benefits and limits of the EMS

Year of the survey	% of respondent organizations able to quantify benefits and limits of EMS	% of private companies able to quantify benefits and limits of EMS	% of public organizations able to quantify benefits and limits of EMS	% of SME organizations able to quantify benefits and limits of EMS	% of large organizations able to quantify benefits and limits of EMS
2004	9.9%	10.3%	5.3%	8.3%	15.9%
2006	11.2%	11.4%	9.0%	10.5%	15.7%
2008	35.4%	37.2%	19.9%	40.3%	16.1%
2010	46.9%	46.6%	38.6%	46.9%	46.7%
2013	44.5%	46.3%	32.5%	43.4%	53.1%

The opinions of Italian organizations relating to the main benefits and limits of an EMS are rather homogeneous over the years. Synthetically we report numerical results regarding only of survey of 2013. As represented in Figure 1, the following items related to the adoption and maintenance of ISO 14001 certification are more important for respondent organizations: identification of legal requirements, competence, training and awareness, management of operational control, preparation and emergency response, monitoring and measurement, assessment of compliance, management review. At the same time, the Italian organizations consider as most difficult requirements the following items: identification of legal requirements, sourcing of resources, competence, training and awareness, management of operational control, assessment of compliance (figure 2).

Figure 1: Main benefits in implementing/maintaining the EMS

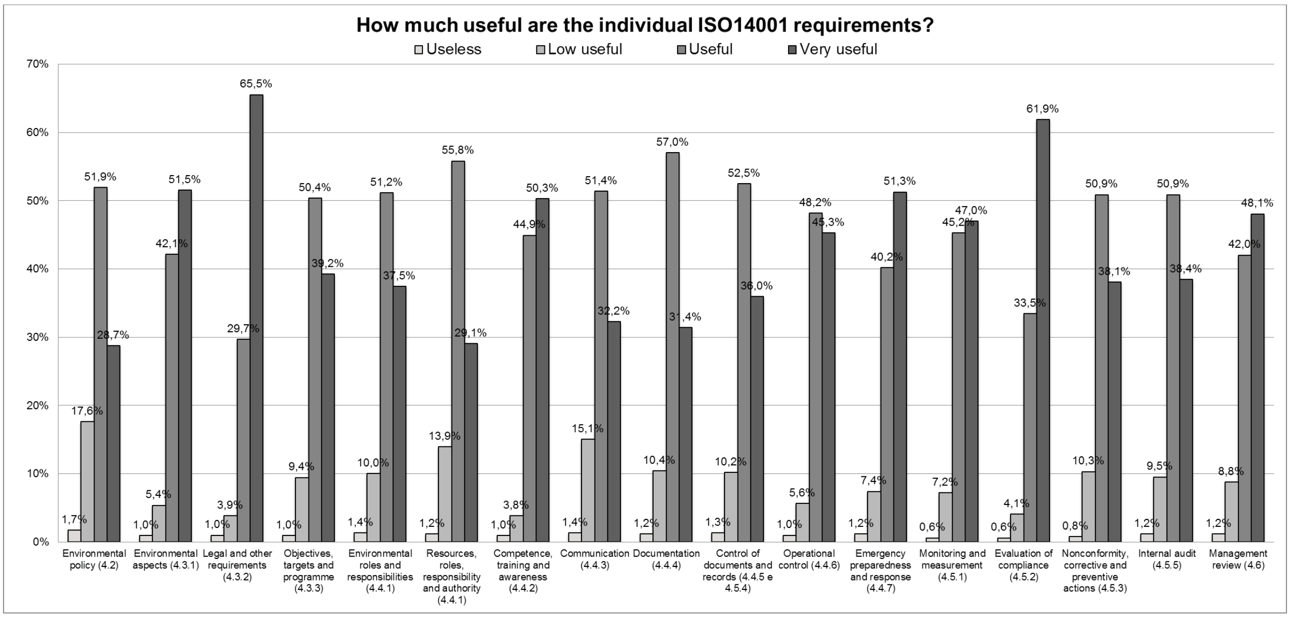
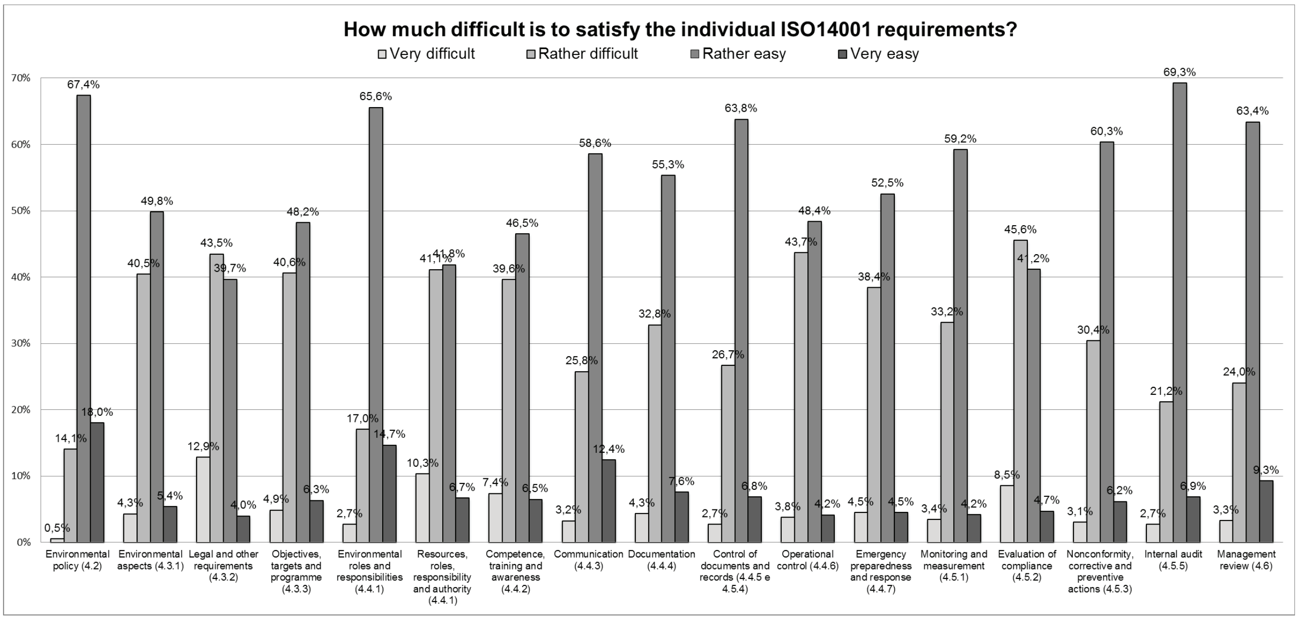


Figure 2: Main limits in implementing/maintaining the EMS



Discussion and conclusions

We can summarize the results of these Italian surveys in comparison with the results of other surveys conducted in recent years in different countries.

The surveys conducted in Italy during the last ten years demonstrate that the Italian organizations with an ISO14001 certified EMS have improved their ability to quantify benefits and limits of EMS; this is in according to Iraldo et al, 2009. This trend is confirmed both for private and public sector, and both large and SME organizations.

However, for many organizations is still difficult to quantify the benefits of an EMS, coeherently with the results of Zutshi and Sohal, 2004-a and 2004-b.

Especially in the public sector it is still difficult to quantify the benefits and limits of an EMS, confiming results of other surveys, as Lozano and Vallés, 2007 and Mazzi et al, 2012.

The most significant benefits for Italian organizations are related to the following requirements:

- legal compliance, according to the results of Bansal et al, 2002; Known et al, 2002; Zutshi and Sohal, 2004-a; Chan and Wong, 2006; Gavronski et al, 2008; Lopez-Gamero et al, 2010; Zeng et al, 2011,
- human resources management, according to Babakri et al, 2003; Zutshi and Sohal, 2004-b; Jabbour C.J.C et al, 2013;
- and performance monitoring, according to Balzarova and Castka, 2008; Frondel et al, 2008; Khan, 2013; Abad et al, 2014.

At the same time, all these items are considered the most difficult requirements to satisfy in ISO14001 certification process, partially according to Babakri et al, 2003 and De Oliveira et al, 2010.

In conclusion, we can summarize the results of this research in three statements:

1. More than 50% of Italian ISO14001 certified organizations has still difficulty in quantifying the benefits and limits of the EMS, especially in the public sector. This result is substantially coherent with many other studies in different countries.
2. For Italian ISO14001 certified organizations the EMS improves the awareness of legislative commitments and the ability to assess environmental performance. Similar results was obtain also from other authors, with similar or different researches.
3. For Italian ISO14001 certified organizations there is a relationship between difficulties and benefits of the standard requirements compliance. This statement is not found in other studies.

To extend this research, it would be interesting to investigate what are specific correlations between the answers, particularly related to the Italian survey conducted in 2013, with suitable statistical methods.

Aknowledgement

The authors thank: ACCREDIA, the Italian Accreditation Competent Body, for having approved and supported the research, all the Italian Certification Bodies for involving certified organizations, and all the organizations which participated in the initiative with their own valuable experience.

References

Abad J., Dalmau I., Vilajosana J., 2014. Taxonomic proposal for integration levels of management systems based on empirical evidence and derived corporate benefits. Journal of Cleaner Production, 78, 164-173.

Ammenberg J., Sundin E., 2005. Products in environmental management systems: drivers, barrier and ezperience. Journal of Cleaner Production, 13, 405-415.

Babakri K.A., Bennett R., Franchetti M., 2003. Critical factors for implementig ISO 14001 standard in United States industrial companies. Journal of Cleaner Production, 11, 749-752.

Balzarova M., Castka P., 2008. Underlying mechanism in the maintenance of ISO 14001 environmental management system. Journal of Cleaner Production, 16, 1949-1957.

Bansal P., Bogner WC., 2002. Deciding on ISO 14001: Economics, Istitutions, and Context. Long Range Planning, 35, 269-290.

Chan ESW., Wong SCK., 2004. Motivations for ISO 14001 in the hotel industry. Tourism Management, 27, 481-492.

Darnall, N., Henriques, I., Sadorsky, P., 2010. Adopting proactive environmental strategy: the influence of stakeholders and firm size. Journal of Management Studies, 47(6), 1072-1094.

De Oliveira O.J., Serra J.R. Salgado M.E., 2010. Does ISO 14001 work in Brazil?. Journal of Cleaner Production, 18(18), 1797-1806.

Frondel M., Horbach J., Rennings K., 2008. What triggers environmental management and innovation? Empirical evidence for Germany. Ecological Economics, 66, 153-160.

Fryxell GE., Szeto A., 2002. The influence of motivations for seeking ISO 14001 certification: an empirical study of ISO 14001 certified facilities in Hong Kong. Journal of Environmental Management, 65, 223-238.

Gavroski I., Ferrer G., Paiva E.L., 2008. ISO 14001 certification in Brazil: motivations and benefits. Journal of Cleaner Production, 16(1), 87-94.

study of ISO 14001 certified facilities in Hong Kong. Journal of Environmental Management, 65, 223-238.

Gavroski I., Ferrer G., Paiva E.L., 2008. ISO 14001 certification in Brazil: motivations and benefits. Journal of Cleaner Production, 16(1), 87-94.

Heras-Saizarbitoria, I., Molina-Azorín, J.F., Dick, G.P.M., 2011. ISO 14001 certification and financial performance: selection-effect versus treatment-effect. Journal of Cleaner Production, 19, 1-12.

Iraldo F., Testa F., Frey M., 2009. Is an environmental management system able to influence environmental and competitive performance? The case of the eco-management and audit scheme (EMAS) in the European union. Journal of Cleaner Production, 17, 1444-1452.

ISO, 2013. The ISO Survey of Management System Standard Certifications - 2012. Executive summary. International Organization for Standardization, ISO Central Secretariat. Available on line: http://www.iso.org/iso/iso_survey_executive-summary.pdf

Jabbour C.J.C., de Souza Jabbour A.B.L., Govindan K., Teixeira A.A., de Souza Freitas W.R., 2013. Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. Journal of Cleaner Production, 47, 129-140.

Khan Z., 2008, Cleaner production: an economical option for ISO certification in developing countries. Journal of Cleaner Production, 16, 22-27.

Kitazawa S, Sarkis J., 2000. The relationship between ISO 14001 and continuous source reduction programs. International Journal of Operations and Production Management, 20(2), 225–48.

Know D.M., Seo M.S., Seo Y.C., 2002. A study of compliance with environmental regulations of ISO 1401 certified companies in Korea. Journal of Environmental Management, 65, 347-353.

López-Gamero, M.D., Molina-Azorín J.F., Claver-Cortés E., 2010. The potential of environmental regulation to chenge managerial perspection, environmental management, competitiveness and financial performance. Journal of Cleaner Production, 18, 963-974.

Miles M.P., Covin J.G., 2000, Environmental marketing: a source of reputational, competitive and financial advantage. Journal of Business Ethics, 23(3), 299-311.

Morrow D., Rondinelli D., 2002. Adopting corporate environmental management system: motivations and result of ISO 14001 and EMAS certification. European Management Journal, 20(2), 159-171.

Pereira-Moliner. J., Claver-Cortés, E., Molina-Azorín J.F., Tarí, J.J., 2012. Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry. Journal of Cleaner Production, 37, 82-92.

Raines S.S., 2002. Implementing ISO 14001 – An international survey assessing the benefits of certification. Corporate Environmental Strategy, 9(4), 418-426

Rondinelli D., Vastag G., 2000. Panacea, common sense, or just a label? The value of ISO 14001 environmental management systems. European Management Journal, 18(5), 499-510.

Vivian B., 1998. Environmental management systems: asset or liability?. Eco-Management and Auditing, 3(3), 32–4

Wagner M., 2008, Empirical influence of environmental management on innovation: Evidence from Europe. Ecological Economics, 392-402.

Zeng, S.X., Meng, X.H., Zeng, R.C., Tam, C.M., Tam, V.W.Y., Jin, T., 2011. How environmental management driving forces affect environmental and economic performance of SMEs: a study in the Northern China district. Journal of Cleaner Production, 19, 1426-1437.

Zutshi A., Sohal A., 2004-a. Environmental management system adoption by Australasian organisations – part 1: reasons, benefits and impediments. Technovation, 24, 335-357.

Zutshi A., Sohal A., 2004-b. A study of the environmental management system (EMS) adoption process within Australasian organisation – Part 2: role of stakeholders. Technovation, 24, 371-386.

Analyzing city networks for the diffusion of environmental innovations: A study of five major Swedish cities

Santiago Mejía-Dugand*[1], Wisdom Kanda[1], Olof Hjelm[1]

[1]Environmental Technology and Management, Department of Management and Engineering, Linköping University. 581 83, Linköping, Sweden
* Corresponding author: Tel.: +46 13 285639; fax: +46 13 149403.
E-mail addresses: santiago.mejia.dugand@liu.se (S. Mejía-Dugand), wisdom.kanda@liu.se (W. Kanda), olof.hjelm@liu.se (O. Hjelm).

Abstract

This paper studies five Swedish municipalities, their memberships in international city networks, the different motivations to be members of them, and the expected and perceived benefits from doing so. A particular focus is put on sustainability, environmental technology, and municipal companies as potential beneficiaries of such memberships. This study is motivated by the fact that networks have been reported by literature to accelerate the diffusion of innovation, give members access to two-way information flows, improve the user-producer relationship and provide legitimacy in the potential recipient regimes. Using a documentation review and interviews with city officials responsible for international city networks, the conclusions relate to the active participation of the studied cities in international networks, but also to the large gaps between the two largest ones and the rest when it comes to the number of memberships and the geographical reach they have through the networks they belong to. Also, cities see benefits for their municipal companies when they belong to such networks, and these companies are usually independent when it comes to choosing and administering their memberships. It was found that the benefits from belonging to international networks are difficult to monitor and measure objectively, and that there is no apparent direct correlation between membership and diffusion of environmental solutions from municipal companies.

Keywords: Environmental Technology; Municipal Companies; Environmental Technology Diffusion; Sweden.

1. Introduction

The city has recently become a popular unit of analysis for scholars and researchers in many fields related to sustainability. This is in great part due to the fact that never before had humanity lived as concentrated as it does today. Although such condition has been driven among other things by the need to concentrate services and improve the reach of utilities and amenities, it has represented a tremendous impact on the surrounding environment and on the environmental services humans rely on in the first place.

In this line of thought, it is possible to understand the attention they are getting in the world agenda. By "world agenda," we mean not only a political one, but one that includes other components of the world's social dynamics, such as the economy and science, the environment, and even arts and leisure (see e.g. Keiner and Kim, 2007; Nicholls, 2008; The World Bank, 2010; UNHABITAT, 2012). In particular, the ever-changing characteristics of their dwellers are of interest. This is so because of the importance that this has on the way the city is seen and experienced, and especially on how decisions are made regarding the possible solution to their problems.

Since environmental technologies are considered to provide strong foundations for both environmental and economic sustainability (Kanda et al., 2013), the urban era represents tremendous opportunities for their diffusion. In this line of thought, cities that have historically enjoyed international visibility and that have reached advanced industrialization levels and made headway with their scientific advances are exploiting this condition, creating strategies and devoting important resources to promote their environmental technology expertise. Nevertheless, the difficulties of translating imaginaries of sustainability are becoming a concern for researchers, decision-makers and businesspeople alike. Hult (2013), for instance, highlights the difficulties that the Swedish government and its Trade Council (Business Sweden) have faced when trying to export their urban development concept by using a marketing tool called SymbioCity. Such difficulties rest on the fact that the holistic approach proposed with this tool is bounded to Swedish lifestyles and particular conditions that have facilitated the development and stability of these solutions at home. This can very well be a problem that many other technology providers face, since components of such solutions have grown in an orchestrated manner with local, coexisting systems and have developed tightly tied to them, something that Mejía-Dugand et al. (2013) also highlight.

In particular, innovations emerging at the municipal level (e.g. energy, and waste and wastewater management systems) face significant barriers in their diffusion. Municipal companies (e.g. utility companies) have been developing solutions and know-how through many years of administering their cities. This has led them with valuable knowledge and tremendous expertise. This in turn represents enormous opportunities for exploiting them from an economic perspective. However, municipal companies do not necessarily play on the same field as private companies, and thus must overcome different obstacles when thinking of benefitting from their knowledge (Kanda, 2014). For example, Kairento and Nygårds (2014) identified in their study of eleven cases of Swedish municipal companies barriers related to human resource constraints between foreign markets and local responsibilities, lack of knowledge about foreign markets and also the difficulties of marketing intangible service offerings. Municipality ownership also induces split political vs. market incentives in diffusion (Kairento and Nygårds, 2014). Swedish municipalities have been developing programs to attract international attention to their solutions, e.g. foreign delegations, conferences and field trips. However, such initiatives take a long time from participation to project realization. In addition, they have not had the expected results so far (Mejía-Dugand, 2013; Kanda, 2014).

It is commonly accepted in innovation theory that diffusion is facilitated by the creation and maintenance of personal connections (see e.g. Pedersen, 1970; Baptista, 2001; Simmie, 2003, Keiner and Kim, 2007). In this article, we suggest that by understanding and taking advantage of the local, regional and international positioning of a city or groups of cities, the process of diffusion of urban innovations can be facilitated. By becoming part of international city networks, cities can have access to knowledge that is collectively supported, maintained, nurtured and shared. Most importantly, and in line with the discussion presented above about the translation of urban imaginaries, city networks can provide legitimacy to its members, something that Kanda (2014) highlights as an essential requirement for the diffusion of environmental technologies, especially at the municipal level (cf. with private companies implementing environmental technologies based on market signals or providers' reputation). Benefits of making use of this knowledge include: entering a flow of incremental innovation that might accelerate forward the diffusion of the innovation (Cooke et al., 2002) and benefit from two-way information flows (Batten, 1995); pacify the competing logics in social and environmental innovations (Guy and Marvin, 1999); find key compatibility factors between the innovation and the regimes in rule and develop flexible and complementary/adaptive solutions (Batten, 1995; Mejía-Dugand et al., 2013); improve the user-producer relations (Cooke et al., 2002); and maximize the network value of an innovation (Cooke et al., 2002).

City networks can thus be particularly beneficial for the diffusion of environmental technologies from municipalities, who in the case of Sweden face several challenges and constraints, as mentioned above. Because of their nature, they often have other cities, governments or public-owned companies as customers, compared to often business-to-business (B2B) customers in the case of private companies. The aim of this study is therefore to understand the dynamics of city networks and how their members benefit from their membership in them. This is done by studying the five largest cities in Sweden and the networks they belong to. A special focus on learning and diffusion of knowledge about urban sustainability and environmental technologies is central. This aim is supported by the following research questions:

- Are large cities in Sweden active members of city networks for sustainability?
- What is the reach they have through the networks they are members of?
- Considering the competence that Swedish municipal companies have gained locally, how can they benefit from these networks to overcome barriers in their current diffusion approaches?

Competition between and among cities has shown to bring individual benefits in many cases. But has it really done the same for collective goals such as global sustainability? Can cities continue to build isolated and individual foundations for a sustainable future? Probably not, especially in a globalized context where humans, capital, goods and labor are highly free to move, stay or leave. Although Guy and Marvin (1999) mentioned that competing visions of sustainable cities emerge due to the diverse nature and composition of groups and collective goals aiming at sustainability, Keiner and Kim (2007) found that competition is less important when cities form networks for sustainability, since they all have the same goals. This is of particular importance when trying to understand the behavior of innovation diffusion for the solution of urban problems and the way in which knowledge is shared among the members of these networks.

2. Methodology

This study is a part of ongoing research focused on understanding the different drivers and barriers that municipalities and municipal companies face when they want to export their knowledge or their products to other cities. Through time, cities (represented by their citizens and municipal employees) accumulate enormous and valuable knowledge on how to solve problems that in many cases are shared by other municipalities around the globe. However, there are factors that influence these activities, both from the perspective of the developer and potential exporter, and from the perspective of the potential adopter.

Such drivers and barriers have been studied mainly through a set of interviews with city officials, managers from companies owned by different municipalities in Sweden, officials from the Swedish Trade Council (i.e. Business Sweden) and other relevant stakeholders from commerce organizations and companies supplying environmental technology locally and abroad.

The data collected and the knowledge accumulated through these projects has provided relevant information about drivers and barriers, as mentioned before. However, it was noted that many of the interviewees mentioned connections to city networks and benefits from belonging to them, which is why this study took shape. For this study, five Swedish municipalities were selected, i.e. Stockholm, Gothenburg, Malmö, Uppsala, and Linköping. These municipalities were chosen based on the total turnover from environmental technologies as reported by Statistics Sweden (see Table 1). Only one, i.e. Uppsala, was chosen based on its total number of inhabitants (it is the fourth largest city in Sweden).

We started by visiting these municipalities' websites to find out about the international networks they belonged to. We considered the municipalities' websites to be the most accurate and easy way to access this information, since it was centralized in one place. We proceeded to analyze each network by visiting their websites, in which we mainly checked the size of the network (amount of members), their geographical reach (where members are located), their nature (the goals or working areas) and the requirements for being a member. This data were collected in a database, which was later used to find patterns and analyze characteristics and trends.

Being aware of possible out-of-date data in the municipalities' websites, we decided to contact those persons that appeared as responsible for the maintenance of the international networks and we arranged interviews with them. Most of these interviews were performed by phone, and one was held face-to-face. The interviews lasted around one hour and were done using a semi-structured approach, in which an interview guide was used mainly as a frame, but conversations evolved freely around the topic. The conversations focused on the expected and perceived benefits from their membership, the assessment and monitoring of the activities and results, and the administrative processes required for joining and maintaining the networks. An important topic that was discussed was the importance that the city poses in its municipal companies in order to address environmental problems and how they have benefitted or expect to benefit from the cities' membership to this kind of network. The interviews were recorded and transcribed, in order to better analyze the data obtained from them. Finally, the interviewees were asked to provide an official list of the networks the city belonged to, in case the one on their website was not accurate or not updated. These data were later analyzed jointly by the research team, by identifying the key topics emerging from the interviews and performing cross-analyses among the cases and with the data found by visiting the different networks' websites.

As mentioned above, we contacted those in charge of the international networks in each city, who provided us with information about the networks. Although the representative from Malmö was contacted, an appointment was not possible to arrange, which is why we had to only trust on the information on the city's official webpage. However, when analyzing other networks, we found the city in the members' list and included it in our database. Linköping presented a similar case: the representative provided us with a list of six international networks, but we found the city in other networks and included it in our database. We are aware of the possibility of missing some networks. However, we trust that the information collected can be useful to reach our conclusions, especially since it was in most of the cases corroborated by city officials in charge of this particular topic.

3. Results

For this study, it was assumed that the studied cities would all have memberships to at least one international network. It turned out to be so, with the number of memberships ranging from six to up to seventy. Also, it was expected that the largest cities would have more memberships than the smaller ones, and it was found to be the case, with the exception of Uppsala, who did not follow this pattern. Gothenburg, although smaller in population terms than the capital city Stockholm, was found to have a similar number of memberships to networks outside Europe. This fact is interesting because capital cities can access numerous networks outside the reach of other cities (for the mere fact of being the capital), so it can be a signal of the importance that the city of Gothenburg poses on memberships to international networks as a strategy to widen their global outreach. In particular, Gothenburg was found to belong to more networks with a clear focus on sustainability issues (both in absolute and relative terms). Although it is difficult to find a causation relation, Statistics

Sweden reports similar levels of activity (in economic terms) of both cities and the regions they belong to when it comes to the exports of the environmental technology sector (see Table 1).

Every city has an office in charge of administering and maintaining the international networks. However, not all networks the cities belong to are administered by this office. Each city prioritizes the most important networks and appoints this office to take care of them. Other networks considered by this study are administered in a decentralized manner, i.e. other departments or municipal companies are in charge of their administration, according to their nature and goals. However, the central office is aware of all the networks the municipality and its branches belong to and keeps a record of them. Some of the cities meet annually or biannually in order to keep good track and inform the government in office about them. As described by the interviewees, one of the main challenges regarding the maintenance of these networks is the monitoring and assessment of the benefits they bring for the city. This is difficult to do because there are no clear and obvious connections to results in all cases. For example, job positions or energy savings are not always easy to relate to a particular membership to a network. In any case, city officials try to analyze the advantages and disadvantages of belonging to certain networks, paying special attention to the resources needed to actually maintain the membership alive (e.g. human resources, trips, reports, fees) vs. the perceived benefits.

It was also found that each city, as expressed by the interviewees, has different expectations from their membership. It can be said that all cities are interested in attracting resources such as international companies, professional talent and even tourism. However, some expressed more interest in finding funds for the development of local projects. What is most important, most cities recognized the potential of city networks to make their cities and their knowledge known abroad, to create milieus were they can contribute with solutions to common problems, to provide important benchmarking opportunities and to allow members to "learn from the best".

Only one of the interviewees mentioned an explicit strategy by the local government in office to increase the number of international networks the city belongs to. In many cases, there are networks to which the city belongs to because of historical or political reasons, but the administration does not see a direct benefit from doing so. Most cities, however, do not see the number of memberships as a determinant factor of their international strategy. Table 1 provides basic information about the studied cities and a summary of the data found about their memberships.

Table 1: Information about the city networks the studied cities belong to.

	Stockholm	Gothenburg	Malmö	Uppsala	Linköping
Population (aprox.) (SCB, 2014a)	900 000	533 000	313 000	205 000	150 000
Turnover in million SEK environmental technology sector in 2012 (larger region) (SCB, 2014b)	34 369	36 714	22 793	4 398	16 231
Number of networks the city is a member of	70	48	12	6	6
Total number of members	115000+	45000+	7000+	500+	1300+
Networks outside Europe	30	23	2	1	2
Geographical span	Global	Global	Global, but mainly within the EU	Global, but mainly within the EU	Global, but mainly within the EU
Memberships to sustainability networks	13	16	6	0	3

As was mentioned before, there is an apparent correlation between the size of the city and the number of international networks it belongs to. Uppsala is the only studied city that does not follow this trend, when compared to Linköping, which is a smaller city. Other relevant findings are classified in different categories for the sake of facilitating the analysis of the data obtained. Each category is explained in the following subsections.

3.1. Membership

The two largest cities, i.e. Stockholm and Gothenburg, have a wider geographical spam through their networks. Although the majority of networks they belong to are focused on a national and a European level, it is clear that their position as large cities or, in the case of Stockholm, as a capital, gives them visibility and allows them to belong to special types of networks outside the reach of smaller cities. It was also found that not all memberships are kept alive because of the perceived benefits, but more because of political or historical reasons. However, some of these networks are being dismantled and cities are starting to focus more on joining or maintaining those networks that are perceived as beneficial for them.

3.2. Subject focus

Each city has its own interests and priorities when it comes to joining networks. The international offices normally report their interest in networks with broader coverage of urban topics, or "umbrella" networks, e.g. dealing with environmental sustainability, economy and social issues. However, municipal companies or specific branches of the city administration are of course interested in more specific networks, e.g. libraries networks, parks and arenas networks or ports networks.

3.3. Strategies to join networks

The studied cities do not have specific strategies regarding their membership to networks in the future. However, it was found that this depends greatly on the administration in office. In some cities, there are plans to revise their current membership in networks and increase them. There are no clear goals regarding the amount, but there are plans to develop assessment methods in order to decide which to keep, which to leave and which to join. Strategic plans to increase the city's international visibility are of course more general in nature, but international networks are seen as a central contributor to this goal by all the studied cities.

3.4. Expected vs. perceived benefits from city networks

It was found that it can be difficult for cities to connect a specific outcome to a specific membership. However, it was clear that smaller networks (e.g. between three or four cities) have more clear aims and benefits, as many times they are created with a very clear and tangible goal, e.g. the improvement of transport infrastructure. Other cities are more concerned about the funding opportunities that some networks can provide them to finance some of their development projects. However, most cities agree that there is not a clear methodology to evaluate benefits, more than perception and the outcomes of regular follow-up meetings with those in charge of the networks and the local administration.

3.5. Challenges/barriers to participation

The most common challenge mentioned by the interviewees was the fact that politicians must be convinced about the benefits and the need to join a particular network. This has more to do with the actual efforts and resources needed to maintain it (e.g. full-time offices like the international office) than with fees, for example. In fact, many of the reported networks did not require the payment of a fee for membership. Smaller cities, however, find some obstacles when thinking of joining some of the networks, because of size requirements.

Although some interviewees reported cultural differences as a challenge when joining international networks, it was clear that this could be solved with diplomacy and information.

3.6. Administration of the networks

It was highlighted during the interviews that cities members of these networks have normally the same right to vote or make decisions as the rest of the members, although it was made clear that being active and participating in meetings and conferences was necessary. This was an important issue to keep in mind when planning to join a network, as it requires the proper allocation of resources. Cities with stable political situations over the past years find it easier to maintain their memberships.

3.7. Participation in sustainability city networks

International city networks for sustainability are seen by most cities as relevant milieus where information and experiences can be shared. In particular, environmental technologies have found arenas where bidirectional flows are present, where cities can learn from the solutions other cities have implemented or also take advantage in order to promote their own solutions. Some cities have focused more on learning and bringing suitable technologies into their society, but the potential of networks as a means to promote their solutions in the future is openly recognized.

3.8. Benefits from international networks for municipal companies

Municipal companies are seen as a necessary contribution to environmental, social and economic issues by all the studied cities. The interviewees from the international offices were not normally in charge of administering these networks to which municipal companies belonged to, which points to the fact that they have some level of independency to choose them and run them. Stockholm and Gothenburg provided the research team with an extensive and thoroughly classified report of all the networks the different agencies and companies of the city belonged to. From this list, it is seen that municipal companies in Gothenburg are more active when it comes to participation in international networks for sustainability, especially in the areas of energy, waste and wastewater management. It the case of Stockholm, the water management company is the most visible one from this perspective. The remaining memberships in both cities are administered either by the municipal government or by agencies in charge of managing e.g. arenas, public parks or transport, and as so were not considered as companies in this study.

4. Analysis/Conclusions

In this study we aimed at answering three research questions. First, we wanted to know if large cities in Sweden are active members of city networks for sustainability. We found in our study that they are, with the exception of Uppsala. We also found that there is a relatively large difference among them, i.e. Linköping belongs to three, while Gothenburg belongs to sixteen. An interesting finding was that most cities want to make part of networks that cover a wide range of issues, as opposed to networks with a very narrow focus on an environmental sustainability issue, e.g. air pollution. The interviewees mentioned that networks with a wide focus provide more flexibility and the opportunity to include more members and benefit more stakeholders. It was found that Gothenburg is the city that belongs to more networks for sustainability in absolute terms and in relation to the total amount of networks in which it is a member (16 out of 48). Stockholm, on the other hand, has access to more members through all of its networks. This is not only because it belongs to more networks than the rest, but also because of its position as the capital city.

The second question we wanted to answer was: what is the reach these cities have through their networks? We found that all the studied cities have access to members around the globe through at least one of their networks (as is the case of Uppsala). However, Stockholm and Gothenburg have the widest reach. This is not only because they are members of more networks outside Europe than the other, but also because of the actual networks they are members of. There are some networks that, because of their nature, offer the opportunity to access a larger amount of members. For example, some networks focus only on cities, while other accept different companies from the same city or have different membership categories (e.g. city governments and individual experts), which increases the number of possible contacts each member has.

The third research question relates to how participating in city networks can facilitate the diffusion of environmental technologies from municipality-owned companies. To provide answers to this question, it is important to understand the barriers to the diffusion of environmental technologies from municipality-owned companies and relate these barriers to the dynamics of participating in city networks presented in the results above.

Export barriers are factors that discourage non-exporters from engaging in export or hinder the export performance of existing exporters (Suarez-Ortega, 2003). Various categories of export barriers are provided in the scientific literature e.g. barriers relating to firm size and export experience, ownership, resources management in export and can be classified as external or internal (Kanda et al., 2012). A common export barrier identified from the municipality-owned companies relates to allocating competent personnel between home and export markets projects. Interviewees reported that project leaders within the company are often reluctant towards export projects since they have to lend out competent personnel which disturbs local municipal responsibilities. Several municipality-owned companies have their local municipal responsibility as top priority and allocating personnel abroad is often problematic. In addition, the municipality ownership also presents some export barriers. Swedish municipality-owned companies are under the municipalities' law not allowed to build and operate large scale environmental technology systems abroad. They are only allowed to export their knowledge and competence on the development and operating of such systems which is regarded as a low risk activity. Other ownership barriers relate to the dependence on aid organizations and domestic operations for export financing. Other export barriers relate to lack of information and knowledge about the export market characteristics relating to consumer preferences, laws, regulations, business opportunities, etc. Differences such as business culture, political systems, levels of industrial developments, etc. can also impede the diffusion of such environmental innovations.

As mentioned in the results section, belonging to international network of cities sharing knowledge and experiences, providing creative solutions and applications, and supporting each other in a continuous matter, represents tremendous benefits and might facilitate the achievement of environmental, development, and commercial goals. In reconciling the barriers to the diffusion of environmental innovations to the dynamics of participation in city networks, we acknowledge that not all barriers can be tackled by participation in such networks. Nonetheless, participation in city networks offers particularly two benefits relating the building legitimacy and access to information which are essential in the diffusion of environmental innovations (Kanda, 2014). Legitimacy refers to social acceptance, the compliance with relevant institutions and regulations including the ability to meet formal and informal expectations (Bergek et al., 2008). Participation in city networks provides the opportunity for municipalities to share information on their environmental challenges and how they have been solved, expose their local company competence and show their expertise to potential customers. Members of several such networks especially with a sustainability focus share common goals which gives the necessary legitimacy to members as being potentially interested in developing competence in such areas. Such legitimacy is what municipal companies can gain from their owner municipalities particularly for the diffusion of environmental technologies. In addition, city networks provide a unique platform for two-way information sharing into member cities and to network members. This exchange of information is done through seminars and exhibitions which allow potential exporters and customers to share information. Gathering and delivering this market information such as consumer preferences, laws, regulations, business opportunities, policy and regulations to municipal companies can prove vital in export.

As can be concluded from the above discussions, city networks have a potential in contributing to the diffusion of environmental innovations and the realization of such benefits depends on several factors such as the subject focus of the network, how the member cities use the networks and also contextual specifics in these member cities. For municipalities in Sweden, their legal restriction to export only knowledge and competence of large technical systems has a limiting effect on how much such companies can export and benefit from their municipality participation in city networks, even though benefits could point more in attracting environmental innovations and foreign companies into the cities. For a broader interest of cities and municipalities around the world with such environmental technology systems for diffusion, these cities can build on networks to provide legitimacy and information to companies which are of keen importance in the diffusion of environmental innovations.

Acknowledgements

The authors want to thank the Swedish Agency for Innovation Systems (VINNOVA) and Tekniska Verken AB for their financial support. A big thank you goes to Malin Parmander, Christian Dahlmann, Fredrik Nielsen and Björn Bertilsson, who kindly shared their time and knowledge with the research team. Also, thanks to Anitha Muralidhara, who was of great help for the collection of information about the cities and their networks. Finally, thanks to the anonymous reviewers who provided valuable comments on the original proposal.

References

Baptista, R., 2001. Geographical clusters and innovation diffusion. Technological Forecasting and Social Change 66, 31-46.

Batten, D.F., 1995. Network cities: creative urban agglomerations for the 21st century. Urban Studies 32(2), 313-327.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme for analysis. Research Policy 37, 407-429.

Cooke, P., Davies, C., Wilson, R., 2002. Innovation advantages of cities: From knowledge to equity in five basic steps. European Planning Studies 10(2), 233-250.

Guy, S., Marvin, S., 1999. Understanding sustainable cities: Competing urban futures. European Urban and Regional Studies 6 (3), 268-275.

Hult, A., 2013. Swedish production of sustainable urban imaginaries in China. Journal of Urban Technology 20(1), 77-94.

Kairento, K., Nygårds, M., 2014. Export of municipal environmental technology knowledge. An analysis of previous activities and incentives. Master Thesis. Environmental Technology and Management, Department of Management and Engineering, Linköping University. LIU-IEI-TEK-A--14/01823—SE.

Kanda, W., 2014. Promotion of environmental technology export. Governmental initiatives and business concepts. Linköping Studies in Science and Technology. Licentiate thesis No. 1673.

Kanda, W., Mejía-Dugand, S., Hjelm, O., 2013 (In press). Governmental export promotion initiatives: awareness, participation, and perceived effectiveness among Swedish environmental technology firms. Journal of Cleaner Production. http://dx.doi.org/10.1016/j.jclepro.2013.11.013.

Kanda, W., Hjelm, O., Mejía-Dugand, S., 2012. Environmental Technology Export Promotion: A study of governmental initiatives in selected countries. Environmental Technology and Management, Linköping University. Report LIU-IEI-R; 12:005. http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-80261 [Accessed September 12, 2014].

Keiner, M., Kim, A., 2007. Transnational city networks for sustainability. European Planning Studies 15(10), 1369-1395.

Mejía-Dugand, S., 2013. Diffusion of environmental technology in a megacity – A case study of Mexico City. Linköping Studies in Science and Technology. Licentiate thesis No. 1574. LIU-TEK-LIC-2013:8.

Mejía-Dugand, S., Hjelm, O., Baas, L., Ríos, R.A., 2013. Lessons from the spread of Bus Rapid Transit in Latin America. Journal of Cleaner Production 50, 82-90.

Nicholls, W.J., 2008. The urban question revisited: The importance of cities for social movements. International Journal of Urban and Regional Research 32(4), 841-859.

Pedersen, P.O., 1970. Innovation diffusion within and between national urban systems. Geographical Analysis 2(3), 203-254.

Simmie, J., 2003. Innovation and urban regions as national and international nodes for the transfer and sharing of knowledge. Regional Studies 37(6&7), 607-620.

Statistics Sweden (SCB), 2014a. Miljösektorn per län, 2012 [Environmental sector, per county 2012]. http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Miljo/Miljoekonomi-och-hallbar-utveckling/Miljorakenskaper/38164/38171/Miljosektorn/317383/ [Accessed September 12, 2014].

Statistics Sweden (SCB), 2014b. Folkmängd i riket, län och kommuner efter kön och ålder 31 december 2013 [Country's, counties' and municipalities' population classified by gender and age December 2013]. http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Befolkning/Befolkningens-sammansattning/Befolkningsstatistik/25788/25795/Helarsstatistik---Kommun-lan-och-riket/159277/ [Accessed September 12, 2014].

Suarez-Ortega, S., 2003. Export Barriers: Insights from small and medium-sized firms. International Small Business Journal 21(4), 403-419.

The World Bank, 2010. Cities and climate change: An urgent agenda. Washington, D.C.: The World Bank.

UNHABITAT, 2012. The future we want. www.unhabitat.org/downloads/docs/11279_1_594479.pdf [Accessed October 21, 2013].

Municipalities' official information on international networks on the internet

- *Gothenburg:* http://goteborg.se/wps/portal/invanare/kommun-o-politik/internationellt-samarbete/om-internationella-avdelningen/!ut/p/b1/jYvBCoJAFEW_pR_w3XGc8c3yJaWFCQpCziYsQgRHN1G_n31A1NkdOIc8dXFsoVKjQWfyc_8ch_4xLnM_fdzbS6tQ81YJcmZAMpx2makUN3oNujXIcimStAS4zA0OUrSNq7WG6P9-fEHw6z-SH68het1ChChFbJlZWXYu0c5QVSzhTsFPex5k8wZsXsFp/dl4/d5/L2dBISEvZ0FBIS9nQSEh/ [Accessed September 14, 2014].

- *Linköping:* http://www.linkoping.se/Om-kommunen/Utveckling-och-samverkan/Internationellt-samarbete/Internationella-natverk/ [Accessed September 14, 2014].

- *Malmö:* http://www.malmo.se/Kommun--politik/Sa-arbetar-vi-med.../Omvarld/Internationellt-arbete/Internationella-natverk.html [Accessed September 14, 2014].

- *Stockholm:* http://www.stockholm.se/OmStockholm/EU--Internationellt-/Internationella-organisationer-och-natverk/ [Accessed September 14, 2014].

- *Uppsala:* http://www.uppsala.se/sv/Kommunpolitik/Internationellt-arbete/Natverk/ [Accessed September 14, 2014].

A SYSTEM FOR SUSTAINABILITY MANAGEMENT IN ENTERPRISES

Jurgis Staniškis, Valdas Arbačiauskas, Loreta Kinderytė
Institute of Environmental Engineering, Kaunas University of Technology
K. Donelaicio str. 20, LT-44239, Kaunas, Lithuania
Valdas.Arbaciauskas@ktu.lt, Jurgis.Staniskis@ktu.lt, oloretaloreta@yahoo.com

Corresponding author: Valdas Arbačiauskas, Institute of Environmental Engineering, Kaunas University of Technology, K. Donelaicio str. 20, LT-44239, Kaunas, Lithuania. Tel: +370 37 300768, Fax: +370 37 209372., E-mail: Valdas.Arbaciauskas@ktu.lt

Abstract

The concept of sustainable development is often considered by industrial enterprises as vague and hardly operational. Moreover, the word "sustainability" in relation to industrial activities has been so heavily overused, with too many different meanings applied to it. To make it operational, sustainable industrial development may be considered as a process of continuous improvement of environmental, economic and social performance in industry. Such a process approach allows specialists to identify particular process performance parameters that could be controlled and managed. In this context, sustainability performance can be interpreted as a result of management of sustainability aspects in enterprises.

Experience shows that sustainable industrial development tools such as cleaner production, eco-design and sustainability reporting are seldom sufficiently integrated in enterprise management systems. Integration of sustainability performance management into the overall business planning is another important aspect to be tackled because efficiency of management systems largely depends on connections between the management systems and strategic/ financial decision making. Enterprises often lack explicit information about their activities, particularly reliable quantitative information on technological processes and various sustainability aspects. Moreover, the existing data information is seldom systemized and made available to decision makers in a form suitable for effective decision making.

The objective of this article is threefold: (i) to select key industrial development tools; (ii) to present a structural model for integration of sustainable industrial development tools; and (iii) to present hierarchical procedure for sustainability management and to provide recommendations related to the selection of performance indicators.

The structural model presents the key elements of environmental management system and other sustainable industrial development tools in a sequence of integration. Distinctive features of the proposed model are integration of sustainability aspects and criteria at operational level, and shift of conventional management system to sustainability management system as. Hierarchical procedure for sustainability management covers process, activity and strategic decision making with legal and other requirements as well as a new scientific knowledge and stakeholder expectations constituting the system input information. Decision makers at different hierarchical levels are provided with the feedback information based on the indicators of enterprise's sustainability performance.

The material presented in this paper is based on the analysis of relevant literature and on practical experience of the authors gained from a number of national and international projects focused on improvement of environment/ sustainability performance and implemented jointly by industrial enterprises and the Institute of Environmental Engineering (APINI), Kaunas University of Technology (KTU).

Keywords: *cleaner production, continuous improvement, corporate environmental management, decision support, performance indicator, sustainable development.*

1. Introduction

Sustainable development at an organizational level is usually described to use a triple bottom line that divides performance into economic, environmental and social dimensions (Topfer, 2000, Elkington, 1998). Hence, sustainable industrial development may be defined as a strategy for adopting activities to meet the needs of enterprises and other stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future. However, the concept of sustainable development is often considered by industrial enterprises as vague and hardly operational. Moreover, the word “sustainability” in relation to industrial activities has been so heavily overused, with so many different meanings applied to it, that it has become quite meaningless (Aras and Crowther, 2009).

To ensure contribution of industry to the process of sustainable development, there is a need to explain in operational terms what the concept of sustainable development means to industry and, more specifically, to an industrial enterprise. To make it operational, sustainable industrial development may be considered as a process of continuous improvement of environmental, economic and social performance in industry. Such a process approach allows industrial specialists to identify particular process performance parameters that could be controlled and managed. In this context, sustainability performance can be interpreted as a result of management of sustainability aspects in enterprises. Thus, sustainability management can be defined as “a profit-driven corporate response to environmental and social issues that are caused through the organization’s activities” (Salzmann et al., 2005).

One of the key approaches to increase sustainability performance of enterprises is cleaner production and environmental management system. However, cleaner production is (in general) diffusing comparatively slowly despite good results achieved (Bonila et al., 2010). It could be also stressed that management systems are often implemented with a “certificate-oriented” approach whose efficiency in terms of sustainability performance improvement is low (Iraldo et al., 2009). Even if management systems are implemented with a “performance-oriented” approach, enterprises might not be able to realize their full potential for performance improvement. One of the reasons is lack of motivation to maintain the system after certification (Pedersen and Nielsen, 2000).

It is generally accepted that preventive approaches, e.g. cleaner production methodology, in some cases make it possible to eliminate the need for pollution control (end-of–pipe) technologies or to reduce the capacity of the pollution control equipment. This may lead to significant financial savings in addition to a reduced impact on the environment, possibly, to improved work conditions and improved product quality (Laurinkeviciute and Stasiskiene, 2011). However, decision-makers are often “too quick” in finding solutions to particular problems. Real causes of a problem are seldom analysed because the solution often seems to be “obvious”, e.g. when a new legal requirement for the emission of a particular pollutant is introduced, decision makers are tempted to go along the easiest, but not the most efficient and economically viable way – to look for pollution control technology that would enable them to capture pollution. Additional data collection and analysis could help identify more alternatives for material substitution, production process modification or better control of the process as a result of additional training of employees. Moreover, enterprises often underestimate the performance improvement potential lying in good house-keeping measures that are easy to implement and frequently do not require financial resources.

It should be also stressed that one of the difficulties in measuring the company's level of sustainability is to determine which directions of change are leading towards sustainability (Krajnc and Glavic, 2004). "When properly done, a sustainability analysis of a system of interest, which can either be products, or processes, or corporations, or even ecosystems, should include indicators used to quantitatively represent the system from the viewpoint of environmental, economic, and societal impacts, in accordance with the basic principles of sustainability" (Sikdar et al, 2012).

There are several internationally acknowledged sustainability/ environmental performance evaluation/ reporting initiatives and methodologies. The first comprehensive list of environmental performance indicators was developed and recommended by the German Environment Ministry (BMU) and Federal Environmental Agency (UBA) in 1997 (Federal Environmental Ministry, 1997). Soon after that, in 1999, international standard ISO 14031 for environmental performance evaluation was introduced by the International Standard Organization followed by sector-specific initiatives, for example, a sustainability performance evaluation initiative of the Britain's Institution of Chemical Engineers (IChemE, 2003). Eco-Efficiency Assessment was developed by the World Business Council for Sustainable Development in 2000 (WBCSD, 2000). Global Reporting Initiative (GRI, 2006) is intended to assist enterprises to assess performance and to improve communication with stakeholders (Dalal-Clayton and Bass, 2002). For selection of initial environmental indicators, the specific indicator systems for particular industrial branches could also be used (Envirovise, 2004; Pohjola, 2005; Enroth, 2006; Viluksela, 2009).

One of the main strengths of the above mentioned methodologies in the context of sustainability performance management is a possibility to use benchmarking, because a standard format is used for reporting of sustainability performance. At the same time, a significant shortcoming of existing sustainability performance evaluation systems is their focus on external reporting and underestimation of the internal information needs for decision-making, i.e. for increased management efficiency and for actual performance improvement. Furthermore, a concern is sometimes expressed that sustainability reports published by enterprises are only "green-wash" intended to improve the company's public image. For example, a review of the frameworks of business sustainability indicators has shown that they present simple lists of indicators with little or no guidance as to how to apply them over time to become more sustainable (Veleva and Ellenbecker, 2001).

These shortcomings can be partly explained by the fact that one of the main driving forces for sustainability performance evaluation is often a pressure on an industrial enterprise from external stakeholders to publish sustainability performance information. It could also be related to establishment of "socially responsible" investment funds and investment rating systems, e.g. "Dow Jones Sustainability Index" (Ballou et al., 2006). It could be stressed that efficiency and the value added of the performance evaluation system for an enterprise depends mainly on the strength of internal motivating factors and ability of enterprises to apply sustainability performance indicators properly. They are to be focused more on the information needs for decision making at an enterprise level (Staniskis and Arbaciauskas, 2009). Generally, main drivers for enterprises to act in sustainable ways are market place demands, changes in business procurement, government legislation and regulation, the rise of socially responsible investment, competitors' actions and the changing expectations of employees (Epstein, 2008, Pryce, 2002).

Integration of sustainability performance management into the overall business planning is another important aspect to be tackled because efficiency of management systems largely depends on connections between the management systems and strategic/ financial decision making. Enterprises often lack explicit information about their activities, particularly reliable quantitative information on technological processes and various sustainability aspects. Moreover, the existing data information is seldom systemized and made available to decision makers in a form suitable for effective decision making. Sustainability performance evaluation based on performance indicators is likely to be the most appropriate tool to solve this problem.

To achieve a wide participation of industrial enterprises in the process of sustainable development and to facilitate effective decision making in the sustainability management process at an enterprise level, key approaches and tools of sustainable industrial development have to be identified. It is evident that industry can not rely on the pollution control technologies because of their limitations and excessive cost, moreover, application of preventive environmental approaches is an important factor of business competitiveness (Dvarioniene et al, 2012). The sustainability approaches used in enterprises include cleaner production, eco-design, corporate social responsibility, stakeholder management, etc. The tools for implementation of these approaches are cleaner production assessment, life cycle assessment, Eco-indicator 99, environmental accounting, etc. The question is which of tools are essential and most effective in moving enterprises towards sustainable development.

Enterprise's system consists of operations and processes, management and strategy, organisational systems, procurement and marketing, assessment and communication (Lozano, 2012). Taking into account that there is no particular standard for sustainability management, researchers and practitioners try to fill this gap.

The objective of this article is threefold: (i) to select key industrial development tools; (ii) to present a structural model for integration of sustainable industrial development tools; and (iii) to present hierarchical procedure for sustainability management and to provide recommendations related to the selection of performance indicators.

The material presented in this paper is based on the analysis of relevant literature and on practical experience of the authors gained from a number of national and international projects focused on improvement of environment/ sustainability performance and implemented jointly by industrial enterprises and the Institute of Environmental Engineering (APINI), Kaunas University of Technology (KTU).

2. Integration of key tools of sustainable industrial development

Sustainable industrial development tools generally address different elements of an enterprise system: operations and processes, management, communication, etc. At the same time, these tools contribute to different dimensions of sustainability (environmental, economic and social). Lozano (2012) proposed a framework for selection of tools (Corporate Integration of Voluntary Initiatives for Sustainability (CIVIS) framework). Main criteria include full coverage of the enterprise's elements and all dimensions of sustainability (including the time dimension).

Analysis of different approaches/ tools suggests that application of the following approaches/ tools covering all key elements of an enterprise system (production, products, management, and communication with internal and external stakeholders) could be used to ensure sustainability performance improvement in enterprises:

- Cleaner production approach to improve production processes. This approach is based on rational use of energy and natural resources and minimization of pollution/ waste at the source where it is generated. Cleaner production assessment can be used as a tool.
- Eco-design approach to improve product characteristics. Checklists and eco-indicator 99 are perhaps the most suitable tools for SME's to implement this approach.
- Integrated management systems to keep continually applied and incorporated into enterprise system above mentioned approaches and to improve management practices. The basis of management systems is development of a cycle for continuous performance improvement.
- Sustainability reporting based on sustainability performance evaluation to improve communication with internal and external stakeholders.

Nowadays, most of the companies integrate their management systems. However, cleaner production, eco-design and sustainability reporting is seldom sufficiently integrated in management systems, despite the fact that efficiency of these tools depends largely on their integration level in the overall strategy of enterprises and everyday activities (Staniskis and Arbaciauskas, 2003).

Experience of the authors suggests that one of the ways to increase motivation of maintaining management system and ensuring its efficiency is systematic/ integrated use of cleaner production and other sustainable industrial development tools listed above. Sustainable industrial development measures may be integrated using a classical "plan – do – check – act" management cycle used in management system standards. Systematic and integrated application of these measures may enable an increase in their efficiency and may lead to cost savings associated with more efficient use of human and natural resources, improved product characteristics, more effective operational procedures, reduced waste generation and harmful emissions to the environment, etc.

Integration of different environmental and other management tools is not particularly novel but practical models for enterprises to meet sustainable development requirements are lacking. In a given case, environmental management system is taken as a basis for integration of sustainable industrial measures (Fig. 1). The structural model presents the key elements of environmental management system and other sustainable industrial development tools in a sequence of integration. The level of improvement of environmental performance depends largely on the planning phase, when the potential for performance improvement is systematically analysed and preventive measures are developed. To identify preventive performance improvement options, cleaner production methodology could be used, when a set of alternatives is developed for each significant aspect. Environmental, technical and economic feasibility analysis leads to development of action programmes for implementation. In the given case, both process and product improvement options are considered. A set of sustainability performance indicators has also to be developed in a planning stage to ensure effective decision making.

Distinctive features of the proposed model are integration of sustainability aspects and criteria at operational level, and shift of conventional management system to sustainable management system and introduction of systematic hierarchical system for sustainability performance management based on sustainability indicators (described in the section 3).

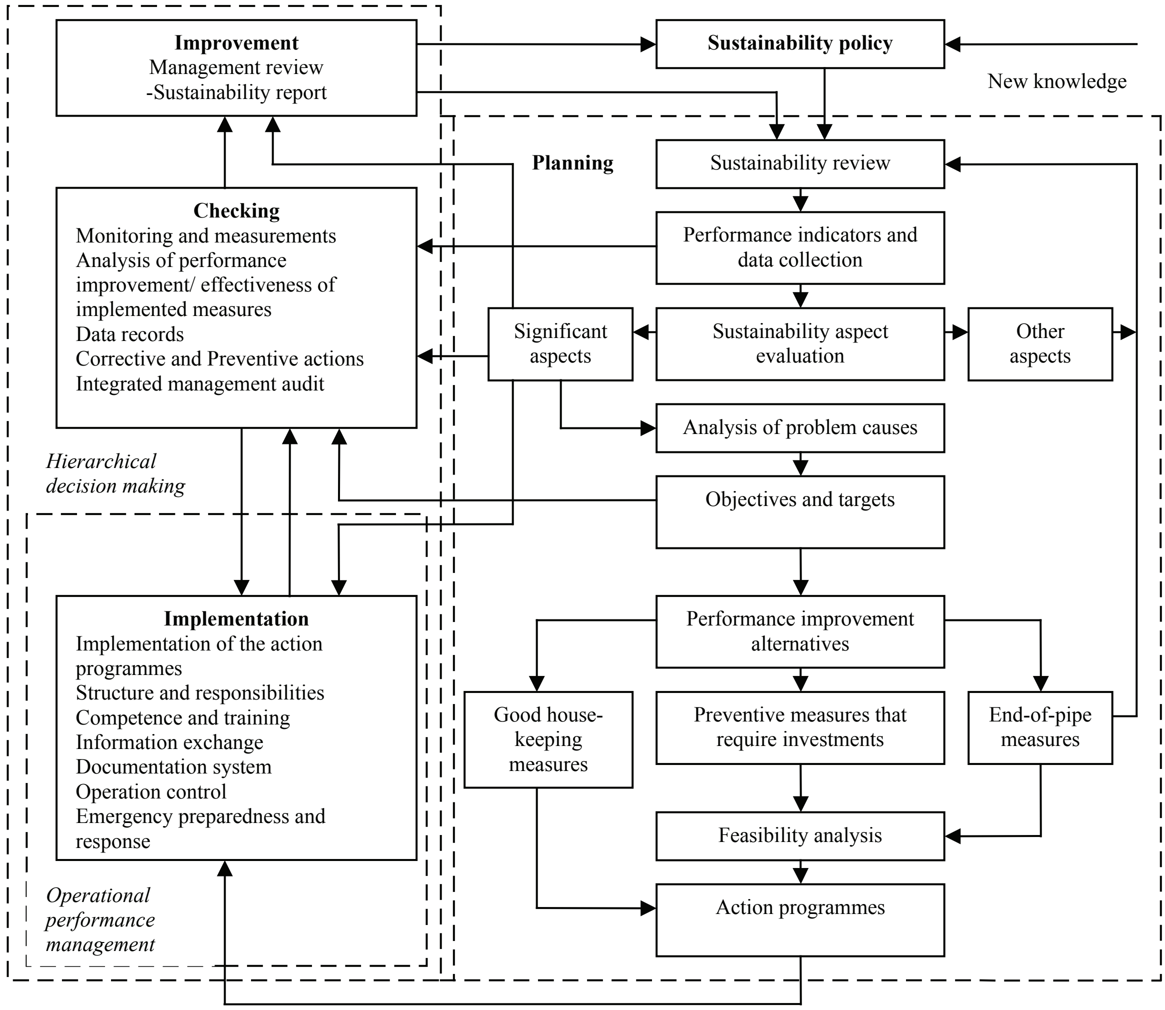


Fig. 1. Structural model for integration of key tools of sustainable industrial development

3. Hierarchical system for sustainability performance management and sustainability indicators

To ensure effective and systematic application of the key tools of sustainable industrial development and to support their integration, enterprises are recommended to use hierarchical system for sustainability management in Fig. 2. Such a system may help to increase effectiveness of the decision making process and to facilitate reorientation of a problem solving approach from reactive to proactive/ preventive.

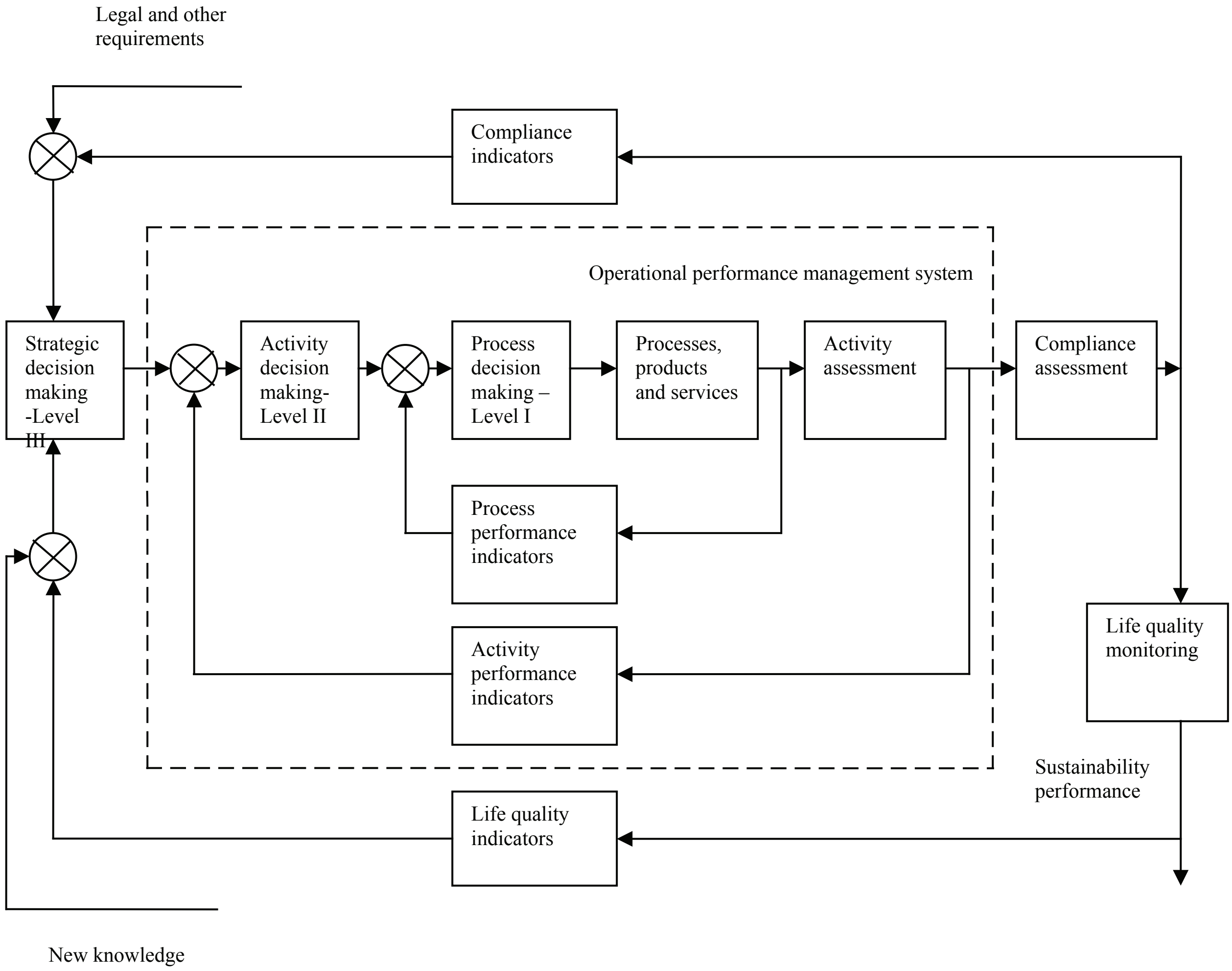


Fig 2. Hierarchical system for sustainability management at an enterprise level

The proposed system of sustainability performance management is based on a hierarchical approach to decision making. The system covers process, activity and strategic decision making with legal and other requirements as well as a new scientific knowledge (stakeholder expectations and scientific knowledge) constituting the system input information. The control system also relies on feed back information from several process stages. Decision makers at different hierarchical levels are also provided with the feedback information based on sustainability performance indicators of the enterprise. Such approach enables to increase participation of employees in problem solving at different levels of enterprises.

Process indicators (level I) provide information to the enterprise personnel on the process efficiency and help identify both the deviations from technological specifications and the measures for improving the process efficiency. In the context of management systems, process indicators facilitate operational control.

Activity performance indicators (level II) are used at process, product, department and enterprise levels and present the “digested” information obtained from a detailed analysis of processes, products and services. These indicators are particularly useful for decision making in terms of identifying the priority areas for sustainability performance improvement and generating particular improvement measures. It is very important to monitor performance indicators to make the right decisions on time.

Compliance and life quality indicators are used in the level III. Compliance indicators cover the following areas: legal compliance, compliance with the other requirements as defined in the management system standards (e.g. requirements specified in the contracts with other organizations), and achievement of objectives and targets specified in the management system documentation or other documents. The information contained in life quality indicators is a result of monitoring or statistical activities performed by the enterprise or other organisations. These indicators cover the natural environment, the work environment, social and economic spheres. Such indicators may reflect air quality in the vicinity, biodiversity in nearby water bodies, quality of the work environment and other health & safety issues, an employment rate in the local community, etc. Life quality indicators may be used in identification of strategic directions to the enterprise’s efforts to reduce an environmental impact and, more generally, to improve sustainability performance.

Generally, an indicator provides useful information about the system; it can be used to describe the state of the system, to detect its changes and to show the cause and result relationships (Mille, 2001). Indicators may be quantifiable (quantitative) and non-quantifiable (qualitative). The best approach is the combination of both methods (Diakaki et al., 2006). It terms of the expression, there are four types of quantifiable indicators: absolute indicators, relative indicators, aggregate indicators and indexed indicators. Aggregate and indexed indicators integrate the data into particular categories or into one number presenting the level of performance. Such indicators may be useful in the overall assessment of the enterprise’s performance, but they lack detailed information and it limits their practical use in terms of improvement opportunity identification for performance optimization. In this respect, the use of absolute and relative indicators is recommended. Nevertheless, indexed and aggregated indicators can be useful in sustainability reporting. Finally, performance indicators can be expressed in natural and monetary units.

Taking into account the nature of decision making (e.g. strategy development, innovation generation), performance indicators can be defined at enterprise, department or process levels. Moreover, to ensure legal compliance and adequate response to negative changes in the environment in relation to enterprise’s activities, a set of compliance and environmental condition indicators has to be selected. In addition to traditional sustainability indicators, such as economic, environmental and social ones, communication indicators may be considered, too. Hower, it should be stressed that although the number and nature of the indicators chosen s may differ from the system type to system type, the alternatives to be compared must use the same set of indicators (Sikdar et al, 2012). A matrix of recommended sustainability performance indicators and their applicability to decision making is presented in Fig. 3.

Environmental/ social/ economic/ communication indicators	Process indicators	Activity indicators	Compliance indicators	Life quality indicators
Absolute indicators	*Process decision making*	*Operational and process decision making*	*Strategic and operational decision making*	*Strategic decision making*
Relative indicators	*Process decision making to a limited extent*	*Operational and process decision making*	*Strategic decision making*	*Strategic decision making*
Indexed and aggregated indicators	*Not applicable*	*Operational decision making*	*Strategic decision making*	*Strategic decision making*

Fig. 3. Matrix of different sustainability performance indicators and decision making levels

The matrix provides an overview of what types of indicators should preferably be used for particular purpose (level of decision making). For example, absolute process indicators (technological parameters) are best suited for process decision making as they enable efficient process control. Relative compliance and life quality indicators are effective in strategic decision making but are not useful for decision making at process level. Generally, indicators at higher hierarchical levels (from process to quality of life indicators) are more useful in strategic decision making. In development of a set of sustainability performance indicators, application of a hierarchical approach that corresponds to the level of the enterprise‘s ambition in its performance evaluation may be useful as it helps industrialist to keep a clear and relevant structure/ composition of the performance evaluation system. The enterprise can start from the evaluation of compliance/ resource use efficiency and with a gradual development of experience it continues with a more sophisticated performance evaluation. The following hierarchy that has five levels in relation to the basic principles of sustainability may be used: (i) facility compliance/ performance (e.g. a number of notices of violations); (ii) facility material use and performance(e.g. heavy metal emissions to water in tons per year); (iii) facility effects (e.g. carbon dioxide emissions from energy use in million tons); (iv) supply chain and product life-cycle (e.g. post-consumer recycled material used); and (v) sustainable systems (e.g. percent of the total energy used from renewable sources harvested in a sustainable way) (Veleva et al., 2003). A particularly important aspect in selecting sustainability performance indicators is a product life cycle approach. Frequently, enterprises limit their performance analyses to the production and other internal processes, sales and general economic indicators. Finally, to develop an operational system to bring value to the enterprise, the key requirements for sustainability performance indicators should be fulfilled. The requirements for good indicator are following: target orientation, comparability, measurability (access to data), meaningfulness (scientific reliability or analytical soundness), integrity (capability to relate to other indicators), continuity, clarity, efficiency (Toth and Arbaciauskas, 2005, Federal Environment Ministry, 1997). For each indicator should be defined key attributes like unit of measurement, type of measurement (absolute or adjusted), period of measurement and boundaries (Veleva and Ellenbecker, 2001). In practice, enterprises seek to have a manageable number of indicators, that are clear and easy to measure/ monitor, that provide possibility to compare with best practices.

The internationally acknowledged sustainability performance evaluation systems, e.g. Global Reporting Initiative, should be preferably used as reference materials. This will help any enterprise develop a functional and effective performance evaluation system that fully reflects its values and needs. This recommendation may be supported by the findings of other researchers (Keeble et al., 2003; Searcy et al., 2005).

To support strategic decision making and reporting to stakeholders, aggregated indicators (sustainability index) could be used. In this case, the scale of assessment should be defined (Kinderyte, 2010). It is suggested to build assessment on a three level scale: worst evaluation – 0, medium evaluation – 0.5 and best evaluation – 1. Min-Max method could be used to normalise quantitative indicators to have an identical range (0, 1) by subtracting the minimum value and dividing by the range of the indicator values. Quantitative indicators can be normalized according formulas:

$$I^{+}_{N,ijt} = \frac{I^{+}_{A,ijt} - I^{+}_{\min,jt}}{I^{+}_{\max,jt} - I^{+}_{\min,jt}}$$ (OECD 2008, Krajnc and Glavič 2005)

where I^{+}_{A} – indicator whose increasing value has a positive impact in the perspective of sustainability, $I^{+}_{\min}$ – indicator with minimum value and positive impact on sustainability, $I^{+}_{\max}$ – indicator with maximum value and positive impact on sustainability, I^{+}_{N} – normalized indicator whose increasing value has positive impact on sustainability, i – sustainable development indicator, j – group of sustainable development indicators: economical, social and environmental, t – time in years.

$$I^{-}_{N,ijt} = \frac{I^{-}_{\max,ijt} - I^{-}_{A,jt}}{I^{-}_{\max,jt} - I^{-}_{\min,jt}}$$ (OECD, 2008)

where I^{-}_{A} – indicator whose increasing value has negative impact in the perspective of sustainability, $I^{-}_{\min}$ – indicator with minimum value and negative impact on sustainability, $I^{-}_{\max}$ – indicator with maximum value and negative impact on sustainability, I^{-}_{N} – normalized indicator whose increasing value has negative impact on sustainability.

In order to minimize sensitivity of the min-max normalization method the following normalization conditions could be used:

1. If an indicator (whose increasing value has negative impact) has constant minimum values (for example, no safety accidents), then it is assumed as the best possible value and by normalization 1 is assigned:

   if $I^{-}_{ijt} = I_{\min} = \text{const}$ then $I^{-}_{N,ijt} = 1$

2. If an indicator (whose increasing value has positive impact) has constant maximum values (for example, recyclability of a product is 100%), then it is assumed as the best possible value and by normalization 1 is assigned:

   if $I^{+}_{ijt} = I_{\max} = \text{const}$ then $I^{+}_{N,ijt} = 1$

3. If an indicator (whose increasing value has positive impact) is expressed in persent, then by normalization: $I^{+}_{N,ijt} = I^{+}_{ijt} / 100$.

4. If an indicator has constant but not possible maximum or minimum value, then by normalization 0.5 is assigned:

if I_{ijt} = const then $I_{N,ijt}$ =0,5

5. If values of indicators are not constant, but the difference is very small, then by normalization 0.5 is assigned:

if $\frac{I_{A,ijt}}{I_{A,ijt+1}}$ ≥0,99 then $I_{N,ijt}$ =0,5

The next step is weighting and aggregation into index. Weights (w_{ij}) could be defined using a ranging method. Aggregation of indicators into sustainability subindices (economical, social, and environmental) is performed using linear aggregagtion – Simple Additive Weighting method. Subindices are calculated according formula (Krajnc and Glavič 2005):

$$I_{B,jt} = \sum_{jit}^{n} w_{ji} * I_{N,ijt}^{-} + \sum_{jit}^{n} w_{ji} * I_{N,ijt}^{+} ,$$

$$\sum_{ij}^{n} w_{ij} = 1 , \; w_{ij} \geq 0 .$$

Enterprise sustainability index (I_{ESI}) is calculated using Simple Additive Weighting and equal weights for subindices.

The level of sustainability is defined according to the value of enterprise sustainability index calculated: $0 \leq I_{ESI} \leq 0.33$ – unsustainable enterprise, $0.33 < I_{ESI} \leq 0.66$ – sustainable enterprise at the basic level, $0.66 < I_{ESI} \leq 1$ – sustainably progressive enterprise.

Generally speaking, indicators should inform decision-makers of what they need to know i.e. they should be informed of the quantities of factors related to environmental impacts, and these should be related to environmental and operational aspects (Upham and Mills, 2006). Analysis of qualitative and quantitative information will result in a package of data for sustainability reports.

5. Discussion and conclusions

To ensure the progress of sustainable industrial development, enterprises have to address the sustainability aspects related to production processes, management practices, products, and communication with internal and external stakeholders by applying cleaner production, product oriented tools (e.g. eco-design), integrated management systems and sustainability reporting based on sustainability performance evaluation.

Experience shows that management systems are often implemented using a “certificate-oriented” approach and their efficiency in terms of sustainability performance improvement is rather vague. Moreover, a lot of enterprises still rely on the end-of-pipe approach when dealing with environmental issues. Integration of sustainability performance management into the overall business planning and integrated application of sustainable industrial development tools discussed in this article leads to environmental, economic and social benefits. One of the side-effects observed is a positive change of employee thinking and improvement of the work culture. Moreover, integrated application of sustainable industrial development tools ensures continuous improvement of sustainability performance.

The proposed system requires features relative simplicity and takes life cycle perspective into account.

Conclusions:

1. To be operational from a perspective of industrial enterprises, sustainable industrial development may be considered as a process of continuous improvement of environmental, economic and social performance in industry. A number of tools are available to industrial enterprises to be applied, but the best results are achieved by applying the key tools in an integrated way, because particular sustainable industrial development tools are mutually supportive, e.g. environmental management systems are more effective when based on cleaner production and cleaner production is applied more systematically when environmental management system is in place. A classical management cycle used in all ISO management system standards is recommended for such integration.
2. To ensure effective decision making aimed at improvement of sustainability performance, a sustainability performance management system based on three hierarchical levels (process, activity and strategic decision making) is recommended for use in enterprises, because it ensures involvement of decision makers at different levels and enables collection of information needed for effective decision making at different managerial and operational levels.
3. To ensure effective information flows for decision making, appropriate performance indicators should be selected. No standard set of performance indicators could be prescribed to an enterprise. To make sustainability performance evaluation meaningful in terms of the better enterprise management, enterprises have to develop their own sets of indicators that reflect their profile and needs. Standard performance evaluation systems could be used as a reference.
4. To satisfy the needs of decision making in enterprises aimed at continuous improvement of sustainability performance, four categories of performance indicators should be used: (i) process performance indicators, (ii) operational performance indicators, (iii) compliance indicators, and (iv) life quality indicators. Relative indicators are particularly useful in decision-making as they enable specialists to observe the changes of particular values (e.g. pollution) in relation to a common denominator (e.g. raw material or production unit). Aggregated indicators may also prove to be valuable in assessing sustainability of an enterprise.

References

1. Aras G. and Crowther D., 2009. Making sustainable development sustainable. *Management Decisions* Vol. 47 No. 6, Emerald Group Publishing Limited.
2. Ballou B.; Heitger, D.L.; Landes, C.E., 2006. The future of corporate sustainability reporting, Journal of Accountancy, Dec2006, Vol. 202, Issue 6.
3. Bonilla S.H.; Almeida C.M.V.B.; Giannetti B.G.; Huisingh D., 2010. The roles of cleaner production in the sustainable development of modern societies: an introduction to this special issue. *Journal of Cleaner Production* Vol. 18 (2010).
4. Dalal-Clayton and Bass, 2002. Sustainable Development Strategies. (first ed.). Earthscan Publications Ltd, London.
5. Diakaki C.; Grigoroudis E.; Stabouli M., 2006. A risk assessment approach in selecting environmental performance indicators. *Management of Environmental Quality: An International Journal* Vol. 17, No. 2, Emerald Group Publishing Limited.
6. Dvarioniene j., Kruopiene j., Stankeviciene, j., 2012. *Clean Technologies and Environmental Policy* Vol. 14, Issue 6.

7. Elkington, J. Cannibals with forks: The triple bottom line of 21st century business: New Society Publishers, 1998.
8. Enroth M., 2006. Developing tools for sustainability management in the graphic arts industry. Doctoral thesis. Royal Institute of Technology, Stockholm.
9. Envirovise, 2004. Key environmental performance indicators in the printing sector, www.envirowise.gov.uk.
10. Epstein M.J., 2008. Making sustainability work: best practices in managing and measuring corporate social, environmental and economic impacts. Greenleaf Publishing Ltd, p. 288. ISBN 978-1-906093-05-1.
11. Federal Environment Ministry, 1997. A Guide to Corporate Environmental Indicators. Bonn.
12. Institution of Chemical Engineers, 2003. The sustainability metrics. Sustainable Development Progress Metrics recommended for use in the Process Industries.
13. Iraldo F.; Testa F.; Frey M., 2009. Is an environmental management system able to influence environmental and competitive performance? The case of the eco-management and audit scheme (EMAS) in Europe, *Journal of Cleaner Production* Vol. 17 (2009).
14. GRI, 2006. *Sustainability Reporting Guidelines*. Version 3.0. Available from internet: http://www.globalreporting.org.
15. Keeble J.; Topiol S.; Berkeley S., 2003. Using indicators to measure sustainability performance at a corporate and project level. *Journal of Business Ethics* Vol. 44 Nos 2/3.
16. Kinderytė L., 2010. Methodology of Sustainability Indicators Determination for Enterprise Assessment. *Environmental Research, Engineering and Management*,. Kaunas, Technologija, Vol. 52, no. 2.
17. Krajnc D., Glavic P., 2004. Indicators for Sustainable Production. Technological Choices for Sustainability.
18. Laurinkeviciute A., Stasiskiene Z., 2011. SMS for decision making in SMEs. *Clean Technologies and Environmental Policy* Vol. 13, issue 6.
19. Lozano, R., 2012. Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives. *Journal of Cleaner Production*. Vol. 25, pp. 14–26.
20. Miller G., 2001. The development of indicators for sustainable tourism: results of a Delphi survey of tourism researchers. *Tourism Management* Vol. 22.
21. Pedersen C.; Nielsen B.B., 2000. Maintaining the momentum: EMS after certifier has left. In Hillary R., editor. *ISO 14001 – case studies and practical experiences*.
22. Pohjola T, 2005. Applications of an environmental modelling system in the graphics industry and road haulage services. *Implementing Environmental Management Accounting: Status and Challenges*. Editors: Rikkardson, P.M; Bennett, M.; Bouma, J.J.; Schaltegger, S. Springer.
23. Pryce V., 2002. CSR - should it be the preserve of the usual suspects? *Business Ethics: A European Review Year.* Vol. 11, iss. 2, p. 140-142.
24. Regulation (EC) No 1221/2009 of the European Parliament and of the Council of 25 November 2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC
25. Salzmann O.; Steger U.; Ionescu-Somers A., 2005. Quantifying economic effects of corporate sustainability initiatives – Activities and Drivers, IMD 2005-28, November 2005, p.24.

26. Searcy C.; Karapetrovic S.; McCartney D., 2005. Designing sustainable development indicators: analysis for a case utility. *Measuring Business Excellence* Vol. 9 No. 2, Emerald Group Publishing Limited.
27. Sikdar S. K., Sengupta D., Harten P., 2012. More on aggregating multiple indicators into a single index for sustainability analyses. *Clean Technologies and Environmental Policy* Vol. 14, Issue 5.
28. Staniskis J. and Arbaciauskas V., 2003. Sustainable industrial development: strategies and tools aimed at industry performance in Lithuania. *Environmental Research, Engineering and Management* Vol. 4(26), Technologija, Kaunas.
29. Staniskis J,. and Arbaciauskas V., 2009, Sustainability Performance Indicators for Industrial Enterprise management, *Environmental Research, Engineering and Management*, 2009, No. 2(48).
30. Topfer K., 2000. The triple bottom line economic, social natural capital. *UN Chronicle* Vol. 36 No. 2.
31. Toth G., Arbaciauskas V., 2005. Environmental performance evaluation. Technologija, Kaunas.
32. Upham P.J. and Mills J.N., 2006. Environmental and operational sustainability of airports: core indicators and stakeholder communication, *Benchmarking: An International Journal* Vol. 12 No. 2, Emerald Group Publishing Limited.
33. Veleva. V.; Ellenbecker M., 2000. A Proposal for Measuring Business Sustainability. *Greener Management International.* 2000, iss. 31.
34. Veleva, V. and Ellenbecker, M., 2001. Indicators of sustainable production: framework and methodology. *Journal of Cleaner Production* Vol. 9 No. 6.
35. Veleva V.; Hart M.; Greiner T.; Crumbley C., 2003. Indicators for measuring environmental sustainability, a case study of the pharmaceutical industry. *Benchmarking: An International Journal* Vol. 10 No. 2, MCB UP Limited.
36. Viluksela P, 2009. Environmental indicators in heatset offset printing. In Proceedings of the 5th International Conference *"EMAN 2009: Environmental Sustainable Development Indicators"* 23-24 April, 2009, Prague, Czech Republic. Usti nad Labem: J.E.Purkyne University in Usti nad Labem.
37. WBCSD, 2000. Eco-efficiency indicators and reporting. Status Report. WBCSD EEM WG, Geneva.

Address c
orrespondence to:
Valdas Arbaciauskas
Institute of Environmental Engineering, Kaunas University of Technology
K.Donelaičio str. 20, LT- 44239 Kaunas, Lithuania
E-mail: Valdas.Arbaciauska@ktu.lt
Tel: +370 37 300768; Fax: +370 37 209372

Possibilities for CO2 neutral manufacturing with attractive energy costs

Agnes Pechmann[1], Ilka Schöler[2], Sabrina Ernst[3]

[1] HS Emden/Leer, University of Applied Sciences, Germany
Constantiaplatz 4; 24627 Emden/Germany
agnes.pechmann@hs-emden-leer.de

[2] HS Emden/Leer; University of Applied Science
ilka.schoeler@hs-emden-leer.de

[3] HS Emden/Leer, University of Applied Sciences, Germany
sabrina.ernst@hs-emden-leer.de

Highlights

- Scenarios for full and partial energy supply of a manufacturing company and its costs
- Costs of the autarkic, renewable energy supply for a manufacturing company
- Feasibility of using an VPP regarding economic benefits and CO2-emissions
- Real case scenario of a manufacturing company located in rural Germany
- Economic aspects of manufacturing in a CO2-neutral way

Abstract

Germany's "Energiewende" is putting stress on the energy system. The transition of Germany`s energy system leading to a sustainable and non-nuclear system, are not only effecting the pressure on the power grid but also burden the financial pocket of the Germans. Energy costs are increasing despite declining power prices at the European Energy Exchange due to governmental induced levies, surcharges and taxes. For reducing energy costs, the self-supply with renewable energies might be an option.
In the article it is shown whether the investment in renewable power plants for the (partial)-self supply could be financially beneficial. A case study approach is used.

Different scenarios for supplying the energy demand of small and medium sized manufacturing companies are calculated using a specifically developed simulation. For the simulation real case data for the energy demand, measured weather data and realistic, calculated energy supply data for the elements of the Virtual Power Plant (VPP) are used. The scenarios range from full energy supply by an energy provider to the other extreme of an autarkic supply by the VPP. All scenarios work with a balanced out supply and are demand based. The balancing interval is 15 min time, the simulation time frame covers a period of one year. The proposed VPPs consist of entities using wind, solar, biomass and storage elements.

Keywords
Virtual Power Plant, renewable energy, CO2 neutral manufacturing, autarkic supply, energy costs, SME

1 Introduction

Germany's "Energiewende" is putting stress on the energy system. The transition of Germany`s energy system leading to a sustainable and non-nuclear system, is not only effecting the pressure on the power grid but also burden the financial pocket of the Germans. The national grid needs to cope with high feed-ins of decentralized, renewable energies and their fluctuating behavior, with the required change towards bi-directional energy transportation as well as the still insufficient capacity of energy storage.

In Germany, energy costs are increasing despite the declined prices for power at the European Energy Exchange over the last years; levies, surcharges and taxes have increased beyond the scope of the price decline. The privileges for energy intensive industry entities have also increased – excluding them partly from the general levies.

The rising energy costs for private households and small and medium sized companies combined with a feeling of being unfairly overburdened to finance the "Energiewende" is putting stress on the financial and emotional budget. In this case stress may have the positive effect of an activator for taking action, e.g. for investigating possibilities to reduce energy costs by investing into the self-supply with renewable energies.

In the article we target the question whether the investment in renewable power plants for the (partial)-self supply is being an attractive option for companies suiting their decision maker's motivation to be green and at the same time economically advisable. Lately, a research focus has been put either on energy intensive companies due to their high energy demand or on private households due to their high number.

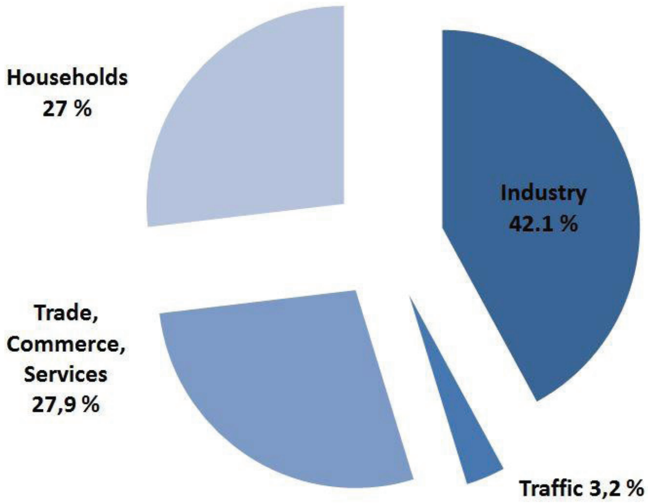


Figure 1 Energy consumption structure in Germany as of 2011(BMWI 2013)

Putting the focus on small and medium sized manufacturing companies

In the research the article is based on, the focus has been put on small and medium sized manufacturing companies due to their short decision paths and their private – often family – based ownership with a generally more medium- to long-term and sustainable profit orientation. They account for half of industry´s power-consumption (see figure 1). In two research projects[1] the possibility of direct usage of energy supplied by a company's own Virtual Power Plant has been investigated. After having shown that for some companies, the technical, organizational and geographical feasibility of such an option is given (see Pechmann, Hackmann 2015), the economic aspects have been looked at. For a specific case, a small company of the metal-working industry, with app. 70 employees, working on a combination of a one to two-shift schedule, a Virtual Power Plant (VPP) has been designed that is able to supply the company's energy demand completely by itself. The feasibility has

[1] For information regarding the projects PREmdeK and REN ProV see http:\\www.e-pps.de.

been shown by a simulation based on real data. The simulation was developed in the research project PREmdeK[1]. The demand data resemble the actual demand of the company for twelve month on a 15 min interval base. The supply data have been generated based on local weather conditions of the same timeframe and realistic energy generation calculations. The location of the company is in rural North-Western Germany with less than 1500 hours of sunshine per year on average and a day length between 16,8 and 8,4 hours per day.

The designed VPP of the real case with the full, autarkic supply of renewable energies consists of the following elements (see figure 2.)

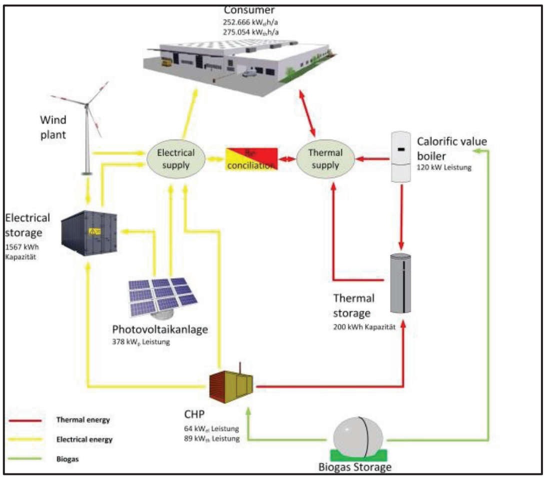


Figure 2 Elements of the VPP for a manfuacturing site (real case)

The Virtual Power Plant as an option to be profitable and green

The investment into a Virtual Power Plant (VPP) is a complex decision problem. If companies want to change from the traditional supply of energy by a central energy provider to the supply by their own VPP, the investment decision has to be based on a technical feasible scenario. What preconditions this scenario has to fulfill for being realistic and applicable, is the first research question that has to be answered. One precondition is the VPP`s ability to supply sufficient energy for the company to operate. The conventional costs of energy provision by a central provider have to be compared to the investment and operational costs for the VPP.

The energy demand of manufacturing companies depends on the order situation and the production environment; the energy supply depends on the design of the VPP and the availability and price of primary energy sources. For example, sun and wind as primary sources are free of costs but not always available - depending on weather conditions, time of day and season.

The second research question whether it is profitable to implement the decentralized power plant in a mid-sized manufacturing company is answered by the economic calculation model. The calculation model simulates the combination between photovoltaic, wind turbine, Combined Heat and Power (CHP), electricity storage and calorific value (condensing) boiler in a decentralized power plant.

The last years development of energy costs indicates a clear upwards trend even though electricity prices are sinking at the German energy exchange in Leipzig (EEX). Temporarily there is so much energy of renewable energy sources feeding the public grid that either wind turbines or solar farm have to be taken off the grid and the energy prices (market clearing price) are going down.
These effects are obvious at EEX, where partially, negative energy price developments can be observed. (Küchler 2013; Ismar and, Lessmann, 2013). Due to this paradox – increasing energy costs at the consumer despite declining prices at the EEX – Virtual Power Plants might become a more and more attractive option for companies.
One question for a small or medium sized company will be if a Virtual Power Plant is financially attractive. This can be shown with figures like amortization time, Net Present

Value and the Internal Rate of Return. Particular attention should be given to the Internal Rate of Return because of the power plants long life cycle.

The transformation of our societies, regardless of how far developed, to sustainable societies calls for an exemplary raw model showing the feasibility of a new manufacturing approach – being competitive, energy effective and CO2 neutral. The scientific community has proclaimed the need to change in order to keep the climate on earth attractive and suitable for mankind. National governments have come far with acknowledging the need to transform our societies away from purely GDP-driven societies to a sustainable and eco-friendly one, but time runs out in order to keep changing. We need to create momentum in order to change. The momentum can be achieved more easily, if required actions are financially beneficial.

2 Simulation and cost calculation approach

The calculation of the energy costs for supplying a manufacturing company with renewable energy is based on a company raw model. The actual energy demand data (see Table 1/ Figure 3) are given on a 15 min time interval. For this company evidence has been provided that an autarkic supply of energy by a Virtual Power Plant (VPP) is possible. The evidence is provided by a simulation with measured energy demand data and realistic energy generations data for the elements of the VPP. For the calculation of energy generation measured local weather data is used, for PV and wind power plants the energy generation calculations have been verified at random with measured data of implemented plants (Ernst et al. 2013). Photovoltaic and wind power are considered as renewable energy sources; Combined Heat and Power (CHP(as well as the calorific boiler are considered as renewable if biogas is used as energy source.

For biofuels the CO2-emission factor is set equal to 0 g/kWh (Graichen et al. 2008, p.10). The CO2 emission equivalent factor for naturalgas is taken from the energy provider EWE AG. It is stated as 200 g CO2 per kWh (Hochschule Emden/Leer 2014). The CO2-emission factor for regular power from EWE is stated as 441 g CO2 per kWh (EWE AG 2012).

Table 1 Monthly energy consumption by case company

	Consumption of Company	
	Power [kWh]	Gas [kWh]
Jan 14	21.501	73.477
Feb 14	21.193	48.282
Mar 14	24.434	30.340
Apr 14	22.714	8.344
May 14	22.485	1.275
Jun 13	18.440	712
Jul 13	20.182	407
Aug 13	20.012	317
Sep 13	21.199	388
Oct 13	22.975	3.162
Nov 13	21.998	49.771
Dec 13	15.533	58.581
	252.666	**275.054**

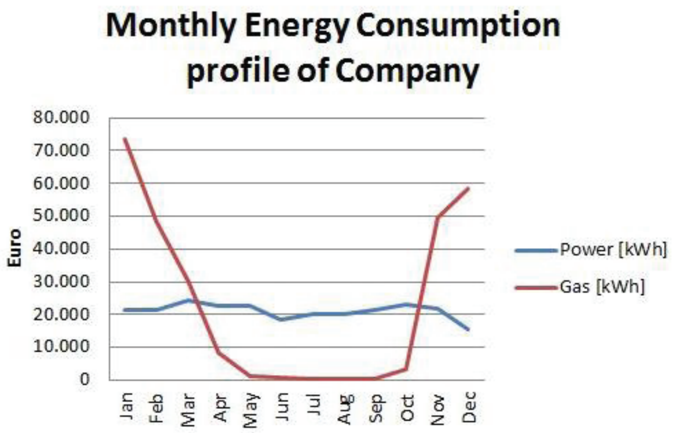


Figure 3 Monthly energy consumption profile of case company

The simulation is covering a timeframe of 12 month based on 15 minutes time intervals. The VPP in the simulation is run in a simple operation mode: The simulation balances the energy demand and supply for power and for heat for every 15 min interval[2]. The demanded energy of the manufacturing site is met by a combined supply of the VPP`s elements. As a backup source, power from the local energy provider via the grid connection is used. The backup source is used as a second priority supply, only used if power from the renewable sources or the electrical storage is not sufficient. If the renewable, fluctuating sources generate more energy than consumed by the company, the excess energy is first used for filling up the storage facilities and is then either fed to the grid or spoiled. In the case of power, excess is fed to the grid. In the case of heat, excess is wasted since in the case example no opportunity exists to sell the heat.

In the simulation, the composition of the VPP can be modular selected. The different compositions used in this study are resembled in different scenarios (see Table 2). All scenarios can be run with naturalgas or renewable biogas. The presented scenarios represent a selection of possible scenarios. As base scenario the provision of energy through the local energy provider for power and naturalgas is taken.

Table 2 VPP-elements in the supply scenarios

Scenarios	21-autarc full VPP	27 w/o wind	2-w/o ElStorage	3 w/o CHP & ElStor	6 w/o Wind,CHP & ElStor	8 w/o wind & CHP	Base Scenario Energy Provider	
	Natural- or Biogas	Natural- or Biogas	Natural- or Biogas	Natural- or Biogas	Natural- or Biogas	Natural- or Biogas	Natural-gas	Biogas
PV	x	x	x	x	x	x	-	-
Wind	x	-	x	x	-	-	-	-
CHP	x	x	x	-	-	-	-	-
Elec. Storage	x	x	-	-	-	x	-	-
Power to grid	x	x	x	x	x	x	-	-

[2] For power, active energy is used as a measure for balancing the system. Aspects like reactive energy or frequency stability are not considered.

Power from grid	no	x	x	x	x	x	x	x

Cost calculation approach

For calculating the energy costs, life cycle cost assessment and cost benefit analysis are applied. The investments for a VPP (Virtual Power Plant) are compared against full provision of energy by an energy provider. The energy contract conditions of the case, the manufacturing company are taken.

Based on these methods, the Internal Rate of Return (IRR), the payback period and the total Net Present Value (NPV) will be calculated. The NPV is calculated in the framework of the cost benefit analysis.

For life cycle costing, a life cycle of 20 years minimum is assumed. For this time frame costs incurring for owning, operating, and maintaining the VPP and for the purchase of energy are considered. In opposite to the LCCA approach (see Fuller, Petersen 1996) the dismantling of the VPP is not included since the expected life time exceed the 20 years here considered. Costs incurred during the 20 years are discounted to their present day value.

For the cost benefit model, those cost and benefit parameters are considered in the calculation that would occur when a scenario other than the base scenario with naturalgas is chosen.

Investment costs are either based on real case implementations of respective objects at the site of the case company or are investigated through requests to suppliers and then verified by experts and sales representatives (price status as of 2013). Exception to this is the price of the electrical storage. Here, the official sales price as given on websites (April 2014) is used. For operating and maintenance costs different sources (empiric data, studies, and estimations by specialist staff) have been investigated and checked against applicability (Schürmann 2013, Suradika 2014).

Assumption and cost data

The following assumptions were made for the life cycle cost analysis and the cost benefit analysis: The planning and design cost is assumed to be included in the investment cost for the plant. The disposal cost of the VPP equipment is neglected and assumed to be less than the generated benefit after the life time of 20 years. The refurbishment and disposal cost highly depends on many factors, for example material prices (Nordahl 2011). One exception to this applies: Due to the lifespan of the Electronic Storage, its full replacement costs are included after ten years. The general discount rate is set to 6,5 % per year (European Photovoltaic Industry Association 2011). All of the costs are considered without value added taxes. A sensitivity analysis is not included in the cost benefit analysis.

Table 3 Energy provision costs

Energy related procuring costs prices, taxes, levies (2014)	**[EUR/kWh]**
Electricity price day (Energy provider)	0,1180
Electricity price night (Energy provider)	0,0980
Biogas price (Internet)	0,1090
Naturalgas price (Energy provider)	0,0460
Costs for peak power has been neglected, same as volume independent charges	
Taxes (not VAT)	0,0205
Levy EEG	0,0624
KW-KG	0,0018
Strom-NEV (Electricity Grid User Charge Ordinance)	0,0009

Energy related selling benefits	**[EUR/kWh]**
Power selling price (Feed to grid) Actual price, is set by German law [3]	0,0450
Heat selling price (Feed to grid)	--

Table 4 VPP investment and maintenance costs considered

VPP Investments & Maintenance costs			
VPP Element	Capacity [kW]	Investment cost [EUR]	Maintenance cost [EUR]
Photovoltaic plant	378	410.400	1.000
Wind turbine	30	93.600	350
CHP el.	64	36.000	350
CHP th.	89		
El. Storage	1567 (netto [kWh])	26.400	100
Gas Tank (if biogas is used)		16.000	neglected (100€)

Besides energy related costs, there is a potential CO_2 reduction cost benefit. Due to the low current and expected future prices for CO_2 certificates in the European Trading System (ETS), this benefit is neglected.

In the following section, the results of the cost calculations for different energy supply scenarios are presented. The cost calculations are done for each scenario twice, once for the usage of biogas and once for the usage of naturalgas. For each scenario, with its chosen elements for the Virtual Power Plant (VPP), the simulation calculates the generated energy (power and/or heat) per plant and the required amount of the energy source in case of the Combined Heating and Power Plant[4] (CHP). If the supply of the VPP is not sufficient to satisfy the demand of the company, the missing energy is purchased by the energy provider. The calculation is done for each 15 min interval of the twelve month time frame. The year of June 2013 to May 2014 is taken as reference base. The results are then aggregated to monthly values. As example for the monthly results of scenario 21 see Table 5. The monthly values build the base for the costs calculations.

[3] For new PV-plants up to 500 kWp the feed in tariff is fixed for 20 years. For plants with a feed in start in August 2014 on non-residential building the feed-in tariff was 0,08 EUR/kWh (http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/Datenmeldungen/EEGVerg_2014_Aug-Sept.xls)

[4] The CHP is using gas as energy source to generate power and heat at the same time.

Table 5 Aggregated monthly values for scenario 21

VPP supply 06/2013-05/2014								VPP demand
	Electricity			Heat				
Month	CHPel [kWh]	PV [kWh]	Wind [kWh]	Condensing-Boiler	CHPth	Elec. Feed to Grid		Gasconsumption
January	18.704,00	625,74	2.573,16	42.612,75	24.658,76	-802,14		82.347,56
February	20.352,00	505,00	1.351,15	25.252,00	26.023,04	0,00		68.652,87
March	21.856,00	1.807,13	1.297,96	14.525,25	28.731,23	0,00		61.693,82
April	17.408,00	5.455,66	330,32	3.076,25	23.661,01	0,00		40.718,08
May	12.384,00	14.279,12	440,19	401,25	17.165,43	-3.321,07		27.137,83
June	0,00	41.087,76	1.506,20	722,25	285,07	-22.081,39		756,83
July	0,00	50.097,78	339,33	481,50	0,00	-29.268,21		469,76
August	0,00	41.546,08	716,59	401,25	0,00	-20.866,92		391,46
September	7.104,00	14.029,28	2.911,11	53,50	10.405,14	-3.346,41		15.380,10
October	16.688,00	4.403,87	3.195,10	508,25	21.421,15	-89,41		36.476,53
November	17.040,00	480,07	5.512,81	29.451,75	21.869,13	0,00		65.577,97
December	12.784,00	882,56	3.697,00	38.974,75	16.289,85	-228,37		65.633,57
Total	**144.320,00**	**175.200,04**	**23.870,93**	**156.460,75**	**190.509,81**	**-80.003,91**		**465.236,39**

3 Results/Findings

Based on the monthly values, energy purchasing costs are calculated and summarized to yearly costs. Maintenance costs are added. The Life Cycle Costs for the time span of 20 years include the yearly discounted costs of the reference year and the investment costs. In Figure 4 the Life Cycle Costs for the scenarios are given when biogas is used as energy source either as input to the CHP or purchased from the energy provider. In Figure 5 the Life Cycle Costs for the scenarios are given when naturalgas is used as energy source.

CO2 emission per scenario is calculated by using the CO2-equivalent factor for the used energy. The result is displayed in Table 6. It should be noted, that the result show the CO2-emissions based on a yearly rate. Negative numbers result from power feed-ins to the grid.

Table 6 CO2-emission per scenario

Scenarios	21- autarc full VPP	27 w/o wind	2- w/o ElStor age	3 w/o CHP & ElStor	6 w/o Wind, CHP & ElStor	8 w/o wind & CHP	Base Scenario Energy Provider	
	Natural gas	Natural gas	Natural gas	Natural gas	Natural gas	Natural gas	Natural gas	Biogas
CO2-Power [t]	-35	-31	28	24	34	38	111	111
CO2- Gas [t]	93	99	44	44	55	44	55	0
CO2 for total consumption [t]	**58**	**68**	**72**	**67**	**89**	**82**	**166**	**111**
	Biogas	Biogas	Biogas	Biogas	Biogas	Biogas	Nat. gas	Biogas
CO2-Power [t]	-35	-31	28	24	34	38	111	111
CO2- Gas [t]	0	0	0	0	0	0	55	0
CO2 for total consumption [t]	**-35**	**-31**	**28**	**24**	**34**	**38**	**166**	**111**

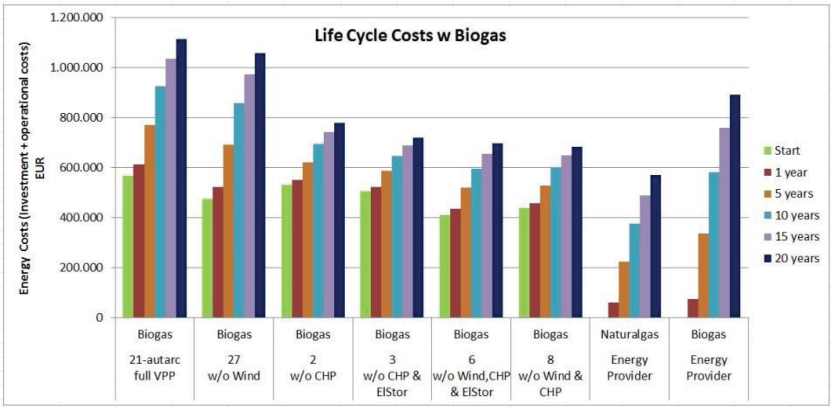


Figure 4 Life Cycle Costs with biogas as energy source

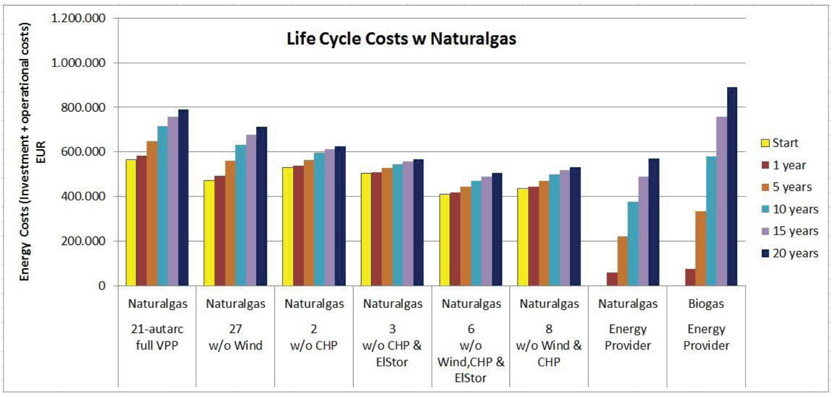


Figure 5 Life Cycle Costs with naturalgas as energy source

The Net Present Value (NPV) is calculated for the usage in the cost benefit analysis. Those applied investment and maintenance costs occur when the VPP, in its various forms as resembled in the scenarios, is used to fully or partly satisfy the energy demand of the company. For instance a condensing boiler (calorific value boiler) is used at the company regardless of the scenarios; the costs are therefore not included. The NPV with the costs as occurring in the numbered scenarios are compared to the base scenario, the provision of energy by the energy provider.

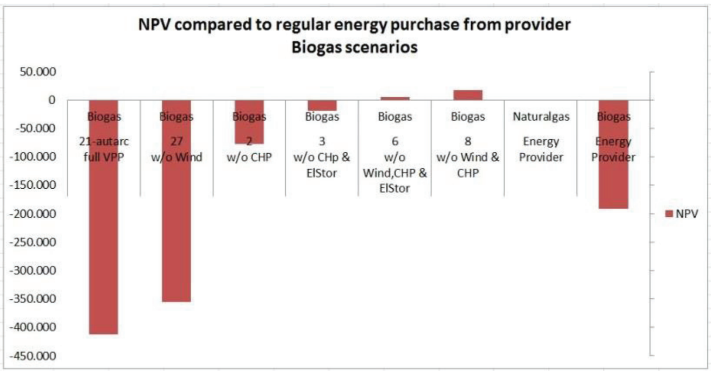


Figure 6 NPV compared to energy purchase from provider (biogas scenarios)

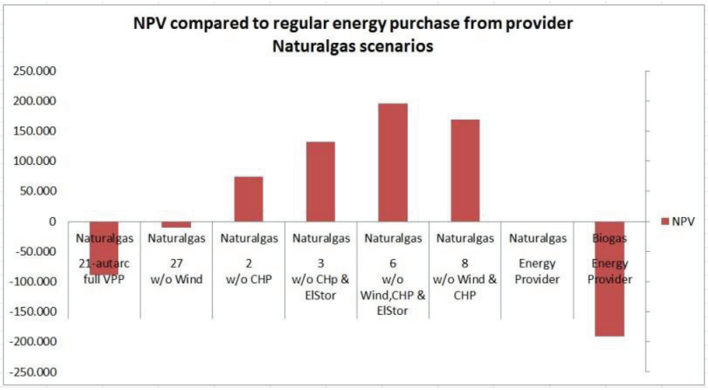


Figure 7 NPV compared to energy purchase from provider (naturalgas scenarios)

In Figure 6 and Figure 7 the NPVs of the different scenarios are shown. In Figure 6 the NPVs are presented if biogas is used as gas type. Second to the right, the base scenario with naturalgas is shown with its NPV value of zero; to the far right the base scenario with biogas can be found. In Figure 7 the NPVs of the scenarios are shown if naturalgas is used. The base scenario is again shown second to the right.

A positive NPV resembles that a scenario is more advantageous compared to the base scenario with naturalgas.

In Figure 8 and in Figure 9 the values for the Internal Rate of Return (IRR) for the different scenarios are given. Only two of the scenarios have a negative IRR, the scenarios 21 and 27 both with biogas as gas supply. Best IRR with looking at the biogas scenario is scenario 8, closely followed by scenario 6.

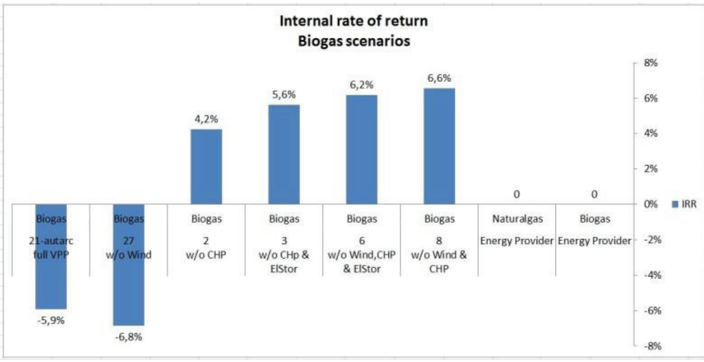


Figure 8 Internal Rate of Return for biogas scenarios

All scenarios using naturalgas as gas type have a positive IRR. Even the scenario 21, where the power supply is done completely autarkic, without using power through the grid, has a positive IRR of 4,4 %

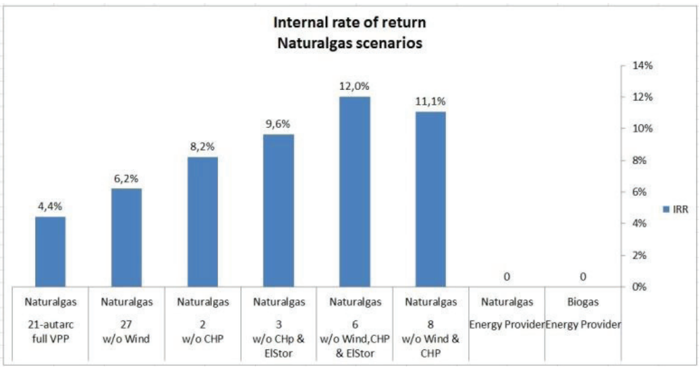


Figure 9 Internal Rate of Return for naturalgas scenarios

In Figure 10 and in Figure 11 the payback rates for the scenarios are shown. The lowest payback period for the biogas scenarios has scenario 8 whereas scenario 6 has the lowest payback rate if naturalgas is used (Figure 11). Scenario 6 and 8 differ only in one point: scenario 6 is not using electrical storage whereas scenario 8 does.

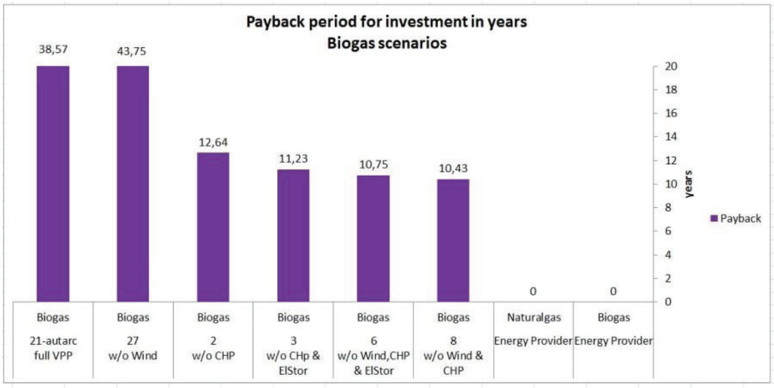


Figure 10 Payback period for investment in years for biogas scenarios

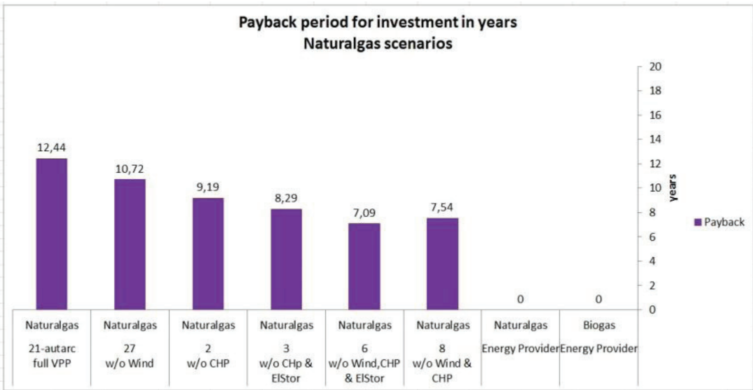


Figure 11 Payback period for investment in years for naturalgas scenarios

4 Conclusions

The need to transition to post fossil carbon societies is taken as granted at the ERSCP 2014 conference, the 17th European Roundtable on Sustainable Consumption and Production. One of the questions to discuss is how the transition process can be accelerated and supported. In Germany, industry has a share of 42% of the energy consumption. About half of it results from activities of small and medium sized companies (SME). If SMEs would satisfy their energy consumption with renewable energies, a big step forward on the road to transition would be achieved. For a SME to switch its energy supply onto CO2-neutral energy, in general two ways are possible: One is the purchasing of green energy through a provider; the other one is the full or partial self-supply by its own Virtual Power Plant (VPP). The more financially attractive and less risky an option appears, the more likely is the chance that SME change their way of energy supply. For the case of a typical metal processing company in Northern Germany several scenarios of full and partial self-supply through a VPP are simulated and its costs calculated. The costs of each scenario are compared to a base scenario with the traditional supply by an energy provider.

For the appraisal of the different supply scenarios, the NPV, IRR, payback period and the LCC have been calculated for the different scenarios.

The only scenario which is fully CO2-neutral at every 15 min interval is scenario 21 with biogas as gas type. This scenario shows, compared to all other scenarios, the least attractive financial results. This is due to the high gas consumption of the CHP to generate power once sun and wind do not provide enough energy and the storage capacity cannot compensate this. The gas demand in this scenario is 465 MWh whereas the original gas consumption from the company, as displayed in the base scenario, is 275 MWh.

One other scenario can be considered CO2-neutral if the balancing interval of 15 min is neglected and instead the full year for CO2-neutrality is considered. Due to the feed-in of CO2-neutral power to the grid and offsetting it with the power taken off the grid, scenario 27 is CO2-neutral as well; more precise it is even causing a CO2-benefit (see Table 6).

When looking at the results it shows that the scenarios 3, 6 and 8 with partial supply through a VPP and a backup strategy through an energy supplier show the most attractive conditions. They are all without the investment in a wind power plant and in a CHP. CHP is an expensive form to generate electricity when the simultaneously generated heat is not of benefit. The technical efficiency for power generation is 36,6%. In the case of the wind turbine, circumstances are different. For once, the dimension of the wind turbine is low compared to the energy demand of the company. This is due to legal restrictions that apply for installing a plant at the company's premises. Furthermore, the yield of the turbine, the generated energy, is lower than expected. Further studies should look into the correctness of the measured weather data once more, especially regarding the wind speed. Another possibility for the low yield might have been that the average wind speed of the concerned year was below the average.

The figures presented in this article give an overview of costs for CO2-neutral and -reduced supply of energy for different energy supply scenarios. It is shown that the CO2-reduced supply of energy with its own VPP as resembled in scenarios 2, 3, 6 and 8 offer more attractive options than the base scenario considering the values of Net Present Value and the Internal Rate of Return. The figures give as well the opportunity to estimate the tradeoff of full CO2-neutrality and reduced CO2 emissions and its respective costs compared to the traditional supply with its CO2-emissions and costs.

For the cost calculation CO2-emission benefits or penalties have been neglected completely due to the low certificate price of under 5 EUR per ton (4,63 EUR, real time course CO2 emission certificate on 10.9.2014). In case the current CO2-certificate price for the total CO2-emission for one year is applied, the difference in costs for one year between the base scenario and the complete CO2-neutral scenario 21 with biogas amounts to less than 1000 EUR per year. The yearly costs for CO2-emissions in case of scenario 21-biogas (the least attractive in financial terms) would need to rise to 14.500 EUR to turn the IRR positive.

The results presented in this article clearly show, that a partial self-supply of renewable energy is a very attractive option in financial terms. This is especially evident for the scenarios where power is generated by Photovoltaic modules and can be directly used. Excess power originating from Photovoltaic panels and feeding to the grid has been priced very low at 0,045 EUR per kWh, not accounting for the specific situation in Germany with its of feed-in tariffs set by law. The results are based on a real case scenario, with mainly measured base data and very realistic calculations for the energy “harvest” of the renewable energy plants.

The results show that a substantial reduction of CO2-emissions can be achieved under very attractive financial conditions for companies being able to install their own Virtual Power Plant, especially Photovoltaic modules.

Acknowledgments

The authors would like to acknowledge the contributions of two Federal Ministries of Germany (BMBF, BMWI) for funding the research projects REN PROV and PREmdeK. Furthermore the authors want to express their gratitude to Annika Menzel for editing and to the former students Ecem Balkan, Dharmaji Suradika and Carla Schürmann who have supported the research work in the framework of their study dissertations.

References

Bundesministerium für Wirtschaft und Technologie- BMWI (2011): Energie in Deutschland, Trends und Hintergründe zur Energieversorgung, 2013, S. 22. Available online at: http://www.bmwi.de/Dateien/Energieportal/PDF/energie-in-deutschland, checked at 08.09.2014.

Ernst, Sabrina; Hackmann, René; Pechmann, Agnes; Schöler, Ilka: A simulation based feasibility study to satisfy the energy demands of SME production sites by their own multi-source renewable power-plants. Publication of the Intelligent Energy Systems (IWIES) Conference, IEEE International Workshop 2013, Wien. Available online at: http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=6698558&tag=1.

European Photovoltaic Industry Association (2011): Solar Photovoltaics Competing in the Energy Sector. Available online at http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiapublications/Competing_Full_MR.pdf&t=1402346989&hash=bb5ed64ec0f463f0a4d78b98b5ace3dbfd074ea4.

EWE AG (2012): EWE Stromkennzeichnung. Woher kommt der Strom von EWE? Energieträger und Umweltauswirkungen (Angaben in Prozent). Available online at http://www.ewe.de/geschaeftskunden/strom-kennzeichnung.php, checked on 15/06/2014

Fuller, S. K.; Petersen, S. R. (1996): Life-Cycle Costing Manual for the Federal Energy Management Program. U.S Department of Commerce Technology Administration National Institute of Standards And Technology. Gaithersburg. Available online at http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf, checked on 25/04/2014.

Graichen, Verena; Schumacher, Katja; Matthes, Felix Chr.; Duscha, Vicky; Schleich, Joachim; Diekmann, Jochen (2008): Climate Change: Impacts of the EU Emissions Trading Scheme on the industrial competitiveness in Germany. Edited by Benjamin Görlach. UMWELTBUNDESAMT. Dessau-Roßlau, updated on 30/01/2009, checked on 17/06/2014.

Hochschule Emden/Leer (2014): PREmdeK. Available online at http://www.hs-emden-leer.de/en/research-transfer/projects/energy-efficiency-in-production/premdek.html, updated on 30/01/2014, checked on 16/02/2014

Küchler, S. (2013): Strompreise in Europa und Wettbewerbsfähigkeit der stromintensiven Industrie. Available online at http://www.foes.de/pdf/2013-01-Industriestrompreise-Wettbewerbsfaehigkeit.pdf

Ismar G.; Lessmann P. (2013): Energiewende - Deutschland verschenkt seinen Strom - Politik - Deutschland - Hamburger Abendblatt. Available online at http://www.abendblatt.de/politik/deutschland/article112688765/Deutschland-verschenkt-seinen-Strom.html, zuletzt aktualisiert am 11.01.2013, zuletzt geprüft am 09.07.2013.

Nordahl, Marcus (2011): The development of a Life Cycle Cost model for an offshore wind farm. Master Thesis, Sweden. Chalmers University of Technology. Available online at http://publications.lib.chalmers.se/records/fulltext/152402.pdf, checked on 21/06/2014.

Pechmann, Agnes; Hackmann, René: CO2 neutral manufacturing: Classification matrix on the suitability of manufacturing sites to run on renewable energies, in: Journal of Cleaner Production, Special Issue: "Towards post fossil carbon societies: regenerative and preventative eco-industrial development", to be published 2015.

Schürmann, Carla (2013): Economic viability of a virtual power plant for an autonomous supply of a company. Hochschule Emden/Leer.

Suradika, Dharmaji (2014): Economic study of a decentralized power plant for small and medium companies based on a case. Masterthesis at the Hochschule Emden/Leer.

Climate Citizens
– Analysis of roles, experiences, challenges and opportunities using the example of the citizens of Heidelberg/Germany –

Frieder Rubik[1]*, Michael Kress[1]

[1] *Institute for Ecological Economy Research (IÖW), Bergstraße 7, D-69120 Heidelberg/Germany*

* *Corresponding author: frieder.rubik@ioew.de, Tel. ++49-6221-649166*

Topic: Experiences with sustainable/smart cities and communities

Abstract

Germany's government decided to phase out nuclear energy which demands the transformation of Germany's energy system encompassing a process of societal change. This process is characterized by new opportunities for action as well as new responsibilities, on a federal, regional and local level. In particular, cities and communities are asked to act and support "their" citizens. This paper describes different roles of citizens using the example of Heidelberg/Germany. First and preliminary empirical insights are presented and some conclusions are drawn.

Keywords: Energy transition, climate protection, consumption behaviour

1. Introduction

The decision of the German government to phase out nuclear energy demands the transformation of Germany's energy system encompassing a process of societal change. This process is characterized by new opportunities for action as well as new responsibilities, on a federal, regional and local level. In particular, cities and communities are asked to act and support "their" citizens.

This forms the background of this paper. In chapter 2, we describe the background, methods applied and objectives of this paper, which is an outcome of an ongoing research project. Empirical insights are presented in chapter 3 using the example of Heidelberg/Germany. First – preliminary – conclusions are presented in chapter 4.

2. Background, methods and objectives

2.1. Research background

The analysis, interpretation and activation of these roles are the main focus of the ongoing[1] research project Klima-Citoyen" ("Climate citizen"). This project is funded by the German Federal Ministry for Education and Research (BMBF), within its national research program "Transformation of the energy system". It is coordinated by the University of Saarbrucken/DE, and its cooperating partner, the Zeppelin University of Friedrichshafen/DE.

The project examines how citizens become aware, take advantage of, and engage in these new opportunities of active participation within the energy transformation process. The particular approach and challenge of the project lies in considering individual motives, influential local framework conditions and effects of the various roles and parameters with reference to each other - respecting possible interactions and spillover-effects. Partner communities are the cities of Heidelberg/DE, Nalbach/DE and the regions Steinfurt/DE and Altmark/DE.

The aim of the project is to analyze how citizens in the different regions perceive possible roles and options for action differently. Moreover, it seeks to identify stimulating and limiting factors for citizens in seeking to exercise their roles. Furthermore, participation methods in the field of energy consumption and its production will be developed and tested. Finally, a guide for municipalities on how to support and activate their citizens will be developed.

2.2. Citizens and their different roles and scope

As "citizens", we understand persons who actively engage in, and responsibly shape, the transformation process – not just as consumers, but also in new or altered 'roles' such as producers, investors and political protagonists:

- The scope for action and influence linked to the role of the 'energy consumer' implies changes in everyday energy consumption, investment in energy efficient household appliances, consumption of green electricity and strategic investment decisions, e.g. energy-efficient refurbishment. In this role, the share of German private households in Germany's final energy consumption is about one third

[1] The project started in April 2013 and runs until March 2016.

(Graichen et al. 2011). However, more than one third of this demand for energy results in dwelling/living compared to areas such as mobility and nutrition.

- Citizens are able to shape the production side of the energy system taking action in the role of 'investors and producers'. On the one hand, citizens can invest in renewable energy facilities (private or common). On the other hand, they can participate in related infrastructural projects such as electricity network expansion. The concept - energy in citizen's ownership - is being implemented already. Almost 40 % of renewable electric power produced in 2010 can be traced back to individual persons (Trend-research/KNI 2011).
- In either a supportive (or obstructive) way, the political commitment by citizens may influence the development of renewable energy and related changes in infrastructure. Beside financial investments, citizens can influence the expansion of renewables and the associated infrastructure needed, by different types of political engagement.
- "Social" effects, in a broader sense, are seen as a crosscutting issue, insofar as effects spread into other fields of action (i.e. in education and formation of public opinion). Thus, social effects will be considered separately.

The following figure 1 gives an overview of the different fields of action for each role (consumer, producer/investor, political activist) as well as role-specific criteria (heat/electricity and formal/informal participation).

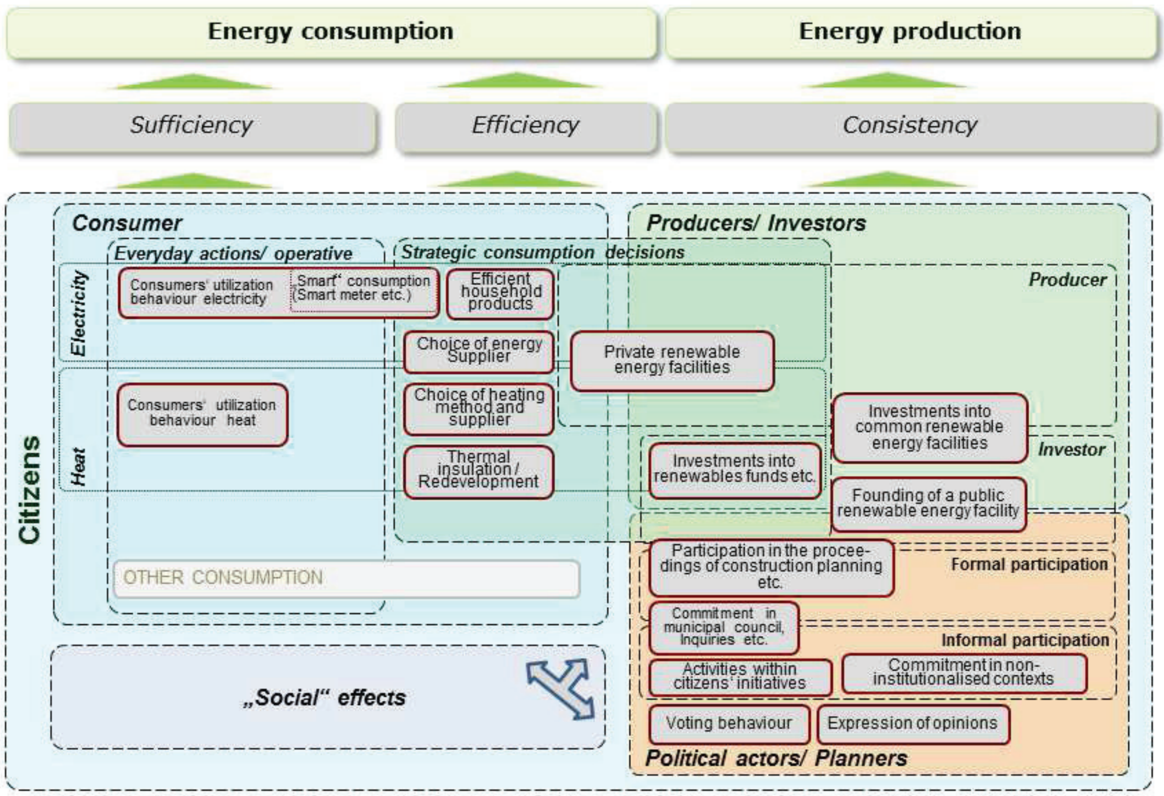


Figure 1: Overview on roles and action areas

As described previously, citizens in their various roles have different capabilities to exert influence on different aspects of the energy transition. In order to ensure a focused analysis, we restrict the scope of the research to:

- Citizens‘ influence on their ‚direct‘ consumption level at home (electricity and heat),
- Citizens‘ influence on the development and expansion of renewable energy.

2.3 Methods applied

The project applies quantitative and qualitative empirical methods:

- Literature review: For each community/region, an extensive document search and analysis has taken place to learn, as far as possible, the current state of debate.
- Stakeholder and expert interviews: A series of face-to-face interviews with local/regional administrations, NGOs, energy consultancies, representatives of potential “handicapped” persons (e.g. migration council, tenant associations) have been carried out to learn opinions and interests.
- In depth interviews with engaged citizens: For the analysis of individual values, opinions and forms of involvement, qualitative interviews had been carried out with engaged citizens from February to April 2014. The choice of participants was based on a questionnaire inquiring as to socio-demographic background and involvement in the respective fields of action. The face-to-face interviews were semi-structured and interpreted applying qualitative content analysis. Furthermore, the analytical categories were generated using both an inductive (data-based), and deductive (theory-based), approach.
- Focus groups: A focus group with 10 participants for each region was conducted in order to complement and reflect on results of the interviews. Additionally, the focus group is seen as a tool with which to highlight issues of group dynamics within particular fields of action. Based on audio recordings and written records of the focus groups, a synoptic content analysis was conducted.
- Survey: In each city/region, a survey was carried out: After selection of districts, a questionnaire was sent by random mail to about 5,000 households per city or region. The return quota was at least 500 answers per region/city, which was judged as reasonably representative. The data was analyzed using SPSS.

2.4. Conceptual background[2]

In the field of consumer science, consumers are regarded as occupying different roles in society and its markets (Reisch 2004), in which they hold different spheres of influence as well as incentive structures. On the one hand, these structures trigger possible behavior change in consumers. On the other hand, consumers are classified into different types, (such as the „trusting“, the „vulnerable“, and „responsible“ consumer), each reflecting different modes of behavior, modes of consumption, and related competencies (Micklitz et al. 2010).

These classifications are practically relevant insofar as the above mentioned roles determine judgments about conditions, decision-making and related motives. If energy policies want to be successful, each consumer group needs to be approached differ-

---

2 Based on a contribution by Lucia Reisch to the project background paper (unpublished).

ently in terms of incentives and arguments (Dolan et al. 2012). These consumer types represent archetypes. In fact, respective modes of behavior might co-exist in different fields of consumption.

However, activities of citizens are partly individual decisions, meaning that one person is responsible for decision-making processes due to intra-individual impulses. We have to consider that social (group) norms act on processes of individual decision-making. Individuals either try to assimilate with, or dissociate themselves from, social norms (Bänsch 2002). Thus, individual decisions stand next to collective decisions. According to Kirchler (1989), decisions can be expected to be collective, if a product or a service affects various persons, is socially prestigious (i.e. for a family) or rarely purchased.

The above mentioned fields of practice on the actors' level are subject to several individual motives, social norms and daily routines as well as external conditions and influences. Each scientific perspective offers different models to describe these diverse factors using discipline-specific variables and methods, which in turn influence possible intervention strategies.[3] The model of environmentally relevant everyday behavior introduced by Matthies (2005) offers a practical approach to condense the various factors of influence (motives, norms, routines etc.). It extends the insights of intervention research with a practical psychological analysis of environmentally relevant behavior, thus enabling a discourse with practitioners in the realms of politics or environmental protection activism. Matthies' framework is grounded in the theory of moral decisions by Schwartz/Howard (1981), and, in parts, supplemented by the theory of planned behaviour (Ajzen 1991). Thus, it takes individual as well as social norms (i.e. expectations of others) and other motives such as benefit expectations into consideration. As for that matter, political instruments that want to change consumer decisions need to consider different modes of behavior, motives as fields of action or possible constraints. Consequently, the maxim of "one size fits all" for designing political intervention seems obsolete. Instead, instruments are required to address the potential target group and to anticipate empirical outcomes. Finally, instruments need to be evaluated on a regular basis (Hübner/Müller 2012; Reisch/Renn 2012).

[3] A range of psychological models tries to explain human behavior and its motives. One of the most popular approaches is the theory of planned behavior (Fishbein/Aijzen 1975) and the norm-activation framework by Schwartz/Howard (1981). Contrary to most frameworks, the HABIT-Modell (Habit assessment and behaviour intervention typology) does not focus on conscious decision-making but on daily routines and habits, as exemplified by everyday energy consumption patterns (Heijs 2007).

3. Case Study Heidelberg[4] - First and preliminary results

3.1 Framework of citizens' participation in Heidelberg

Some time ago, Heidelberg introduced a local concept of citizens' participation for all policy fields (Stadt Heidelberg 2012). A culture of open public communication supports the development of citizens' participation. In the long run, regular lively discussions between political stakeholders, the local government and the citizens will be institutionalized. By doing this, and apart from concrete projects of citizens' participation, a public discourse on sustainable urban development will be ensured and implemented.

In the time of virulent energy issues, the elaboration process of the "Master plan 100% climate protection" (Stadt Heidelberg 2014) has been supported by six different working groups and three public conferences. Within this project, citizens have been actively involved in developing and implementing short-term as well as medium-term measures. In addition to that, a stakeholder forum of about 90 groups accompanied this process.

3.2 Activities and motives of active citizens in Heidelberg

Options of action and motive structure

Active citizens are committed to diverse actions and roles while also showing different biographical and normative backgrounds. They have a clear idea of how the goals for a successful energy transition should be implemented. According to their opinion, a sustainable energy system should exclusively focus on renewable energy sources (apart from biomass, whose promotion has been criticized) while being decentrally organized. Furthermore, a sustainable energy system should pursue aims of sufficiency and be citizen-owned.

In the field of **energy consumption**, conscious consumerism, the usage of green energy in the household plus changing routines (e.g. conscious use of electronic equipment, avoidance of stand-by mode) as well as investment in energy-efficient and durable technologies, are seen as possible options of action. Concerning energy efficiency and energy saving, financial as well as ecological motives play a role. In addition, active citizens want to act as role models for others.

Compared to energy consumption the field of **sustainable investment and (energy) production** is perceived as even more influential by active citizens (although the target group necessarily entails having enough financial resources). Existing options for

---

4 Heidelberg is a city of about 150,000 inhabitants. Its university is among the top German universities. Heidelberg has a modest share of industrial production. 87% of employed persons work in the tertiary sector. The city Council is dominated by a left wing-green majority, whereas the mayor has been nominated by the conservatives/right wing parties. Heidelberg is a city of lively debate.

In 2006, Heidelberg produced an amount of 21 GWh electricity and 46 GWh thermic energy from renewable resources, which is 2.6 % of the total electricity consumption and 2.3 % of the total heat consumption (Eisenmann 2008 and personal communication from 6.12.2013). In June 2014, the City Council proposed a strategy to reduce its greenhouse gas emissions by 95% by 2050 compared with 1990 and to cut its energy consumption by 50% in the same period. Although Heidelberg started its climate protection activities in the 1990ies, the implementation of the master plan will start in 2014 and continue in the following years.

activities in the field of investments are energy-efficient house-building. Besides, active citizens invest into individual or community renewable energy facilities, options which several of the respondents are involved in. Financial resources and home ownership (except for community facilities) are perceived as limiting conditions. Regarding investments, financial motives slightly outweigh ecological ones. For community facilities, social and local aspects such as strengthening the region seem especially important, but also affinity for technology and technical independence.

Active citizens are ambivalent about their influence as **politically committed persons**. On the one hand, political engagement on an individual and societal level is considered necessary. On the other hand, people are disappointed, due to a lack of feedback and assessability of effects for past projects. Citizens as political protagonists are involved in party work, elections, participation programs in Heidelberg, the work of associations, demonstrations and other forms of public activities. Politically committed citizens are mostly ecologically motivated (interest in climate issues and sustainability) when pursuing their visions. Moreover, they want to make a difference as being part of a collective movement. Time resources, the social environment, and (infra-) structural conditions are considered as important external factors. Next to their political involvement, citizens of Heidelberg also perform a role as socially committed persons. Socially committed citizens reinforce their role through social interactions and discussions with family members, friends or neighbours. In the past, some of the socially committed people were confronted with skepticism towards energy issues that brought about a more cautious strategy in approaching others. Rather, socially committed people bring up energy issues if they perceive a good opportunity to do so. Also, they prefer being a role model to inspire potential imitators.

Interaction between the different roles and fields of action

Some respondents describe the different roles as entangled. They do not strategically plan activities in the fields of energy consumption, investments or political engagement. However, single decisions can at some point cause a behaviour which then, triggers new decisions that have no obvious reason at first sight. Keeping this in mind, behaviour in one field of action can possibly influence a person's actions in other contexts. One female respondent, for example, describes that individual behaviour, once visible to others, can also shape political processes.

In addition, an external view of citizen biographies reveals further interactions: At the beginning, some of the respondents are committed to one activity, complemented by other activities in other areas of action at a later point in time. Although one cannot draw any causal conclusions from that, it seems plausible that the respective behaviour affected behaviour in other contexts (i.e. through social norms).

From a psychological viewpoint, the different roles seem to harmonize with each other. Existing time and financial resources might determine the degree of involvement. With the aid of projective methods (i.e. using symbols), participants in the focus group used particular items to show positive and negative entanglement of roles. Positive effects were described as spillover effects, insofar as one behaviour impacted positively on another. However, participants mostly described negative effects such as classical rebound effects or licensing effects. Licensing effects occur for example, if people who produce their own energy show higher levels of consumption. Having solar panels on the rooftop does not legitimize underfloor heating, as one participant ironically noted. Others reaffirm that view, saying that acting sustainably does not free somebody to cause ecological damage in another context instead (in other words, that you use green energy, but still take a plane to your next holiday destination).

3.3 Attitudes and potential of activation of citizens in Heidelberg

In the representative household survey in Heidelberg (n=524), we looked – among others – for the allocation of responsibility to contribute to local energy measures. The community is attributed most responsibility (93%), whereas the policy/legislator level is attributed 82%. The degree of responsibility for energy suppliers is rated with 82%, whereas the accountability of the federal state amounts to 83%. The branches of local economy and industry are seen to have slightly less responsibility. According to the participants of the survey, other citizens are seen to impact even less on contributions regarding energy activities (63%). Similar to this statement, a self-assessment regarding possible contributions to the transformation of the energy system also revealed that participants rate themselves as least able to exert influence on energy issues (60%).

Households have been asked to rank their motives for conscious energy consumption, for investments and for acting as politically committed persons. They should also declare, which framework conditions would improve their chances of acting in each role.

Concerning energy savings, participants mainly pursue economic and ecological motivations: Respondents mention the will to save money (83.6%), giving a contribution to the field of climate protection (87.2%) as well as the general will to save resources (89.5%). The social environment (friends, relatives) exerts less of an impact on individual saving behavior (7.6%).

Investments in renewable energy are mainly motivated by a contribution to climate protection (73.9%) and a general preserving of the environment (72.4%). Saving money as well as independence from energy suppliers are equally valued as motives (58.6%), followed by the wish to strengthen the local economy (34.9%). Investments in own energy production mainly depend on homeownership, and whether the construction of the house (static of the roof, south facing roof) supports it i.e. installing a solar system. Furthermore, the presence of information on renewable energy issues given by the media and specialized information centers is seen as an important factor. In addition, financial capital and legal parameters are highly important.

Moreover, motivations for political engagement in the field of renewable resources are the preservation of the environment as well as a perceived contribution to climate protection. Both motives have mainly been mentioned by persons less than 39 years old. About half of the respondents would participate to actively shape local development and to make use of their civil rights of participation.

Households were also asked which of the different roles would contribute most effectively to a transformation of the energy system. About 76% ranked the role as conscious energy consumer as the most important one, followed by the other roles which were ranked on nearly the same level, namely as investor in own energy production installments (19%), as investor in community energy production installments (20%) and as politically committed person (18%)

4. Conclusions

The background of this paper is still a current research project. Therefore, we must restrict ourselves to some preliminary conclusions/impressions based on the current state of research.

In general, the transformation of the German energy system seems to have "arrived" at the local level: A strong majority of citizens agree to this transformation and also to local production using renewables. If the latter is true, the often highlighted VERLAGERUNG strategy "Not in my neighborhood" (NIMBY) might have changed. Is this a new corridor of acceptance?

It is interesting to notice the hierarchy of responsibility which favours local, regional and federal policy structures which might conflict with the perception and ranking of the different roles. We conclude that self-commitment to act as consumer is an accepted role. Only a small minority of people believe in greater self-responsibility. The general responsibility is – still – allocated to government institutions, to energy providers and to business.

To activate and establish these different roles, the financial bottleneck should be overcome, e.g. by increasing financial incentives (e.g. by subsidies) or by more own capital. The improvement of personal information and knowledge has also been highlighted as an important tool to overcome role limitation.

Altogether, the dimension "encourage", "enable" and "engage"[5] should be strengthened to activate citizens, both with regard to a single role to interaction between roles. By doing so, households/consumers have to be treated in different ways considering the "trusting", the „vulnerable", and „responsible" consumers.

References

Ajzen, I., 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50, 179–211.

Bänsch, A., 2002. Käuferverhalten, 9., durchges. und erg. Aufl. Oldenbourg, München, Wien.

Dolan, P., Hallsworth, M., Halpern, D., King, D., Metcalfe, R., Vlaev, I., 2012. Influencing behaviour: The mindspace way. Journal of Economic Psychology 33, 264–277.

Eisenmann, L., 2008. Bilanzierung der Endenergie und CO2-Emissionen der Stadt Heidelberg bis 2006. Kurzbericht. http://energy-cities.eu/IMG/pdf/7_2_energy_co2_balance_2006.pdf. Accessed September 22, 2014.

Eisenmann, L., Pehnt, M., Dünnebeil, F., Kutzner, F., Hertle, H., Paar, A., Hoeg, J., Blömer, S., Schmidt, C., Schopper, T., 2014. Konzept für den Masterplan 100 % Klimaschutz für die Stadt Heidelberg. Endbericht. http://ww1.heidelberg.de/buergerinfo/getfile.asp?id=241520&type=do. Accessed September 22, 2014.

Fishbein, M., Ajzen, I., 1975. Belief, attitude, intention and behavior. An introduction to theory and research. Addison-Wesley, Reading, Mass.

Graichen, V., Gores, S., Penninger, G., Zimmer, W., Cook, V., Schlomann, B., Fleiter, T., Strigel, A., Eichhammer, W., Ziesing, H.-J., -2007,12. Energieeffizienz in Zahlen. Endbericht, in: Deutschland, Climate change. Umweltbundesamt, Dessau-Roßlau, Dessau.

Heijs, W. Residential energy use: Habitual behavior and possible interventions, in: European Council for an Energy-Efficient Economy, Act! innovate! deliver! Reducing energy demand sustainably : ECEEE 2009 Summer Study : conference proceedings. ECEEE, Stockholm.

---

[5] This is based on the 4-E model developed bySDC/NCC (2006).

Hübner, G., Müller, M., Röhr, U. Erneuerbare Energien und Ökostrom – zielgruppenspezifische Kommunikationsstrategien. Abschlussbericht zum BMU-Verbundprojekt (FKZ: 0325107/8). http://www.genanet.de/fileadmin/downloads/Strom_Wechsel_Frauen/Oekostrom_kurzfassung.pdf. Accessed September 22, 2014.

Micklitz, H.-W., Oehler, A., Piorkowsky, M.-B., Reisch, L.A., Strünck, C., 2010. Der vertrauende, der verletzliche oder der verantwortungsvolle Verbraucher? Plädoyer für eine differenzierte Strategie in der Verbraucherpolitik. Stellungnahme des Wissenschaftlichen Beirats Verbraucher- und Ernährungspolitik beim BMELV. http://www.bmelv.de/SharedDocs/Downloads/Ministerium/Beiraete/Verbraucherpolitik/2010_12_StrategieVerbraucherpolitik.pdf?__blob=publicationFile. Accessed September 22, 2014.

Reisch, L.A., 2004. Principles and Visions of a New Consumer Policy: Discussion Paper by the Scientific Advisory Board for Consumer, Food, and Nutrition Policy to the German Federal Ministry of Consumer Protection, Food, and Agriculture. Journal of Consumer Policy 27, 1–42.

Reisch, L.A., 2013. Verhaltensbasierte Elemente einer Energienachfragepolitik – Oder: Wie kann die Nachfrageseite für die Energiewende gewonnen werden?, in: Held, M. (Ed.), Grenzen der Konsumentensouveränität. Metropolis, Marburg, pp. 139–159.

Renn, O., Reisch, L., 2012. Baden - Württemberg auf dem Weg zu einer Verbraucherenergiepolitik. Empfehlungen der Verbraucherkommission Baden-Württemberg für eine verbraucherfreundliche Energiewende. http://www.verbraucherkommission.de/servlet/PB/show/2931396/VK_Positionspapier_Energiewende_271012.pdf. Accessed September 22, 2014.

Schwartz, S.H., Howard, J.A., 1981. A Normative Decision-Making Model of Altruism, in: Rushton, J.P., Sorrentino, R.M. (Eds.), Altruism and helping behavior. Social, personality, and developmental perspectives. L. Erlbaum Associates, Hillsdale, N.J., pp. 189–211.

SDC [Sustainable Development Commission] / NCC [National Consumer Council], (2006a): I Will If You Will. Towards Sustainable Consumption; London.

Stadt Heidelberg, 2014. Beschlußvorlage Masterplan 100 % Klimaschutz - Beschluss zum ifeu-Konzept "Masterplan 100 % Klimaschutz für die Stadt Heidelberg" - Kenntnisnahme Ideensammlung für Klimaschutzmaßnahmen aus der Bürgerbeteiligung. http://ww1.heidelberg.de/buergerinfo/vo0050.asp?__kvonr=21690&voselect=4880. Accessed September 29, 2014.

Stadt Heidelberg. Leitlinien für mitgestaltende Bürgerbeteiligung in der Stadt Heidelberg. http://www.heidelberg.de/site/Heidelberg_ROOT/get/documents/heidelberg/PB5Documents/pdf/12_pdf_Buergerbeteiligung_LeitlinienEnd.pdf. Accessed September 22, 2014.

Trend-research, KNI, 2011. Marktakteure Erneuerbare – Energien - Anlagen in der Stromerzeugung. Im Rahmen des Forschungsprojektes: Genossenschaftliche Unterstützungsstrukturen für eine sozialräumliche Energiewirtschaft. http://www.kni.de/media/pdf/Marktakteure_Erneuerbare_Energie_Anlagen_in_der_Stromerzeugung_2011.pdf. Accessed September 22, 2014.

Analysis and exploitation of resource efficiency potentials in industrial small and medium sized enterprises – Experiences with the EDIT Value tool in Central Europe

V. Dobes [a, b, *], J. Fresner [b], C. Krenn [b], P. Růžička [a], C. Rinaldi [d], S. Cortesi [d], C. Chiavetta [d], C. Dorer [e], D. de Graaf [e], P. Grevenstette [e, f]

[a] Enviros, Prague, Czech Republic

[b] International Institute for Industrial Environmental Economics at the Lund University (IIIEE), Lund, Sweden

[c] Stenum GmbH, Graz, Austria

[d] ENEA, Bologna, Italy

[e] Federal Environment Agency, Germany

[f] TU Berlin, Germany

Running title: Analysis of resource efficiency potentials with the EDIT Value tool

Keywords: Cleaner production, life cycle approach, stakeholder analysis, enterprise strategy, management systems, efficiency improvement assessment, ecodesign, complex assessment, initial diagnosis, initial review

***Corresponding author**

Vladimir Dobes

Mailing address: Kovary 42, 273 28 Zakolany, the Czech Republic

E-mail: vladimir.dobes@iiiee.lu.se; Phone: +420 603 178 642

Highlights

- Holistic approach to identify the most interesting resource-efficiency potentials
- Pilot testing in six Central European countries ...
- Need driven and complex evaluation of most appropriate interventions within small and medium size enterprises

Abstract

Despite the fact that material and energy costs represent 45-50% of the entire cost structure in small and medium-sized enterprises (SMEs) and there is high potential for improvement of resource efficiency, capacities for exploration of this potential are very limited. Existing tools utilised for exploration of resource efficiency potential have different limitations and are either tool driven, solely of qualitative nature or not addressing all levels of a business and therefore missing some important opportunities. An international team developed a complex need-driven and quantitative diagnosis tool building on available experience in the resource efficiency field. This tool was piloted in six Central European countries. Evaluation of results showed significant potential for resource efficiency improvements and feasibility of its exploration through the chosen diagnosis approach.

1. Introduction

1.1 Problem addressed

Natural resources such as material (metals, minerals), fossil energy resources and water encounter growing demand worldwide. This causes growing scarcity of many resources which are needed in products and, hence, industrial production processes with the result of increasing prices and environmental damage associated with raw material extraction. One prominent example is the extraction of bauxite (aluminium) in e.g. Brazil, which is accompanied with deforestation/habitat destruction, heavy metal and acidic pollution of soil and water through red mud disposal, and loss of biodiversity. Due to strong price signals from material and energy markets, big companies mostly react to resource scarcity by resource efficiency measures of different kind: i) establishment of resource efficiency/environmental accounting units, ii) managerial measures (introduction of environmental management systems), iii) eco-design of products, iv) introduction of resource efficient processes and appliances. In striking contrast to big companies, the majority of small and medium-sized enterprises (SMEs) hardly pursues measures to decrease its material and energy demand. Resource efficiency means are not considered although potentials for improvement exist and material and energy costs represent 45-50% of the entire cost structure, with energy being responsible for roughly 3%. This phenomenon (failure of response to growing cost pressure) can be explained by a lack of time and knowledge in SMEs to consider resource efficiency as an effective mean to realise cost reductions. Moreover, many SMEs are not aware of their actual cost structure. Thus, in order to benefit from resource efficiency measures, SMEs need to be enabled to unveil the cost reduction potentials hidden in their business in the first place. This issue was considered in an EU funded transnational project in the Framework of European Territorial Cooperation (ETC) termed PRESOURCE (Promotion of Resource Efficiency in SMEs in Central Europe).

1.2 Introduction of the PRESOURCE project

The PRESOURCE project (www.presource.eu), co-financed by the Central Europe Programme and carried out by 8 Institutions from 6 Central European countries (Poland, Czech Republic, Germany, Austria, Hungary and Italy) was initiated to develop a scheme for resource efficiency (RE) improvements in industrial SMEs. This scheme intends to trigger tangible RE measures which lower environmental impacts of companies. The scheme, which comprises a set of RE analysis instruments, was termed EDIT Value (Eco-innovation Diagnosis and Implementation Tool for Increase of Enterprise Value) applies a holistic approach to develop company specific solutions for RE improvements and which design and testing is focus of this paper. A pilot phase to EDIT Value application in SMEs from all partner countries was performed during the implementation phase of the project.

Since the implementation of RE measures requires investment, an advanced cost benefit analysis was developed to better communicate the positive effects of RE in monetary terms to creditors and thereby facilitate the acquisition of loans. Such an instrument is needed since measures for eco-innovation/resource efficiency face a high level of uncertainty about their economic feasibility. This was one finding from over 100 interviews with financing institutions in the Central European region. These interviews also formed the basis of the "Financial Guide for SMEs" which provides a comprehensive overview of relevant actors and instruments in the field of resource efficiency and eco-innovation.

Activities within the PRESOURCE project reflected not only the environmental and economic, but also the political dimension through a RE competence platform (www.resourceefficiencyatlas.com). Member states are asked to respond to EU initiatives such as the "Roadmap to a resource efficient Europe" and, hence, have a need for all kind of information on the issue. The platform provides free of charge and easy access to a broad range of relevant information on resource efficiency. The online platform includes institutional and other relevant actors and their activities (funding, publications, consulting services), a calendar with relevant events, a catalogue of publications and documents (studies, political papers etc.), technological good practice examples and, finally, tools helping SME in improving their resource efficiency. Workshops in the partner countries dealing with different above mentioned RE aspects were held to facilitate exchange of experience and information. These activities targeted political stakeholders as well as business associations, chambers, consultants and other intermediaries.

1.2 Research focus

Based on experiences made by project partners from promoting RE in industry and implementation of the Initial Review for Sustainable Consumption and Production (Dobes, 2007), the authors have developed the thesis that available methodologies for an initial review in the field of RE could be further improved in order to be more effective in exploring RE potentials. In a second step, this should lead to better exploitation of potentials by optimizing the companies' measures on this issue. Enterprises are continuously approached with offers from consultants and suppliers who believe that it is just their product or service what the enterprise needs. In contrary to this supply-driven approach the desirable diagnosis tool should help to select the most eligible Resource Efficiency (RE) tools from the perspective of an enterprise within its existing situation and framework conditions (SME need perspective). Existing methodologies contain a lot of very valuable elements which can provide the basis for the development of a complex need-driven and quantitative diagnosis tool for promotion of RE within SMEs. Such a tool could be very interesting also for the service providers who would have means for setting up an initial relationship with a new client and to implement their services within need driven situations.

The following research question was developed based on this thinking:

Is it effective and manageable for promotion of RE in SMEs to implement a need-driven and quantitative initial analysis of RE potentials within all levels of a business?

1.3 Model for promotion of Resource Efficiency within a SME

In order to address the research question we utilise the model of the management pyramid based on system and learning theory as described in De Palma and Dobes, 2010. The classical model to represent a management system as used in management system standards like ISO 9001, ISO 14001 or ISO 50001 is a pyramid, with the production processes as the basic level, on top of which the management system and the policy are located. The management pyramid of the EDIT Value model is reversed as shown within Figure 1 showing the entire EDIT Value process described in chapter 3. On top of the pyramid the products are located: They generate value from the clients. That is why they are considered the central result of enterprise activities. The underlying levels are processes, management system, strategy, vision, and on the bottom the stakeholders (clients, authorities, neighbors, etc.). Thus the pyramid signals in agreement with the system theory, that the stakeholders provide the very basis for any business and drive the vision of the enterprise. On the basis of the vision, a strategy is defined which again is the foundation for the management system that designs and controls all processes. These processes finally result in the combination of resources into products and services.

1.4 Methodology and structure of the paper

The methodology for addressing the research question is based on the model derived from the management pyramid and based on system and learning theory. It provides the basis for analysis of existing tools as described within chapter 2 and for development of a need-driven and quantitative initial analysis of RE potentials named EDIT Value tool described within chapter 3. Chapter 4 is dedicated to EDIT Value tool testing through transnational pilot applications in SMEs and evaluation of results based on an independent review. Learning experience is described within discussion and conclusions at the end.

2. Review of existing approaches

Utilising the above presented model, we can derive the following two basic questions for looking for an effective and objective diagnosis tool for SMEs:

- Does the diagnosis tool aim on identifying the most interesting potentials for improvement from perspective of an enterprise within the vertical complexity of its whole management pyramid?

- Does the diagnosis tool allocate an optimised set of improvement tools, which would be most feasible for addressing these potentials in a comprehensive way and supporting organisational learning?

These questions provided basis for a desk research on available diagnosis tools. Altogether there were against these questions and the above described model reviewed more than 50 tools focusing on an initial review in the area of RE. This analysis resulted in identification of the following basic characteristics of the tools reviewed which prevent them in being fully effective in identification of the RE potential: selective, quantitative and tool-driven.

Selective concerning management pyramid

Not all levels of the management pyramid are analysed. Based on the model this prevents the most effective leverage points within the whole business to be identified. As a typical selective tool the Excel-based tool Eco Inspector 2.1 (University of Applied Science Basel, 2003) can be presented. This well-designed initial review tool supports in a systematic way evaluation of RE potentials within production processes (and partly also management systems). It is based on semi-quantitative analysis of data collected within a Quick-Scan with descriptive graphical presentation of results. At the same time it focuses only on selected areas of the management pyramid and can hardly bring new insights into enterprise potentials and learning how to explore them in comparison with what is already known by enterprise members and/or involved external experts based on the limited Quick-Scan evaluation.

Solely Qualitative

Potential for RE is within the existing diagnosis approaches often not quantified. Qualitative analysis leads on one hand for example to further questioning flows with no reasonable potential and/or on the other hand to omitting some of the important but hidden sources of losses and pollution.

Example of a qualitative approach can be The Efficient Entrepreneur Calendar Assistant (UNEP and Wuppertal Institute, 2001). This well-presented twelve steps methodology for improvement of environmental performance within a small or medium-sized business has many advantages - among others it reaches all levels of the management pyramid and utilises a simple step-by-step methodology in calendar form to teach an entrepreneur on possibly significant environmental aspects and on addressing them through preventative approaches in an economically profitable way. However, the price for this simplicity is the qualitative nature of the diagnosis tool. Potentials for RE are not quantified which can lead to further questioning areas and flows with no potential. The qualitative approach also misses hidden potentials which were not known before the review.

Tool-driven

Within the analysed tools, the assessment is often carried out with the imagination of an “ideal enterprise” suggesting to utilise a set of "optimal" tools with a hidden assumption that it makes sense to use all recommended RE approaches and tools which are available. Priorities are set up based on an absence of procedures / measures which could be useful. This leads to further exploration of areas that are not the most important ones for various reasons, or an enterprise is compared with an "ideal" state, that is not relevant for the given enterprise. For these reasons, the limited resources of an enterprise are not allocated for the areas with the highest potential for improvements.

As an "tool-driven" could be characterised most of the tools reviewed. Even the tool with focus on all levels of the management pyramid “Three Steps to Eco-Efficiency” (Industry Canada, 2011), which includes also a "Benefit-Cost Analysis" in order to help an entrepreneur "to get the biggest bang for eco-efficiency buck" cannot be characterised as a need-driven tool from the perspective of our research. Limitation of this diagnosis approach is within identification of potentials that is based on qualitative data and driven by an absence of measures and tools which should have "an ideal enterprise" (therefore based on an assumption that an ideal state is implementation of all available RE tools)

Each reviewed tool included at least one of the abovementioned characteristics. All non-selective tools were found to be “ideal enterprise” driven and/or qualitative only.

Tools which are based on quantitative analysis are mapping material, water and energy flows (at least at the level of an input-output analysis), working with resource efficiency indicators etc. They often utilise benchmarking or identification of non-product output costs as an indication of potential for improvement.

3. Tool for complex review of resource efficiency potential

Within the application of the EDIT tool all levels of an enterprise’s management pyramid are assessed in a systematic way from the perspective of possible RE opportunities for improvements which could enhance the enterprise’s value. EDIT is implemented at four basic levels: products, processes, systems and stakeholders, identifying the most effective RE innovations and projects for the given company.

The EDIT Value tool is designed based on experience from Initial Review for Sustainable Consumption and Production (Dobes, 2007) and on a desk review of other existing diagnosis tools. It is developed as an integrated approach to identify opportunities for sustainable improvement in whichever level of the management pyramid: Along the lifecycle by involving suppliers or redesigning a product to reduce consumption of resources during the use of the product or to facilitate recycling at the end of the useful life of the product. At the same time the tool guides through analysing the policy, management system, as well as the production level. The tool is based on a questionnaire, and on worksheets to collect more detailed information on stakeholders, the product life cycle and on input, outputs, non product outputs of the actual production process and on management systems. The entire EDIT Value process is shown within the Figure 1.

Particular steps of EDIT include:

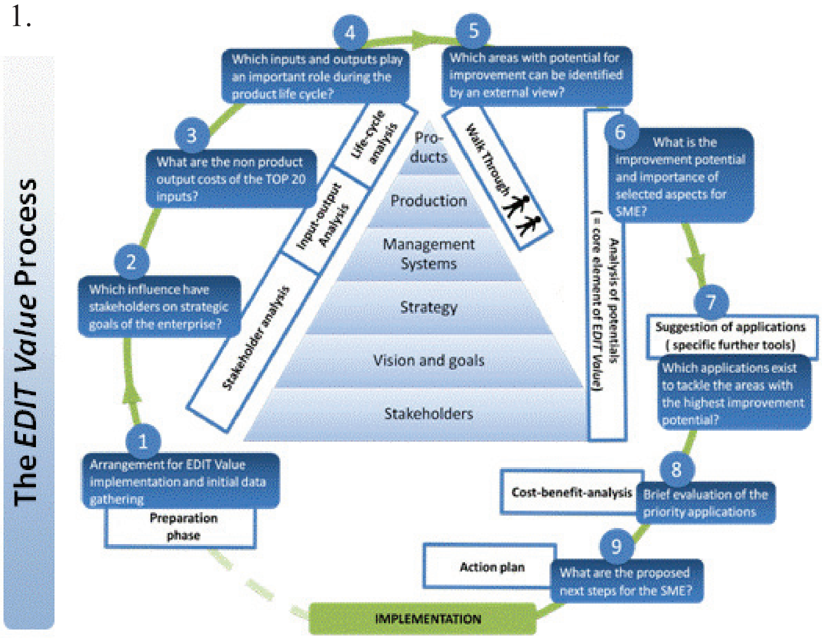


Figure 1: The EDIT Value process

Aspect	Austria	Czech Republic	Germany	Hungary	Italy	Poland
Number of piloting SME	3	2	2	2	1	5
Involved sectors of the piloting phase (according to the NACE code)	• Manufacture of beverages (1x) • Manufacture of food products (1x) • Manufacture of electrical equipment / Manufacture of machinery and equipment (1x)	• Manufacture of paper and paper products / Manufacture of rubber and plastics products (1x) • Manufacture of furniture (1x)	• Manufacture of basic metals (2x)	• Manufacture of structural metal products (1x) • Manufacture of chemicals and chemical products (1x)	• Manufacture of fabricated metal products, except machinery and equipment (1x)	• Manufacture of wearing apparel (2x) • Manufacture of textiles (2x) • Manufacture of basic metals (1x)
Total time invested by the SME	In average 20 h; between 15 h and 30 h (distributed on several visits and data gathering)					
Total time needed by the consultant(s)	In average 5 days; between 3 days and 7 days (including preparation, communication with the SME, evaluation of the data and final report)					
Major identified potentials per SME regarding						
stakeholders	?					? ? ? ?
vision & strategy	?					? ? ? ?
management	?					? ? ? ?
Processes	?					? ? ? ?
products	?					? ? ? ?

Table 1: Basic results from implementation of EDIT tool within small and medium size enterprises in six countries (to be completed).

- The Identification of potentials which are most interesting for exploration within the given framework conditions.
- Allocation of the most effective applications to the potentials identified and a cost benefit analysis. Applications are tools or simple methods which ideally can be applied by an enterprise on its own to realize a potential
- Planning the most effective intervention in the field of RE including its financing.

Identification of potentials for improvement is the core step of EDIT and provides basis for its value added. It starts with collection of data and focus on their analysis in dialogue with an enterprise.

The stakeholder analysis helps to better understand enterprise goals and strategy, how an enterprise reflects interests of stakeholders its business is based on. Gap between the importance of a given stakeholder and reflection of this significance in enterprise activities and communication provide basis for the first “Aha!” effects. For this analysis, a worksheet is provided.

The potential for improvement on process level is implemented through a simple input – output analysis at the enterprise boundary level (not for specific processes). It estimates total losses related to inefficient use of natural resources within the processes (so called Non Product Output costs) by quantifying volumes and cost of material and energetic inputs and waste and emissions.

At this stage data on major process inputs (materials and auxiliaries, water and energy) and their inclusion within the desired product should be collected using a dedicated form derived from traditional Cleaner Production Assessments where is known under the title "TOP 20". This analysis is done only for most significant inputs within the company system boundary and it’s based on annual figures from previous business year. The TOP 20 table has within EDIT Tool less items and it enables to quantify process loss for each important input (raw materials, auxiliary materials, energy, water or packaging). The result provides an insight into efficiency of the use of important input materials, costs of pollution and provides background information for estimation of potential for improvement. Data gathered within TOP 20 together with data on annual production can be in some cases used for benchmarking, which can provide further insight into the quantification of the potential for improvement.

An indicative analysis of the life cycle of enterprise product(s) provides input into working with a dedicated form. Similar like within the input/output analysis on the company level material and energy flows are entered also for the other phase of life cycle and can provide basis for semi quantitative evaluation of selected inputs and outputs at specific stages of the life cycle.

Identification of potentials is done through a set of aspects which can be source of any potential for improvement. The EDIT methodology is straight forward in ”switching off” those aspects with no or little potential according to the judgment of the company representatives and the experts doing the analysis in the questionnaire. Only aspects which can possess a significant potential for improvement are further explored.

The core piece of the analysis is a questionnaire which asks for the relevant areas with potential effect on sustainable consumption and production. It was build synthesizing important elements in the stakeholder dialogue, vision, strategy, management system, process and product levels from a literature review and the personal experience of the involved experts.

For all the areas the questions ask for the existence and the actual implementation of the identified aspects, rating their actual implementation from “no respective action in the enterprise at present” to “proactive use of the respective action”. Relevance and weight of the aspect are evaluated, using the results of the preparatory analysis (stakeholder, input/output, management systems, life cycle). For all the areas, applications (appropriate tools) are listed.

Within the final step the most effective applications are identified to realize the identified potentials from improvement in the relevant and important areas. Out of this, an action plan is developed in a discussion between enterprise representatives and consultants. EDIT includes also mechanisms how to identify suitable sources of financing for investment needing measures.

4. Piloting the EDIT Value tool in SME

The developed EDIT Value tool was tested in two to five SME in the six partner countries of PRESOURCE, namely Austria, the Czech Republic, Germany, Italy, Hungary and Poland. Overview of companies participating in the pilot phase and its major findings are provided in Table 1.

The timeframe for the pilot phase was limited from March to September 2014 in order to evaluate findings before the end of the project. For this reason, mainly SME with a previous cooperation as a basis of trust were accessed. One to three consultants facilitated all pilot applications, sometimes further experts outside of the SME were consulted for discussing results and suggested measures. The facilitators were free to adapt the order and conduction of analyses according to their previous experiences and the availability of participating persons from the SME.

The intention of the pilot phase was to test the approach of the developed tool, its ability to reveal potentials from all levels of the management pyramid, its acceptance and impacts. For this reason, several industrial sectors were involved to approve the broad application of the tool. The project partners decided to restrict the pilot phase only to industrial SME as they have a great impact on the environment and resources.

Although, the pilot phase took part in six countries at the same time, the flexibility in conduction and the chosen sector limits country-specific deductions.

For evaluation, a structured interview of 13 questions was developed and carried out by a third party to assess the opinions regarding the pilot phase from both participating contact persons of the SME and facilitating consultants. This evaluation focussed on:

- The effectiveness:
  What was achieved: potentials and suggested measures
  Which analysing steps of the tool contributed to the identification of potentials and measures?
- The approach:
  Evaluation of each step of the tool
  Assessment of time
  Investigation of challenges and suggested improvements for further development of EDIT Value
  Cooperation between SME and consultant

- The acceptance and the impact:
  Why did the SME take part in the pilot phase?
  How likely the suggested measures will be implemented
  What were learning effects for the SME?
  Were SME satisfied with the tool? Would they recommend this tool to other enterprises?

An independent person from the Technical University of Berlin carried out the interviews and the evaluation. Furthermore, all project partners presented and discussed the case studies during partner meetings and one workshop between June and September 2014.

5. Discussion

In most cases, EDIT Value revealed several potentials for resource efficiency. The lowest number of potentials was identified in Austrian pilot enterprises, which implemented resource-efficient measures for several years within the frame of Ecoprofit. Potentials could be attributed to at least two levels of the management pyramid: the “process level” in each SME, and the “stakeholder / vision / strategy or management level” in most SME. Interestingly, potentials and appropriate measures regarding energy and material efficiency were identified with almost the same ratio. Hence, the EDIT Value tool was effective to show potentials even in sophisticated SME with respect to resource efficiency.

However, the grade how concrete the individual measures were formulated depended also on the previous experience of the consultant. Although, SME appreciated the broad external view on their SME and were surprised about the findings and fruitful discussions initiated by the set of analyses, the highest acceptance for the application was found where both “soft = managerial measures” and “hard = technical measures” were formulated as final result and were connected with low investments, low efforts and a convincing financial win. One reason might be that the implementation “soft measures” often depends on the process of change management and may engender internal resistance.

Nevertheless, the applied tool revealed to be more than just a “diagnosis”. The variety of different analyses and the time taken to carry out these analyses, hade several by-effects: (i) the exercise of gathering qualitative and quantitative data helped to develop and new view, how to monitor resource efficiency, (ii) the analyses that were introduced can be used for further internal monitoring and evaluation with regard to resource management, and (iii) awareness for a reliable consumption of resources was raised and the need to raise awareness of the total staff in the enterprise. The driving force for taking part in these analyses and a possible later application was primarily the reduction of costs. More rarely mentioned aspects were an advantage at the market due to a greener image or the fulfilment of legal requirements.

The conduction of EDIT Value by external consultants was acknowledged. In most cases, trust was created by a previous successful cooperation with the consultants. The need for consultancy was high as the single analyses were unknown to the SME, the complete EDIT Value tool is complex, based on broad theoretical fundament and the evaluation of data and formulated recommendation requires a good practical managerial and technical knowledge. For this reason, results were discussed with other experts after the visits in the SME. For instance, in Austria four experienced consultants discussed the different cases and solutions together. However, a major attribute of consultants should be the ability to listen carefully to the representatives of the SME and to consider the internal knowledge of the SME.

Given a convincing expectation of financial benefits, SME were willing to support time in the process. Often staff of the SME invested about 20 hours for the EDIT Value process – the process to identify the most relevant measures. Especially the gathering of data for the input-output-analysis was experienced as very time-consuming. Facilitators stated a total time volume of 4-6 days to prepare and assess the analyses and to process the data within EDIT Value process. Nevertheless, the intensive concern with all the included aspects was appreciated at the end.

A contribution to reduce the time of the instrument might be: (i) to give very clear information how the tool works, why these analyses are necessary and how they are interrelated, (ii) to develop a more automated and guided version, avoiding repetitiveness and considering common problems in application, which were mainly dedicated to the application of the input-output-analysis, (iii) to establish a network of specialized consultants in EDIT Value that can easily exchange and deliver sector-specific advice, and (iv) country-specific adaptations that may concern current supporting schemes, financing or legal requirements related to resource-efficiency. A pre-requisite for all application is the availability of a national language version to avoid the language barrier and to be able to reach all interested SMEs.

It would be interesting to evaluate the impacts of EDIT Value in all visited SME after about one year and to quantify the win-win situation: financial savings and reduction in the reduction in resource consumption. In spite of all positive aspects of resource efficiency, possible negative impacts due to rebound effects should be assessed and considered as well.

6. Conclusions and recommendations

Pilot applications of the EDIT Value tool showed that it is manageable and effective and to promote RE in SMEs by a need-driven and quantitative initial diagnosis. The main benefit of EDIT is the holistic approach covering all levels of a business even within SMEs. Comparing EDIT Value with other methodologies for a complex diagnosis in the field of RE and sustainability of industrial enterprises:

- EDIT provides a complex review thus not omitting any significant opportunity for improvement
- EDIT is based also quantitative analysis thus pointing out the most effective priorities.
- The EDIT tool instead of comparing assessed enterprises with an ideal “sustainable site” or benchmarks in the first place focuses on opportunities for improvements and innovations within the given enterprise first; suitable instruments for improvements and innovations are assigned to these opportunities only after completion of an initial analysis thus ensuring a need driven approach.

The application of the pilot version of EDIT Value in 15 manufacturing SME in six Central European countries helped to assess its usefulness, to understand challenges and to establish an improved and SME-tailored version contributing to resource efficiency.

- ➢ The EDIT Value tool is useful to identify potentials for resource efficiency linked to different areas of the management pyramid. Most SME appreciated the holistic view and emphasized the uniqueness of this instrument. The majority of the SME confirmed that the implementation of identified measures will clearly contribute to reduce costs.
- ➢ SME perceived the tool as a “complex check” that is advantageous due to the gathered quantitative and qualitative data, e.g. for partaking in support schemes or even as basis for applying an environmental management system. The quantification of inputs and

outputs supports a measurement resource efficiency within the SME and allows to set targets or to identify unexpected losses.

- As the tool concerns many steering aspects, such as the stakeholder relations or questions regarding the vision, strategy or management, leading staff of the SME should take part in the application of EDIT Value. In most cases of the pilot SME, the owner engaged in the analyses itself.
- The EDIT Value tool showed a particular strength in awareness raising and in initiating internal discussions about resources, environment and cleaner production. This way, the tool generated several learning effects: Monitoring systems were re-thought and analyses practised that may be repeated at a different time according to the plan-do-act-check scheme. Furthermore, the discussions accelerated the implementation of resource-efficient measures that were already in mind of SME personnel.
- The tool was regarded as complex and relatively theoretical. For this reason, assistance of an experienced consultant or facilitator is needed for a fruitful application. However, repetition of single or several analyses of the EDIT Value tool might be repeated self-dependently by SME. Both for consultants and independent users of SME, an advanced version including more automated elements may help to reduce complexity and to increase user-friendliness.
- Although the EDIT Value tool enables a broad look at the enterprise, SME still appreciate "concrete" and "hard" measures particularly on the process level. For this reason, a sector-specific expert or an expert specialized for a "well-accepted area", such as energy efficiency, could be helpful allowing both the specific and the broad view. Especially smaller enterprises emphasized this aspect. In addition, several SME mentioned, they would wish not only to apply this initial review but to continue consultancy beyond during the implementation phase.
- A basis for further application of EDIT Value and similar tools is trust in their usefulness. Well-acknowledged multipliers such as the chambers of commerce might be a good basis to ensure trust and to offer an advisory before applying the tool.
- The "added value" of EDIT Value may be limited for SME with an advanced environmental management system and recently implemented resource-efficient measures. Nevertheless, the holistic approach may still lead to surprising findings.

Acknowledgements

This pilot was possible due the active engagement of all partners involved in the EU project PRESOURCE funded by the Central Europe Programme of European Commission: Austria - STENUM Ltd.; Czech Republic - ENVIROS Ltd.; Germany - Federal Environment Agency, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and Fraunhofer Center for Central and Eastern Europe; Hungary: Corvinus University of Budapest; Italy - ENEA, National Agency for New Technologies, Energy and Sustainable Economic Development; Poland - Research and Innovation Center Pro-Akademia. The authors are especially grateful to the donor and to the SMEs that were engaged both in the EDIT Value process and in the evaluation of the tool itself.

References

De Palma, R., Dobes, V., 2010. An integrated approach towards sustainable entrepreneurship - experience from the TEST project in transitional economies. Journal of Cleaner Production 18, 1807-1821.

Dobes, V., Vavrinek, J. 2007. Project Partnership for Sustainable Consumption and Production and Methodology of Initial Review for SCP Innovations. In: Environmental Aspects of Entrepreneurship, CEMC, 2007/1, pp. 23-26. ISSN 1211-8052.

Industry Canada, 2011. Three Steps to Eco-Efficiency

UNEP, Wuppertal institute, 2001. The Efficient Entrepreneur Calendar Assistant http://www.efficient-entrepreneur.net/custom/user/downloads/EN_EE_Assistant.pdf

Smart Urban Energy Development Graz-Reininghaus

Stephan Maier, Institute of Process and Particle Engineering,
Inffeldgasse 13/III, stephan.maier@tugraz.at

Ernst Rainer, Institute of Urbanism,
Rechbauerstraße 12, ernst.rainer@tugraz.at

Werner Lerch, Institute of Thermal Engineering,
Inffeldgasse 25/B, werner.lerch@tugraz.at

Thomas Mach, Institute of Thermal Engineering,
Inffeldgasse 25/B, thomas.mach@tugraz.at

Thomas Wieland, Institute of Electrical Power Systems,
Inffeldgasse 18/1, t.wieland@tugraz.at

Michael Reiter, Institute of Electrical Power Systems,
Inffeldgasse 18/1, m.reiter@tugraz.at

Ernst Schmautzer, Institute of Electrical Power Systems,
Inffeldgasse 18/1, schmautzer@tugraz.at

Hans Schnitzer, Institute of Process and Particle Engineering,
Inffeldgasse 13/III, hans.schnitzer@tugraz.at

Yvonne Bormes, Institute of Urbanism,
Rechbauerstraße 12, bormes@tugraz.at

**all Graz University of Technology, Austria*

Abstract

World's growing cities need an integrated and holistic urban development due to its complex requirements because of high density of settlement structures including different purposes of usage. The City of Graz is currently the fastest growing capital city in Austria. The demand for living space has grown rapidly in recent years and, according to forecasts, will continue to grow in the coming decades.

Reininghaus is a former brewery site and the biggest underdeveloped urban area in the City of Graz. The research project ECR (Energy City Graz-Reininghaus) aims to develop urban strategies for the new conception, construction, operation and restructuring of the city district Graz Reininghaus. In order to cope with this complex task, a large interdisciplinary team, including five institutes of the Graz University of Technology, works together on this research project.

This paper discusses the energy development of two city quarters[1] within the smart urban energy development of the city district Reininghaus in Graz, Austria. It describes a first brickstone for a process-oriented approach of urban development to create flexible and adaptive developments as a foundation not only for this project development but also for further regional and urban planning.

Highlights:

- Exploration of smart energy system networks to cover energy demand of an urban development
- Determination of price ranges and price limits and feasibility levels of renewable energy technologies
- Feasibility of renewable energy technologies and waste heat

Keywords: Smart city, Urban energy development, Urban energy systems, Process synthesis

1. Introduction

1 For the purpose of this project the city district is separated into quarters which must not be confused with a possibly bigger city quarter.

In fast growing cities green- or brownfield areas are valuable spaces for urban development. Herein for a sustainable development this can lead to a chance to develop urban areas with open system boundaries of interdisciplinary considerations and planning. Collective discussions of technical, architectural, socio-economic and ecological aspects can lead to integrated development of sustainable and alternative energy supply strategies, an integration of ecological aspects (e.g. sufficient trees, wind system), mobility, public transport, etc.

Figure 1: Localisation of Reininghaus area in city context of Graz (source: ECR team)

For urban standards the Reininghaus area is an underdeveloped plot of land (a former brewery area) situated about
1,800 m from the centre of the middle-sized city Graz (ca. 270,000 inhabitants). It offers about 110 ha space and a possible full capacity for about 12,000 future inhabitants on a maximum net floor area of about 560,000 m². Architects and other stakeholders variably focus on different quarters of the city district. In the following case study the quarters 1 and 4a of altogether twenty quarters will be discussed.

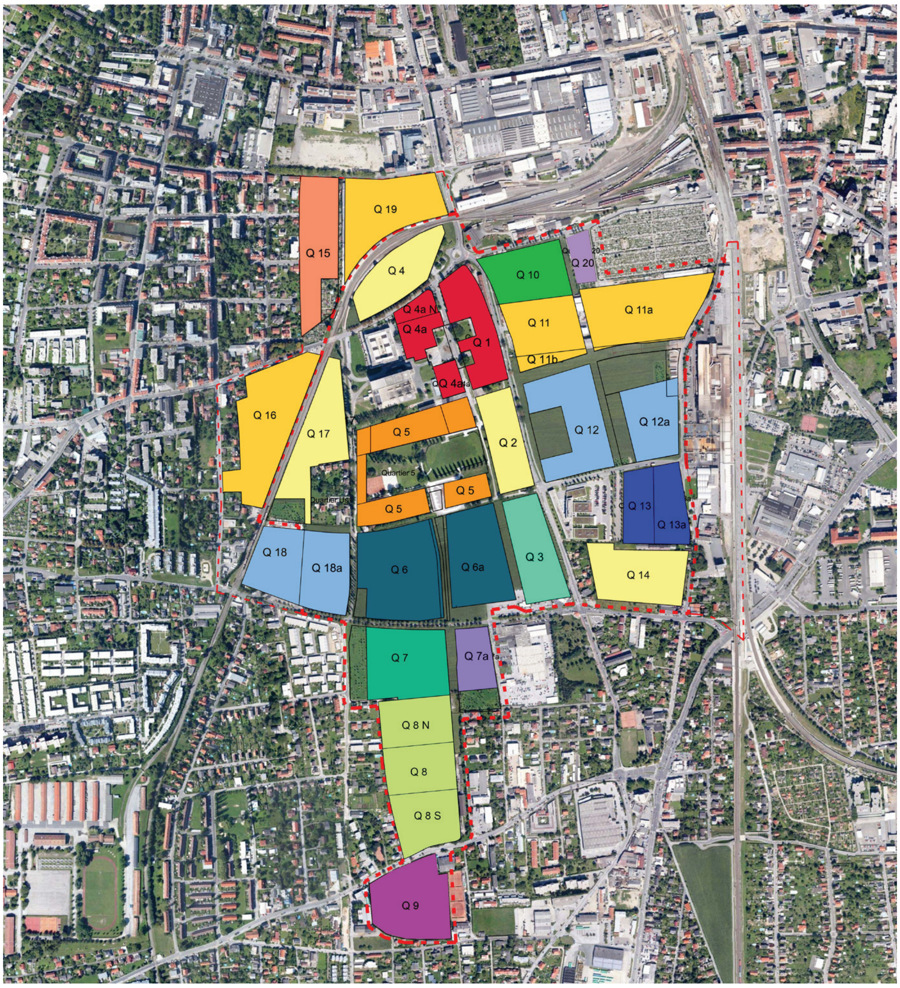


Figure 2: Quarters of Reininghaus area (source: ECR team)

The quarters 1 and 4a (red marking) are located well in the north of the district and are owned by the real estate developer group Erber. At this area a few less well-preserved functional buildings can be found. These buildings should facilitate the transformation from a historic industrial site to a modern district under the aspect of the smart city concept. The real estate developer wants to create around 670 rental apartments for up to 1,800 people. At the core of the area childcare facilities, medical offices, pharmacies, offices, local shops, restaurants and cultural and educational institutions shall find place. The total investment – including the purchase of land – is about approximately 170 million euros. International architects were invited to a two-stage competition concerning architecture and green space proposals based on an urban framework plan Reininghaus (developed by the City of Graz and Graz University of Technology).

The Institutes of Electrical Power Systems, Process- and Particle Engineering, Urbanism, the Institute of Thermal Engineering and the Institute of Technology and Testing of Building Materials work on a “framework energy plan” for the case study area based on the idea of an energy self-sufficient and CO_2-neutral city district. This plan is part of the smart city development of Graz and shall lay the foundations for an integrated smart urban development of the city district and show alternatives of further developments within the city Graz. The framework energy plan concerns various fields of investigation. Electric energy, thermal energy and embodied energy has to be taken into account as well as the methods of urban design and the rules and mechanisms of the local authorities.

2. Case Study

The methods are applied in a smart development of urban energy supply of the greenhouse area Graz-Reininghaus. The city district is situated in a brown- and green-field-area of Graz. 110 ha are available for a new city quarter development with mixed use which should be as energy efficient, smart and sustainable as possible. Approximately half of this area (about 49 ha) can be used for building sites and so partly be sealed with buildings for private use, offices and commerce. The area was separated into 20 quarters in the case study, in this paper the focus lies on the quarters 1 and 4a in the north of the total city quarter with an area of more than 43,500 m². Using this area, 17,577 m² of building area and a gross floor area of 99,694 m² can be reached. According to the typical mix of building demand the following shares of the total space were defined.

Table 1: Gross floor area of Reininghaus quarters 1 and 4a

	Gross floor area			
	Quarter 1		Quarter 4a	
Living	56 %	35,744 m²	61 %	21,891 m²
Office	24 %	15,237 m²	16 %	5,913 m²
Commerce	20 %	12,561 m²	23 %	8,348 m²

3. Methodology

The initial working hypothesis describes the conception of an energy self-sufficient city district. This should be seen as a visionary approach to force the project team to examine local energy potentials as far as possible and to anticipate upcoming future developments. The main focus of the examination is the aim of the inter-linkage of buildings and industrial energy resources as more or less sustainable energy producers. Central supply solutions will be confronted with semi-centralized and decentralized possibilities of inter-linkage. For example, taking advantage of the cooling energy potential of the existing brewery cellars or the waste heat of industrial processes already located in the city district.

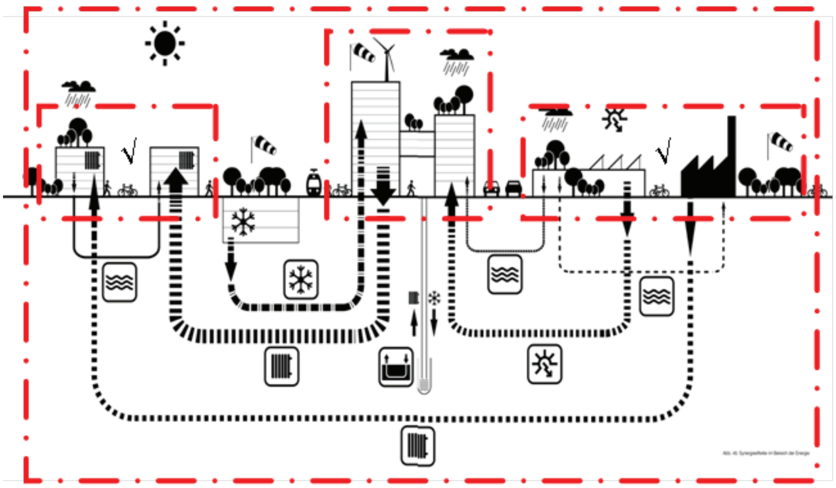


Figure 3: schematic sketch to illustrate the changing of single system borders to a holistic approach

The implementation of this approach is performed by the participating institutions on the basis of different tools. It consists of calculation of demand and supply, selection and dimensioning of energy technologies, financial aspects and symbiotic reflections including ecological evaluation of possible settlement structures.

3.1 Transient System Simulation to investigate the heating- and cooling demand (TRNSYS)

The Institute of Thermal Engineering uses the simulation environment TRNSYS (Transient System Simulation Tool) for the simulation of thermal systems. In the TRNSYS simulation environment the balancing of the occurring energy flows for active and passive components in a building can be numerically modelled. This includes space distribution components like heating, cooling and ventilation systems, as components representing the local energy supply (e.g. solar thermal systems, heat pumps, storage tanks, district heating).

One of the key factors in TRNSYS' success over the last 25 years is its open, modular structure. The source code of the kernel as well as the component models is open to the end users. This simplifies extending models to make them fit due to the user's specific needs. A typical application for TRNSYS is the transient simulation of buildings, in order to analyse their behaviour in dependence of climatic conditions and the interaction with the HVAC system. [1], [2].

3.2 New methodology for dimensioning of electrical installation equipment

In this methodology the estimation of the electrical energy demand, the electrical energy generation and the installed power to dimension the required electrical equipment (e.g. transformers and medium voltage lines) for the different quarters (1-18) in the Reininghaus area are shown. The dimensioning and selection of the electrical equipment is done by conventionally coincidence factors [3], [4] and within probabilistic coincidence factors and these results in various maximum power demands.

Usually the dimensioning of electrical installation equipment e.g. LV and MV voltage power lines, transformers and protection devices is based on the total sum of the electric power of loads multiplied by coincidence factors which consider the simultaneity of the use of electric appliances. This procedure often leads to a relevant overdimensioning of the electrical installation equipment and therefore to high costs. The overdimensioning caused by the conventional approach can be avoided by a new method using utilisation factors derived by a probabilistic method where the different groups (office, medium scaled industry, household and industry) of loads and generators in the Reininghaus area are observed.

3.3 Total Energy System with Process Network Synthesis (PNS)

Process Network Synthesis (PNS) is a method to optimise systems of material- and energy flows. Methodical background is the p-graph method using combinatorial rules [5]. For urban and regional planning the software tool PNS Studio is used to find sustainable technology systems [6].

Starting point of a PNS analysis is to set up a maximum structure. Hereby all available raw materials and resources (including waste heat flows) can be defined as well as the technology network which can convert them either to intermediates which can be used in other processes or to products which can be sold on the market. Capacities of technologies as well as availability, amount and quality structure of materials are user-defined. Moreover time bound availabilities of resources, the specific demand of products, mass- and energy flows, investment and operating costs of the whole infrastructure, cost of raw materials, transport and selling prices for products must be defined.

Result of the PNS is the output of a maximum structure. The method is carried out with PNS Studio [7]. The programme creates an optimum structure which contains an optimum technology network. For this application the generation of the economically most feasible technology network is in the centre of consideration by setting the revenue for the whole system as target value.

3.4 Energetic Longterm Assessment of Settlement Structures (ELAS)

The ELAS (Energetic Longterm Assessment of Settlement Structures) calculator was developed to analyse urban structures ranging from single houses to whole settlement structures regarding to their energy situation [8]. evaluation of existing households, buildings or settlements as well as planned projects (new buildings, demolition, renovation, enlargement), predefined values as default values, estimate future developments

Core of the calculator is a fundamental data research about site-specific data containing matters like energy consumption and supply in relation to number of residents, mobility and distances between different locations concerning type of usage, influence of lifestyles, lifecycle of buildings, living space, type of energy resources, road and waste facilities and energy cost.

Results of the ELAS-calculator contain energy demand, ecological footprint (Sustainable Process Index – SPI), CO_2 life cycle emissions and regional economic impact (turn over, value added, imports, jobs) of the user defined settlement. This information gives municipalities a base for sustainable energy supply and appropriate policy decisions or privates an impression about individual energy consumption and its economic and ecological effects.

5. Discussion

Relating to the planned building structures energy demand and energy supply potentials of the quarter Reininghaus were calculated. To create a basis for exact quarter development the energy demand was calculated by the institutes as thermal and electrical energy demand. These demands were then used in the calculations finding an optimum total energy system.

5.1 Energy demand and specific energy supply solutions

Calculation of thermal energy characteristics

The climatic boundary conditions have a strong influence on the heating load and the energy demand of a building. The buildings, used in the simulations are assumed to be sited in Graz, whereby a climate dataset based on hourly values, generated with METENORM 6.1.0.9 [9], is used. The design ambient temperature for the calculation of the heat load of buildings in Graz is -12 °C. The interior room temperature was defined with 22 °C for the heating demand and 26 °C for the cooling demand.

The simulations are performed for a building stock representing two different levels of heat protection (low energy building (LE) and passive house building (PH)). The buildings are designed depending on the OIB guideline 6 on a national level defined minimum level of heat protection of buildings [10]. Due to these requirements for the LE the heat transfer coefficient (U value) for the external wall is 0.35 W/m²K, for the ground area is 0.40 W/m²K, for the ceiling area is 0.21 W/m²K and for the windows is 1.4 W/m²K. For the PH the U value for the external wall, for the ground area and for the ceiling is 0.15 W/m²K and for the windows is 0.8 W/m²K. The DHW (domestic hot water) demand was defined depending on the SIA fact sheet 2024 [[11]]. The DHW demand for the office space amounts 6 kWh/m²a.

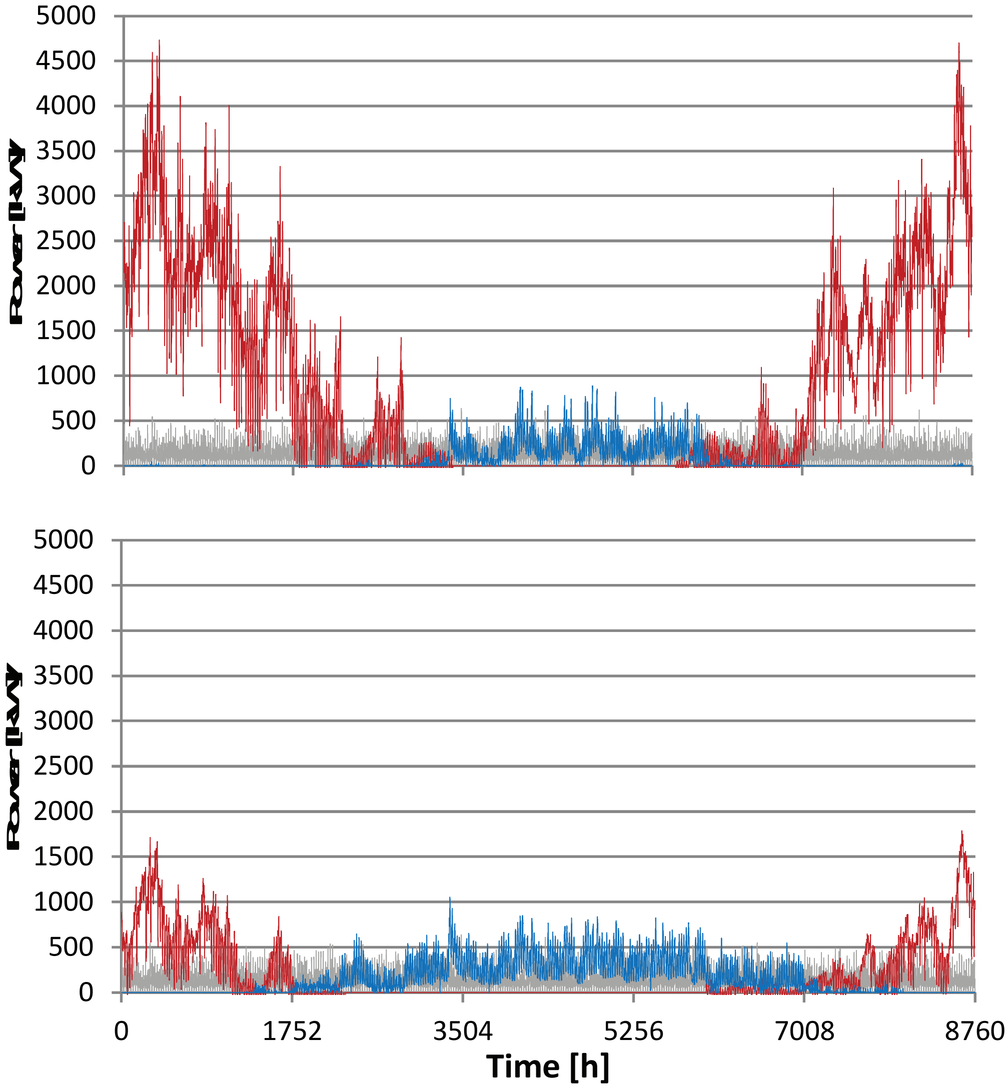


Figure 4: DHW, Heat and Cooling Power for LE and PH, Quarter 1 & 4a

Figure 4 shows the hourly data for the power demand for one year for domestic hot water (DHW), heating and cooling for the two different building concepts "low energy" and "passive house" as explained in chapter 3.3.

The figure shows that the difference of the two building concepts (level of heat protection and heat recovery in the ventilation system) leads to substantial differences in the thermal demand of the investigated building stock. On the basis of a higher insulation standard the annual heating demand significantly decreases from 7,502 MWh/a to 1,655 MWh/a. But on the other hand the annual cooling demand increases from 589 MWh/a to 1,370 MWh/a), as well as the length of the cooling season.

Concurrently to the demand the needed power for the investigated building stock is substantial different. The maximum occurring power for heating in the low energy scenario is 4,729 kW and 1,788 kW in the passive house scenario. The maximum occurring power for cooling is 886 kW in the low energy scenario and 1,053 kW in the passive house scenario.

Based on the gross floor area of 105,895 m² the maximum power for heating achieves 44.7 W/m² (for cooling 8.4 W/m²) in the low energy scenario and 16.9 W/m² (for cooling 10.0 W/m²) in the passive house scenario.

The annual energy demand for domestic hot water (DHW) for the investigated building stock (Quarters 1 and 4a) is 1,002 MWh/a. The maximum occurring power for DHW reaches a value of 637 kW. These figures are not affected by the building concepts and therefore the same in both concepts. Based on the gross floor area of 105,895 m² the maximum power for DHW achieves 6.0 W/m².

Calculation of electrical load characteristics

The estimation of the electrical energy demand for the individual groups (office, medium scaled industry, household and industry) which are used in the project ECR can be done with specific surface energies or state of the art load profiles (household H0, medium scaled industry G0-G7) [12]. The existing load profiles for different groups (e.g. household, bakery, supermarket) are estimated by an in-dept analysis. The used profiles differ between working day, Saturday, Sunday and varying for winter, summer and the transition period [13] and describe the collective electrical behaviour of each individual group for a whole year.

Especially in Graz-Reininghaus the area is dominated by households and so the electrical load profile of residential households in an urban area have been measured by smart meters and analysed using statistical methods. Resulting from these measurements are power density functions for weekday, Saturday, Sunday for winter, summer and transition period [14] which lead to new probabilistic coincidence factors [15].

Calculation of generation characteristics of PV

The generation profiles for the photovoltaic power plants are based on long-term global irradiance measurements within a 15-minute time-step resolution for the Reininghaus area in Graz [16]. The dependence of PV generation output power P_{PV} within a 15-minute time step resolution is shown by the following equation (1) [17].

(1)

The output power P_{PV} is highly dependent on the PV area A_{Mod}, the global radiation G_{Mod}, the ambient temperature T, the mounting angle γ_E and the azimuth angle α_E of the PV panels.

In this project the following three different scenarios for the photovoltaic generation are investigated:

- no photovoltaic generation
- moderate photovoltaic generation (~7 % of rooftop surface used)
- intensive photovoltaic generation (33 % of rooftop surface and 60 % of the facade area (south, east, west, north) excluding windows (30 %) used)

The photovoltaic profiles include the different orientations α_E (south, east, west and north) and the different angles γ_E of the PV panels (90 (intensive) or 35° (moderate)).

Resulting electric load, generation and energy balance

The primary analysis area of Graz-Reininghaus consists of various quarters (1-18) which includes building topologies and individual groups (office, medium scaled industry, household and industry). Figure 5 shows the detailed investigation for the load and the generation units (PV intensive and moderate) for the groups 1 and 4a.

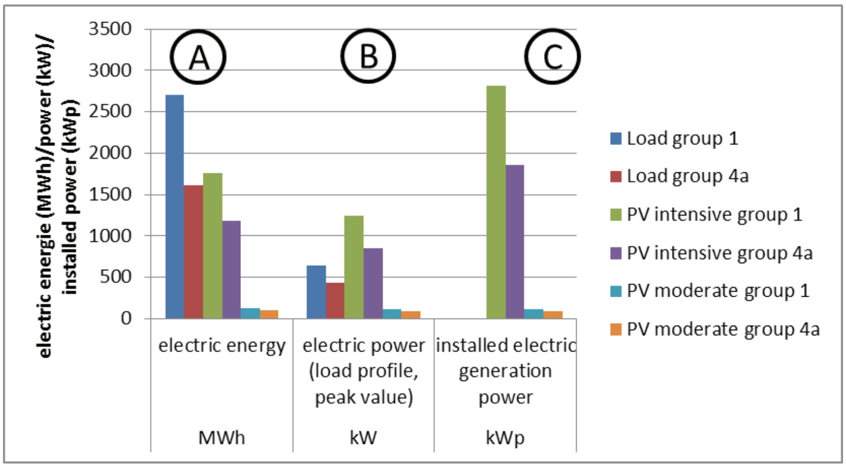


Figure 5: Annually produced and consumed energy (A), peak value of load profile (B), installed electric generation power (C) for the groups 1 and 4a

As shown in Figure 5: the annual energy (A) of the moderate PV as well as the intensive PV is to not high enough to supply the electrical load of group 1 and 4a. The solar coverage factor for quarter 1 and 4a for intensive PV is about 65 % and 74 % and shows how much energy can be met by the photovoltaic system, without taking the time dependency into account.

The peak power shown in Figure 5: (electric power, load profile (B)) of the intensive PV quarter 1 and 4a can nearly supply the load of the quarter 1 and 4a but the installed electric generation power is about 1,95 respectively 1,98 times higher than the peak power of the load.

The factor between the installed electric generation power (kWp) for the intensive PV (C) is about 44 % compared to the peak value of the load profile. This is due to the modelling of the different orientations (east, west, south, north) of the facade.

To take the time dependency into account the residual power p_{RES} between the source (photovoltaic power p_{PV}) and the load (load P_{Load} quarter 1, 4a) for each time step Δt has to be calculated, which is shown in equation (2) [18]:

(2)

A positive residual power ($p_{RES} > 0$) can be stored in an electrical storage unit or will be fed-back into the electrical grid. If the electrical power ($p_{RES} < 0$) is negative, the stored energy from the electrical storage unit can be used to supply the electrical load. Without an electrical storage unit the electric grid has to supply the electric load [9]. Only by the calculation of the residual power the degree of autonomy and the degree of own-consumption

The degree of autonomy calculated for each time step Δt by the residual load can be balanced over a period of time (e.g. 1/4 h, day, week, month, season, year) and shows how much energy can be provided by the photovoltaic power plant to supply the electric load. The degree of autonomy for the intensive PV/moderate PV is for quarter 1 (42 % / 5 %) and for quarter 4a (43 % / 6 %).

The degree of own consumption shows how much energy of the photovoltaic plant is used by the load. The results for the intensive PV/moderate PV is for quarter 1 (65 % / 100 %) and for quarter 4a (59 % / 100 %). The degree of autonomy as well as the degree of own-consumption can be increased by the usage of electric storage units [9] significantly.

Maximum Power demand of load and the generation units

The probabilistic coincidence factors can be used to determine the power demand of the individual groups (office, medium scaled industry, household and industry) for the whole area of Reininghaus. The results of the conventional approach (TAEV [1], VDE [2]) and the probabilistic approach (99.99 % quantile) of the calculated rated power for quarter 1, 4a and for the whole area of Reininghaus are shown in Table 2.

Table 2: Maximum power demand (conventional and probabilistic approach) for quarters 1 and 4a and for Reininghaus

maximum power demand

	load (conventiona l approach)	load (new probabilistic approach, 99,99 % quantile)	intensive generation (photovoltaic)
	[MW]	[MW]	[MWp]
Quarter 1	2.3	1.3	2.8
Quarter 4a	1.3	0.7	2.0
Total Reininghaus	**22.4**	**12.5**	**33.2**

The maximum power demand of the quarters 1 and 4a which are shown in Table 2: can be used for the selection of the transformers and the dimensioning of the cross-section of the medium and low voltage lines as well as for the protective devices.

5.2 Future prospects: Power to heat

With an increasing share of electricity generated by wind power plants and photovoltaic installations, there is a need to include these sources into the load management of the electricity grid. The conversion of electricity (power) into heat is an easy technology to be integrated into the grids as soon as electricity is cheap and available in excess. It can be used for load management and also for energy storage. Power to heat installations can easily and quickly be switched on and off.

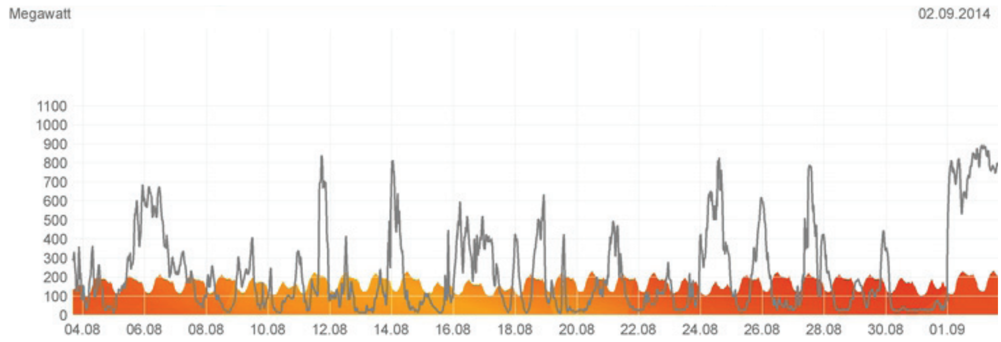


Figure 6: Consumption (coloured area) and production (line) of wind energy in the Austrian province Burgenland in August 2014 showing times of high overproduction [[19]]

There are two possibilities to convert power into heat: electric resistance heaters and compression heat pumps driven with electric motors.

An electrically powered boiler is a cheap installation but inefficient, if discussed from the viewpoint of thermodynamics. While the energetic efficiency is quite good, the exergetic efficiency is lousy. This is the reason why this technology has a bad image so far. It has been used so far mainly on a small scale (single apartments) in order to make use of cheap electricity at night. Now more and more large installations of several MW are in operation, especially in regions with a high amount of wind energy. The temperature for the storage system can be very high, since there are almost no limitations.

Compression heat pumps driven by electric motors offer a much higher 2nd law efficiency but are more expensive and slower in reaction to load variations. They should be used if the periods of cheap electricity are longer and the temperatures required on the storage side are low.

Both systems are not reversible, although a heat pump could theoretically be used as an Organic Rankine Cycle power plant if operated in reverse.

5.2 Total energy system

With Process Network Synthesis (PNS) a maximum structure was generated. This maximum structure contains a variety of possible technologies which can provide energy needed. In each of the quarters of the case study area fossil gas driven CHP units and gas furnaces, solarthermal plants, heat pumps with or without integration of waste heat, photovoltaic power plants and air conditioner can provide heat, domestic hot water, cooling energy and electricity needed. This energy can either be provided directly at the quarters (decentral technologies) or by big central supply technologies (central technologies) as shown in Figure 7.

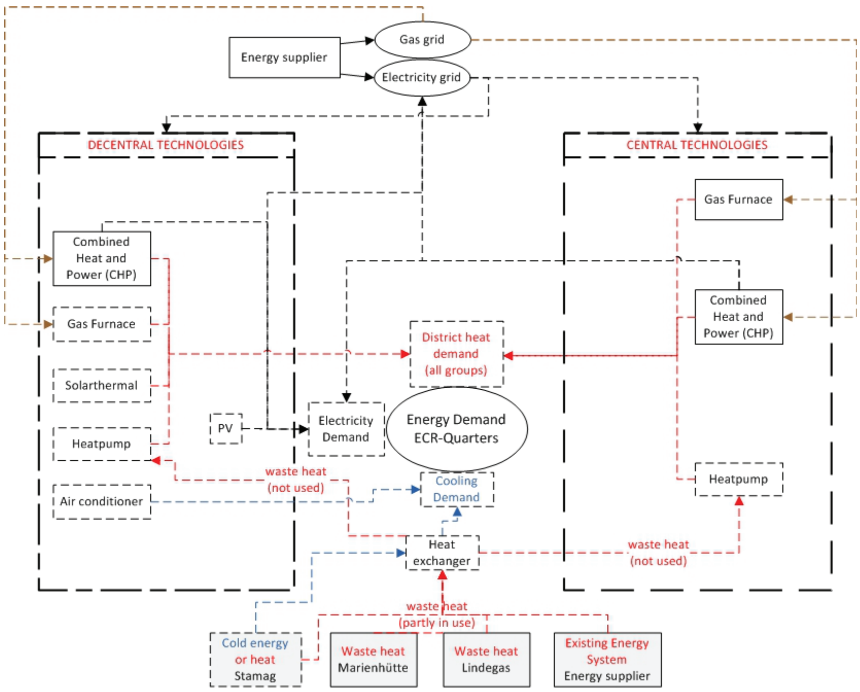


Figure 7: Maximum Structure, central and decentral technologies

Providing the quarters 1 and 4a with energy an optimum technology network was created by Process Network Synthesis. The following Figure 8 shows first PNS results of a basic optimum structure of the total energy system.

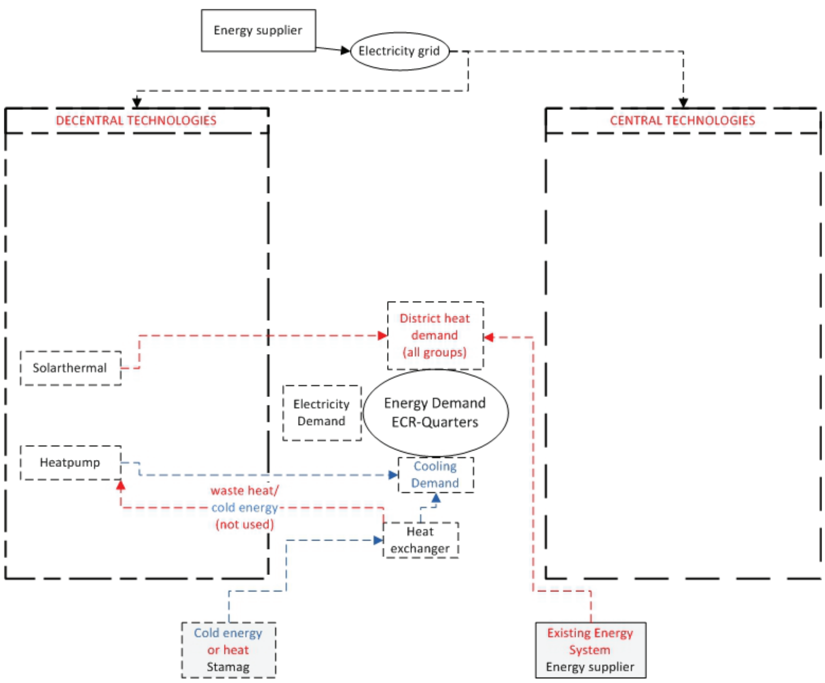


Figure 8: Optimum Structure for quarters Q1 and Q4a only

The technologies in the optimum structure for the quarters 1 and 4a only are heatpumps, solarthermal installations, cold energy from malthouse Stamag and heat from the existing district heat supplier. Located at the malthouse are cooling basins which have potential water deep wells with a temperature level around 10°C. All new technologies are suggested to be installed decentrally. The status of this optimum structure will be further discussed in scenarios because the economic data must be justified to withstand further use. Around 9,000 MWh/a shall be supplied by existing district heat net to cover the energy needed for heating demands. Additionally 242 MWh/a could be provided by solarthermal installations on the roofs of the planned buildings. Cooling can be satisfied for the quarters with 774 MWh/a cold energy coming from Stamag deep well. Using heatpumps directly at the quarters 1 and 4a the energy demand of 7,503 MWh for heating, 1,003 MWh for hot water and 589 MWh for cooling can be covered by the described energy system. Electricity demand of new constructed energy supply units is considered in the optimum structure, whereas electricity demand of the buildings is not considered. Setting required flows of electricity to fully supply the buildings with electricity the demand will be covered with combined heat and power (CHP) and photovoltaic (PV) units.

Afterwards the results of the PNS scenario were entered into the ELAS calculator (Energetic Longterm Assessment of Settlement Structures). Together with site-specific data about the case study districts the following socioeconomical and ecological results could be identified.

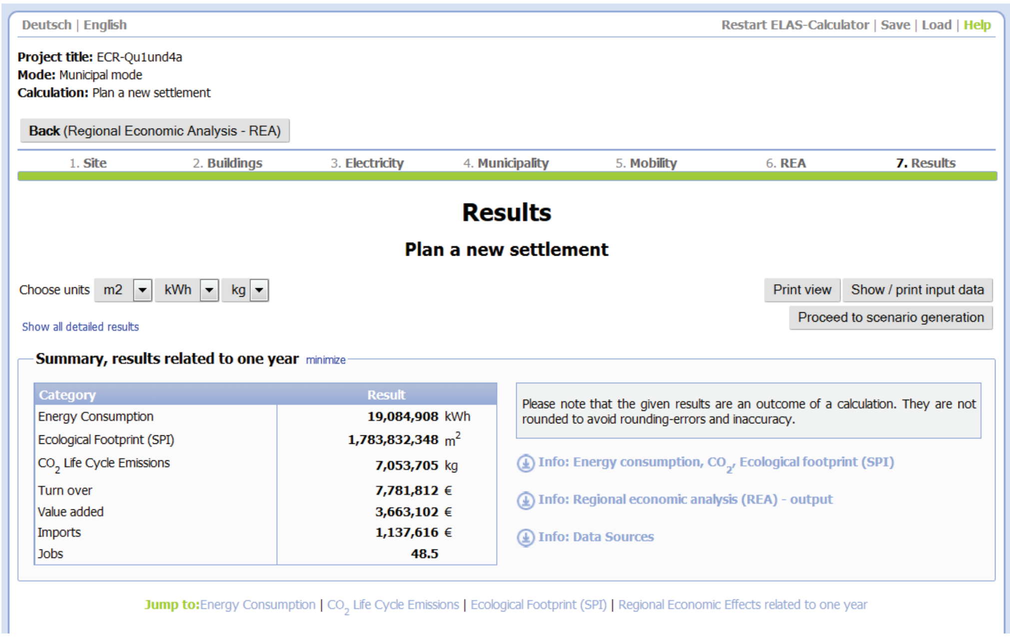


Figure 9: Energetic Longterm Assessment of Settlement Structures (ELAS) of quarters 1 and 4a

In the results of the ELAS calculator different categories are listed. One number is the energy consumption which summarises the total energy demand of the quarters 1 and 4a to an amount of around 19,085 MWh. The ecological footprint and CO_2 life cycle emissions for a supply with the existing district heat system would be very high because 90 % of the district heat comes from fossil resources. That shows that from an ecological point of view this basic optimum technology network is not ecologically optimal. The development of additional employment of the quarters can develop far more independently. The ecological footprint could be reduced drastically with each renewable technology replacing existing fossil fuels.

5.3 Synthesis

After the full project time the outcome of a multi-layered analysis of the interdisciplinary group will provide a useful optimum energy technology network and a catalogue of measurements for a smart energy development of the city district. Continuing feedback circles between the departments and stakeholders shall further make it possible to create scenarios to provide the city, stakeholders and the public with relevant information for smart energy planning in the city. The project team understands this work as a helpful tool open for the planning and it is open for discussion about further technology development and integration of smart technology solutions which can be parts of the technology system in future. The last example given in the future prospects part shows how such a system could look like in using power overproduction to fill heat production gaps.

6. Conclusions

Basically urban structures can change quickly but in case of a more or less empty strip of land also an inhomogeneous development on different places of construction in different periods of time leads to difficulties in defining optimum energy systems to guarantee a smart energy supply also for changing urban density. Parallel scenarios about energy systems for the total area as well as energy supply for specific quarters shall improve the possibility to find optimal pathways to supply city districts as smart and sustainable as possible. Process oriented work in progress during the project reveals and still is revealing pathways which can be adopted and the consideration of the ecological, social and economic chain which goes along with is long and considerably tricky to handle. Ultimately actions of this and further smart city quarter developments can draw on experiences which are freshly made by an as far unique combination of an interdisciplinary workflow.

Acknowledgements

The team of ECR Reininghaus wants to thank all funding partners, project partners and experts for their support during the project time. The research project ECR Energy City Graz Reininghaus is funded by the City of Graz, the Federal State of Styria and the Programme "Building of Tomorrow" of the Austrian Federal Ministry of Transport Innovation and Technology (BMVIT) via the Austrian Research Promotion Agency (FFG).

References

1[] TRNSYS 17. A Transient System Simulation Program: V17.01.0025. Solar Energy Lab, University of Wisconsin – Madison, USA;2012

2[] Heinz A., Application of Thermal Energy Storage with Phase Change Materials in Heating Systems, Dissertation at the Institute of thermal engineering, Technical University Graz, 2007

3[] TAEV, „Technische Anschlussbedingungen für den Anschluss an öffentliche Versorgungsnetze mit Betriebsspannungen bis 1000 Volt",“ Österreichs Energie, Wien, 2012.

4[] DIN VDE 0100-100, Errichten von Niederspannungsanlagen, 2009.

5[] Friedler, F., Varga, J. B., Feher, E., Fan L. T., 1996. Combinatorially Accelerated Branch-and-Bound Method for Solving the MIP Model of Process Network Synthesis, Nonconvex Optimization and Its Applications, Computational Methods and Applications. Floudas, C.A., Pardalos, P.M. (Eds.). Kluwer Academic Publishers, Dordrecht. State of the Art in Global Optimization, Nonconvex Optimization and Its Applications, Volume 7, pp. 609-626. doi: http://dx.doi.org/10.1007/978-1-4613-3437-8_35, url: http://link.springer.com/chapter/10.1007%2F978-1-4613-3437-8_35, ISBN: 0-7923-4351-4.

6[] Narodoslawsky, M., Niederl, A., Halasz, L., 2008. Utilising renewable resources economically: new challenges and chances for process development. Journal of Cleaner Production, 16, 2, 164-170.

7[] Friedler, F., Tarjan, K., Huang, Y.W., Fan, L.T., Varga, J.B., Feher, E., 2011. P-graph: p-graph.com/pnsstudio, PNS Software Version 3.0.4. www.p-graph.com, last accessed on 21/08/2014.

8[] ELAS calculator: Energetic Longterm Assessment of Settlement Structures, 2011, www.elas-calculator.eu, last accessed on 27/08/2014.

9[] Meteotest. Meteonorm 6.1.0.9. Global Meteorological Database for Engineers, Planner und Educations. Software and Data on CD-Rom, Meteotest, Bern, Switzerland, 2009

10[] Österreichisches Institut für Bautechnik, OIB-330.6-094/11, OIB Richtlinie 6, Energieeinsparung und Wärmeschutz, OIB Richtlinie 6 Ausgabe Oktober 2011

11[] SIA. Merkblatt 2024, Standard-Nutzungsbedingungen für die Energie- und Gebäudetechnik, schweizerischer ingenieur- und architektenverein, Ausgabe 2006

12[] Energie-Control, 2011. Zählwerte, Datenformate und standardisierte Lastprofile, Sonstige Marktregeln Strom, Österreich.

13[] Schieferdecker, B., 1999. Repräsentative VDEW-Lastprofile, VDEW Materials. Frankfurt.

14[] Reiter, M., 2014. Probabilistische Auslastungsanalyse einer Verteilnetzstruktur auf Basis statistischer Auswertungen von realen Smart-Meter-Messdaten, Institut für Elektrische Anlagen, Technische Universität Graz.

15[] Wieland, T., Reiter, M., E. Schmautzer, E., Fickert, L., 2014. Gleichzeitigkeitsfaktoren in der elektrischen Energieversorgung – Konventioneller & probabilistischer Ansatz. Springer.

16[] Meteotest. Meteonorm 6.1.0.9. Global Meteorological Database for Engineers, Planner und Educations. Software and Data on CD-Rom, Meteotest, Bern, Switzerland, 2009.

17[] Schubert, G., 2012. Modellierung der stündlichen Photovoltaik- und Windstromeinspeisung in Europa,“ in *12.* Symposium Energieinnovation, Graz/Austria.

18[] T. Wieland, E. Schmautzer, B. Domenik und L. Fickert, „Optimal sizing of electric and thermal energy storage units for residential households with decentralized generation units in the low voltage grid,“ in Electric Power Quality and Supply Reliability Conference (PQ 2014), Rakvere/Estonia, 2014.

19[] Net Burgenland: http://www.netzburgenland.at/ from Sept. 2, last accessed on 02/09/2014

Sustainable Urban Mobility Applications projected in the city of Graz

Birgit Kohla, Carlos Varela Martín, Antonia Nakova, Martin Schnalzer, Markus Anton Lindner, Yvonne Bormes, Ernst Rainer, Elena Just-Moczygemba, Mark Thaller.

17th European Roundtable on Sustainable Consumption and Production.
14. – 16. October 2014. Portoroz, Slovenia

Abstract

Travel behaviour is one of the main aspects subject to improvement in the context of urban sustainability. The main gains would come from reducing the use of the private car, and promote walking, cycling and the use of public transport or car sharing and taxi. There are several potential advantages derived from this policy, starting with the reduction of energy consumption and emissions of pollutants associated with the use of cars. Moreover, other benefits of a diminishing traffic are less noise and a more social city because of the possible communication between the inhabitants while walking or using the public transport. Thus, there exists a general interest in promoting the low-carbon modes of transport, especially the electric mobility.

The city of Graz is attracted by this discussion, as it foresees to apply policies of sustainable mobility because the city is faced with problems of air pollution due to its geographical situation in a valley. In existing projects of development areas in the city of Graz, for example Smart City Graz West, there are started already the research to get a sustainable city.

This paper will overview the plans of Graz towards a more sustainable mobility. It starts with a theoretical background from literature and good practice examples from a number of cities and follows on with more specific topics and a discussion of the decisions taken so far towards the design of a sustainable mobility in "Smart City Graz", considering also several scales of application. The paper follows with the role of sustainability in designing multifunctional districts in which daily amenities and services are reachable by walking distance. Then the importance of the different mobility behaviour will be highlighted, and the synergies that can be produced when combining with public transport such as bus or tram. At this point the possibility of combining different travel services (as public transport, bicycle parking, car sharing and similar) in one area will be presented. In his way the inhabitants' need for a private car ownership can be reduced without compromising the convenience, regardless of how long the distance to their target is.

The discussion derived from the previous topics includes e-mobility as background topic, counting with the possibilities of implementing electricity-powered bicycles and cars.

1 Introduction

1.1 Historical precedent

In the current socioeconomic context, that generally recognizes the advantages of the sustainability, there is ongoing discussion about how to make inhabitants more responsible with the environment and at the same time increasing their quality of life, following an urban development that some authors call “Smart City”.

Individual mobility is an integral component of the “Smart City” discussion. First of all, mobility is a main feature of the personal and social life of the inhabitants and for that a basic need for every human. People want to displace from point A to B in a reasonably cost-effective, safe and quick way. This need can be addressed by providing appropriate infrastructure and travel options.

The need of displacing between two points has been met along the history in many different ways; for centuries the horse or the caravan were the most employed ways of land transport, until the revolution introduced by the railroad, alongside the Industrial Revolution. There is however one mode of transport that has been determinant for the cities along the 20th century: the car.

Since the release of the Ford T in 1908, the car has served as a vehicle for individual mobility all over the world, having a far-reaching influence in the development of public infrastructures, and shaping the urban development along the century, especially in the United States. After the Second World War, the United States started the construction of the biggest public work ever made, the Interstate Highway System, in parallel development with the expansion of the car ownership in the country. The new urban developments of the time were adapted to this tendency of increased motorization and the extension of range in travel. Large areas dedicated for a single land use came up, implying that their residents had to use the car for shopping or going to work. In turn, the increasing affluence of cars fostered the creation of bigger highways and a more extensive road system, which promoted further car use in a positive feedback. With the extension of cars in urban spaces, non-motorized transport was progressively displaced. This kind of development resulted in urban sprawl and low density of settlements. By the end of the century the developed world was highly dependent of the car, a tendency that hasn‘t been reverted since then.

This preference of the car over other modes of transport, as public transport, cycling or walking, has a series of negative consequences that are essentially incompatible with the purposes and the objectives of a “Smart City” concept. Reducing the car ownership can save space and resources in a city, as well as reducing energy consumption and levels of pollution. Besides, the general costs are less than the resulting from a private car. Furthermore, the reduced probability of accident is a benefit for the citizens.

A car consumes five times more energy compared to the public transports, and it is around three times more pollutant per passenger and unit of distance (Table1). The menace of the global warming means this is simply an unacceptable cost. Pollutants emitted by the cars are not limited to CO_2, but include also particles and NOx that deteriorate air quality in particular inside the city. Air pollution can be an especially sharp problem in cities placed in particular geographical locations, as it is with the city of Graz.

Table 1: Energy cost and emissions per passenger and by transport mode (Department for Transport, 2010; University of Columbia, 2010)

Mode of transport	Energy cost (MJ/100 passenger/km)	CO_2 emissions (kg/100 passenger/km)
Walking	20	0
Cycling	16	0
Tram	30	8
Bus	40	10,7
Car (1 person)	200	24
Car (5 people)	40	5

Moreover, there are other inconveniences derived from an excessive presence of the car, making in general the city less pleasant for pedestrians. Traffic safety decreases for non-motorized road users, as the cars cause severe accident due to high speed. All road users compete for the public space, whereas the network for non-motorized transport often lacks, making the city harder to navigate for them. This in turn is also detrimental to the social life in public space, with a street design that discourages a comfortable walk, to rest or to stop for a talk using streets as a meeting point. With traffic reduction a city can get more social and animated and the quality of life is appreciably higher for the inhabitants. Last, cars produce noise, that disturbs residents as well as other road users.

1.2 Trends behind the sustainable mobility

For all the previous, there exists general consensus about the need of changing the paradigm of mobility in cities; especially in the called “Smart Cities”. There are several trends that can be mentioned when talking about this shift, as described below. These trends will be reflected with different intensity when talking about more specific initiatives in Graz (see section2).

1.2.1 Detracting priority from the car

Currently, the car frequently enjoys a privileged position in comparison with other modes of transport. For instance, providing enough parking spaces is one of the first worries in the urban development. In public areas, spaces reserved for car parking reduces options of alternative use, e.g. for cycling, walking or other urban activities. The objective is to reverse the relative importance given to the car, placing it as the least desirable mode of transport. Meanwhile, walking and cycling should be on top of the priority list, because they do not produce emissions and promote social interaction. Public transport (rail, bus or tram) is a basic option of modern mobility, especially in cities. With moderate environmental impacts compared to private car public transport and further on the car sharing initiatives, together with the use of taxi should be somewhere in-between car and non-motorized transport in priority (Figure 1).

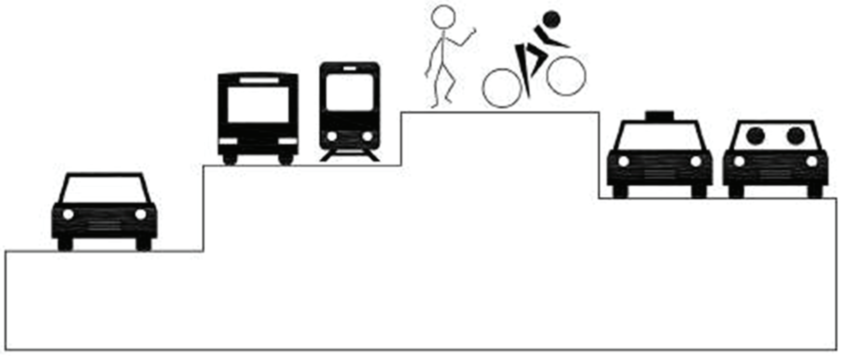


Figure 1: Graphic representation of the priority given to different modes of transport according to the principles of sustainable mobility

1.2.2 Use of the e-mobility

As mentioned, the electric motors have some decisive advantages over those running on fossil fuels: less pollutant, less noisy, and can run sustainably, as long as the electric supply is produced by renewable energies.

A main disadvantage is a high cost of batteries so far and the limitations of the e-mobility, the possible distance travelled. Nevertheless, using an e-car in the city can have a lot of benefits, as reduced parking fees, less environmental impact and reduced levels of noise.

Electricity has tradition as propulsion technology in urban mobility, for instance on trams. Continuous improvement in battery technology makes it progressively independent from permanent electricity supply and therefore more suitable for other modes of transport, especially those that benefit from the lower marginal cost of running on electricity.

Electric buses or electric cars for car sharing are applications that will be more present in the future, as the technology improves and the price of the fossil fuels continues to rise. The decreasing cost of batteries also fosters the use of personal electric bikes, increasing the comfort and the range compared to a traditional bike.

1.2.3 Use of sharing and rental vehicles

As mentioned, technological improvements do not suffice to solve all of the problems with cars in the city, especially those related to limited space and traffic issues. Sharing or rental vehicles can help to solve those problems. Combined with electric technologies, a city can experience a better environment and less noise, as it has been mentioned

1.2.4 Embodiment of Information and Communication Technologies

Information and Communication Technologies (ICT) are often quoted as one of the main ingredients of a Smart City, in the way everything is interconnected and the information can be used to improve effectively the quality of life or reduce the environmental impact. The ICT have witnessed a considerable success in the mobility field, in good part thanks to the recent introduction of the 'Smartphones'. The ability to consult information on trip and in real time has improved the potential of using already existing information: for instance travel options, temporal and spatial availability, planning of trips, ticketing, routing and navigation applications. Besides, the mobile phone applications support some new ideas like sharing of vehicles, as previously mentioned and further described in section 2.4.

1.3 Context in the city of Graz

Graz is the second biggest city of Austria with near a quarter million inhabitants and growing. In the last years, the city has developed a strong focus in sustainability with the “I live Graz” project. This project is a series of objectives for the year 2050, and intermediate goals for 2020, which covers most of the aspects of the sustainability at city level. This includes topics as ecology, economy, society, waste management and, mobility[1].

Boosted by this set of objectives, Graz has planned to implement high standards of sustainability in large areas based on a project known as “Smart City Graz”. This is an opportunity for implementing the previously mentioned principles of sustainable mobility, to be developed for the increasing population and serve as a showcase for other cities.

Moreover, the motivations include public health concerns, because the placement of Graz in a valley makes it prone to have air pollution problems, especially during wintertime. Over the last years, the levels of the pollution in general have improved in the city, but the fine-particle and nitrous oxide values are still worrying (Land Steiermark, 2012). To point out the threat of the air pollution to residents, it is worth to consider that fine-particle air pollution is associated with more than 455 thousand

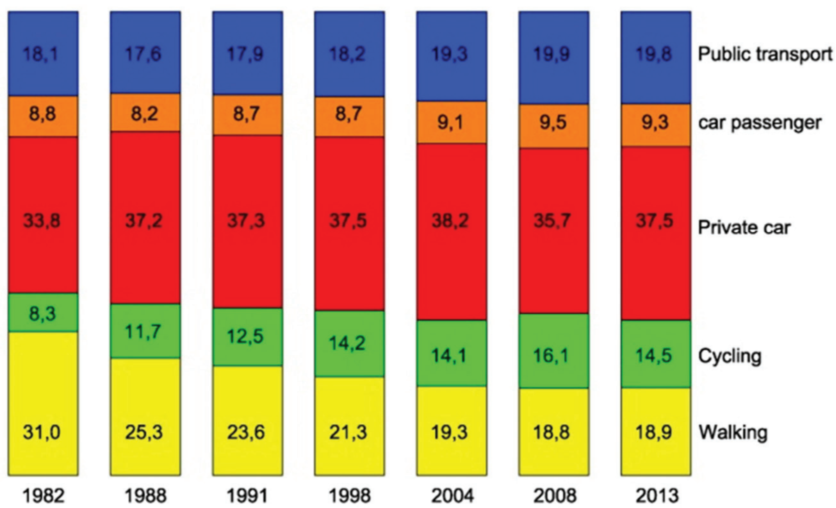


Figure 2: Modal split in Graz

1: http://www.stadtentwicklung.graz.at/cms/beitrag/10214647/4631044/

premature deaths every year in the EU’s 27 Member States (European Commission, 2011). Despite the reasonable public transport and bike network in Graz, there is without any doubt room for improvement, as the car still hoards 46.8% of displacements in the city (Figure 2).

To curb the use of the car, Graz will design specific mobility plans for each urban development, and of course put these plans in coordination with more general guidelines at city level. This paper focuses on the area of development named “Smart City Graz West”, which includes four areas of development. The area placed at the north of the main railway station receives the name of “Waagner-Biro”. There already exists a more or less detailed plan of “Smart Mobility” for this area. This plan includes the distinction of “pull” and “push” measures: The “pull” ones incentive explicitly the use of bike, bus or car sharing by improving these services; meanwhile the “push” measures discourage actively the use of the car, hindering it in favour of other modes. Although the mentioned document is especially made for a part of “Smart City Graz West”, it could be modified and applied to other areas of development, including the largest potential area of urban expansion within the city of Graz, known as “Reininghaus”. This area is placed at the southwest of the main railway station and is also involved in the initial stages of urban development.

The area of Reininghaus has benefited from a framework plan sponsored by the European Union[2], thanks to which it has been possible to coordinate the efforts of the city of Graz and of private investors[3] in order to find middle grounds for the request of one and another. Fruit of this effort, a spatial plan of land use and mobility paths in Reininghaus is a consensus carried over more than two years.

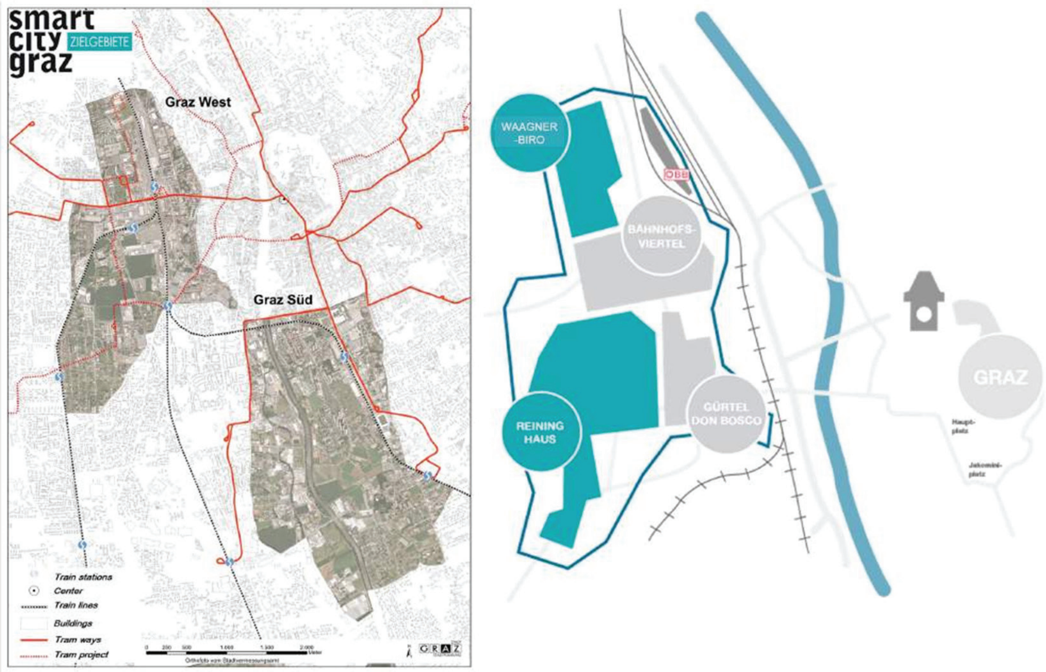


Figure 3: Scheme of the placement of the different areas of intervention in the "Smart City Graz" projkect.

2: http://www.stadtentwicklung.graz.at/cms/beitrag/10136566/2858034/
3: http://www.graz-reininghaus.at/index.php?id=4

The other two areas of development considered in “Smart City Graz West” are named “Bahnhofsviertel”, and “Gürtel Don Bosco” (Figure 3). These areas have not received attention about their urban development so far, but it can be assumed that the principles of sustainable mobility can be applied to them as well.

Graz has the will of serving as a model, but anyway it receives strong influence from other cities. Virtually, all the ideas and initiatives considered have been already tested somewhere across the globe; and there are a number of examples of districts and cities that have a very well developed concept of Smart Mobility. In Amsterdam, for instance, the bike accounts up to 38 percent of the trips[4]. This is an impressive figure, but also consequent with how compact the city is and how difficult it can be moving by car through its narrow streets. The Dutch capital is a good showcase of enforcing non-motorized mobility by compact and car-unfriendly urban structures.

Copenhagen ranks also very high in use of the bike with a 26% of trips and a very high percentage of walking, which means a low use of private car.[5] The big success of Copenhagen is creating an extensive network of bike lanes that extend up to 22 km from the centre of the city. Many of these bike lanes can be considered “bike highways”, counting with especial width, or featuring a “green wave” of traffic lights to average cycling speed by reducing the number of stops.[6] In this way the use of the bike is fostered, despite the fact that Copenhagen is not as compact as Amsterdam.

Freiburg is another city with a remarkably low use of car, with around 0,4 per inhabitant (Foletta and Field, 2011), thanks to a good network of public transport and a street design that encourages a comfortable walk and supports the hierarchies in the street by reducing the speed. This has been used especially on new developed city districts, as Vauban. Here, the tram line that makes the district access able was installed in the first stages of the development. So people got used to the public transport when changing residence or visit the district from the first time on and dispensed with the car. Other cities like Copenhagen and Stockholm have followed the same approach with good results (Hall, 2008, p 267, 237). Freiburg also does a good work with “push” measures, for instance with parking management (restrictions and high fees), which is also followed by Graz.[7]

The previous examples are just some of the main influences for the city of Graz. Besides them, and due to the problems of air pollution, Graz plans to pay special attention to the electricity-powered mobility, pondering on the introduction of electric bikes and cars.

4: http://www.iamsterdam.com/en-GB/Media-Centre/city-hall/dossier-cycling/Cycling-facts-and-figures
5: http://www.cycling-embassy.dk/2013/06/03/6995/
6: http://denmark.dk/en/green-living/bicycle-culture/cycle-super-highway/
7: http://www.vauban.de/

2 Analysis by mode of transport

The planned “push” and “pull” measures fall in several categories, more or less matching with each one of the modes of transport to boost.

2.1 Walking

As discussed, pedestrians are on the top of the preferences for sustainable transport. There is a focus on establishing walking as the default transport mode for the inhabitants as long as the distance is not excessive.

This can be achieved at great extent by designing multifunctional districts, pretty much in an opposite way than the urban sprawl does. Instead of creating large areas dedicated to residential areas and then plan the commercial and working areas for those citizens, the objective is mixing up these land uses, introducing also in the urban tissue medical and educational facilities, and places for leisure and relax. In a multi-functional district, due to short distances, it is perfectly possible to go by foot or bicycle for daily trips. Public buildings like schools or kinder garden are planned appropriately, in the way that its accessibility is maximized. The same applies to other facilities, with variable exigency about their accessibility; green areas are supposed to be at walking distance, meanwhile hospitals or police stations can be expected to be more sparsely distributed along the district. Figure 4 highlights a matrix of trip purposes. It can be observed that about 80% of the displacements start or end at home, and most of the destinations are work or shopping. In a “city of short distances” these destinations are placed nearby the residential areas, and ideally the displacements are short enough as to cover daily-life trips by walking.

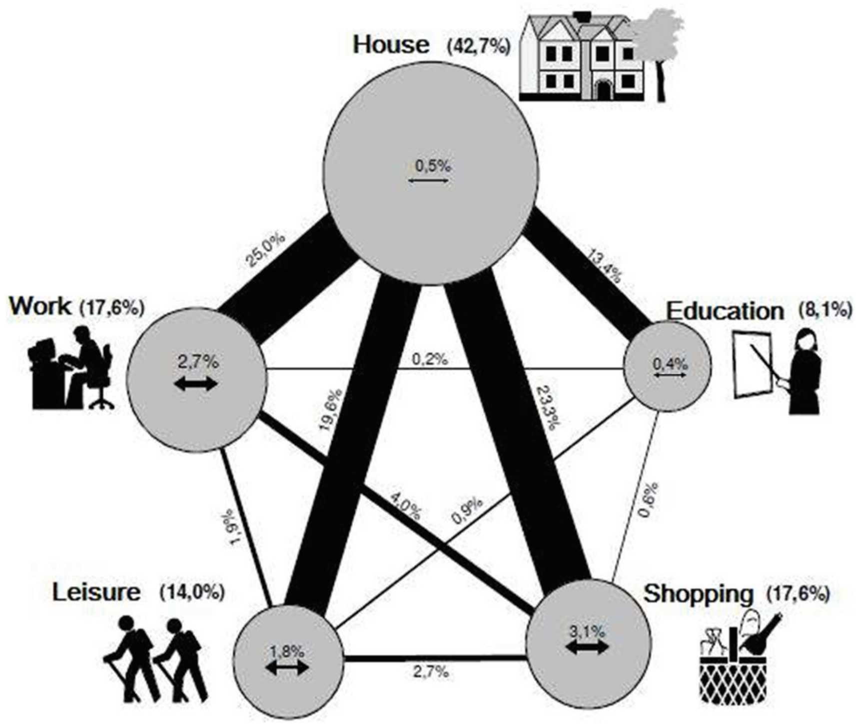


Figure 4: Displacements in the city of Graz

As a complement to this policy of short distances, there is a focus on creating a pleasant space for pedestrians, to encourage further walking over other modes of transport. One option to make urban space more comfortable to pedestrians is a reduction of noise and pollution as well as an improvement of safety, e.g. by traffic reduction. Another option is reorganization of public space in favour of pedestrians. Other measures are rather aimed at the creation of green areas and other attractive spaces, which encourage slowing down and using urban space for social interactions, fostering in that way the social cohesion of the district.

2.2 Cycling

Riding a bicycle is another preferred mode of transport, as it allows moving around three times faster than walking, without CO_2 emissions and even with more energy efficiency than by foot, according to Table1. It is also a versatile mode of transport, with access to almost any place. On top of that, walking and cycling foster the public health by providing a daily dose of exercise.

The area of “Smart City West” is between two to five kilometres by bicycle from the centre of Graz. Well exploited, this short distance can place the bicycle as a feasible way of transport from and to “Smart City West”, which multiplies its potential for sustainability.

In order to untap this potential, it is planned a bicycle network, more or less resembling a grid, as seen on Figure 5. Lines of dark green represent separated cycling paths, lines of light green represent shared space with motorized transport. Existing infrastructure is marked as solid line; planned infrastructure is marked as dashed line. This is a quite dense network of attractive bicycle connections in the city. The quality of the bike lanes is also a point to consider, distinguishing between Radweg and Radroute. The difference between both is that the first consists in a separated lane from pedestrians and motorized vehicles; which makes cycling safer and more comfortable. Meanwhile, the Radroute forces the bikes to share the road with cars; a second option not preferred for the new developments, however it is true that uses less space in the driveway, and in those streets with limited speed with cars can be a perfectly feasible solution.

An extended version of the Radweg could be “cycle highways”, which are especially designed to allow a faster flow of bicycles. This can be achieved making a sharp spatial separation between cyclists, and other modes of transport. With a well-spaced width of the cycle highway, it is easier to overpass other riders and maximize the speed. In Graz the cycle highway seems to be especially useful to join “Smart City Graz West” with the historical centre of Graz, allowing moving in a comfortable and sustainable way between the oldest and the newest part of the city.

The current trend in the city consists in closing the gaps in the bicycle network, rather than improving already existing corridors. So the idea of “cycle highways” will receive further attention in the future once the bicycle network has become denser.

Together with the investment in infrastructure, the possibility of establishing a bike rental system in Graz is examined. There are numerous examples of these kinds of initiatives across Europe, some of them undoubtedly successful, for instance in Paris, Seville or Brussels. This can be a very useful way of transport for those users who do not use a bicycle in daily-life mobility. It can be a gateway for acquire a private bicycle later on. A rental system can combine very well with public transport, especially attractive to non-residents. The system essentially consists on a network of rental

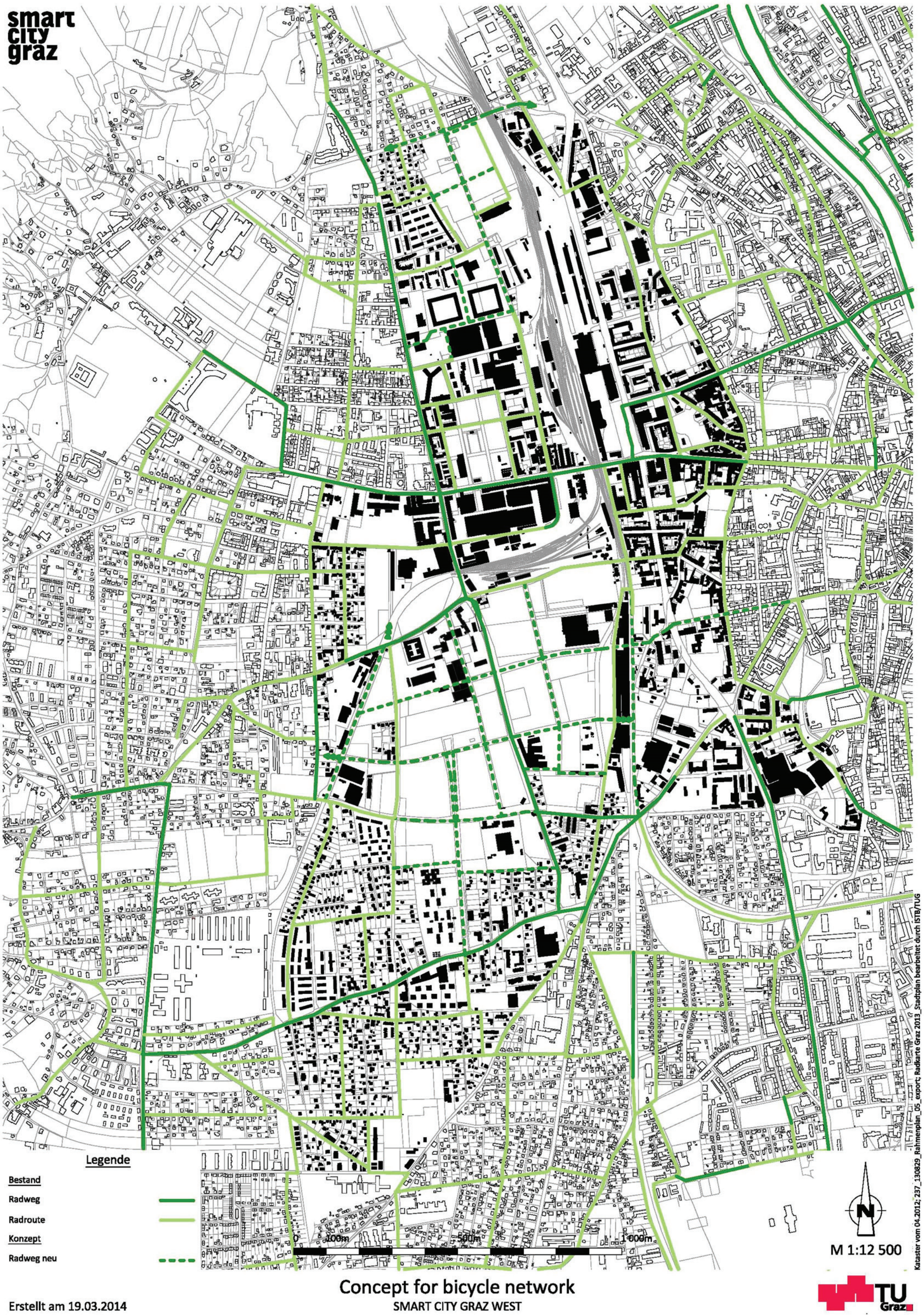


Figure 5: Concept for a bicycle network in Graz West

stations. Free floating systems allow rental and return of bicycles at different stations along the city. The prices are normally charged both from an annual subscription fee and from the individual use of the bike per time. There are different models with variety free time of charge at the beginning. The first ten or fifteen minutes of use (in Vienna the first hour) are usually free of charge. Such a system may encourage more people to use a bicycle, but has also disadvantages. It requires a strong initial investment that usually relies on the city, as well as a continuous supervision and management activities like repairing vandalized bikes or moving them from the full parking stations to the empty ones[8]. The decision to establish such a system of bike rentals in a city depends largely of a careful balance of the public advantages versus the public cost of the system. This will depend at some extent on the particularities of the city.

As Graz is a ‘Cycling City’, many people in Graz already own a private bike. Moreover there is a bike sharing system which extends the offer of the 'Cycling City'. Nevertheless the moderate size of the city makes the synergy between bike and public transport weaker. Different issue is the rising popularity of electric bikes. Bike charging systems may be implemented in interconnection points (see section 2.5)

The implementation of an electric bike sharing system is a good gateway for potential users by testing this new technology. As additional mode for trips with longer distances or hilly ground the electric bike could reduce the use of the car inside the city.

With the purpose of exploring these possibilities, Holding Graz has started a network of bike rentals[9], with the particularity of offering a wide variety of vehicles, from electrified cargo bikes to tandem ones. In this way, the service also covers a variety of demands, which can help in popularize it.

2.3 Public transport: bus and tram

The public transport is an important part of the integral plans of “Smart city Graz”, as it guarantees a basic mobility, in particular for people who are not able to move by bicycle or walking for any reason. Also, public transport is more efficient than private car use (Table 1).

One of the main objectives of “Smart City Graz” and “I live Graz” is making the public transport available for all citizens. Therefore the public transport stations are distributed in a way that every place is at a maximum of 300 meters away from an stop; the equivalent of 5 minutes walking time.

8: Notorious is the case of users that take the bike downhill, and later on take the public transport uphill; in this way some parking stations are always full, others empty.
9: http://grazbike.at/de/web

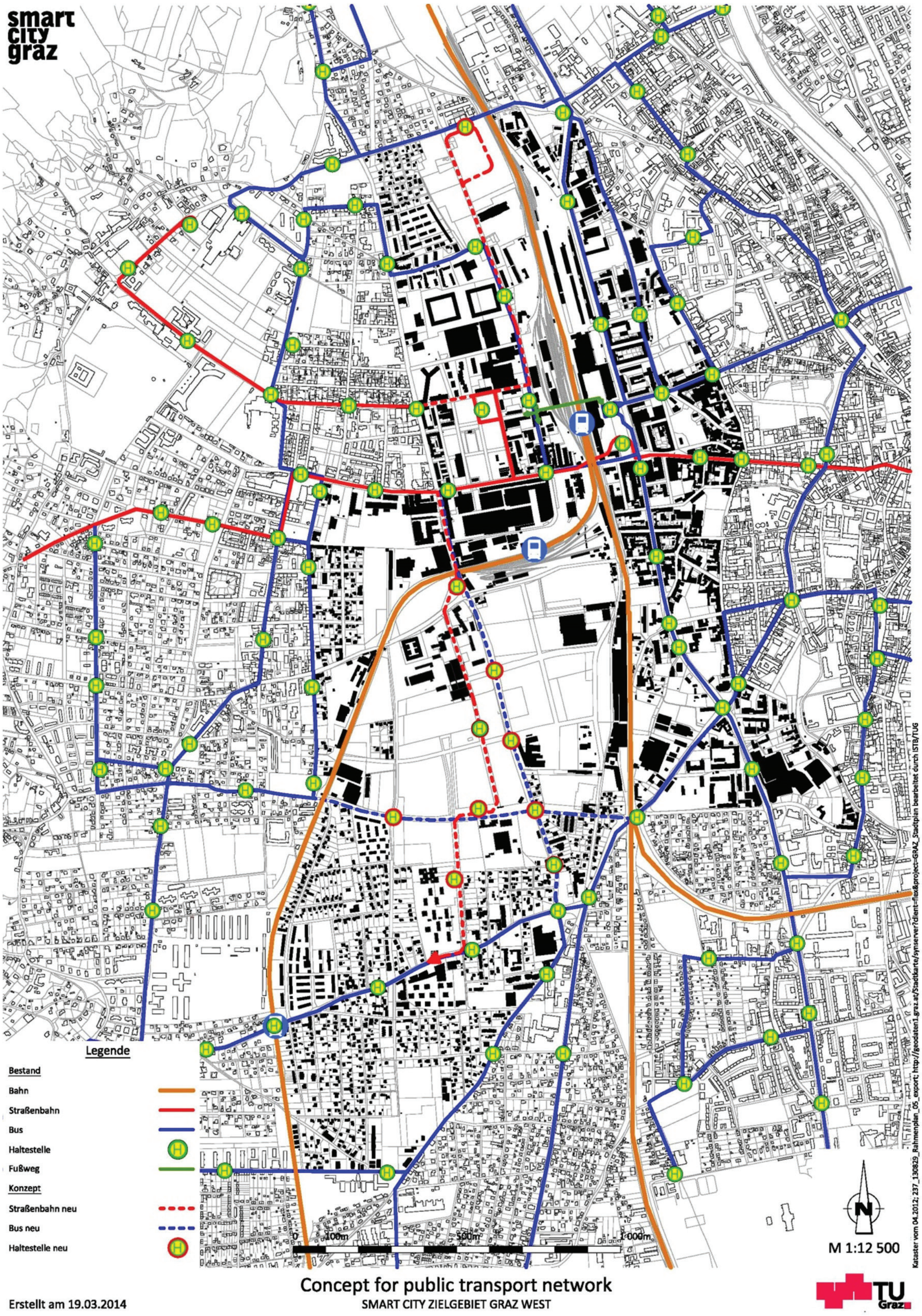


Figure 6: Concept for a public transport network in Graz West

Another of the principles to apply to public transport is the early implementation, regardless of the profitability at that time. This approach has demonstrated to be an important driver for the sustainability of new districts and quarters, for instance in

Oresund (Copenhagen) or Vauban and Reisenfeld (Freiburg) (Hall, 2011, p. 267, 237). As has been seen, establishing a public transport system from the very beginning of the development leads to a better user acceptance and allows the inhabitants to dispense easily with the car. As a consequence, the above- mentioned districts present a low rate of car ownership.

Public transport has a crucial importance in “Smart City Graz West”, as the main train station of Graz is at its heart, a fact that can have pivotal importance for the connection of new developments with suburbs and nearby cities for daily commuting. Despite this potential, inner-city connections with tram and bus lines are developed in an ongoing process. The distribution of the public transport lines on Smart City Graz West (Figure 6) will be modified in the future based on bus and/or tram lines. Therefore existing tram and bus lines will be extended to reinforce the main transport axis, or they will be diverted to other areas with lower density of population

For the area of Waagner-Biro there is a feasibility study in progress, analysing the extension of a tramline, which starting from the Southeast of Graz, passes the downtown and the main railway station to end up in the new district. In the area of Reininghaus there exist short-term and long-term strategies concerning public transport. So far, the plan is to install a bus line crossing the Reininghaus district from north to south and passing Don- Bosco, a transport interchange in Graz. Given enough demand for the long term, it is planned to extend a tram line passing the downtown and the main railway station.

A general decision on tram or bus is a discussion in which should be balanced the advantages and disadvantages of both modes of transport. The tram has a big advantage with running on electricity, and therefore no local emissions while driving. In part thanks to its higher capacity, energy cost per passenger and associated CO2 emissions are smaller than those of the bus (see table 1). This helps to make the tram less expensive in the long term, although the initial investment on rail infrastructure is higher than in a bus. Also, there is a phenomenon by which users prefer the tram over the bus. Under the same conditions a tram line will have more acceptance than a bus line, although the causes of this phenomenon are unclear[10]. Advantages of the bus system are a lower initial cost of deployment, and a higher versatility, as buses do not depend on fixed railways. An important disadvantage of conventional buses is the air pollution derived from the combustion engines. Electric buses are budding, however this alternative seems for the moment to have an initial cost too high for an effective deployment. Anyway, research on the area is going on.

These discussions are an important part of the work to do in defining a sustainable mobility for “Smart City Graz West”, and will be subsequently addressed in the next months.

10: Probably there is an occurrence of different factors: The tram is usually identified as more comfortable, modern or sustainable. Also, it is a mode of transport more embedded into the city thanks to the always present railways; users assume that a tram will pass by when rails exist. And people feel the tram to be more independent from traffic jams than the bus.

2.4 Car sharing

The advantages on sustainability and quality of life that the modal shift to bike and public transport can provide are evident, but it is hard for these modes to compete with the range, flexibility and comfort of the car. For covering all the spectrum of mobility needs and obviating the need of private cars, one good option is offering car sharing. This can imply numerous advantages for users: lower costs up to a yearly mileage of about 10.000 km/a[11], availability of a versatile vehicle fleet, no burden on car servicing as well as reserved car parking, sometimes exempt from fees. Also for the city and the environment it is a benefit.

Martin et al. (2010) show that the average number of vehicles per household can drop by more than half when adhere to car sharing initiatives; most of this shift produced by one car households becoming carless. As a result, the mobility behaviour of the inhabitants can change and the air pollution can be reduced. The analysis also yielded that car sharing had taken 9 to 13 private vehicles off the road for each car sharing vehicle. This leads to a reduction in dwell time per car and helps reducing the number of parking cars in public streets.

Essentially, the objective of a car sharing initiative is allowing the same comfort that a private car offers, having more benefits at the same time. Using car sharing instead of a private car is cheaper and reduces the CO_2 emissions. In general terms, there are two well differentiated ways of organizing the car sharing: by floating fleet, or by network station. It can be discussed which way fits better in a certain city.

The free floating system consists in a number of cars distributed along the city that can be find by a Smartphone application. After use they can be parked anywhere (as long as it is a legal place) inside a defined area, and it is charged by time used. The service relies on urban areas with high density of population and seems to be profitable in cities from a million inhabitants. Therefore this system usually competes with public transport.

The alternative consists in the creation of a network of stations from which the cars can be taken, and where can be left back. This means a more rigid system, but allows for a better control of the city planning because the location of the stations can be defined. This system intends to be subsidiary to public transport, as it can be realized in areas of lower density as well. It is designed for specific trips, starting and ending at the same place, which are hardly feasible by other modes of transport. A crucial advantage of the car sharing network station alternative is that it opens the possibility of electric-powered vehicles, as the charging points can be implemented easily in the stations[12]. In Austria there exist already examples of car sharing, with the city of Vienna as a spearheading. One of the companies well established in the capital is “Car2go”[13], that provides a floating fleet of seven hundred “smarts”, mostly of

11: "Bundesverband Carsharing", Germany (http://www.carsharing.de/)
12: There exists however a model of business of “Car2go” in which is combined the use of electric cars and floating fleet. The cars can but do not have to be plugged in at a series of charging points after use, and although this is not compulsory for the users, it offers the advantage of providing “free minutes of driving” for the next use.
13: http://car2go.com/en/wien/

combustion engine but also some of them electric. Another company is "carsharing.at"[14], an initiative of American "Zipcar". Its model is similar to the "Car2go", but focuses its business model more in offering a wide variety of vehicles to rent, rather than on the possibilities of a large floating fleet of homogeneous vehicles. The difference of "carsharing.at" is that it is not a free floating system and for that reason users are bound to hours of operation.

About systems of network stations, it is remarkable the case of the Parisian "Autolib"[15], that offers a network of stations along the city where two thousand electric cars can be rented. In Austria are also remarkable examples in which relatively small municipalities offer the possibility of renting shared vehicles; usually electric, to foster this kind of mobility[16]. So far, the pursued objective is to avoid the ownership of more than one private vehicle per household, instead of trying to substitute the first one.

In Graz there currently exists a weak implementation of "carsharing.at". As mentioned, in practice the floating fleet business model is not so attractive to providers in medium-sized cities, which prevented Graz from the implementation of a company like "Car2go" so far. The future of car sharing in Graz most probably depends on the actions of the municipality; especially Holding Graz and e-mobility Graz GmbH. The solution to adopt should be invariably of electric nature, as reducing the air pollution inside the city is priority; which in turn determines the stations network as preferred solution. In a first step there are planned a couple of stations in the area of "Waagner-Biro" and there exist some concepts for the area of Reininghaus.

This is just the beginning of a project that should grow for meeting significant sustainability objectives. There are possible pitfalls in this process. Obstacles of administrative nature, for example, as the Styrian building regulation specifies for urban development the strict figure of one car parking per household. Although this regulation can be lowered by municipalities in case of good public transport or by administrative order, this elevated number shows certain support for the private car use, which is in tension with the objectives of sustainability in the city of Graz. Solving these legal problems is an integral part of discourage the use of the car in the city.

2.5 Interconnections within modes of transport

The local authorities of the city of Graz and Holding Graz work together in order to establish a network of stations that implement different mobility services, having public transport as a backbone. The different solutions of transport exposed previously can work well by their own, but can also be combined to maximize the benefits. Mobility behaviour is expected to become more multimodal in the future, as people use different modes of transport to manage their trips. The underlying idea is to foster the synergy between modes of transport that complement each other.

For enhancing sustainable mobility in Graz it is planned an integral approach, especially including public transport, bike and car sharing. For this purpose is proposed certain infrastructure that serve as interconnection between these modes of

14: http://carsharing.at/de/pub/
15: http://www.autolib.eu/en/
16: http://www.drive-bea.at/ and http://ow.ly/w7nnH

transport, and perhaps include additional features. Figure 7 displays an early concept of such an interconnection node. It consists on a public transport stop that holds also a bike parking and lockers, combining in a seamless way bike and public transport as well as car sharing. Moreover, there are a number of ideas about the features that can be included in these nodes; for instance, they could include charging stations for the discussed service of car sharing, or also e-bikes. Next to the station, there exists the possibility of integrating taxi ranks. The station's shelter can be placed at a cape, as it is the case of Figure 7. Also it can be integrated architecturally into a building, as seen on Figure 8.

Figure 7: Concept of a mode-charging interconnection placed in the street

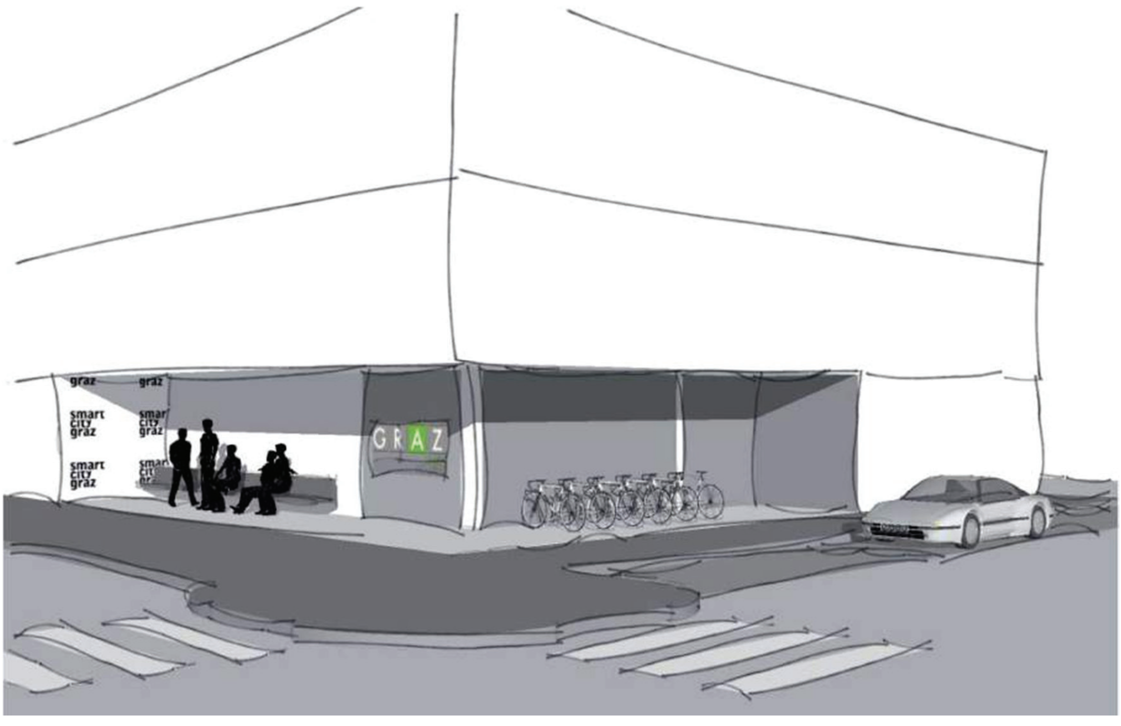


Figure 8: Concept of a mode-charging interconnection taking advantage of a corner in a building

A further idea is the implementation of a unified payment system over all connected modes of transport. An example of a universal card that allows rent a bike or a car, and using the public transport or a taxi, can be find in the German city of Bremen[17].

These features, together with others like mobile phone charging by solar panels, will be discussed in the next months. With the objective of involving students from the Graz Technical University and FH- Joanneum, a student's competition on the most innovative ideas of these interconnection nodes paired with the best design is in process.

17: http://mobilpunkt-bremen.de/

3 Discussion

3.1 Potential of the Product-Service Systems in a sustainable mobility

The last years have witnessed a rise in the called Product-Service Systems (PSS), in contrast with the more traditional business model focused on products[18] (see for instance Baines et al., 2007). The core idea of the PSS is that it is not necessary to "own" something in order to enjoy its advantages.

There are several ways to achieve this, for instance relieving a client from the end-of-life of the product; or conceiving a "pest control service" for agriculture instead of buying the pesticides. The two previous examples illustrate PSS focuses on increasing the value of the life cycle; or how delivering final results to customers. A way to do PSS, as defined by the UNEP (United Nations Environment Programme), is providing services that enable clients accessing products, tools, opportunities or capabilities. Car sharing is an obvious application of this kind of PSS, allowing driving a car without the need of owning it. Common features of this kind of PSS are Information and Communication Technology solutions, as they allow easy mobile access to tools or services.

PSS does not imply explicitly more sustainability, but because the provider use to maximize the lifespan of the product and save material resources, in practice the PSS relate with an increase environmental care. In the case of the pest control service, the company will try to obtain the same results with the lowest possible pesticides; or in the case of car sharing, the company in charge will try to maximize the life span of vehicles. In general, it can be assumed that along with a decrease of material ownership in society, the environmental impact is reduced.

It is observed how the car ownership is decreasing among young adults, especially in cities[19] . The car is somehow regarded as a burden, in comparison with other modes of transport that do not have the heavy costs of a private vehicle[20]; and probably is less regarded as the symbol of status that has been in the past.

Summarizing, the social tendencies towards valuing more the service than the product lead to a decrease on car ownership, and can be important drivers for achieving a more sustainable mobility. The public bodies should take care on highlighting the advantages of car sharing, at the time that increasing the disadvantages of car ownership with some of the strategies previously commented. The market will adapt invariably to the new preferences of the consumers. It is important for the public bodies to insure influence on these developments by establishing a fluent

18: According to the UNEP, "A Product-Service System can be defined as the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands."
19: http://www.ifmo.de/lt files/publications content/2013/ifmo 2013 Mobility Y en.pdf
20: According to the web calculator of ADAC (http://www.adac.de/infotestrat/autokosten/default.aspx), owning a car like Volkswagen Golf has a net cost over 500€ per month.

communication with former car manufacturers (who tend to become mobility provider) and other private providers. In this way, the market opportunities might be better yield and at the same time the environmental concerns can be cared.

3.2 The role of the Graz public body

The city of Graz, and especially its subsidiary Holding Graz, are directly responsible of encouraging sustainable mobility. Below are described some of the tasks expected from their work:

3.2.1 Coordination

It has been commented that the market can be an ally for the sustainable mobility, but naturally private interests do not need to match with the public ones of a sustainable mobility. The city of Graz will have to take advantage of its function of service provider to catalyse the change to a more sustainable mobility, and to make a proper assessment of the technologies available, considering the cost and the benefits including the environmental and social externalities.

About the cost of the different solutions adopted, it seems important to keep under supervision their feasibility; after all, the economy is a pillar of the sustainability. Some of the planned works will not produce economic revenues (just social ones), as can be the investments on bike lanes; because of this it seems important to maximize the revenues from other investments. Instruments like Public Private Partnerships (PPP) could be used in cases where the attraction of private capital is easier, like in car sharing business model, which open new possibilities for car manufacturers.

The coordination of the different initiatives taken can lead to a convergence in the use of the different services; for instance a single account could work for taking public transport, or for driving a shared car. This kind of integration of different modes of transport can be especially positive when combined with the mentioned interconnections for different modes of transport.

Certainly, the city of Graz has done already some of the most important work on coordination, thanks to having defined common objectives in projects like the “I live Graz” project, so the implementation of policies that involve several administrative units will be easier. Indeed, thanks to it Graz is so far the only Austrian city that implements indicators of “Smart city” in its urban development concept (Stadt Graz, 2013) (Stadtentwicklungskonzept).

3.2.2 Care about administrative barriers

Many times the obstacles on the path towards sustainability are not as related with technological problems as are related with behavioural, legal, administrative and financial barriers. To identify these barriers is important; suppressing them makes easier the implementation of sustainability measures, and solving them is sometimes matter of political agreement; thus, the city of Graz as well as responsible bodies of Styria and Austria have an especial responsibility here.

The obligation of constructing one parking space per household (with exceptions) in new developments is one example of these obstacles. But there exist some exeptions, allowing local governances varying from this number. Thereof the city of Graz regulates the number of parking space in binding development plans (“Bebauungspläne”) of larger districts under development. Depending on location, land development and infrastructure the number of required parking space is regulated flexible by defining lower as well as upper limits. In addition, the city of Graz uses mobility contracts since a couple of years. These contracts between real estate developers and the city contain agreements on realising mobility measures like public transport tickets for free, bike sharing options or other measures targeting the reduction of private motorised transport. Besides that, these contracts allow a further reduction of parking space in developing districts. An application of this instrument is planned for the area of Waagner-Biro as well as for the area of Reininghaus.

Another important administrative barrier can sometimes be the federal road traffic act (Straßenverkehrsordnung) that does not regulate new realities in the private mobility; like car sharing, or public charging of e-cars. The legal vacuum creates an additional obstacle for the implementation of these kinds of initiatives.

3.2.3 Care about public participation

Mobility is a topic that can trigger a strong emotional response, so the public participation is important. The traffic is inherently something not pleasing, but people have to get involved earlier on the decision-making to avoid the rejection of measures that try to reduce the traffic. In Vienna for instance, the street of Mariahilferstrasse was recently banned to cars, following a general discontent with the measure; the public opinion was however reverted after a long campaign of public awareness. That said, it seems wisdom to start these interventions precisely in the areas where exist more complains about the traffic and congestion.

The city of Graz works already on the implementation of an adequate public participation system, and on adapting the plans of mobility including also the desires of the population. Besides working effectively in communicating the advantages of sustainable mobility, there are plans for taking this communication to a next level, doing a personalized “mobility coaching”. The objective is to advise on an individual basis about how to dispense with the car in the daily commuting, offering alternatives based on public transport and bike.

3.3 Conclusions

In its way towards the “Smart City” ideal, Graz needs to address the issue of sustainable mobility. The modal split in the city has not changed significantly in the last decades. The mobility plan of Graz[21] includes as one of its main objectives a significant change of this situation. The idea of a city in which car, public transport and bike can coexist without compromises looks well on the paper, but in practice it is needed to disincentive the use of the private motorized transport in order to achieve reasonable levels of sustainability.

[21] Mobilitätsstrategie der Stadt Graz: http://www.graz.at/cms/beitrag/10155063/2346678/

Following this, Graz is trying to address the future of its mobility in a holistic way; not only planning walkable districts, or giving reasons to not use the car, but also giving reasons to take the tram, the bike or the bus; making them more accessible and easy to use.

The strategy of merging in a single place different transport modes is in line with this desire of creating a flexible yet solid mobility infrastructure. Further ideas like the mobility coaching and an increasing public participation should help together in creating a Graz with less motorized traffic, and overall more sustainable.

4 References

Baines T. S., et al. (2007) State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221.10: 1543-1552.

European Commission (2011) Cities of tomorrow: challenges, visions, ways forward. Publications Office of the European Union, Luxembourg.

Foletta, N. and Field, S. (2011) Europe's Vibrant New Low Car(bon) Communities. ITDP Europe.

Holding Graz(2013) Mobilitätszahlen - Mobilitätserhebung der Grazer Wohnbevölkerung. URL: http://www.graz.at/cms/beitrag/10192604/4438856

Land Steiermark (2012) Dokumentation zum Thema Luftreinhaltung. Steiermärkische Landesregierung.

Martin, E., Shaheen, S. A., Lidicker, J. (2010) Impact of carsharing on household vehicle holdings. Transportation Research Record: Journal of the Transportation Research Board 2143 (1): 150–158.

Stadt Graz (2013) 4.0 Stadtentwicklungskonzept Graz.

Department for Transport (2010) UK greenhouse gas emissions from transport. Factsheet, Transport statistics.

University of Columbia (2010) Energy cost of transport. URL: http://c21.phas.ubc.ca/article/energy-cost-transport%22.

Food sustainability: Contrasting consumers' perceptions with science based information

Viera Grace[a], García Maruxa[b], Bech Anne[c], Nielsen Thorkild[a], Pop Bianca[d]

[a]Aalborg University, Denmark

[b]Azti Technalia, Spain

[c]Consumer Insight, Denmark

[d]Tritecc, Romania

Abstract

Agriculture is the human activity with the highest impact on ecosystems, with problems related with the use of land and water, greenhouse gases emissions, biodiversity loss, disruption of nitrogen and phosphorus cycles, among others. The high impacts of agricultural activities, combined with an expected population increase of 50% for the year 2050, have created concerns about future developments in agriculture and the sustainability of the system. Thus, attention on food impacts and food sustainability issues has upraised. People are becoming aware that their food choices have an impact, and are encouraged to act accordingly. Nevertheless, lay consumers´ guiding principles could be based on wrong assumptions. Focus groups were carried on in Spain, Denmark, and Romania to explore consumers´ perceptions of food sustainability. Clear similarities were observed along the 3 countries. Focus groups showed that consumers relate sustainability mainly with local food, healthy food, labelled products (organic, fair-trade, quality), and to some degree with waste. Results suggest that the different discourses that have evolved in relation to sustainable food consumption do not necessarily line up with science based information on food impacts. To unfold consumer´s real knowledge of environmental issues, the present paper contrasts the different themes identified in the focus groups with literature data on food related environmental studies. The current piece discusses the implications of the matching and mismatching points between these two perspectives.

Keywords: food sustainability, consumers 'perceptions, science based knowledge, comparison.

1 Introduction

Current agriculture production is linked to ecosystems and biodiversity losses, soil degradation, groundwater contamination, water scarcity, and increasing adverse levels of nitrogen and phosphorus (Tilman et al. 2002; Kastner, Kastner, and Nonhebel 2011). Agriculture causes high soil erosion and degradation, which is connected with the abandonment of about 30% of the world´s cropland. With the majority of productive areas already in use, agriculture expansions occur mainly in marginal land, which is associated with 80% of deforestation rates (Wood et al. 2006) (Moomaw, W., T. Griffin, K. Kurczak, J. Lomax 2012).

The high impacts of agricultural activities, combined with an expected population increase of 50% for the year 2050, raise concerns towards the sustainability of food production systems and its ability to satisfy future needs (Smith and Gregory 2013). Furthermore, due to expected improved economic conditions and its connected change in food consumption patterns, it is expected that the food demand will double in the next 50 years (Tilman et al. 2002). In light of the current situation and perspectives, there is mounting pressure on food systems to satisfy demand in a more sustainable way.

People, as end consumers of food products, have been identified as key actors towards achieving sustainability in food systems. We have witnessed the emergence of a wide range of sustainability efforts at consumers and producers level. Campaigns and tools have been launched to create awareness and sustainable choices for consumers; resulting in more than a 129 food sustainability information schemes only in Europe (Grunert, Hieke, and Wills 2014) and many campaigns directed to increase awareness on food related impacts. Additionally, public entities have put a strong focus on sustainability issues (e.g. European Round table for Sustainable Consumption and Production ERSCP, UN global compact, FAO at Rio +20). Despite current efforts to include sustainability into food chains the results accomplished so far have not been encouraging, and current trends forecast rather negative scenarios.

The purpose of this study is to explore some of the reasons why current efforts towards sustainability might not give the expected results. The paper explores consumers' perception of sustainability and the accuracy of their assumptions when confronted with scientific data. Focus groups are used to gather consumers' knowledge and perceptions regarding sustainability issues to later on contrast this data with literature information.

2 Methodology

As part of the 7th framework project SENSE "Harmonized Environmental Sustainability in the European food and drink chain" in spring 2013, 6 focus groups studies were carried out in Spain, Romania, and Denmark. A total of 62 people participated, all considered themselves positive or neutral towards sustainability issues, they were between 18-65 years old, with approximately equal distribution between males and females.

A focus group guide was prepared, in which the main topics to be discussed (i.e. sustainability in the food chain, methods to communicate sustainability, access to food sustainability information) and procedures were stated. Inside the different topics consumers were allowed and encouraged to include all the aspects they considered relevant. The focus groups were video and audio recorded. All 6 focus groups (2 per country) were performed in their national language and later on were transcribed and translated to English.

For the analysis, data was grouped into recurrent themes and coded. This paper focuses on the similarities in perception among the 3 countries, purposefully leaving aside country specific conditions that might divert consumers´ focus from general sustainability towards country specific issues. The different themes that were identified through the focus groups were contrasted with data from food environmental studies. The points of agreement and discrepancy between consumers´ perceptions and environmental data are highlighted and possible reasons for the differences and consistencies are brought forward.

3 Consumers´ perceptions of sustainability

People in all 3 countries were asked about their perception of sustainability in the food chain, and the positive and negative aspects that could be related with sustainable food consumption and production. The current section presents main results from the six focus groups. It starts with main common themes for all focus groups, and continues to present country snapshots. The present paper does not go into specific country conditions that shape different sustainability perceptions but focuses on communalities, targeting general themes that consumers relate to sustainability in different countries.

3.1 General understanding of sustainable food products

There are some country specific beliefs and small variations related to what is a sustainable food product. Nevertheless, there are issues that are consistently repeated among the 3 countries. Local products are deemed sustainable in all the countries. The reasons why local products are considered sustainable vary and could include contributions to local economy, more credibility, perceived better soils, less transportation, technological differences; there are strong connections in consumers' minds between local products and sustainability.

Another recurrent issue was health. It is considered that sustainable products are healthy, under the premise that "what is good for the environment is good for us". Emphasis was made on possible negative effects from the usage of agrochemicals; and the need to know what is in the products we are consuming, considering the effects of unnatural components such as artificial flavors, genetically modified organisms GMOs, and preserving agents among others. This issue is often connected to the perception that organic products are healthier and more sustainable.

Additionally, a general perception is that products that have a label are more sustainable. Being organic, fair trade, low carbon, or other perceived green characteristic positively accepted. Despite the agreement that in general terms labeled products could be better from a sustainability point of view and often also better for health, in all 3 countries consumers were concerned about the reliability of the information they were getting. There were some issues with consumers´ trust over brands and whether "brands, media, or advertisement" deliver what they promise.

Other topics were brought out during the focus groups, but were mainly secondary to the ones already described. Especially in Denmark, consumers were concerned about waste and the need to use resources more efficiently. The need for better grocery planning and to reduce food waste was highlighted. Also, other aspects such as future generations, biodiversity, working conditions, animal welfare, were mentioned in the 3 countries but in a more marginal way. Not surprisingly and consistently among the 6 focus groups negative aspects related to sustainability were price and convenience; lack of availability and high price being a barrier to consume environmentally friendly food products.

3.2 Spanish focus groups

Products with some kind of label were, in general terms, considered sustainable. Nevertheless, other issues such as origin were prioritized over other perceived sustainability characteristics. In the participants´ minds local products were identified as sustainable products, regardless of the type of product or production methods. Additionally, there was a general mistrust towards products whose origin is not clear: "*if it is really ecological, I think a negative thing is trust, I could pay more for milk, if you see that a woman with a bucket of milk comes and it is fresh, but if you have a tetra pack that says it is eco, well…*"

The importance of "knowing" the producers and where the product comes from was emphasized, even for goods produced in Spain: "*Is very different to go to a supermarket and to buy chicken that you do not know where it comes from, than to going to your own butcher, that you see the chicken, it tastes different, fries different, sure the price goes up*". Moreover, past practices in which people were closer to production chains and knew the food source were connected with sustainable ways of living. For instance while talking about consuming seasonal products and the limitations that it can represent for consumers: "*I do not see it as a problem, I think one has to get used to it, a bit like people used to live before, now they bring mangos who knows where from and it is transport and it is not sustainable*"

The notion of sustainable food was strongly connected and often blended with health; people tend to think that sustainable food is healthy, being to a certain extent environmental topics relegated or assumed to be already included in. This can be illustrated by the following quote:

"*I think with food sustainability you can take more care of your health, we have a more balanced diet, more healthy, and it is also good for the environment*"

Additionally, there were some more general concerns (e.g. workers, waste, animal welfare, legislation´ transparency) that were briefly discussed or mentioned.

3.3 Romanian focus groups

In general products with some kind of an eco or bio label are valued as sustainable. In consumers´ minds they all belong to a "green products" list. Additionally, these labelled products are strongly related to health and a way of living. This can be illustrated by the following opinions put forward by consumers:

"*I have always been for eco and bio products and I have always been drawn to this side and I support it; positive aspects, a healthy life style, a lot of beneficial aspects related also to health*" "*they are more healthy, they hold better the vitamins and minerals, even the enzymes, they probably use organic fertilizers, they are healthy*"

"*positives: they are healthy, they have a positive impact on life, they do not have negative effects even if you over consume them, the taste and the aroma is better and more real, they are beneficial to the environment*"

Other aspects that were highlighted during the focus groups were traceability, and the need to know the source of the products, the production chain, and to be able to guarantee safeness and quality. The view of consumers is reflected in the following quote:

"*All products should be labeled accordingly, with name of the producer, and the whole route of the products should be known, starting with the birth of the calf and until the veal gets to the store as an end product*"

When giving examples of different stages in the food chain other issues such as transport, waste, local foods, and legislation were mentioned among others. The term sustainability blends with aspects of local production, safeness, and healthier products. The following quote summarizes the general view on sustainable food products and most of the concerns expressed during the discussion: "*the obtainment of foods that do not contain E numbers, chemicals, that are of high quality, taste good, that support local and small producers, automatically more jobs will be created, more communities in the whole country, not only in some places; the environment will be less polluted if no chemical fertilizers will be used, the avoidance of GMOs and thus degrading that particular species, reduction of transportation expenses*"

3.4 Danish focus groups

When asked about their understanding of sustainability and the positive aspects related to it, emphasis was placed on local food, with the majority of respondents convinced that local food is the main way to achieve a sustainable diet. And it overrides other things that consumers widely recognize as sustainable (i.e. organic). There is a general agreement among participants that local products are the ultimate form of sustainability. This is illustrated by the following text:

"*Organic milk from Thise, those cartons come from Italy. The non-organic milk in Denmark those cartons come from here. There the sustainability is ruined to organic. I do not say it to provoke but I think you should be careful so that you do not compare organic and sustainability. Sometimes sustainability is better than organic*"

"*Tomatoes in the South of Spain, where you have this desert like soil and covered it all with plastic, what is best for sustainability? To use a lot of electricity in our own greenhouses or transport them from Spain to Denmark…*"

Another aspect mentioned in relation to sustainability is organic food. Organic food production is widely considered good for health and good for the environment among participants. Emphasis was put on the need for healthier products, with no medicines or additives in them, and of higher quality. This could be illustrated in the following dialog between two Danish participants of the focus groups:

C1: "*When it is sustainable you assume that you do not use things which should not be put into the soil or eaten by pigs, and everything that does not come from unnatural things in a food product should as such to be healthier*"

C2: "*Minus all the es. There is a lot of e numbers, which are artificial, flavors, additives, and things like that, which should not appear in sustainable food products*".

Also, to a lesser degree sustainable diets were related to an efficient use of resources at consumers' level and farm level. Topics such as waste and a more efficient use of resources emerged.

"*I try not to buy 20 bananas at a time and throw half of them in the trash and then I thought to myself that sustainability is when you try to adjust your consumption, adjust your shopping to your consumption*"

"*Looking from the consumer´s point of view regarding sustainability, more inspiration and creativity considering leftovers. When you live alone and buy a whole root celeriac there will be food for 3 days and you have to push yourself to be more creative if sustainability is essential to you and consider how to use it. It is about the decrease of food waste if you really use all of it to the final little part of it. From the consideration of buying the product, which you choose to assume to be sustainable if you select and organic product…*"

In general terms it was seen that consumers have a notion that labeled products might be better products but without clear understanding of what different labels stand for and with a certain degree of mistrust regarding if labels really mean better products or are being used as a marketing strategy. Also, in consumers 'minds there seem to be a connection between products that have a better taste/quality and are healthier with products that are better for the environment. This can be illustrated by the following quote:

C1: "*With other products she was better to taste the difference than I was, she was better at guessing when it was organic than I was*"

C2: "*I also think that this is the case with meat. I have a father in law who had a great interest in organic products. Christmas eve we had both an organic duck and one that was not. He did not tell us which one was organic and the same thing happened for Christmas with an organic and non-organic roasted pork. If you really choose to buy the pig living in the field, free and organic, then you really, I think it can be an illusion because we knew that one of them was organic but not which one, but in that case I think there was a difference*"

Additionally the need to be open and flexible and therefore buy knowingly not sustainable products in some occasions was emphasized, it was expressed that it is important that sustainability does not become a "sacred" act.

4 Contrasting consumer´s beliefs with environmental data from the literature

Currently there is no agreed overarching methodology to measure environmental impacts of food. Furthermore, due to food chains´ complexity there are challenges regarding access to product information from cradle to grave. Different production systems or inputs can result in different environmental profiles among like products. Most used methodologies to measure environmental food impacts include ISO standards, life cycle assessment, footprinting, along with a wide range of private initiatives.

A recent attempt to harmonize efforts towards environmental impact assessment of food products is the Envifood protocol (by the European food sustainable production and consumption SCP round table). It uses LCA approaches to address impacts such as climate change, ozone depletion, ecotoxicity for aquatic fresh water, human toxicity, particulate matter, ionizing radiation, photochemical ozone formation, acidification, eutrophication, resource depletion, and land use change. For practical reasons, the current work focuses only on the environmental impacts identified through the focus groups as well as major themes overlooked by consumers. The bulk of the literature used is based on LCA or LCA inspired analyses.

4.1 Local products

Throughout the focus groups there was a general agreement on the sustainability of local products, overriding aspects like production system, seasonality, organic and others. Weber and Matthews (2008) report that most GHG emissions related with food products come from the production phase. Food´ transport on average is responsible for less than 15% of the total GHG emissions of a product throughout its life cycle. Their study concludes that for instance a reduction of less than 25% in red meat and dairies would achieve the same positive results for the environment as a 100% local diet (under an unrealistic scenario of 0 transport related emissions).

An aspect often associated with local products is eating seasonally. Foster et al. (2014) states that seasonality is not always a good indicator of food sustainability, concluding that yields and agricultural practices are stronger indicators of environmental performance than supply time, meaning that seasonality does not per se equal environmentally friendly. The study uses an LCA approach to compare raspberries´ impacts at different times of the year in sold in UK supermarkets (May, July, and November). The differences in global warming potential and other parameters were relatively small; water footprint being the only prominent difference.

Literature data (e.g. Edwards-Jones et al. 2008) question the common believe that local products are the ultimate form of sustainability. Likewise, there are studies that highlight environmental and other benefits of local production (e.g. Blanke and Burdick 2005). The intention of this section is to show that there are several possible outcomes of environmental studies and that locally produced food might or might not be better from an environmental point of view. Other factors such as transportation type, production system, technologies, local conditions, should be taken into consideration.

4.2 Healthier products

From the focus groups it can be concluded that a general perception is that sustainable food is not only good from an environmental point of view, but also healthier than its not sustainable counterparts. This only holds true depending on the food products consumed. A healthy diet is not sustainable per se, correspondingly an unhealthy diet could be sustainable. A heathy diet is about nutritional content, portion size, and food products´ combinations. Furthermore, consumers´ knowledge of nutritional guidelines and recommendations is limited (Dickson-Spillmann and Siegrist 2011).

What recent literature shows is that there is no incompatibility between healthy and sustainable diets (Carlsson-Kanyama and Gonzalez 2009) (Macdiarmid 2013). Being both, sustainable and healthier diets, at the moment focusing on limited amounts of animal products and an increased amount of legumes and plant based ingredients. Literature shows that there is no nutritional difference between conventional food products and for instance their "sustainable" (i.e. organic) counterpart.

4.3 Labels (e.g. organic products)

In the EU alone there are more than 129 food sustainability information schemes (Grunert, Hieke, and Wills 2014). These initiatives, while being tools to guide more knowledge based consumption, typically focus on single issues, often generating confusion in end buyers. Bio, eco, organic, fair trade, and other labels are in general related with sustainable products in consumers‘ minds, nevertheless how these issues are interconnected or should be considered/prioritized is not clear. Moreover, the degree to which the advertised positive product features are really understood by consumers and their effectiveness towards encouraging sustainable choices is questionable.

Efforts to translate technical information to consumers still need to be fine-tuned. For instance in the UK with the carbon labeling scheme for food products (Gadema and Oglethorpe 2011) analyze the different aspects that could hinder the success of carbon labelling. The authors emphasize the need for learning campaigns to socialize environmental impacts and the scheme itself; as well as obligatory measures that guarantee market proliferation, giving consumers the opportunity to use the system to compare between products.

4.4 Overlooked environmental information

Non-CO_2 greenhouse gases are responsible for most of food related climate impacts, being emission from fertilizers (i.e. nitrogen application (N_2O), manure (CH_4)), and other land use practices important when talking about food impacts. These conditions are seen along all food production, but concentrate more in animal production because of low efficiency in animal systems to convert plant energy into livestock. Additionally, ruminant animals due to enteric fermentation represent a source of methane (CH_4) (Weber and Matthews 2008).

Main food impacts are associated with a diet high in animal products. Scarborough et al. (2014) compare CO_2 emissions of diets of high meat eaters, medium meat eaters, low meat eaters, fish eaters, vegetarians, and vegans in the UK, and find that the level of CO_2 emissions positively relates to the amount of meat and animal products in a diet. With high meat eaters responsible for approx. double the amount of $KgCO_2e$/day compared to vegans. In the UK food is responsible for roughly 20% of the country CO_2 emissions; the average consumer generally exhibits a high meat eater behavior.

In the last 40 years global meat production has increased more than 60%. The conversion rate from grain to feed stock is 1kg meat from 3 to 10 kg of grain, depending on the system and production specific techniques. Consequently production intensity has increased, causing environmental concerns associated with antibiotic resistant diseases, air and water pollution, and manure management (Tilman et al. 2002). This is of special concern if considered that under the current trends an increase of protein demand by a factor of four could be expected for 2050.

5 Discussion

In the environmental science literature there seems to be a common agreement on environmental impacts of animal products. But since the actual measure depends on production methods, assumption and calculations, and local conditions among others, this information seems to diffuse before reaching consumers. There is a lack of agreement on the ways to produce and consume sustainable food products and this could add to the confusion.

Additionally, when people are faced with different food choices, sustainability competes with other issues like health, appearance, family preferences, quality, price, etc. Results from consumers´ studies (Liz Owen et al. 2007) show that in a complex process consumers main concerns while grocery shopping are “health, quality, and indulgence”. This coincides with the focus groups findings, in which sustainability concerns somehow tend to align with convenience.

In line with the findings current trends show that in Europe and in the United States organic and locally produced food products are gaining popularity (Weber and Matthews 2008) .Organic consumption in the food sector has grown steadily in the last decade. These are positive trends; nevertheless their overall impact in environmental sustainability is questionable. It is perhaps a good sign, but it cannot be deemed a final or unique solution.

The authors do not imply that local production, eco-labels schemes, or like systems are not positive, but aim to show that they have traditionally focused on more simplistic solutions directed towards making consumers pay more for products with a higher environmental performance rather than tackling urgent problems such as overconsumption of animal products. At the moment there is enough scientific evidence that environmentally sustainable and nutritiously desirable diets require changes in our food choices.

6 Conclusions

Programs and efforts to accomplish an environmental behavior from a consumers’ perspective assume that we have not been able to achieve sustainability improvements because consumers fail to act according to their environmental statements and commitments. This piece concludes that consumers´ food sustainability knowledge is limited. Results from the focus groups show that within 3 different European countries, with very different economic and natural conditions, there are some recurrent themes concerning understanding of sustainability. The authors believe that the issues identified in this study such as consumers’ perception of sustainable products, with some local variations, do represent common views of sustainable food products. And that consumers´ food sustainability perceptions focus generally on local, healthier, and labelled products.

There is no harmonized methodology on the ways in which food impacts need to be measured, and the complexity of food chains makes it harder to gather all the needed information, and different agricultural systems, inputs, and country specific conditions complicate the calculation process. Nevertheless, environmental literature consistently shows general overall results of different impacts of different food products. Therefore it is important to, additionally to the encouragement of local, healthier, labelled products and other solutions, to embrace the need for diet changes.

Switching food consumption habits is the alternative with the highest environmental benefits. Different food groups have different environmental impacts. Buying more responsible products that are linked to improvements in local conditions, animal welfare, or make a better use of resources will be a progress compared to the current situation and should be encouraged; nevertheless unless we make an effort and change our diets and consumption patterns, the improvements towards food sustainability will only be marginal.

Acknowledgements

This research was financed by the 7th framework project SENSE "Harmonized Environmental Sustainability in the European food and drink chain". The opinions presented herein are those of the authors and do not necessarily represent overall SENSE project results.

7 References

Blanke, Michael, and Bernhard Burdick. 2005. "Food (miles) for Thought - Energy Balance for Locally-Grown versus Imported Apple Fruit (3 Pp)." *Environmental Science and Pollution Research - International* 12 (3): 125–27. doi:10.1065/espr2005.05.252.

Carlsson-Kanyama, A., and A. D Gonzalez. 2009. "Potential Contributions of Food Consumption Patterns to Climate Change." *American Journal of Clinical Nutrition* 89 (5): 1704S–1709S. doi:10.3945/ajcn.2009.26736AA.

Dickson-Spillmann, M., and M. Siegrist. 2011. "Consumers' Knowledge of Healthy Diets and Its Correlation with Dietary Behaviour: Consumers' Knowledge of Healthy Diets." *Journal of Human Nutrition and Dietetics* 24 (1): 54–60. doi:10.1111/j.1365-277X.2010.01124.x.

Edwards-Jones, Gareth, Llorenç Milà i Canals, Natalia Hounsome, Monica Truninger, Georgia Koerber, Barry Hounsome, Paul Cross, et al. 2008. "Testing the Assertion That 'local Food Is Best': The Challenges of an Evidence-Based Approach." *Trends in Food Science & Technology* 19 (5): 265–74. doi:10.1016/j.tifs.2008.01.008.

Foster, Chris, Catarina Guében, Mark Holmes, Jeremy Wiltshire, and Sarah Wynn. 2014. "The Environmental Effects of Seasonal Food Purchase: A Raspberry Case Study." *Journal of Cleaner Production* 73 (June): 269–74. doi:10.1016/j.jclepro.2013.12.077.

Gadema, Zaina, and David Oglethorpe. 2011. "The Use and Usefulness of Carbon Labelling Food: A Policy Perspective from a Survey of UK Supermarket Shoppers." *Food Policy* 36 (6): 815–22. doi:10.1016/j.foodpol.2011.08.001.

Grunert, Klaus G., Sophie Hieke, and Josephine Wills. 2014. "Sustainability Labels on Food Products: Consumer Motivation, Understanding and Use." *Food Policy* 44 (February): 177–89. doi:10.1016/j.foodpol.2013.12.001.

Kastner, Thomas, Michael Kastner, and Sanderine Nonhebel. 2011. "Tracing Distant Environmental Impacts of Agricultural Products from a Consumer Perspective." *Ecological Economics* 70 (6): 1032–40. doi:10.1016/j.ecolecon.2011.01.012.

Liz Owen, Hazel Seaman, Nicki Wilson, and Sam Prince. 2007. "Public Understanding of Sustainable Consumption of Food: A Report to the Department for Environment, Food and Rural Affairs." DEFRA. http://www.scp-knowledge.eu/knowledge/public-

understanding-sustainable-consumption-food-report-department-environment-food-and-r.
Macdiarmid, Jennie I. 2013. “Is a Healthy Diet an Environmentally Sustainable Diet?” *Proceedings of the Nutrition Society* 72 (01): 13–20. doi:10.1017/S0029665112002893.
Moomaw, W., T. Griffin, K. Kurczak, J. Lomax. 2012. “The Critical Role of Global Food Consumption Patterns in Achieving Sustainable Food Systems and Food for All, A UNEP Discussion Paper”. UNEP. http://www.unep.org/resourceefficiency/Portals/24147/scp/agri-food/pdf/Role_of_Global_Food_Consumption_Patterns_A_UNEP_Discussion_Paper.pdf.
Scarborough, Peter, Paul N. Appleby, Anja Mizdrak, Adam D. M. Briggs, Ruth C. Travis, Kathryn E. Bradbury, and Timothy J. Key. 2014. “Dietary Greenhouse Gas Emissions of Meat-Eaters, Fish-Eaters, Vegetarians and Vegans in the UK.” *Climatic Change* 125 (2): 179–92. doi:10.1007/s10584-014-1169-1.
Smith, Pete, and Peter J. Gregory. 2013. “Climate Change and Sustainable Food Production.” *Proceedings of the Nutrition Society* 72 (01): 21–28. doi:10.1017/S0029665112002832.
Tilman, David, Kenneth G. Cassman, Pamela A. Matson, Rosamond Naylor, and Stephen Polasky. 2002. “Agricultural Sustainability and Intensive Production Practices.” *Nature* 418 (6898): 671–77.
Weber, Christopher L., and H. Scott Matthews. 2008. “Food-Miles and the Relative Climate Impacts of Food Choices in the United States.” *Environmental Science & Technology* 42 (10): 3508–13. doi:10.1021/es702969f.
Wood, Richard, Manfred Lenzen, Christopher Dey, and Sven Lundie. 2006. “A Comparative Study of Some Environmental Impacts of Conventional and Organic Farming in Australia.” *Agricultural Systems* 89 (2-3): 324–48. doi:10.1016/j.agsy.2005.09.007.

The Paradox of Pedagogy: Education for Sustainable Development and Transformative Learning

Carol Scarff Seatter[1], Kim Ceulemans[2] & Rodrigo Lozano[3]

1 University of British Columbia, Faculty of Education, 3333 University Way, Kelowna, BC, V1V 1V7, Canada

2 KU Leuven - University of Leuven, Centre for Economics and Corporate Sustainability, Warmoesberg 26, B-1000 Brussels, Belgium

3 Utrecht University, Copernicus Institute for Sustainable Development, Heidelberglaan 2, NL-3508 Utrecht, The Netherlands

Abstract

As the result of the difficult challenge of teaching Sustainable Development in Higher Education, students—as future citizens—are left without insight, commitment and a sense of their position regarding meaningful sustainability belief and action. Within sustainability classes, instructors and students encounter a paradox. This paradox arises when educators approach a sustainability curriculum with the potential to transform students' thinking and actions with a reductive and non-substantive pedagogy. This paper examines varied pedagogical and curricular approaches within sustainability courses as a means of sorting out and disclosing where the core of the problem lies. The paper is based on an epistemological and pedagogical analysis of relevant literature to redefine, clarify, and provide a more systematic and holistic understanding of a transformative pedagogy required for learning. The central thesis of the paper juxtaposes three sustainability curricular positions with three pedagogical models that vary decidedly in their emphasis on the prerogative of the learner's prior knowledge and beliefs, the engagement of the learner and the potential for critical thinking and transformative learning. It is found that a transformative pedagogy overcomes and eliminates the paradox, helping move societies to become more sustainability-oriented.The authors offer a philosophical model of pedagogy that best facilitates effective teaching and learning of sustainability issues and challenges.

1. Introduction

Higher Education for Sustainable Development (HESD) is inspired by aims to help students to develop sustainability attitudes, skills and knowledge that inform decision-making for the benefit of themselves and others now and in the future, and to act upon these decisions (UNESCO, 2009). Thus, Higher Education Institutes (HEIs) can make a significant impact in the promotion of sustainable development as they take on various roles and responsibilities. Some of these include an education for a sustainable society (James & Card, 2012; Leal Filho et al., 1996); developing future professionals as change agents (Moore, 2005; Svanström, et al., 2008), as well as facilitate spaces where ideas are expressed freely, paradigms are challenged, creativity is promoted and new knowledge acquired and generated (Barth et al., 2007; Cortese, 2003; Lozano, 2006).

At present, HEIs are rooted in a rationalism that leads to objectivity and certainty (Lambkin, 1998; Sipos et al., 2008; Wals & Jickling, 2002); replicating Newtonian and Cartesian models (Lozano, 2011). As a result, knowledge is fragmented into disciplines (Birch, 1998 in Sipos et al., 2008; Laurillard, 2002) and teaching is delivered in large group lectures (Tormey et al., 2008) not conducive to the interaction of ideas in anything other than a superficial fashion (Curzon, 1997; Laurillard, 2002; Prosser & Trigwell, 1999).

Different kinds of models for teaching and learning are required to meet UNESCO's challenge; the very nature of sustainable development is much more complex than certain, and multidisciplinary at many levels. The goal of higher education is to support students in developing capacity for recognizing and understanding the complexity of sustainability issues, thinking critically about assumptions, biases, beliefs and attitudes while actively participating in their resolutions.

Despite an urgent need for young people to gain vital knowledge and understanding of sustainability matters—and don the role of pro-sustainability citizens in thought and action—the very nature of the pedagogy that neglects to tend to students' prior knowledge and lectures 'a right position' is untenable, and thus in the lives of the students, unsustainable. A paradox exists as a contradiction between HESD *as a message* that provokes thinking and action through transformative learning and current HESD pedagogy that lacks the sustenance to facilitate sustainability thinking and behaviour. This paradox pertains to a lack of sustenance within the method and message of current sustainability pedagogy, often stymied by a transmissive and lecture-driven delivery (Ceulemans & De Prins, 2010). Some questions that come to mind query this chasm between the transformative element in HESD lifelong learning and the actuality, what there is to comprehend about models of teaching that could make a difference, and whether or not sustainability courses, as they are currently conceptualized and implemented, incite learning that matches initial goals.

This paper critically analyses key philosophical teaching models for effective teaching and learning of sustainability concepts in HESD. It also emphasis key implications for HESD curricula for pedagogy. This paper is based on an epistemological and pedagogical analysis of relevant literature to redefine, clarify, and provide a more systematic and holistic understanding of transformative pedagogy required for effective HESD. Once key approaches and teaching practices are unpacked, it is the goal of the paper to coalesce key ideas to form a perspective on current teaching practices and propose possible solutions.

The paper considers the conception of transformative learning as it pertains to teaching HESD concepts and its relationship to critical mindedness. Definitions of approaches to sustainability (Alvarez & Rogers, 2006) with a focus on the epistemological and pedagogical shifts involved, are presented and discussed in light of HESD teaching and learning. The authors juxtapose approaches to sustainability with three basic teaching styles (Roberts & Silva, 1968), three philosophical models and learning types including 'learning loops' (Lozano, 2011) that offer an in-depth critique of the necessary conditions for an effective teaching pedagogy in acquiring an understanding of, and engaging in, sustainability-related issues and solutions. The paper positions the concept of transformative learning—catalyzed by critical thinking—as a reference point for effective HESD instruction and attempts to overcome an existing paradox of a powerful sustainability message delivered via a powerless pedagogy that results in current teaching practices that lead to unsustainability.

2. Literature Snapshot of Current HESD challenges

The current task facing HESD educators can be better understood with a glimpse of current practices and challenges revealed in the literature. The challenges are placed in order from the general to the more specific. The first challenge presents students' common misconceptions of sustainability concepts, while the second challenge reveals the tendency by many HESD instructors to infuse the curriculum with a particular agenda. The third challenge refers to three specific approaches to curriculum found throughout HESD. Together, these challenges enhance the need for the articulation of an HESD curriculum comprising transformative content and pedagogy.

2.1 Obstacles to understanding Sustainability: Student Misconceptions

Education for Sustainability is framed by radically different ways of understanding learning that requires teachers who are prepared for transformative education with the accompanying personal transformation required (Wooltorton, 2002, p. 26-27). In order to decipher students' comprehension of their learning of sustainability, Segalàs et al. (2010) found that students perceived sustainability as mainly related to technology and saw little relevance in the social and attitudinal aspects. A second finding showed an increase in student knowledge of Sustainable Development from courses that apply a more community-oriented and constructive, active learning pedagogical approach. In a more recent study, Segalàs et al. (2012) discovered a 'mismatch' among the 'experts' and students' understanding of sustainability. Students' complexity index was very low revealing that either students perceive sustainability as unrelated to social and institutional aspects or they barely perceive sustainability as a complex issue. In calling for more systems and multidisciplinary thinking, a greater societal focus, a closer look at how we use the pedagogical methodologies than the methodologies themselves and a shift to active learning education, or "the reorientation of the pedagogy and the learning processes is a must" (Segalàs, 2012, p. 302)

In their attempt to overcome obstacles to understanding HESD, Lourdel, et al. (2006), pointed out numerous authors who face problems of establishing effective courses in HESD (Leal Filho, 2000; Thomas, 2004; Velazquez, 2002) and described 'denial'. Distancing themselves from the problem often results in students not reaching their full capacity in such courses. Sustainability is compared to a never-ending staircase with a series of steps in the right direction but with no prospect of reaching 'the nirvana of complete sustainability" (Lourdel et al., 2006). It is clear that the many misconceptions about the nature of sustainability and the limited feasibility of making a difference, students are lacking feelings of optimism and motivation important to transformative learning in HESD.

2.2 Steering Practices

The second challenge to effective HESD discussed in this paper is the potential for imposing on students a particular agenda. In fact, many argue that the goal of current HESD is to steer students to locate themselves within the boundaries of a more or less preformed identity. One example is the work of Morris (2002), whose goal is that students "journey to and [arrive] at a particularly essentialized conception of what ecological consciousness is" (Morris, 2002 in Hayes-Conroy & Vanderbeck, 2005, p. 313). From this perspective, HESD is viewed as work directed towards a particular end, an eco-centric worldview. Kowalewski (2002) conceptualized his classroom as a "space for students to both critique (and reject) mainstream anthropocentrism and to work towards an acceptance of a deep ecological worldview". The extreme findings are often found in pedagogy of the environmental element of sustainability, a major component of sustainability studies. Hayes–Conroy & Vanderbeck (2005) spoke of the numerous scales utilized to determine where students stand in the sustainability debate and their scores that indicate where students *should be* locating themselves in relation to sustainability debates and what sorts of actions should be considered consistent with a particular pro-sustainability position.

However, understanding and identifying with a particular worldview *among several* should be seen as indicative of the contestability and complexity of sustainability studies (Carew & Mitchell, 2008) and an opportunity for the facilitation of critical thinking (Scarff Seatter, 2011). Rather than utilizing the complexity of HESD subject matter to support student thinking, HESD is being utilized as an opportunity to manoeuvre students into one viewpoint or another.

Fundamental changes that include a broadening of democratic structures that engage people in formulating goals, need to be an integral component of any class, course or program (Rathzel & Uzzell, 2008). For example, dominant forms of environmental education aim mainly to transmit information (Wals & Jickling, 2002). As course titles changed from Environmental Education to Education for Sustainability and Education for Sustainable Development there is no evidence that the pedagogical approach altered. This is often the case even of some supporters of strong sustainability[1] (Huckle, 2006). Thus, they re-produce within learning situations the existing relations of power, constituting learners as consumers, instead of acknowledging them as active participants in a transformative process (Rathzel & Uzzell, p. 271). Such studies provide evidence that HEIs attempt to shape sustainability subjects (Carew & Mitchell, 2008; Cotton, 2006; Short, 2010) and raise student concerns regarding the shaping and steering occurring in sustainability classes (Hayes-Conroy & Vanderbeck, 2005). Such teaching reduces thinking and learning substantially.

2.3 Sustainability Curriculum: Three Positions

Contrary to popular belief and practice at HEI's, curriculum is not limited to course content, although it is an essential component of curriculum (Egan, 2012). When a curriculum position or emphasis is chosen, two key epistemological questions should be answered. First, 'What is it that students should know and understand as a result of this course? That is, what content really matters?' and second, "How should it be taught?' (Egan, 2012; Gibson, 2012) This is important to consider because it follows that curriculum decisions of *what* we teach determine *how* we teach.

Alvarez & Rogers (2006) described three dominant emphases of HESD curriculum, synthesized from diverse approaches to teaching HESD throughout the literature (see Discussion section). These three basic curricular positions serve as a framework to examine various approaches to teaching and learning HESD that will be put forward for the readers' consideration in the following section of this paper. Alvarez & Rogers allow readers a glimpse of the content component of curriculum; it is the authors' opinion that the content of the curriculum determines the pedagogical component of the curriculum.

The first curriculum emphasis focuses on *definitions* of sustainability—"where they have emerged from, what they attempt to achieve and how they can be compared" (Baker, 1997 in Alvarez & Rogers, 2006). Many courses are designed with such an emphasis that supports an insubstantial and reductionist curriculum.

The second curriculum emphasis focuses on *implementation*, establishing what is unsustainable, how to make practices more sustainable and how to evaluate sustainable

[1] In Rathzel & Uzzell (2008, p. 272), strong sustainability is depicted as 'transformative environmental education' and ideally features a dialogical and reciprocal direction of education.

outcomes. This modus operandi is prescriptive: environmental targets, audits, energy and water efficiency, involving "checklists, indicators, triple bottom-line accounting and ecological footprints" (Alvarez & Rogers, 2006; Wackernagel & Rees, 1996). When HESD courses are designed to emphasize implementation and results from a numeric prescriptive perspective alone, the result is similar to the first curriculum emphasis, supporting an insubstantial and reductionist curriculum.

The third curriculum emphasis focuses on sustainability as *discourse*, a way of both defining and controlling an agenda for change and development worldwide (Darier, 1996; Luke, 1999; Sachs, 1993; Sandilands, 1996,1999 in Alvarez & Rogers, 2006). Such work has to do with sustainability understood as a contested 'on the ground' discourse utilized by competing individuals, groups and cultures with an emphasis placed on the complexity conceptions of sustainability. The concept of discourse, with origins in the process of reasoning, includes written or spoken communication or debate that demands engaging in conversation and has implications of more than one viewpoint under study. When an HESD course emphasizes open-ended discourse, communication and reasoning, the curriculum opens up to be more inclusive, interactive and substantial.

The challenges to HESD described above are related to questionable pedagogical decision-making. First, students view sustainability and associated issues as simple, and straightforward, with a 'right answer' mindset. As such, sustainability is perceived as unrelated to attitudes, community and society. The second challenge relates to the diminution of the complexity and scope of HESD and the lack of engagement of the students' voice in an undemocratic classroom setting. The third challenge indicates that two of three of the different conceptions of HESD curriculum are, for the most part, insubstantial and reductionist.

3. Transformative Learning and Critical Thinking: Key elements in the Literature

The concepts of transformative learning and critical thinking matter deeply when devising an effective HESD, and therefore play a key role in the dissection and investigation of three pedagogical models and the accompanying curricular positions on Sustainability (see Section 5).

The concept of transformative learning is utilized as a point of reference for individual/personal change, in this case change of one's position on "How best to be sustainable". The concept of critical thinking is introduced as a trigger for transformative learning and is unpacked to include what critical thinking involves, as opposed to a limited view of many instructors.

3.1 Transformative Learning

Traditional education is enacted through transferring knowledge from the one who knows to those who do not. This approach does not prepare learner for change; rather it prepares them for acceptance of the status quo, and discourages reflection and questioning. A transformative pedagogy demands asking critical questions,, continually searching for new sources and ideas (Åke Bjørke, 2014). Mezirow (1997) highlighted understanding as the meaning of our experiences as the defining condition of being human. Often any 'uncritically assimilated explanation' by 'experts' will suffice while in today's world of sustainability issues and challenges it is essential to make our own interpretations, rather than act on the 'purposes, beliefs, judgments, and feelings of others. In this way, transformative learning develops autonomous thinking while transformative learning theory states that it does this through 'effecting change in a *frame of reference* (Cranton, 1994, 1996; Mezirow, 1991, 1995, 1996).

It is the transformative learners who move toward a frame of reference that is more inclusive, discriminating, self-reflective, and integrative of experience.

Transformative learning is a process that allows students to question taken for granted frames of reference to become more discriminating, open and reflective (Greene, 2001), that produces major changes in thinking, feeling, acting, relating and being (Bennetts, 2003), and allows for evaluating values and assumptions for their effectiveness towards shared goals (Bhaskar, 2009). The conception of Transformative Learning appears in the literature as the 'mechanism' and 'process' for change at all levels of education (Green, 1973; Sterling, 2001). The HESD literature depicts transformative learning as an outcome, goal or result. It is described as the 'competence' to understand multiple ways of looking at the world (Svanström et al., 2008; Wals and Blaze Corcoran, 2006), and an 'ultimate goal' that integrates action into one's new view of the world (Hauenstein, 1998; Sipos et al., 2008). This leads to talk of transformation learning operationally as a shift and subsequent action. In a discussion focusing on Transformative learning and HESD, the authors acknowledge essential skills of reflecting on personal beliefs, opening up to and having the competence to consider and understand the range of perspectives of others and moving towards a new frame of reference that is more inclusive and more aware.

3.2 Critical Thinking

Thinking critically accents the quality of thinking required to competently pose and solve problems, reach sound decisions, analyze issues, plan and conduct thoughtful inquiries (Case & Daniels, 2002). Critical thinking is equated with quality thinking not through the lens of a particular process, schema, or recipe but simply as a distinctive, well-crafted judgment (Scarff Seatter, 2011). It is reasonable and reflective thinking aimed at making a decision about what to do and what to believe (Ennis, 1987); it accents the quality of thinking required to competently pose and solve problems, reach sound decisions, analyze issues, plan and conduct thoughtful inquiries—operationally speaking, thinking critically occurs when a person thoughtfully seeks to assess what would be reasonable to believe or do in a given situation (Case & Daniels, 2002; Mogensen, 1997; Paul, 1982; Siegel, 1988).

Critical thinking is a necessary component of the learning process as students must learn to be comfortable with complexity, ambiguity, and multiple—often contradictory—perspectives (Sprain & Timpson, 2012); they must be enabled and self-autonomous (Short, 2010). The facilitation and utilization of critical mindedness is a necessary component in enabling students to become actively engaged with information and ideas and take action (Scarff Seatter, 2003; Shor, 1993; Short, 2010; Tormey et al., 2008). Tsui (2002) offers evidence from four institutional case studies of fostering critical thinking through effective pedagogy. The operational definition of critical thinking, provided for this study, refers to students' abilities to 'identify issues and assumptions, recognize important relationships, make correct inferences, evaluate evidence or authority and deduce conclusions" (Tsui, 2002, p. 743).

As a means to ensure that students are thoughtfully and actively engaged in understanding HESD concepts, the competency of thinking critically is advocated strongly within the HESD literature (Carew & Mitchell, 2008; Jensen & Schnack, 1997, 2006; Siegel, 2009). It provides a crucial underpinning for HESD as it allows one to see, believe, and act differently than when one's thinking is uncritical.

3.3 Critical Thinking triggers Transformative Learning

At its inception, transformative learning relies on a critical awareness (Boehnert, 2010), which has been raised and developed in HESD seminars and courses. The catalyst for transformative learning is critical thinking; transformative learning has been described as an 'achievement' resulting from critical reflection of one's knowledge and experiences, assumptions and beliefs and to act accordingly (Svanström et al, 2008). Mezirow (1990,) examines how critical reflection triggers transformative learning by drawing a distinction between meaning *schemes* (sets of related and habitual expectations) and meaning *perspectives* (e.g., higher order schemata, theories, propositions, beliefs and 'networks of arguments'). Thinking critically provides the leap from schemes of habitual expectations to perspectives of higher order thinking.

The nature of sustainability—a contested concept featuring an internal conflict due to its inherent trans-disciplinarity (Carew & Mitchell, 2008; Moore, 2005)—demands the facilitation of critically thoughtful judgments and actions. An understanding of sustainability is rife with an internal clash among the three components: people [society], planet [environment] and profit [economics] (Carew & Mitchell, 2008). A healthy, just and sustainable future cannot be found by unthinkingly and uncritically continuing on the same tracks (Mogensen, 1997; Wals & Jickling, 2002). It involves speculating on assumptions and their impact on decision-making (Carew & Mitchell, 2008), critically reflecting on one's knowledge and experience, whilst continuously questioning assumptions and beliefs (Svanström et al., 2008).

Within the context of HESD literature are found concrete sustainability challenges of critical introspection and subsequent transformative learning. Orr (1992) indicated that "a paradigm change that involves seeing the unfamiliar in the familiar", to begin to see "more than meets the eyeball" (Hanson, 1958); Sterling (2001) postulated a third transformative level of learning, a "creative re-visioning" which changes our ability to "participate, to belong and to negotiate meaning." If transformative learning occurs there is a change in beliefs and action and that transformation is evident, especially to the learner. The evidence is an increased awareness of bias and assumptions that accompanies a reassessment of one's position and offers a clearer, more authentic view of the sustainability challenge.

Finally, the linked concepts of critical thinking and transformative learning are found in connection with 'action competence', a conception proposed by Scandinavian researchers that speaks to actions related to fostering a sustainable world (Jensen & Schnack, 1997; Mogensen, 1997; Mogensen & Schnack, 2010). Their writing challenges educators to develop a radical philosophy of education that is critical and controversial, rather than one of accommodation.

In order for higher education institutions (HEIs) to become effective change agents, Svanström, et al. (2008) articulated the goals of transformation in terms of learning outcomes that relate directly to students' professional and personal lives; while Transformative Sustainability Learning (TSL) offers a series of learning objectives corresponding to the cognitive (head), psychomotor (hands), and affective (heart) domains (Sipos et al., 2008). Sipos et al. claim an approach to achieving transformative learning in sustainability through uniting pedagogies that inform both sustainability and transformative education; the authors acknowledge and appreciate methodologies such as community service-learning, critical emancipatory pedagogy and problem-based learning, where HEI's can enact both personal and societal transformations to sustainability.

4. Philosophical Models and Styles of Teaching

HESD remains for the most part entrenched in unidirectional, lecture-style pedagogy that is didactic and void of critical thinking and subsequent transformative learning (Lozano, 2011). HESD is lacking in the development of students who are critically mindful of the challenge involved in long-term pro-sustainability thinking and behavior.

The challenges to HESD teaching can be framed and unpacked via three teaching styles as part of a continuum from teacher-directed to extreme student-centered (Roberts, 1996; Roberts & Silva, 1968). Within this work are located the epistemological and pedagogical underpinnings of three basic approaches to teaching which can be effectively applied to instruction for HESD. The three communication styles of teaching are the Trialogue style (this teaching style includes students' ideas as an integral essential, and significant part of the learning discourse), the Imposition style (The teacher holds the final answers and informs students what is meaningful and what is not), and the Abandonment style (The teacher's prerogative and responsibility to stand for and coach students about the reasons behind various viewpoints is usurped and student sense making is accepted as the objective of the teaching).

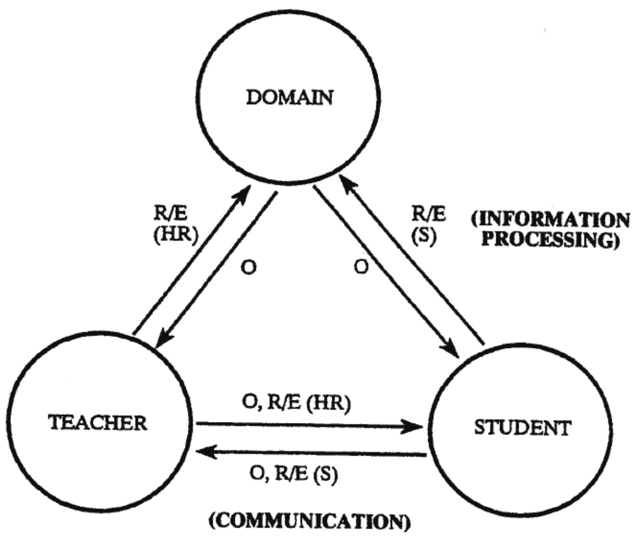


Figure 1: The "Trialogue" Style

Code: "O" = Observation(s); "R/E" = Representation and/or Explanation; "S" = By the Student; "HR = By (Others of) the Human Race (Roberts, 1996; Roberts & Silva, 1968).

Trialogue Style teaching is represented here by a triangular Figure 1, suggesting a three-way dialogue among teacher, student and the domain of knowledge that is under investigation in the classroom. The students, as well as the instructor, 'observe' the events in the domain and bring to class some constructed representations and explanations[2] of their own to the

[2] Due to the cumbersome usage of students 'representations and explanations' throughout the descriptions of the three models. the authors replace 'representations and explanations' with 'ideas' for the remainder of this paper.

investigation under study. Students' individually constructed ideas comprise 'prior knowledge' that forms the basis for Constructivist learning theory. On both epistemological and ethical grounds, "The existence of a student's prior conceptions is acknowledged, and their legitimacy at the student's level of understanding is taken as given" (Roberts, 1996, p. 422). Roberts & Silva (1968) portray the Trialogue teacher as a coach who is obliged to share with students the reasons for the differences between their own ideas ("R/E") and the portion of their intellectual heritage under study (designated O, R/E {HR}).[3] Communication depicted by duo-directional arrows between domain and students illustrate this continual process of sense making and information processing between the domain and the student's world of knowledge, beliefs, and experiences. The students in turn contribute and test their ideas during classroom discussion.

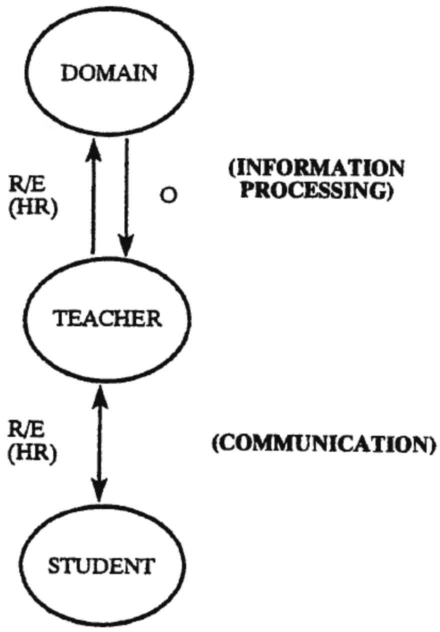


Figure 2: The "Imposition" Style

Code: "O" = Observation(s); "R/E" = Representation and /or Explanation; "S" = By the Student; "HR" = By (Others of) the Human Race (Roberts, 1996; Roberts & Silva, 1968).

It is not necessarily that all topics need to be treated in a manner shown in a Trialogue style but only that students be able to critique their prior knowledge and assumptions and develop their understanding further through classroom discussions. What is important here is that communication by the teacher must be organized into the existing experience of the learner, or it becomes nothing but *mere* words (Roberts & Silva, 1968, p. 423).

Student 'ideas', in this context, stands for students' representations and explanations' of the domain of knowledge under study and of their own experiences.

[3] Roberts & Silva (1968) use symbols to simplify diagrams. On each of the three, Trialogue, Imposition and Abandonment styles of teaching, "O" represents observation; "R" represents representations; "E" represents explanations and "HR" represents the human race, and speaks to the teacher's knowledge and understanding of the entire domain of knowledge developed throughout history on the topic under study.

The Imposition Style teaching is represented in Figure 2 by a uni-linear figure, where students are denied the chance to exercise their prerogative to develop their own ideas or compare their own ideas with those in the greater domain of knowledge. The label of "Imposition' style is to emphasize the point that the student's intellectual position is being 'imposed'" (Roberts, 1996, p. 424). The instructor holds the final answers and maintains the access to the domain of knowledge and understanding of topic under study, essentially informing the student what is meaningful and what is not. Within this model, students are allowed opportunity for discussion but it is essentially the teachers' agenda that defines the dialogue; it is left up to the student to determine how their ideas connect with the domain of knowledge under study, which allows the student to make the material meaningful. Roberts (1996) suggests that students require a metacognitive ability to follow through on why what is being learned is a better way—or not—to deal with the domain, than their own way.

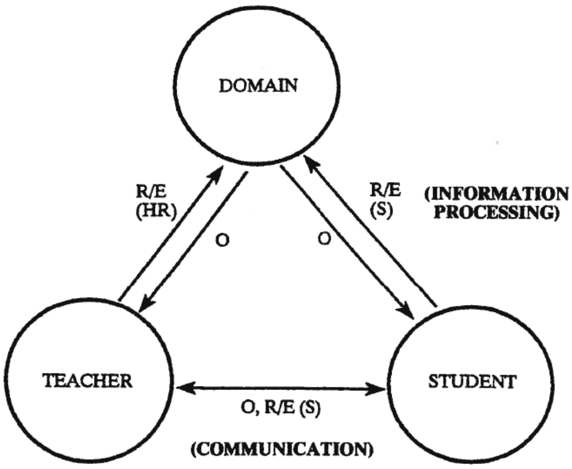


Figure 3: The "Abandonment" Style

Code: "O" = Observation(s); "R/E" = Representation and/or Explanation; "S" = By the Student; "HR" By (Others of) the Human Race (Roberts, 1996; Roberts & Silva, 1968).

The Abandonment Style teaching is also represented in a three-way triangular figure (Figure 3), suggesting a three-way dialogue among teacher, student and domain of knowledge. The label is intended to suggest that students are effectively abandoned to their own devices and ideas. The single double-headed communication arrow indicates that there is much discussion between teacher and student but it is limited to the students' questions and ideas. In such a teaching style, "the teacher's prerogative and responsibility to stand for and coach students about the reason behind the acceptance of particular explanations are insufficiently recognized" (Roberts, 1996, p. 425). Abandonment overemphasizes the student's prerogative and "student sense making, of whatever quality, is accepted as the objective of the teaching" (Roberts, 1996, p. 425).

4.1 Other Models of Teaching and Learning

Scheffler (1973) depicted three philosophical models of teaching that coincide at many points with Roberts & Silva's (1968) teaching styles. First, the 'Impression Model' is the simplest and most wide-spread of the three, picturing the mind essentially as sifting and storing the external impressions to which it is receptive. Second, the 'insight' model represents a radically different approach in that it denies the possibility of the 'Impression' Model, and states that knowledge is vision or insight into meaning, which makes the crucial difference between simply storing and reproducing learned sentences, on the one hand, and understanding their basis and application on the other. This model does not coincide directly with any of the Roberts & Silva (1968) models but connects possibilities found within the Trialogue style. Third, the 'Rule' model looks to reason as always a matter of abiding by general rules or principles. Reason stands in contrast with inconsistency and with expediency, in the judgment of particular issues. (Scheffler, 1973, pp. 68-79). The similarity here between Scheffler's (1973) Rule Model and Roberts & Silva's (1968) Trialogue is found in the role of the Trialogue teacher as coach, who is obliged to share with students the *reasons for the differences* between student ideas and the domain of knowledge. That is, both the Rule Model and Trialogue justify knowledge through sound reasons that are supported with evidence. It is the teacher's role to facilitate this process. The Rule Model offers a more direct link to discussion and critical thinking when speaking of making judgments according to particular criteria. In summary, Scheffler's (1973) models reveal that teaching should be geared not simply to the transfer of information or even to the development of insight, but to the inculcation of principled judgment and conduct.

Turning from Models of Teaching to theories of learning, Lozano (2011), in his work on creativity and organizational learning, presents a schema that aligns with the learning loops theory of Argyris (1977). The learning loops are organized into single, double and triple-loop learning. Although speaking about how organizations learn, the three concepts of learning are particularly commanding for thinking about teaching and learning sustainability concepts.

Single-loop learning involves solving present problems, but without questioning current standards. It involves focusing on a particular task set in front of one in order to achieve particular objectives. Double-loop learning occurs when "assumptions, norms, objectives, policies, goals and programs are questioned, opened to confrontation, and submitted to comprehensive periodic reassessment against established standards, to ensure relevancy" (Argyris, 1977 in Lozano, 2011, p. 7). Double-loop learning focuses on immediate problems but 'delves deeper into the structure of the system to identify root causes' (Lozano, p. 6) and looks at consequences from a wider perspective (Miladinovic, 2014). Triple-loop learning engages in developing new processes. The image that emerges paints single-loop learning on a linear path, whereas a circular path outlines both double and triple-loop learning.

5. Discussion

The authors have presented and discussed the three most common curriculum positions found in Sustainability courses and coupled them with the accompanying pedagogical model best suited to each (see Table 1). For the purpose of this paper, each of the three discrete sections, depicts a distinct pedagogical and epistemological stance[4]. The three units are 'Discourse Sustainability as Trialogue', 'Implementation Sustainability as Imposition, and Definitional Sustainability as Imposition.

The three approaches to sustainability (Alvarez & Rogers, 2006) are viewed through the lenses of the three teaching styles of Roberts and Silva (1968), Scheffler's (1973) philosophical models of teaching, and Argyris' (1977) learning loops. As a tool to consider and analyze some of the current practices of teaching in HESD, this chart serves as a necessary starting point for program design, implementation and teaching in sustainability courses.

---

[4] As in all continuums and categories, there are elements of overlap within the various sections. The separation into three distinct units is for emphasis as well as ease and clarity of discussion.

5.1 The Curriculum, Pedagogy & Learning Table

The juxtaposition of the three curriculum emphases in Sustainability—synthesized into three from numerous models in the work of Alvarez & Rogers (2006) with the three teaching models presented in the writings of Roberts and Silva (1968) and Roberts (1996)— is offered as a lens through which to conceptualize the influence of curriculum on teaching and, subsequently, the effect of teaching on transformative learning.

5.1.1 Sustainability as Discourse and Trialogue Teaching

Trialogue teaching style is the only model that supports a pedagogical emphasis on *Sustainability as Discourse*. The students' prior knowledge and current ideas are integral to teaching and learning in this model. An in-depth engagement among learner, teacher, other learners and the field of study[5]— to the level that the student is making a judgment about what is simply opinion and what to believe— is inherent within constructivist learning theory. Here prior conceptions and beliefs are contrasted and compared with current knowledge under study and new understandings are constructed (Phillips, 1995).

Justified belief results from bringing one's ideas to the table, considering viewpoints of peers as well as the compilation of knowledge previously acquired on the topic. In today's world, education for sustainability is caught in a high-pressured polemic where it is essential to take a thoughtful stand of one's own (Scarff Seatter, 2011) to avoid blindly accepting 'any of many' diverse, contested positions. Students' ideas as a central component of the curriculum serve as a classroom catalyst for individual introspection and evaluation of assumptions, beliefs and attitudes that influence decision-making. Here is support for critical thinking, indeed it is critical thinking in action, and subsequent transformational learning can occur.

As double-loop learning (and critical thinking) occurs when "assumptions, norms, objectives, policies, goals and programs are questioned, opened to confrontation, and submitted to comprehensive periodic reassessment against established standards" (Argyris, 1977 in Lozano, 2014, p. 7), the *Trialogue* teaching style offers possibilities for both single-loop (solving present problems) and double-loop learning. It is also the only one of the three teaching styles that has the potential to accommodate triple-loop learning, which involves thinking creatively and engaging in the development of new processes. Through discourse, debate and an honest sharing of beliefs—engagement with others' ideas—transformative learning can be nurtured.

Scheffler's (1973) rule model focuses on reasons, searching for and recognizing solid reasons according to particular criteria or rules. It is the student's ideas inserted into the teaching of a sustainability topic that enriches the learning experience for teacher and students; engaging learners in the exploration of reasons and the articulation of one's beliefs that rest on solid reasons have a firm place in the *Trialogue* classroom within a contested discourse of sustainability focus.

---

5 One element omitted from Roberts' (1996) *Triagolue* diagram is that of peer discussion and the power of peers learning from each other. As the authors consider this omission, it is the opinion of this paper that within the teacher/Student communication double arrow there is room for multiple students participating in the conversation.

Table 1: Curriculum, Pedagogy & Learning Table

Authors juxtapose three Approaches to Sustainability (Alvarez & Rogers, 2006, p.177)	**Three basic teaching styles (Roberts, 1996) and Argyris' (1977) learning loops theory with accompanying appropriate pedagogical opportunities (developed by authors)**
Emphases on *Sustainability as a Discourse*—a contested discourse that is spoken and claimed by competing groups and cultures, rather than a concept that can be pinned down and identified in the real world	*Trialogue* teaching style -Authentic 'field' excursions -Case Study[6] -Community Service-Learning[7] -Active Learning (Double Loop learning) Critical Thinking and Transformative Learning fostered
Emphases on Sustainability *Implementation*—what is unsustainable, how to make practices more sustainable and how to evaluate sustainable outcomes	*Imposition* teaching style -Lecture -"As if" situation problem solving (Single Loop learning) Little Critical Thinking or Transformative Learning takes place
Emphases on *Definitions* of Sustainability--where they have emerged from, what they attempt to achieve and how they can be compared	*Imposition* teaching style -Lecture -Traditional lab exercises - Question & Answer - Assessment: Exam and/or Essay (Single Loop learning) Neither Critical Thinking nor Transformative Learning are fostered

5.1.2 Sustainability Implementation and Imposition Teaching

The *Implementation* emphasis is described as the most reductive of the three emphases as it is a reaction against 'endless discussions over meanings and definitions' coupled with a plea to 'get on with the task' (Alvarez & Rogers, 2006, p. 177). 'Getting down to business' means mathematically determining, 'What practices are unsustainable?', How such practices are made more sustainable' and 'How outcomes are best evaluated' (Wackernagel & Rees, 1996). As described above, such courses consist of a series of 'lists, indicators, triple bottom-line accounting and ecological footprints.' The very premise of this managerial approach is

[6] Sprain & Timpson (2012) offer ten case-based approaches for teaching about and for sustainability. This pedagogy equips students to encounter complexity, uncertainty and produce innovative strategies and solutions.
[7] Sipos et al. (2008) detail Community service-learning, Problem-based learning and other pedagogical models that relate to sustainability and transformative education.

that once we get enough of the 'right kind of knowledge' sustainability will happen (Alvarez & Rogers, 2006, p. 177).

The pedagogical approach that best facilitates this kind of curriculum is the *Imposition* Style. The student's prerogative to offer his or her ideas is usurped due to a strong teacher's agenda. In Robert's (2006) words, 'the student's intellectual heritage is being imposed' (p. 425), however it is left up to the learner to uncover what place his or her beliefs, biases and attitudes hold in the discussion (if any exists).

The possibility for thinking critically at a shallow level exists within this approach as students grapple with ideas of why a practice is unsustainable and how to fix it. However, posed within the reductionist restraints of this model, there is little room for any in-depth look at how student ideas fit into the picture presented by the instructor and any self-examination of bias, beliefs and attitudes, which is inherent within the critical thinking process and the subsequent transformative learning. Justified belief versus opinion is not addressed in these courses as there *is* one 'right answer' and the teacher holds it.

With its focus on solving present problems, without questioning current standards, the process of linear thinking and single-loop learning finds a place within the Imposition teaching style with an Implementation Focus. However, if students are given the opportunity to share their ideas of why certain practices are more sustainable than others and evaluate them, the possibility for double-loop learning also exists to some degree.

Scheffler's (1973) I*mpression* Model serves best here as the desired end result of such teaching is the "accumulation of the learner of basic elements *fed in from without*, organized and processed in standard ways, but not generated by the learner" (Italics added, p. 68). It is easy to picture how Imposition and Impression Models contribute to the success of meeting the goals of the Implementation emphasis for sustainability as there is no input or engagement required from the student to do so.

5.1.3 Definitions of Sustainability and Imposition Teaching Style

The most common approach to teaching sustainability is the curriculum emphasis on *definitions* of sustainability. The process here is best described as information delivery as the inclusion of student ideas and class discussion is unnecessary when instructing how sustainability is defined, the derivation of definitions and their purpose. The knowledge being conveyed in such courses is delivered from the instructor directly to the learner; it is only the instructor that has access to the field of knowledge and this information is communicated via uni-directional pedagogy. As in the implementation emphases, the student's intellectual heritage is being imposed and his or her prerogative to be part of the conversation is denied. There is a dead end when it comes to thought of justified belief and unpacking differences between the students' input and that of the instructor's. Such a climate does not foster critical thinking nor subsequent transformative learning.

Single-loop learning can occur within the Imposition Style teaching of sustainability definitions but only if students have the opportunity to compare different definitions according to specific criteria. Evaluation of the various definitions could lead to elements of double-loop learning as well. Scheffler's Impression Model works best here as it reinforces the key elements of the Imposition Style of teaching, as discussed above.

Each of the three approaches to sustainability depicted in the table above is subject to the Abandonment Style of teaching (Roberts, 1996; Roberts & Silva, 1968). As an example of an extreme relativist interpretation of constructivist theory, 'Abandonment' allows student prior knowledge, ideas and beliefs to reign supreme; indeed these provide the source and framework for the process and outcomes of classroom topics (Scarff Seatter, 2003). Students in several studies (e.g., Hayes-Conroy & Vanderbeck, 2005) speak of the comfort level found in ESD classes where their passion and emotional responses to sustainability work are supported and nurtured. Although an instructor who listens, cares for and supports his or her students exhibits necessary educator qualities, there is little evidence that students are encouraged to make judgments based on evidence and critical reflection in Abandonment style classes. The Abandonment style of teaching is in evidence when students arrive at class with a particular mindset, which is reinforced and remains unchallenged.

5.2 Bringing Curriculum Pedagogy and Transformative Learning Together

Transformative learning refers to a change in frame of reference, moving from a personal framework of individual ideas into one that references multiple views. Within this change in frame of reference comes decision-making that is truly more enlightened and more likely to be based on sound reasoning. An understanding of sustainability, with its three-fold frame of reference, and internal conflict among its components of societal, environmental and economic sustenance, requires teaching that facilitates transformative learning. Effective HESD is only possible where transformative learning conditions exist. It follows that transformative learning can occur in other places and with other mentors (e.g. parents and community leaders), but within the classroom an instructor can either stand in the way of (Imposition Style teaching) or facilitate (Trialogue Style teaching) transformative learning.

Curriculum choices of *what* we teach determine *how* we teach (Egan, 2012; Gibson, 2012). Pedagogical decisions determine how well students learn curriculum and how *effectively* we teach it. What an HE instructor believes is the best way sustainability should be taught affects greatly whether or not transformative learning is facilitated in his or her classroom. A topic such as sustainability is a personal one on many levels to each one of us. Therefore, especially with such topics that affect us personally, instructors cannot escape our own passion and beliefs of what it is important for students to know and understand. An intention to follow a constructivist Trialogue design of learning is often insufficient as personal beliefs in a particular perspective of sustainability tend to override intentions of sound pedagogy and result in a swing towards Imposition design. As the circle continues, students' beliefs are imposed once again. Furthermore, even if we believe transformative learning is necessary for learning sustainability concepts most instructors do not know how to go about facilitating it. It is hoped that the criteria of the Trialogue pedagogical style, coupled with the 'Sustainability as Discourse' curriculum emphasis presented in this paper, will encourage instructors of HESD to consider critically their current frame of reference and be open to others.

6. Conclusion

Present and future ESD program administrators, designers, implementers and instructors should be aware of the disparate approaches in emphases and teaching styles of sustainability and their implications for student learning. The continuum table included within the discussion section of pedagogical teaching styles and sustainability emphases can be seen as a starting point for further inquiry into the essential elements of effective pedagogy for Education for Sustainability.

There is a paradox within the educational community of teaching and learning sustainability. HESD potentially supports and facilitates transformative learning, that is, within the topic itself and its sense of urgency young scholars can examine their biases, beliefs and values, be motivated to seek and assess that which is reasonable in forming new judgments and construct new knowledge and understanding that serves them, and others, well for their future. This seldom happens.

The paradox lies in the lack of sustenance within Education for Sustainability curricula and pedagogy that tends to reinforce a reductionist agenda that negates the need for individual student's thinking, transforming and making sound judgments. Today's students need to be able to recognize the unsustainability of contemporary problem solving, cease searching for the 'one right answer' and think instead in terms of good ideas and best solutions. The inarguable quotation below best describes the position of the authors of this paper:

> *Nobody has a single right vision of what a 'good' lifestyle entails. Nobody yet knows how to best to sustain the earth's ecosystems for the benefits of ourselves, our children…it is a myth to think that there is a single right vision or a best way to sustain the earth or what kind of earth should be sustained* (Wals & Jickling, 2002)

With this open-minded perspective of the challenge of solving the problems of sustainability we can begin to think in terms of open-minded transformative pedagogy in order to overcome the paradox of a powerful sustainability message framed within a powerless pedagogy.

References

Åke Bjørke, S. (2014). Transformative pedagogy. Retrieved from: *http:ufbutv.com/e-learning/transformative-pedagogy*.

Alvarez, A. & Rogers, J. (2006) "Going 'out there': learning about sustainability in place. International Journal of Sustainability in Higher Education, Vol. 7(2), pp. 176-188.

Argyris, C. (1977). "Double loop learning in organizations". *Harvard Business Review,* September-October, pp. 115-125.

Barth, M., Godemann, J., Rieckmann, M. & Stoltenberg, U. (2007). International Journal of Sustainability in Higher Education, Vol. 8(4), pp. 416-430.

Bennetts, C. (2003). "The impact of transformational learning on individuals, families and communities." International Journal of Lifelong Education, Vol. 22(5), pp 457-480.

Bhaskar, R. (2009). *Scientific Realism and Human Emancipation,* Routledge: NY

Boehnert, J. (2010). "The teach-in, designing a process for transformative learning." Retrieved April 23, 2010 from http://www.eco-labs.org.

Carew, A. & Mitchell, C. (2008). "Teaching sustainability as a contested concept: capitalizing on variation in engineering educators' conceptions of environmental, social and economic sustainability," Journal of Cleaner Production, Vol. 16, pp. 105-115.

Case, R. & Daniels, R (2002) Introduction to Critical Thinking. http//www.sd38.bc.cA :8004/~(TC)2/ *The Critical Thinking Consortium*, Richmond, BC

Ceulemans, K. & De Prins, M. (2010). Teacher's manual and method for SD integration in curricula. *Journal of Cleaner Production*, 18(7), 645-651.

Cortese, A. (2003). "The critical role of higher education in creating a sustainable future", Planning for Higher Education, Vol. 31(3), pp. 15-22.

Cotton, D. (2006) "Teaching controversial environmental issues: neutrality and balance in the reality of the classroom" Education Research, Vol. 48(2), pp. 223-241.

Curzon, L. (1997). Teaching in Further Education: An Outline of Principles and Practice, 5th Edition, Cassell: London.

Darier, E. (1996). "Environmental governmentality: the case of Canada's green plan," Environmental Politics, Vol. 5(4), pp. 585-606.

Egan, K. (2012) "What is Curriculum?", Chapter Two in *Canadian Curriculum Studies: Trends, Issues , and Influences,* Susan Gibson (Ed.), Vancouver: Pacific Educational Press

Ennis, R. (1987), "A taxonomy of critical thinking dispositions and abilities. In J. Baron & R. Sternberg (Eds.). *Teaching thinking Skills: theory & Practice*, pp.9-16. New York: Freeman.

Gibson, S. (2012) *Canadian Curriculum Studies: Trends, Issues, and Influences*, Vancouver: Pacific Educational Press.

Greene, M. (1973). Teacher as Stranger: Educational Philosophy for the Modern Age. Wadsworth Publishing.

Hanson, N. (1958). Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science. Cambridge University Press.

Hauenstein, A. (1998). A Conceptual Framework for Educational Objectives: A Holistic Approach to Traditional Taxonomies, University Press of America: Lanham, MD.

Hayes-Conroy, J. & Vanderbeck, R. (2005) "Ecological identity work in higher education: Theoretical perspectives and a case study," Ethics, Place & Environment, Vol. 8(3), pp. 309-329.

Huckle (2006) Education for Sustainability: Some Guidelines for Curriculum Reform, retrieved from http://john.huckle.org.uk/publications_downloads.jsp.

James, M. & Card, K. (2012). "Factors contributing to institutions achieving environmental sustainability," International Journal of Sustainability in Higher Education, Vol. 13(2), pp. 166-176.

Jensen, B. & Schnack, K. (1997). "The action competence approach in environmental education," Environmental Education Research, Vol. 3(2), pp. 163-179.

Jensen, J. & Schnack, B. (2006).The action competence approach in environmental education, Environmental Education Research, 12(3-4), pp. 471-486.

Kowalewski, D. (2002). " Teaching deep ecology: a student assessment," The Journal of Environmental Education, Vol. 33(4), pp. 20-27.

Laurillard, D. (2002). Rethinking University Teaching: A Framework for the Effective Use of Learning Technologies, 2nd ed. Routledge: London.

Leal Filho, W., MacDermot, F. & Padgam, J. (1996). Implementing sustainable development at university level: A manual of Good Practice. Association of European Universities—Copernicus European Research and Training Centre on Environmental Education, Geneve, Bradford.

Leal Filho, W., Pakalnis, R., Sakalauskas,L. (Eds) (2000). Sustainable Development in the Information Society, Proceedings of the International Conference, October 3-5, 2000, Vilnius (Lithuania). Botany Institute, Vilnius, 2001, ISBN 966-662-17-6 (see http://www.mii.lt/SDIS)

Lourdel, N., Martin, J. & Bererd, O. (2006). “Overcoming obstacles to understanding sustainable development – an approach based on personal experiences, preented at EESD, Lyon, Franc

Lozano, R. (2006). “ Incorporation and institutionalization of SD into universities: breaking through barriers to change, *Journal of Cleaner Production*, Vol. 14, pp. 787-796.

Lozano, R. (2011). “Creativity and organizational learning as means to foster sustainability”, *Sustainable Development* Wiley Online Library. DOI: 10.1002/sd.540

Lozano, R., Ceulemans, K. & Scarff Seatter, C. (2014). “Teaching organizational change management for sustainability: designing and delivering a course at the University of Leeds to better prepare future sustainability change agents,” *Journal of Cleaner Production*, in press. http://dx.doi.org/10.1016/j.jclepro.2014.03.031

Luke, T. (1999). “Environmentality as green governmentality,” in Darier, E. (Ed.), Discourses of the Environment, Blackwell: Oxford.

Mezirow, J. (1990).“How critical reflection triggers transformative learning”, *Fostering Critical Reflection in Adulthood*, Jossey Bass, pp 1-20.

Mezirow, J. (1997). “Transformative learning: theory to practice”.*New Directions for Adult and Continuing Education*, no. 74, Summer 1997, Jossey-Bass.

Mezirow, J. (2000) “Learning as Transformation: Critical Perspectives on a Theory in Progress,” The Jossey-Bass Higher and Adult Education Series. Jossey-Bass Publishers: San Francisco, California.

Miladinovic, M. (2014). Unity in Diversity: Celebrating Diversity for Common and Shared Values. Retrieved from: http://www.afs.org/blog/icl/.

Mogensen, F. (1997). “Critical thinking: a central element in developing action competence in health and environmental education,” Health Education Research, Vol. 12(4), pp. 429-436.

Mogensen, F. & Schnack,K. (2010). The action competence approach and the ‘new’ discourses of education for sustainable development, competence and quality criteria, Environmental Education Research, Vol. 16(1), pp. 59-74.

Morris, M. (2002). “Ecological consciousness and curriculum,” Journal of Curriculum Studies, Vol. 34(5), pp. 571-578.

Orr, D. (1992). *Ecological Literacy: Education and the Transition to a Postmodern World*, SUNY: New York

Paul, R. (1982). “Teaching critical thinking in the “strong” sense: A focus on self-deception, world views, and a dialectical mode analysis,” Informal Logic Newsletter, Vol. 4(2), pp. 2-7.

Perry, W. (1999). Forms of Intellectual and Ethical Development in the College Years, Jossey-Bass: San Francisco, CA.

Phillips, D. (1995).”The good, the bad, and the ugly: the many faces of constructivism”. *Educational Researcher*, 24(7), pp. 5-12.

Prosser, M. & Trigwell, K. (1999). Understanding Learning and Teaching: The Experiences of Higher Education, Open University Press: Buckingham.

Rathzel, N. & Uzzell, D. (2009). “Transformative environmental education: a collective rehearsal for reality,” Environmental Education Research, Vol. 15(3), pp. 263-277.

Roberts, D. (1996), “Epistemic authority for teacher knowledge: The potential role of teacher communities: A response to Robert Orton” Curriculum Inquiry, Vol. 26(4), pp. 417-431.

Roberts, D. & Silva, D. (1968). “Curriculum design, teaching styles and consequences for students,” Samplings, Vol. 1(4), pp.16-28.

Sachs, W. (1993). Global Ecology: A New Arena for Political Conflict, Zed Books: London.

Scarff Seatter, C. (2011) “A critical stand of my own: complementarity of responsible environmental sustainability education and quality thinking,” Journal of Educational Thought, Vol. 45(1), pp. 21-58.

Scarff Seatter, C. (2003). “Constructivist science teaching: intellectual and strategic teaching acts,” Interchange, Vol. 34(1), pp. 63-87.

Scarff Seatter, C. (1998). “ An analysis of the concept of teaching in elementary school science education” Doctoral dissertation, SFU.

Scheffler, I. (1977). “In Praise of the Cognitive Emotions,” *Teachers College Record*, Vol. 79(2).

Segalàs, J., Ferrer-Balas, D. & Mulder, K. (2010).”What do engineering students learn in sustainability course?” Journal of Cleaner Production 18 (2010) pp. 275-284.

Segalàs, J., Mulder, K., & Ferrer-Balas, D. (2012). “ What do EESD “experts” think sustainability is? Which pedagogy is suitable to learn it?” *International Journal of Sustainability in Higher Education*, 13(3), pp. 293-304.

Shor, L. (1993). “Education is politics: Paulo Freire’s critical pedagogy”, in McLaren, P. and Leonard, P. (Eds), Paulo Freire, A Critical Encounter, Routledge: London, pp. 25-35.

Short, P. (2010). “Responsible environmental action: its role and status in environmental education and environmental quality. *The Journal of Environmental Education*, Vol. 41(1), pp. 7-21.

Sibbel, (2009). “Pathways towards sustainability through higher education,” International *Journal of Sustainability in Higher Education*, Vol.10(1), pp. 68-82.

Siegel, H. (2009). *Oxford handbook of Philosophy of Education*, Oxford University Press.

Siegel, H. (1988). Educating Reason: Rationality, Critical Thinking, and Education. Routledge: London.

Sipos, Y., Battisti, B. & Grimm, K. (2008). “Achieving transformative sustainability learning: engaging head, hands and heart,” International Journal of Sustainability in Higher Education, Vol. 9(1), pp. 68-86.

Sprain, S. & Timpson, W. (2012). “Pedagogy for sustainability science: case-based approaches for interdisciplinary instruction. Environmental Communication: A Journal of Nature and Culture, pp. 1-19.

Sterling, S. (2001). Sustainable Education: Re-visioning Learning and Change. Totnes, UK: Green Books for the Schumacher Society.

Svanström, M., Lozano-Garcia, F. & Rowe, D. (2008) Learning outcomes for sustainable development in higher education,” International Journal of Sustainability in Higher Education, Vol. 9(3), pp. 339-351.

Tormey, R., Liddy, M., Maguire, H. & McCloat, A. (2008). " Working in the action/research nexus for education for sustainable development: Two case studies from Ireland," International Journal of Sustainability in Higher Education, Vol. 9(4), pp. 428-440.

UNESCO (2009). "UNESCO world conference on education for sustainable development." Retrieved June 16, 2010.

Wackernagel, M & Rees, W. (1996). "Our Ecological Footprint; Reducing Human Impact on the Earth," New Society Publishers: Gabriola Island.

Wals, A. & Blaze Corcoran,P. (2006) "Sustainability as an outcome of transformative learning," Education for Sustainable Development in Action, Technical Paper No. 3, in Holmberg, J. and Samuelsson, B. (Eds), *Drivers and Barriers for Implementing Sustainable Development in Higher Education*, UNESCO: Paris.

Wals, A. & Jickling, B. (2002) "Sustainability in higher education: from doublethink and newspeak to critical thinking and meaningful learning," International Journal of Sustainability in Higher Education, Vol. 3 (3), pp. 221-232.

Title:

Self-Organization in Food Consumer Groups:

Micro- and Macro-Transformative Roles of Sharing and Entrepreneurship

Author:

Domenico Dentoni

Isabel Miralles Lorenzo

Affiliations:

Department of Social Sciences, Management Studies Group, Wageningen University

Email: domenico.dentoni@wur.nl. Telephone: +31 646 801736

Hollandseweg 1, (Building no. 201), 6706 KN Wageningen, the Netherlands

Self-Organization in Food Consumer Groups:

Micro- and Macro-Transformative Roles of Sharing and Entrepreneurship

1. Introduction

The economic crisis afflicting Europe and the US, together with global environmental and social catastrophes, has led a niche of consumers to self-organize to change their nutrition and social patterns in the way they procure and share goods. Since 2009, Europe is afflicted by risks of bailout, high unemployment rates and low growth rates relative to national debt (Shambaugh 2012; CBS News 2013). In the US, subprime mortgage crisis first hit the country in 2007, as well as the subsequent recession up to 2009 and the public debt-ceiling crises in 2011 and 2013 (GAO 2012; WSJ 2013). Recent natural and social catastrophes made problems of overexploitation of global resources, climate change, environmental degradation, pollution and poor waste management more tangible to public opinion (Rosenbaum 2013; Hannigan 2014). During these events, the number of citizens that started self-organizing in food purchasing groups (e.g., Retegas 2014), consumer-producer partnerships (Dubuisson-Quellier et. al 2011; AMAP 2014) and consumer-led community-supported agriculture (SAR 2011; Galt 2011) is Europe and North America has peaked since late 2000s. Although no direct link exists between crises and quest for alternative solutions, the formers have corroborated the concerns of those seeking more sustainable ways of organizing their food procurement and their personal, household and social life around it (Sheth et al. 2011; Bossy 2014).

Against this large picture, this research analyses how the emergence of self-organizing groups has: 1) generated micro-transformations in group participants - who shifted from being individuals concerned for their future in society into self-actualizing agents - yet has so far 2) missed to reach large scale and stimulate macro-transformations in society. The study cases are provided by *food sharing distribution systems*, including Consumers Solidarity-Based Purchasing Groups (SPGs) in Italy (Brunori et al. 2011; Schifani and Migliore 2011; Cembalo et al. 2013; Retegas 2014), consumer groups in Spain (Miralles et al. 2014); consumer-producer partnerships in France (Dubuisson-Quellier et. al 2011) and Japan (Kingsbury and Maeda 2010); and by *food sharing production systems*, including consumer-led Community Supported Agriculture (CSA) models in USA, Canada and UK (Wilkinson 2001; Adam 2006 Vickers and Lyon 2012) and community gardens in Spain (Miralles et al. 2014). The research integrates evidence from specialized literature on these food sharing systems and secondary data from government reports and social medias with interviews with participants in thirty-six food sharing systems in Spain and Italy.

The research finds that how self-organizing mechanisms has micro-transformational “ripple effects” on its participants’ purchasing patterns, lifestyle and self-discovery through two key elements: sharing and, seen in a broader perspective, entrepreneurship. The first ingredient of transformation is sharing. While most of the literature has so far focused on impersonal forms of sharing mediated by IT (Belk 2014), these empirical cases illustrate the effects of personally sharing tangible resources during production, distribution and consumption stages: a substantial changes in participants’ daily time schedule, social and nutrition habits in sharing individuals’ lives. The second ingredient is entrepreneurship. Entrepreneurship involves combining resources innovatively to seek opportunities for value creation (Shane and Venkataraman 2000). While the mainstream concept of entrepreneurship is exclusively associated with producers’ creation of “exchange value” (Shane and Venkataraman 2000), a recent and broader view of entrepreneurship accepts to see consumers as entrepreneurs seeking opportunities to create “user value” (Shah and Tripsas 2007;

Priem et al. 2012). In the described cases, participants assign themselves into different tasks to recombine human, social, physical and financial resources to share food. Opportunities for user value creation include access to higher quality food, food at lower prices relative to mainstream, optimized transportation and distribution systems, and/or organization of food-related events in more learning, social and enjoyable settings. Taken together, these two ingredients of self-organization build participants' confidence into their own and peers' means, stimulate their self-actualization, and thus transform their consumption patterns and lifestyles.

Despite evidence of these micro-transformational effects, and partially in contradiction with the sustainability concerns of its participants, these self-organizing groups have so far struggled to stimulate macro-transformations. First, reliance on personal rather than impersonal co-ownership, with poor IT support systems, imposes organizational limits to the number of participants in each group. Second, while self-organizing mechanisms fuels the "ripple effect" on its participants, this effect seems hardly transferrable outside each group – including other similarly organized groups yet originating from other historical traditions and participants' concerns. This inability to connect with other self-organizing systems makes them hard to connect into large-scale institutions, attract large numbers of new participants, exercise social pressure and thus to achieve positive systems change. Our interpretation is that macro-transformation for sustainability is still unachieved because participants' micro-transformations in self-organizing groups is often still incomplete: the self-actualizing vis-à-vis a restricted group of peers, yet not in the broader societal context.

2. Theoretical Underpinnings

2.1. Self-Organization and Self-Actualization

As a broad concept applied to both life and social science, self-organizing systems refer to structures that are: emerging from internal mechanisms and local interactions between its components; and without central control, but based on complex collective behaviors raised from simple local individual interactions (Serugendo et al. 2004). A classic example from life science is the collective process of ants food foraging: based on local interactions among participants, self-organizing systems develop emergent characteristics that develop over time in interaction with the external environment (Serugendo et al. 2004). While most of the literature in business has focused on self-organizing producing systems, primarily companies (Collier and Esteban 1999; Kanter 2011; Shipper et al. 2014), there is a dearth of research on self-organizing consumers. Thus, transformation processes of self-organizing consumers are to be explored too.

Self-actualization is a key concept in psychology (Maslow 2006), including consumer psychology (Brooker 1975; 1976). It is "the tendency for the individual to become actualized in what he is potentially" (Maslow 2006) In Maslow's hierarchy of needs, it occupies the highest level of needs that individuals may want to satisfy, as it represents "the desire to become more and more what one is, to become everything that one is capable of becoming" (Maslow 2006). Self-actualization has established measurement scales (Maslow 2006), also adapted to consumption settings (Brooker 1975). The business literature has investigated how product marketing (Hogg and Mitchell 1996) and participation to organizations (Hersey et al. 1988; Marta et al. 2013) stimulate self-actualization.

In between self-organizing systems and self-actualizing processes, there seems to be a missing link. How do self-organizations influence the processes to "become more and more what one is"? To what extent? Is this a process of micro-transformation (i.e. transformation of the individuals that are part of the self-organizing group), or are there also "feedback loops" from the individual to the organization and its environment, i.e. macro-transformations? These questions seem to be still open. Partially tackling these questions, Toffler (1980) and then Kotler (1986) suggested that a segment of consumers across post-industrial societies ("prosumers") undertake self-actualizing processes when producing goods and services by themselves. Evidence from this research builds upon Toffler (1980) and Kotler (1986) yet it looks at self-organizing rather than self-producing processes towards self-actualization. The difference is notable: in the case of food sharing systems, collective rather than individual processes are at the roots of participants becoming "more and more what one is" and "everything that one is capable of becoming" (Maslow 2006).

2.2. Sharing

In its strict sense, sharing means co-owning resources (Belk 2010). New and diverse forms of sharing systems have progressively emerged worldwide in the past two decades and are transforming society and markets (Belk 2010; Lamberton and Rose 2012). Sharing systems of consumption emerge and grow because individuals realize (or expect) that owning goods jointly with others gives them more value than owning them individually (Lamberton and Rose 2012). Rapidly growing forms of sharing - which nowadays generated macro-transformations in the network society - include information through Wikipedia, music via Spotify, car transportation with Zipcar or Blablacar and houses on Airbnb. Given their proven impact on society, it is not surprising that these forms have gained increased attention in marketing and management theory (Bardhi and Eckhardt 2012; Belk 2014; Corciolani and Dalli 2014).

Along with these widely studied IT-based and impersonal forms of sharing, there are other typologies of sharing systems that perhaps unsurprisingly - since they are "niche" as opposed to mainstream – remain still less unexplored. Food sharing systems, which constitute the empirical case of this study, have three major differences relative to the widely studied cases of Linux, Airbnb, Zipcar and Spotify. First, these sharing systems involve interpersonal relationship instead of anonymity in sharing as most of the IT-based forms of sharing (Belk 2010; Bardhi and Eckhardt 2012). Second, they are "club" forms of sharing (Lamberton and Rose 2012). Similarly to cultural associations, sport clubs and churches, they are based on non-rival but exclusive sharing among a restricted number of individuals (Ostrom 2003). Third, differently from most of the IT-based forms of sharing, the shared goods are tangible – such as food – rather than intangible, such as knowledge or information (Belk 2010; Bardhi and Eckhardt 2012).

While self-organization is often effective for regulating sharing resources when the participants interact with each other, an open question remains: how does sharing impacts its participants? The question is relevant because only if participants experience positive impacts through sharing they will continue to participate and stick to the jointly agreed rules. The work of Ostrom has documented that, when sharing public resources, self-organization mechanisms among the sharing actors are more effective than public control over the common resources (Ostrom 1990; 2000). Self-organization mechanisms include jointly making rules and designing incentives to enforce the rules (Ostrom et al. 1992). These mechanisms are effective also when participants have different initial resources and goals to share, depending on the nature of the types of goods and property rights (Ostrom 2003). In the work of Ostrom, incentives to participants have economic nature, that is, group members have lower financial costs than benefits from sharing resources based on self-regulating mechanisms (Ostrom 1990; Ostrom et al. 1992). Instead, there is virtually no discussion on the psychological impacts of self-organizing and sharing, which provide a different and more hidden set of incentives to participation to this form of collective action. Thus, food sharing systems provide a case study to understand how self-organization leads to participants' self-actualization through sharing.

2.3. Entrepreneurship and "User Value" Creation

A widely accepted definition of entrepreneurship suggests that it involves the nexus of two phenomena: the existence of opportunities for value creation and the presence of individuals that discover, evaluate and exploit them through new means-end relationships (Shane and Venkataraman 2000). While several aspects of the nature of entrepreneurship have been discussed in more recent years, this section focuses on four key elements that are considered relevant to further understand the nature of entrepreneurship in sharing consumption systems. First, relative to previous definitions (Venkataraman 1997), Shane and Venkataraman (2000) emphasize that entrepreneurship involves the study of processes that individuals undertake to discover, evaluate and exploit of entrepreneurial opportunities, not just of enterprising individuals. The second key element relates to the nature of entrepreneurial opportunities. Eckhardt and Shane (2003) and Shane (2012) clarify that entrepreneurial opportunities are situations where not only new goods and services, but also new raw materials, markets and organizing methods can be introduced to create value for the individuals that discover, evaluate and exploit them. Thus, price of new goods and services is not necessarily a good indicator to evaluate opportunities, and entrepreneurial processes can create value also by saving resources in the process of recombining and experimenting new means-ends relationships (Eckhardt and Shane 2003). The third relevant element is that entrepreneurship does not require new venture creation, but can include it (Shane 2012). For example, individuals may decide to pursue and exploit entrepreneurial opportunities by being part of an existing organization or, alternatively, by acting in the market without creating one. The fourth element is that entrepreneurship "examines many outcomes other than business performance, which is the focus of strategic management (e.g., entrepreneurship is concerned with how identification and exploitation of opportunities affect societal wealth and individual happiness)" (Shane 2012). This implies that entrepreneurship may lead to profit, but it may lead also to other non-monetary outcomes that impact society beyond the enterprising individual.

More recently, the field of entrepreneurship has progressively developed the idea that consumers are in a favorable position to become entrepreneurs (Shah and Tripsas 2007; Chandra and Coviello 2010). User entrepreneurs pursue entrepreneurial opportunities by combining "use value" - that is, value based on consuming the shared goods - with "exchange value" – that is, exchanging and recombining resources for sharing consumption goods (Priem et al. 2012). For example, some consumers of juvenile products act entrepreneurially to adapt these goods to their specific needs and the needs of other users (Shah and Tripsas 2007). Also, eBay users create value by buying and reselling computer hardware worldwide (Chandra and Coviello 2010). Still, these cases focused on users that, after having accidentally found an opportunity for creating exchange value, become "producing" entrepreneurs and create their own venture. This research does one step further and illustrates, based on the case of food sharing systems, that entrepreneurship takes place also among groups of consumers.

While self-organizing mechanisms stimulate participants' entrepreneurship, especially when they are engaged in the creation of social value (Di Domenico et al. 2010), the link between entrepreneurship and participants' self-actualization is still unexplored. Di Domenico et al. (2010) found that participants taking jointly agreed, independent and improvised decisions in groups are more likely to develop entrepreneurial processes – this is what they refer as "social bricolage" (Di Domenico et al. 2010). Yet, to what extent does entrepreneurship in self-organizing groups influence participants' psychology? Would self-organizing groups where participants do not need to be entrepreneurial stimulate micro- and macro-transformations for society?

3. The Case of Food Sharing Systems

3.1. Origins and Self-Organizing Nature

The self-organizing nature of food sharing systems has historical roots: a "subtle thread" links each emerging system to others within the same country. The first traced example in each country one or more "visionary leaders" first inspired their development, yet without providing any regulation or direction apart from effectively communicating a vision. These "leaders" often travelled in other country, had an "epiphany" observing radically different ways of organizing food procurement relative to purchasing food in stores, through self-producing or directly purchasing consumer groups, decided to imitate them when back in their country of origin and, if successful, to promote them to others. The examples had a multiplicative effect on others within countries, so that the number of food sharing systems exponentially grew (from very small numbers) within a few years (Table 1).

Insert TABLE 1: Origins of Food Sharing Systems in Six Countries

Inspired by an example that pursues a shared vision applied in their own context, groups of 2 to 5 people (friends or a couple) started to self-organize their own shared food production, distribution or purchasing. In most of the cases, but not always, the group of founders was already part of the same network. Only in few cases in Spain (Miralles et al. 2014), there is evidence of municipalities selecting participants to groups according to criteria of unemployment and social disadvantage. Social networks from which the food sharing systems emerged include:

- Cultural associations and training for food organic production (Wilkinson 2001);
- Environmental Non-Governmental Organizations (NGOs) (Wilkinson 2001);
- Social movements (Dubuisson-Quellier et. al 2011)
- Social services for the unemployed (Miralles et al. 2014);
- Neighborhood committees/assemblies: “food in their balconies” (Miralles et al. 2014);
- University experiments (Schifani and Migliore 2011);
- Farmer-consumer friendships, or friendships among consumers (Cembalo et al. 2013).

Since the food sharing systems started based on inspiration and examples provided by other group rather than formal institutions, they had no specific rules to comply with given by the external environment. Legal frameworks regulating the functioning of these groups were very general: in all the six mentioned countries, apart from laws on contracts of selling and the creation of cultural associations, food sharing systems had no specific public regulation to comply with. All food production, distribution and consumption processes are informal; thus, groups do not have to pay value added taxation or business license, not to follow established official sanitary standards or certification. Thus, each group just followed the example of other groups, embraced a shared vision and adapted the activities to their own needs and preferences. The “subtle thread” of shared vision involves that the emerging food sharing systems are meant to be:

1. Environmentally appropriate, in the sense of exchanging and sharing food that travels less mileage, saves energy during production and requires less packaging;

2. Socially equitable, thus improving social relationships, sense of community, participants' responsibility and trust;
3. Economically viable, which means improving the local economy, supporting the community around the group and achieving food sovereignty.

Insert TABLE 2: Self-Organizing Mechanisms in Food Sharing Systems

The result of these few "ingredients" in common across group – shared vision and very different and few self-organizing norms – led the groups to undertake widely heterogeneous - and often chaotic - processes to develop their organizational structure (Miralles et al. 2014).

3.2. The Micro-Transformational Effects of Sharing

The described self-organization mechanisms "regulating" food sharing systems lead them to act as "clubs". They have a club nature because shared goods - food and its related knowledge - are exclusive yet non-rival (Lamberton and Rose 2012). They are exclusive since joining food sharing systems goes hand in hand with becoming part of the social network where they are embedded. In most of the cases, they emerge from networks of people with a common passion for food or common social, environmental or political views; thus, from pre-existing social networks (Migliore et al. 2013). Individual members that are disconnected from the initial network join them with the intent of becoming part of the network within a short lapse of time. To take decisions on production, procurement and distribution of shared food requires frequent meetings and the informal interactions, and that re-iterates the network-building process. Either way, there is no access to food sharing systems without being or becoming part of a restricted social network.

In these "clubs", sharing generally takes place during food production, distribution and/or consumption. Food production and its needed resources (land ownership or rental, water, equipment, seeds, etc.) are shared for example in community gardens and urban orchards especially in North America (Armstrong 2000; Twiss et al. 2003) and Europe (Firth et al. 2011; Bendt et al. 2013). Food distribution - which is the stage from picking the food from farmers' field or gate to dividing it among members – takes place for example in consumer-led CSA in Europe and North America, consumer-producer partnerships in Europe and Japan as well as in solidarity-based purchasing groups in Italy. Sometimes food distribution is also coupled with food consumption, such as in some consumer groups in Mediterranean countries and in US, where participants organize food events to share food, new recipes and develop further a sense of convivial communities (Table 3 and 4).

Based on the described self-organization mechanisms, these sharing processes have a transformational effect on participants. Two major segments of participants found and join food sharing systems in the attempt of improving the fit between their values and they daily actions. A first segment of participants are unemployed or doing occasional jobs and, when they joined, they were concerned with their current financial situation; feeling oppressed and even angry with the mainstream market-based system where they are unable to fit in. A second segment of participants have full time jobs or are retired, yet when they joined they were looking for healthier, more social and more just lifestyle. Despite they have more than sufficient financial access to purchase in mainstream stores, they felt a sense of frustration and disorientation with consumption patterns which were not fitting with the ideals that they fought for in their past experiences in social and environmental movements.

While participants' intentions were mainly to change their food consumption patterns when choosing to join these clubs, their transformation has been much deeper. The "ripple effect" of joining these clubs through sharing first involved consumption patterns. Participants increased their intake of fruit and vegetables and reduced processed food; reduced (but apart few exceptions, did not eliminate) their shopping in food stores; and spent more evaluating and choosing produce based on its attributes. Sharing was essential to changing even the individual food consumption patterns, because participants provide examples to each other and exercise forms of peer pressure on eating healthier and sustainable food also beyond what is actually shared. After involving changes in food consumption, the second transformational effect of sharing processes was on participants and their household lifestyles. Since only few rules are established in the clubs and participants had to decide how to share the food, they naturally had to spend more time in meetings to organize how to participate their activities. This required more social time and broadening the network of acquaintances. Many participants reported the participation to these "club meetings" as an unprecedented experience for them. On the one hand, differently from the meetings of other cultural associations or social movements, participants had to take very practical and tangible logistic decisions such as where to stock food, which members go to pick up orders from farmers, or jointly assessing the quality of some procured vegetables. On the other hand, differently from decisions made within each family, now these types of practical decisions had to be made with a number of acquaintances that often members hardly know. The intense social dimension around decision-making on the shared food had three further outcomes on participants' lifestyles:

- **Family & friends' involvement in clubs events.** Many participants found that club meetings could become social activities not only for themselves but also for the family. During food stages, many food sharing systems organized recreational and learning events for kids. Food distribution events became opportunities to spend social time with their partner, retired parents or close friends. In other words, beyond food, clubs provided the chance of becoming points for social aggregation.
- **Reduced importance of clothing and physical appearance.** The focus of attention in meetings was mainly food, often involved contact with land and produce. Club members realized that, differently from when they participated to other social meetings, this focus of attention was making the environment much more informal and, ultimately, decreased the pressure on clothing and physical appearance of their members. In other words, members across clubs often felt at ease dressing at club meetings with informal, working clothing independently from their age, gender and social status.

- **Passion for lifelong learning.** All segments participating to clubs had to broaden their learning horizons through group participation. Young participants, either students or unemployed, learned from agricultural or logistic practice. Full-time employees participating to the clubs found new hobbies. Farmers and retired participants had to re-discuss their assumptions on society, especially through their relation with younger generations in the club. Then, finding new avenues for learning stimulate passion and enthusiasm for lifelong learning in general outside the sharing activity context.

Yet, the sharing process transformed participants more profoundly than in their food consumption and lifestyle: it changed them also in the way they look at themselves in relation to society. Five aspects of personal transformation - towards dimensions that Maslow (1970) considers as aspects of self-actualization - are specifically rooted into the sharing processes undertaken by participants:

- **Distinguishing between means and ends.** Through tangible sharing experiences, participants changed their perspective on the relative importance of owning versus accessing resources such as land and income for food. A segment of participants, especially students, young unemployed and retired, over time found at ease dedicating half-time or even full-time of their working week for the club: they mentioned that the learning and social experience represented their choice over seeking insecure or poorly paid jobs which could not guarantee savings.
- **Deepening relationships with others.** A large number of participants reflected on a renewed sense of being together and knowing each other through concrete goals that emerged from the sharing experience. By finding a space where to procure food, meet friends and stay with their loves ones at the same time, participants were able to take more time in this social setting to deeply know others, their families and themselves.
- **Finding mission in life with a broader sense of community.** A segment of participants mentioned they were able to finally find a way to expressing themselves through the activities of these food clubs. After having sought sustainable collective forms of lifestyles

for longtime in their past experiences, many were disillusioned that a right formula for being in peace with their communities could not be found. Instead, the sharing process revived their hopes to "find their mission" in balance with the community around them.

- **Feeling awe for basic things in life.** An example mentioned by many participants in food production systems is the collective sense of excitement looking at the growing of their shared watermelons and zucchini. For food distribution systems, the realization that more than half of their dietary income could be actually produced and purchased directly from farmers within few miles provided the same sense of excitement. Involving kids and families in learning activities also helped raising "enthusiasm for the essential" as many participants referred to.

3.3. The Micro-Transformational Effects of Entrepreneurship

Entrepreneurship is the second key "ingredient" leading the self-organizing mechanisms of food sharing systems to transform its participants and to let them undertake a self-actualizing process. Participants in food sharing systems act as entrepreneurs because they 1) establish a nexus with opportunities for value creation; and 2) seek innovative means-end relationships to combine resources to create value.

First, since the self-organizing mechanisms provide large freedom of action its members, each individual participants of food sharing systems seek to seize opportunities that create value in innovative ways. This is one of the key informal criteria for admission to the clubs. Thus, some members focused mainly on pursuing opportunities for financial value creation, while others pursued objectives to create value for society and the environment. Thus, tasks are divided in a way that some participants specialize in the procurement of new food; others in the distribution and storage of food; others instead focus on keeping and updating distribution lists and orders; others on the organization of events, either for the club members or for the broader community; finally, others work on seeking to promote the food sharing systems model for others to follow this example (Table 4).

Furthermore, participants in food sharing systems recombine the following set of resources in innovative ways:

- **Human capital.** First and foremost, participants invest their own *time* to create value through the described activities. Some of the participants spend their spare time out of their income-generating activities; others are retired and spend most of their time on the club activities. Together with time, participants put their individual *competencies* at stake: some have stronger knowledge of food quality and agronomy; others have a better understanding and ability to convince consumers to join groups; others have an ability in organizing logistics and food transportation; finally, others are apt to organizing social events for the group. Often, these competencies are improvised and improve with the experience and specialization of roles rather than by being based on an educational or career background.
- **Social capital.** This is a key resource that is combined in every action undertaken by members attempting to seize opportunities for value creation. Members seeking to create value have a stake in their social networks: with farmers and with peer members when they procure new foods; with peer members and potential new members when they seek new participants; with peer members when they organize the logistics of transportation and storage, and when they organize social events to share food knowledge.
- **Financial capital.** Independently from the entrepreneurial action that they may undertake, every member regularly pays a monthly or annual fee in exchange for food and its knowledge and distribution. Based on decisional processes that vary across clubs (which are not the focus of this research), the pooled funding from membership fees is used by other members to implement the entrepreneurial actions described above. In many circumstances, members also contribute with some of their own financial resources to these actions. For

example, members seeking to procure new foods do pay for their own fuel costs to visit farmers and bargain and close deals on procurement agreements with farmers.

- **Physical capital.** Finally, members put at stake their own car, to procure and transport food, or their own house, fridge and storage room as a pick-up point. Moreover, it is not rare that members get creatively organized to combine resources among groups of them: one person has time, thus leverages his/her social network to borrow a car or storage from a (busier) peer member to organize food distribution and meetings with farmers. In other words, members seek ways to exploit any underused asset available to improve the organization of distribution and delivery of food from farm to plate.

Since the mechanisms were deliberately self-organizing and based on personal trust and reciprocity - since the individuals are used to meet often - participants were able to “position their contribution to the group” by considering what the other members were doing, what they were able and willing to do, and what the groups needed. This process of informally seeking a tangible role within a group of acquaintances also helped participants to transforming and getting to know themselves better. Thus, this collective entrepreneurial process stimulated participants to move from an initial start of concern, angriness, oppression, frustration and disorientation with the sustainability in the current market systems. Through this entrepreneurial process, participants undertook a personal transformation towards four aspects of self-actualization:

- **Feeling serene and undisturbed.** Despite the persisting personal challenges, participants found a concrete way to deal collectively with financial and sustainability problems that they were frustrated with. While they realize that uncertainty in their lives and in society persists, participants acknowledge that being active in the clubs gives them a sense of accomplishment for the solutions found collectively.
- **Resolving life dichotomies.** Before joining the clubs, participants were contrasted between dividing their time and money on their job (or searching jobs), shopping, and family and friends. Through their entrepreneurial work within the sharing systems, many members

realized over time that their creativity in food sharing systems could help reducing these conflicts.

- **Closer to ideal selves.** “We have been living in this neighborhood since many years, but we did not know anyone around us. We were just going to work and back, with no opportunities to meet the others. Now that we work together with many of our neighbors, and that we found our own tasks to contribute to our community, we feel that we better know who we are and what we can offer to others” mentioned one of the participants. While at the start many were quite reluctant to undertake new initiatives in the group, over time people become more confident and aware of their potential. Another participant mentioned that spent two years in the group only picking products from farmers to group members, but later - when she felt encouraged to suggest new activities in groups – started also organizing field excursions and linking members’ families with farmers. This made her confident on her social and management skills, and since then became a “serial” organizer of social events for the group and within her neighborhood.
- **Feeling limitless horizons.** Starting from a state of frustration for living in a static system affected by economic crisis and environmental and social degradation, participants over time gained confidence over their personal means and talents. Within one year, some participants were able to introduce up to six tangible innovations in the group activities – organizing field activities for external members; restoring degraded land and thus expanding the arable land, introducing new systems of accounting. Importantly, several participants felt confident to “dream bigger” and discuss how to develop mess media technologies, local institutions and civil society to achieve larger-scale transformation.

Importantly, not everyone found his or her way within these clubs. Interviews focused only on members that remained in groups and found a task, yet we assessed that around one third of former participants left the clubs because they understood that this was not fitting with what they were seeking, or because they were too busy with outside activities to remain actively involved. Thus, to some extent, it could be argued that these entrepreneurial processes in sharing systems also helped some of the members to self–exclude themselves when realizing that this was not the way that they wanted to spend their time.

3.4. The Missing Link: from Micro- to Macro-Transformation

Despite these results in terms of micro-transformations, at today food sharing systems have not achieved scale and generated macro-transformation. One interviewee from Spain sees potential for continuity with the macro-transformation promises that social movements made in the 1990s before food sharing systems emerged:

"*Many things have changed and we need to know how to read reality and celebrate our triumphs. The emergence of the 15M movement did not result in an organisation which currently has a significant number of members. The 15M movement is a social movement. This means, it has served as a catalyst for "moving" social collectives, associations, non-mobilized people, initiatives… and in this sense it still exists today, as another step in the spiral of social reactivation*".

Yet, for the time being after decades after the emergence of the first food sharing systems, specialized literature illustrates that scale has not been reached on any level of macro-transformation: neighborhood level, city level, national level and international level. Specifically:

- **Neighborhood level**: community gardens and consumer groups had positive effects for the restoration of plots of land in urban and peri-urban areas (Okvat and Zautra 2011). Yet, there is no documentation of restored land size being larger than two acre per food sharing system. Moreover, there is no evidence of having more than 80 food sharing systems per city (Murtagh, A., 2010; Ohberg, L., and CoDyre, M., 2013). Thus, the impact on land restoration and landscape transformation is very limited. Also, while the sharing systems have created a sense of community for its members and their households, there is no evidence of social transformations at an entire neighborhood level as a consequence of these sharing systems.

- **City and regional level** (Schupp and Sharp 2011; Mount 2012; Andretta and Guidi 2014);
- **National level** (Cone and Myhre 2000; Andretta and Guidi 2014; Forno and Graziano 2014);
- **International level** (Henderson & Van En., 2007; Haenfler et al. 2012; Cox et al. 2013).

Constraints to the macro-transformation are both institutional and organizational. Institutional constraints involve substantial gaps in the regulation of these organizations (on food standards, taxation on transactions and land, governance), which remain often informal, and the lack of public investments complementing the private ones by participants. The existing legislation does not formally recognize certain activities and transactions, or when it does is wrongfully applied to the sharing economy models as it was developed for conventional systems (Business Innovation Observatory EU, 2013). Accordingly, several policies or restrictions have caused the appearance of informal or sometimes illegal forms of food systems within and around the cities (FAO, 2007). This constitutes a significant constrain for the different food sharing systems to grow and expand. As an example of this institutional bottlenecks, a look into the urban European context is proposed where the AFNs are a relevant phenomenon that is getting spread in many different forms like CSA and farmer-consumer groups (Atkinson 2013). The legal positions of CSAs in different European countries were analyzed in the first European meeting on CSA, held in 2012 in Milan. The outputs stated a general illegal status in countries like Austria or Slovakia and for the rest of the analyzed countries, the CSA models were coexisting in grey areas of the law by adopting alternative or innovative forms of activity. Likewise, from an organizational perspective different studies (Murtagh 2010; Ohberg and Codyre 2013) claim the lack of appropriate knowledge to understand the internal organization among members in the distinct AFNs. In the report of the first European meeting on CSA (urgenci.net), clear differences appeared in the level of activity and network development of the CSA groups that attended the meeting.

Regarding organizational constraints, evidence from interviews and the cited specialized literature on food sharing systems highlight six major constraints, which are closely related to sharing and entrepreneurship:

1. **No time to spend spent out of the sharing group.** Participants "vote with their time" on which type of value they want to create. First of all, they need and want to dedicate time to their sharing group, and only after on macro-transformations through networks across groups. The focus on the sharing group first is given sometimes by necessity, and other times by the vision of achieving macro-transformations through providing example to others of a well functioning group model. For example, some sharing groups have dedicated time to develop videos or other social media for communication and dissemination of their model out of their group. Apart from this case, though, the time spent overall by participants on outside activities to network with similar sharing groups, or to engage stakeholders other than consumers and farmers, is very limited.
2. **Too heterogeneous to network.** Food sharing groups have wide differences in origins, pre-existing networks, self-organizing mechanisms. These differences make the sharing groups also very heterogeneous in values, cultures, languages and organization. Coupled with a tendency of food sharing groups of remaining as "pure as possible" in terms of sticking to their founding ideals (since joint vision is one of the few biding elements of sharing groups), this heterogeneity makes the networking across various forms of sharing groups very limited.
3. **Reciprocity only within the group.** Most of the entrepreneurial spirit is given by participants' feelings of reciprocity for the other group members; which, in turn, is developed mainly through face-to-face meetings and getting to know each other. Since the networking across sharing groups cannot necessarily be in person, the trust and reciprocity feelings that support entrepreneurial actions of participants are weaker or do

not exist. As discussed above, the entrepreneurial action of sharing group members is crucial for the survival and growth of the sharing groups.

4. **Fatigue to recruit new participants in society.**
5. **Seeking stability and efficiency over time, not increased complexity.**

4. Discussion and Conclusion

This research investigates describes self-organization in food consumer groups as a bottom-up approach to innovation for sustainable development. While most of the literature on sustainable development focuses on top-down approaches of sustainable development (such as sustainable development strategies undertaken by corporations, governments and universities), only a minority of studies has so far focused on bottom-up approaches (Brunori, et al. 2012; Di Domenico et al. 2012; Seyfang and Longhurst 2013). In particular, this study focuses on how the organization of food consumer groups generates (or does not generate) transformative effects on the participants and on society. Two key organizational elements are identified: sharing and entrepreneurship. Results based on primary data from interviews with consumer group participants in Spain and Italy – combined with literature on sharing systems on other four countries (US, UK, France and japan) – demonstrate that these self-organization mechanisms have a positive, transformative effect on its participants. However, no tangible effect is found on large-scale change towards sustainable development. While the participants intensely learn, change personality and even "find themselves" as part of the sharing and entrepreneurial experience in these groups; they are often unable and unwilling to dedicate further time to operate outside their groups for a large-scale transformation of their neighborhoods, city, country or world. Several drivers related to organizational and institutional constraints are identified.

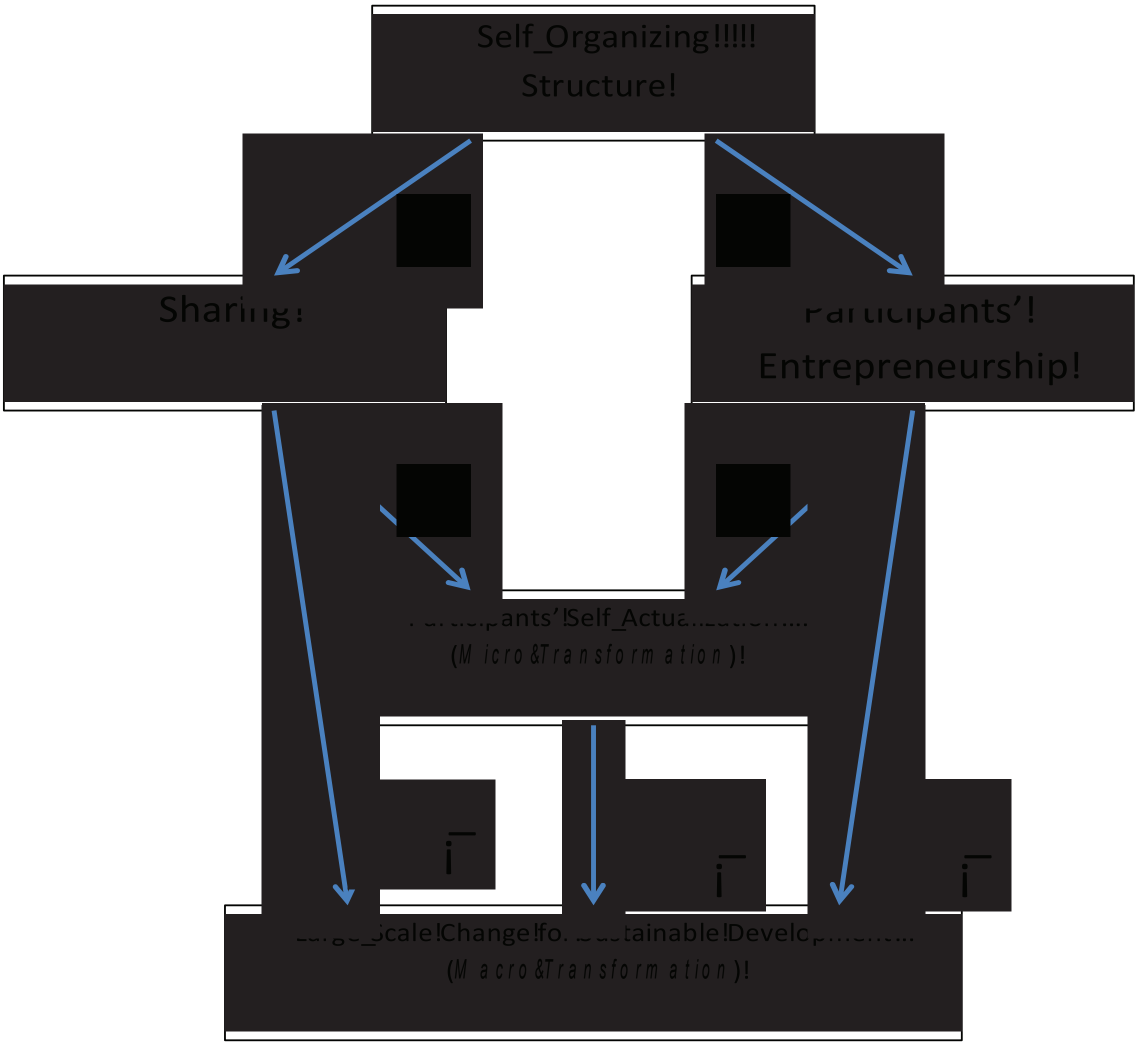


FIGURE 1: The Inductive Theoretical Framework

These results lead inductively to a set of propositions to be tested in future research (Figure 1). First, sharing and entrepreneurship are two key mediators between the self-organizing structure of food consumer groups (which makes them truly bottom-up) and their impacts. On the one hand, sharing and entrepreneurship are positive mediators on participants' micro-transformation towards their self-actualization. On the other hand, they are negative mediators on the macro-transformation of food sharing systems on sustainable development at various levels (from neighborhood to international level). Evidence from this study is based on a limited amount of interviews and on a nascent field of specialized literature that has not collected enough evidence to provide a clear-cut picture on these proposed relationships. Thus, it is appropriate that future research tests this framework with a larger sample both on a more representative number of food consumer group cases and in other cases of bottom-up innovations for sustainable development where self-organizing mechanisms are developed. These propositions can be actually tested by adapting the existing measures on self-organizing mechanisms (Serugendo et al. 2004), sharing systems (Lambertom and Rose 2012; Belk 2014), Entrepreneurship (Shane and Vankataraman 2000), self actualization (Maslow 1970) and large-scale change (Waddell et al. 2014).

The practical questions with managerial and policy implications that remain open based on these results are: what should participants in food sharing systems do (or could do) differently to stimulate large-scale change for sustainable development? And what external stakeholders, including universities, governments, and companies should do? Despite the results are not encouraging in terms of any macro-transformation achieved, there seem to be no specific advise to give to participants in food consumer groups. Many of them would certainly benefit from trainings on information technology and communication; as well as on other managerial and organizational skills to further improve the self-organizing mechanisms that they developed so far. However, participants are already "bootstrapping" their time, human capital, financial and physical resources for creating value in their group, so the advice would not be very feasible and helpful. Instead, from a cultural standpoint, food consumer group should avoid to ideologically "close themselves" from the rest of the world – including groups with different values and other stakeholders: while sharing group vision is crucial for their perpetuation, closing off to external influences would not allow any large-scale learning even if opportunities to enhance large-scale collaboration would arise. Regarding implications for external stakeholders, Elinor Ostrom (1990) would advise to avoid any interventions by external agents that are not based on careful interaction with the (local) self-organizing actors. Taking stock from Ostrom, this implies that research on the complexity of the organizational mechanisms of food consumption groups should precede interventions by governments (such as regulation or public investments), companies and universities (such as proposed partnerships). Yet, since knowledge and interaction among stakeholders and food consumer groups is crucial, universities and NGOs could play key roles as facilitators and trainers across groups – in a way that macro-transformation could be achieved starting from the bottom-up innovation ideas of the food consumer groups, yet without asking them to shift resources from within their groups to outside their groups. In other words, universities and NGOs could play a "public good" role – thus with public and foundation funds rather than private funds – to building bridges and training how to build bridges across food consumer groups.

References

Adam, K. L. (2006). *Community supported agriculture*. ATTRA, National Sustainable Agriculture Information Service: Butte, MT.

Adler, T.R., Scherer, R.F., Barton, S.L. and Katerberg, R. (1988). An empirical test of transaction cost theory: validating contract typology. *Journal of Applied Management Studies* 7(2): 185–200.

Ajzen, I. 1991. The theory of planned behavior, *Organizational Behavior and Human Decision Processes* 50 (2): 179–211.

Austin, J., Stevenson, H., and Wei-Skillern, J. (2006). Social and commercial entrepreneurship: same, different, or both? *Entrepreneurship Theory and Practice* 30(1), 1-22.

Bardhi, F., & Eckhardt, G. M. (2012). Access-based consumption: The case of car sharing. *Journal of Consumer Research* 39(4), 881-898.

Becker, B. W., and Connor, P.E. (1981). Personal values of the heavy user of mass media. *Journal of Advertising Research* 21: 37-43.

Belk, R. (2010). Sharing. *Journal of Consumer Research* 36(5), 715-734.

Belk, R. (2007). Why not share rather than own? *The Annals of the American Academy of Political and Social Science* 611(1), 126-140.

Belk, R. (2014). You are what you can access: Sharing and collaborative consumption online. *Journal of Business Research* 67 (8), 1595-1600.

Besanko, D., Dranove, D., Shanley, M. and Schaefer, S. (2009). *Economics of strategy*. John Wiley & Sons.

Birkinshaw, J., Brannen, M.Y. and Tung, R.L., 2011. From a distance and generalizable to up close and grounded: reclaiming a place for qualitative methods in international business research. *Journal of International Business Studies* 42 573–581.

Botsman, R. and Rogers, R. (2010). *What's mine is yours. The Rise of Collaborative Consumption.* Collins.

Brunori, G., Rossi, A. and Guidi, F. (2012). On the new social relations around and beyond food. Analysing consumers' role and action in Gruppi di Acquisto Solidale (Solidarity Purchasing Groups). *Sociologia Ruralis* 52(1), 1-30.

Brunsø K. and Grunert, K.G. (1995). Development and testing of a cross-culturally valid instrument: Food-related life-style. *Advances in Consumer Research* 22, eds. Frank R. Kardes and Mita Sujan, Provo, UT : Association for Consumer Research, 475-480.

Brunsø, K., J. Scholderer, and Grunert, K.G. (2004). Closing the gap between values and behavior. A means-end theory of lifestyle. *Journal of Business Research,* 57(6), 665–670.

Byrne, B.M. (2013). *Structural equation modeling with EQS: Basic concepts, applications, and programming*. Routledge.

Cameron, A.C. and Trivedi, P. (2013). *Regression analysis of count data*. United Kingdom: Cambridge University Press.

Carlstrom, C.T. and Fuerst, T.S. (1997). Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis. *The American Economic Review* 87 (5), 893-910.

Cembalo, L., Migliore, G. and Schifani, G. (2013). Sustainability and New Models of Consumption: The Solidarity Purchasing Groups in Sicily. *Journal of Agricultural and Environmental Ethics* 26(1), 281-301.

Corciolani, M. and Dalli, D. (2014). Gift-giving, sharing and commodity exchange at Bookcrossing.com. New insights from a qualitative analysis. *Management Decision* 52(4), 7-7.

Dacin, P.A., Dacin, M.T. and Matear, M. (2010). Social entrepreneurship: why we don't need a new theory and how we move forward from here. *The Academy of Management Perspectives* 24(3), 37-57.

Davidsson, P., and Wiklund, J. (2001). Levels of analysis in entrepreneurship research: Current research practice and suggestions for the future. *Entrepreneurship Theory and Practice* 25(4), 81-100.

Di Domenico, M., Haugh, H., & Tracey, P. (2010). Social bricolage: Theorizing social value creation in social enterprises. *Entrepreneurship Theory and Practice* 34(4), 681-703.

Dubuisson-Quellier, S., Lamine, C. and Le Velly, R. (2011). Citizenship and Consumption: Mobilisation in Alternative Food Systems in France. *Sociologia Ruralis* 51 (3), 304–323.

Eckhardt, J.T. and Shane, S.A. (2003). Opportunities and entrepreneurship. *Journal of Management* 29(3), 333-349.

Eisenhardt, K.M. (1989). Building theories from case study research. *Academy of Management review* 14(4), 532-550.

Floyd, S.W. and Wooldridge, B. (1999). Knowledge creation and social networks in corporate entrepreneurship: The renewal of organizational capability. *Entrepreneurship Theory and Practice* 23(3), 123–144.

Galt, R.E. (2011). Counting and Mapping Community Supported Agriculture (CSA) in the United States and California: Contributions from Critical Cartography/GIS. *ACME: An International E-Journal for Critical Geographies*, 10(2).

Glaser, B.G. and Strauss, A. (1967). L.(1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.

Graziano, P.R. and Forno, F. (2012). Political Consumerism and New Forms of Political Participation The Gruppi di Acquisto Solidale in Italy. *The Annals of the American Academy of Political and Social Science* 644(1), 121-133.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010). *Multivariate Data Analysis*, 7th Edition, Prentice Hall: Upper Saddle River, NJ.

Hechter, M., Nadel, L. and Michod, R.E. (1993). *The origin of values.* New York: Walter de Gruyter.

Hobbs, J. E. (1997). Measuring the importance of transaction costs in cattle marketing. *American Journal of Agricultural Economics* 79(4), 1083-1095.

Homer, P. M., and Kahle, L.R. (1988). A Structural Equation Test of the Value-Attitude-Behavior Hierarchy. *Journal of Personality and Social Psychology* 54(4), 638-646.

Inglehart, R. (1971). The silent revolution in Europe: Intergenerational change in post-industrial societies. *American Political Science Review* 65, 991-1017.

John, G. and Weitz, B.A. (1988). “Forward integration into distribution:an empirical test of transaction cost analysis.” *Journals of Law, Economics, and Organization* 4(2), 101–17.

Kanter, R. M. (2011). How great companies think differently. Harvard Business Review.

Kaplan, D. (2007). *Structural Equation Modeling: Foundations and Extensions*. Sage Publications: California, CA.

Kingsbury, A. and Maeda, Y. (2010). Marketing the'Slippery'Local with the Contrived'Rural': Case Studies of Alternative Vegetable Retail in the Urban Fringe of Nagoya, Japan. International *Journal of Sociology of Agriculture & Food* 17(2).

Kristiansen, C.M., and A.M. Hotte (1996). Morality and the self: Implications for the when and how of value— attitude-behavior relations. In: *The psychology of values: The Ontario symposium*, ed. C. Seligman, J. M. Olson, and M. R. Zanna, 77-106. Mahwah, NJ: Lawrence Erlbaum.

Lamberton, C.P. and Rose, R.L. (2012). When is ours better than mine? A framework for understanding and altering participation in commercial sharing systems. *Journal of Marketing* 76(4), 109-125.

Maio, G.R., Olson, J.M., Bernard, M.M. and Luke, M.A. (2003). Ideologies, values, attitudes, and behavior. In J. Delamater, *Handbook of social psychology* (pp. 283–308). ed. New York: Kluwer Academic/Plenum Publishers.

Marschan-Piekkari, R., Welch, C. (2004). Handbook of Qualitative Research Methods for International Business. Elgar Publishing, Cheltenham.

Ménard, C. (2008). A new institutional approach to organization. In: *Handbook of new institutional economics*, ed. Menard, C. and Shirley, M.M., 281-318. Springer: The Netherlands.

Ménard, C. and Valceschini, E. (2005). New institutions for governing the agri-food industry. *European Review of Agricultural Economics* 32 (3), 421-440.

Micheletti, M. (2003). *Political virtue and shopping: Individuals, consumerism, and collective action*. Palgrave Macmillan: UK.

Migliore, G., Schifani, G., Guccione, G. D. and Cembalo, L. (2013). Food Community Networks as Leverage for Social Embeddedness. *Journal of Agricultural and Environmental Ethics*, 1-19.

Munro, I. (2010). Nomadic strategies in the network society: From Lawrence of Arabia to Linux. *Scandinavian Journal of Management* 26(2), 215-223.

Nambisan, S. and Baron, R.A. (2013). Entrepreneurship in Innovation Ecosystems: Entrepreneurs' Self-Regulatory Processes and Their Implications for New Venture Success. *Entrepreneurship Theory and Practice* 37(5), 1071-1097.

Ostrom, E. (1990). Governing the commons: The evolution of institutions for collective action. Cambridge university press.

Ostrom, E., Walker, J., & Gardner, R. (1992). Covenants with and without a Sword: Self-governance Is Possible. American Political Science Review, 86(02), 404-417.

Ostrom, E. (2000). Collective action and the evolution of social norms. The Journal of Economic Perspectives, 137-158.

Ostrom, E. (2003). How types of goods and property rights jointly affect collective action. Journal of Theoretical Politics, 15(3), 239-270.

Panzar, J. C. and Willig, R.D. (1981). Economies of scope. *The American Economic Review* 268-272.

Peredo, A.M. and Chrisman, J. J. (2006). Toward a theory of community-based enterprise. *Academy of Management Review* 31(2), 309-328.

Peredo, A.M., and McLean, M. (2006). Social entrepreneurship: A critical review of the concept. *Journal of world business* 41(1), 56-65.

Prahalad, C. K. and Hamel, G. (1993). The core competence of the corporation. *Organization of Transnational Corporations* 11, 359.

Prothero, A., Dobscha, S., Freund, J., Kilbourne, W. E., Luchs, M. G., Ozanne, L. K. and Thøgersen, J. (2011). Sustainable consumption: opportunities for consumer research and public policy. *Journal of Public Policy & Marketing* 30(1), 31-38.

Re, A.P.C.B.H. (1997). Organization of electronic markets: contributions from the new institutional economics. *The Information Society* 13(1), 107-123.

Retegas (2014). *Archive of Solidarity Purchase Groups in Italy*. Available at the Retegas website: www.retegas.org. [Accessed 06 July 2014].

Rogers, J., and Fraszczak, M. (2014). 'Like the Stem Connecting the Cherry to the Tree': The Uncomfortable Place of Intermediaries in a Local Organic Food Chain. *Sociologia Ruralis*, In Press.

Rokeach, M. (1973). *The Nature of Human Values*. New York: Free Press.

Schifani, G. and Migliore, G. (2011). Solidarity purchase groups and new critical and ethical consumer trends: First results of a direct study in Sicily. *New Medit* 3, 26-33.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In: *Advances in experimental social psychology*, M. Zanna 25, 1–65. Academic Press: New York, NY.

Schwartz, S. H., Melech, G., Lehmann, A., Burgess, S. and Harris, M. (2001). Extending the cross cultural validity of the theory of basic human values with a different method of measurement. *Journal of Cross Cultural Psychology* 32, 519–542.

Sebastiani, R., Montagnini, F. and Dalli, D. (2013). Ethical consumption and new business models in the food industry. Evidence from the Eataly case. *Journal of Business Ethics* 114(3), 473-488.

Serugendo, G. D. M., Foukia, N., Hassas, S., Karageorgos, A., Mostéfaoui, S. K., Rana, O. F., ... & Van Aart, C. (2004). Self-organisation: Paradigms and applications. In Engineering Self-Organising Systems (pp. 1-19). Springer Berlin Heidelberg.

Seyfang, G. and Longhurst, N. (2013). Growing green money? Mapping community currencies for sustainable development. *Ecological Economics* (86), 65-77.

Shah, S.K. and Tripsas, M. (2007). The accidental entrepreneur: The emergent and collective process of user entrepreneurship. *Strategic Entrepreneurship Journal* 1(1-2), 123-140.

Shane, S. and Venkataraman, S. (2000). The promise of entrepreneurship as a field of research. *Academy of management review* 25(1), 217-226.

Shane, S. (2012). Reflections on the 2010 AMR decade Award: delivering on the promise of entrepreneurship as a field of research. *Academy of Management Review* 37 (1), 10–20.

Shepherd, D.A. and Patzelt, H. (2011). The new field of sustainable entrepreneurship: studying entrepreneurial action linking "what is to be sustained" with "what is to be developed". *Entrepreneurship Theory and Practice* 35(1), 137-163.

Strauss, A. and Corbin, J. (1994). Grounded theory methodology. *Handbook of qualitative research* 273-285.

Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of management journal* 49(4), 633-642.

Taylor, M. (1999). The small firm as a temporary coalition. *Entrepreneurship and Regional Development* 11(1), 1-19.

Teo, T. S. and Yu, Y. (2005). Online buying behavior: a transaction cost economics perspective. *Omega* 33(5), 451-465.

Troye, S.V. and Supphellen, M. (2012). Consumer Participation in Coproduction:"I Made It Myself" Effects on Consumers' Sensory Perceptions and Evaluations of Outcome and Input Product. *Journal of Marketing* 76(2), 33-46.

Urbano, D. and Alvarez, C. (2014). Institutional dimensions and entrepreneurial activity: An international study. *Small Business Economics* 42(4), 703-716.

Venkataraman, S. (1997). The distinctive domain of entrepreneurship research. *Advances in entrepreneurship, firm emergence and growth* 3(1), 119-138.

Vinson, D. E., and J. M. Munson. (1976). Personal values: an approach to market segmentation. In: *Marketing, 1877-1976 and beyond*. ed. K.L. Bernhardt, Chicago American Marketing Association.

Vinson, D. E., Scott, J. E. and Lamont, L.M. (1977). The role of personal values in marketing and consumer behavior. *Journal of Marketing* 41(2), 44–50.

Viswanathan, M., Sridharan, S., and Ritchie, R. (2010). Understanding consumption and entrepreneurship in subsistence marketplaces. *Journal of Business Research* 63(6), 570-581.

Welter, F. and Smallbone, D. (2011). Institutional perspectives on entrepreneurial behavior in challenging environments. *Journal of Small Business Management* 49(1), 107-125.

Wilkinson, J. (2001). Community supported agriculture. *Office of Community Development (OCD) Rural Development Technote*, U.S. Department of Agriculture, 20, 1-2.

Williams, C.C. (2008). Beyond necessity-driven versus opportunity-driven entrepreneurship A study of informal entrepreneurs in England, Russia and Ukraine. *The International Journal of Entrepreneurship and Innovation* 9(3), 157-165.

Zepeda, L. and Li, J. (2006). Who buys local food? *Journal of Food Distribution Research* 37(3).

References not in text

Others studying link self-organization on individual learning, but not mediated by sharing and entrepreneurship:

Collier, J., & Esteban, R. (1999). Governance in the participative organisation: freedom, creativity and ethics. *Journal of Business Ethics*, *21*(2-3), 173-188.

Collier, J., & Esteban, R. (2000). Systemic leadership: ethical and effective. *Leadership & Organization Development Journal*, *21*(4), 207-215.

Apshvalka, D., & Wendorff, P. (2005, September). A Framework of Personal Knowledge Management in the Context of Organisational Knowledge Management. In *ECKM* (pp. 34-41).

Zhang, Z. J. (2009). Personalising organisational knowledge and organisationalising personal knowledge. *Online Information Review*, *33*(2), 237-256.

Appendix 1 – Tables and Figures

TABLE 1: Origins of Food Sharing Systems in Six Countries

Japan, 1971	The modern movement known as Teikei emerged in the early 1971. It rose from a group of woman conscious with the harmful effects that the use of pesticides on food could cause in human health. It was born as the organic food movement in which not only the way of producing was of relevance but also the relationships between consumer and producer was of primary importance. It became popular around 1975 when several groups of woman were gathering to buy healthy food directly to the farmers for their kids. The movement spread rapidly and the Japan Organic Agriculture Association was founded. However, the reality of the Teikei in Japan today shows stagnation (Hatano 2008).
USA, 1980s	
Italy, 1990s	The first network among SPGs appeared in Italy in early 1997, providing a helpful support to SPGs to connect and build institutional relationships. The network distributed an informative bulletin of all the SPGs among them and together with the creation of the website it became an essential tool for information and experience sharing. Within three years, the number of SPGs doubled, reaching approximately 30 in 1999. According to the most recent data (Retagas 2014), the national SPGs network, more than 900 groups were registered by 2012, meaning that at least twice the number was existing across Italy (Grasseni et. al., 2013). It is believed that the trajectory that brought to the establishment and diffusion of this type of AFN is due to the early creation of SPGs networks.
France, 2001	The first consumer-producer partnerships (AMAP) started to operate in France on April 2001, when Denise and Daniel Vuillon decided to introduce in their farm in Oulioulle, France, a model of community supported agriculture (CSA) that they discovered during a trip to the US. In 2007 the AMAP were about 500 (AMAP 2014). In 2011 approximately 3,000 farms were established according to this model across France. Political consumerism and social activism are at the main aims of the AMAP project (Dubuisson-Quellier et. al 2011).
Spain, 2000s	
UK, 2000s	In 2011, 80 trading CSA farm models were mapped in the UK and around 80 more underdevelopment. Attending to the statics, a big growth took place from 2009 to 2011 due to the support of different associations and funding (Soil Association report, 2011). Rough estimations calculate that over 1,300 hectares of land were being used to feed more than 12,500 people with an annual turnover of approximately £7,000,000. It implies a 0.01% of the population taking part in these initiatives by 2011 and providing around a 0.2% of the total income from farmlands in England.

Source: Own elaboration from data from referenced papers.

TABLE 2: Common Self-Organizing Mechanisms agreed in Food Sharing Systems

Rules for selection of shared goods	• Organic/local or better self-produced • Food box principle, “we eat what is available locally, not what we want/on demand” • If any transaction, only direct selling farmers-consumers, no involvement of food shops. No willingness to replicate supermarkets or “local/organic labels”, nor “farmers' markets”.
Rules for network-building	• “General assemblies” in almost all groups, but no joint binding decisions in them • Committees with voluntary participation and rotation: a coordinator, a finances person, a group informer, a volunteer coordinator, among others. All the committee members are volunteers and they rotate after a certain period of time (usually one or two years). • Direct communication with farmers to create sense of brotherhood • Familiarizing dinners in public spaces
Rules for participant admission	• No formal criterion. Only when municipalities provide free assets (i.e. degraded land), then only socially disadvantaged people. • Participating in person after an initial email/phone contact, promise active involvement, and build trust over time.

Source: Own elaboration of interviews with food sharing systems' participants in Spain and Italy.

TABLE 3: Common Dimensions of Food Sharing Systems

Common Dimensions	Level	Description
Temporality	**High**	Participants have seasonal or annual memberships that are often renewed over the years. During membership, acquisition of shared food is frequent (twice a week, weekly, bi-weekly or monthly depending on the product and members' request).
Interpersonal Anonymity	**Low**	Participants know each other well and they actively seek to meet each other in social settings to share knowledge on food and perform recreational or information seeking activities (for example, on how to procure new foods within the shared system, or how to better store or cook the shared food).
Consumer Involvement	**High**	Participants undertake a number of activities as part of the sharing process. Some participants make group orders from farmers; others drive to pick up the goods in designated locations; others store and prepare the shared food for members' distribution.
Functionality of goods	**Medium**	Participants share both the food and the experience of exchanging knowledge and socially learning about food attributes, its production and preparation. The sharing experience extends also to share knowledge beyond food itself, for example about each other's' lifestyle and socio-political choices.

Source: Own elaboration from data from referenced papers nterviews with food sharing systems' participants in Spain and Italy.

TABLE 4: Heterogeneous Dimensions of Food Sharing Systems

Heterogeneous Dimensions	Lower Level (example and description)	Higher Level (example and description)
Market mediation	In Italian SPGs, French AMAPs and Japanese Seikyou, participants' distribution of products from food producers to consumers and among consumers in the sharing system is directly managed and diffused as opposed to concentrated into few market mediators (Brunori et al. 2011; Rogers and Fraszczak 2014).	In some US CSAs (Wilkinson 2001; Adam 2006), participants hire a farmer to grow specific crops or other products and the subscribers make most management decisions. In others, consumers and producers jointly participate to own resources (land, farm inputs, transport and storage rooms) and together manage all aspects of the program. .
Political consumerism	In US CSAs (Wilkinson 2001; Adam 2006) and Japanese Seikyou (Kingsbury and Maeda 2010), participants often have the main goal to provide better and safer food quality, from trusted farm source and in pleasant social settings, and at a lower price (Troye and Supphellen 2012). Politics is a less common reason for joining these sharing consumption systems.	In French AMAPs (Dubuisson-Quellier et. al 2011) and some Italian SPGs (Schifani and Migliore 2011, Graziano and Forno 2012), participants take share consumption to support a social, environmental or political cause; for example, enhancing sustainable development, supporting the local small businesses, critiquing mainstream growth models of agribusiness, or preserving local culinary traditions.

Entrepreneurship	In some US CSAs (Wilkinson 2001; Adam 2006), farmers or group of farmers organize and market a CSA program, recruiting subscribers and determining most of management decisions. These types of CSAs where the farmers plays the entrepreneurial role as opposed to consumers is closer to sharing consumption systems such as Zipcar, Blablabla and Airbnb described in the extant literature (Belk 2007; 2010; Lamberton and Rose 2010; Bardhi and Eckhardt 2012).	Similarly to Italian SPGs (see Section 4.1), in French AMAPs (Dubuisson-Quellier et. al 2011) and Japanese Seikyou (Kingsbury and Maeda 2010), participants create value by 1) approaching new local farmers and proposing them to join the sharing system as suppliers; 2) recruiting new consumers to reduce per unit costs through economies of scale. In the case of Japanese Seikyou, participants also create workers' co-op dedicated to food processing and manufacturing after harvesting and before consumption (Kingsbury and Maeda 2010).

Source: Own elaboration from data from referenced papers.

Title:

Organizational structures of sharing economy in the EU food and agricultural sector: Alternative Food Networks in Valencia

Authors:

Isabel Miralles[1], Domenico Dentoni[1*], Stefano Pascucci[1]

Affiliations:

[1] Management Studies Group, Department of Social Sciences, Wageningen University

*Corresponding Author: Dr. Domenico Dentoni

Email: domenico.dentoni@wur.nl. Telephone: +31 646 801736

Hollandseweg 1, (Building no. 201), 6706 KN Wageningen, the Netherlands

Organizational structures of sharing economy in the EU food and agricultural sector: Alternative Food Networks in Valencia

Abstract

Despite their transformative potential in urban and peri-urban contexts, sharing economy systems in the agricultural and food sector remain a niche compared to mainstream agricultural and food supply chains. They are emerging in Europe, the US and Australia under the broad definition of alternative food networks (AFNs) with comparable yet highly context-specific organizational frameworks. Through a case study in the city of Valencia (Spain), this research uses mixed methods to analyse the organizational heterogeneity of AFNs in an urban and peri-urban context to drive managerial and policy conclusions on why these systems to not develop faster and become mainstream. For this purpose, two main lenses are combined in this research: 1) a new institutional economics perspective to describe the governance mechanisms of AFNs. These governance mechanisms are conceptualized as hybrid forms or networks, thus analyzing the type of contracting and coordination for resource pooling, the role of leadership, stakeholder participation, and their decision-making processes; 2) a sharing systems perspective to identify the heterogeneous set of resources co-owned in different models of AFNs. Through these two lenses, the research identifies three clusters of AFNs that - although being all sharing economy systems - are characterized by diametrically opposed organizational features: “Own consumption community gardens” (Cluster 1), “Commercial community gardens” (Cluster 2) and “Consumer groups” (Cluster 3). To fully express their transformative potential, these clusters will require differently tailored policies and management practices, as well as building networks across them.

Keywords: Sharing economy, Alternative food networks, Community gardens, Consumer groups, Organizational structure, Governance.

Organizational structures of sharing economy in the EU food and agricultural sector: Alternative Food Networks in Valencia

1. Introduction

The sharing economy is increasingly rooted in our lives. Car or bike sharing programmes, clothes swapping or tools sharing groups, accommodation exchanges, co-working spaces, community gardens, and food or renewable energy cooperatives are examples of sharing economy initiatives that are spreading worldwide (Orsi, 2013). By sharing is now possible to access many goods and services once people had to own (Belk, 2013).

Sharing economy refers to social models based on sharing goods and services while diminishing the need of ownership (Botsman and Rogers, 2010; Gansky, 2011). Opportunities for the development of sharing economy are created by technology for people to get connected, access information and offer services or physical objects from which they can profit (Gaskins & Stehfest, 2010). This has empowered regular citizens and small enterprises to easily create commercial ventures with a low budget investment (Smith, 2014). Next to it, cities and urban contexts have become the ideal platform for sharing. The population growth projections and its effect to higher urban density have created a sparked interest to implement sharing initiatives inside the neighbourhoods (Gansky, 2011). Different expectations of the growth of sharing economy have been predicted (Sacks, 2011; Contreras & Snir, 2011; Standage, 2013), but either way showing increasing numbers on how sharing economy activities that involve co-production, co-design, co-creation, co-working or collaborative consumption are becoming relevant from an economic point of view.

Within the agricultural and food sector innovative sharing economy systems and organizational structures are also emerging and establishing. Although still remaining a niche if compared to mainstream agricultural and food supply systems, sharing economy systems are emerging in Europe, the US and Australia with comparable organizational frameworks. In the context of food and agriculture, sharing economy models are usually included in the definition of alternative food networks (AFNs). Similar to sharing economy systems, AFNs are formed by a heterogeneous group of actors which have the sharing of a specific set of resources and values around food as central motivation (Pascucci, 2010). Some examples of AFNs that present clear features of sharing economy are the Community Supported Agriculture initiatives, Solidarity Purchase Groups, community gardens or kitchen gardens among others (Orsi, 2013).

According to prior research at least three reasons have led to the appearance of sharing economy systems in general and particularly in the agri-food sector. First, it is arising from an ideological opposition to the principles of a capitalist industrialised system (Baum, 2009). The participation of consumers in different AFNs is being motivated with an increased distrust in the fairness and quality of large corporations' brands (Gansky, 2011). Second, environmental pressures require different models that can deal with an uncertain future frightened by climate change and the shortage of natural resources (Goodman, 2003). Together with the lack of transparency of the actual systems, consumers are turning into producers so they can ensure the quality of the produce (Colding & Barthel, 2013). Third, the economic crisis is hampering the access to primary goods and services due to price inflation, salary reduction and large unemployment rates (Goodman & Goodman, 2007). Food prices, for example, experienced an 80% increase from 2006 to 2008 worldwide (Loewenberg, 2008). It is a fact that in times of economic depression or crises the allotment areas and/or community gardens increases in number (Colding, 2007). Many factors are contributing towards a change in society and economy; and therefore to the building of a sharing economy.

Despite a wide number of compelling reasons for re-organizing and re-thinking mainstream agricultural and food systems, sharing economy systems in the agri-food sector are still a niche relative to mainstream models. Thus the question is why are they not emerging more rapidly and what are the organizational and institutional bottlenecks limiting the outreach of sharing economy systems? The goal of this research is to contribute to tackle this broad question by focusing on cases of sharing economy systems in the European agricultural and food sector. We start from further analysing the role of the existing EU policy framework which is identified as one of the most relevant institutional bottlenecks seemingly preventing the expansion of sharing economy systems in the EU context. The lack of a specific legislation that applies to sharing economy systems seems to lead in important constraints to even legally formalise many AFNs in several European countries, such as the Solidarity purchase groups in Italy or the Community supported agriculture (CSA) in the UK (Business Innovation Observatory EU, 2013; European Sharing Economy Coalition, 2013). Accordingly, several policies or regulations have inspired the appearance of sharing economy in informal, or sometimes illegal, forms of food systems within and around the cities (FAO, 2007). A review into the AFNs in an urban European context showed that many CSA models coexist in grey areas of the law by adopting alternative or innovative forms of activity (Urgenci, 2013). This seems to constitute a significant bottleneck that constrains the development of the different AFNs. Likewise, from an organizational perspective, different studies (Murtagh, 2010; Ohberg & CoDyre, 2013) claim the lack of appropriate knowledge to understand the internal organizational features, and relational elements among AFN members and participants. The large differences on the level of activity and network development of the CSA groups in the European context demonstrate the necessity of: (1) mapping the different forms to similar AFNs (in this research the sharing economy systems in the agricultural and food sector) highlighting their similarities and differences; (2) establishing a clearer definition of the different features involved in the different AFNs to be able to replicate them in other contexts, countries and sectors (Urgenci, 2013).

To investigate and analyse factors limiting or hampering the further development and diffusion of food and agricultural sharing economy systems in the EU we decided to focus on a relatively rich and informative case. More specifically we investigate both the role of policies and regulations, as well as the organizational features of several AFN organizations in the urban and peri-urban area of Valencia, Spain. We tried to highlight the main commonalities and differences with regard to other sharing economy models based in the EU. We based the analysis and classification of the sharing economy systems on their organizational elements, then comparing their heterogeneity. As such, this research provides scholars and practitioners with a systematic description and clustering of the organizational structures of the sharing economy systems in the agricultural and food sector, using a specific urban setting such as Valencia as first informative case study. Importantly, investigating differences across sharing economy systems stimulates reflection on the type of policy and institutional interventions the EU and its countries and regions should tailor to enhance the positive transformational effects of these models.

Valencia is a medium-large sized city in the European context, comparable in size and inhabitants with Amsterdam, The Netherlands; Lyon, France; Turin, Italy; Porto, Portugal; and Stockholm, Sweden (Demographia World Urban Areas, 2014). Similar to many European urban areas, the city of Valencia has an agricultural background that is disappearing over time due to urbanization (PAT, 2014), however still leaving the metropolitan area with an integrated orchard placed very close to the city centre. Lastly, Valencia is an example of an area affected by the economic crisis like many other southern European cities. These are diverse characteristics that present the city of Valencia as a replicable example to many other European cities and cities beyond. However, the high context-specificity of the distinct AFNs evidences the need to understand and clearly define the infrastructure, distribution and network options of the AFNs towards up-scaling (Ohberg & CoDyre, 2013).

The paper is organised as follows: we first introduce our theoretical framework (section 2) and then discuss our methodological approach (section 3). In section 4 we present main findings while in section 5 and 6 we discuss implication for scholars and practitioners respectively.

2. Conceptual framework

2.1. Sharing and the role of ownership

Interest towards issues of shared or dis-ownership is increasing in Western societies. For example more than 50% of Americans take part in sharing economy activities, and more than 80% are willing to join those activities rather than buying a product (Sunrun, 2013). We are stepping in an era in which people get more value by owning less (Jurich, 2013). Subsequently, the concepts of ownership and sharing are crucial to understand the evolution of the different economic activities. But the term “sharing” is cause of diverse understandings and interpretations. Sharing activities imply joint ownership and/or usufruct rights; in contrast to other activities such as gift giving or commodity exchange based on the transfer of ownership (Belk, 2010). Nonetheless, a wide range of different practices are concentrated under the concept of sharing (Belk, 2010). Using Belk’s definition sharing implies “*the act and process of distributing what is ours to others for their use or vice versa, receiving something from others for our use*”. However, the concept of sharing is quickly evolving and it has become an alternative to private ownership where the benefits or costs from owning something are being shared (Belk, 2007). For example from a social logistics point of view “sharing” is seen as creating community particularly for the sharing economies of consumption (John, 2013). Sharing is conceived by the different actors involved as a type of communication (online sharing of links, photos, videos) or as a type of distribution (offline sharing of cars, bikes). John (2013) distinguishes between two types of economies of sharing: one of *production*, such as Wikipedia or Linux, mainly based on people sharing their work as well as shared inputs and outputs; and another one of shared *consumption*, in which the concept of sharing is used in two different ways, as equal access to common goods or as sharing properties with others (John, 2013). An attempt to establish clear differentiations of access in contrast to sharing and ownership has been recently developed (Bardhi & Eckhardt, 2012). The study builds a body of information through a detailed procedure of variables that shape access versus sharing or ownership. However, it also confirms sharing as an enabler of access and contributes to strengthen commonalities between access and sharing, since neither implies transfer of ownership (Belk, 2007; Bardhi & Eckhardt, 2012).

Providing evidence of the relevance for analyzing the different types of ownership among the existing resources involved in the sharing economy activities.

The literature sustains that to find a suitable categorization for the sharing economy activities is a laborious task. Already some typologies have been developed according to different focuses, varying from a market perspective (Botsman, 2013), governance (P2P foundation, 2012, pp.47) or others (P2P foundation, 2012, pp.51); like the *Mesh Sharing Directory* by Lisa Gansky (Mesh, 2014). Many sharing economy systems have broad organizational differences for example in terms of ownership status of the shared resources. In detail, the shared resources present diverse types of ownership as they can belong to commercial or non-profit companies, communities or individual participants (P2P foundation, 2012). Accordingly, ownership status of the shared resources is one key element to investigate in order to analyse AFNs as systems of shared economy. Next to it, the conditions of sharing are strongly dependent on the different agreements adopted by the participants (P2P foundation, 2012, pp.186). In principle permits and privileges should be common-oriented in order to allow a joined use of the resources (P2P foundation, 2012, pp.186). This suggests that the stakeholders' participation might be key to understand how the different types of relationships among actors involved may lead to one or other type of shared economy settings in similar initiatives.

2.2. Key features of sharing economy systems

Sharing economies are characterised by similar features and consider collaborative consumption to be a crucial one. Already different typologies and categorizations of sharing economy systems co-exist as well as disagreements among scholars (Botsman, 2013; Collaborative Economy Coalition, 2014; Gansky, 2014; Lamberton & Rose, 2012; Smith, 2014). Several characteristics have to be taken into account in order to consider an activity belonging to a sharing economy. Particularly differences need to be made between some issues like (i) working towards a common objective (i.e. the engineers of a company creating a pool of knowledge towards a new development) and just sharing, (ii) the diverse ownership models and (iii) the governance and control processes between different sharing systems (P2P foundation, 2012).

On the basis of the existent literature, six features have been identified as common for the activities pertaining to a sharing economy system:

1) A crucial aspect is the *collaborative consumption*. This was first coined to refer to the participation of individuals in activities like sharing, trading, or renting among others leading in collectives making use of common goods and resources to save time, money or contribute to better environmental practices (Botsman, 2013). However, Belk Russell, an expert researcher on the meanings of possessions, collecting, gift-giving, sharing, and materialism, finds the definition of collaborative consumption stated by Botsman too broad, mixing terms such as marketplace exchange, gift giving, and sharing. Belk narrows down the definition and states that the collaborative consumption is people coordinating the acquisition and distribution of a resource for a fee or other compensation (Belk, 2013). The latter being a concrete and precise explanation that facilitates the identification of the different sharing economic activities.

2) A *pool of resources and services* is shared to create value for them; the goal of the business goes beyond profitability (John, 2013). The activities encompassed in this model are identified by two purposes; to be linked by common means that profit from common resources and to work towards a common end that increases the common wealth (Orsi, 2013).
3) The *power is distributed* among the different actors involved since they do not work as institutions with centralized models. The power is shifting to a network of individuals or communities that are getting organized in new and different ways (Botsman, 2013). Increasingly, the economic forces are emerging from the bottom up; the emphasis is shifting from the voice of the company to the voice of the crowd (Gansky, 2014).
4) The uniqueness of the sharing hinges on *trust among the different individuals* involved, as they not necessarily know each other (Orsi, 2013; Botsman, 2013; Business Innovation Observatory EU, 2013). The different actors, clients or suppliers engaged with sharing economy activities or businesses establish meaningful relationships (Gold, 2003).
5) These models are built towards an *innovative and more efficient utilization of assets* like for example the unused resources (Orsi, 2013).
6) The sharing economies are happening between *small economic actors*, as it provides an opportunity for individuals to profit from their properties or skills (Orsi, 2013). For example in highly populated cities, ideal places for sharing platforms, the urban micro-entrepreneurs are now many (Gansky, 2014).

In the context of this research the six features characterising sharing economy (Collaborative consumption, Pool of resources & services, Distributed power, Trust, Innovative use of assets, Small economic actors) are proposed for the analysis of the AFNs, in order to check their fitting as sharing economy activities.

2.3 Alternative Food Networks (AFNs)

Alternative food networks (AFNs) is a broad concept that refers to food system innovations with different rules and structures of production, consumption and distribution if compared to main stream supply chains. The main distinctive features rely on three commonalities; the AFNs entail new ways of communication among the actors involved, incorporate social and/or environmental values in the food chain and, create and share meanings around food (Brunori et. al., 2012). AFNs have established innovative infrastructures with the support of technology to achieve a greater freedom of choice than the determined by the main supply chain. As an example, in some models, the consumers take part in the food production decisions; in others, the participants share risks. In short, the stakeholders involved for their different reasons are part of a movement that creates an alternative to the big food players and push towards a change in the food system. These models have created a completely new food network that is performing pressure from the political, business, academic and civil society perspective to reconstruct the standard food systems (Brunori et. al., 2012).

Similar to other sharing economy systems, AFNs are formed by a heterogeneous group of actors which have the sharing of a specific set of values around food as central motives (Pascucci, 2010). Yet, not all AFNs have the identified features of sharing economies. Widely studied models of AFNs such as organic food markets and farmers' markets are not based on pooling complementary resources for food production and distribution; they are rather based on one party (the producer) producing and distributing the product, and another party buying it, thus without resource sharing (Migliore et. al., 2012; Renting et. al.,2003). In this research, we focus on AFNs which more than others seem to present features of sharing economy systems and particularly we investigate the cases of community supported agriculture groups and community gardens among others (Orsi, 2013). However we first provide a broader description of different alternative food networks in the western world and particularly in Europe such as Community supported agriculture (CSA) in the UK, Associations pour le maintien d'une agriculture paysanne (AMAP), in France, and Solidarity purchase groups (SPGs) in Italy (Urgenci, 2013; Cicia et. al., 2011).

Community supported agriculture (CSA) refers to the engagement of nearby farmers and consumers that commit to each other. The model was settled to guarantee the farmers financial support. The people, who eat the food the farmer produces, consciously agree to share the risks and the benefits of each harvest by paying in advance. This was a crucial and unique point of the CSA models in their origins; however the CSA initiatives have evolved and different approaches to CSA co-exit. In the UK, many variables concerning the initiators of the initiative and their goals, the availability of resources, the member´s arrangements and participation lead to similar approaches with different conformations (Soil Association report, 2011). Nevertheless, these models are characteristic for establishing direct relationships between stakeholders (farmer and consumer) and they also follow organic principles in the vast majority of cases (Henderson & Van En, 2007; Schnell, 2007). Moreover, the CSA is a powerful approach to reconnect people and agriculture, to give transparency to the food system and to respond to sustainability concerns about food production and consumption. These characteristics are direct motives for individuals with environmental and social concerns to join the initiatives (Henderson & Van En, 2007).

Another extended approach of AFNs is known as AMAP, an association created to promote organic and family agriculture and to ensure its survival along the main stream food industry. The first AMAP initiatives appeared in 2001 and nowadays approximately 3,000 farms are established according to this model across France (Soil Association report, 2011). The main principle of the AMAP is to directly link consumers and producers who engage to decide together on fair prices for the produce and contribute to a responsible agricultural future, by ensuring the small farm scale viability (AMAP, 2014). Briefly, the consumers in these models sign a contract and compromise to support the producer for at least one complete year. They fix a price for the share in such a way that ensures both a fair economic viability for the farmer and an affordable price for the members (AMAP, 2014). The AMAP scheme introduces consumers as a part of the production system.

The latter example focuses the interest in Italy where different forms of AFNs have also arisen, in this case, the most extended model is known as solidarity purchase groups (SPGs) (Cicia et. al., 2011). The main difference regarding SPGs groups and CSA initiatives has to do with the actor that initiates the activity. SPGs are an example of AFNs started by consumers; opposite to CSA models mainly driven by producers or producer-consumer partnerships (Brunori, et. al., 2012). Solidarity Purchasing Groups or *Gruppi di Acquisto Solidale* refer to groups of consumers organized jointly to directly buy goods from nearby producers in accordance with fair environmental practices and social justice (Grasseni, 2014; Colombo, 2012). The SPGs are diffusers of the role consumer plays in choosing another food system and act as a motor group to increase consumers' awareness. The majority of the SPGs consume mainly seasonal and/or organic products. Also, the SPGs strongly promote the development of synergies and the close relationships within the actors in the network based on trust, cooperation and transparency (Colombo, 2012; Brunori, et. al., 2012). The SPGs promote values of justice and sustainability around the food chain which translated into organization criteria requires a strong focus on local sourcing logistics that ensures the promotion of the economy in the nearby area. They also operate with actions that try to achieve an efficient use of the resources, time and knowledge (Brunori, et. al., 2012). Recently, some SPGs have expanded their scope to the non-food sector by opening new trade channels with textile producers and/or sustainable services, such as renewable energies or eco-tourism (Grasseni, 2014; Colombo, 2012).

2.4. Organizational structures

Since the analyses of the most successful European AFNs indicate a variety of organizational features among them, in this section we focus on distinguishing the main organizational elements that may characterize AFNs as organizational structures of sharing economy. Following the debate of organizational diversity and plural forms we look at AFNs as hybrid modes of organizations in which two or more partners (participants) decide to pool strategic resources and decision rights while simultaneously keeping separate ownership over other key resources (Ménard, 2013). Particularly we focus on the main governance mechanisms of AFNs conceptualized as hybrid forms or networks, thus analyzing the type of contracting and coordination for resource pooling, the role of leadership, stakeholder participation, and their decision-making processes. If we look at the literature on the governance of sharing economy systems we still observe a variety of definitions and several gaps (Community Enterprise Law, 2014; P2P Foundation, 2012). Notwithstanding, to better understand how sharing economy systems work it is relevant to figure who is in charge to set the rules, norms, conditions and procedures on the use of the key strategic resources pooled and used by participants. While the organization and governance of sharing economy systems may be analyzed through different conceptual lenses, in this research we propose a more systematic categorization of governance mechanisms according to a new institutional economic and network perspectives. Particularly we look at AFNs as what have been described as hybrid form of governance (Williamson, 1991; Ménard, 2004). The hybrid governance is happening between parties who decide to pool together some resources and share decision and property rights, while keep different decision and property rights and stay independent on other key assets (Ménard, 2013). Accordingly, hybrid forms are characterised by three characteristics such as pooling, contracting and competing (Ménard, 2004; 2013). Hybrid forms tend to arise in highly competitive environments where pooling resources can be beneficial for all involved parties, as well as exploiting complementarities. The primary motivation comes from increase benefits while share risks and costs of the pooled assets. The main requirements for the functioning rely on ensuring a continuous relationship among partners as well as a proper communication channel. This is achieved with different contractual forms, monitoring and internal enforcement mechanisms ranging from strictly formal to informal (i.e. relational and trust-based) types (Ménard, 2004). Actors participating in a hybrid form face a number of hazards due to the difficulties to clearly define rules on pooled resources (i.e. how to share benefits and control opportunism), as well as how to adapt to uncertain changing environment. As highlighted by Ménard (2004) in hybrids four main governance forms seem to prevail: (1) first, hybrid forms coordinated through "trust" mechanisms, thus relying on decentralised decision-making, influenced by informal relationships and mutual influence/dependency; (ii) second, hybrids coordinated by mean of “relational networks”, thus relying on more formalised mechanisms, tighter coordination and long-term based relationships with exploitation of complementarities among parties; (iii) then hybrids coordinated through “leadership” thus relying on specific actors (or strategic centres), or (iv) through strong monitoring mechanisms and “formal government”, very similar to hierarchy forms. Since AFNs as organizations of sharing economy deal explicitly with how to share and pool strategic resources (Pascucci, 2010), understanding differences and impacts on the level of sharing due to differences in terms of governance is key. In literature it is often emphasised that sharing economy systems rely on trust based and relational networks (Adler 2001). However it may be the case that in some circumstances sharing activities are strongly influenced by selected and powerful actors, thus more looking like hierarchical and/or bureaucratically (formally) coordinated organizations.

In this perspective it is useful to integrate the new institutional economics approach with the literature on network governance. This type of governance emerged and rooted in different industry sectors as a useful mechanism to gain economic advantage when complex products or services where involved in uncertain or competitive markets (Jones et. al., 1997). The network governance relies in social relations as the form of engagement among the different actors involved in the joint generation of a product or a service to ensure coordination and secure transactions. The key feature of this type of governance is present in the contracts model which does not refer to any legal or authoritarian form. However the agreements are far from trivial and do not exclude the existence of formal contracts. The network generally builds on persistent encounters that facilitate the existence of suitable patterns for frequent exchanges (Jones et. al., 1997). The interaction of four particular exchange conditions has been detected necessary for the network governance to arise and prosper. Briefly, consumer demand uncertainty, task complexity, customized exchanges with high human specific assets and the frequency of exchange. All in all, bringing a high need for network governance models to adapt, coordinate and safeguard exchanges (Jones et. al., 1997). A solution to overcome this needs is proposed by Jones (1997) according to diverse social mechanisms such as restricted access, macroculture, collective sanctions and reputations. Lastly, the study revealed that the network size is determinant for the optimal level of social connections, ranging from more tight to loose.

The knowledge accumulated around different types of governance with the lenses of new institutional economics and network governance is used in this research to discuss and categorize the different empirical cases of the AFNs in Valencia accordingly. Thereby, contributing to describe and shape the organizational governance of the sharing economy systems found in the urban and peri-urban area of Valencia.

3. Methods

To understand the different types of organizations fitting the sharing economy principles, a case study method is a suitable approach to inductively draw conclusions on the studied phenomena (Merriam, 2002). The qualitative approach allows exploring the information-rich context of the urban and peri-urban area of Valencia in which the AFNs studied take place. One case study is not sufficient to generalize the theory (Yin, 2009) to other AFNs in other settings, yet the research can give valuable insights by comparing the different organizational structures of each AFN in the same conceptual category (Eisenhardt, 1989).

The research is divided in two broad processes aimed to (1) identify and understand the organizational elements shaping AFNs with specific forms of collaborative consumption and/or production; (2) establish a broad categorization of sharing economy activities in the agricultural and food sector according to their different organizational structures in order to open the discussion for further action.

The first process consisted in an in depth diagnosis of existing literature in order to gain sufficient theoretical knowledge to clearly map and distinguish the existing AFNs that fit as sharing economy systems in the urban and peri-urban area of Valencia. A key understanding of the principles, characteristics and values that shape these particular AFNs was required as a starting point to ensure the sufficient expertise of the researcher to tackle this innovative topic. The review relied on a background study on three theoretical pillars to develop this work; the sharing economy, organizational governance and extended AFNs in Europe. The specific theoretical lenses guide the information that should be achieved through the empirical research. This contributes to a systematic data gathering and to a deep understanding of the factors defining and affecting the different AFNs.

The information extracted from literature was used to define and set the limits of the research sample, approach known as theoretical sampling. Theoretical sampling ensures the clear definition of the population that will be object of the research, avoiding rare variables to appear and contributing to define the limits of the findings (Eisenhardt, 1989). The selected sample for this research embraces the AFNs based on collaborative production and/or consumption of food within the urban and peri-urban area of Valencia. The selection criteria yielded a population sample of 20 consumer groups and 19 community gardens meeting the requirements in the urban and peri-urban area of Valencia. Although it was intended to gather information from the totality of cases, the final research sample consisted on 6 consumer groups and 12 community gardens. The reduction of the sample was not due to a selection process but the willingness to participate, also the interviewee and the place of the meeting was subjected to the process evolution. The interviews were performed in the months of March and April of 2014 in the urban and peri-urban area of Valencia, Spain.

To ensure an accurate data collection the interviews were designed containing all the relevant constructs found in the literature review. This approach intended to create an interview pattern for the empirical cases of sufficient validity to achieve appropriate understanding on the organizational elements of the AFNs. The questionnaire was semi-structured in order to offer flexibility of response and avoid restrictions in the participants' answers. The interviews were designed in four general blocks concerning the origin of the initiatives; the availability of resources and their ownership status; the type of contracts and relationships among the actors involved; and lastly the main constraints affecting the group development. Besides, the data was collected from different sources; not only interviews, but from observation, archival data and field notes. The combination of multiple data sources gives validity to the case study research (Yin, 2009). The combination of quantitative and qualitative data, not only contributes to the validity of the research but it is also highly recommendable to facilitate the sometimes difficult translation of narrative data in the analysis (Eisenhardt, 1989). Also to ensure reliability, the consistency in the observations of a case (Gibbs, 2008), the interviews were recorded and the additional material gathered by observation is presented in photos or transcripts.

Transcripts derived from the interviews and other data collected in the empirical research were analysed using a within-case method first. This approach allows a precise definition and description of the relevant facts of each case, to facilitate a clear understanding and focus of the research (Eisenhardt, 1989). It consists on a quantitative content analysis of sample within the Valencia case study to understand first the variables affecting each case, and then look for recurrent themes to further develop types or families of cases. Therefore, it was the chosen method aiming to clearly map and define the AFNs of the urban and peri-urban area of Valencia. The data derived from the analysis was coded (assigned a word or a short phrase) according to an open coding approach that implies a process of extracting, comparing and modifying the many concepts as new data emerged. Many of the codes tried to relate key concepts from the literature study in order to contribute to the selection of the data needed to provide answers to the research questions. Furthermore, a coding structure is developed to guide the data interpretation. It consisted on collapsing the response of the AFN participants in seven general domains or elements, in this work: (1) Resource pooling, (2) Contracting / Relationships, (3) Operational mode, (4) Scope, (5) Constraints, (6) Land use, and (7) Actors involved (appendix A). As an example, the domain 1 of Resource pooling contained the codes of production assets, technology, labour, agricultural knowledge, etc.; the domain 2, Contracting, concerned variables such as legal status, formal contracts, trust, member's requirements and so on. One author was independently in charge of the coding, however revision on the transcript notes and coding was provided by a second author. The internal validity of the research is ensured with the combination of the interpretation between researchers' observation and the theoretical concepts derived from the extensive literature research to obtain the most representative constructs for a suitable and systematic data collection from the AFNs (LeCompte & Goetz, 1982).

The second process of this research aimed to categorize and analyse the researched AFNs according to their different organizational structures. The combination and comparison of theoretical knowledge with field data expected to provide sufficient skills to make an acceptable analysis and a proper interpretation of the subsequent results (Verschuren & Doorewaard, 2005). Various analyses are performed to ensure accurate results in the large amount of qualitative data encountered in this work. Descriptive analyses and statistical analyses are combined to complement each other and ensure validity.

The descriptive analyses involve a cross-case searching analysis method, an approach that can be executed with several techniques. The first procedure in this work consists in comparing the sampled cases with previously selected categories found through literature study. The aim is to provide an overview of the similarities and differences happening between cases (Eisenhardt, 1989). This technique is used twice during the data analysis of this research. First, an analysis to understand whether the selected sample of AFNs happening in Valencia can be identified as sharing economy systems according to the six main features key to the sharing models is performed. Second, in order to find different characteristics surrounding the organizational structures of the AFNs in Valencia, an organizational theory lens was selected in this research to perform a systematic analysis. Two theoretical perspectives were combined to extract variables to perform the analysis, coming from the literature on organizational governance and extended European AFNs. It is the aim of this work to use a pattern of organizational assessment extracted from own theoretical assumptions on the literature review to provide a new lens on the categorization of sharing economy systems in the agricultural and food sector. The detailed academic review provided five categories of analysis Governance mode, Leadership/Ownership initiative, Stakeholders involved, Aim and Key features. Moreover, the analysis was supported with a second technique to cross-case searching, a detailed comparison in between pairs of cases to find new categories of analysis that might be relevant (Eisenhardt, 1989). The repeated inspection of the empirical data provided four more categories of analysis Origin, Constraints, Number of members and Lifetime of the initiative. By combining both methods, a template with nine categories was selected as relevant to define the 18 researched cases according to their organizational structures in this research.

Statistical methods constitute the other pillar to analyse the results in this research. In order to understand how the organizational elements characterize the various cases analysed, a two-stage process proceeded. The first step was to conduct a Multiple Correspondence Analysis (MCA) with the goal of exposing the relationship between the different variables describing community gardens and consumer groups. This descriptive analysis allows using categorical variables and calculates factorial components for further analysis. The first component retains the maximum explained variance, the second the second largest variance and so on (Husson et al., 2010). For this analysis, all the categorical variables found when performing the variable coding in the within-case study (appendix A) together with the number of members and the years of existence as additional variables are used. Subsequently, a Hierarchical Clustering on Principal Components (HCPC) where the main components were obtained from the MCA is performed. The HPCP groups ("cluster") the different cases of study according to the different variables that better describe them from the data set. Accordingly, it allows determining the relationships between the different groups of individuals ("clusters"). The HCPC requires defining a distance and an agglomeration criterion (Husson et al., 2010). In this analysis the clusters are joined using a metric matrix distance (distance between pairs of observations) and binding criteria (distance between sets of observations). In this study the matrix distance was calculated using the Euclidean distance and the agglomeration criteria was Ward's criterion (minimizing within cluster variance). The hierarchy is represented by a tree named dendrogram which is indexed by the gain of within-inertia. Besides, to learn more about the variables that characterize the partition of clusters a χ^2-test is performed in the HPCP. The analyses are performed with the "FactoMineR" package in the statistical program “R” version 3.1.1 (Husson et al., 2013). In order to obtain reliability, the analysed data is interpreted in triangulation with other researchers in the team. The participation of multiple investigators increases the validity of the research as it will provide different points of views, insights and judgements to the analysis of the research (Eisenhardt, 1989).

4. Empirical findings

4.1. Six sharing economy features

The findings proved that the researched AFNs in the urban and peri-urban area of Valencia fit as sharing economy activities and corroborate that consumer groups and community gardens are comparable models, however not likely to cluster in the same category. Both groups presented characteristics in common with the six features identified in literature as intrinsic to the sharing economy systems, yet these characteristics differed largely between both groups. For example, the collaborative lifestyles in the consumer groups was detected as they collectively organize to perform the food ordering, distribution and purchase; in contrast in the community gardens the collective production of food was the main common stage of action to all the investigated cases. Next to it, community work, collective investments and distribution were also applicable in some community gardens ranging from more to less frequency of activity. Another output highlighted the many different approaches to perform a joint management and decision making. 50% of the consumer groups and 25% of the community gardens were functioning in assembly way; and another 25% of the community gardens rely in volunteer management boards, among other models.

The results of the analysis to categorize the AFNs in the urban and peri-urban Valencia found that there were many different organizational structures and processes to build these structures within the sharing economy systems. Hence, the findings illustrate different viable organizational paths to achieve sharing economy systems in the agri-food sector.

4.2. Typology of sharing economy systems in the agri-food sector in Valencia

The MCA allowed reducing the data set of 68 qualitative variables and 2 quantitative ones extracted from the coding of the interview transcripts into principal components. The first three components explain 56.46% of the explained variance of the system. However the first nine components were used for the hierarchical cluster analysis because they reach a higher variance percentage and it is intended to select the components that explain as much as possible. The percentage of explained variance indicates that the variables immersed in the first nine components summarize the 88% of the information on the system. Experts have stressed to not use the last axes of the MCA because they are considered as noise and would make the clustering less stable (Husson et al., 2010). Therefore, only the information of the variables that were present on each of the first 9 axis of the MCA was used. The HCPC suggests a division of the researched AFNs in Valencia in three main clusters (figure 1). Cluster 1 and 2 are integrated by community gardens while cluster 3 by consumer groups. In addition, further analysis performed with the HCPC determined that the variables that most influenced the characterization of the 3 clusters were Collective.Production, Collectively.Purchase, Distribution.decision.right, Participatory.certification, Food.transactions and Own.consumption (appendix B). Moreover, also the characteristics defining each cluster were presented. These variables provided a sufficient body of information to group the 3 clusters under the labels of “Own consumption community gardens” for Cluster 1, “Commercial community gardens” for Cluster 2 and “Consumer groups” Cluster 3 (figure 1).

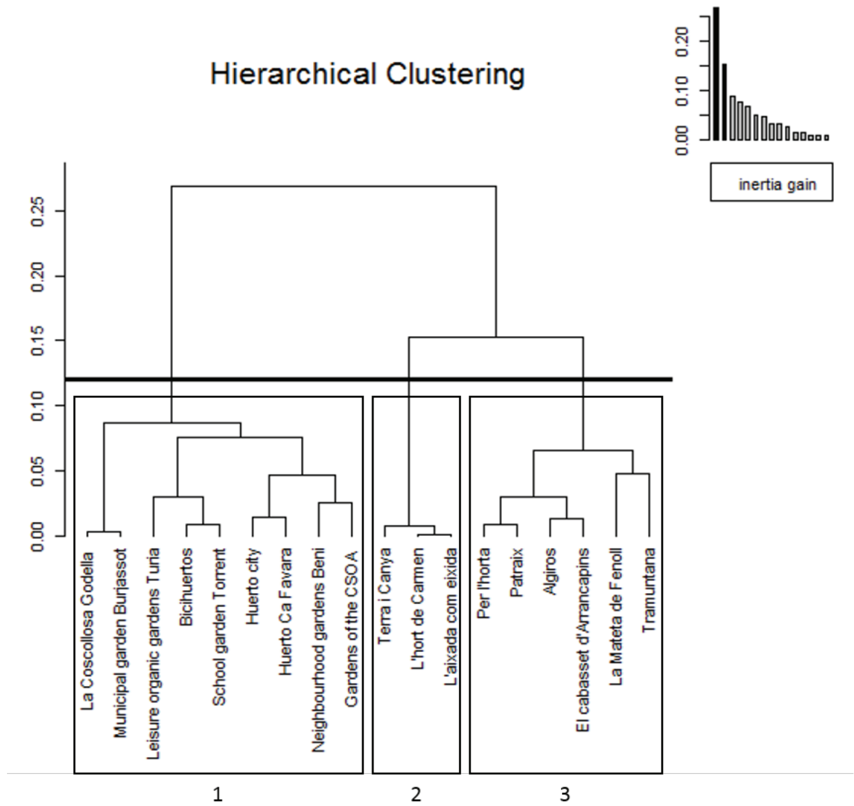


Figure 1. Hierarchical classification on the principal components describing the similarity between different community gardens and consumer groups. The boxes with numbers indicate the cluster.

The partitioning in three clusters is represented on a map produced by the first two principal components (figure 2); the individuals are grouped in coloured circles according to their cluster. Cluster 1 is circled in blue, Cluster 2 is circled in green and Cluster 3 in orange. The graph shows that the three clusters are well-separated on the first two principal components. It allows a visual differentiation of the studied community gardens and consumer groups according to the axis of the components 1 and 2 of the MCA.

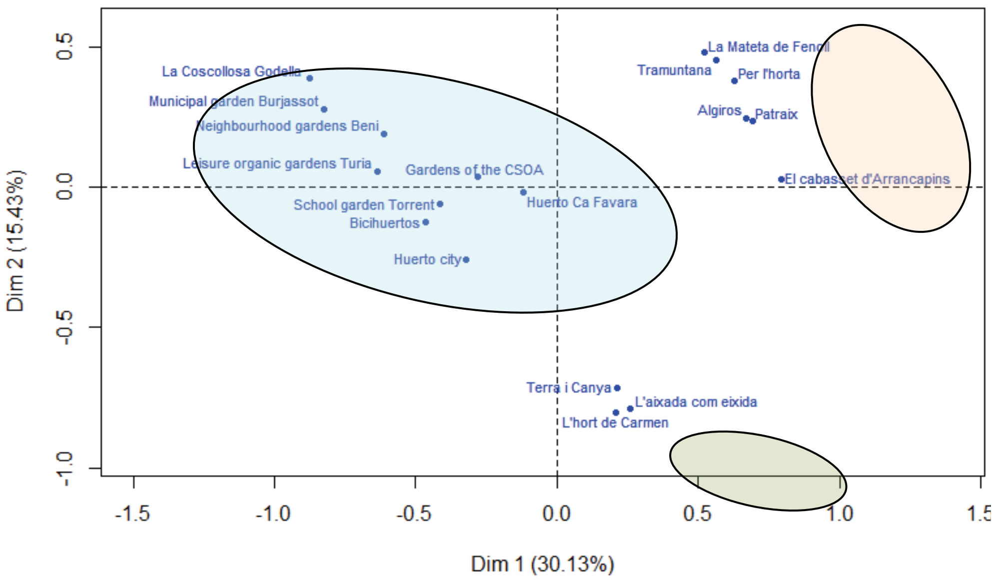


Figure 2. Representation of the clusters on the map induced by the first two principal components.

All together the statistical analyses conclude in the 3 cluster typology of the AFNs according to their most representative organizational elements. Cluster 1 presented the community gardens where the food is produced compulsorily for own consumption and accordingly the selling of food is prohibited. The profile of this community gardens was mainly defined by relationships founded in the basis of food transactions such us, no participatory certification, no irregular purchases, no fixed order/deliver, no email transactions and more (see appendix A to better understand the meaning of this variables). Cluster 2 included the cases of community gardens based on food transactions for livelihood. This cluster was firstly characterised by lacking on distribution decision right which meant that the distribution mechanism was not chosen by the gardeners involved. Also the targeted cases showed a close relationship among the actors in the group indicated by a high frequency on the variables product quality feedback (meaning that the groups presented assigned channels for that purpose) and direct visits. Moreover, the main constraint for the development of the community gardens in this cluster was pointed out by the variable lacking awareness meaning that the main stream consumer lacks on understanding of this market segment. Lastly, email transactions were recognized as the main trading channel and the financial investments as the most characteristic pooled resource. In cluster 3 were grouped the 6 researched consumer groups. They are characterised by performing collective purchase of products but not collective production of food and neither having decision right on the production portfolio. Next to it, the consumer groups do not present pooled natural resources such as land or water, among other features.

A key factor differentiating community gardens (clusters 1 and 2) from consumer groups (cluster 3) had to do with the *timing of collective participation*. This is time of production in community gardens versus the performing of collective food orders and purchase in consumer groups. Moreover the main feature shaping the distinction among cluster 1 (Own consumption community gardens) versus cluster 2 and 3 (Commercial community gardens and Consumer groups) was based on the scope of the initiatives. In the first it was compulsory the use of food for own consumption while in the latter clusters food transactions were the reason for the groups to emerge. In consequence the approaches from cluster 1 do not need to have a certification process for the produce since producer and consumer is the same actor and no food transactions happen. In contrast the models in cluster 2 and 3 presented certification process and in all cases is done in a participatory manner not needing to follow any formal procedure. The last relevant factor shaping the differences between clusters relies in the right for the actors involved to decide on the distribution mechanisms being possible for the initiatives in cluster 1 and 3 (Own consumption community gardens & Consumer groups) and not for the ones in cluster 2 (Commercial community gardens).

4.3. Resource sharing across the sharing economy systems typology

The analysis highlights the sharing character of the different resources along the food chain stages in the researched AFNs as grouped in the three proposed clusters. The food stages were categorized as Production, Distribution, Purchase (or sale) and Consumption. However, this study did not focus in the consumption stage of the different activities and consequently was left out from the analysis. Also the resources were grouped in five blocks concerning natural, human, physical, financial and social capital in order to achieve an accurate display of the data and a clear interpretation of the information. For a common understanding, table 1 presents a visualization of the analysis performance.

First of all, the findings evidenced a ranking from higher to lower resource sharing starting from the commercial community gardens, followed by the own consumption community gardens and finalising in the consumer groups. Next to it, it was possible to detect that the commercial community gardens shared resources of all kind, natural, human, physical, financial and social, while the consumer groups were only sharing resources concerning human and physical capital. Also it was detected on the analysis that the own consumption community gardens share their resources mainly at the production stage. Moreover, food was detected as the only shared resource that all the studied initiatives had in common and it just happened at the distribution stage. Similarly another parameter affecting all the 18 cases in this research was the lack of external funding at any stage for any type of initiative.

Stages --> Resources	Production	Distribution	Purchase (or sale)	Consumption
Food				
Natural capital				
- Land				
- Water				
Human capital				
- Labour				
- Information exchange				
- Agricultural knowledge				
- Associative capabilities				
Physical capital				
- Production assets				
- Distrib./Purchase space				
- Technology				
Financial capital				
- Investments				
- External funding				
Social capital				
- Training				
- Events				
- External support				

Table 1. Resource sharing stages along the food chain in consumer groups (orange) own consumption community gardens (blue) and commercial community gardens (green). The white cells determine none shared resources or irrelevant parameter and the grey cells lacking information. Note:

a parameter was considered to be shared in the whole cluster when at least half of the initiatives plus one were searing the resource.

Specifically, the pooled resources (which and where) were identify to largely differ among the AFN initiatives. Subsequently, it is found significant to provide a detailed description of the resource sharing along the food chain according to the three clusters typology. The commercial community gardens, on cluster 2, include the initiatives with the highest resource sharing rate. As mention, they are the only group pooling resources from the five blocks of resource capital. The strong focus of these initiatives to share human and social capital reflects the multiple actors' capabilities of the individuals involved in this type of AFNs. These models mainly miss the associative component and the participation on trainings or their organization, generally caused by lack of time but not for lack of interest. Next to it, natural capital (land and water) was pooled along the complete food chain as various activities such as pick up points, events or lunch meetings, were sometime happening on the field of production. Also the physical capital was pooled in these initiates implying the use of diverse technology. The last relevant finding detected that these initiatives are the only ones were money is pooled among the actors involved in order to contribute to the prosperity of the group.

Cluster 1 known as own consumption community gardens ranged second in the degree of resource pooling, yet the amount of shared resources at the production stage is equal to the previous cluster of commercial community gardens. The main differences are that in this case associative capabilities and trainings are present and in contrast, events and financial investments are left out of the pool. In practise, this kind of community gardens subdivides a piece of land into several plots and assigns them to different actors. The plots are generally cultivated independently by a group of people and always with non-commercial purpose. Accordingly, the initiatives pertaining to the own consumption community gardens presented limited shared resources in the distribution stage and none in the purchase moment. However, the different aims and setting ups between both types of community gardens, cluster 1 and 2, justifies the divergent parameters within both groups.

Lastly, cluster 3, comprises the consumer groups which have ranged lowest in resource sharing. Despite the lack of resource pooling relevant information is extracted from the analysis. First the consumer groups' initiatives do not participate in the production stage at any level, second they do not exchange information or actors capabilities and lastly they are not functioning to provide or participate in events, trainings or external support. Facts that contrast strikingly with the goals and objectives that consumer groups stated in interviews. One of the main motivations for the consumer groups to emerge is to spread a conscious and responsible consumption however they lack on dissemination focus to transmit the ideals and on time to capture participants. This creates inconsistency between the goal the consumer groups persecute and their ways of functioning.

All in all, the analysis contributes to advance knowledge to the categorization on the three cluster typology from a resource sharing point of view and consequently to achieve a better understanding of the AFNs happening in Valencia. Many different resources are pooled among the actors involved in the various initiatives. Hence, to provide a complete description of the cases that could contribute to replicate the sharing economy systems in the agricultural and food sector and to answer the main research question, a deeper analysis on the organizational structures is presented.

4.4. Organizational elements of the AFNs in Valencia

The analysis provides significant results on the different organizational structures of the researched cases in Valencia. The categorization of the 18 cases was performed following a template with nine categories of analysis, yet not all the categories were found to be generic to the three clusters classification. The final outcome was presented according to six elements such as: Governance mode, Leadership/Ownership initiative, Stakeholders involved, Aim, Constraints and Origin of the initiatives. It was possible to respectively categorize the analysed consumer groups and the commercial community gardens initiatives in one common cluster under the selected variable set. In contrast, the cases presented in the cluster of own consumption community gardens had larger differences that emerged in a three type sub-categorization of the initiatives (table 2).

The findings show that there is prevalence in network governance mode for clusters 2 and 3 (Commercial community gardens and Consumer groups). It was found in the case of the consumer groups that the initiatives were based on informal arrangements to ensure the participation of the individuals involved. They did not present any type of contracts with legal forms but rather they were based in the trust among participants, as well as the commitment of each individual to participate. To ensure the group functioning, the management and decisions were collectively performed. Although it is difficult to find consensus among a large number of individuals, two premises that facilitate this task come into play in these cases. First, all individuals present in the group have common goals which generally concern three basic pillars, a) to provide an alternative to the mainstream food system by supporting local economies; b) to gain knowledge on the food origin and production systems by getting closer to the production chain; and c) to build community. The other premise has to do with the little participation of the individuals in the group which on one side difficulties growth but also reduces the contact time to the product orders. In this way, only the most relevant issues are displayed for discussion, hence facilitating assembly decision making.

Similar to the consumer groups, the commercial community gardens are also proposed as network governance models. Accordingly, it is proved that the network governance modes are independent of the leader of the initiatives as they can be led by either consumers or producers. The initiatives belonging to the consumer groups' cluster, the creators and promoters of the initiatives are the consumers, contrary to the commercial community gardens where the leaders of the initiatives are exclusively producers. Surprisingly, this is the biggest difference between the two clusters in terms of the organizational structure although the initiatives from both clusters operate in different stages of the food chain. The consumer groups target the food purchase and distribution stages while the commercial community gardens are focussed on the food production stage. Both clusters coordinate internally with informal structures that guarantee joint decision making and management. They also present very similar goals and organizational operation modes. Besides this, one of the greatest constraints of the commercial community gardens is correlated with the impossibility of the gardeners to multitask as producers, traders and consumer awareness raisers.

Lastly, for cluster 1, the own consumption community gardens, it is suggested a three type sub-categorization of the initiatives. The proposed variable set with six different categories to better understand the diverse organizational structures did not allow one common generalization for the nine researched cases in this cluster. Three sub-groups were identified and characterized in two types of governance modes, again a network model for one of them and hybrid governance for the other two sub-groups (table 2). Hybrid governance was identified in the combination of formal mechanisms (i.e., legal contracts, garden rules and control bodies for the correct functioning of the diverse approaches) and informal mechanisms (i.e., gardeners with enough independence to manage the field, getting organized through networks on how perform common activities and decide on the “food portfolio”). The combination of these features together with an appropriate communication channel establishes a system that can ensure a continuous relationship among partners. The most prominent feature to classify these initiatives into two sub-categories has to do again with the agents involved in the initiative. Governmental institutions were the promoters in one of the groups while the initiatives pertaining to the other sub-category were created by small entrepreneurs. Similarly, both sub-categories presented various differences in the goals pursued and the difficulties faced. The government-led initiatives aimed for a social and environmental improvement of the neighbourhoods where the gardens were created. While the entrepreneurial-led initiatives implied primary a monetary component by renting plots and usually together with an educational focus. The first cases experiencing mainly managerial difficulties to coordinate the many participants in the gardens while the latters biggest constraint faced a lack of participants and/or users’ involvement.

Furthermore, the third sub-category that emerged from the own consumption community gardens cluster presents again a network governance mode type. Similar to the initiatives form cluster 2 and 3 these models do not present legal contracts and are based on trust among members to participate in the different activities. Moreover, some of the initiatives pertaining to this sub-category have jointly created by the participants involved rules and statutes to ensure the gardens and group functioning. In this case, the leadership of the initiatives is merged between consumers and producer-led as the actors involved perform both roles. Similar to the governmental-led initiatives, the approaches from this sub-category are founded on a strong social and environmental base that aims to build social cohesion, recover degraded urban land and provide a space to learn and interact as primary goals. The participants from these groups ensured that the human organization was the main difficulty to get gardens to evolve or run more smoothly. However, in various cases, the gardens’ evolution was constrained by the big struggle required to obtain the rights to use the land.

The information from the cross-case analysis contributes to gain knowledge on the organizational structure that was adopted in the researched AFNs in the urban and peri-urban area of Valencia according to the three cluster categorization.

AFN	Governance mode [(a)(b)]	Leadership of the initiative	Stakeholders involved [(c)]	Aim	Main constraints	Origin
Consumer groups (Cluster 3) n = 6	Network (No contracts. Participatory groups. Joint management & decision making. Trust and compromise based.)	Consumer-led initiatives	Community of consumers, local farmers and/or local/close by producers.	1. Create an alternative to the main stream food system. 2. Potentiate small and local producers. 3. Build community. 4. Food sovereignty. 5. Reconnect people and land.	Lack of members and participation. Lack of products. Orders' irregularities.	15 M movement (50%) and Conscious consumers (50%)
Own consumption Community gardens (Cluster 1) n = 9	Hybrid (Legal contracts & garden rules. The city hall is a control institution. The gardens are self-managed by participants. Volunteer board, management & communication.)	Government-led (City hall)	Citizens/producers/consumers and council technicians.	1. Give the opportunity to citizens to work the land. 2. Recover degraded urban land. 3. Connect the people from the neighbourhood.	Resource scarcity. Management difficulties to coordinate many participants.	Environmental office from the city council.
	Hybrid (Legal contracts and garden rules. The owner controls the gardens. Agricultural technician supervises & coordinates. Users independently work the field & share the food.)	Entrepreneurial-led initiatives	Land owner & gardeners (66%); Entrepreneurs & pedagogy association (33%)	1. Provide small plots to enjoy own consumption gardening. 2. Make profit. 3. Provide training to future gardeners.	Lack of users' involvement. Lack of participants (66%). Fail on management & coordination (33%).	Small entrepreneurial project.
	Network No contracts. Participatory group. Collective tasks. (75%) Rules & statutes jointly developed by the gardeners & not legal. Volunteer management board to coordinate diverse tasks.(25%)	Consumer/producer-led initiatives (citizens)	Community of producers/ consumers. Neighbourhood association (25%)	1. Recover degraded land. 2. Create social cohesion & work in community. 3. Encourage urban gardens 4. Provide a space to learn and interact.	Participation & human organization. Obtain the right to use the land (25%). Infrastructure (25%).	A group of neighbours with different interests.
Commercial Community gardens (Cluster 2) n = 3	Network (No contracts. Joint management & decision making. Based on strong commitment and trust)	Producer-led initiatives	Farmers and consumers.	1. Promote short supply channels 2. Food sovereignty. 3. Enhance biodiversity. 4. Recover local varieties. 5. Create an alternative economic pillar. 6. Earn the living.	Give commercial exit to the products (no time to be farmer & trader). Lack of consumer understanding. Participation (66%).	Interested individuals looking for land to cultivate and produce.

Table 2. Characteristics shaping the organizational structure of the sharing economy systems in the agricultural and food sector in Valencia. *Source:* Own elaboration after (a) Williamson 1991 (b) Ménard 2004 (c) Pascucci 2010.

5. Contribution to theory

The information extracted contributes with a step forward to understand the current situation of the sharing economy systems in the agri-food sector and their main bottlenecks. The combination of findings from the various analyses performed in this work allowed establishing a complete set of features defining each proposed category for the AFNs in the urban and peri-urban area of Valencia. The description and categorization of the organizational structures helps understand what is happening inside the sharing models pertaining to similar AFNs. In sum, the heterogeneous goals, structures and functions found in the various approaches present a large difficulty to create or establish common regulations to support these models.

The research contributes to the existing literature from various perspectives. To begin with, it provides a solid body of information to understand the internal organization among members in the distinct AFNs (Murtagh, 2010; Ohberg & CoDyre, 2013). This contributes to fill a gap in knowledge as the largest amount of information found when researching the AFNs in Europe and beyond is presented on a rural sociology and/or development perspective (Veen et. al., 2012; Tregear, 2011; Holloway et al., 2007). Consequently, the findings of this research are a significant complement to the vast literature from rural sociology exploring these phenomena. Furthermore, this research constitutes the first attempt in the literature to distinguishing sharing economy models for sustainable development in the agri-food sector. Moreover, it is the first time that this is performed with systematic analysis involving quantitative methods. Involving first a Multiple Correspondence Analysis (MCA) that transforms the qualitative variables defining the cases in Valencia, into non-correlated variables; and afterwards, a Hierarchical Clustering Principal Components (HCPC), in which the principal components of the MCA are used as input variables, to group the individual initiatives into AFN types. The typology that emerged from the analysis provides useful insights to guide future research on the sharing models in the agri-food sector. Despite the large differences of the sharing systems the consumer groups in Valencia provided comparable results to the Solidarity purchase group (SPG) initiatives in Italy and the *Teikei* in Japan (Grasseni, 2014; Brunori, et. al., 2012; Cembalo, et. al. 2012). Similarly the findings on commercial community gardens in this research are found sufficient for an examination with the CSA and AMAP initiatives. Accordingly, the case study in Valencia contributes to aggregate knowledge on the field and provides an innovative perspective to overcome organizational constraints limiting the growth of these models.

The information on the AFNs models in Valencia expands evidence on the fact that many different approaches to the establishment of the same type of AFNs exist (Tregear, 2011; Renting et. al., 2003; Hatano, 2008). For example, many types of community supported agriculture (CSA) are adopted with different resource sharing schemes, production models and members' participation level (Henderson & Van En, 2007; Schnell, 2007; Community Supported Agriculture for Europe project, 2013). More specifically, an already recognized division to differentiate diverse approaches to the CSA initiatives in the UK depends on the ownership and/or leadership of the initiative (Soil Association report, 2011). Similarly, the information extracted from the AFNs in Valencia provided a set of five different types of leadership and/or ownership; producer-led initiatives, consumer-led initiatives, consumer/producer-led, government-led and entrepreneurial-led initiatives; in 18 reviewed cases. This shows the relevance of the ownership and/or leadership of the initiative as an influential parameter to the AFNs structure. Furthermore, the AFNs in this research were classified according to the governance modes of hierarchy, market, hybrid and network derived from organizational theories on new institutional economics and transaction cost economics (Williamson, 1991; Ménard, 2004; Jones et. al., 1997). It resulted also in two different governance modes which vary among the sampled cases.

The high heterogeneity of sharing economy systems in AFNs provides serious challenges to develop 1) common legislation for the sharing models in the agri-food sector and 2) networks among similar models to share and leverage knowledge and achieve scale across individual initiatives. One of the reasons for this diversity concerns the multiple aims and goals amongst the various approaches, ranging from a sustainable and environment-friendly food system focus; from the building of community as a core principle or to just accepting profit as an aim. The heterogeneity on the approaches aim was found to affect both the organizational structure of the initiatives and the network building among AFNs. In the case of Valencia, the number of initiatives that had created partnerships with similar groups in order to benefit each other and work together towards a common end was very low. Moreover, a first network that was functioning at a regional level with a coordinating role started to operate yet in a very initial phase and without a defined structure. The lack of a solid network with a recognized function towards the AFNs functioning might be slowing down the evolution of the sharing economy initiatives in the agri-food sector.

6. Implications for policy and practice

The typology of the AFN initiatives in Valencia fitting with the sharing economy features aims to contribute to the managerial and policy implications that affect the development of these types of AFNs. First of all, as the case of Valencia illustrates, AFNs such as consumer groups and community gardens are getting established as a solid phenomenon happening in urban and peri-urban areas of medium/large cities in southern Europe. However, the lack of integration of these activities in the policy was detected to have, in some cases, negative effects. As an example, community gardens that squatted degraded urban land to build the initiatives derived, in various causes, in long struggles and fights between the land owners and the users. Accordingly, it might be a strategic point for policy makers seeking to regulate and/or support the growth of sharing economy models to develop solid laws towards the right to use the land in these particular cases. It might be a possibility to create a regulation that recognizes our right as citizens to access unused and degraded land with the purpose of growing food. Nonetheless, minimal regulation might be ideal as the approaches are too different from each other, and might not be possible to find a one size-fit-all regulation. Next to it, it is important to notice that the trust or willingness to cooperate of the actors in the AFNs with the governmental institutions is generally low. There several reasons for this like an interest of the AFN models to operate outside the scope of the established system or feelings of abandonment or disregard as the AFNs been long time neglected and still are. Consequently, an approximation to the initiatives environment to understand their specific needs and constraints is paramount to provide institutional support that can propel their development and not hinder it.

Secondly, the outcomes of the research together with evidence from literature discover some factors that can be translated into recommendations for the actors involved in the initiatives, the current leaders in sharing economy models. It is found primordial to strengthen the groups learning among each other. On the one side, concerning improvements in terms of the organization, it is needed to further integrate technology in the AFN models in order to facilitate interactions and reduce labor. For example, concerning the consumer groups, it is highly recommended to perform the food transactions through available free software instead of using email groups for that purpose. The groups incorporating a software transaction method showed less managerial difficulties and more efficient performance, yet just a third of the sampled cases incorporated and/or new this system. Besides, it is recommended to work on stronger connections between farmer and consumer. The findings showed that the commercial productive gardens' main constraints are the lack of understanding from the consumers and the little time left for the producers to multitask as farmers, distributors and/or sellers. Accordingly, a major involvement from consumers to labour or financial support and/or stronger loyalty could facilitate the establishment of these types of AFNs. Next to it, the consumers of the commercial community gardens, which are many times consumer groups, should consider sharing risks with the producers at some levels in order to ensure the viability of the AFNs. On the other side, it is necessary to raise consciousness on the key paper of an alternative food networks to support a local economy, sustainable practices and community building. The current leaders in sharing economy models should encourage the diverse AFNs to adopt a stronger role in the diffusivity purpose. Introduce the potential of the AFNs to guarantee the survival of the medium/small farmers; the reduction of food travelling miles; the support of sustainable food production practices and to strengthen engagement among the actors involved.

References

Adler, P. S. (2001). Market, hierarchy, and trust: The knowledge economy and the future of capitalism. *Organization science*, 12(2), 215-234.

AMAP (2014). National Directory of AMAP. http://www.reseau-amap.org/amap.php [Cited June 2014]

Bardhi, F., & Eckhardt, G. M. (2012). Access-based consumption: The case of car sharing. *Journal of Consumer Research*, *39*(4), 881-898.

Baum, R. (2009). The Story Of Stuff. http://cen.gext.acs.org/articles/87/i20/Story-Stuff.html

Belk, R. (2007). Why not share rather than own? *The Annals of the American Academy of Political and Social Science*, *611*(1), 126-140.

Belk, R. (2010). Sharing. Journal of Consumer Research, 36(5), 715-734. Belk, R. (2007). Why not share rather than own?. The Annals of the American Academy of Political and Social Science, 611(1), 126-140.

Belk, R. (2013). You are what you can access: Sharing and collaborative consumption online. Journal of Business Research.

Botsman, R. (2013, Nov). Fast Company. "The Sharing Economy Lacks A Shared Definition". http://www.fastcoexist.com/3022028/the-sharing-economy-lacks-a-shared-definition#4 [cited January 2014].

Botsman, R., & Rogers, R. (2011). *What's mine is yours: how collaborative consumption is changing the way we live*. Collins.

Brunori, G., Rossi, A., & Guidi, F. (2012). On the new social relations around and beyond food. Analysing consumers' role and action in Gruppi di Acquisto Solidale (Solidarity Purchasing Groups). Sociologia Ruralis, 52(1), 1-30.

Business Innovation Observatory, European Union (2013). “The Sharing Economy: Accessibility Based Business Models for Peer-to-Peer Markets”. http://ec.europa.eu/enterprise/policies/innovation/policy/business-innovation-observatory/files/case-studies/12-she-accessibility-based-business-models-for-peer-to-peer-markets_en.pdf [cited January 2014].

Cembalo, L., Migliore, G., & Schifani, G. (2012). Consumers in postmodern society and alternative food networks: the organic food fairs case in Sicily. New medit: Mediterranean journal of economics, agriculture and environment= Revue méditerranéenne d'economie, agriculture et environment, 11(3), 41-49.

Cicia, G., Colantuoni, F., Teresa, D. G., & Pascucci, S. (2011). Community Supported Agriculture in the Urban Fringe: Empirical Evidence for Project Feasibility in the Metropolitan Area of Naples (Italy). International Journal on Food System Dynamics, 2(3), 326-339. Colombo, L. A., (2012, Sep). AICCON Ricerca. The GAS as laboratories of civil economy. http://www.aiccon.it/ricerca_scheda.cfm?wid=297&archivio=C

Colding, J. (2007). ‘Ecological land-use complementation’for building resilience in urban ecosystems. *Landscape and Urban Planning*, *81*(1), 46-55.
Colding, J., & Barthel, S. (2013). The potential of ‘Urban Green Commons’ in the resilience building of cities. *Ecological Economics*, *86*, 156-166.
Collaborative Economy Coalition (2014). http://www.collaborativeeconomycoalition.org/what-is-the-collaborative-economy/ [cited May 2014].

Colombo, L. A., (2012, Sep). AICCON Ricerca. The GAS as laboratories of civil economy. http://www.aiccon.it/ricerca_scheda.cfm?wid=297&archivio=C

Community Enterprise Law (2014). http://communityenterpriselaw.org/forming-community-enterprise/participatory-governance-models-for-the-sharing-economy/ [cited May 2014]

Contreras, J. & Snir, T. (2011, Dec). MIT Sloan Experts. “MIT Sloan grad on the “sharing economy,” the next big trend in social commerce” http://mitsloanexperts.mit.edu/mit-sloan-grad-on-the-sharing-economy-the-next-big-trend-in-social-commerce/#sthash.NFvDJqhm.dpuf [cited May 2014]

Cox, R., Holloway, L., Venn, L., Dowler, L., Hein, J. R., Kneafsey, M., & Tuomainen, H. (2008). Common ground? Motivations for participation in a community-supported agriculture scheme. Local Environment, 13(3), 203-218.

Demographia World Urban Areas. (2014, May). Demographia World Urban Areas: 10th Edition (201405 Revision). [cited July 2014]

Dubuisson-Quellier, S., Lamine, C., & Le Velly, R. (2011). Citizenship and consumption: Mobilisation in alternative food systems in France. Sociologia ruralis, 51(3), 304-323.

Eisenhardt, K. M. (1989). Building theories from case study research. Academy of management review, 14(4), 532-550.

European Sharing economy Coalition (2013) Press release, http://www.euro-freelancers.eu/european-sharing-economy-coalition/ [cited January 2014].

FAO (2007). Food and Agriculture Organization of the United Nations. The urban producer's resource book - A practical guide for working with Low Income Urban and Peri-Urban Producers Organizations.

Galt, R. E. (2011) Counting and Mapping Community Supported Agriculture (CSA) in the United States and California: Contributions from Critical Cartography/GIS. Gibbs, G. R. (2008). Analysing qualitative data. Sage.

Gansky, L. (2011, Jan). TED speech. “Why the future of the business is the mesh” https://www.ted.com/talks/lisa_gansky_the_future_of_business_is_the_mesh [cited May 2014]

Gansky, L. (2014, May). Co.Exist. “5 Signs That The Collaborative Economy Is Going Through Puberty” http://www.fastcoexist.com/3030564/5-signs-that-the-collaborative-economy-is-going-through-puberty [cited May 2014]

Gaskins, K. & Stehfest, N. (2010) Latitude Research & Shareable Magazine. “The New Sharing Economy Report” http://latdsurvey.net/pdf/Sharing.pdf [cited May 2014]

Gibbs, G. R. (2008). *Analysing qualitative data*. Sage.

Goddard, W., & Melville, S. (2004). Research methodology: An introduction. Juta and Company Ltd.

Gold, L. (2003). Small enterprises at the service of the poor: The economy of sharing network. *International Journal of Entrepreneurial Behaviour & Research*, *9*(5), 166-184.

Gold, L. (2003). Small enterprises at the service of the poor: The economy of sharing network. International Journal of Entrepreneurial Behaviour & Research, 9(5), 166-184.

Goodman, D. 2003. The quality “turn” and alternative food practices: Reflections and agenda. *Journal of Rural Studies*19:1–7.

Goodman, D., & Goodman, M. (2007). Localism, livelihoods and the ‘post-organic’: Changing perspectives on alternative food networks in the United States. *Constructing alternative food geographies: Representation and practice*, 23-38.

Grasseni, C. (2014). Seeds of trust. Italy's Gruppi di Acquisto Solidale(Solidarity Purchase Groups). *Journal of Political Ecology*, *21*, 178-192.

Hatano, T. (2008). The Organic Agriculture Movement (Teikei) and Factors Leading to its Decline in Japan. Journal of Rural and Food Economics, 54(2), 21-34.

Henderson, E., & Van En, R. (2007). Sharing the harvest: A citizen’s guide to community supported agriculture, revised and expanded. White River Junction, VT: Chelsea Green Publishing.

Holloway, L., Kneafsey, M., Venn, L., Cox, R., Dowler, E., & Tuomainen, H. (2007). Possible food economies: a methodological framework for exploring food production–consumption relationships. Sociologia Ruralis, 47(1), 1-19.

Husson, F., Josse, J., & Pages, J. (2010). Principal component methods-hierarchical clustering-partitional clustering: why would we need to choose for visualizing data. Applied Mathematics Department.

Husson, F., Josse, J., Le, S., & Mazet, J. (2013). FactoMineR: multivariate exploratory data analysis and data mining with R. R package version, 1, 102-123.

John, N. A. (2013). The social logics of sharing. The Communication Review,16(3), 113-131. Jones, C., Hesterly, W. S., & Borgatti, S. P. (1997). A general theory of network governance: Exchange conditions and social mechanisms. Academy of management review, 22(4), 911-945.

Jones, C., Hesterly, W. S., & Borgatti, S. P. (1997). A general theory of network governance: Exchange conditions and social mechanisms. *Academy of management review*, *22*(4), 911-945.

Jurich, L. (2013, Jan). “Why This CEO Doesn't Own A Car: The Rise Of Dis-Ownership” http://www.fastcoexist.com/1681112/why-this-ceo-doesnt-own-a-car-the-rise-of-dis-ownership Jan 2013[cited May 2014]

Lamberton, C.P. and Rose, R.L. (2012). When is ours better than mine? A framework

for understanding and altering participation in commercial sharing systems. *Journal of Marketing* 76(4), 109-125.

LeCompte, M. D., & Goetz, J. P. (1982). Problems of reliability and validity in ethnographic research. Review of educational research, 52(1), 31-60.

Loewenberg, S. (2008). Global food crisis looks set to continue. *The Lancet*,*372*(9645), 1209-1210.

Ménard, C. (2004). The economics of hybrid organizations. Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft, 345-376.

Ménard, C. (2013). Plural Forms of Organization: Where do we stand?.*Managerial and Decision Economics*, *34*(3-5), 124-139.

Mesh (2014). “The Sharing Directory” http://meshing.it/ [cited May 2014]

Migliore, G., Cembalo, L., Caracciolo, F., & Schifani, G. (2012). Organic consumption and consumer participation in food community networks. New Medit, 4, 46-48. Murtagh, A. (2010). A quiet revolution? Beneath the surface of Ireland's alternative food initiatives. Irish Geography, 43(2), 149-159.

Murtagh, A. (2010). A quiet revolution? Beneath the surface of Ireland's alternative food initiatives. *Irish Geography*, *43*(2), 149-159.

Ohberg, L., & CoDyre, M. (2013). Toward alternative food systems development: Exploring limitations and research opportunities.

Orsi, J. (2013, Sep). The sharing economy just got real. http://www.shareable.net/blog/the-sharing-economy-just-got-real [cited Jan 2014]

P2P Foundation (2012). "Synthetic Overview of the Collaborative Economy". Available Online: http://p2p.coop/files/reports/collaborative-economy-2012.pdf. [cited May 2014].

P2P foundation (2014, Feb). http://p2pfoundation.net/Key_Concepts_and_Practices_from_the_P2P_Open_Agriculture_Revolution [cited Jun 2014]

Pascucci, S. (2010). Governance structure, perception and innovation in credence food transactions: the role of community networks. Proceedings in Food System Dynamics, 647-660.

PAT (214). Plan de Acción Territorial de Protección de la Huerta de Valencia. Conselleria de Medio Ambiente, agua, urbanismo y vivienda. Generalitat valenciana. http://www.cma.gva.es [cited August 2014]

Renting, H., Marsden, T. K., & Banks, J. (2003). Understanding alternative food networks: exploring the role of short food supply chains in rural development. Environment and planning A, 35(3), 393-412.

Sacks, D. (2011, April). Fast Company magazine. "The Sharing Economy" http://www.fastcompany.com/1747551/sharing-economy [cited May 2014]

Schnell, S. M. (2007). FOOD WITH A FARMER'S FACE: COMMUNITY-SUPPORTED AGRICULTURE IN THE UNITED STATES. *Geographical Review*,*97*(4), 550-564.

Smith, S. (2014, Feb). Lift Conference. "Is This Really The Sharing Economy?". http://videos.liftconference.com/video/9491052/scott-smith-is-this-really-the-sharing

Soil Association report (2011). The impact of community supported agriculture soil association. http://www.soilassociation.org/LinkClick.aspx?fileticket=I3kfHnNhvxg%3D&tabid=373

Standage, T. (2013, Mar). The Economist. "The rise of the sharing economy". http://www.economist.com/news/leaders/21573104-internet-everything-hire-rise-sharing-economy [cited May 2014]

Sunrun (2013, March). Sunrun. "New Survey Reveals 'Disownership' is the New Normal." http://www.sunrun.com/why-sunrun/about/news/press-releases/new-survey-reveals-disownership-is-the-new-normal/ [cited May 2014]

Tregear, A. (2011). Progressing knowledge in alternative and local food networks: Critical reflections and a research agenda. Journal of Rural Studies, 27(4), 419-430.

Urgenci. (2013). The International Network of Community Supported Agriculture. http://urgenci.net/en-gb [cited Jan 2014]

Uwe, F. (1998). An introduction to qualitative research. Veen, E. J., Derkzen, P., Wiskerke, J. S., & Renting, H. (2012). Motivations, reflexivity and food provisioning in alternative food networks: case studies in two medium-sized towns in the Netherlands. International Journal of Sociology of Agriculture and Food, 19(3), 365-382.

Veen, E. J., Derkzen, P., Wiskerke, J. S., & Renting, H. (2012). Motivations, reflexivity and food provisioning in alternative food networks: case studies in two medium-sized towns in the Netherlands. *International Journal of Sociology of Agriculture and Food*, *19*(3), 365-382.

Verschuren, P. & Doorewaard, H. (2005). Designing a research project.

Williamson, O. E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. Administrative science quarterly, 269-296. Yin, R. K. (2009). Case study research: Design and methods (Vol. 5). sage.

Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

Evaluation of improvement strategies in ecodesign with the use of Cost Benefit Analysis

Ilke BEREKETLI ZAFEIRAKOPOULOS[a], Konstantinos ARAVOSSIS[B]

[a] ibereketli@gsu.edu.tr, Galatasaray University, Industrial Engineering Department, Istanbul, Turkey

[b] arvis@mail.ntua.gr, National Technical University of Athens, School of Mechanical Engineering, Sector of Industrial Management and Operational Research, Athens, Greece

Abstract:

One of the biggest problems of our time is the drastic change in the environment, mostly due to the consequences of mistakes done in production systems. In order to overcome those problems, we need to transform the traditional ways of production into sustainable ones. Ecodesign is an approach aiming to fulfill this task. Engineers, using ecodesign methods and tools, develop several improvement strategies to make a product environmental friendly. However it is a hard task for decision makers to choose the optimum strategy among others. Therefore it is important to use an appropriate integrated technique to assess both the economic and the environmental performance of each improvement strategy. In order to evaluate the economic performance, Cost Benefit Analysis will be applied in this paper by focusing on its feasibility step. Environmental performance will be evaluated through Life Cycle Assessment. The proposed method will be applied for an Electrical and Electronic Equipment (EEE). At the end of the analysis, the ecodesign improvement strategy to be implemented will be selected.

Keywords: Ecodesign, Cost Benefit Analysis, Life Cycle Assessment, Strategy Alternatives, Decision Making.

1. Introduction

Excessive production and consumerism caused several hardly reversible environmental problems starting at the last century, such as resource depletion, climate change, pollution, etc. To eliminate those problems, changing the consuming habits or providing solutions in waste management are not enough. Sustainable, healthy and environmental production systems should be developed to go down to the core of the problems. Ecodesign is a method developed, aiming to transform classical production systems into sustainable ones and to delete or to reduce environmental problems occurred during the whole life cycle of the products, without compromising the quality, cost, functionality, aesthetics, etc. of the product (Karlsson and Luttropp, 2006; Gurauskiene and Varzinskas, 2006; Pigosso et al., 2010).

Ecodesign is based on the notion of sustainability, and sustainability can only be achieved if the proposed solutions and environmental or social improvements are economically viable.

The main problem that this paper deals with is how to evaluate ecodesign improvement strategies.

There are several potential improvement strategies mentioned in the literature to implement ecodesign (Brezet et al., 1997; Wimmer et al., 2004; Luttropp and Lagerstedt, 2006). However none of them proposes a structured model to show the decision makers which strategy to implement by considering different factors required for a successful product development. They usually tend to neglect the cost for the implementation and the possible effects, which may lower the product quality. Therefore it is crucial to add the economic parameters in the evaluation of the most suitable ecodesign improvement strategies for the studied product. The novelty of this paper stands on this approach.

In previous studies (Bereketli and Erol Genevois, 2013), the ecodesign improvement strategies have been developed through a multi-aspect QFD for Environment (QFDE) technique and their weights have been obtained. To complete these quality based works, it is necessary to add the economic criteria and to decide on which strategy to implement in order to obtain both environmental and economic product. To do that, a proper economic analysis tool is required.

Cost Benefit Analysis (CBA) is a widely used method, in which the investments are mainly assessed through the calculation of their evaluation indicators, namely benefit/cost (B/C) ratios, as well as the quantification of their financial, technical, environmental and social risks (Karmperis et al., 2012b). CBA uses the B/C ratio in order to demonstrate that the project's benefits are greater than the relative costs. CBA is a suitable tool to deal with the problem taken into consideration in this study and chosen for the economic assessment of the improvement strategies.

To conduct the environmental assessment part of the problem, the Life Cycle Assessment (LCA) approach is chosen. LCA is an objective process to evaluate environmental burdens associated with a product, process, or activity, by identifying and quantifying energy and materials used and waste released to the environment (Fava et al., 1991). LCA provides valuable information for designers to improve environmental performance. Therefore its use is suitable to fulfill the aim of this study.

CBA and LCA are applied for an Electrical and Electronic Equipment (EEE). EEE attracts a significant interest because of its negative impacts on the environment and human health, and it is crucial to manage ecodesign of EEE mainly for two reasons: On one hand they include hazardous substances, which harm the environment, especially when they become waste (Widmer et al., 2005; Aizawa et al., 2008). On the other hand they include valuable metals, which cause resource depletion (Widmer et al., 2005; Chancerel et al., 2009).

2. Literature Review

CBA is regarded originally as the main investment evaluation technique, through the quantitative summation of the investment's anticipated impacts on consumption benefits and resource costs (Almansa and Martínez-Paz, 2011). In the relevant literature there exist CBA applications, as well as several multi-criteria decision making methods (Damart and Roy, 2009; Jung, 2012), for the evaluation of an environmental project's alternatives, especially in the field of waste management (Karmperis et al., 2012a; Karmperis 2012b; Karmperis et al., 2013). In general, those projects are examined in a case-by-case basis, as the environmental benefits and costs are correlated with the project scope. There are also some studies, which combined CBA and LCA (Wightman et al., 1999; Weidama, 2006; Georgakellos 2012; Reza et al., 2013; Møller et al., 2014). Mizsey et al., (2009), Buytaert et al. (2011) and Hoogmartens et al. (2014) analysed the relation between CBA and LCA and compared these two methods. Almost all of those studies use the relevant approaches to evaluate projects rather than products. Among all these efforts, there is a lack in evaluating a product's ecodesign improvement strategies through economic and environmental criteria together.

3. Theoretical model

3.1. Cost Benefit Analysis

The benefit–cost ratio (BCR) are formulated as equation

$$BCR = B/C \tag{1}$$

or

$$BCR = B - C \tag{2}$$

where *B* represents the equivalent value of the benefits associated with the project and *C* represents the project's net cost. A *B*/*C* ratio greater than or equal to 1.0, or a B-C greater than or equal to 0 indicates that the project evaluated is economically advantageous. Nevertheless, the commonly used method for the investment evaluation is the discounted cash flow analysis (DCFA), where the cash flows arising in different years are adjusted in net present value (NPV) with the use of the discount rate (Karmperis et al., 2012b). In order to obtain a net present value (NPV), discount rate (x) applies to cash flows (CF) across T years as indicated by eq.3:

(3)

The equation indicates how the NPV can be calculated in order to deal with long time horizons. If the NPV is positive, the project achieves the imposed profitability requirements (Hoogmartens et al., 2014).

According to European Commission's (EC) guide to CBA of investment projects (EC, 2008), Cost Benefit Analysis is structured in six basic steps: 1) context analysis and project objectives, 2) project identification, 3) feasibility and option analysis, 4) financial analysis, 5) economic analysis, 6) risk assessment. The specific guide to CBA (EC, 2008) suggests carrying out a simplified financial and economic analysis for each project's alternative, in order to compare them and then to select one.

Generally, a project's alternatives are evaluated in the third step according to economic criteria. Therefore this paper will focus on the third step of the Cost Benefit Analysis, where the feasibility of the ecodesign improvement strategies is evaluated according to economic criteria.

3.2. Life Cycle Assessment

Life cycle assessment is a methodological framework used to quantify a wide range of environmental impacts that occur over the entire life cycle of a product or process (Guinee et al., 2002). It is often referred to as a "cradle to grave" analysis (Rebitzer et al., 2004), and the assessment generally includes a quantification of the resource use and emissions associated with all of the major phases of the production chain, including the extraction and processing of raw materials, manufacturing processes, transportation at all stages, use of the product by the consumer, and recycling or disposal of the product after use (Consoli, 1993).

The purpose of an LCA can be (1) comparison of alternative products, processes or services; (2) comparison of alternative life cycles for a certain product or service; (3) identification of parts of the life cycle where the greatest improvements can be made (Roy et al., 2009).

In this study LCA will be used with the purpose of comparing life cycle performances of the same product's different ecodesign improvement strategies alternatives.

4. Case study – Hand Blender

For the application of the suggested methodology, a product from EEE family, a hand blender is used.

A hand blender is a kitchen appliance to blend ingredients or puree food in the container in which they are being prepared. The exemplary product is disassembled. All parts are weighted and energy consumption levels are measured. General information about the product is given on Table 1 (Bereketli, 2013).

Table 1 Product and life cycle data for the hand blender

Environmental Parameters – general information	
Weight	0,85 kg (including packaging)
Volume	354x120x102 mm (=4,33dm³)
Lifetime	4 years
Functionality	Mixing food to soups
Functional Unit	Blending one liter of soup for 1 min.
Power	170 W (max. 180 W)
Environmental Parameters – life cycle information	
Materials used	Blender: 190 g Copper, 120 g PP, 30 g PVC, 220 g stainless steel; 10 g printed circuit board (PCB) Mixing beaker: 70 g PS; Wall mounting: 30 g PP, 2 g stainless steel; Packaging: 10 g LDPE, 170 g cardboard All together: 190 g Copper, 222 g stainless steel, 10 g printed circuit board, 150 g PP, 30 g PVC, 70 g PS, 10 g LDPE, 170 g cardboard
Problematic materials	PVC in cables hanging loop, PCB, PS
Manufacture	
Production technology	Injection molding (housing 120 g PP, wall mounting 30 g PP, mixing beaker 70 g PS) Extrusion (packaging 10 g LDPE, cable 30 g PVC) Stranded Cable (20 g Copper) Coiling Engine (170 g Copper) Cutting (220 g steel) Cutting and gluing (170 g cardboard)
Product use	
Energy consumption	Blending vegetables and fruits to make soups or shakes. 400 uses in lifetime (2 uses a week for 1 min) equals 1,15 kWh
Emissions	None
End of life	
Reusability	Reuse of parts is not possible (0%)
Recyclability	The materials are not recycled (0%)
Incineration (toxic waste)	100% of total weight
Landfill	No landfilling (0%)

Possible ecodesign improvement strategies suggested for the hand blender (Bereketli and Erol Genevois, 2013) are as follows:

- Alternative Scenario 1 - using non-hazardous materials:
    - Replacing PCB by 25 g of copper wire.
- Alternative Scenario 2 - optimizing product use:
    - Changing the design of the handle to improve the ergonomics (assumes no additional cost).
    - Adding pulse mode and different speed levels by replacing the current motor by a more powerful one (250W).
- Alternative Scenario 3 - using recyclable materials:
    - Replacing low recyclability level materials PS and PVC by higher recyclability level materials Expanded PS (EPS) and HDPE respectively.
- Alternative Scenario 4 - using reusable parts and materials:
    - Reusing the motor of the product.
- Alternative Scenario 5 - reducing energy consumption in use phase:
    - Adding speed level button to make it possible to lower the motor speed, no need to change the motor (average use of 150W).

The main assumptions in this study are summarized as follows:

- Expected lifetime of the hand blender is four years.
- The interest for the NPV calculation is set as 8%.
- For the alternative scenario – 3, the motor is reused only once.
- In the original and alternative scenarios 1, 2, and 5, the product wastes are treated through toxic waste incineration, while for scenarios 3 and 4, 50% of the waste is incinerated and 50% is disassembled for further treatment.
- For the economic assessment, the labor cost is assumed the same for each alternative scenario. Therefore it is not added to the comparative evaluation calculation.
- The capital is the same for each alternative scenario and it is assumed there is no additional investment cost.
- For the alternative scenarios 3 and 4, it is assumed that the product is returned to the factory by the municipality collectors or by the customers themselves. Therefore no take-back system cost is included.

The changes in materials' amount and processes, and in cost can be seen on Table 2 and 3 respectively.

Table 2 Changes in materials and processes for each alternative scenario

	Copper (g)	PS (g)	EPS (g)	PVC (g)	HDPE (g)	PCB (g)	Motor - Electricity (kWh)
Original	190	70	-	30	-	10	1,15
Scenario 1	215	70	-	30	-	0	1,15
Scenario 2	190	70	-	30	-	10	1,65
Scenario 3	190	0	70	0	30	10	1,15
Scenario 4	190	70	-	30	-	10	Reused
Scenario 5	190	70	-	30	-	10	1,02

Table 3 Changes in cost for each alternative scenario comparison to original product

	Material input & Energy
Original	8 $/unit
Scenario 1	-2,83 $/unit
Scenario 2	+1 $/unit
Scenario 3	+0,81 cents/unit
Scenario 4	-3 $/unit
Scenario 5	+ 20 cents/unit

Given all the data and the assumptions made, the economic and environmental assessments of the hand blender are made through CBA and LCA approaches.

4.1. Economic Assessment – CBA

In this part of the study, the material input and energy cost of different alternatives are compared in NPV. For the four years of lifetime of the hand blender, the cash flow and NPVs associated with each alternative scenario, with an interest rate of 8% are presented in Table 4.

Table 4 Cash flows of original and alternative scenarios in four years and their NPVs ($)

Years	Original Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1	8	5,17	9	8,01	5	8,2
2	8	5,17	9	8,01	5	8,2
3	8	5,17	9	8,01	5	8,2
4	8	5,17	9	8,01	5	8,2
NPV 1 (ir=8%)	**26,50**	**17,12**	**29,81**	**26,52**	**16,56**	**27,16**
NPV 2 (ir=6%)	**27,72**	**17,91**	**31,19**	**27,75**	**17,33**	**28,41**

As it is observed on Table 4, all NPVs have positive values. Therefore all scenarios are considered as feasible. Nevertheless, considering the changes in comparison to the original scenario, only alternative scenarios 1 and 4 have lower NPV cost values than the original one. Even with an interest rate of 6%, the findings remain the same. Hence it is concluded that only alternative scenarios 1 and 4 are eligible for implementation in ecodesign of the product since they are the only ones, which are more profitable than the original scenario.

4.2. Environmental Assessment – LCA

The data collected for the product hand blender, including the original disposal scenario, are set in LCA software SimaPro. The network created by SimaPro and the contribution (%) of each material input and process to the environmental performance is seen on Figure 1.

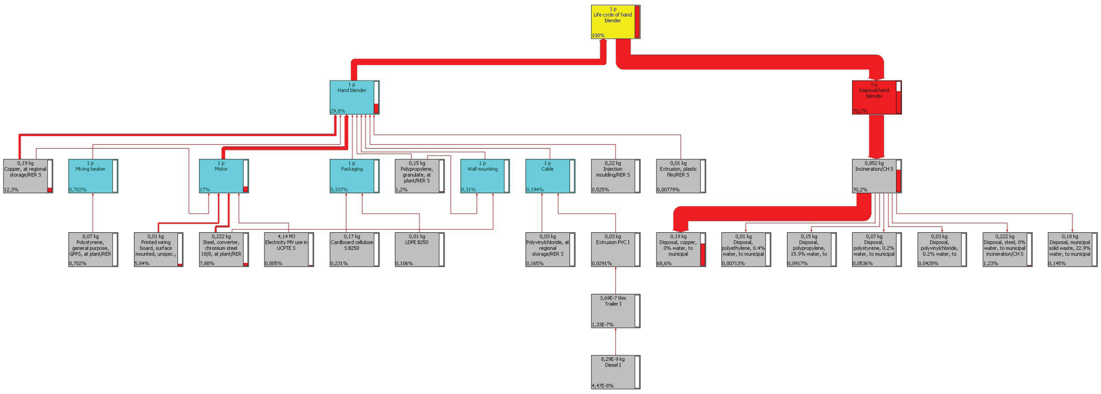


Figure 1 Network scheme of original life cycle scenario (0-cut).

After setting the original product model, the parameters related to each alternative scenario are defined in the software. Through calculation setup module, choosing the Eco-Indicator99 methodology, the comparison results of the alternatives are obtained in a single environmental index (Pt). The single environmental index with the unit of measure expressed in Pt is calculated by weighting the different environmental effects and by totaling them. The essential feature of the impact analysis is to compare the effects with reference values (Ning et al., 2013).

The comparison chart is seen on Figure 2.

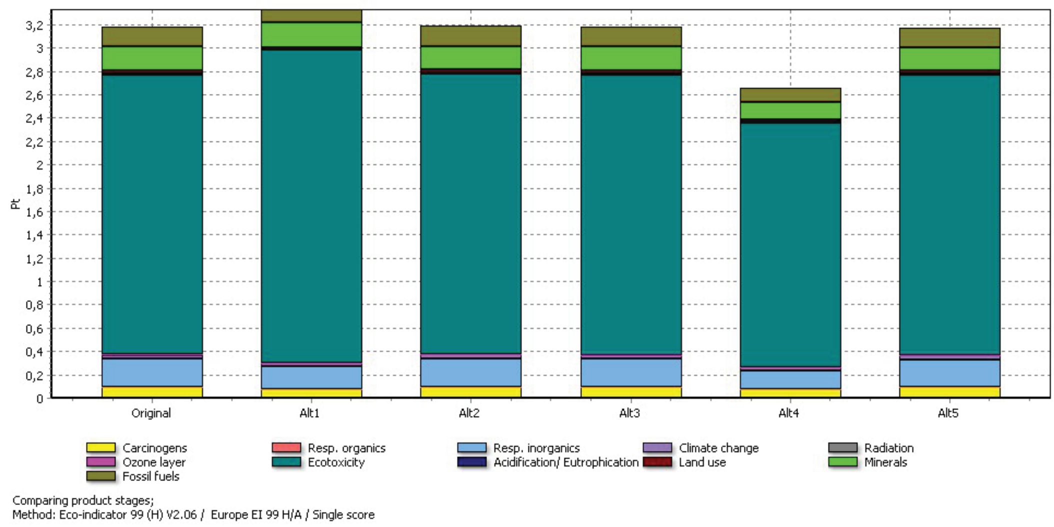


Figure 2 Comparison of original and five alternative scenarios impact assessment single score results

As the Figure 2 shows that only alternative 4 and 5 have lower environmental impact than the original product scenario. Moreover, the most defining impact category for each scenario is observed as Eco-toxicity. On the other hand, the alternatives scenarios have no significant effect on impact categories Respiratory Organics, Radiation and Ozone Layer.

4.3. Results/Discussion

First, the economic assessment made in Section 4.1 had shown that alternative scenarios 1 and 4 are the only candidates to be implemented among the other ecodesign improvement strategies. Secondly, observing the Figure 2, it is seen that alternative scenario 1 has a higher environmental impact than the original scenario, while the alternative scenario 4 has a lower one.

The conventional B/C ratio tells how feasible is the evaluated project. Higher the benefit, lower the cost, more advantageous is the project. In this study the benefit analysis is done through the environmental assessment, where lower impact values mean higher environmental benefit. Therefore to calculate the final BCR of each alternative, the formula in eq.1 is converted to the following one:

$$I \times C = \text{Impact} \times \text{Cost} \qquad (4)$$

In this case, lower the impact and the cost values, higher the feasibility of the project.

Table 5 I x C values of the evaluated alternative scenarios

	Original	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Total Impact (Pt)	3,176	3,329	3,187	3,179	2,657	3,173
Total Cost	8	5,17	9	8,01	5	8,2

($)						
I x C	25,410	17,211	28,687	25,454	13,283	26,022

The results seen in Table 5 show that alternative scenarios 1 and 4 are the only scenarios viable to implement both in economical and environmental terms, by having smaller I x C values than the original scenario. It is concluded that replacing PCB by copper and reusing the motor have significant positive effect on the economic and environmental performance of the hand blender. Nevertheless alternative scenario 4 is more advantageous than scenario 1 by having the smallest I x C value, i.e. it has the lowest cost and causes the least damages to the environment.

The limitation of this study is the lack of exact data for some cost parameters. A more detailed analysis can be done to compare the outcomes, when the data is available. The current calculations consider the major costs (mostly material and energy input) which can affect the feasibility of the improvement strategies. In addition, the costs are calculated based on current prices (July 2014), which can increase or decrease in the future, and this may also influence the results of the evaluation study.

5. Conclusion

Although several sustainability methods and tools are presented in the literature, it seems there is a gap in the field of evaluating ecodesign improvement strategies. This paper aims to fulfill this gap by adapting widely accepted approaches into the topic, and the originality of this study stands on this aim. In the current literature, there exist studies, which work on combining CBA and LCA, however none of them is focusing on the ecodesign improvement strategies of the same product. Moreover, the studies that work on the selection of the optimal ecodesign improvement strategies are rare and they mostly use only the environmental parameters for the selection.

In this study the combined evaluation methodology with the use of CBA and LCA is proposed and applied to an EEE product, a hand blender. The NPV and impact assessment calculations are made as the economic and environmental assessment respectively, for every alternative scenario of improvement strategies. According to the results, the most economically and environmentally viable alternative is found to be reusing the motor of the hand blender and chosen to be implemented by the producers.

Currently this paper lacks the integration of social parameters for the evaluation of improvement strategies. For future work, social aspects will be added to the methodology. This paper can be also improved by calculating eco-efficiency of each alternative with the help of Data Envelopment Analysis.

6. References

Aizawa, H., Yoshida, H., and Sakai, S. (2008). Current results and future perspectives for japanese recycling of home electrical appliances. Resources, Conservation and Recycling, 52(12):1399–1410.

Almansa, C., Martínez-Paz, J.M., (2011). What weight should be assigned to future environmental impacts? A probabilistic cost benefit analysis using recent advances on discounting. Sci. Total Environ. 409, 1305–1314.

Bereketli, I. (2013). An Integrated Ecodesign Methodology For Electrical And Electronic Equipment, PhD. Thesis, Galatasaray University, Istanbul.

Bereketli, I., Erol Genevois, M. (2013). An integrated QFDE approach for identifying improvement strategies in sustainable product development. Journal of Cleaner Production, 54, 188-198.

Brezet, H., Van Hemel, C., Böttcher, H., Clarke, R., Industry, U. N. E. P., (Paris)., E., Hague)., R. I. . T., and of Technology (Delft)., D. U. (1997). Ecodesign: a promising approach to sustainable production and consumption. UNEP.

Buytaert, V., Muys, B., Devriendt, N., Pelkmans, L., Kretzschmar, J. G., & Samson, R. (2011). Towards integrated sustainability assessment for energetic use of biomass: A state of the art evaluation of assessment tools. Renewable and Sustainable Energy Reviews, 15(8), 3918-3933.

Chancerel, P., Meskers, C. E., Hagelüken, C., and Rotter, V. S. (2009). Assessment of precious metal flows during preprocessing of waste electrical and electronic equipment. Journal of Industrial Ecology, 13(5):791–810.

Consoli, F. (1993). Guidelines for life-cycle assessment: a code of practice. Society of Environmental Toxicology and Chemistry.

Damart, S., Roy, B. (2009). The uses of cost–benefit analysis in public transportation decision-making in France. Transport Policy, 16(4), 200-212.

European Commission, (2008). Guide to Cost-Benefit Analysis of Investment Projects, Directorate General Regional Policy, Brussels.

Fava, J.A., Denison, R., Jones, B., Curran, M.A., Vigon, B., Selke, S., Barnum, J. (Eds.), 1991. Technical Framework for Life-cycle Assessment. SETAC Society of Envi- ronmental Toxicology and Chemistry, Washington, DC.

Georgakellos, D. A. (2012). Climate change external cost appraisal of electricity generation systems from a life cycle perspective: the case of Greece. Journal of Cleaner Production, 32, 124-140.

Guinee, J. B., Gorree, M., Heijungs, R., Huppes, G., Kleijn, R., De Koning, A., et al. (2002). Handbook on life cycle assessment. Operational guide to the ISO standards, pages 1–708.

Gurauskiene, I. and Varzinskas, V. (2006). Eco-design methodology for electrical and electronic equipment industry. Environmental research, engineering and management= Aplinkos tyrimai, inžinerija ir vadyba, 37(3):43–51.

Hoogmartens, R., Van Passel, S., Van Acker, K., & Dubois, M. (2014). Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environmental Impact Assessment Review, 48, 27-33.

Jung, Y. J. (2012). Evaluation of subsurface utility engineering for highway projects: Benefit–cost analysis. Tunnelling and Underground Space Technology, 27(1), 111-122.

Karlsson, R. and Luttropp, C. (2006). Ecodesign: what's happening? an overview of the subject area of ecodesign and of the papers in this special issue. Journal of Cleaner Production, 14(15-16):1291–1298.

Karmperis, A. C., Sotirchos, A., Tatsiopoulos, I. P., & Aravossis, K. (2012a). Environmental project evaluation: IRR-based decision support with a Monte Carlo simulation algorithm. Civil Engineering and Environmental Systems, 29(4), 291-299.

Karmperis, A. C., Sotirchos, A., Aravossis, K., & Tatsiopoulos, I. P. (2012b). Waste management project's alternatives: A risk-based multi-criteria assessment (RBMCA) approach. Waste management, 32(1),194-212.

Karmperis, A. C., Aravossis, K., Tatsiopoulos, I. P., & Sotirchos, A. (2013). Decision support models for solid waste management: Review and game-theoretic approaches. Waste management, 33(5),1290-1301.

Luttropp, C. and Lagerstedt, J. (2006). Ecodesign and the ten golden rules: generic advice for merging environmental aspects into product development. Journal of Cleaner Production, 14(15-16):1396–1408.

Mizsey, P., Delgado, L., & Benko, T. (2009). Comparison of environmental impact and external cost assessment methods. The International Journal of Life Cycle Assessment, 14(7), 665-675.

Møller, F., Slentø, E., & Frederiksen, P. (2014). Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic Cost Benefit Analysis. Biomass and Bioenergy, 60, 41-49.

Ning, S. K., Hung, M. C., Chang, Y. H., Wan, H. P., Lee, H. T., Shih, R. F. (2013). Benefit assessment of cost, energy, and environment for biomass pyrolysis oil. Journal of Cleaner Production, 59, 141-149.

Pigosso, D., Zanette, E., Filho, A., Ometto, A., and Rozenfeld, H. (2010). Ecodesign methods focused on remanufacturing. Journal of Cleaner Production, 18(1):21–31.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.-P., Suh, S., Weidema, B., and Pennington, D. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment international, 30(5):701–720.

Reza, B., Soltani, A., Ruparathna, R., Sadiq, R., & Hewage, K. (2013). Environmental and economic aspects of production and utilization of RDF as alternative fuel in cement plants: A case study of Metro Vancouver Waste Management. Resources, Conservation and Recycling, 81, 105-114.

Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., and Shiina, T. (2009). A review of life cycle assessment (lca) on some food products. Journal of Food Engineering, 90(1):1–10.

Weidema, B. P. (2006). The integration of economic and social aspects in life cycle impact assessment. The International Journal of Life Cycle Assessment,11(1), 89-96.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., and Boni, H. (2005). Global perspectives on e-waste. Environmental Impact Assessment Review, 25(5):436–458.

Wightman, P., Eavis, R., Batchelor, S., Walker, K., Bennett, R., Carruthers, P., & Tranter, R. (1999). Comparison of rapeseed and mineral oils using Life-Cycle Assessment and Cost-Benefit Analysis: Lipochimie et développement durable.OCL. Oléagineux, corps gras, lipides, 6(5), 384-388.

Wimmer, W., Züst, R., and Lee, K.-M. (2004). Ecodesign implementation: a systematic guidance on integrating environmental considerations into product development, volume 6. Kluwer Academic Pub.

Source – Google Images, Anonymous works.

Towards a New Development Paradigm: Critical Analysis of Gross National Happiness

Gaurav Daga

May 2014

Abbreviations

S.No	Abbreviations	Full form
1	GNP	Gross National Product
2	GDP	Gross Domestic Product
3	GNH	Gross National Happiness
4	PQLI	Physical Quality of Life Index
5	GPI	Genuine Progress Indicator
6	HDI	Human Development Index
7	HPI	Happy Planet Index
8	BLI	Better Life Index
9	OCED	Organization for Economic Co-operation and Development
10	CIW	Canadian Index of Wellbeing
11	SPI	Social Progress Index
12	PEI	Policy Effectiveness Index

Executive Summary

The concept of GDP emerged out of crisis. A crisis of economic measurement where governments could know the amount of goods and services with a country so that they could manage resources for their wartime needs. It was 1940s, which trigged the measurement crisis. Today, in 2014 we are facing a similar crisis – but for sustainable needs. Our climate is changing, our fisheries are depleted, our soils are degraded, our water supplies are overextended, our psychological well being is unknown and our culture is getting affected by modernity. Today we are in a dire of measurements, which can go beyond the annual output of a country (GDP). We dire for measurements, which look at wealth in its entirety— combining social, human, natural, mental, physical and economic capital.

In the past few years, economists and social scientists have made great strides in developing well being and development measurements. Starting from Morris D. Morris's Physical Quality of Life Index later refined to Human Development Index by Mahbub ul haq and Amartya Sen to Green GDP by Joseph Stiglitz, their measurements techniques have deepened our understanding of well being beyond the traditional income dimensions. Optimistically, measurement and survey techniques used by government of Bhutan – Gross National Happiness – offers us an alternative view to look at country's progress. Its domains range from health, education, culture, time use to governance, ecology, community and living standards. GNH's goal is to improve happiness and create institutions, which can promote such endeavor.

This master thesis on '*Towards a new development paradigm: Critical Analysis of Gross National Happiness'* is an analysis of GNH and a contribution to a quite widespread debate on how to move beyond GDP. It is not intended to be a comprehensive review of the 'state of the art' or an update of the Stiglitz Commission's work or Green GDP or even Gross National Happiness. Rather, it presents the following details, which may prove useful in various ways and help advance the debate and sustain its momentum.

The *Section 1* in this thesis gives an introduction to the idea of GDP, its criticism and followed by a problem statement. The *Section 2* deals with the realm of shifts in well being and development measurement techniques to discovery an alternative to GDP. *Section 3* takes one of the alternatives – *Gross National Happiness (GNH)* – endorsed by Bhutanese government, UN, economist like Jeffrey Sachs and analyses its domains, indicators, measurement techniques, methodology, weighing rationale and the idea of GNH. *Section 4*, the critical part of this thesis deals with the analysis of GNH from its advantages, shortcomings, recommendations, comparisons and areas of further research. Lastly, *Section 5* raises the need of reforming policy criterion and justifies its necessity.

Gaurav Daga
May 2014

Towards a New Development Paradigm: Critical Analysis of Gross National Happiness

Happiness is the meaning and the purpose of life, the whole aim and end of human existence.

— Aristotle

■ **Introduction**:

■ Idea of GDP:

GDP was introduced in the late 1940's when the Great Depression and then World War II pushed Washington to start counting government spending on services and war as a net positive for the economy. The construction of GDP statistics was not simple; it took decades for more than a handful of countries to create national accounts and for economists and statisticians to create methods for comparing GDP over time and across nations. It was not until late 60's when economic characteristics of a country become the measures of a country's development.

GDP a composite index, based on a complicated formula that tells us whether an economy is growing or shrinking. It is really just a number, but in the relatively obscure world of economic indicators, GDP became '*the defining indicator of the last century*, *a celebrity among statistics*'.

Economist, statisticians become interested in variety of indicators of measurements such us GDP per capita, percentage of labor force in agriculture, per capita energy consumption, GDP growth rate and so on to indicate and classify the condition of region/country's economy. Today there is not a country on this planet that ignores GDP as a measure of economic health.

Measurement of GDP is not only of important for policymakers but also for consumers since it equals the total income within an economy. It became so essential that today's macroeconomics 101 classes begin with understanding the concepts of GDP and its derivatives.

- **Critic of GDP:**

Having acquired the celebrity status, there was also an emerging consensus that GDP had shortcomings.

For example, in the wake of the 2008 recession, Andrew Haldane from the Bank of England pointed out that according to the UK's national accounts, contribution to GDP grew at the fastest rate on record in the fourth quarter of 2008 – the quarter that began a fortnight after Lehman Brothers collapsed.[28] Or to its contrary, according to the economist at MIT - Erik Brynjolfsson, information sector of the US economy (software, telecoms, publishing, data processing, movies, TV) has scarcely grown over the past 25 years as measured by GDP. One of the reason, brynjolfsson et all reckon that because every year consumers in the US are enjoying an extra $100bn of services online for which they don't have to pay. [28] (Harford, 2013)

Similarly GDP also ignores transaction cost, social costs, environmental impacts and income inequality. It has nothing to say about the damage caused to environment due to production of goods and services. And, although GDP growth is taken as a proxy for progress, it was never intended to measure happiness or welfare. Simon Kuznets, its chief architect, warned exactly for the same reason - *equating its growth with well-being*.

Finally, with all such shortcomings question arises - whether the GDP model misjudges the contributions to the economy considering all factors? Given the problems of inequality, poverty, economic safety, health, environment and many more.

Measuring the future we want:

As Robert F. Kennedy once said '*it measures everything except that which makes life worthwhile'.* It is true that what citizen's value is beyond GDP, and that the way we adopt our measurements will determine our future. GDP in some sense underpins the notion that we live in the society of risk. Given the changing nature of society's relation to production, distribution and its relation to environment and well being, futurist began to hunt for an alternative measurement for wellbeing and development. Hence, they started measuring the future one desires. *Section 2 'Need for alternatives'* deals about the various initiatives taken up by futurist on their pursuit for alternative measures.

Need for alternatives:

The hunt for need for alternative measurements of GDP started way back in 1974 when Drenowski's work on the measurement of levels of living and welfare and the OECD research programme on the measurement of social well being and development were created. However, it was Morris David Morris's *Physical Quality of Index* (PQLI)*[1i], which received some limelight. Later, it was in the mid 80's, when Nobel laureate Amartya Sen developed a firm theoretical basis (deriving from PQLI) for the use of certain social indicators to be employed in assessing well-being. Sen argued in favor of focusing on the capability to function, that is, on what a person can do or can be, rather than the standardized concentration on opulence or utility.[27] (Mitra, 2006)

■ Human development Index:

Later in 90's Mahbub ul Haq with Amartya Sen rolled out a very important and continuing, contribution to measure the status of development and well-being through UNDP's annual publication of the Human Development Report. Human development index emerged as a critic to the conventional idea of GDP – that - the more it grows, the better a country and its citizens. Human development index as commonly known as HDI is not just an index of a country's entire economic output — a tally of, among many other things, manufacturers' shipments, farmers'

*[1] ***PQLI*** *tired to incorporate the average of three indicators:* ***basic literacy rate, infant mortality, and life expectancy*** *at age one, all equally weighted on a 0 to 100 scale. The PQLI method is considered superior because it is devoid of those flaws, which exist, in per capita GDP measure.*

harvests, retail sales and construction spending but also on life expectancy and education. (Citizens' education, based on adult literacy and school-enrollment data, and its citizens' health, based on life-expectancy statistics)

Going technical, Like PQLI, HDI also attempts to rank all countries on scale of 0 (lowest HD) to 1(highest HD) based on 3 goals or end products of development: (1) Longevity is measured by life expectancy at birth, (2) Knowledge as measured by a weighted average of adult literacy (two–thirds) and mean years of schooling (one–third weight), and (3) Income as measured by adjusted real per capita income (i.e., adjusted for the differing purchasing power of each country's currency and for the assumption of rapidly diminishing marginal utility of income). Using these three measures of development and applying a formula to data for different countries, the HDI ranks all countries into three groups: low HD (0.0 to 0.50), medium HD (0.51 to 0.79) and high HD (0.80 to 1). However, critics later emerged saying HDI measures relative, not absolute levels of human development. It stresses on the 'ends of development' like longevity, knowledge and material choice, rather on the 'means' that has been the case of GNP per capita.

Fittingly even Amartya Sen agrees on the point and once said '*I told Mahbub that it's vulgar to capture in one number an extremely complex story, just as G.D.P. is vulgar. And he called me back and said: 'Amartya, you're exactly right. What I want you to do is produce an index as vulgar as G.D.P. but more relevant to our own lives.*'[11] (Gertner, 2010)

And later on Mahbub's request, Sen developed a figure that compresses the immensity of a national economy into a single data point of surpassing density. The first issue of the Human Development Report (HDR) was introduced in the 1990. Since then, Human Development Index has undergone a continuously refinement.

One of the most fascinating thing HDR has done to the global community is that – it has changed the governments view that only one statistic, the measure of gross domestic product, cannot really show whether things seem to be getting better or getting worse. This was one of the reasons that in 2008, Nobel laureates Amartya Sen, Joseph Stiglitz and the French economist Jean-Paul Fitoussi went on to a commission established by the former President Nicolas Sarkozy of France to consider devising a framework for alternatives to G.D.P.

■ The Stiglitz-Sen-Fitoussi Commission

Since the initial work on Human Development Index, the world had changed radically. There were much better survey data, which allow for new types of economic and social measurement. Problems associated with climate change, environment, sustainability became more pressing than ever before.

In September 2009, the Stiglitz-Sen-Fitoussi commission formally concluded the commission by releasing a 300 pages long report, which offered a comprehensive list of suggestions, some methodological and some philosophical, for measuring the progress of nations in the 21st century. Also, the commission recognized both main criticisms of the GDP i.e.

- One, fixing the economic measure to better represent individuals circumstances today and
- Two, every country should also apply other indicators to capture what is happening economically, socially and environmentally.

The commission needed a metaphor to explain what it meant. Eventually it settled on an automobile. Accordingly Joseph Stiglitz said, '*Suppose you're driving. You would like to know how the vehicle is functioning, but when you check the dashboard there is only one gauge. (It's a peculiar car.) That single dial conveys one piece of important information: how fast you're moving. It's not a bad comparison to the current G.D.P., but it doesn't tell you many other things: How much fuel do you have left? How far can you go? How many miles have you gone already? So what you want is a car, or a country, with a big dashboard — but not so big that you can't take in all of its information'*. [11] (Gertner, 2010)

Using the metaphor, Stiglitz-Sen-Fitoussi commission concluded that assessing a population's quality of life will require metrics from at least seven categories: ***health, education, environment, employment, material well-being, interpersonal connectedness and political engagement***. They also concluded that any nation that was serious about progress should start measuring its 'equity' — that is, the distribution of material wealth and other social goods — as well as its economic and environmental sustainability.

Analytically, one challenge the commission puts in for countries is that it does not tell how they should measure progress but rather tells about how they should think about measuring progress. In other words, it is recommending using new set of indicators to measure different endeavors but not expressing how to do it. For instance – environment and sustainability can be examples of measuring different endeavors but measuring them remained a challenge.

■ Green GDP

Soon after the Stiglitz-Sen-Fitoussi commission, Joseph Stiglitz went on to built an indicator, which could measure externalities with an aim to separate it from economic growth inscribed in GDP. That is, to measure the costs or benefits that are not reflected in market prices, meaning not included in our measurements of GDP. His basic idea was - if there are significant differences in the level of externalities or other unmeasured aspects of economic welfare between economies, then our failure to take them into account may distort the comparison of living levels or well being in a country and between the countries.[11] (Gertner, 2010)

There are many examples of such externalities that we would wish to take into account if trying to assess the quality of life. Pollution and congestion are some examples. For instance, congestion during traffic jams may increase GDP as a result of the increased use of gasoline, but obviously not the quality of life. Moreover, if citizens are concerned about the quality of air, then statistical measures, which ignores air pollution, provides an inaccurate estimate of what is happening to citizens' well being. Hence, there is need to distinguish such results from GDP. And logically, pollution can be monitored, and we could assemble data for emissions of key pollutants such as CO2, and we could then compare between countries. However such measures cannot readily be incorporated into the GDP measure, but must sit alongside it.

Also while seeking to monitor the quality of life (or "sustainable development"), governments need to focus on wide range of indicators covering various aspects of well-being. Hence, Green GDP helps in taking account of consequences caused in environment and resource depletion.

This is particularly important in developing countries like India, China, and Indonesia where huge number of trees, forests are being cut and nothing sustainable is being done. An example – were IMF thought Argentina was doing great in the early 1990s came out to its contrary.[23] (Luis Maia et all, 2003) The GDP growth rate of around 13%, which Argentina witnessed around the 1990's period, came out to be unsustainable. GDP proved to be a wrong indicator measuring for country's internal structure and sustainability. Hence Green GDP tries to take externalities and harm done to be public goods in account.

However, the problem with Green GDP approach is that it becomes impossible to make use of data for international comparisons. Furthermore, monitoring the overall change in a country over time also becomes challenging.

One of the most popular measures of Green GDP systems is Genuine Progress Indicator (GPI).

■ Genuine Progress Indicator (GPI)

Genuine Progress Indicator – is expressed in monetary units, making it more readily comparable to GDP. Specifically, it considers annual income, net savings, wealth and environmental costs and benefits. The metrics is constructed by consolidating 26 indicators critical economic, environmental and social factors into a single framework in order to give a more accurate picture of the progress – and the setbacks –a country has made.

From the costs of crime, pollution, commuting and inequality to the value of education, volunteer work, leisure time and infrastructure, GPI tires to portray the true impacts of policies and gives a picture of adjusted economic measures. Crucially, GPI also considers income distribution. In other words, a dollar's worth of increased income to a poor person boosts welfare more than a dollar's worth of increased income does for a rich person. And a big gap between the richest and the poorest in a country — as in the United States and, increasingly, in China and India — correlates with social problems, including higher rates of drug abuse, incarceration and mistrust, and poorer physical and mental health.

Robert Costanza and others (in *Nature*, 2014) shows that a 2013 study comparing the GDP per capita and the GPI per capita of 17 countries comprising just over half the global population found startling divergences between the two metrics.[3] The measures were highly correlated from 1950 until about 1978, when they moved apart as environmental and social costs began to outweigh the benefits of increased GDP. Figure 1 explains the difference in per capita income by GDP and GPI.

Figure 1 – Difference in measurement of per captia income by GDP and GPI [3]

Therefore it can be concluded that life satisfaction is highly correlated with GPI per capita, but not with GDP per capita.

Encouragingly, governments are taking up this alternative measurement of development and well being seriously, and have adopted GPI as a measure of progress. The two states in the United States - Vermont and Maryland have specifically implemented policies aimed at improving GPI.

An alternative to Genuine Progress Indicator is to try modifying GDP for environmental factors, ***with subjective measures of well being drawn from surveys***.

- **Green GDP with subjective measures**

This Green GDP school of thought believes that to build a comprehensive picture of sustainable societal well being, one should integrate subjective and objective indicators together. One example of such combination is ***Happy Planet Index*** (HPI), introduced by the New Economics Foundation in 2006. Happy plant index tires to multiply life satisfaction by life expectancy and divides the product by a measure of ecological impact.[24]

$$\text{Happy Planet Index} \approx \frac{\text{Experienced well-being} \times \text{Life expectancy}}{\text{Ecological footprint}}$$

HPI combines the subjective measures of well-being using Gallup World Poll's data with objective measures of life expectancy and ecological footprint by UNDP's HDI and WWF's measurement on resource consumption respectively.

Another example of Green GDP measurement using subjective and objectives indices is ***Better Life Index*** (BLI) - developed by the Organization for Economic Co-operation and Development (OECD). BLI believes that – '***There is more to life than the cold numbers of GDP and economic statistics'.*** It tries to compare well-being across countries, based on 11 topics the OECD has identified as essential, in the areas of material living conditions and quality of life. Its 11 topics include – *housing, income, jobs, community, education, environment, civic engagement, health, life stratification, safety and work-life balance*. It's website - http://www.oecdbetterlifeindex.org/ allows users to choose different weighing variables for different domains, revealing how weights can change countries' ranking.

One quick shortcoming of better life index is that it allows comparison only between select groups of countries from Europe, Americas and few others.

Criticism of models of Green GDP:

In terms of the models proposed as a way forward from GDP to Green GDP such as Genuine Progress Indicator (GPI), Happy Planet Index, Better life Index and so on *2, the most important critique to GPI is that it arbitrarily includes or implicitly excludes as contributors to or detractors from welfare. That is, the GPI corrects for income inequality but does not include corrections for the degree of political freedom or degree of equality between the sexes. The inclusion of almost every environmentally harmful item (like commuting costs, loss of leisure, noise pollution) has been challenged because it is unclear whether or not these costs have already been factored into household and worker decisions.[26] (John Talberth et all, 2007). Moreover, as GPI framework requires an subjective judgment of what does and does not count towards welfare and what does and does not count as a self-justifying expenditure, it therefore cannot serve its desired role as an objective measure of sustainable economic welfare.

Another criticism to the models of Green GDP is that it fails to accommodate aspects of psychological and physical well being of citizens. That is, areas like mental health, spiritual well being, cultural importance, skills, usage of time, sleep, life satisfaction, emotions are not being weighed. As Joseph Stiglitz himself quotes '*You might say, If we have unemployment, don't worry, we'll just compensate the person. But that doesn't fully compensate them... losing a job can have repercussions that affect a person's social connections (one main driver of human happiness, regardless of country) for many years afterward'*. (Gertner, 2010)

---

*2 *Refer Appendix 1 for on alternative national indicators of welfare and well-being*.

Hence, critics believe that measurement of social capital should also include psychological and physical well being aspects of citizens in understanding country's wellbeing and development. And in this regard, governments should also start focusing on building a indicator of which end result is an index that attempts to measure our collective welfare in terms of principles of sustainable development drawn from the economic, social, and environmental, psychological and cultural domains.

■ Subjective measures of well-being.

Subjective well being are increasingly becoming the most appropriate measure of capturing societal progress. Instruments of subjective well being measures are also incorporating some of the critics of Green GDP models which were incapable of capturing data's on time use, psychological wellbeing and so on. Among many*[3], the one of the most popular wellbeing and development indices of this domain is,

1. **The Canadian Index of Well-Being** (CIW): It is a national instrument used to measure whether quality of life of Canadians, in all its key dimensions, is getting better or worse. The CIW currently covers eight domains, all with their specific metrics and analysis. These include *arts, culture and recreation, community vitality, democratic engagement, education, environment, healthy populations, living standards and time use*.

*[3] *Refer Appendix 1 for other subjective indicators of welfare and well-being*

This realm of shift from PQLI to Subjective measures of well being in this section has helped us understand that the economy's character of a country and what citizen's value is beyond GDP and that the way we measure the economy will determine the way we want things to be. *Section 3* of this thesis takes one of the alternatives - '*Gross National Happiness'* and deals with the philosophy of its index, domains and indicators, methodology and weighing techniques, followed by its critical analysis in *Section 4*. Gross National Happiness is one such unique index that combines subjective and objective measures of wellbeing and development.

Gross National Happiness

Introduction:

We strive for the benefits of economic growth and modernization while ensuring that in our drive to acquire greater status and wealth we do not forget to nurture that which makes us happy to be Bhutanese. Is it our strong family structure? Our culture and traditions? Our pristine environment? Our respect for community and country? Our desire for a peaceful coexistence with other nations? If so, then the duty of our government must be to ensure that these invaluable elements contributing to the happiness and wellbeing of our people are nurtured and protected. Our government must be human.

- Extract from His Majesty of Bhutan's speech during the Madhavrao Scindia Memorial Lecture on 23 Dec. 2009

Coined in 1972 by Bhutan's fourth king, ***Gross National Happiness*** refers to the nation's policy of balancing modernity with preservation of traditions, mostly by resisting laissez-faire development.[1] (Wall Street Journal, 2013) The concept implies that sustainable development should take a holistic approach towards notions of progress and give equal importance to non-economic aspects of wellbeing.[2] Its four pillars have often explained the concept of GNH: ***good governance, sustainable socio-economic development, cultural preservation, and environmental conservation***. The four pillars have been declassified into nine domains in order to create widespread understanding of GNH and to reflect the holistic range of GNH values. The nine domains are: ***psychological wellbeing, health, education, time use, cultural diversity and resilience, good governance, community vitality, ecological diversity and resilience, and living standards***. Furthermore, the nine domains together comprise 33 clustered indicators, each one of which is composed of several variables. When unpacked, the 33 clustered indicators have 124 variables. Each domain represents components of wellbeing of the Bhutanese people, and the term 'wellbeing' refers to fulfilling conditions of a 'good life' as per the values and principles laid down by the concept of Gross National Happiness.[2]

Legally stating the Constitution of Bhutan (2008, Article 9) directs the State '*to promote those conditions that will enable the pursuit of Gross National Happiness*' (Karma Ura et all, 2013). In other words, if the government cannot create happiness for its people, there is no purpose for the government to exist. After the establishment of a constitutional monarchy in 2008 and the coronation of the Fifth King, the Government of Bhutan is legally obliged to specify this objective such that policies and programmes advanced by the new democracy continue to be coherent with it.

In principle,

- GNH seeks to be policy-sensitive – changing over time in response to public action.
- Its indicators try to reflect public priorities directly.
- It tries to address the strengthening or deterioration of social, cultural, and environmental achievements whether or not they are the direct objective of policy.
- GNH indicators are carefully chosen so that they stay relevant in future periods as well as at the present time in order to measure progress across time and
- Finally, the GNH Index consists of sub-group consistent hence decomposable by regions and groups.

Nonetheless some of these principles will be challenged in the *Section 4* '*Critical analysis of GNH Index*' of this thesis.

Domains of GNH:

This section explains how each of the domains and indicators in GNH has been constructed as well as their cutoffs have been set. Talking about the domains, there are 9 domains of 2,3 or 4 indicators. Table no.1 explains such variations,

	Domain	Indicators
1	Psychological well-being	4
2	Health	4
3	Time use	2
4	Education	4
5	Cultural diversity and resilience	4
6	Good Governance	4
7	Community vitality	4
8	Ecological diversity and resilience	4
9	Living standards	3
	Total	33

Table 1 - Overview of GNH domains and indicators

On unpacking each indicator, Figure no. 2 breakdowns the sub sections it has.

Figure 2 – 33 GNH Indicators

Explaining the methodology of its construction, we now consider each domains and indicators one by one,

1) Psychological Wellbeing:

Psychological wellbeing is a characteristically significant and coveted state of being. Diener, et al (1997) categorize indicators of psychological wellbeing according to reflective or affective elements,[9] while the Sen-Stiglitz and Fitoussi commission emphasizes the importance of using diverse wellbeing indicators. It states, '*different aspects (cognitive evaluations of one's life, happiness, satisfaction, positive emotions and negative emotions)…should be measured separately to derive a more comprehensive appreciation of people's lives* (Jeffrey Sachs et all 2013)

Besides the reflective life evaluations and hedonic experiences, GNH also considers spirituality as one of the indicator that needs to be emphasized.

Explaining each indicator - **Life satisfaction** - combines individuals' subjective assessments of their happiness levels with respect to health, occupation, family, standard of living and work-life balance. The respondents are asked to say how satisfied or dissatisfied they were in these five areas on a five-point scale (1= very dissatisfied, 5=very satisfied).*[4]

*[4] - *Because of its length (42 page document), the Second Gross National Happiness Survey Questionnaire April 2010 could not be attached in the Appendix section. If required, can be provided on request.*

The life satisfaction indicator sums their responses across the five areas. It could have a score as low as 5 (low satisfaction) or as high as 25 (high satisfaction). The sufficiency threshold for the life satisfaction score is set at 19.

The **positive and negative emotions indicator** reports the emotions such as compassion, generosity, forgiveness, contentment and so on for positive emotions and while selfishness, jealousy, anger, fear and worry were used to represent negative emotions.

For both sets of emotions the respondents are asked to rate the extent to which they have experienced them during the past few weeks with reference to a four-point scale. The scale ranges are: 1 'never', 2 'rarely', 3'sometimes', and 4 'often'.

Both the positive and negative emotion indicator scores run from 5 to 20 (from low to high incidence of positive or negative emotions). For positive emotions, a sufficiency threshold of 15 is set. The negative emotion indicator the threshold level is set in regards to its sub indices. That is, 5 (for two items with maximum score of 8) and 7 (for three items with maximum score of 12) were set respectively for two sub-indices of negative emotions.

Considering **Spirituality** indicator - It covers a person's self-reported spirituality level on the frequency with which they experience karma, prayer recitation, and meditation. The indicator runs on spirituality level of citizens', which measures from 'very spiritual' to 'not at all'. Scores range from 4 to 16 with 16 indicating a greater degree of spirituality. The threshold has been set at 12, which implies that at least three of the four indicators must be rated 'regularly' or 'occasionally' for individuals to be defined as happy.

2) Health

In GNH system, health has always been associated with both physical health and mental health. Considering it as an outcome of relational balance between mind and body, between persons and the environment, its four indicators are -

Self-reported health status: It is used as a proxy measure to complement other health indicators - healthy days, mental health and disability. For a person to be sufficient in self-reported health status, he or she must have a rating of 'excellent' or 'very good'

The **Healthy days -** indicator reports the number of 'healthy days' a respondent enjoyed within the last month. For instance, answers can be 26 days health days, so it allow for deviants from normality. Similarly for **mental health** indicator

The **Long-term disability** examines an individual's ability to perform functional activities of daily living without any restriction. Citizens are asked whether they had any longstanding illness that had lasted over six months so that causality can be traced out. The threshold is set such that those individuals who are disabled but are 'rarely' or 'never' restricted from doing their daily chores are classified as sufficient. Conversely, individuals with a disability whose daily activities are restricted 'sometimes' are classified as deprived.

3) Education

GNH tries to highlight the importance of a holistic educational approach, which ensures citizens gain a deep foundation in traditional knowledge, common values and skills. In addition to just studying, reading, writing, math's, science and technology, students are also encouraged to engage in creative learning and expression. The indicators include – **literacy, educational qualification, knowledge and values.**

For **knowledge** – the indicator attempts to capture learning, which could have occurred either inside or outside formal institutions. Five knowledge variables are chosen: *knowledge of local legends and folk stories, knowledge of local festivals knowledge of traditional songs, knowledge of HIV-AIDS transmission, and knowledge of the Constitution*. The responses for each question follow a five-point scale, which ranges from 'very good knowledge' to 'very poor knowledge'. The threshold is set to 19, which implies that citizens should have an average of 'good' knowledge across the five variables.

With **values** indicator – respondents are asked whether they considered five destructive actions to be justifiable: *killing, stealing, lying, creating disharmony in relationships and sexual misconduct*.

4) Culture

Preservation and promotion of culture should be highly valued both by government and the people and GNH rightly tires to capture it. Culture is not only viewed as a resource for establishing identity but also for mitigating it from negative impacts such as its effects on forms of language, traditional arts and crafts, festivals, events, ceremonies, drama, music, dress and etiquette and so on (Jeffrey Sachs et all 2013). To assess the strength of various aspects of culture, four indicators have been considered: **language, artisan skills, cultural participation and the way of harmony.**

Language - it is a self-reported indicator, which is measured by a fluency level in one's mother tongue on a four-point scale. The ratings vary from 'very well' to 'not at all'. It assumes that since everyone must be fluent in their mother tongue, a high threshold is necessary to maintain standards.

Artisan skills - This indicator assesses people's interest and knowledge in thirteen arts and crafts and reports on number of skills possessed by a respondent. These skills and vocations are the basis of historical material culture of Bhutan when it was trading far less.

For the indicator, people were asked if they possessed any of the 13 listed*[5] arts and crafts skills. A sufficiency threshold was set at one, which implied that a person must possess at least one skill to be identified as sufficient.

Socio-cultural participation - In order to assess people's participation in socio-cultural activities the average number of days within the past 12 months is recorded from each respondent. The days are grouped on five-point scale ranging from 'none', and '1 to 5 days' to '+20 days'. The threshold was set at 6 to 12 days per year. It identifies 33.2 per cent to have achieved sufficiency.

---

*[5] *The 13 arts and crafts include - 1) weaving, 2) embroidery, 3) painting, 4) carpentry, 5) carving, 6) sculpture, 7) casting, 8) blacksmithing, 9) bamboo works, 10) goldsmiting and silversmithing, 11) masonry, 12) leather works and 13) papermaking*.

The Way of Harmony is expected to rate citizens' behavior of consuming, clothing, moving especially in formal occasions and in formal spaces. Respondents are asked to rate its importance on a three-point scale of being very important to not important. In addition, respondents were also asked if there were any perceived changes in the practice of this particular form of etiquette over the years.

5) Time Use

The balance of time between paid work, unpaid work and leisure is important for one's wellbeing. Similarly, a flexible working life is vital for the wellbeing of individual workers and their families and communities. In the GNH, simple time use diaries are administered - asking respondents to recall their activities during the previous day collects information on how people use their time. Different categories spent on different kinds of activities such as work, leisure, sleep, personal care and so on are recorded.

Time use data also helps to reveal the gap between GDP and non-GDP activities that reflects the gap between market and household economy sectors. Such data are helpful in accounting for a more comprehensive output of goods and services that GDP omits (Karma Ura et all, 2013).[5]

Working hours - The GNH definition of working hours includes even unpaid work such as childcare, labor contribution to community works, voluntary works and informal helps. Accordingly to Bhutanese law, eight hours is also the legal limit, applied to formal sector, for a standard workday. Since a main objective of the indicator is to assess people who are overworked, those who work for more than eight hours are identified as time deprived.

Sleeping hours - Sleep is clearly beneficial for a person's health and impacts nearly every area of daily life. However, sleep requirements can vary substantially with different human beings. In general most healthy adults need an average of seven to eight hours of sleep for proper functioning. Hence, eight hours is considered the amount necessary for a well functioning body for everyone. With this threshold, about 66.7 per cent achieve sufficiency.

6) Good Governance

Four areas of measures are developed to signify effective and efficient governance. These include in the domain of *fundamental rights, trust in institutions, performance of the governmental institutions and political participation*. The good governance indicators try to combine political activities with access to government services. The **fundamental rights** indicator includes – right to vote, freedom of speech, join a political party, to be free of discrimination and a perceptual indicator on government performance.

The **political participation –** the indicator asks two questions based on –

- The possibility of voting in the next election and
- The frequency of attendance in community meetings.

The respondents are asked if they would vote in the next general election and the response categories are simply 'yes' or 'no' or 'don't know'. An individual has to report 'yes' in the voting criteria and has to attend at least one meeting in a year to be classified as sufficient in political participation.

For voting, the threshold is straight forward because it is agreed by everyone that developing true democratic processes requires the active participation from citizens – minimally, by voting. In terms of attendance in meetings the threshold has been set to one time.

Third, the **government performance** indicator captures the performance of government at national and local level. It asks questions related to employment, inequality, health services, environment, basic services, agriculture, sanitation, education and so on. It even attempts to assess people's perceptions about the functioning of human rights in the country as enshrined in the Constitution of Bhutan. The seven questions related to political freedom ask people if they feel they have: freedom of speech and opinion, the right to vote, the right to join political party of their choice, the right to form association or to be a member of some, the right to equal access and the opportunity to join public service, the right to equal pay for work of equal value, and freedom from discrimination based on race, sex and so on. All have three possible responses of 'yes', 'no' and 'don't know'.

The thresholds for all rights were set to 'yes'. So, a person has a sufficient condition in the indicator if he or she has all seven rights fulfilled.

Lastly, the **Service delivery** - This indicator tires to test people's perceptions of overall service delivery in the country. Respondents are asked to rate the performance of the government in the past 12 months on seven major objectives of good governance: employment, equality, education, health, anti-corruption, environment, media, law, culture and many more. These outcome-based questions enable respondents to rank the services on a five-point scale from 'very good' to 'very poor'. The overall indicator has a maximum value of 35 and minimum value of 7.

A threshold of 28 was adopted, which means that a person has to perceive that public services are 'very good' or 'good' in at least five of the seven objectives.

7) Community Vitality

From a GNH standpoint, a community must possess strong relationships amongst the community members and within families, must hold socially constructive values, must volunteer and donate time and/or money, and lastly must be safe from violence and crime.

The indicators in this domain cover four major aspects of community: 1) social support which depicts the civic contributions made 2) community relationship, which refers to social bonding and a sense of community 3) family relationships, and 4) perceived safety.

All these are subjective indicators and thresholds weights are set minimally.

8) Ecological Diversity and Resilience

According to the Constitution of Bhutan, every Bhutanese citizen shall *'...contribute to the protection of the natural environment, conservation of the rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual and physical pollution…'*

The environmental domain includes three subjective indicators related to perceptions regarding environmental challenges, urban issues and responsibilities, and one more objective question, related to wildlife damage to crops. Like other subjective indicators, the interpretation of these indicators is clouded by different and possibly shifting frames of reference, so they the weighing thresholds are minimally – 10%.

The **pollution** indicator – tries to capture citizens' environmental awareness and their ability to perceive environmental problems. Seven environmental issues of concern were shared with respondents, and their responses follow a four points scale from 'major concern' to 'not a concern'.

They are not added into a single number but rather a conditional threshold is applied whereby an individual is insufficient if he or she has rated 'major concern' or 'some concern' in at least five of the seven environmental issues. Their reference frame is within the past 12 months.

The **environmental responsibility** indicator **-** attempts to measure the feelings of personal responsibility towards the environment. It is crucial to reinforce attitudes that will encourage people to adopt eco-friendly approaches and also to identify any deterioration in the current very environmentally aware views of citizens. The responses also run on a four point scaling system and the threshold is set at 'highly responsible'.

Wildlife - The wildlife indicator incorporates information on damage to crops. The wildlife indicator is rural-specific since it pertains to farmers. This indicator is later offset by the urban issue indicator, which in turn applies to urban dwellers only.

Urban issues - Since urbanization has both positive impacts on human wellbeing and negative effects these adverse impacts on wellbeing have been incorporated into the GNH index. Respondents are asked to report their worries about four urban issues: traffic congestion, inadequate green spaces, lack of pedestrian streets and urban sprawl. The threshold is set such that a person can report any one of the issues as major threat or worry to be sufficient.

This indicator mainly acts as a proxy for sustainable urban development, which is one of the major objectives of the government.

9) Living Standards

It refers to the material wellbeing of the Bhutanese people. It ensures the fulfillment of basic material needs for a comfortable living. There are wide ranges of indicators used in the literature to assess standards of living. The three indicators to assess people's standards of living are - **household per capita income, assets and housing conditions**. Assets include livestock, land and appliances, while housing conditions pertain to room ratio, roofing and sanitation. These are included so that there are enough complementary measures for self-reported household income.

Household income – indicates income earned by all the individuals in a household from varied sources within or outside of the country. The household income here has been adjusted for in-kind payments received.

Moving on the **Assets** - indicator uses data on selected household assets, such as durable and semi-durable goods of everyday use, to describe household welfare. The concept is based on evidence that income/expenditure measures are incomplete measures of the material wellbeing of households especially in developing countries where such data may have higher measurement errors.

Further, asset data were found to be more reliable and easier to collect. Commonly, appliances such as a mobile phone, radio or TV or bicycle define asset indicators; however, because of the sociocultural context, livestock and land ownership were also considered assets. Livestock is understood as an integral component in agricultural and rural economies in Bhutan. *Even animals* are included in asset list.

The asset indicator is created consisting of three major components: 1) appliances (mobile phone, fixed-line telephone, personal computer, refrigerator, color television and washing machine) 2) livestock ownership and 3) land ownership.

The thresholds are applied at two levels: they are set initially on each of the three indicators and then later, an overall threshold is applied to classify insufficiency in the asset indicator.

Lastly about **Housing quality** indicator – it tries to capture the housing space, size, conditions and so on from an individual's as well as from a community perspective. On the individual level, having one's personal space is considered fundamental for one's biological, psychological and social needs since it is a place where most spend a significant part of their everyday lives. And from community level, roofing and toilet in a house are considered important. Hence, the quality of housing indicator is composed of three indicators: the type of roofing, type of toilet and room ratio. The thresholds have been set based on the Millennium Development Goals such as corrugated galvanized iron (CGI) or concrete brick or stone for roofing, pit latrine with septic tank for toilet and two persons per room for overcrowding, and all three conditions must be met.[9]

So, overall an individual is sufficient in housing if he or she lives in a house that has a good roofing structure (CGI or concrete brick or stone), a pit latrine with a septic tank, and uncrowded rooms. The threshold is set about 46.2 per cent are sufficient in housing quality.

■ Weighting and Methodology:

This section explains the weighting and methodology of the domains of GNH. The index uses two kinds of thresholds to satisfy one as happy -

- Sufficiency thresholds, and
- Happiness threshold.

Sufficiency thresholds: show us how much a person needs in order to enjoy sufficiency in each of the 33 indicators. Meanwhile, the **happiness threshold** seeks to answer the question of "how many domains or in what percentage of the indicators must a person achieve sufficiency in order to be understood as happy"?

The GNH also weights all the domains of its indicators as equally because it believes all are of equal importance, and non can be permanently ranked as more important than others. However, among the 33 indicators some are self-report indicators, which are subjective, thus having lighter weights. The below table 2 helps us to understand the different weights,

Domain	Indicators	Weight	Domain	Indicators	Weight
Psychological wellbeing	Life satisfaction	33%	Time use	Work	50%
	Positive emotions	17%		Sleep	50%
	Negative emotions	17%	Good governance	Political participation	40%
	Spirituality	33%		Services	40%
Health	Self reported health	10%		Government performance	10%
	Healthy days	30%		Fundamental rights	10%
	Disability	30%	Community vitality	Donation (time & money)	30%
	Mental health	30%		Safety	30%
Education	Literacy	30%		Community relationship	20%
	Schooling	30%		Family	20%
	Knowledge	20%	Ecological diversity & resilience	Wildlife damage	40%
	Value	20%		Urban issues	40%
Cultural diversity & resilience	Zorig chusum skills (Thirteen arts & crafts)	30%		Responsibility towards environment	10%
	Cultural participation	30%		Ecological issues	10%
	Speak native language	20%	Living standard	Per capita income	33%
	Driglam Namzha (Etiquette)	20%		Assets	33%
				Housing	33%

Table 2: Weights on the 33 indicators

As mentioned the GNH index uses two kinds of thresholds or cutoffs: **sufficiency thresholds, and the happiness threshold**. One of the reasons for second cut-off is to allow for variation or fluctuations in the measurement. So, in reporting the GNH, the population is different into four sub groups (unhappy, narrowly happy, extensively happy, and deeply happy) and their achieved sufficiency is marked with 50%, 66%, and 77% of the weighted indicators.

Furthermore, all these groups can also be analyzed in dimensions which they lack sufficiency, and how these change by gender, region, age, and occupation.

Conceptually, the GNH is constructed using the Alkire-Foster method, which is often used for measuring multidimensional concepts such as poverty, wellbeing or inequality.

However, it does not strictly use the Alkire-Foster method, the GNH Index is created from two quantities:

- Headcount ratio: % of people who are happy
- Breadth: % of domains in which people who are not-yet happy enjoy sufficiency (this is similar to "intensity" in poverty measures using the Alkire-Foster method)

To construct the GNH Index using this methodology six steps are followed:

1. Choose indicators
2. Apply sufficiency thresholds (who has enough)?
3. Apply weights for each indicator
4. Apply the happiness threshold
5. Identify two groups:
    a. Happy people (extensively and deeply happy)
    b. Not-yet-happy people (policy priority) (unhappy and narrowly happy)
6. Identify among the not-yet-happy people, what percentage of domains they lack sufficiency, and in what percentage they enjoy sufficiency.

Now, to calculate the GNH, the data of the population are aggregated into a decomposable 'Adjusted Headcount M0' measure that is sensitive to the 'breadth' of achievements (Alkire and

Foster, 2007, 2011). M0 is constructed by multiplying HnAn, where Hn represents the percentage of people who have not achieved sufficiency in 6 domains thus are identified as not-yet-happy, and An is the average proportion of dimensions in which those not-yet-happy people lack sufficiency.

The Adjusted Headcount ranges in value from 0 to 1, with larger numbers signifying greater insufficiencies and less happiness. In order to create the GNH Index in which a higher number reflects greater happiness, the Adjusted Headcount is subtracted from 1 to obtain the GNH. Therefore, GNH = 1- HnAn.

For instance, if we take the following three numbers -

1. The percentage of happy people - Hh is 43%.
2. The percentage of not-yet-happy people - Hn is 57%.
3. The percentage of domains in which not-yet-happy people enjoy sufficiency – As - is 48.9%.

Then the final GNH formula would answer as follows: GNH=(Hh+HnAs) = 43% + (57% x 48.9%) = 0.7309. Now, applying the adjusted headcount, then –> 1 – 0.307 = 0.2691 = 26.91%. Therefore, only 26.91% of the populations are deeply happy, rest needs dire attention of the government.

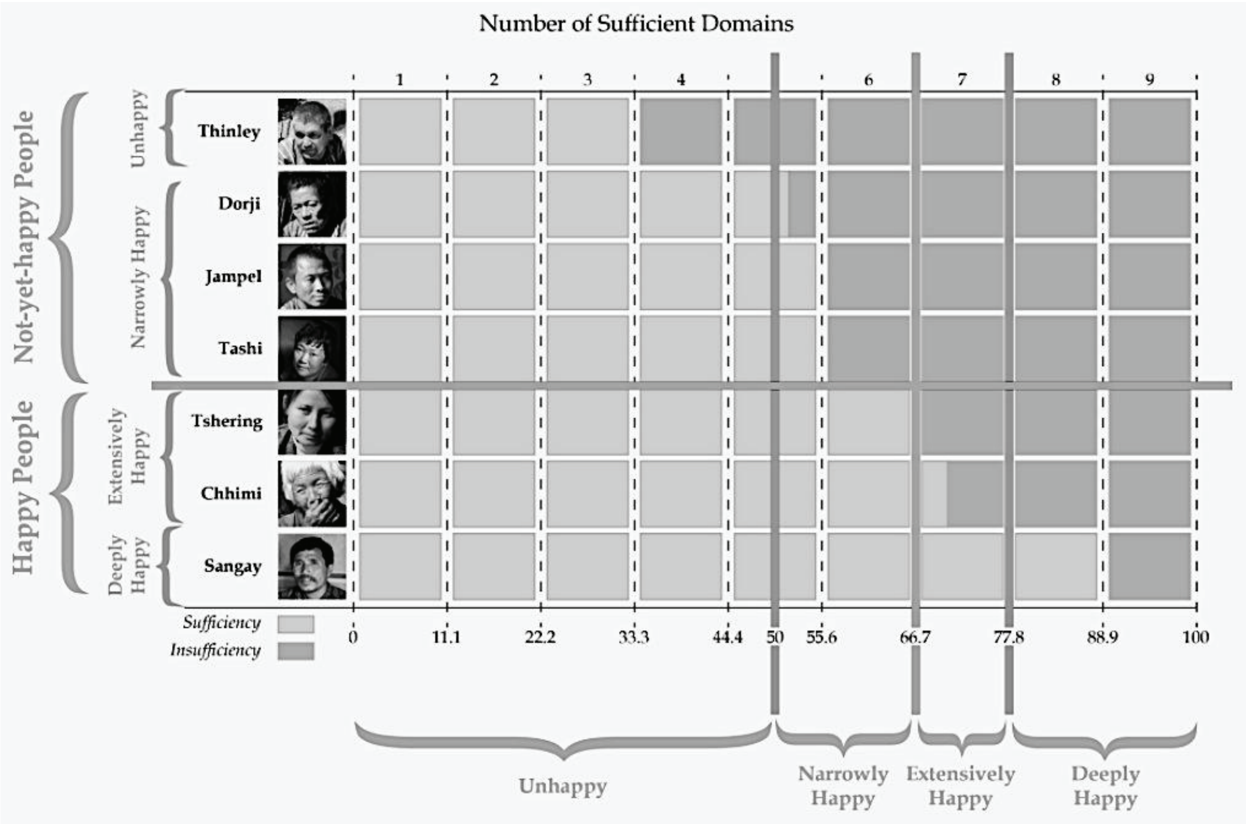


Figure 3 – Happiness gradient

Also, to identify the happiness gradient, two additional cutoffs of – 50% and 77% are placed. As Figure 3 shows, when we apply the 50% cutoff we find that only one person, Thinley, is unhappy. Looking between 50-65% we find three people are narrowly happy: Dorji, Jampel and Tashi. Two people have sufficiency in 66-76% of domains: Tshering and Chhimi. And finally, one person, Sangay, is deeply happy with achievements in over 77% of domains. We can compute the average sufficiency for each group also: for example, in the case of the narrowly happy people, the average sufficiency is [(4.6/9 + 5/9 + 5/9)/3] = 54%. Similarly, sufficiency can be computed for other groups of people.

Is GNH a practical tool for policy implications?

Having explained the idea, domains, indicator, methodology and technique of GNH measurements – the most important question arises whether GNH can serve well as a practical tool that will help Bhutan's leaders and practitioners in government, business and civil society to implement policies and programmes informed by the measurement?

Section 4 of this thesis '*Critical Analysis of GNH Index*', deals with the advantages, shortcomings, comparisons, areas of further research and inference from GNH.

Critical Analysis of GNH Index

Advantages of GNH:

1. **Setting an alternative framework of development**: Bhutan's GNH vision of development is distinctively holistic. The nine domains of GNH, taken together, portraits more about citizen's life and well being than the standard welfare measure of GDP per capita.
2. **Allocating resources in accordance with the need of people:** The index provides an overall picture of how GNH is distributed across the population and also gives an ability to zoom in to look at who is happy, unhappy, narrowly happy, extensively happy, and deeply happy. It also tells us about wellbeing by different subcategories of gender, rural-urban area, districts, age and so on. All of these functions make it a useful tool for policymakers as they seek to address the question of 'how can GNH be increased?' and also it allows them to compare problems across subcategories.
3. **Providing indicators for sectors to guide development**: The GNH Index helps policy makers provide certain indicators that can guide development by monitoring activities in a particular domain. For example "electricity," a component of the GNH, is a priority in the 10th five-year plan.[29] Insofar as the GNH indicators monitor outputs, the GNH Index will provide impetuses to administrators, in light of the fact that their achievements will noticeably help achieve higher GNH.
4. **Usage of GNH screening tools**: Bhutanese government rightly understands that while the composition of the GNH may not be a sufficient guide for policy, a clear understanding of

how the achievements and shortfalls in different dimensions of GNH vary over time and space is necessary. Hence, it's screening tools mechanism, which uses the GNH indicators as a checklist, come handy to convey if a particular policy can be implemented, or not.

5. **Measuring people's happiness and well-being**: The index and its component aims to capture human well-being in a fuller and more profound way than traditional GDP, socio-economic measures of economic development, human development or social progress have done. One of the important aims of the measurements is to make general public understand what it is for. And rightly, GNH provides case studies of differently happy people, so that citizens can assess whether the index broadly seems intuitive and has room for their own aspirations and values.
6. **Measuring progress over time**: The indicators of the GNH are to be sensitive to changes taking place over time. In other words, it tries to be responsive to relevant changes in policy action. In this way, the composition of well-being, as well as its overall level, can be observed over decades. Similarly, inequalities among groups and populations that require special attention can be identified. Again GNH Survey results come handy.
7. **Sustainable Development**: At a time when countries like China are moving towards market friendly policies, it is compelling to see that Bhutan is pursing more environment, ecological, well being based policies. Furthermore, GNH also tries to give people more voice and information so that the policies are made in line to the recommendations made by the public.

8. **GNH is not only an outcome indicator but also a process indicator.** That is, it helps administrators to identify the link between processes and outcomes. Accordingly it helps in modifying, examining and implementing policies.

Shortcomings of GNH:

1. **Defining happiness:** The measurement of GNH reflects the fact that happiness is a deeply personal matter and subjective. However arriving at a definition of happiness and working it out is difficult. Hence, debates are needed to see if it frames and captures the philosophy of GNH.
2. **Measurement Problems**: In regards to having such vast array of indicators and domains, one problem with survey based subjective measurements is that citizens might choose to under/over report some of the issues. Furthermore, when Bhutan is pursuing policies like forbidding immigration, restricting tourism, it becomes even challenging to assess the impact and effectiveness of GNH. Hence, it is crucial to analysis what it preaches.*[6]
3. **Practicality of carrying out GNH surveys:**
   - Since Bhutan has a population of around 700,000 people, it can be said that it is feasible to do subjective surveys for 7,000 people. However it becomes difficult to carry out such surveys in countries like India, China, Indonesia, and United States where factors like –

*[6] ***Note*** *- In its 2011 survey – nearly about 59% of Bhutanese people reported as not-yet-happy and they were more deprived in all 33 indicators than the happy people*

population, geography, topography, resources constraints, budget constraints kicks in. Hence, uncertainty arises on the question of 'Can GNH be exported to other countries'

- The GNH survey questionnaire, which has 249 questions with 750 variables are objective, subjective, and open-ended in nature. The Centre for Bhutan Studies & GNH Research reveals that it takes minimum 5-6 hours to complete a survey from a respondent. It might be very well true that respondent might lose interest after a certain point of time because of a tedious interrogation. And also not only respondent's education but also his/her exposure to the outside world plays an important part in the choice of answer they pick. Moreover, out of 20 districts in Bhutan only 12 districts were covered in the 2010 GNH survey.[22] Hence it can be concluded that there are problems related to selection biases in the surveys.
- The latest 2010 GNH survey took nearly 9 months to complete the survey. Given constant changes in the political, social, economic and various other conditions questions can be raised on the validity and relevance's of the answers.[22]

4. **GNH Surveys – Is it necessary?** National statistical data of Bhutan says that youth unemployment (5.8% in urban areas and 2% in rural areas), need for universities, access to health care (need for modern hospitals and indigenous dispensaries) and education (63% of literacy for 6 and above), inflation and transportation are some of the most hard-hitting problems of Bhutan's society. Furthermore, it also revealed high acceptance levels of domestic violence - around 70 percent of women felt they deserved to be beaten if they refused to have sex with their husbands, argued with them, or burned the dinner. Also, people

in rural areas are deprived of basic living standards and so on. Thus, question arises - Is philosophy of GNH reflected in the pursuit of GNH?

5. **Cultural intolerance**: The cultural domain of GNH model has inclinations to Bhutanese traditional culture. On one hand, such indicators are necessary to see the effects of modernity on culture. However, on other hand it ignores the cultural values of 25% Hindus and 5% of others (Muslims and Christians) who live in Bhutan. In other words, besides preserving and promoting Bhutan's culture, the government is also defining, limiting and sometimes even inventing it. For instance, the compulsory rule of wearing national dress and use of national architectural pattern is very Buddhist centric. When many Hindu nepali’s resisted to wear the national dress, around 100,000 people of 800,000 population ended up leaving the country. Furthermore, some schools even dropped the third national language – Nepali – from the school curriculum.
6. **Interpretation of survey forms**: It is not clear whether people’s answers to survey questions in different languages and in different cultures really mean the same thing.
7. **Limits in Indicators**:
    - **Education** - Schooling plays an important role in developing children’s mental well-being and development. GNH, which tries to capture a holistic development of child’s cognitive development, fails to capture the capacity of soft skills. Skills such as self-control, perseverance, the capacity to delay gratification, and the ability to cope with shocks are some of the strong predictors of positive wellbeing development. Indicators like – knowledge, value in education domain tires to capture but they fail

in its entirety. Capturing the lack of soft skills issues also inspire teachers to nurture them accordingly.

- **Health** - Mental health is a major determinant of overall health. The GNH survey result, which talks about people's perception on mental health, yet has not established a single institution to tackle mental problems. For instance, alcoholism in Bhutan - GNH survey results show us that around 65% of people are involved in alcohol, yet there are no rehabilitation centers in place to tackle such issues.
- **Service delivery –** Its indicator tries to capture the access to basic services and institutions for the citizens. However, it completely rules out 'access to education' as one of its vital part.
- **Spirituality –** Since GNH tires to give subjective measures lighter weights; it overlooks spirituality indicator in this regard.

8. **International comparison:** When different countries are adopting different methods of happiness measurements (like – HPI, BLI) it becomes difficult to do transnational comparisons. Moreover with huge number of variables used in GNH approach it becomes impossible to make use of data for international comparisons. Henceforth, evaluation of GNH becomes restrictive.
9. **GNH or GDP** - Many scholars believe that 'the vast majority of Bhutanese are only paying lip service to GNH as they vigorously pursue the goods, services, and lifestyle of their GDP measuring counterparts' (David Luechauer, 2013)

Recommendations for improving GNH:

1. **'Guidelines on Measuring Subjective Wellbeing' can help solve measurements problems:** Given subjective wellbeing has been examined extensively in academic literature, including from the perspective of which subjective wellbeing measures to collect, and how to collect them, there was until now no consistent set of guidelines for national statistical agencies to draw on. However recently, OECD released a report on '*Guidelines on Measuring Subjective Wellbeing'*,[32] which represent an important step forward in moving the measurement of subjective wellbeing from a primarily academic activity to the sphere of official statistics. Hence some of the problems of measurement in GNH can be resolved.
2. **Incorporating natural capital in accounting system:** The objective elements of well being measurement are important in assessing their country's overall well-being. In the year 2011-12, the forestry share to the GDP increased from 16.1% to 17%. This meant that more environmental degradation was taking place. However, no indicators are established to find effectiveness of the forest use and replantation. Hence Bhutan needs to incorporate natural capital and the ecosystem services it provides into its national accounting framework to help screen GNH based policies.
3. **Report on survey evaluation is must**: Since GNH involves surveying around 7000 citizens out of its 700,000 populations, it is not clear by the government reports or by GNHC reports on how the survey is conducted and what technique is used. The Center for Bhutan Studies needs to bring out a report on its survey evaluation for public scrutiny.

4. **Include indicators for natural disasters** – In the last 34 years from 1980-2014, nearly about 68,000 people have suffered from some of kind disaster in Bhutan. Getting idea of people's need, their perception of government in disaster prone times, supplying of basic needs and others can help improve government manage disasters in a better way.
5. **Expansion and contraction of GNH**: If certain dimensions of GNH contracts, or are being crowded out by material progress, then GNH Index needs to convey such information as the imbalances enter. In order to do so, it needs to create a platform for public deliberation.

Comparison of GNH to Social Progress Index and Policy Effectiveness Index:

Also with the advent of outcome oriented evidence-based indices, tools like Social Progress Index, Policy Effectiveness Index that builds up to an important legacy of measuring wellbeing unlike GDP. It becomes challenging to see whether GNH can serve well as an important tool that can be used by leaders in government, business and civil societies to benchmark success, improve policy, and catalyze action. The principle of *actionability* built in Social Progress or Policy Effectiveness index tests the importance of GNH.

The ***Social Progress Index***[34] (SPI), which measures social progress directly, independently of economic development, is a holistic and rigorous construct of measurement. It consists of three dimensions: *Basic Human Needs, Foundations of Wellbeing, and Opportunity*. Each dimension is composed of four components, and each component contains between two and six indicators.*[7]

Similarly, ***Policy Effectiveness Index*** (PEI) developed by Jindal School of Government and Public Policy[33] is a multidimensional and a multi-indicator measure, which is a composite of four component indices, namely: *Livelihood Opportunity Index; Social Opportunity Index; Rule of Law Index; and Physical Infrastructure Development Index*.*[8]

Both these indices try to reflect human wellbeing from basic needs to being able to enjoy: livelihood opportunities; a socially meaningful life; security of life and rule of law; and amenities for a sustained improvement in living standards. They provide a worthy tool for understanding holistic, objective, outcome-based measure of a country's wellbeing that is independent of GDP per capita.

When compared to *Gross National Happiness*, both the indices do not follow the core methodology approach of measuring citizens well being through surveys. SPI, which promotes

[7] *The first dimension, Basic Human Needs, assesses how well a country provides for its people's essential needs by measuring whether people have enough food to eat and are receiving basic medical care, if they have access to safe drinking water, if they have access to adequate housing with basic utilities, and if they are safe and secure. Overall SPI has 12 components and 54 distinct indicators. More can gathered by visiting - http://www.socialprogressimperative.org/*

*[8] ***Policy effectiveness index – PEI*** *– is an India based index, which tries to assess policies based on the four domains from the period 1981 to 2011. It attempts to provide evidence for some commonly made observations on India's development process and some other less recognized outcomes. Its report –* ***India Public Policy Report*** *finds that at the all-India level there is a gradual, but only a marginal, improvement in the policy effectiveness index over the three decades. It is being compromised by a near stagnancy in expansion of livelihood opportunities and deterioration in law and order and justice dispensation environment in the country. The state level analysis is instructive for undertaking policy correctives to address the chronic development gaps. More can be gathered by visiting - http://www.jsgp.edu.in/content/india-public-policy-report*

the principle of *actionability*[9] believes that subjective survey measures of wellbeing provide little guidance on what wellbeing actually means in terms of its components. SPI believe that there is no way to empirically explore causation, since the factors driving the perception of citizens cannot be disaggregated. Also, nor can results be robustly compared over time and between countries, since subjective perceptions are hard to benchmark and hold consistent.

However, Gross National Happiness which incorporates economic indicators with non-economic indicators believe that – happiness data can be disaggregated and can hold the principle of *actionablitiy* valid. It might be true that with subjective measures citizens may report higher levels of life satisfaction for reasons that we believe are inconsistent with social progress, such as by prioritizing current consumption at the expense of the environment, or by discriminating against minorities. But GNH as PEI or SPI also informs,

- **Governments** – about outcomes of policies executed and it even gathers information on what citizen's value and think. It creates a bottom line approach for governments to act on issues rather than just governments aspiring to commit. Furthermore, democratically elected governments generally stay only for 4 to 5 years. If a problem or issue is deep rooted then governments generally deployed a task force and it takes years to report on. Hence, GNH as SPI or PEI creates *accountability* and comes handy in tackling the problem through system.

  Also we often realize that governments often don't look on issues broadly. For instance, a Department of Health might just focus on few indicators of health and would not think

*[9] *A practical tool with sufficient specificity to help leaders and practitioners in government, business, and civil society to benchmark performance and implement policies and programs that will drive faster social progress.*

beyond on issues like – how much water is required, how much education is required to deliver health policies and so on. In that regard GNH*[10] (which is done once in two years) can help government track programs and help citizens make informed decisions.

- For **Businesses** – GNH helps them do evidence based policies, so that firms which are tackling basic needs of society can deliver them more effectively and efficiently. Public Private Partnership models are perfect examples, which can benefit from such indexes.

  Also, the broader message of GNH, PEI and SPI is that not only governments but also businesses, civil society should be committed in tackling social problems and help developed a sustainable path. Credit rating agencies can use such indices to rate firms on their progress to create solutions.

- **Civil society** - with the help of these survey/index results can make leaders, governments, and political parties *accountable* and *actionable*. Unlike PEI or SPI, it is true that GNH is limited in measuring the efficiency of effort put by governments or business in pursing the aim. Yet GNH can serve civil society well in understanding the path taken by government and various other stakeholders.

Succinctly, GNH does hold the principle of *actionability* valid to a certain extent when compared to SPI or PEI. It positively holds government *actionable* for the work done and can topple regimes if they don't deliver. For businesses, GNH does provide a framework and guideline on how a policy should be shaped and how it should be implemented. It is true that rigid labor regulations, stiffer rules to get business licenses are some of the reasons for Bhutan scoring 141

*[10] *Even SPI can do but only if it is rolled out more frequently.*

out of 189 countries in the World Bank's 2014 "*Doing Business*" Index. Nonetheless, GNH's policy screening tool serves businesses well enough to be committed to pursue Bhutan's vision – happiness.

However detailed study might be required to understand how happiness and business mix in Bhutan and how GNH till now has served as a practical and effective tool for government leaders and policymakers for fulfilling need based policies.

■ Areas of further research in GNH:

1. **Moving beyond cost benefit analysis**: Designing policies to enhance social and personal wellbeing is a new field, but the innovation of evaluating changes in wellbeing, rather than income, remains a concern. The traditional Cost Benefit Analysis becomes irrelevant in such scenarios. For instance, valuing an extra unit of wellbeing to someone already experiencing a high level of wellbeing when compared to someone who has low initial wellbeing becomes tricky. Work needs to be done in such areas. Governments, think tank organizations, funding agencies need to act on it. More experimentation in the design of policies would help inform policymakers on what works and what doesn't.
2. **Study needed on understanding the effectiveness of GNH**: It's compelling to see that GNH tires to give communities and citizens more information so that informed decisions are made. However, we don't know the counterfactual. Priorities of public policies differ from person to person. Hence it is vital to understand or do a research on effectiveness of GNH index in public policy priorities ranking.

3. **Freedom & Liberty**: One question, which is crucial in understanding the policies and use of GNH is that – is it impeding into the freedom and liberty of its citizens? In recent years, Bhutanese government has put ban on sale of tobacco, restrictions on tv channels & internet usage, mandatory usage of traditional dresses in public places, surrender of citizen's passport on return from their travel abroad trips and so on. It leads to the question - whether authoritarian policies are being adopted by the Bhutanese government. However, a study would be required in order to understand whether Bhutanese government is promoting its own version of happiness or of its citizens. An analysis of freedom & liberty in Bhutan is vital.
4. **Are happiness and sustainability compatible?** : An important challenge for GNH is to address the perceived tensions between happiness and sustainability. These tensions relate to trade-offs between individuals and society, short-term and longer-term goals, present and future generations, and human and nonhuman welfare. People can be happy and benefit from unsustainable government policies, even from ecological destruction.
5. **Is GNH a crude measure of happiness:** The GNH survey records for both subjective factors, such as how satisfied respondents are with their lives, and objective factors, like standard of living, health, and education, as well as participation in culture, community vitality, ecological health, and the balance between work and other activities. However, it remains to be seen whether such diverse factors correlate well with each other. Also, when trying to reduce them to a single number, it requires value judgments to be made. Therefore, it is crucial to understand the crudeness involved in measuring happiness.

6. **Is Bhutan using different policies for different needs of the population?** Having the ability to allocate different resources in accordance with the need of people, it is not sure if Bhutan is pursing needs based policies.

Inference from GNH:

The intent of GNH is laudable and rhetoric. It in some sense tries to promote a wider public dialogue around the index so that people can share their own understandings and appreciate how they could increase their own GNH. Tools like screening methods are being used on policies so that all agencies whether public or private are encouraged to think holistically.

Implementing and assessing new methods of economic development and models of sustainable growth requires political will, time, and a host of resources. Bhutan is in its premature stage, which needs better conceptualize, operationalize, measurement techniques, and critical evaluation of its indicators. It can be too early to say Bhutan/ GNH provides an ideal model to be followed or rejected. One has to remember that Bhutan is trying to build the future - the world's desire - that it is better to be approximately right than precisely wrong.

Hence the take away from Bhutan's GNH model is that - we should measure wellbeing more often and do so comprehensively. This would help governments improve policies, develop appropriate development plans and people live more satisfying lives. For policy makers from all walks of life the message is:

- Environment, ecology, culture, community, health, education should also be important criteria in measuring country's wellbeing and development.
- Such criteria's should also be a major criterion in policy choice.

Public policy does not lend itself to the controlled trials, but rather to the future evaluative research, which help in reforming the status quo. In the meantime, *Section 4* of this thesis has raised some uncertainties about GNH – an alternative to GDP, but conclusive evidence has yet to be produced.

Conclusion

The global community faces an enormous challenge in improving people's lives in a way that is sustainable, equitable and socially just. Measurement futurist can play a central role in meeting this challenge, and can change the way in which governments measure progress. One important point is clear that to increase human well-being, we need to ensure environmental sustainability, maintain cultural existence and community togetherness.

With changes to what is systematically measured, comes the opportunity to change what is widely deemed important, and that can facilitate changes to what is done in the name of progress. Hence, if governments can move beyond GDP and alter their measurement systems to give environmental sustainability and well-being their due weight, then they help pave the way for a happy, fulfilling and sustainable future for their own citizens, for others throughout the world, and for future generations.

Obviously their exists barriers but these can be overcome, not least through persistent pressure on the part of officials, thinkers, academics, the media and others, and through bold leadership that helps to shift the idea of sustainability in its entirety. As Albert Einstein observed: '*We can't solve problems by using the same kind of thinking we used when we created them*'. In other words, the successor of GDP should be a new set of metrics that integrates current knowledge of how ecology, economics, psychology and sociology collectively contribute to establishing and measuring sustainable well-being and development. Moreover, creating such successor will not only help measure a country's well being but also help measure the progress of new set of UN's Sustainable Development Goals (SDGs).

Care should be taken that devising and measuring new indices has become a growing industry where very little evidence is know of such measurements influencing policies. For instance, the UNDP advocates the conception of human development, and the more limited conception of it as measured by the HDI. UNDP does not use HDI to allocate its funding for development, rather it uses GDP per capita! Similarly, policymakers devoted a lot of time in refining the participatory action learning methods. Yet there is little evidence that district and village planning is informed by the outcomes of these exercises. Again must agree with Einstein that: '*Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted*." Therefore, arriving at conclusion about any indices, critical analysis is essential.

After that governments and global community can turn their attention to policy and political action. If undertaken with sufficiently broad participation, the hunt for the successor to GDP can be completed by 2015. Once that future is near then the global community can be hopeful about really improving lives, sustaining nature, protecting culture and being a global village.

Bibliography

1. (Oct 20, 2013) *Unhappy Journalists in 'Happy' Bhutan,* South Asia section, Wall street journal. URL - http://blogs.wsj.com/indiarealtime/2013/10/20/why-journalists-are-unhappy-in-happy-bhutan/ - Accessed on 30 March 2014
2. *Bhutan GNH Index*, The Centre for Bhutan Studies & GNH Research. URL - http://www.grossnationalhappiness.com/articles/ - Accessed on 30 March 2014
3. Costanza, Robert; Kubiszewski, Ida; Giovannini, Enrico et all (15 January 2014) *Development: Time to leave GDP behind,* Comment, Nature, Issue 7483, Volume 505. URL - http://www.nature.com/news/development-time-to-leave-gdp-behind-1.14499 Accessed on March 24, 2014
4. Royal Government of Bhutan (2012) *The Report of the High-Level Meeting on Wellbeing and Happiness: Defining a New Economic Paradigm*, New York: The Permanent Mission of the Kingdom of Bhutan to the United Nations. Thimphu: Office of the Prime Minister. URL - http://www.uncsd2012.org/content/documents/519BhutanReport_WEB_F.pdf Accessed on March 24, 2014
5. Ura, Karma; Alkire, Sabina; Zangmo, Tshoki; Wangdi, Karma (May 2012) *An Extensive Analysis of GNH Index* Centre for Bhutan Studies, Thimphu, Bhutan. URL - http://www.grossnationalhappiness.com/wp-content/uploads/2012/10/An%20Extensive%20Analysis%20of%20GNH%20Index.pdf Accessed on March 24, 2014

6. Kubiszewski, Ida; Costanza, Robert; Franco, Carol et all (2013) *Beyond GDP: Measuring and achieving global genuine progress,* Analysis, Ecological Economics 93, pp. 57–68, Elsevier. URL - http://www.uvm.edu/giee/pubpdfs/Kubiszewski_2013_Ecological_Economics.pdf Accessed on March 24, 2014
7. Hoellerer, Nicole (2012) *The Use of Qualitative and Ethnographic Research to Enhance the Measurement and Operationalisation of Gross National Happiness*,Volume 27, Journal of Bhutan Studies, Bhutan pp. 26-54. URL - http://www.bhutanstudies.org.bt/publicationFiles/JBS/JBS_Vol23/V23-2.pdf Accessed on March 24, 2014
8. Stiglitz, Joseph; Sen, Amartya; Fitoussi, Jean-Paul (2009) Report by the Commission on the Measurement of Economic Performance and Social Progress, Sarkozy commission URL - http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf Accessed on 28 March 2014
9. Sachs, Jeffrey; Helliwell, John; Layard, Richard (2013) *World Happiness Report*, New York: UN Sustainable Development Solutions Network. URL - http://faculty.arts.ubc.ca/jhelliwell/papers/WorldHappinessReport2013_online.pdf Accessed on 28 March 2014
10. Bhutan at a Glance 2013, National Statistics Bureau Royal Government of Bhutan URL - http://www.nsb.gov.bt/publication/files/pub6sh3499qo.pdf - Accessed on 28 March 2014

11. Gertner, Jon (May 13, 2010) The rise and fall of the G.D.P. , New York Times URL - http://www.nytimes.com/2010/05/16/magazine/16GDP-t.html?pagewanted=all&_r=2& - Accessed on 28 March 2014
12. Van der Lijn, Nick (2005-06) *Measuring well-being with social indicators, HDIS, PQLI, and BWI for 133 countries,* Faculty of Economics and Business Administration, Tilburg University, The Netherlands. URL - http://arno.uvt.nl/show.cgi?fid=3198 - Accessed on 28 March 2014
13. Ball, Philip (6 September 2010) *The price of happiness,* Column: Muse, Nature, doi: 10.1038/news.2010.447. URL - http://www.nature.com/news/2010/100906/full/news.2010.447.html - Accessed on 28 March 2014
14. Luechauer, David (July 21, 2013) *The False Promises of Bhutan's Gross National Happiness,* Global South Development Magazine URL - http://gsdmagazine.org/2013/07/21/the-false-promises-of-bhutans-gross-national-happiness/ Accessed on 28 March 2014
15. Luechauer, David (September 23, 2012) *Dr David's critique of Bhutan's GNH story,* IPA Journal URL - http://ipajournal.com/2012/09/23/dr-davids-critique-of-bhutans-gnh-story/ - Accessed on 28 March 2014
16. Results of the second national wide 2010 survey on gross national happiness, The Centre for Bhutan Studies & GNH Research URL -

http://www.grossnationalhappiness.com/docs/2010_Results/PDF/National.pdf - Accessed on 28 March 2014

17. Singer, Peter (13th September 2011) *Can We Increase Gross National Happiness?*, Project Syndicate URL - http://www.project-syndicate.org/commentary/can-we-increase-gross-national-happiness- - Accessed on 28 March 2014
18. Constanza, Robert (13th September 2011) *The Pursuit of Happiness*, Al Jazeera URL - http://www.stwr.org/economic-sharing-alternatives/gross-national-happiness-an-alternative-measure-of-progress.html#Costanza - Accessed on 28 March 2014
19. Heinberg, Richard (2011) *End of the growth*, Gross national happiness, chapter 6, part 3, Post Carbon Institute URL - http://www.postcarbon.org/article/488976-gross-national-happiness-end-of-growth - Accessed on 28 March 2014
20. (Dec 16th 2004) Bhutan - *The pursuit of happiness*, Thimphu, The economist. URL - http://www.economist.com/node/3445119 -Accessed on 29 March 2014
21. (2010) *The pursuit of happiness - A symposium on Bhutan's strategy of promoting well-being,* #614, SEMINAR. URL - http://www.india-seminar.com/2010/614.htm - Accessed on 29 March 2014
22. *2010 GNH survey results*, The Centre for Bhutan Studies & GNH Research. URL - http://www.grossnationalhappiness.com/survey-results/index/ - Accessed on 29 March 2014
23. Luis Maia, José and Mercedes Kweitel (September 15, 2003) Argentina – sustainable output growth after the collapse, Dirección Nacional de Políticas Macroeconómicas, Ministerio de Economía-Argentina. URL -

http://www.proargentina.gov.ar/documentos/dem_documentos/MECON%20-%20%20sustainable%20output.pdf - Accessed on 31 March 2014

24. Happy Planet Index – About page – URL - http://www.happyplanetindex.org/about/ - Accessed on 31 March 2014
25. OCED Better Life Index – Homepage – URL - http://www.oecdbetterlifeindex.org/ - Accessed on 31 March 2014
26. Talberth, John; Clifford Cobb, and Noah Slattery (February 2007) *The Genuine Progress Indicator 2006 - A Tool for Sustainable Development*, Redefining Progress, Oakland, CA URL - http://rprogress.org/publications/2007/GPI%202006.pdf - Accessed on 31 March 2014
27. Mitra, Sophie (2006) *The Capability Approach and Disability*, Journal of Disability Policy Studies, DOI: 10.1177/10442073060160040501. URL - http://www.flinders.edu.au/medicine/fms/sites/southgate_old/documents/journal%20club/2010/October/Capability%20Approach%20and%20Disability.pdf - Accessed on 31 March 2014
28. Harford, Tim (December 12, 2013) *The gross distortions of GDP,* FT Magazine. URL - http://www.ft.com/intl/cms/s/2/fadd10ea-6131-11e3-916e-00144feabdc0.html#axzz2xXsD8y5s - Accessed on 1st April 2014
29. (June 2011) *10th five year plan (2008-2013) – Mid term review report,* Gross national happiness commission, royal government of Bhutan. URL - http://www.gnhc.gov.bt/wp-content/uploads/2011/07/MTR_book_final.pdf - Accessed on 1st April 2014

30. (2013) *Happiness: Towards a New Development Paradigm, Report of the Kingdom of Bhutan,* Royal Government of Bhutan. URL - http://www.newdevelopmentparadm.bt Accessed on 1st April 2014

31. Seaford, Charles et all (2012) *Paper 2 – Beyond GDP measuring our progress,* Global Transition 2012. URL - http://www.stakeholderforum.org/fileadmin/files/PAPER%202_BEYOND_GDP_Final_vj(2).pdf - Accessed on 1st April 2014

32. OECD (2013), *OECD Guidelines on Measuring Subjective Well-being*, OECD Publishing. URL - http://dx.doi.org/10.1787/9789264191655-en Accessed on 1st April 2014

33. Malhotra, Rajeev et all (2014) *India Public Policy Report*, Centre for Development and Finance at Jindal School of Government and Public Policy, Oxford University Press, India. URL - http://www.jsgp.edu.in/pdf/IPPR-Summary.pdf

34. Porter, Michael; Scott Stern and Michael Green (2014) *Social Progress Index 2014*, Social Progress Imperative, United States. URL - http://www.socialprogressimperative.org/data/spi

Note - *Section 3* of this thesis '*Gross National Happiness'* heavily uses on Karma Ura et all's book on *An Extensive Analysis of GNH Index* published by Centre for Bhutan Studies, Thimphu, Bhutan as its core material.

Appendix

Some alternative of national indicators of welfare and well-being,

Indicator	Type	Units	Domains	Indicators	Area coverage	Temporal Coverage	Ref.	Website
Index of Sustainable Economic Welfare (ISEW) and Genuine Progress Indicator (GPI)	GDP modification	$	4	26	17 countries, several states and regions	1950-various	1-3	http://genuineprogress.net/
Genuine Savings	Income accounts modification	$	3	5	140 countries	1970-2008	4,5	http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTEEI/0,,contentMDK:20502388~menuPK:1187778~pagePK:148956~piPK:216618~theSitePK:408050,00.html
Inclusive Wealth Index	Capital accounts modification	$	4	8	20 countries	1990-2008	6	http://www.ihdp.unu.edu/article/iwr
Australian Unity Well-Being Index	Survey-based index	Index #	14	14	Australia	2001-present	7	http://www.deakin.edu.au/research/acqol/au wbi/index.php
World Values Survey	Survey-based index	Index #	10	100's	73 countries	1981-2008 intermittent	8,9	http://www.wvsevsdb.com
Gallup-Healthways Well-Being Index	Survey-based index	Index #	6	39	50 states in US	2008-present	10	http://www.well-beingindex.com/
Gross National Happiness	Survey-based index	Index #	9	33	Bhutan	2010	11	http://www.grossnationalhappiness.com/
Human Development	Composite Index	Index #	3	4	177 countries	1980-present	12	http://hdr.undp.org/en/
Happy Planet Index	Composite Index	Index #	3	3	153 countries	3 yrs	13,14	http://www.happyplanetindex.org/
Canadian Index of Well-Being	Composite Index	Index #	8	80	Canada	1994-present	15	https://uwaterloo.ca/canadian-index-wellbeing/
National Well-Being	Composite Index	Index #	5	5	56 countries	1 yr	16,17	http://www.ons.gov.uk/ons/guide-method/user-

OECD Better Life Index	Composite Index	Index #	11	25	36 OECD countries	1 yr	18,19	http://www.oecdbetterlifeindex.org
Well-Being of Nations	Composite Index	Index #	20	63	180 countries	1990-2000	20	http://sedac.ciesin.columbia.edu/data/set/cesic-wellbeing-of-nations
Sustainable Society Index	Composite Index	Index #	5	22	150 countries	2 yrs	21	http://www.ssfindex.com/

Endnotes:

[i] PQLI is objected on the ground that it is a limited measure, it has not included social and psychological properties, which is suggested by the term 'quality of life' – security, freedom, justice, human rights, satisfaction, happiness and so on. This was one the reason why 'Population Action International' prepared the 'International Human Suffering Index' in 1987, which measured the difference in living.

The PQLI measure keeps in view the welfare considerations, and it attaches the fruits of economic growth with human betterment. The GDP on the other hand, is criticized for its incapability to throw light on the distribution of income. Whereas the PQLI also analyses the nature of distribution of income as the more life expectancy, decrease in IMR and increase in literacy rates can become possible due to better distribution of income. The PQLI can also be used like GNP method to make comparisons between countries.

Realizing SCP in the companies: the SURESCOM model

Gintė Jonkutė*, Jurgis K. Staniškis

Institute of Environmental Engineering, Kaunas University of Technology
K. Donelaičio str. 20, LT-44239 Kaunas, Lithuania. E-mails: ginte.jonkute@ktu.lt, jurgis.staniskis@ktu.lt

Abstract

The encouragement of sustainable consumption and production (SCP) means in order to continuously improve the well-being of present and future generations is the most important goal and the main challenge stated in the European Union (EU) Sustainable Development Strategy, which was renewed in 2006.

Recently not only the companies and organizations are becoming more and more interested in implementation of sustainability principles in their business activities, consumers are also showing more concern about their consumption patterns. Unfortunately, actual consumption behaviour is changing very slowly and achievements in industrial efficiencies don‘t ensure significant positive changes. However, the responsibility for the present consumption patterns shouldn‘t be attributed only to companies and consumers. Progress in the area of SCP can be only achieved when all the interested groups in the SCP system, such as business, society, government and academic community, etc. are participating and cooperating. Therefore, in order to determine the most suitable direction for the actions, it is essential to analyse the relation between consumption and production systematically, considering all the aforementioned stakeholders in this system.

Although there are many attempts to propose sustainable business models for companies on purpose to implement SCP, the detailed model that can integrate aspects of all three dimensions (economic, ecological and social) of sustainable development, present practical engineering solutions and help to integrate engineering tools is still missing.

The SURESCOM (SUstainable and RESponsible COMpany) model that is presented in this paper is based on a classical closed loop cycle scheme for management system and suggests plan for consistent integration of SCP principles in organization‘s practices. Model integrates a set of well-known and wide accepted measures and tools, such as Resource Efficiency and Cleaner Production (RE & CP), Industrial Ecology (IE), Life Cycle Assessment (LCA), Eco-design, Eco-labelling and Environmental Product Declarations (EPD), Corporate Social Responsibility (CSR) according to ISO 26000 standard and sustainability reporting according to Global Reporting Initiative (GRI), that can be applied to the three main areas of company’s activities, namely manufacturing processes, products/ services and cooperation with stakeholders. According to the industrial ecology concept, the objective of this model is to minimize energy and material use as well as waste output, ant to eliminate the undesirable ‘‘rebound’’ effect. The model proposed is universal enough to be adapted for companies from various sectors of activities involving different manufacturing enterprises as well as service companies and organizations.

The model proposing implementation and systemic application of RE & CP and IE that improves manufacturing processes, LCA/ eco-design that develops products characteristics, integrated management system that refines management practices as well as CSR and sustainability reports that improves the communication with internal and external stakeholders can unsure more sustainable business development and could help to realize the broader SCP goals.

Keywords:
Sustainable Consumption and Production (SCP), companies, consumers, stakeholders, model, tools.

* corresponding author

1. Introduction

Sustainable Consumption and Production (SCP) was firstly put on the global policy agenda at the United Nations (UN) Conference on Environment and Development in Rio de Janeiro in 1992 (Szlezak et al., 2008) where unsustainable consumption and production patterns were recognized as the main factors influencing unsustainable world‘s development (Jackson, 2006; Liu et al., 2010; Szlezak et al., 2008). According to the classical definition of sustainable development (SD), The UN Commission on Sustainable Development described SCP as the consumption of products and services that are necessary to satisfy the essential needs and to ensure better quality of life, while reducing consumption of natural resources, emissions of toxic substances and wastes through all their life cycle on purpose not to cause the threat for the demands of future generations (Norris et al., 2003; Welfens et al., 2010; Welford et al., 1998). After 10 years from Rio conference, during the World Summit on Sustainable Development, that took place in Johannesburg in 2002, transformations in SCP models were recognized as one of the fundamental goals on the way to SD (Jackson, 2006), since without the essential changes in production and consumption system the global sustainable development goal can’t be achieved (Szlezak et al., 2008; Watson et al., 2010).

Although consumption is the most important factor for economic grow (Abeliotis et al., 2010), it can affect the environment in many different ways (Abeliotis et al., 2010; Hansen and Schrader, 1997; Orecchia and Zoppoli, 2007). Current unsustainable pattern of consumption and production determines climate change, pollution, accumulation of hazardous wastes, depletion of natural resources and decline in biological diversity as well as it influences increase in global migration, differences in economic and social welfare between and within countries (Čiegis and Zeleniūtė, 2008; Nash, 2009). Higher levels of consumption influence higher levels of production, which require larger inputs of energy and material as well as generate larger quantities of waste by-products (Kletzan et al., 2002; Orecchia and Zoppoli, 2007).

During the last decades initiatives in sustainable production have successfully focused on improving the resource efficiency in the manufacturing systems (Jackson, 2005; Sikdar, 2011). However, despite the improvement in results of environmental practices of many individual producers, increase in amount of general consumption often exceeds the achieved progress (the so-called *rebound* effect) (Staniškis and Stoškus, 2008; Staniškis et al., 2012; Stø et al., 2006). Thus, it is becoming obvious that technological approaches are not enough to realize the goal of SD without the critical assessment of human choices (Hertwich, 2005a; Jackson, 2005).

Consumers are more environmentally and socially aware today, but they still do not generally consume with concern (O’Rourke, 2005). Many different authors proposed that consumer behaviour is not only strongly influenced by such worldwide tendencies as globalization and rise in global economy, technological progress and innovations as well as demographic changes, but it is also influenced by many various elements of socio-cultural system and interactions between socio-cultural, economical, technological and many other factors (Goedkoop et al., 2003; Hofstetter et al., 2006; Hutter et al., 2010; Jackson, 2008; Kletzan et al., 2002; Mont and Power, 2010; Orecchia and Zoppoli, 2007; Peattie and Collins, 2009; Soron, 2010; Welfens et al., 2010). On purpose to influent more sustainable choices of consumers, first thing is to change their attitudes by shaping the demand for more sustainable products and services (Krantz, 2010). Consumers will not change their consumption habits as long as their sustainability awareness is low, and there is no sufficient information concerning production and product environmental performance (Staniškis et al., 2012). They also won‘t demand improved products until compelling alternatives are available in the market (O’Rourke, 2005).

Thus, in order to determine the most suitable direction for the actions towards SCP, it is essential to analyse the relation between consumption and production systematically, considering not only producers and consumers, but also all the other interested groups in the SCP system, such as government, NGOs, shareholders, suppliers, academic community and media, etc. Pressures from customers, government and other various stakeholder groups are identified as important triggers for companies to effectively incorporate sustainability issues into their business activities (Gold et al., 2010). However, integrating sustainability thinking and practice into organizational structure requires a systems approach with an appropriate management framework (Azapagic, 2003)

Therefore, first of all, the review of the most significant, in authors‘ opinion, models, frameworks, roadmaps and approaches, related to corporate sustainability as well as sustainable consumption and production are introduced in this paper. Then, as the analysis demonstrates the absence of detailed and universal model for realization of SCP goals in the company, that integrates environmental, social and economic aspects of sustainability, offers clear and practical solutions, incorporates appropriate, well-known engineering, management and communication tools and measures, controls characteristics of industrial processes, products and services as well as engages various stakeholders, the SURESCOM (SUstainable and RESponsible COMpany) model is presented.

2. Business role in promoting sustainable consumption and production

Sustainable or sustainability-oriented business is interpreted as multidimensional and normative idea about social, ecological and economic concerns (Lüdeke-Freund, 2010; Welford et al., 1998), where economic responsibility is defined as both beneficial for the producer and for those that are involved in the manufacturing process (Welford et al., 1998). The main challenge for sustainable enterprises is to improve competitiveness and business success through outstanding and voluntary social and ecological performance (Lüdeke-Freund, 2010) and to continuously apply the integrated strategy to manufacturing processes and products in order to avoid, or at least to minimize, the generation of all kinds of wastes (De Ron, 1998).

In the beginning of the twenty-first century many companies claim to be committed to sustainable development, assuming economic, ecological and social responsibility (Belz, 2006) and currently this concern is still growing (Venselaar et al., 2010). Entrepreneurs have already realized that their competitiveness and profitability are inextricably linked with the achievement of sustainability objectives in their companies (Hutter et al., 2010; Li and Leigh, 2010). Environmental and ethical matters are finally to become corporate core issues themselves, on an equal footing with conventional economic considerations (Gold et al., 2010). Sustainability is already seen not only as the possibility to increase efficiency or the necessity to meet legal requirements, it is now also about the fundamental changes in the organization of business and global consumption patterns, including rethinking of business models and supply chains in all the industrial sectors (Hutter et al., 2010).

Theorists and practitioners highlight the importance of business for progress in SCP (Lüdeke-Freund, 2010; Michaelis, 2003; Narson and Plc, 2007). The corporate sector must be the leader for sustainability because it is the engine of economic activity and development in the world (Hartman et al., 1999). Companies have a responsibility for promoting sustainable consumption through the design, production and distribution of products and services (Hansen and Schrader, 1997; Michaelis, 2003; Moratis and Cochius, 2011) and a responsibility for making consumers aware of the arguments for sustainable consumption (Moratis and Cochius, 2011). Producers need to improve the efficacy of resources use, promote the application and development of new environmentally friendly technologies, evaluate all the supply chain, materialize recycled or used products and resources as well as to minimize the generation of wastes (Staniškis and Stoškus, 2008). Companies can also contribute to SD by changing their own consumption practices by paying attention to office design, energy, water and waste management, as well as to office location and transport management. In doing so, they can also influence the environmental awareness and broader consumption patterns of their employees (Michaelis, 2003). Considering the fact that employees and their families are consumers themselves, engaging them on sustainability may also have a direct impact on society (Hutter et al., 2010). Moreover, businesses also play a vital role in building more sustainable society by practicing and promoting their more socially and environmentally responsible practices along the supply chains (Mont et al., 2010), providing incentives for their suppliers to conform to higher environmental and social standards (Michaelis, 2003).

However, integrating sustainability thinking and practice into organizational structure is not a trivial task and it requires a vision, commitment and leadership. It also requires a systems approach with an appropriate management framework that enables design, management and communication of corporate sustainability policies (Azapagic, 2003). The European Commission (EC) has recognized that challenges to achieve SCP are interlinked with resource use, available technologies, product design and consumer demands. Fundamentally, as SCP is dependent upon behavioural evolution from traditional and cultural patterns of choice to sustainable and energy efficient products and services, the over-arching challenge in realizing SCP is the creation of a whole circle incorporating life-cycle thinking, stimulating demand for better products, supporting eco-innovation and encouraging consumers to make better choices (EC, 2008; Nash, 2009). The analogous aspects to realize SCP goals, namely consumer engagement, life cycle metrics and exchanging innovation were also identified in the World's Economic Forum Annual Meeting in Davos in 2010 (Hutter et al., 2010).

3. Review of the models, frameworks and recommendations for sustainable business

Thus, to apply the discussed measures and initiatives systematically, companies need to change their business patterns (Charter, 2006) or even to define new business models focused on value creation rather than material throughput, to work towards closed loop systems (Hutter et al., 2010; Krantz, 2010), to support the adoption of cleaner products and processes, sustainable supply chains and further contributions towards SCP (Lüdeke-Freund, 2010). According to the raising demand to approach more sustainable consumption and production patterns, lots of various promising models, frameworks, roadmaps and recommendations have been created for companies to help on the way to sustainability. As sustainable consumption and production, equally like sustainable development, is a multidimensional process, it is unsurprising that the models and frameworks proposed represent different science branches and subjects, such as management and economics, business strategy and ethics, socio-economics, market research, consumer studies, environmental research, engineering, systems theory and others. So, it is evident that successful and efficient model for realizing SCP in the companies should definitely be interdisciplinary approach, integrating not only engineering tools, but also socio-economic measures. The review of the most significant, in authors' opinion, models, frameworks, roadmaps and approaches, related to corporate sustainability as well as sustainable consumption and production are chronologically presented further, covering the period from 1995 to 2013.

The review of the previous authors' frameworks and models for sustainable business has started by surveying some early attempts suggested by Gladwin et al. (1995), van Someren (1995), Starik et al. (1996), Rydberg (1995), Welford (1997) and Welford et al. (1998).

Gladwin et al. (1995) proposed a framework for corporations sustainability, practically based on the scheme of environmental management system (EMS), emphasizing not only reporting performance to stakeholders, but also actively influencing them to support organization's sustainable development behaviour through two-way communications and the development of real dialogue.

Van Someren (1995) suggested a product oriented framework, proposing creation of environmentally orientated innovations for products, processes and organization as one of the prerequisite characteristics of the ideal sustainable corporation, also emphasizing the importance of supply chain management.

Starik et al. (1996) developed a three-step (initial, analysis, improved) environmental strategy process, also partly based on EMS, called MOSAIC (mission, objectives, strategic orientation, action plan, implementation, controls), which involves the company to identify its current strategic environmental situations, to investigate actual and potential changes in stakeholders and issues, and finally, to develop strategic environmental responses to the combination of their current situations and future environmental conditions.

Rydberg (1995) offered a model, created under the Nordic Project for Sustainable Product Development, which is based on a broad life cycle approach. Author suggested three methods that are complementary in covering requirements of the customer, the producer as well as society and the environment. According to him, life cycle assessment (LCA) covers long-term environmental needs; life cycle cost (LCC) covers economy of the product (in the production and provision phases) and customer (in the use phase); and quality function development (QFD) assesses the requirements of the user relating to the quality aspects in a broader concept. This model requires assessing the full life cycle of the product or service, performing effective supply chain management and engaging various stakeholders in the two-way communication.

Welford (1997) proposed a three-dimensional approach to achieve sustainability in the business organization by examining impacts on people (a broadly social dimension), the planet (broadly environmental) and product (which include goods, services and profits). Author emphasizes the importance of stakeholder assessment, ensuring the priority to the employees, social audits and dialogue between the company and all interested parties. Traditional environmental management techniques were suggested to be used for the planet dimension together with environmental auditing as well as education and campaigning. One of the benefits of the proposed model is the potential to link targets to tools and, in turn, tools to reports (Welford et al., 1998).

Welford (1997) also advocated a model combined of many earlier authors attempts and brought together many of the issues discussed in the previous frameworks. It is based on six-Es consisting of the environment, empowerment, economics, ethics, equity and education - the areas where the business should have a clear policy and agenda for change. To realize this task, author suggested a list of indicative tools for each of six areas, e.g. LCA and EMS for environment, equal opportunities for empowerment, profits/ surplus for economics, transparency of objective for ethics, fair trade policy and activity for equity as well as training, customer information and community involvement for education, etc. (Welford et al., 1998)

Welford et al. (1998) suggested the conceptual framework for SCP in the service sector based on Welford‘s previous six-Es approach. The model was extended with seventh E, namely employment. As previous model was too static, authors introduced supply chain management into new model. This was done by recognizing that SCP is made up of supply side issues and demand side issues. In managing sustainable production there is a need to consider not only practices of the firm, but also to put the pressure on other firms further down the supply chain. Equally, in influencing sustainable consumption, it is important to influence consumers' choices and to manage provision of the products and services. The operationalization of this framework was proposed to be based on three stages, namely planning, evaluation and review that are closely related to the classical EMS scheme. In summary, authors provided three things: a framework for building a vision on SD at the corporate level that integrates supply chain management; a measurement framework based on idea of continuous improvement; and a process of SD dialogue that involves two-way communications between firms and their stakeholders.

Later recommendations for companies to promote SCP as well as sustainability at a broader context were proposed by Robèrt (2000), Lee (2001), Michaelis (2003), Azapagic (2003), Panapanaan et al. (2003), Kjaerheim (2005), Howarth and Hadfield (2006), Diakaki et al. (2006), Čiegis and Grunda (2007), Geng et al. (2007), Waage (2007) and Maon et al. (2008).

Robèrt (2000) offered a framework for sustainable development followed by various concepts and tools for measuring and monitoring the activities, such as EMS, LCA, ecological footprinting, etc., that together form the general 5-leveled model composed of principles of ecosphere (social and ecological constitution), system conditions (principles of sustainability), strategy (principles of sustainable development), activities as well as concepts and tools (metrics).

Lee (2001) offered a framework for developing sustainable tourism destinations that integrates such SD tools as cleaner production (CP), EMS, eco-labelling and Local Agenda 21. Author proposed that CP in this model acts as an integrating factor that links all the other tools and concepts and could not only promote pollution prevention but also can contribute to the efforts in sustainable development when applied in the integrative manner with other tools. Integrating the aforementioned tools and concepts in the model could combine their strengths and compensate weaknesses and though it won‘t be easy to integrate them, it is clear that such combining could bring significant benefits.

Michaelis (2003) demonstrated that corporation is only a part of a broader system of economic, social, cultural and technological influences. Author suggested the role of business on purpose to promote SCP could be in three different types of change, precisely development of new technologies and practices; changes in the economic and legal incentives that shape both production and consumption; as well as changes in the values and discourses that shape the culture of business, government, media and civil society. He concluded with the idea that though businesses have an important role to play in a shift towards sustainable consumption, corporate culture is only likely to change as a part of a wider shift, demanded and promoted by civil society.

Azapagic (2003) presented a framework for a Corporate Sustainability Management System (CSMS) that is potentially applicable across industry and can help corporations to contribute to a further understanding and application of sustainability on the practical level. The model is based on a systems approach and developed in collaboration with industry to provide a structured step-by-step guide to organizations in defining a sustainability strategy and designing a practical course of action that will help them to become more sustainable. To facilitate an easier integration into the organizational structure, this system has been modelled to be compatible with the familiar structure of the general management system standards, such as Quality Management as well as EMS.

Panapanaan et al. (2003) presented an initial framework for managing corporate social responsibility (CSR) management processes and prospects in Finnish companies that could serve as an initial guide in understanding, streamlining and managing CSR. In this framework, CSR management goes through the five essential activities as follows: organization and structure; planning; implementation; monitoring and evaluation; as well as communication and reporting. An important aspect of these management steps is an overarching principle and commitment to continuous improvement and constant communication that proves this framework is based on a classical management scheme.

Kjaerheim (2005) suggested how the present CP model can be improved and how CP concept can be expanded to address the needs of developing countries more directly. As there is a demand for continuous improvement in environmental work, author proposes to think about continuous improvement in methodologies for sustainable society. In order to reach this aim, he attempted to incorporate the phase of continuous improvement into the CP training methodology for stakeholders (industrial companies, universities, consultants, etc.) by integrating this tool in the EMS, where other classical SD tools, such as LCA, environmental product declarations (EPD), eco-design, etc. should be also included.

Howarth and Hadfield (2006) proposed a practical model for assessment of SD aspects of a product not by evaluating the specific product only but also taking into account manufacturing company and its manufacturing site. During the analysis the impact of each issue/ concern is scored (0-10) and linked to one of the three dimensions of SD (social, environmental or economic) and the level of impact (high, medium or low), and finally defined as a benefit or risk.

Diakaki et al. (2006) proposed an approach based on the principles of risk assessment technique that have a potential to cover all the aspects of organisation activities as well as to provide a basis for the identification of most significant indicators for environmental performance evaluation (EPE). Authors also offered a generic closed loop approach for EPE to identify and assess appropriate performance indicators, that is composed of six steps, such as identification of environmental aspects, definition of environmental goals, identification of initial set of performance indicators, identification of final set of performance indicators, EPE as well as process evaluation. Each indicator is identified to assess the progress towards the particular environmental aspect of the organisation‘s activities and a related environmental risk is assessed to determine the most significant ones.

Čiegis and Grunda (2007) presented business transformation into sustainable business strategic management model composed of the stages of transformation planning, changes implementation and results evaluation that are further divided into coherent steps. Authors suggested incorporating of various tools, such as industrial ecology (IE), CP, eco-design, green procurement, EMS and many others in the implementation stage of the model. The model concept is obviously based on a classical closed-loop management cycle.

Geng et al. (2007) suggested an integrated model for implementing eco-industrial development in China companies that is composed of four key elements, such as policies and regulations, economic instruments, information system and capacity building. This integrated approach could help to consider not only the demands of all stakeholders, but also the current situation in a specific country. Although the authors proposed this model to be implemented in the companies of China, it is definitely could be adapted to the other developing countries as well.

The practical roadmap for integration of sustainability issues in the company proposed by Waage (2007) is built on previous frameworks for understanding the interconnections between various assessment principles, strategies, actions and tools related to IE, human and labour rights and CSR. The suggested roadmap is a process composed of four-phases, namely establishment of sustainability context, definition of sustainability issues, assessment as well as act and receives feedback that can be clearly linked to the typical design process. The latter involves successive phases - understand, explore, define and refine as well as implement. The explore approach can help company to focus on critical sustainability impacts across a full systems- and life cycle-oriented perspective on materials and processes in ecological and social systems. Author also noted that government regulation and standards could significantly contribute to these voluntary approaches.

Maon et al. (2008) proposed an integrative framework for designing and implementing CSR, based on plan-do-check/improve (partly closed loop)-mainstream scheme and composed of four closed loop stages (sensitize-unfreeze-move-refreeze) with nine steps, namely raising CSR awareness inside the organization; assessing corporate purpose in its societal context; establishing a vision and a working definition for CSR; assessing current CSR status; developing a CSR-integrated strategic plan; implementing the CSR-integrated strategic plan; communication about CSR commitments and performance; evaluating CSR-integrated strategies and communication and institutionalizing CSR. Authors strongly emphasized the role of continuous dialogue with stakeholders during all the stages. They also identified factors that are critical to the successful development and implementation of CSR in the corporate, organizational and managerial levels.

The ultimate group of newest guidances to incorporate sustainability issues into the core of the business was submitted by Jenkins (2009), Birkin et al. (2009, 2009a), Staniškis and Arbačiauskas (2009), Svensson et al. (2010), Lüdeke-Freund (2010), Welfens et al. (2010), Li and Leigh (2010), Bagdonienė and Paulavičienė (2010), Venselaar et al. (2010), Laurinkevičiūtė and Stasiškienė (2010), Kinderytė (2010, 2011) as well as Kinderytė et al. (2010), Dobes (2011), Staniškis et al. (2012) and Leitão et al. (2013).

Jenkins (2009) suggested a „business opportunity“ model of CSR for small and medium enterprises (SMEs) that is composed of five main steps, namely values setting, scoping, corporate social opportunities, strategy and benchmarking. These steps are integrated in a closed loop cycle that allows implicating that the aforementioned model is based on a classical management scheme. Author emphasized the identifying and engaging key stakeholders as well as prioritizing key areas as crucial aspects for realizing this model.

Birkin et al. (2009, 2009a) reviewed a set of steps developed by a consortium of Nordic companies on purpose to integrate SD into existing business models rather than revising the business models itself. These steps are investigating, internalizing, integrating and innovating and they should be implemented in three key areas, namely capability and understanding, commitment and partnerships. Each step within every area has a clear list of all recommended actions, although this model is designed mainly for managing social dimension of the sustainability in the company and there is a clear lack of direct technological aspects.

Staniškis and Arbačiauskas (2009) presumed that to ensure sustainable industrial development, systematic application of the following tools is needed, namely CP to improve production processes; product oriented measures based on LCA approach, particularly eco-design, to improve product characteristics; integrated management systems to improve management practices; as well as sustainability reporting to improve communication with internal and external stakeholders. These SD measures were proposed to be integrated using the classical total management cycle, which could be taken as a basis for incorporation of the key SD development tools.

Svensson et al. (2010) created a corporate model of sustainable business practices that can be divided into five separate, but at the same time interconnected elements, namely foundation, communication, guidance, outcome and reconnection. According to authors, the model should be continuous and an iterative process. It could provide an approach to solve the issue of complexity in developing, managing and monitoring sustainable business practices from an ethical perspective and has a challenge to combine the sustainability of business practices with ethical concerns in the marketplace and society. However, to become more sustainable, it is not enough for business to improve only one social dimension of sustainability without positive changes in two remaining pillars.

Lüdeke-Freund (2010) proposed the business eco-innovation model based on four pillars, namely value proposition, infrastructure management, customer interface as well as financial aspects and their nine building blocks - key partners, key activities, key resources, cost structure, value proposition, customer relationships, channels, customer segments and revenue streams. The aforementioned model is an integral eco-innovation part of a conceptual framework, which also combines transformational strategies (sufficiency, efficiency and consistency), the role of business models and pivotal ideas about value creation with regard to private and public benefits.

Welfens et al. (2010) integrated research on pedagogic expertise and environmental psychology theory that support translating sustainable mind-set and behaviour into recommendations for educational practice of SCP. Authors proposed that the necessary steps towards SCP are raising awareness of consumers and producers through education for sustainability and communication campaigns; greening markets through taxes, subsidies and labelling; and making sustainable consumption easy through suitable infrastructure that allows easy access to sustainable products and services, as well as transparent markets and labelling.

Li and Leigh (2010) suggested environmental process flowchart that illustrates the integration between EMS and EPE and provides a systematic approach for companies to improve their environmental sustainability. The presented process flowchart is based on a classical EMS scheme as a framework for companies to achieve better outcomes in environmental performance. As EPE should be fully integrated in the environmental management process, it is proposed to be done through adopting and developing measurement model and selecting appropriate indicators as well as implementing effective initiatives. Authors developed EPE model by using Balanced Scorecard (BSC) approach. They emphasized the strategic objectives such as good environmental culture, improving employee skills and environmental awareness, enhancing the communication channels across the supply chain as well as improving the use of new technologies to be all critical for achieving sustainability in any organization. The strategic mapping tool associated with BSC approach was also generated for the case study company with examples of environmental performance indicators (EPIs) and examples of initiatives for implementation. However, it should be noted that the model is mostly adapted for the evaluation of environmental sustainability, but not for the overall sustainability of the company.

Bagdonienė and Paulavičienė (2010) adopted a model based on integrated management system with „Plan-do-check-improve“ cycle as a tool for controlling social responsibility issues in organization. Authors proposed that such an integrated management system is one of the alternatives to associate social responsibility with a management on purpose to help the organizations to improve their sustainability. However, concentrating mainly on the social aspects with a lack of engineering instruments, make this model not sufficient enough to guarantee desirable changes in the overall sustainability of the companies.

Venselaar et al. (2010) presented FOCISS (focusing innovation for a sustainable strategy) framework for developing a sustainable business strategy that can help to determine real core business related sustainability issues for an individual company. Authors proposed a stepwise approach covering themes, issues, sensible innovations and priorities that must be essential element of a company‘s strategy for taking part in sustainability transitions. To get a complete overview of all the aspects (planet, people and profit), the matrix covering the whole production chain and product life cycle as well as all sustainability issues was suggested for critical assessment. However, this model could be not clear enough for companies to implement it independently because of the absence of concrete measures and tools.

Kinderytė et al. (2010, 2011) as well as Kinderytė et al. (2010) proposed an original integrated sustainability assessment-management model for practical improvement of enterprise's sustainability. This model was created on the basis of a processing model, Deming cycle, an environmental performance algorithm by ISO 14031 standard, integrated into the environmental management system. The set of 20 qualitative indicators that are universal to any industrial enterprise and the set of 24 quantitative indicators that should be adjusted to a certain industry sector (in this case it was printing industry sector) were identified using experts' survey. In order to improve a composite sustainability index and to integrate qualitative and quantitative indicators, the methodology of composite index, suggested by Krajnc and Glavič (2005) as well as Singh et al. (2007) was used, consisting of such steps as selection of indicators, normalization, weighting of indicators, aggregation of qualitative, quantitative and level of actions taken towards sustainable development sub-indices as well as interpretation of results showing the sustainability level of the company.

Laurinkevičiūtė and Stasiškienė (2010) suggested a sustainable development decision-making model for SMEs, based on the integration of sustainability management accounting (SMA) and composite sustainable development index methodologies. The adoption of SMA part enables companies to identify their key SD problems based on financial aspects and to select sustainability performance indicators that are related to these problems. As aforementioned indicators do not reflect the overall enterprise sustainability and includes only problematic aspects, the composite sustainable development index methodology, proposed by Krajnc and Glavič (2005) as well as Singh et al. (2007) and also applied in earlier reviewed algorithm by Kinderytė et al. (2010), was integrated into a sustainability decision making model. The composite sustainable development index, consisting of economic, environmental and social sub-indices can help companies to improve their sustainability performance.

Dobes (2011) developed a methodology for the Initial Review of Innovation Opportunities for Sustainable Consumption and Production (IR SCP) both for industrial enterprises and for practitioners from private sector and academia. Within this methodology all levels of an enterprise's management pyramid are assessed in a systematic way from the perspective of possible SCP opportunities for improvements which could enhance enterprise's value. IR SCP is suggested to be implemented at four basic levels - products, processes, systems and stakeholders, proposing the most appropriate voluntary instruments for SCP innovations for the given company at each level, such as eco-design and eco-labelling for products level, CP for processes, EMS for management system and strategy levels as well as CSR and environmental reporting for both visions and aims and stakeholders levels. Author proposed initial review procedure composed of four steps - screening, determination of areas for improvements, instrument selection and instrument analysis that were followed by subsequent development of innovation project procedure. Aforementioned methodology was created within the project Partnership for Sustainable Consumption and Production implemented in the Czech Republic by ENVIROS Prague and was pilot base implemented in tens organizations. This assessment procedure is also partially based on EMS scheme, however it doesn't provide clear and comprehensive structure for activities to realize this methodology in the company.

Staniškis et al. (2012) developed a model of a system of SCP. The model corresponds to the type II model in accordance with industrial ecology concept with the objective to minimize energy and material use as well as waste output, and to eliminate the ‘‘rebound’’ effect. The system is governed by life cycle approach, and its functionality is ensured by application of practically tested preventive tools that enable sustainability performance improvement of production processes, products and sufficient information flow to consumers. In order to provide the information about sustainability performance of production and products for consumers, sustainability reporting, environmental product declarations and eco-labels are suggested to use. Although, authors presumed that SCP will not be possible if any of the elements or the flows of the system fail. However, it should be noted that this theoretical model does not propose the particular algorithm for its implementation and adaptation to be practically applied in the enterprises.

Leitão et al. (2013) proposed a roadmap to support the development of new business models, their implementation and evaluation, composed of a set of tools to support each stage from business model design to its evaluation. The proposed model consists of four typical phases: analysis, design, implementation and evaluation that each is divided into a set of activities and suggests different methods and tools to drive companies in the new business models definition and management.

Summarising all the models, frameworks, roadmaps and recommendations discussed above, it should be noticed that the major part of them was created on a basis of the closed loop cycle proposed by Dr. Deming or, in other words, classical management system scheme for continuous improvement. The examples of such models were proposed by Welford et al. (1998), Azapagic (2003), Panapanaan et al. (2003), Kjaerheim (2005), Diakaki et al. (2006), Čiegis and Grunda (2007), Maon et al. (2008), Jenkins (2009), Staniškis and Arbačiauskas (2009), Li and Leigh (2010), Bagdonienė and Paulavičienė (2010), Kinderytė (2010, 2011) as well as Kinderytė et. al. (2010), Staniškis et al. (2012) and Leitão et al. (2013); whereas Gladwin et al. (1995); Starik et al. (1996), Welford (1997), Waage (2007), Birkin et al. (2009, 2009a) and Dobes (2011) adopted this scheme only partially.

As sustainable development is composed of three dimensions of equal value, the definite requirement arises to consider all of them referring the models for SCP in the companies. However, the analysis of surveyed publications showed that not all of the models proposed are structured according to this request. The suggestions to manage aspects related with ecological, social and economic segments together were observed in the studies of van Someren (1995), Starik et al. (1996), Rydberg (1995), Welford (1997) and Welford et al. (1998), Robèrt (2000), Lee (2001), Michaelis (2003), Azapagic (2003), Kjaerheim (2005), Howarth and Hadfield (2006), Čiegis and Grunda (2007), Geng et al. (2007), Waage (2007), Staniškis and Arbačiauskas (2009), Lüdeke-Freund (2010), Welfens et al. (2010), Li and Leigh (2010), Venselaar et al. (2010), Kinderytė (2010, 2011) as well as Kinderytė et al. (2010), Laurinkevičiūtė and Stasiškienė (2010), Dobes (2011), Staniškis et al. (2012) and Leitão et al. (2013). Some of the authors highlighted only one dimension of sustainability, generally social, emphasizing the role of CSR management on the way to corporate sustainability. The models and frameworks based on CSR were suggested by Gladwin et al. (1995), Panapanaan et al. (2003), Maon et al. (2008), Jenkins (2009), Birkin et al. (2009, 2009a) and Svensson et al. (2010).

The treating of stakeholders in an ethically and socially responsible manner has been seen as the core of CSR (Singh et al., 2007). These various external parties have a strong influence with regard to sustainability issues of the enterprise (Ayuso, 2006), thus the efficient cooperation between company and its stakeholders are especially stressed in the suggestions of van Someren (1995), Starik et al. (1996), Rydberg (1995), Welford (1997) and Welford et al. (1998), Michaelis (2003), Azapagic (2003), Kjaerheim (2005), Geng et al. (2007), Waage (2007), Staniškis and Arbačiauskas (2009), Welfens et al. (2010), Li and Leigh (2010), Bagdonienė and Paulavičienė (2010), Venselaar et al. (2010), Dobes (2011), Staniškis et al. (2012) as well as Leitão et al. (2013).

The significance of business in raising the environmental awareness and more sustainable purchasing and consumption choices and behaviour of their customers through information providing, education and many other practices are unquestioned responsibility of organizations. Despite this assumption, only few authors, namely Welford et al. (1998), Michaelis (2003), Panapanaan et al. (2003), Geng et al. (2007), Birkin et al. (2009, 2009a), Welfens et al. (2010) as well as Staniškis et al. (2012) excluded consumers as a separate group within the stakeholder universe in their approaches for realizing SCP in the companies.

However, not in all of these aforementioned models and frameworks, that incorporate every dimension of sustainability, the presence of clear, concrete and wide-known tools and measures were observed. The ultimate lack was noticed especially in the case of engineering tools. The recommendations to collectively employ various classical SD tools and measures, such as CP, IE, LCA and eco-design, etc., that could combine their strengths and compensate weaknesses, were presented by Rydberg (1995), Welford et al. (1998), Robèrt (2000), Lee (2001), Waage (2007), Čiegis and Grunda (2007), Staniškis and Arbačiauskas (2009) as well as Staniškis et al. (2012). Moreover, several attempts to integrate these tools into the “plan-do-check-improve” cycle of management system, that could guarantee their effective operation and control, were suggested in Azapagic (2003), Staniškis and Arbačiauskas (2009), Kjaerheim (2005) and partially in Dobes (2011) publications.

4. The SURESCOM (SUstainable and RESponsible COMpany) model

Consequently, the comprehensive analysis that was performed in the previous section demonstrates that there are lots of scientific aspirations to propose progressive sustainable business models for companies on purpose to reach the worldwide goal of SCP, however, a detailed and universal model, that integrates environmental, social and economic aspects of sustainability, offers clear and practical solutions, incorporates appropriate, well-known engineering, management and communication tools and measures, controls characteristics of industrial processes, products and services as well as engages various stakeholders is still absent. And what is more, there is also a deficiency of a clear and detailed algorithm for the implementation of such model, that should assess the current sustainability conditions of the company and, according to them, could help to select and introduce the most suitable tools for the particular enterprise to achieve its environmental and social performance goals.

Considering the lack of complete framework and recommendations for companies to realize SCP, the SURESCOM (SUstainable and RESponsible COMpany) model is presented in this paper (see Fig. 1).

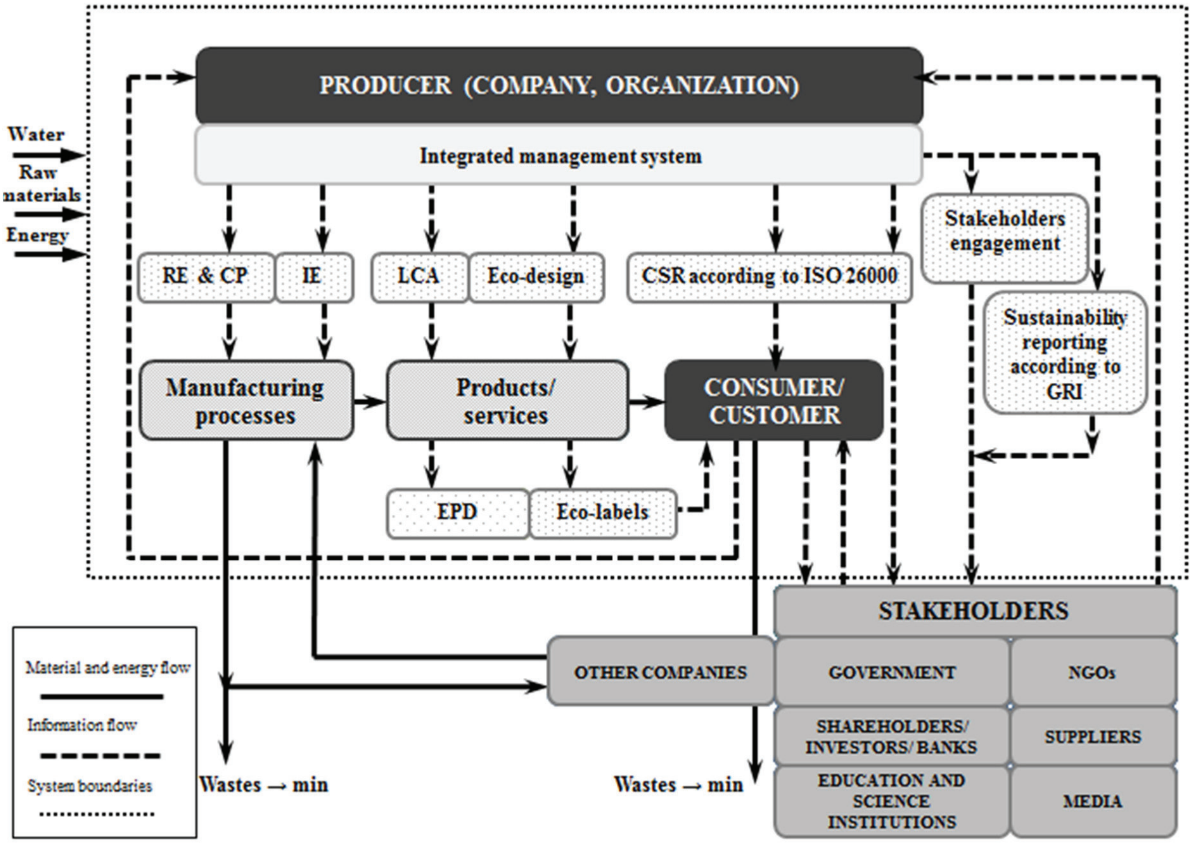


Fig. 1. The SURESCOM (SUstainable and RESponsible COMpany) model

This model is based on a classical closed loop cycle scheme for management system and suggests plan for consistent integration of SCP principles in organization‘s practices. Model integrates a set of well-known and wide-accepted SD measures and tools that can be applied to the three main areas of company’s activities, namely manufacturing processes, products/ services as well as cooperation with stakeholders. The framework, similarly to the real life SCP system in a broad sense, is a complex structure, composed of a number of links not only in the manufacturing cycle, but also between producer (company), consumers/ customers as well as various groups of stakeholders. These links in the model are presented as the flows of materials, energy and information, circulating in the system and crossing its boundaries. According to the industrial ecology concept, the objective of this model is to minimize energy and material use as well as waste output, and to eliminate the ‘‘rebound’’ effect, which can be observed when achievements in industrial efficiency is compensated by unsustainable changes in consumer behaviour.

The detailed structure and operation of this model is described below.

Businesses, governments as well as other interested groups have developed many methodologies and patterns to promote SCP (Narson and Plc, 2007) and the variety of them are still growing rapidly (Robèrt et al., 2002). Thus, currently there are a number of tools aimed at reducing environmental impacts and improving sustainability performance (Staniškis et al., 2012) that address specific aspects and issues of sustainability (Lee, 2001). As these different tools are directed towards different objects and fields they can‘t easily replace one another (Finnveden and Moberg, 2005). However, a systems approach consistent with basic principles and the requirements of sustainability shows that these tools are complementary and can be used in parallel for strategic sustainable development (Korhonen, 2004; Robèrt et al., 2002). Integrating various measures could help to combine their strength and to compensate their weaknesses (Allenby, 2000; Lee, 2001; Seiffert and Loch, 2005).

Research and practical experience shows that to ensure sustainable industrial development, the following tools should be systematically applied, such as CP to improve production processes, eco-design to improve product characteristics, integrated (environmental, quality and occupational health and safety) management systems to improve management practices, sustainability reporting based on sustainability performance evaluation to improve communication with internal and external stakeholders (Staniškis and Arbačiauskas, 2009; Staniškis et al., 2012). However, this variety of tools has led to some confusion regarding the questions how best to apply them (Robèrt et al., 2002). As it is obvious that sustainability must be integrated in all the parts of the organizational structure (Cowan et al., 2010), the systematic approach is needed, such as EMS which could systematically combine elements from other tools and concepts (Lee, 2001) and ensure that all the environmental issues are appropriately identified, controlled and monitored (Glavič and Lukman, 2007). It provides a mechanism for responding to changing environmental conditions and requirements, reporting on environmental performance and reinforcing continual improvements, also embracing supply chain management activities (Glavič and Lukman, 2007). Whereas EMS can be used as an administrative tool for systematic management of activities and meeting the targets and objectives (Lee, 2001), without it, the implementation of comprehensive principles in an effective operational way would be difficult or even impossible (Robèrt et al., 2002).

Companies are confronted with the urgent demand to manage environmental, quality as well as health and safety issues all at the same time. In spite of originating from different aspects of the company's performance, these management systems have a lot in common. The productive activities of all them have to be understood, planned systematically, implemented, realized, controlled, audited and improved (Fresner and Engelhardt, 2004). The beneficial idea is to develop an integrated management system that could combine these separate management systems (Fresner and Engelhardt, 2004) and help to control them altogether. Considering this potential, as a basis for a model integrated management system was chosen that combines and manages all the other tools.

Progress in the process of sustainable industrial development depends on the enterprises that systematically apply sustainable industrial development tools enabling them continuous performance improvement aimed at production processes, products, and communication with internal and external stakeholders (Staniškis et al., 2012). Consequently, three groups of tools are subdivided in the model, namely resource efficiency (RE) and CP as well as IE, that are applied to manufacturing processes; LCA, eco-design, partially eco-labels and EPD that are employed to products/services; and CSR, stakeholders engagement activities as well as sustainability reporting, that altogether with aforementioned eco-labels and EPD compose the set of measures for stakeholder management.

Resource efficiency and cleaner production. RE and CP is the strategy to reduce environmental impacts of businesses by systematically applying the principles of prevention. It mainly focuses on the industrial aspects (Fresner and Engelhardt, 2004; Glavič and Lukman, 2007; Lee, 2001) and contributes to the efforts in sustainable development when applied in an integrative manner with other tools and concepts (Lee, 2001).

Industrial ecology. IE is an objective and multidisciplinary tool (Allenby, 2000; Clift, 2006; Geng et al., 2007; Von Hauff and Wilderer, 2008) that optimizes material and energy use in products and processes, systemically making them analogous to natural systems in the industrial environment (Geng et al., 2007). IE is often considered as an essential step to develop systemic attitude while seeking to reduce environmental impacts of consumption (Hertwich, 2005) and it can expand the concepts of cleaner technologies and CP behind the boundaries of companies (Kovács, 2008). The aim of IE application in this model is to catalyse the use of the wastes that are generated in manufacturing processes of one company by utilizing them as raw materials or fuel in the industrial processes of the other company(-ies) and vice versa.

Life cycle assessment. LCA, altogether with IE, is considered as one of the main analytic tools with the systematic basis for environmental management (Clift, 2006). It can help to assess the eco-efficiency of a product by applying the life cycle assessment tools from the product's design stage to its termination (Clift, 2006; Finnveden and Moberg, 2005; Kjaerheim, 2005; Li and Leigh, 2010; McLellan et al., 2009; Ness et al., 2007; Nissinen et al., 2005; Robèrt, 2000; Roy et al., 2009). Application of tools that are based on life cycle thinking allows determining the most problematic phases in the overall life cycle of product and considering them helps to create new design strategy by adopting the best alternative (Rocha et al., 2006; Roy et al., 2009; Solgaard, 2003).

Eco-design. Tools that are based on LCA can also successfully link cleaner production with sustainable consumption (Sonnemann and de Leeuw, 2006). One of the examples that is integrated in the model is eco-design, which takes into account the complete life cycle of a product and considers environmental aspects at all stages of a process, in order to create products that make the lowest possible environmental impact throughout their life cycle (Glavič and Lukman, 2007).

Eco-labelling. The main barriers for consumers to make correct and more sustainable choices during their purchasing practices are the lack of clear and available information about environmental and social impacts of products and services, the gaps of knowledge and the lack of consciousness (Nissinen et al., 2007; Snoek et al., 2010) as well as the fact that consumers do not trust the information provided by firms (O'Rourke, 2005). Therefore, producers and business in the broad sense must undertake the educator role (Welford et al., 1998), trying to provide clear, comprehensible and correct information about the results of their environmental activities (Moratis and Cochius, 2011; Staniškis and Stoškus, 2008; Stevens, 2010). This missing information for consumers can be subjected in the form of various mandatory and voluntary eco-labels and EPD (Nash, 2009; Peattie, Collins, 2009; Snoek et al., 2010; Staniškis and Stoškus 2008) that currently encompass wide range of separate products and their groups (Snoek et al., 2010). The fact of transparency of the provided information can be guaranteed by third-party certified type I eco-labels (Horne, 2009; Snoek et al., 2010).

Environmental product declarations. EPD is a good example of practical application of LCA methodology. Although it is attributed to the category of type III eco-labels that provide quantified environmental data of a product's life cycle in the wider form of reports (Horne, 2009), however, considering its significance, this tool is incorporated in the model as a separate measure. A third-party certified EPD can help companies to prove the environmental benefits of their products according to the health, environmental and resources criteria in comparison with analogous characteristics of other competitive alternatives in the market (Kjaerheim, 2005; Rocha et al., 2006).

Corporate social responsibility. According to the well-known Stakeholder theory that forms the basis for CSR, organizations have obligations to many individuals and groups who both affect and are affected by the organization (Ayuso, 2006; Roca and Searcy, 2012). Nowadays CSR is an integral part of the business vocabulary and is regarded as a crucially important issue in management (Übius and Alas, 2009). Many such activities described as CSR come under legal compliance, such as environmental legislation (Brilius, 2010; Castka and Balzarova, 2008; Jenkins, 2009; Kovács, 2008; Lozano, 2010; Von Hauff and Wilderer, 2008), including the concerns of internal and external stakeholders (Von Hauff and Wilderer, 2008) and meeting ethical responsibilities expected by society (Castka and Balzarova, 2008). There are probably hundreds of various codes of conducts, industry norms, global initiatives (Castka and Balzarova, 2008) and other high-level declarations of principles related to CSR as well as a growing number of national standards and guidance documents that instrumentally deal with the CSR agenda (Castka and Balzarova, 2008). Responding to the demand for a globally acceptable standard that would outline a generic approach in the area of CSR (Castka and Balzarova, 2008), the International Organization for Standardization (ISO), initiated the development of ISO 26000 - an international standard for CSR (Castka and Balzarova, 2008; ISO, 2010; Jonkutė at al., 2011; Schwartz and Tilling, 2009), Guidance on social responsibility in 2004, scheduled for release in 2010 (Waddock, 2008). Considering its universality and clarity, precisely this standard is included in the model for CSR implementation and management in the company.

Stakeholder engagement. Stakeholder management has been regarded as the tool to connect company's strategy to social and ethical issues (Labuschagne et al., 2005; Singh et al., 2007). According to Birkin et al. (2009), the growing number of supporting, well-informed stakeholder groups and improvement in sustainability conditions of the company are directly related. Each of the stakeholder groups has a specific set of priorities, expectations and strengths, and thus different possibilities to influence the environmental situation of the company (Madsen and Ulhøi, 2001). The theory of the firm was formerly based on the view that business interacts with external parties only through the market. Today, this simplistic model has been replaced by an understanding that the firm and society have many non-market interactions, some of which are governed by forces other than purely economic ones, e.g. political, cultural and moral forces (Madsen and Ulhøi, 2001).

The separate stakeholder group in the model, lying within the system boundaries, is appointed to consumers/ customers that have not only the major role for successful company's operation, but also for efficient implementation of SCP initiatives in the company in a broad sense. Currently businesses are encouraged to go beyond the legal obligations and assume roles previously occupied by the public sector, such as supporting education (Jenkins, 2009). In this case, the responsibility of the company regarding the consumers' management in the area of SCP mainly spreads out through the aforementioned initiatives, such as supply of fair and comprehensive information about the impacts of products/ services in the form of eco-labels, as well as through education and training actions, public campaigns, etc. Moreover, companies can also influence consumers' choices through the suitable supply as it is a necessary prerequisite for sustainable consumption (Hansen and Schrader, 1997; Welford et al., 1998).

Although the other stakeholder groups in the model, namely government, non-governmental organizations (NGOs), shareholders/ investors/ banks, suppliers, education and science institutions, media and other companies as well as others, are yet behind the system boundaries, however, they are strongly connected with company through various specific interactions that depend on the particular case. To enable more sustainable patterns of consumption and production will ultimately mean that new forms of cooperation and partnership will need to be created, especially between governments and companies (Charter, 2006; Michaelis, 2003). Company can also be included in societal initiatives and public campaigns, cooperating with different NGOs (Welford et al., 1998). It is also very important for enterprise to consider the actions towards other companies in the supply chain (Welford et al., 1998), influencing their suppliers and even sub-suppliers to correspond the appropriate environmental and social criteria (Kovács, 2008; Mont et al., 2010; Sonnemann and de Leeuw, 2006). In this context, not only the supply of goods but also company's communication policies are relevant (Hansen and Schrader, 1997). Suppliers often have a lack of knowledge on the impacts of their practices, so the education programs for suppliers can help to create long-term cooperation and to ensure their support spreading sustainable initiatives of the company (Mont et al., 2010). On purpose to realize SCP issues, closer collaboration between companies and education or science institutions, media as well as other companies are also very relevant. Contribution between different enterprises can help to promote collective solutions for general problems, to disseminate knowledge (Mouzakitis et al., 2003) and to share the experiences, tools and methodologies (Hutter et al., 2010).

Sustainability reporting. Environmental and social aspects of the current business activities are commonly managed, controlled and communicated in the form of public reports according to a widely known triple bottom line concept (Birkin et al., 2009). Voluntary sustainability reports have two goals - to assess the present condition of the organization as well as to demonstrate the attempts and progress in economic, environmental and social aspects for the various stakeholder groups and broad society as well. The most widely recognized standards for sustainability reporting are the standards of ISO 14000 series, Eco-Management and Audit Scheme (EMAS) as well as Social Accountability 8000 standard, however the leading role belongs to Global Reporting Initiative (GRI) sustainability guidelines (Glavič and Lukman, 2007; Krajnc and Glavič, 2005, 2005a; Lozano, 2010) launched in 1997 by the UN Environment Programme (UNEP). GRI uses a hierarchical framework in three focus areas, namely social, economic and environmental (Azapagic, 2003; Kinderytė, 2010; Singh et al., 2009, 2012)

According to its wide acceptance and clear triple bottom line concept, it is recommended to use the GRI guidelines for sustainability reporting in the model. Although, it must be noted that GRI framework offers a wide set of performance indicators that are not likely to be all relevant to each organization. Thus, companies should follow GRI recommendations only partially, individually selecting the most suitable indicators for reporting the actions in particular company.

Feedback mechanisms from consumers to companies as well as between various stakeholders in SCP system. On purpose to operate the model successfully, the efficient feedback mechanisms to company from consumers and other stakeholders as well as interconnections between them own are necessary. Recent studies highlight pressures from customers, government and other various stakeholder groups as triggers for firms to effectively incorporate sustainability aspects into their management schemes (Gold et al., 2010). According to Kovács (2008), consumers have the strongest external pressure for companies to realize sustainability issues. Through their purchases and behaviour, consumers can demand more sustainable approaches from companies in terms of both their products and processes. They can create markets for sustainable products, stimulate enterprises to innovate and develop new efficient technologies (O'Rourke, 2005) as well as they can stimulate the competition between companies regards the sustainability achievements (Hertwich, 2005; Snoek et al., 2010). Moreover, consumers can play varying roles in the market not only as buyers, but also as protestors or witnesses of companies' reputation boycotting unsustainable enterprises (Iles, 2007; O'Rourke, 2005).

Not only companies might be expected to demand products from their suppliers that fulfil specified environmental requirements, it seems that the opposite is also true (Madsen and Ulhøi, 2001). However, without the strong leadership from government, the changes in overall SCP system would be hardly obtained (Jackson, 2008). Intervention of governmental institutions is needed in establishing policy framework conditions that promote SCP (Staniškis et al., 2012). The major influencing potential of government can be realized mainly through economic measures, such as quotas and penalties, bans for harmful products, mandatory requirements and financial incentives. NGOs have a potential to act as the mediators between business and consumers (Snoek et al., 2010). Their respond can be materialized through the pressure to establish environmental policies of the company and to present annual public sustainability reports as well as through various information campaigns for companies and consumers, experience sharing seminars, contests, etc. The examples of impacts that education and science institutions can adjust towards companies involve theoretic and practical training, consultations for the most problematic aspects, most suitable tools, assessment of the overall sustainability state of the company, recommendations for adapting and applying of innovations, etc. It should also be remarked that stakeholders can stimulate the SCP initiatives in the model not only through the direct feedback to companies, but also indirectly through the cooperation actions between one another. The press and media have such a significant indirect influence on all the other stakeholders (Madsen and Ulhøi, 2001) through the exclusive role to publicize the information about unsustainable enterprises, their negative impacts, activities and harmful products that indirectly determines companies' reputation and the demand for their products.

To conclude, business itself can undertake a fair part of the agenda towards SCP, however, the problems in many SD areas are too complex for companies to deal them alone. On purpose to solve these problems, business should work in a closer collaboration with various stakeholders, sharing the knowledge, tools and innovative thinking in order to catalyse behavioural change leading to more sustainable practices, increased competitiveness and a healthier environment (Barber, 2007; Narson and Plc, 2007).

5. Conclusions and considerations

The comprehensive analysis of earlier studies displayed that despite the variety of sustainable business models for companies on purpose to realise SCP, a detailed and universal model, that integrates environmental, social and economic aspects of sustainability, offers clear and practical solutions, incorporates appropriate, well-known engineering, management and communication tools and measures, controls characteristics of industrial processes, products and services as well as engages various stakeholders is still absent.

Corresponding to that need, the SURESCOM (SUstainable and RESponsible COMpany) model is presented in this paper. This theoretical model is based on a classical closed loop cycle scheme for integrated management system and suggests plan for consistent integration of SCP principles in organization‘s practices. The model integrates a set of well-known and wide-accepted SD measures and tools, such as RE & CP, IE, LCA, eco-design, eco-labels, EPD, CSR, stakeholders engagement activities as well as sustainability reporting, that can be applied to the three main areas of company's activities - manufacturing processes, products/ services as well as communication with stakeholders.

The model proposes a complex structure, composed of number of links not only in the manufacturing cycle, but also between producer (company), consumers/ customers as well as various groups of stakeholders, that are presented as the flows of materials, energy and information, circulating in the system and crossing its boundaries. According to the industrial ecology concept, this model can help to minimize energy and material use as well as waste output, to increase consumers acceptance while eliminating the undesirable ‘‘rebound’’ effect.

Moreover, the model proposed is universal enough to be adapted for companies from various sectors of activities involving different manufacturing enterprises as well as service companies and organizations by applying particular modifications. It also can be helpful for companies that already have implemented their management systems. In such case, only part of the presented recommendations would have to be integrated additionally.

References

1. Abeliotis, K., Koniari, C., Sardianou, E., 2010. The profile of the green consumer in Greece. Int J Consum Stud. 34, 153-160.
2. Allenby, B., 2000. Industrial ecology, information and sustainability. J Future Stud Strat Think Policy. 2, 2, 163-171.
3. Ayuso, S., 2006. Adoption of voluntary environmental tools for sustainable tourism: analysing the experience of Spanish hotels. Corp Social Resp Environ Manage. 13, 207-220.
4. Azapagic, A., 2003. Systems approach to corporate sustainability. A general management framework. Trans IChemE. 81, 303-316.
5. Bagdonienė, D., Paulavičienė, E., 2010. The integration of social responsibility and organization‘s management system (in Lithuanian). Econ Manage. 15, 366-373.
6. Barber, J., 2007. Mapping the movement to achieve sustainable production and consumption in North America. J Clean Prod. 15, 499-512.
7. Belz, F.-M., 2006. Marketing in the age of sustainable development. Proceedings: Changes to Sustainable Consumption, Copenhagen. 20-21 April, 2006, pp. 299-314.
8. Birkin, F., Cashman, A., Koh, S.C.L., Liu, Z., 2009. New sustainable business models in China. Bus Strat Environ. 18, 64-77.
9. Birkin, F., Polesie, T., Lewis, L., 2009a. A new business model for sustainable development: an exploratory study using the theory of constraints in Nordic organizations. Bus Strat Environ. 18, 277-290.
10. Brilius, P., 2010. Dynamic model of dependencies between economic crisis and corporate social responsibility contribution to sustainable development. Econ Manage. 15, 422-429.
11. Castka, P., Balzarova, M.A., 2008. ISO 26000 and supply chains - on the diffusion of the social responsibility standard. Int J Prod Econ. 11, 274-286.
12. Charter, M., 2006. Sustainable consumption & production, business and innovation. A discussion document. Proceedings: Changes to Sustainable Consumption, Copenhagen. 20-21 April, 2006, pp. 243-252.
13. Clift, R., 2006. Sustainable development implications for chemical engineering. Chem Eng Sci. 61, 4179-4187.
14. Cowan, D.M., Dopart, P., Ferracini, T., Sahmel, J., Merryman, K., Gaffney, S., Paustenbach, D.J., 2010. A cross-sectional analysis of reported corporate environmental sustainability practices. Regul Toxicol Pharm. 58, 3, 524-538.
15. Čiegis, R., Grunda, R., 2007. Strategic management process of business transformation into sustainable business (in Lithuanian). Manage Org Syst Res. 44, 19-34.
16. Čiegis, R., Zeleniūtė, R., 2008. Sustainable development aspects in economic development (in Lithuanian). Appl Econ Syst Res. 2/1, 37-54.
17. De Ron, A.J., 1998. Sustainable production: the ultimate result of a continuous improvement. Int J Prod Econ. 56-57, 99-110.
18. Diakaki, C., Grigoroudis, E., Stabouli, M., 2006. A risk assessment approach in selecting environmental performance indicators. Manage Environ Qual. 17, 2, 126-139.
19. Dobes, V., 2011. Initial Review for Sustainable Consumption and Production - diagnosis tool overcoming barriers for cleaner production. Proceedings of 2nd International Conference SCP: how to make it possible, Kaunas. 29-30 September, 2011, pp. 25-27.
20. European Commission communication on the sustainable consumption and production and sustainable industrial policy action plan. COM, 2008; 397/3 at 3.
21. Finnveden, G., Moberg, Å., 2005. Environmental systems analysis tools - an overview. J Clean Prod. 13, 1165-1173.

22. Fresner, J., Engelhardt, G., 2004. Experiences with integrated management systems for two small companies in Austria. J Clean Prod. 12, 623-631.
23. Geng, Y., Haight, M., Zhu, Q., 2007. Empirical analysis of eco-industrial development in China. Sust Dev. 15, 121-133.
24. Gladwin, T.N., Klause, T.S., Kennelly, J.K., 1995. Beyond eco-efficiency: towards socially sustainable business. Sust Dev. 3, 1, 35-43.
25. Glavič, P., Lukman, R., 2007. Review of sustainability terms and their definitions. J Clean Prod. 15, 1875-1885.
26. Goedkoop, M.J., Nijdam, D.S., Wilting, H.C., 2003. Tools and indicators to assess consumption patterns. Report of the First International Workshop on Sustainable Consumption, Arcadia Ichigaya, Tokyo. 19-20 March, 2003, pp. 1-10.
27. Gold, S., Seuring, S., Beske, P., 2010. Sustainable supply chain management and inter-organizational resources: a literature review. Corp Social Resp Environ Manage. 17, 230-245.
28. Hansen, U., Schrader, U., 1997. A modern model of consumption for a sustainable society. J Consum Policy. 20, 443–468.
29. Hartman, C.L., Hofman, P.S., Stafford, E.R., 1999. Partnerships: a path to sustainability. Bus Strategy Environ. 8, 255-266.
30. Hertwich, E.G., 2005. Consumption and industrial ecology. J Ind Ecol. 9, 1-2.
31. Hertwich, E.G., 2005a. Life cycle approaches to sustainable consumption: a critical review. Environ Sci Tech. 39, 13, 4673-4684.
32. Hofstetter, P., Madjar, M., Ozawa, T., 2006. Happiness and sustainable consumption. Psychological and physical rebound effects at work in a tool for sustainable design. Int J LCA. 1, 105-115.
33. Horne, R.E., 2009. Limits to labels: The role of eco-labels in the assessment of product sustainability and routes to sustainable consumption. Int J Consum Stud. 33, 175-182.
34. Howarth, G., Hadfield, M., 2006. A sustainable product design model. Mater Des. 27, 1128-1133.
35. Hutter, L., Capozucca, P., Nayyar, S., 2010. A roadmap for sustainable consumption. Deloitte Review. 7, 47-58.
36. Iles, A., 2007. Making the seafood industry more sustainable: creating production chain transparency and accountability. J Clean Prod. 15, 577-589.
37. International Organization for Standardization (ISO), 2010. Guidance on social responsibility (ISO 26000:2010).
38. Jackson, T., 2005. Live better by consuming less? Is there a “double dividend” in sustainable consumption? J Ind Ecol. 9, 1-2, 19-36.
39. Jackson, T., 2006. Readings in sustainable consumption. Earthscan, pp. 1-23.
40. Jackson, T., 2008. The challenge of sustainable lifestyles. State of the World. WorldWatch.
41. Jenkins, H., 2009. A „business opportunity“ model of corporate social responsibility for small- and medium-sized enterprises. Bus Ethics. 18, 1, 21-36.
42. Jonkutė, G., Staniškis, J.K., Dukauskaitė, D., 2011. Social responsibility as a tool to achieve sustainable development in SMEs. Environ Res Eng Manage. 3(57), 67-81.
43. Kang, Y., Ryu, M.-H., Kim, S., 2010. Exploring sustainability management for telecommunications services: A case study of two Korean companies. J World Bus. 45, 415-421.
44. Kinderytė, L., 2010. Methodology of sustainability indicators determination for enterprise assessment. Environ Res Eng Manage. 2(52), 25-31.
45. Kinderytė, L., Čiegis, R., Staniškis, J.K., 2010. Assessment of enterprise performance for efficient sustainability. Transform Bus Econ. 9, 3(21), 104-118.
46. Kinderytė, L., 2011. Sustainability assessment of enterprises in printing industry. Environ Res Eng Manage. 4(58), 59-64.
47. Kjaerheim, G., 2005. Cleaner production and sustainability. J Clean Prod. 13, 329-339.
48. Kletzan, D., Köppl, A., Kratena, K., Schleicher, S., Wüger, M., 2002. Modelling sustainable consumption. From theoretical concepts to policy guidelines. Empirica. 29, 131-144.
49. Korhonen, J., 2004. Industrial ecology in the strategic sustainable development model: strategic applications of industrial ecology. J Clean Prod. 12, 809-823.
50. Kovács, G., 2008. Corporate environmental responsibility in the supply chain. J Clean Prod. 16, 1571-1578.
51. Krajnc, D., Glavič, P., 2005. A model for integrated assessment of sustainable development. Resour Conserv Recyc. 43, 189-208.
52. Krajnc, D., Glavič, P., 2005a. How to compare companies on relevant dimensions of sustainability. Ecol Econ. 55, 551-563.
53. Krantz, R., 2010. A new vision of sustainable consumption. The business challenge. J Ind Ecol. 14, 1, 7-9.
54. Labuschagne, C., Brent, A.C., van Erck, R.P.G., 2005. Assessing the sustainability performances of industries. J Clean Prod. 13, 373-385.

55. Laurinkevičiūtė, A., Stasiškienė, Ž., 2010. Sustainable development decision-making model for small and medium enterprises. Environ Res Eng Manage. 2(52), 14-24.
56. Lee, K.F., 2001. Sustainable tourism destinations: the importance of cleaner production. J Clean Prod. 9, 313-323.
57. Leitão, A., Cunha, P., Valente, F., Marques, P., 2013. Roadmap for business models definition in manufacturing companies. Forty Sixth CIRP Conference on Manufacturing Systems 2013. Procedia CIRP. 7, 383 - 388.
58. Li, X., Leigh, S., 2010. Integrating environmental management system with environmental performance evaluation across the supply chain: a systematic and balanced scorecard approach. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010.
59. Liu, J., Wang, R., Yang, J., Shi, Y., 2010. The relationship between consumption and production system and its implications for sustainable development of China. Ecol Complex. 7, 212-216.
60. Lozano, R., 2010. A guideline to corporate voluntary efforts to contribute to sustainable development. Knowledge Collaboration and Learning for Sustainable Innovation. ERSCP-EMSU conference, Delft, The Netherlands, October 25-29, 2010.
61. Lüdeke-Freund, F., 2010. Towards a conceptual framework of business models for sustainability. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010.
62. Madsen, H., Ulhøi, J.P., 2001. Integrating environmental and stakeholder management. Bus Strategy Environ. 10, 77-88.
63. Maon, F., Lindgreen, A., Swaen, V., 2009. Designing and implementing corporate social responsibility: an integrative framework grounded in theory and practice. J Bus Ethics. 87, 71-89.
64. McLellan, B.C., Corder, G.D., Giurco, D., Green, S., 2009. Incorporating sustainable development in the design of mineral processing operations - review and analysis of current approaches. J Clean Prod. 17, 1414-1425.
65. Michaelis, L., 2003. The role of business in sustainable consumption. J Clean Prod. 11, 915-921.
66. Mont, O., Kogg, B., Leire, C., 2010. Sustainable businesses practices in supply chains: experiences from Swedish companies. Knowledge Collaboration and Learning for Sustainable Innovation. ERSCP-EMSU conference, Delft. 25-29 October, 2010.
67. Mont, O., Power, K., 2010. Understanding the complexity of consumer behaviour and implications for the sustainable consumption discourse. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010
68. Moratis, L., Cochius, T., 2011. ISO 26000: the business guide to the new standard on social responsibility. Greenleaf Publishing Limited, Sheffield, pp. 2-7.
69. Mouzakitis, Y., Adamides, E., Goutsos, S., 2003. Sustainability and industrial estates: the emergence of eco-industrial parks. Environ Res Eng Manage. 4 (26), 85-91.
70. Narson, N., Plc, J.M., 2007. Sustainable consumption and production. a business primer. University of Cambridge programme for industry.
71. Nash, H.A., 2009. The European Commission's sustainable consumption and production and sustainable industrial policy action plan. J Clean Prod. 17, 496-498.
72. Ness, B., Urbel-Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools for sustainability assessment. Ecol Econ. 60, 498-508.
73. Nissinen, A., Grönroos, J., Heiskanen, E., Honkanen, A., Katajajuuri, J.-M., Kurppa, S., Mäkinen, T., Mäenpää, I., Seppälä, J., Timonen, P., Usva, K., Virtanen, Y., Voutilainen, P., 2007. Developing benchmarks for consumer-oriented life cycle assessment-based environmental information on products, services and consumption patterns. J Clean Prod. 15, 538-549.
74. Nissinen, A., Heiskanen, E., Grönroos, J., Honkanen, A., Katajajuuri, J.-M., Kurppa, S., Mäkinen, T., Seppälä, J., Timonen, P., Usva, K., Virtanen, Y., Voutilainen, P., 2005. Developing LCA-based benchmarks for sustainable consumption - for and with users. Proceedings of 10th European Roundtable on Sustainable Consumption and Production (ERSCP), Antwerp. 5-7 October, 2005, pp. 1-21.
75. Norris, G.A., 2003. Revisions to LCA needed to address sustainable consumption. Report of The First International Workshop on Sustainable Consumption, Arcadia Ichigaya, Tokyo. 19-20 March, 2003, pp. 1-13.
76. Orecchia, C., Zoppoli, P., 2007. Consumerism and environment: does consumption behaviour affect environmental quality? CEIS Working Paper No. 261.
77. O'Rourke, D., 2005. Market movements. Nongovernmental organization strategies to influence global production and consumption. J Ind Ecol. 9, 1-2, 115-128.
78. Panapanaan, V.M., Linnanen, L., Karvonen, M.-M., Phan, V.T., 2003. Roadmapping corporate social responsibility in Finnish companies. J Bus Ethics. 44, 133-148.

79. Peattie, K., Collins, A., 2009. Guest editorial: perspectives on sustainable consumption. Int J Consum Stud. 33, 107-112.
80. Robèrt, K.-H., 2000. Tools and concepts for sustainable development, how do they relate to a general framework for sustainable development, and to each other? J Clean Prod. 8, 243-254.
81. Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M., 2002. Strategic sustainable development - selection, design and synergies of applied tools. J Clean Prod. 10, 197-214.
82. Roca, L.C., Searcy, C., 2012. An analysis of indicators disclosed in corporate sustainability reports. J Clean Prod. 20, 103-118.
83. Rocha, C., Frazão, R., Zackrisson, M., Christiansen, K., 2006. The use of communication tools and policy instruments to facilitate changes towards sustainability. Proceedings: Changes to Sustainable Consumption of the Workshop of the SCORE! Network, Copenhagen. 20-21 April, 2006, pp. 169-175.
84. Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., Shiina, T., 2009. A review of life cycle assessment (LCA) on some food products. J Food Eng. 90, 1-10.
85. Rydberg, T., 1995. Cleaner products in the Nordic countries based on the life cycle assessment approach - the Swedish Product Ecology Project and the Nordic Project for sustainable product development. J Clean Prod. 3(1/2), 101-105.
86. Schwartz, B., Tilling, K., 2009. „ISO-lating“ corporate social responsibility in the organizational context: a dissenting interpretation of ISO 26000. Corp Social Resp Environ Manage. 16, 289-299.
87. Seiffert, M.E.B., Loch, C., 2005. Systemic thinking in environmental management: support for sustainable development. J Clean Prod. 13, 1197-1202.
88. Sikdar, S.K., 2011. Analysis of systems for sustainability and decision making. Book of abstracts of the 2nd International Conference SCP: how to make it possible, Kaunas. 29-30 September, 2011, p. 18
89. Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2007. Development of composite sustainability performance index for steel industry. Ecol Ind. 7, 565-588.
90. Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2009. An overview of sustainability assessment methodologies. Ecol Ind. 9, 189-212.
91. Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2012. An overview of sustainability assessment methodologies. Ecol Ind. 15, 281-299.
92. Snoek, M., Safaya, S., Simili, E., 2010. Transparency is the key towards sustainable production and consumption. Knowledge Collaboration and Learning for Sustainable Innovation. ERSCP-EMSU conference, Delft. 25-29 October, 2010.
93. Solgaard, A., 2003. Life-Cycle thinking - a thrust for sustainable consumption. Report of The First International Workshop on Sustainable Consumption, Arcadia Ichigaya, Tokyo. 19-20 March, 2003.
94. Sonnemann, G., de Leeuw, B., 2006. Life cycle management in developing countries: state of the art and outlook. Int J LCA. 1, 123-126.
95. Soron, D., 2010. Sustainability, self-identity and the sociology of consumption. Sust Develop. 18, 172-181.
96. Staniškis, J.K., Stoškus, L., 2008. Recommendations for putting sustainable consumption and production into practice in Lithuania. Results of the conference "Time for Action - Towards Sustainable Consumption and Production in Europe". Environ Res Eng Manage. 3(45).
97. Staniškis, J.K., Arbačiauskas, V., 2009. Modelling sustainable management process on enterprise level. 5th International Vilnius Conference, EURO Mini Conference KORSD-2009, Vilnius Gediminas Technical University, Vilnius. 30 September - 3 October, 2009.
98. Staniškis, J.K., Arbačiauskas, V., Varžinskas, V., 2012. Sustainable consumption and production as a system: experience in Lithuania. Clean Techn Environ Policy. 14, 1095-1105.
99. Stevens, C., 2010. Linking sustainable consumption and production: the government role. Nat Resour Forum. 34, 16-23.
100. Starik, M., Throop, G.M., Doody, J.R., Joyce, M.E., 1996. Growing an environmental strategy. Bus Strategy Environ. 5, 1, 12-21.
101. Stø, E., Throne-Holst, H., Strandbakken, P., Vittersø, G., 2006. A multi-dimensional approach to the study of consumption in modern societies and the potentials for radical sustainable changes. Proceedings: Changes to Sustainable Consumption of the Workshop of the SCORE! Network, Copenhagen. 20-21 April, 2006, pp. 13-20.
102. Svensson, G., Wood, G., Callaghan, M., 2010. A corporate model of sustainable business practices: an ethical perspective. J World Bus. 45, 336-345.
103. Szlezak, J., Reichel, A., Reisinger, H., 2008. National sustainable consumption and production (SCP) strategies in the EU - a comparative review of selected cases. Environ Res Eng Manage. 3(45), 54-60.

104. Übius, Ü., Alas, R., 2009. Organizational culture types as predictors of corporate social responsibility. Eng Econ. 1(61), 90-99.
105. Van Someren, T.C.R., 1995. Sustainable development and the firm: organizational innovations and environmental strategy. Bus Strategy Environ. 4(1), 23-33.
106. Venselaar, J., van der Kelft, D., van Aart, R., 2010. Fociss: a framework for developing a sustainable business strategy. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010.
107. Von Hauff, M., Wilderer, P.A., 2008. Industrial ecology: engineered representation of sustainability. Int Res System Sust Sci. 3, 103-115.
108. Waage, S.A., 2007. Re-considering product design: a practical ''road-map'' for integration of sustainability issues. J Clean Prod. 15, 638-649.
109. Waddock, S., 2008. Building a new institutional infrastructure for corporate responsibility. Academy of Management Perspectives. August, 2008, pp. 87-108.
110. Watson, D., Hansen, M.S., Lorenz, U., Szlezak, J., Mortensen, L., Stanners, D., 2010. A framework for indicator-based reporting on sustainable consumption and production. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010.
111. Welfens, J.M, Liedtke C, Nordmann, J., 2010. Sustainable consumption: between unsustainable reality and people's willingness to act. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft. 25-29 October, 2010.
112. Welford, R.J., 1997. Hijacking environmentalism: corporate responses to sustainable development. Earthscan, London.
113. Welford R., Young, W., Ytterhus, B., 1998. Towards sustainable production and consumption: a literature review and conceptual framework for the service sector. Eco-Manage Audit. 5, 38-56.

Exploring the gap between vision and practice of corporate sustainability in SMEs, experiences from 18 Dutch cases

ir. Sjors Witjes[1], Dr. Walter J.V. Vermeulen[2], Prof.dr. Jacqueline M. Cramer[3]

Keywords:
Corporate Sustainability, SME, integration, business activities, change agent trigger, management system.

A B S T R A C T

Although there is a growing awareness among companies of the importance of Corporate Sustainability (CS), they struggle in getting CS integrated into their business activities. Most of the literature and research on CS focus on large corporations, with limited debate on Small and Medium Sized Enterprises (SMEs). Research shows that most CS initiatives have been developed in isolation of business activities, and have not yet been integrally linked to the business activities. This gap between vision and practice can be overcome by developing a clear vision on CS and letting this vision be integrated in the organization by a change agent.

The research question of this article is how Dutch SMEs fill the gap between CS vision and practice supported by external change agents. The research presented analyses eighteen SMEs with an explicit need for support filling this gap. To gather the research data, the change agents applied a pragmatic toolbox on general company data, CS integration triggers and management tools. The data was gathered during the execution of a consultancy project on the integration of CS. Due to the membership of the companies with the consultancy firm, the change agent had a long-term relationship with the company and its development that helped to interprete the data colelcted.

From the outcomes of this research it can be concluded that a vision on CS integration can be found independently on the developmental stage of the company towards sustainability. This widens the field of companies that will go for the integration of CS as literature suggests only to focus on proactive companies. The triggers for a company to integrate CS into its business activities were found to differ: reactive companies gave priority to both internal and external, proactive companies to external and the sustainable company to the internal triggers. In their development towards more CS integration, companies have an increasing amount of management system certifications. At the same time this research found out that the management system itself is least used to assure the integration of CS. More important for this assurance is a clear and quantifyable vision and strategy on CS integration and most of all the presence of an internal CS champion. This person motivates the people in the company to undertake activities with both a physical and social focus. The research showed that the more balanced these two focusses are, the more sustainable the company is.

For future research we suggest to analyze in further detail the connection between CS integration approaches and their use in practice. Besides, it seems to be fundamental to analyze retrospectively organizational processes influencing the CS ambition and the translation to operational activities.

1 Corresponding author, Copernicus Institute of Sustainable Development, Utrecht University, s.witjes@uu.nl

2 Copernicus Institute of Sustainable Development, Utrecht University

3 Utrecht Sustainability Institute, Utrecht University

1. Introduction

Companies are showing an increase in awareness of their impact on the sustainability of their direct and indirect context (Searcy, 2014). The Dutch national knowledge network for corporate social responsibility, MVO Nederland, also predicts a further growth of this awareness in The Netherlands for the near future (Lageweg, 2012). This increased awareness is being accompanied by a growth of demands for sustainable business performance from both internal and external stakeholders. The awareness by businesses that sustainability should be integrated in the business system and its objectives has been growing over the last 20 years (Salzmann et al., 2005).

Already in the 1980s and 1990s a large number of integration approaches, in those days mostly focusing on environmental management, have been developed and made applicable on company level (cleaner production, pollution prevention, The Natural Step, environmental management systems, life cycle assessment, zero emission, ecodesign, etc.). Some authors have made an effort to map these approaches and show the interrelatedness of the various approaches (Robèrt et al, 2002). More recently, comparable approaches have been suggested and elaborated for corporate sustainability (CS) management, taking a broader scope than only environmental issues (Azapagic, 2003; Maon et al. 2009). More recently scholars have researched the assumption that a systems perspective should lead to a better integration of CS (Yin and Schmeidler, 2009).

However, various authors who analyzed the integration of these approaches in practice, have challenged this basic assumption. For example, Mac (2002) observed that cdecisions taken by companies do not match the decisions prescribed by environmental management approaches. Often a gap exists between the use of these approaches and the decisions taken by the companies (Székely en Knirsch, 2005). They state that "...the reason is that most sustainable development initiatives have been developed in isolation of business activity and are not yet directly linked to business strategy..." (idep). In order to bridge the gap between the vision on CS and practice, it is essential to develop a clear set of sustainability mission, vision and values (Székely and Knirsch, 2005), which need to be an integral part of the business activities (Cramer, 2005). So the challenge is to apply approaches which elements become effectively an integral part of the business activities. Although much research has been conducted in the field of CS integration, not many scholars have been able to capture its application in SMEs (Pastrana and Sriramesh, 2014).

The purpose of this article is to understand how Dutch SMEs[4] integrate their vision on CS into their business activities. To be able to do so, this article is based on data collected by external change agents. After having participated in several round-table meetings on CS, the companies asked these change agents to support them with CS related topics. During the following project, the external change agent collected the additional research data applying a toolbox with 4 CS tools developed by the consultancy firm the agents worked for. These change-agents-tools were based on the change agents´ experience with similar projects, and were used for the change agent´s understanding of the integration of CS within the business activities as well as in discussions with the companies to define future steps in the integration of CS. For the research, the tool results were used as a company shared assessment with the researcher as an interpreter. Due to the long-term relationship of the change agents with the companies, the data was based on unique longitudinal and ethnographic experience with the companies and its process to integrate CS.

Section 2 will discuss the concept of CS, focusing specifically on the integration of CS in SME business activities leading to an understanding that will serve to interpret the findings of the research. Section 3 describes the methods for data collection and analysis. In section 4 the findings are presented; followed by the discussion of the findings within the scope of the literature review; and finally the conclusions with proposals for future research.

2. CS integration in companies

In recent years several scholars have stressed the increasing importance of CS as organizations face pressures to address the environmental and social impact they directly or indirectly cause (Dunphy, et al., 2006; Dyllick & Hockerts, 2002; Epstein and Roy, 2001; Baumgartner, 2009; Székely and Knirsch, 2005; Lozano, 2013). This implies that companies simultaneously need to achieve mutually interdependent sets of values: the Triple Bottom Line of planet, people and prosperity, thus integrating economic, social and environmental issues (Elkington, 1998). To address this tripartite focus of the corporate values, it is necessary to use a holistic understanding of CS (Linneluecke et al., 2009; Dyllick and Hockerts, 2002): while reducing the environmental impact and assuring compliance with organizational goals, simultaneously companies need to improve social and human welfare.

This research therefore focuses on the holistic understanding of the integration of the elements of this tripartite model in the business activities.

4 According the EU (EU recommendation 2003/361) an SME has more than 10 and less than 251 employees. For this research we also included business units of big or multinational enterprises that correspond to the same size.

2.1. The CS scope for businesses

The awareness of the role of CS in relation to the company´s main business makes it easier for the company to define the steps to take to enable the integration of CS (Dunphy et al. 2006). Dunphy et al. (2006) argue that a model for development can be used to characterize the way an organization employs its physical and social resources, and to trace historically the organization's development and draw a path forward. The awareness of the current and historic situation on the employment of its resources to enable CS integration is therefore crucial to be able to define what steps to take next.

The scope of CS for businesses has increased towards having to deal with all its stakeholders, including clients, suppliers, employees and the community (Wells, 2007). Dyllick and Hockerts (2002) emphasize the importance of the needs of both direct and indirect stakeholders of the company, and as they argue, not only needs in the present, but also in the future, thus including the time element in the definition of CS, like many others do (IISD et al., 1992). This makes CS integration for a company a concept that has to be seen in historic, present and future perspective.

Several scholars have researched the triggers of companies investing in CS related activities (e.g. Wells, 2007; Cramer, 2005). These vary per company but generally include reactivities on demands from stakeholders (Bansal and Roth, 2000). While integrating CS, a company should consider the demands of all stakeholders on a sustainable outcome (Bagherti and Hjorth, 2007) in time.

Company strategies related to a vision can be seen at all cultural levels of the organization, as stated by Baumgartner (2009). In this way, the company triggers on CS integration do not only include the company´s economic vision and mission, but also how employees treat each other and what organizational culture the company strives for (Clarke and Room (1999)).

Therefore it can be concluded that this broad scope of triggers, seen in historic, present and future perspective, together with the company´s awareness of the evolution of its resource employment enabling CS, creates the basis for a company to define what activities have to be taken to integrate CS in the business activities.

2.2. CS in SMEs

Research on CS in SMEs shows that the triggers for integrating CS are primarily the pressure from supply chain partners or from the inside of the company itself (Ciliberti, 2008). In competition with the bigger companies in the market, the disruptive innovation is the power of the SME. Smaller organizations can leverage their capacities for entrepreneurial innovations and organizational change, thereby, learning to achieve advantages over larger organizations (Moore et al. 2009). The organizational development processes of smaller firms may also constitute a built-in engine for addressing the challenges of disruptive innovation and change (idep). The adaptability of an SME, to be able to address the challenges of disruptive innovation and change, defines its success, emphasizing the importance of both the physical and social conditions of the company while integrating CS.

Macpherson (2007) showed that the SME's ability to create suitable management systems is an important antecedent for growth. It is therefore to be expected that SMEs that have a vision on CS, have CS oriented activities integrated in their management systems. This research analyses the data gathered at 18 Dutch SMEs and their process of integrating CS in their business activities. It is therefore to be expected to find CS integrated in the management system with both a focus on the physical and social conditions of the company.

2.3. The role of the change agent

To integrate CS in the company's business activities, the vision on CS has to be translated into action (IISD et al., 1992). Several authors have described possibilities for companies to integrate CS (see Dunphy et al., 2006; Lozano, 2012c; Robert et al., 2002). More practically, Siebenhüner and Arnold (2007) conclude that a company, in order to do so, should make changes focusing on physical (Hart, 1997) and managerial (Lozano, 2012c) issues of the organization. This leaves out the focus on the organizational culture with its social issues (Baumgartner, 2009; McKenzie, 2004). The focus on both physical and social activities in defining how to integrate CS in the company´s business is important to make this integration more successful.

Having a clear mission and vision defined (Székely and Knirsch, 2005) with CS being an integral part of the organizational culture, helps making the bridge to the activities (Cramer, 2005). To lead this process of integrating CS strategy in activities of the people that have to execute them, a CS champion is crucial (Hannon, 2012). A champion is an individual that is intensely interested with the general CS goals and takes them as a high priority in his or her daily tasks (Chakrabarti, 1974). The main task of this champion is to create a transformational environment with conditions for the organization to be able to integrate CS in business activities (Marion, 2002). The champion is the main factor influencing the behavioral and cultural variables towards CS (Siebenhüner and Arnold, 2007). Similarly, Harris and Crane's (2002) study suggests that it is possible for these champions to advance the integration of CS principles, although such attempts might be moderated by the power and resources available to such actors.

Both the physical and social conditions of a company are key for the champion to be able to support the process of bringing the CS integration to activities in the company. To enable the influence of the champion and to avoid the influence of contra-powers from the company itself, this research analyses data of cases where an external change agent is the enabler of the first steps towards CS integration. In some cases also an internal CS champion was present.

2.4. Assuring CS in the business activities

Decisions made from a clear mission and integrated within an organization that works conform, for example, the ISO 14001:2004 standard, should lead to a more sustainable company (Yin and Schmeidler, 2008). Often the internal change agent, responsible for sustainability related topics, is also responsible for integrating of and complying with the requirements of the standard, whereas the management team takes the decisions. To get the connection between the change agent and the decision takers within a company, several management system standards require specific activities. The ISO 14001:2004 standard, for example, requires the assignation of a management representative who carries the responsibility for the management system and is part of the management team. Moreover a company with a ISO 14001:2004 certificate should carry out a management review: an evaluation of the effectiveness of the management system (Normcommissie 390 012 "Milieuzorg" (2004)). Mac (2003) however observes that decisions taken by companies do not match the requirements prescribed by environmental management methods. There is a gap between the instruments used to integrate CS and the decisions taken by the companies.

It can be concluded that the insurance of CS, although it consists of a clear mission and is implemented within a management system, is not necessarily leading to CS. All companies, participating in this research, have some kind of management system certificate. Therefore a sub goal of this research is to analyze what companies, having these certificates, do to integrate CS into their business activities.

In the following chapter the applied methods will be explained.

3. Method

Most research on CS integration is done with momentum-data-gathering-methods and using, for example, questionnaires or checklists. Not many longitudinal and field study research methods have been applied. To be able to capture both the physical and the social focus on the integration of CS in the company, qualitative field-based data methods were used in this research to identify the approaches applied by the company to integrate CS. It is not the goal of this research to generalize on basis of the observations done as being it representative of all similar situations. In absence of a well-developed set of theories regarding CS integration in SMEs,, case study research is a valid method for theory building (Eisenhardt, 1989, McGutcheon and Meredith, 1993). Case study research is based on analytical rather than statistical generalization as was mentioned by Yin (2009). Stuart et al. (2002) argued that case study research does not have the goal of being representative but rather exemplary. Having 18 companies participating in this research, a comparative analysis between these examples is included. By using the application of the long term knowledge and experience of the change agents with the company, an explanation for how the company got to integrate CS is included increasing the generalizability (Yin, 2013). As mentioned by Eisenhardt (1989), the limitation of external validity of the study is a disadvantage of case study research. This limitation is often compensated by using large samples or using “before” and “after” experiments (Cook and Campbell, 1979). A check on the validity of the data of this research was included by letting the results be approved by the companies themselves. Besides, this research aims to contribute to the construction of theory and therefore make it possible to apply large scale samples and “before” and “after” design in the future, making it possible to generalize future outcomes.

3.1. Research context

Between 2008 and 2010 more than 300 Dutch companies met, on a quarterly basis, to exchange experiences on the integration of CS. These sustainability roundtables were organized by the researcher, then external change agent at the consultancy firm. The main end-result of the round tables was that the companies agreed upon avoiding “window dressing”: to legitimize questionable business and deceive stakeholders (Cai et al, 2011). In other words: the vision of a company on CS, expressed in policy documents and external communication, has to coincide with the activities carried out by the same company. From these round-table meetings, several companies chose to follow up with a project on CS integration supported by the consultancy firm.

The consultancy firm is since 20 years a renowned support for Dutch SMEs in Quality, Health and Safety, and Environmental matters. Many companies that seek for the consultancy´s support, have a long term relationship with the consultancy firm due to a membership: by paying an annual fee, the companies receive frequent meetings with the external change agent in which the latest developments are discussed and ways to support the firm are being defined. Through this long term relationship, the external change agents have access to an extensive body of knowledge and experience with the companies participating in this research.

This research analyses the data, gathered by the change agents, working in these projects, to better understand the processes leading to CS integration in these SMEs. It is based on the data collected from 2009 until 2013. The moments of data collection per company depended on the moment of a need of support of the company. Only for the duration of project, the change agent was able to apply the tools and gather data. As part of this research, 18 Dutch SMEs were selected from a larger group of companies requesting support on CS integration. The selected companies had a vision on CS, had a certificatied management system, and asked the consultancy firm for support with the integration of CS in their business activities.

3.2.Change agent tools

To be able to gather the data on the integration of CS by the 18 SMEs, the external change agents applied a pragmatic toolbox derived from their own experience with the aforementioned round table on CS and projects on CS integration done with clients. The toolbox comes from an iterative learning process of the external change agents on CS integration. During the period of data collection used for this paper, the tools did not change.

For the change agents the goal of the application of the tools in the toolbox is threefold: 1. support the change agents in analyzing the CS integration in the company, 2. communicate the results with the company, and 3. create an input for a debate between the change agents and the company to define further steps of the company towards a better integration of CS. For this research the data collected with the application of the 4 tools in the toolbox is used to understand how the companies integrate CS in their business activities at the moment of the collection of the data. The change agents give the description of the different elements of the tools. They are also the ones to determine which element of the tools is applicable to the company. The 4 tools and their elements are not meant as full conclusive. Although the literature gives more sources for determining the CS situation of a company, these tools are determined to be useful for this research.[5]

3.2.1.Tool 1: the CS growth curve

The CS growth curve of a company was set up in the context of the projects to create awareness of the past present and future of the company´s development. Its use helped especially to indicate the difference between the current and desired situation on CS integration. The consultancy firm distinguishes the following phases of growth:

A. Reactive

The company reacts to stakeholder's demands without proactively engaging in processes that could prepare compliance with these demands. Compliance with these demands often results in ad hoc activities.

B. Proactive

The company assures compliance with stakeholders demands by making the activities, leading to compliance, part of its business activities, therefore avoiding the ad hoc-nature of it.

C. Sustainable

The company focuses on its own strengths by acting from the internal stakeholder abilities in complying with the external stakeholders demands.

3.2.2 Tool 2: the CS triggers

The triggers for the companies to start to integrate CS are used to understand why a company started the process of integrating CS in its business activities, and, moreover, as a quick scan to start a debate with the company on how to improve this integration. The triggers are grouped in internal and external:

a. Internal:

- The expressed vision of a high-level person or group of persons within the company on CS.
- The CS impact of the primary processes of the company
- The physical relocation of the company
- The internal organizational changes
- The requirements from the parent company
- Responding to emergency situations

b. External

- The requirements of direct customers of the company

5 The following scholars have been researching on tool-related subjects:
CS growth rate stages: e.g. Ahaus 2003;, Dunphy, 2009; Uhlaner et al, 2010
CS triggers: e.g. Skarmeas and Leonidou, 2013; Young and Dhanda, 2013
Physical and social focus of CS: e.g. Graafland, 2003; Baumgartner, 2010; Linnenluecke, 2010; Schein, 2004
CS assurance elements: e.g. Cramer, 2005; Dunphy, 2009

- The developments in the market in general
- The CS performance of related companies. These companies can be competitors.
- The requirements of the law and regulations (particularly environmental and health & safety legislation)
- The advantage of integrating CS in comparison with competitors.

3.2.3. Tool 3: the physical and social focus of the CS integration activities

The third tool is used to clarify the focus of CS integration activities. Especially the difference between physically and socially focused activities was important for the consultancy. A physical focus is related to the sustainability performance of the company´s primary processes. The social focus relates to the influence of the social dynamics of the people individually or in groups on these primary processes,

Physical factors

- Results
  Besides making revenue, the company´s processes can have other results often represented by indicators. A company could prioritize these indicators in the process of CS integration (e.g. activities to influence the company´s KPIs). Doing so they take results oriented activities.

- Process
  By controlling the primary processes, the above mentioned performance indicators can be influenced. Besides, primary processes are being supported by secondary or supporting (for example administrative processes, human resources, quality health safety and environment, maintenance) and management processes (for example defining policy, management review, adjusting goals) by e.g. setting up procedures or working instructions. All requirements of management system standards are included in these activities. By controlling these processes the company takes CS integration process oriented activities.

- Product
  CS integration activities can also be taken from a product, and/or service perspective. The product and/or service is the main subject of the trade with which the company makes its revenue. Activities to adjust the CS performance from a product perspective (e.g. redesign, setting up LCAs) are defined as product oriented activities.

- Resources
  The process inputs necessary to create the product or service can also influence the sustainability performance of the company. Besides adjustments to product related resources, also adjustments to non-product related materials (e.g. lubricants, energy) are defined as resource oriented activities.

Social factors

- Behavior
  The behavior of the people, directly or indirectly working with the company's processes, has an influence on the company's performance. E.g. a sales person that acts friendly and respectfully towards clients has a bigger change to receive orders. Behavior oriented activities try to influence the behavior of people. People of all layers of the company´s organizational structure can initiate these activities.

- Leadership
  People within an organization influence each other. This interpersonal influence can be done consciously by providing the necessary conditions to be able to reach set goals. E.g. helping others to adjust their behavior so the company´s performance is being influenced in a positive way. Activities providing these conditions are defined as leadership oriented activities.

- Shared belief
  Having a shared belief among a group of people in the vision on how CS should be integrated in the business activities also influences the behavior of these people. The more people share a belief, the more influence this believe will have on the activities taken by these people. Activities leading to this believe are defined as shared-vision activities.

3.2.4. Tool 4: the CS assurance elements

The consultancy firm defined five elements that, according to their experience, play an important role in assuring CS integration in business activities: in this research defined as assurance elements:

1. The vision on CS - when the expressed vision of high level person(s), as part of tool 1, is becoming part of the organization and its culture (both physical and social), it is defined as assured.
2. The strategy to CS - the vision on CS is being translated into planned, programmed and organized activities

that will clearly contribute to activities aiming at this vision.

3. A management system in which the CS activities are included - all participating companies have at least one certificate for its management system. This enables the assurance of CS into business activities included in the management system.
4. The presence of CS champions as mentioned in section 2.
5. An assessment of the CS performance - the company is aware of its impact on CS by having a qualitative and/or quantitative indication of its CS performance.

3.3 Data collection and analysis

In this multi-company research the data collected by the change agents was included in a database to enable the comparison between the companies. To characterize the participating companies, also data on the legal form of the organization, the size of the company, its sector, and the type of management system certificate present were included.

The change agents defined the position of the companies within the tools by interpreting the given situation using their long term and project related knowledge and experience with the company. This process of getting to valid interpretations from analyzing understanding in general (Dilthey & Jameson, 1972) is called hermeneutics and is based on the interpretation of human understanding (Seth & Thomas, 1994). The application of hermeneutics allows giving a valid understanding of the situation of the company participating in the research by the long term relationship of the company with the consultancy firm and its change agents, and being the consultancy firm renowned in The Netherlands for their support on CS integration in SMEs,

For the validation of the data, coming from the application of the tools, the change agents used the tool results in their presentation of the advise to the company. When necessary, the database, with data from the company, was adjusted to the output of the presentation.

To analyze the data stacking comparable cases (Miles and Huberman, 1994) was used: the data was included in tables to analyze each case. It also enabled a cross-case analysis by using a meta-matrix. By condensing this, a systematic comparison was possible to enable the identification of sequences and contingencies.

4. Findings

This section will give more details on the findings. In this section the tables for each tool of the toolbox, coming from the meta-matrix, are presented and followed by a descriptive analysis. To enable this analysis, in the tables, the companies are first ranked according their position on the CS growth curve. Secondly, when applicable, within a specific CS growth curve stage, the companies are ranked according the amount of management system certification present. For contextualization and comparison of the data from the different companies, general data about the companies is given.

4.1. General data of the companies

Table 1 gives an overview of the companies and the CS growth stage they are in according the consultants (r: reactive, p: proactive, s: sustainable). As with the other 3 tools, assigning a CS growth stage to a company was done by the change agent. Table 1 also gives an overview of the amount of employees working for the company (expressed in full time equivalent (FTE)), the ownership of the company (h: holding, f: family) and the management system certifications for ISO 9001 (quality), ISO 14001 (environment) and/or OHSAS 18001 (health and safety) each of the companies had at the moment of the project. The standard industrial classification (SIC)[6] is used to identify the sector the company is working in.

Table 1 - General data of the companies

6 The SIC system is internationally used for classifying industries by using a four digit code. See appendix for explanation of the SIC codes of the participating companies.

Companies	Growth curve	FTE	Ownership	SIC codes	9001	14001	18001
1	r	150	h	3270	x		
2	r	200	h	3086	x		
3	r	50	h	2821	x		
4	r	25	f	3490	x	x	
5	r	170	h	3390	x	x	x
6	p	200	f	3442	x		
7	p	170	h	2821	x	x	
8	p	100	f	2821	x	x	
9*	p	150	h	1731	x	x	
10*	p	100	f	1623	x		x
11	p	50	f	3390	x		x
12	p	100	f	7600	x		x
13	p	50	h	3390	x		x
14	p	230	h	2600	x	x	x
15	p	180	f	2800	x	x	x
16*	p	200	f	2833	x	x	x
17	p	250	h	3442	x	x	x
18	s	200	f	2600	x	x	x

Among the 18 participating companies the majority is defined as proactive (12 of 18). Only 1 company is defined as sustainable. Among the companies, 9 were family owned companies and 10 were part of a holding. All 18 were ISO 9001 certified, 10 ISO 14001 and 9 companies had a valid OHSAS 18001 certification at the moment of the participation in this research. 8 companies had 2 certifications, and 6 companies had the triple certification (9001, 14001 and 18001) at the moment of the project. There is a positive correlation between the amount of management system certifications and the CS growth curve stage.
The majority of the companies are active in the manufacturing industry. According their FTEs, the companies are big SMEs. 15 of the 18 participating companies complied according their amount of FTEs with the EU definition of SMEs. 3 companies (see*: 9, 10 and 16) were in total bigger. But the unit of the company, where the project was done and the data was collected, complies with the EU definition of SMEs.

The following paragraphs contain the findings of the application of the tools at the 18 participating companies. The CS growth curve and the amount of management system certificates are used as a basis for organizing the findings of the other 3 tools. Therefore each of the following 3 tables contain the findings of the application of these 3 tools, connected to the CS grow curve and management system certificates.

4.2. Tool 2: Triggers to integrate CS
Every company has it´s own set of triggers to integrate CS in the business activities. As in table 1, table 2 shows these triggers ordered according the growth stage of CS of the company. The proactive companies are, as in table 1, ordered according the amount of management system certificates present.

Table 2: Triggers to integrate CS

Companies		1	2	3	4	5	presence reactive	6	7	8	9	10	11	12	13	14	15	16	17	presence proactive	18	presence sustainable	Quantity
	Vision	x	x		x	x		x		x	x	x	x	x	x			x			x		13
	Impact		x			x									x		x				x		5
	Relocation							x	x														2
Internal	Organizational changes		x			x	37%	x	x			x		x	x	x		x		38%	x	67%	10
	Parent company		x						x		x				x	x			x				6
	Emergence	x		x				x		x									x		x		6
	Direct customers	x	x	x		x		x		x	x	x	x	x		x	x	x	x				14
	Developments in market	x	x					x	x		x	x					x	x			x		9
External	Situation in other companies					x	40%		x			x	x	x		x		x		57%		40%	7
	Legislation		x										x		x								3
	Competitive advantage		x		x			x	x	x	x	x	x	x		x	x		x		x		13

The three most mentioned triggers to integrate CS are: direct customers (14 times), competitive advantage, vision on CS (both 13 times).
There is a positive correlation between the CS growth curve stages and the presence of internal triggers for integrating CS. The external triggers are at their maximum (57%) for proactive companies.
The ratio internal/external triggers for the reactive companies is almost 1 (37%/40%), for the proactive companies smaller than 1 (38%/57%), for the sustainable company bigger than 1 (67%/40%).

These findings mean that for reactive companies internal and external triggers are equally important in their decision to integrate CS in their business. For proactive companies the external triggers are more important than the internal triggers. For a sustainable company the internal triggers are more important than the external triggers to integrate CS in their business activities.

4.3. Tool 3: Physical or social activities
Observing the activities the companies defined as being contributing to sustainability, the consultants divided them over physical focused and social focused. Table 3 shows the focus of each company. The level of presence of a physically or socially focused activity was indicated as: 1: not present, 2: present, and 3: strongly present. As in table 1, table 3 shows the triggers ordered according the growth stage of CS of the company. The proactive companies are, as in table 1, ordered according the amount of management system certificates present.

Table 3: Physical or social CS activities

Companies		1	2	3	4	5	average reactive	6	7	8	9	10	11	12	13	14	15	16	17	average proactive	18	average sustainable	average element
	Processes	2	2	2	2	2		2	2	3	3	3	3	2	3	2	3	2	2		2		2,3
Physical	Resources	2	3	2	2	3	2,2	2	2	2	3	3	3	3	3	3	3	3	2	2,5	3	2,7	2,6
	Product	2	2	2	3	2		3	2	2	2	3	3	2	3	2	3	1	2		3		2,3
	Behavior	1	1	1	1	1		1	2	2	1	2	2	2	2	2	2	2	2		2		1,6
Social	Leadership	2	2	1	2	1	1,5	2	2	2	2	2	2	2	2	1	2	2	2	1,9	3	2,7	1,9
	Triggers	2	3	1	2	1		3	1	2	2	1	1	1	2	2	3	1	3		3		1,9

There is a positive correlation between the CS growth rate and the level of presence of both physical and social focus. The ratio between the level of presence of the focus on physical and social for the reactive and proactive companies is the same (0,7). This same ratio is bigger for sustainable companies (1,0).
There is an increase of both the level of presence of physical and social activities contributing to sustainability when a company grows from reactive, through proactive to sustainable. In the transition from proactive to sustainable, the level of presence of focus is shifting from more physical to both physically and socially oriented activity contributing to sustainability. Within the physical focus activities focused on resources have the highest average.
The amount of management system certificates does not have an influence on the physical or social focus of integration activities.

From these findings it can be concluded that more physical and social focused activities of CS integration can by found the more advanced the company is in CS growth curve. Social oriented activities become as important as physical oriented ones when the company gets to the final, sustainability stage. Overall the presence of activities focused on resources is the highest through all CS growth curve stages.

4.4. Tool 4: CS assurance elements

The change agents indicated the way the companies assured CS in their business activities by indicating which assurance element was present, as indicated by table 4. As in table 1, table 4 shows the triggers ordered according the growth stage of CS of the company. The proactive companies are, as in table 1, ordered according the amount of management system certificates present:

Table 4: Company´s assurance of CS

Companies	1	2	3	4	5	average reactive		6	7	8	9	10	11	12	13	14	15	16	17	average proactive		18	average sustainable		quantity elements
						element	total													element	total		element	total	
Vision on sustainability		x		x	x	60%		x		x					x			x	x	42%		x	100%		9
Strategy to sustainability	x	x			x	60%		x				x					x	x	x	42%		x	100%		9
Management system						0%	36%			x	x	x				x	x		x	50%	52%	x	100%	100%	7
CS champion	x		x		x	60%		x	x	x	x	x	x	x	x	x	x	x	x	100%		x	100%		16
Sustainability assessment						0%					x	x			x					25%		x	100%		14

There is a positive correlation between the CS growth curve stages and the amount of assurance elements. This is in general but also for every element individually. For the sustainable company all assurance elements were present. There is correlation between the amount of management system certificates does not have an influence on the assurance elements. Although all companies have their management system certified, some even more than once, the assurance element management system has the lowest quantity.

To be able to assure CS in their business activities, the more sustainable the company, the more assurance elements can be found. Going from reactive to proactive the management system as assurance element to integrate sustainability in the business is increasing considerably (from 16,7% to 44%). Besides, also the presence of someone championing CS for the company and the sustainability assessment grows fast, going from reactive to proactive.

In the following section, the conclusions of the findings will be put in the framework of the literature review as presented in this paper.

5. Discussion

The findings of this research show that independently on the CS growth stage a company can have a vision on CS integration. The triggers to start creating this vision differ per CS growth stage: for proactive companies the external and for sustainable companies the internal triggers. In their development towards more CS integration, companies have an increasing amount of management system certifications. The management system itself is least used to assure the integration of CS. More important for this assurance is a clear and quantifyable vision and strategy on CS integration and most of all the presence of an internal CS champion. This person motivates the people in the company to undertake activities with both a physical and social focus. The research showed that the more balanced these two focusses are, the more sustainable the company is.

This research shows that the integration of CS in business activities can be analyzed by letting external change agents apply a pragmatic toolbox.

The pro-activeness as precondition for companies to seek their contribution to sustainability (Lozano, 2012c) cannot be confirmed by this research. Also reactive companies, focusing on compliance with applicable legislation, are seeking this contribution. The rigidness of the management system and the dynamic character of the SME practice (Moore et al. 2009) with the additional focus on the social issues within the company issues when implementing CS (Graafland et al. 2003), create a challenge for SMEs though. In developing towards the sustainability stage, the importance of certifying this management system with the use of more standards is even increasing. The additional focus on social issues can only be seen in the transition from the proactive to sustainability stage. The presence of only one company in the sustainability stage could create a bias in the findings of this research though.

The main triggers for SMEs to implement CS are coming from the SC partner or the inside of the company itself (Ciliberti, 2008). This is confirmed and even specified by this research: besides the external demands of customers and the fact that competitors are also integrating CS, the vision of an internal (group of) persons is an important trigger. This is confirmed by Székely and Knirsch (2005).Triggers from direct and indirect stakeholders are important (Dyllick and Hockerts, 2002). The outcomes of this research show that customers and competitors, as direct stakeholders, are more important than indirect ones in triggering the companies to integrate CS.

In case of the CS champion, the findings of Marion et al (2002) were also confirmed but at the same time specified: the CS champion is key to the success of embedding CS in the company's business activities. It is important to notice that the company cases included in this research had an external change agent present as well. The influence of this external change agent on the presence of the internal change agent was not part of this research.

The outcomes of this research show that sustainable companies have a more balanced priority on physically and socially focused activities. Reactive and proactive companies tend to have more physically than socially focused integration activities. The fact that SMEs depend for their growth strongly on the development of their social component (Macpherson, 2007) in combination with the fact that companies in the sustainability phase already focus on the creativity and competences of their employees, makes that SMEs have a build-in precondition to make the step to the sustainability stage.

In contrary to what is stated by Siebenhuner and Arnold (2007) this research shows that a qualitative and/or quantitative assessment of the sustainability performance of a company is important to be able to make steps towards CS integration. Literature shows that compliance is not an important trigger for companies to go for CS. The 18 SMEs used compliance with applicable legislation as one of the least important triggers to go for CS.

CS should become an integral part of business activities and the vision on CS should be seen in all levels of the organization (Cramer, 2005; Baumgartner, 2009; Clarke and Room, 1999). The results of this research cannot confirm, neither neglect this conclusion. To be able to do so, a more in depth, longitudinal empirical research should be executed accompanied by the use of qualitative or even ethnographic models.

6. Conclusions

This paper provides a closer look at the integration of CS in business activities of 18 Dutch SMEs. The sample used and the method applied, do not make it possible to generalize on the findings, moreover they are meant to contribute to the construction of theory.

The necessary data collection was done in cooperation with a Dutch consultancy firm. In their projects with client companies, the external change agents collected data applying a pragmatic toolbox coming from their own experience with CS. These tools were related to the triggers of integrating sustainability in the business, the distinction between the social and physical focus of the activities taken by the company to integrate CS and the way in which the company choose to assure the integration of CS in their business activities.
The application of these tools, together with their long-term knowledge and experience with the firms, gave the change agents the necessary information to determine the CS situation of the companies using the tools. The outcomes of the tools served as input for advising on future activities to be taken to integrate CS further in the business activities. By discussing this advise with the company, it also gave a validation check on the tool results.

From the outcomes of this research it can be concluded that a vision on CS integration can be found independently if a company is determined as being reactive, proactive or sustainable. This widens the scope on companies that will go for the integration of CS. In the company development towards CS integration this research found a broad scope of triggers. The importance of the triggers were found to differ according the CS growth stages: reactive companies gave priority to both internal and external, proactive companies to external and the sustainable company to the internal triggers. Within this research in general the direct stakeholders are more important than the in-direct ones. Besides, the fact that the participating companies asked the external change agents for help with improving the integration of CS showed that the approaches the companies are using to integrate CS, and that are being included in the analysis of this research, are not sufficient. It is therefore recommendable to research on these approaches and its application in practice.

The management system standards of ISO 9001, 14001 and OHSAS 18001 are related to the development of the integration of CS in the business activities: the more certificates a company has, the more sustainable the company is. It is important to notice here that having a certified management system is a precondition for companies in this research. This research showed that the management system itself is the least used to assure CS integration in the business activities. To be able to do so, the assignation of a central person to coordinate this process is key. The CS champion should motivate the people in the company to undertake activities with both a physical and social focus. For companies that want to make the final step in the CS growth curve, these activities should be physically and socially balanced making it possible to connect the CS integration activities to the business culture (Baumgartner, 2009; Clarke and Room, 1999).

This research was not able to capture the influence of historic activities on the current CS situation. Due to the restricted timeframe, this research relies on current activities. Literature showed that awareness of historic activities is important to determine the strategy on CS integration. It is therefore suggested to research retrospectively organizational processes integrating CS.

References

Aya Pastrana, N., & Sriramesh, K. (2014). Corporate Social Responsibility: Perceptions and practices among SMEs in Colombia. *Public Relations Review*, *40*, 14–24.

Azapagic, A. (2003). Systems approach to corporate sustainability: a general management framework. *Process Safety and Environmental Protection*, *81*(5), 303–316.

Bagheri, A., & Hjorth, P. (2007). Planning for Sustainable Development: *Sustainable Development*, *96*, 83–96.

Bansal, P., & Roth, K. (2000). Why companies go green: a model of ecological responsiveness. *Academy of Management Journal*, 717–736.

Baumgartner, R. J. (2009). Organizational culture and leadership: Preconditions for the development of a sustainable corporation. *Sustainable Development*, *17*(2), 102–113.

Cai, Y., Jo, H., & Pan, C. (2012). Doing Well While Doing Bad? CSR in Controversial Industry Sectors. *Journal of Business Ethics*, *108*, 467–480.

Chakrabarti, A. K. (1974). The role of champion in product innovation. *California Management Review*, *17*(2), 58–62.

Ciliberti, F., Pontrandolfo, P., & Scozzi, B. (2008). Investigating corporate social responsibility in supply chains: a SME perspective. *Journal of Cleaner Production*, *16*, 1579–1588.

Clarke, S., & Roome, N. (1999). Sustainable business: learning - action networks as organizational assets. *Business Strategy and the Environment*, *8*(5), 296–310.

Cook T, Campbell D. 1979. Quasi-Experimentation – Design and Analysis Issue for Field Settings, Houghton-Mifflin: Boston, MA.

Cramer, J. (2005). Company learning about corporate social responsibility. *Business Strategy and the Environment*, *14*(4), 255–266.

Curkovic, S., & Sroufe, R. (2011). Using ISO 14001 to promote a sustainable supply chain strategy. *Business Strategy and the Environment*, *20*(2), 71–93.

Dilthey, W., & Jameson, F. (1972). The rise of hermeneutics. *New Literary History*, *3*(2), 229–244.

Dunphy, D., Griffiths, A., & Benn, S. (2006). *Organizational Change For Corporate Sustainability : A guide for leaders and change agents of the future*. *Organizational Change For Corporate Sustainability* (pp. 3–29).

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*(2), 130–141.

Elkington, J. (1998). *Cannibals with Forks: the Triple Bottom Line of 21st Century Business*. *Conscientious Commerce* (pp. xvi, 407).

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*.

Epstein, M. J., & Roy, M. J. (2001). Sustainability in action: Identifying and measuring the key performance drivers. *Long Range Planning*, *34*(5), 585–604.

Fassin, Y., Van Rossem, A., & Buelens, M. (2011). Small-business owner-managers' perceptions of business ethics and CSR-related concepts. *Journal of Business Ethics*, *98*(3), 425–453.

Graafland, J., Van de Ven, B., & Stoffele, N. (2003). Strategies and instruments for organising CSR by small and large businesses in the Netherlands. *Journal of Business Ethics*, *47*(1), 45–60.

Hannon, M. J. (2012). *Co-evolution of innovative business models and sustainability transitions: The case of the Energy Service Company (ESCo) model and the UK energy system*.

Harris, L. C., & Crane, A. (2002). The greening of organizational culture: Management views on the depth, degree and diffusion of change. *Journal of Organizational Change Management*, *15*(3), 214–234.

Hart, S. L. (1997). Beyond Greening: Strategies for a Sustainable World. *Harvard Business Review*, *75*, 66–76.

International Institute for Sustainable Development (IISD) (1992). Deloitte&Touche, World Business Council for Sustainable Development (WBCSD). Business Strategy for the 90s. IISD: Manitoba.

Lageweg, W. (2011). *Blik op MVO; tien trends en ontwikkelingen*. Downloaded on 22 February 2012 from http://issuu.com/mvonederland/docs/blikopmvo

Linnenluecke, M. K., Russell, S. V., & Griffiths, A. (2009). Subcultures and sustainability practices: the impact on understanding corporate sustainability. *Business Strategy and the Environment*, *18*(7), 432–452.

Lozano, R. (2012c). Addressing Stakeholders and Better Contributing to Sustainability through Game Theory. *The*

Journal of Corporate Citizenship.

Lozano, R. (2013). A holistic perspective on corporate sustainability drivers. *Corporate Social Responsibility and Environmental Management*

Mac, A. (2002). When firms make sense of environmental agendas of society. *Journal of Cleaner Production*, *10*(3), 259–269.

Macpherson, A., & Holt, R. (2007). Knowledge, learning and small firm growth: a systematic review of the evidence. *Research Policy*, *36*(2), 172–192.

Maon, F., Lindgreen, A., & Swaen, V. (2009). Designing and implementing corporate social responsibility: an integrative framework grounded in theory and practice. *Journal of Business Ethics*, *87*(1), 71–89.

Marion, R., & Uhl-Bien, M. (2002). Leadership in complex organizations. *The Leadership Quarterly*, *12*(4), 389–418.

McCutcheon, D. M., & Meredith, J. R. (1993). Conducting case study research in operations management. *Journal of Operations Management*.

McKenzie, S. (2004). *Social sustainability: towards some definitions* (No. 27) (p. 31).

Miles, M. ., & Huberman, A. . (1994). *Qualitative data analysis: An expanded sourcebook (2nd ed.)*. *Qualitative data analysis: An expanded sourcebook (2nd ed.).*

Moore, S. B., & Manring, S. L. (2009). Strategy development in small and medium sized enterprises for sustainability and increased value creation. *Journal of Cleaner Production*, *17*(2), 276–282.

Normcommissie 390 012 "Milieuzorg" (2004). *NEN-EN-ISO 14001:2004 (nl): Milieumanagementsystemen - Eisen met richtlijnen voor gebruik (ISO 14001:2004,IDT)*, paragraph 4.1., 4.6, 12 and 17.

Reinhardt, F. (2000). Sustainability and the Firm. *Interfaces*.

Robèrt, K. H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J. L., Kuehr, R., … Larderel, J. A. De. (2002). Strategic sustainable development — selection, design and synergies of applied tools. Journal of Cleaner Production, 10(3), 197–214.

Salzmann, O., Ionescu-somers, A., & Steger, U. (2005). The Business Case for Corporate Sustainability:: Literature Review and Research Options. *European Management Journal*, *23*, 27–36.

Searcy, C. (2014). Measuring Enterprise Sustainability. *Business Strategy and the Environment*

Seth, A., & Thomas, H. (1994). Theories of the Firm: Implications for Strategy Research. *Journal of Management Studies*, *31*, 165–191.

Siebenhüner, B., & Arnold, M. (2007). Organizational learning to manage sustainable development. *Business Strategy and the Environment*, *16*, 339–353.

Székely, F., & Knirsch, M. (2005). Responsible Leadership and Corporate Social Responsibility: *European Management Journal*, *23*(6), 628–647.

Uhlaner, L. M., Berent, M. M., Jeurissen, R. J. M., & de Wit, G. (2010). Family ownership, innovation and other context variables as determinants of sustainable entrepreneurship in SMEs: An empirical research study. *EIM Research Reports, Reference*, (H201006), 1–29.

Van Bommel, H. W. M. (2011). A conceptual framework for analyzing sustainability strategies in industrial supply networks from an innovation perspective. *Journal of Cleaner Production*, *19*(8), 895–904.

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management*.

Wells, G. (2007). The sustainable firm as an ethical construct, 52–62.

Yin, H., & Schmeidler, P. J. (2009). Why do standardized ISO 14001 environmental management systems lead to heterogeneous environmental outcomes? *Business Strategy and the Environment*, *18*(7), 469–486.

Yin, R. K. (2013). Validity and generalization in future case study evaluations. *Evaluation*, *19*(3), 321–332.

Yin, R. K. (2009). *Case Study Research: Design and Methods*. *Essential guide to qualitative methods in organizational research* (Vol. 5, p. 219).

Appendix 1

List with SIC codes of the participating companies

3270 - Concrete, Gypsum & Plaster Products

3086 - Plastics Foam Products

2821 - Plastic Materials, Synth Resins & Nonvulcan Elastomers

3490 - Miscellaneous Fabricated Metal Products

3390 - Miscellaneous Primary Metal Products

3442 - Metal Doors, Sash, Frames, Moldings & Trim

1731 - Electrical Work

1623 - Water, Sewer, Pipeline, Comm & Power Line Construction

3390 - Miscellaneous Primary Metal Products

7600 - Services-Miscellaneous Repair Services

2600 - Papers & Allied Products

2800 - Chemicals & Allied Products

2833 - Medicinal Chemicals & Botanical Products

Load Balancing potential of SME manufacturing sites in North Western Germany – a bottom up case study

Agnes Pechmann[1], Max Chonin[2], Nanke Steenhusen[3]

[1] PECHMANN, AGNES (HOCHSCHULE EMDEN/LEER; UNIVERSITY OF APPLIED SCIENCE)
agnes.pechmann@hs-emden-leer.de

[2] CHONIN, MAX (HOCHSCHULE EMDEN/LEER; UNIVERSITY OF APPLIED SCIENCE)
max.chonin@gmx.de

[3] STEENHUSEN, NANKE (HOCHSCHULE EMDEN/LEER; UNIVERSITY OF APPLIED SCIENCE)
nanke.steenhusen@stud.hs-emden-leer.de

Highlights

- Overview of studies of Load shifting potential in German
- Methodology for identifying load shifting potentials in manufacturing companies
- Case study of technical load shifting potential
- Technical Load shifting potential in different manufacturing industries
- Technical Load shifting potential in North-Western Germany

Abstract

Load Balancing is an important aspect in future grids which have to cope with an increasing intake of fluctuating energies from renewable power plants. In line with research regarding the technical feasibility of small autarkic energy systems to supply production sites with 100% renewable energy the question came up whether the potential of load management in small and medium sized manufacturing companies is high enough to be of use for balancing purposes in the distribution grid. Recently a couple of studies in the German language area have been published on the topic of load balancing, mostly dedicated towards high volume consumers. A quantitative analysis based on real data for non-energy intensive companies is missing.

In this article the results of a bottom-up analysis regarding load balancing potential of typical medium sized manufacturing companies in rural areas of Germany are presented. Based on a detailed analysis of a manufacturing company specialized in metal processing the technical load balancing potential is determined and then scaled up for the North-West-region. Real data from additional companies is used in this scaling up process.

Keywords

sustainable consumption, case study, SME, load balancing, demand side management

1 Introduction

Load Balancing is an important aspect in future grids which have to cope with an increasing intake of fluctuating energies from renewable power plants. In the two research projects REN ProV and PREmdeK[1] the autarkic supply of a manufacturing company with renewable energies was investigated. Demand Side Management was one important aspect in such an autarkic energy system to keep it in balance. In line with research regarding the technical feasibility of small autarkic renewable energy systems the question came up whether the potential of load management in small and medium sized manufacturing companies is high enough to be of use for balancing purposes in the distribution grid.

While in energy intensive companies load shedding as one meaning of Demand Side Management is a known and applied method for keeping the consumed power below a specified threshold, average companies are not familiar with any method of steering and controlling the demand. Due to this, the potential of Demand Side Management to influence the energy load in manufacturing is not well known in the manufacturing industry. Recently a couple of studies in the German language area have been published on the topic of load balancing to identify the actual potential. The studies have been dedicated mostly towards high volume consumers or private households. They are mainly based on qualitative research. A quantitative analysis for manufacturing companies is missing.

In this article the results of a bottom-up analysis regarding load balancing potential of typical medium sized manufacturing companies in the rural area of North-Western Germany are presented. Based on a detailed analysis of a manufacturing company specialized in metal processing, working in a make-to-order mode with mainly small- to medium sized series with some repetitive orders, the general load balancing potential is determined and then scaled up for the region of north-western Germany. Real data from additional companies are used in this scaling up process.

1.1 Approach and structure of article

After an extensive literature review in the field of load balancing and demand response management, several studies have been analyzed regarding the applicability of the used methods and their results in the field of load balancing at manufacturing companies of small and medium size. Based on these studies a first methodology has been developed to determine the potential at a case company with detailed information regarding its load. The newly developed methodology has been applied to the already used case and three additional goods producing companies. The application of this first methodology and its results were evaluated and the methodology was then refined.
Results of this first phase of methodology development are documented in detail in a student project documentation in German (Chonin, Steenhusen 2014).
For coming up with an estimation of the technical load balancing potential for manufacturing companies in the region of North-Western Germany the approach was as following: First the term “North-Western Germany” was defined. Then a top-down-bottom-up method was developed to scale up the results of the load potential of the case companies to the region. Starting from top-down, the statistical databases (Destatis) of Germany and its states were used to come up with the power consumption of the manufacturing industry and average data for companies in their respective industry classification. The average data in combination with the already determined load balancing profile were then used to calculate the potential for the region of North-Western Germany.

[1] See http://www.e-pps.de

In the next section more background information is given regarding the region of North-Western Germany, the technical challenges for balancing the grid and Demand Side Management. A short overview of recent published studies on load balancing potential in the German language area is closing that section. The developed methodology for determining the load balancing potential in manufacturing companies, the scale-up method for determining the potential in the named region as well as the quantitative results are presented section 0.

1.2 Balancing zones in the power grid

The European integrated network is covering the grids of Great Britain, Scandinavia, the Baltic States and the European continental grid. They are connected by high-voltage direct-current transmission lines. On the supply-side the grid is still dominated by hundreds of large fossil and several nuclear power plants. The transportation of the power is taking place on different voltage levels that are connected by transformer stations.

While largescale power plants feed to the high-voltage grid, consumers take the power off the distribution grid. More and more small and medium renewable power plants are erected and feed into the grid on different levels, thereby transforming it into a more decentralized one.

Mainly, the largescale power plants feed into the two highest levels of the grid system, whereas renewable power plants feed in on different lower levels. The grids in the European integrated network are on a net frequency of 50 Hz. To maintain this frequency, a constant balance of power feed and energy consumption has to be secured. For controlling purposes, the grid is split up in several balancing zones. For each one of them a transmission system operator is responsible for its stability. In Germany, four system operator companies are responsible for the different balancing zones. Each of these zones is split up further into regional balancing zones/accounting grids, in which actions are applied to keep the frequency stable.

The region North-Western Germany is belonging mainly to one of the balancing zones in Germany, grid zone 2 (Figure 1). In Figure 2 the ratio of power feed-ins by renewable energies to consumption for certain counties in North-Western Germany is shown. Obviously, in some counties we have a yearly excess of energies caused by renewables in the system, daily figures should even show more extreme results.

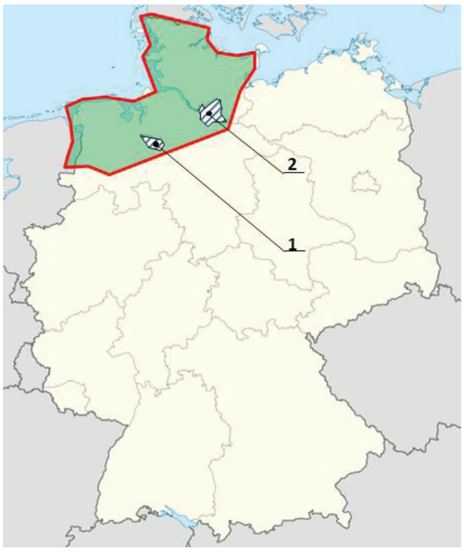
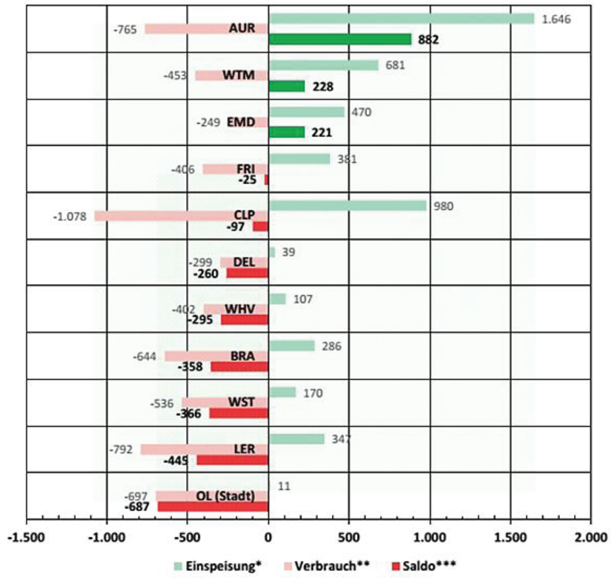


Figure 1 North-Western Germany / Balancing zone 2 without the cities of Bremen and Hamburg

The total power consumption in the scaling region is about 32741 GWh per year, the SME industry accounts for 9912,08 GWh of it.



* Power feed-ins of only renewable energies
** Consumption without large scale industry connected to the 110-kW Grid
*** Feed-in minus consumption

Figure 2 Yearly power feed-ins of renewable energy and power consumption in part of North-Western Germany (Kröcher et al. 2013)

Traditionally it is assumed that the load in a regional balancing zone is determined by the demand of the consumers and cannot be influenced by the energy provider. The demand is deterministic. Consumers are grouped into different classes for which standard load profiles are used to forecast the power demand. Differences in forecasted demand and actual demand have to be met by less or additional power capacity. This power is called control energy and is provided as a system service offered to the grid operator.

The system of largescale power plants supplying energy and consumers extracting it worked very reliable in recent years. The system of average interruption duration index (SAIDI) gives a value of 15.91 min as average value for the duration a consumer has been cut off from the grid in 2012 (Bundesnetzagentur 2013).

The transformation of the power grid to a grid with decentralized, renewable energies is changing the whole system. While the power plants of the traditional grid have been controllable in their supply, power generated by sun and wind, depends on the weather. They are called fluctuating energies. The higher the share of renewable energies in the grid the higher is the portion of fluctuating energies. The challenges to keep the grid stable by balancing the deterministic demand and the partly fluctuating (deterministic) supply increase regarding timing, duration and volume.

The supply can be altered by using the mechanisms of regulating power, mainly switching flexible power plants (e.g. gas power plants) on and off or using different types of storage. Energy can be stored in electrical, chemical, mechanical or physical systems. Typical storage systems applied in the grid are presented in Figure 3.

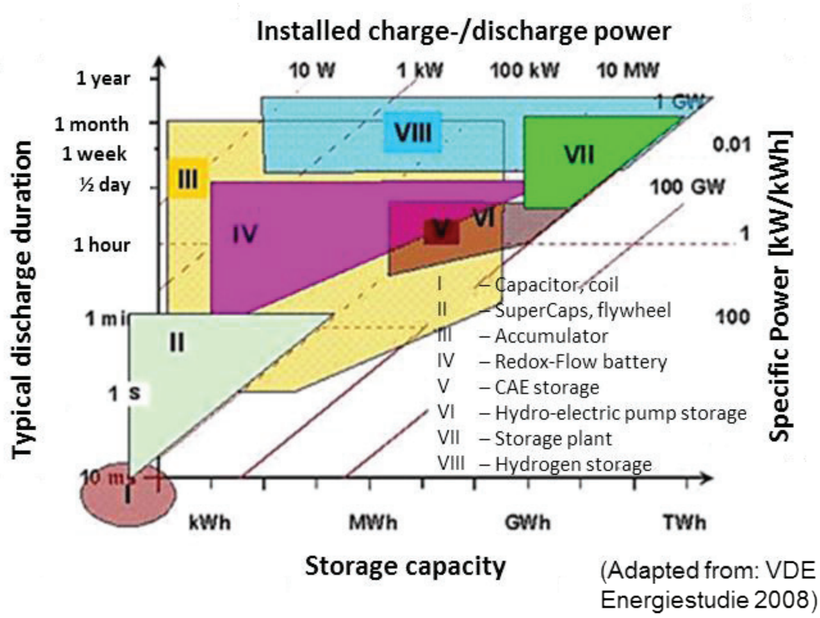


Figure 3 Overview of storage types and their appliance

They differ in the time they offer requested energy, in volume size and duration. The aim to transform the energy system to a system with no CO2-emissions implies an increased share of renewable energies that are mainly of fluctuating nature. Consequently, it further implies a need for increasing the balancing capacity in the net. Though the technology regarding the storage system is very advanced, the technical storage volume is limited by restrictions concerning geography, environment, required space, finances and others. The forecasted technical storage volume seems not to be sufficient for the future balancing needs.

1.3 Demand Side Management and Demand Response

In the traditional top-down energy system the consumer demand is postulated as deterministic. If this tenet is abandoned, the conception of time as balancing element comes into play. To shift the time of energy consumption to a more suitable point in time may be beneficial for balancing the grid, to better match the consumption to feed-ins of renewable energies.

Recent studies have looked at the option of influencing the consumption patterns of private households (eTelligence; EWE AG 2012) and of energy intensive companies (Klobasa 2009). For households, the results are less promising as originally expected since e.g. rebound-effects come into play and in addition, the financial and technical requirements are very high (Lünsdorf 2012). Nevertheless, the concept of Demand Side Management offers an option and needs to be looked at further.

Demand Side Management subsumes actions that are targeted towards optimization of the energy system by changing the demand behavior on the consumer side. The actions result in a demand reduction or a deferred demand. Demand reduction can be achieved temporarily through load shedding or permanent through energy efficiency activities. Deferred demand does not reduce the energy demand on the consumer side since the time of demand is shifted; nevertheless it is an effective method to change the demand profile towards a more favorable profile for keeping the grid stable. The avoidance of load peaks and load valleys or opposite the creation of peaks and valleys can be the goal – depending on the requirements to balance the grid. Actions to defer the demand fall under the category Demand Response. They can be steered and controlled by the grid operator, by the customer or by a technical control device at the consumer side. Different requirements for Demand Response actions exist, e.g. a sufficient communication infrastructure. The effects of Demand Response actions are presented in Figure 4 with a dashed line.

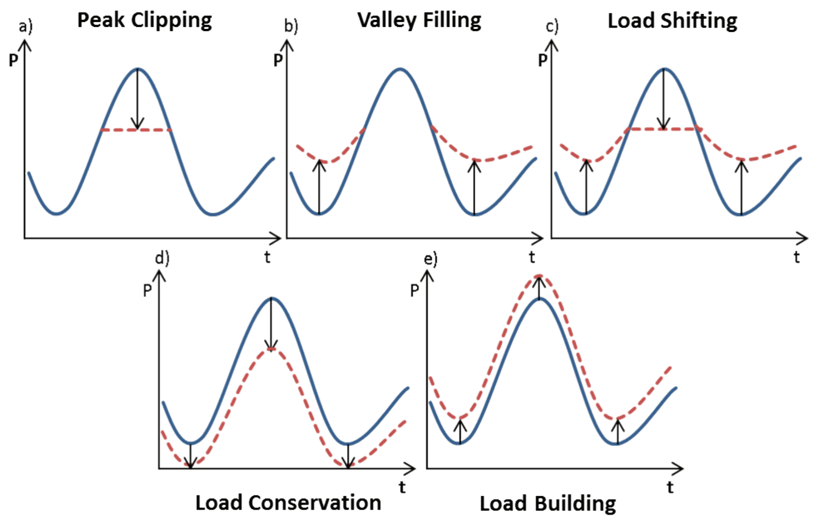


Figure 4 Effects of Demand Response actions

To carry out Demand Response actions costs effort and impacts the processes at the customer. To estimate the benefits of Demand Response the potential of the load shifting needs to be estimated regarding volume and duration. Different terms regarding the load shifting potential exist, see Figure 5.

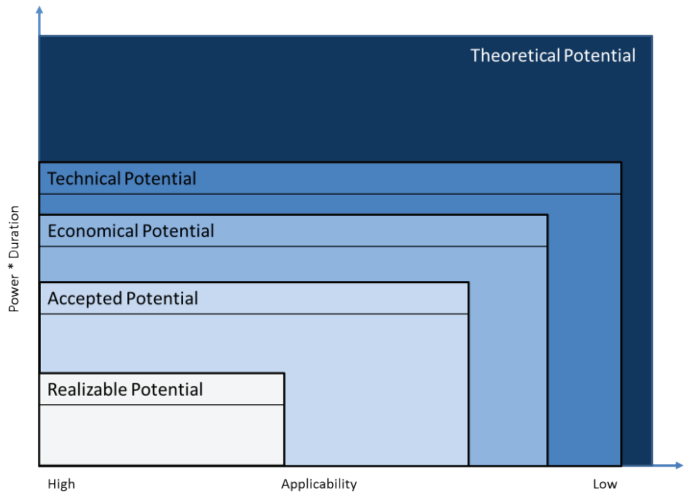


Figure 5 Load shifting potentials

The theoretical potential is limited by technical restrictions. Technical restrictions exist if an appliance cannot be switched off for technical or organizational reasons, its power demand is lowered or its operation carried on with stored power. The technical restriction is lowered by the economic framework, e.g. the financial drawback of postponing a production step might be lowered too. A further restriction to the potential is the acceptance of Demand Response actions. The accepted potential is especially important if the comfort zone of people is interfered with.

1.4 Recent studies in the German language area on load shifting potential

In a recent literature survey regarding the topic of load management potential, several studies published in German emerged. Five of them will be introduced in short:

In the first study „Dynamic simulation of load management and integration of wind energy into an electricity grid“ (orig. title in German, Klobasa 2009), a doctoral dissertation, it is investigated if there is a rising demand of balancing power due to increased wind energy penetration rates in the German power supply and to what extent the required balancing effort can be met by Demand Side Management strategies. The author examines the technical and economic load shifting potential of several energy intensive industry branches and develops a simulation model that analyzes the efficiency of grid operation with wind power and Demand Side Management (DSM). The author calculates load shifting potential in the range of several gigawatts. Negative and positive load balancing potential is not distinguished.

The second study „Short- to medium term feasible market potentials for the application of Demand Response in the industrial sector“(orig. title in German, Focken, Bümmerstede, Klobasa 2011) was published as a project closing report. The authors analyze different industrial branches and applications and determine which of those have the most promising prospects for a successful medium-term implementation of load management. The aim of the study was to calculate an economically feasible load shifting potential for commercial applications. The authors identify the most relevant processes and analyze their geographic dispersion. Additionally, the financial effort for installing a required communication infrastructure to leverage the potential is thoroughly investigated.

The third study, again a doctoral thesis „Self organization of virtual devices for load management of small consumers“ (orig. title in German, Lünsdorf, 2012) is targeted toward the possibilities of exploiting balancing power on the demand side in private households. The study approaches the question by grouping household appliances into virtual devices using a self-organizing pooling strategy. The author analyzes the specific challenges of implementing Demand Side Management on the household level and develops several formalized load shifting strategies and approaches to coordinate the modelled devices.

The fourth study „Load shifting potentials of infrastructural facilities in Switzerland“ (title orig. in German, Müller, Graf, Kobel, 2013), was carried out as a study regarding the technical feasibility and was commissioned by the Swiss Federal Energy Office. In the study the capability of Swiss infrastructural facilities to supply positive and negative balancing power as system service to the Swiss electricity grid was investigated. Several existing facilities, e.g. waste incineration plants and water supply stations, serve as case examples. The calculated potentials are scaled-up to determine the potential of Switzerland as a whole.

The fifth study „Load shifting potentials in small and medium-sized enterprises and determining factors for their enhancement“ (title orig. in German, Karg, Jagwitz, Baumgartner, 2013) was commissioned by the Austrian ministry of transport, innovations and technology. Part of the study was an analysis of 30 commercial enterprises based on a primary qualitative survey. The load shifting potentials, and the preconditions and possibilities to exploit them are identified. Additionally, important parameters for a quick, inexpensive implementation are discussed.

2 The load shifting potential in manufacturing

As stated before (see Figure 5), the load shifting potential can be determined for different levels. The developed methodology offers the possibility to determine the potential starting from the technical potential down to the realizable potential. The methodology is presented in the next subsection (section 2.1). The application of the methodology up to Stage 3a will result in numbers for the pure technical potential, neglecting further restriction due to very company specific organization requirements. The pure technical potential is needed as input to the scaling process for deriving at the load shifting potential for a region. The developed scaling method is presented in section 2.2.

Following the presentation of the developed methods, the results for the load shifting potential of the case company (see 2.3) and for the region (see 2.4) will be presented.

2.1 Methodology to determine Load Balancing Potential in manufacturing companies

The developed methodology of identifying load shifting potentials for small and medium-sized enterprises is a six-stage process that reflects the breakdown structure of the different levels of potential from the theoretical potential to the feasible potential. The overall process consists of both qualitative assessments and quantitative calculations. The theoretical potential is narrowed down to the feasible potential through technological, organizational, economical and other considerations such as enforcement and accepted degradation of user convenience. For an overview of the six stages see Figure 6.

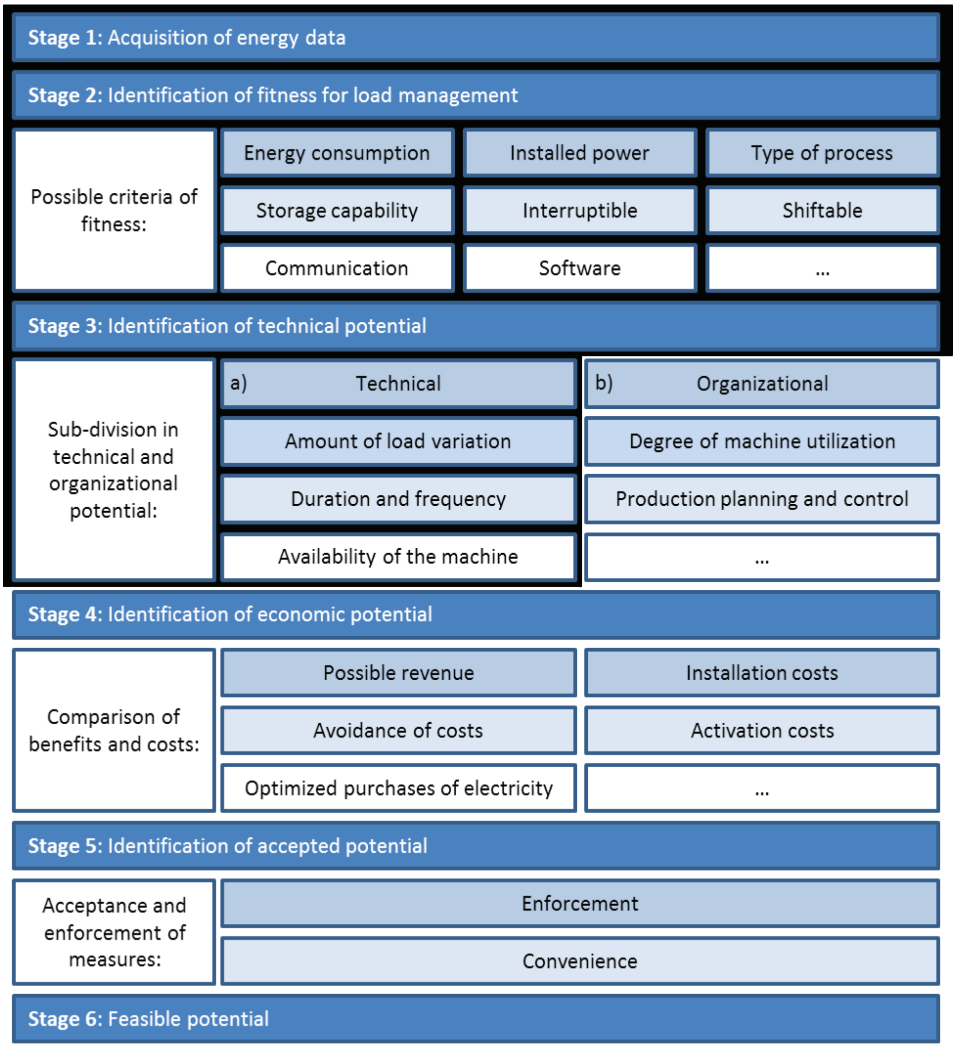


Figure 6 Methodology to determine Load Balancing Potential in manufacturing companies

In Stage 1, the energy data of the company and its single power consuming resources are acquired. If the data is not already available the input power of a given application is measured, analyzed and then condensed for a 15-minute interval. The production load data, if possible per measured resource, is to be collected and matched to the resource data.

In stage 2 the fitness of the company for load management is identified. There are applications and processes in a production environment that are by design better suited for implementation of load management. Determining factors include, but are not limited to, energy consumption, rated power and the ability to flexibly pause or shift processes or reduce their input power without diminishing the product/process quality. Previous studies indicate that thermal storage capabilities have a large impact on the load shifting potential.

In stage 3, the technical potential is identified. This stage is a twofold process that examines the pure technical potential first and then analyzes the organizational potential.

a) The technical potential in a narrow sense is determined by how much the input power can be increased or decreased and for how long and how often such a load alteration can be conducted. This consideration yields the energy that can be shifted from a pure technical point of view without considering consequence of it onto other processes or the whole production organization.

b) The organizational potential takes into account the possible repercussions that load shifting may have onto the production organization, especially the planning and control. As load management may result in planned machine downtimes, the consequences to process interlinkages, the production schedule and delivery dates must be thoroughly examined.

In stage 4, Identification of the economic potential takes place. The primary incentive for the industry to participate in load management is a financial one. In this stage possible monetary benefits of load management and costs that are associated with the implementation are analyzed. As it is desirable to achieve a quick recuperation of financial investments, this stage calls for a holistic approach that covers all costs. These costs can be grouped into initial investments and operating costs. The benefits depend on the financial incentive scheme of the grid operator and possibly the local energy provider.

The purpose of stage 5 is the identification of the accepted potential. Economically feasible load shifting potentials are not necessarily accepted by the user. A perceived degradation of convenience is particularly important to be kept in mind for household applications. For industrial applications, financially attractive load shifting must be clearly supported by management and then enforced in day-to-day operations. Visible management commitment and raising awareness among the workforce are essential criteria for acceptance.

In stage 6 the feasible potential will emerge. The intersection of all financially attractive load shifting measures and those measures, that are also accepted or can be enforced, constitutes the feasible potential that can be exploited in the near-term future.

Stages one to three have been applied on the case example (see 2.2).

2.2 Methodology to scale up the single case potential to a higher geographical level

The technical potential for load shifting in a reference company can serve as a baseline to be scaled-up to a larger number of instances, such as the entire industrial branch of the reference company in a specific area. A five-stage procedure was developed as depicted in Figure 7.

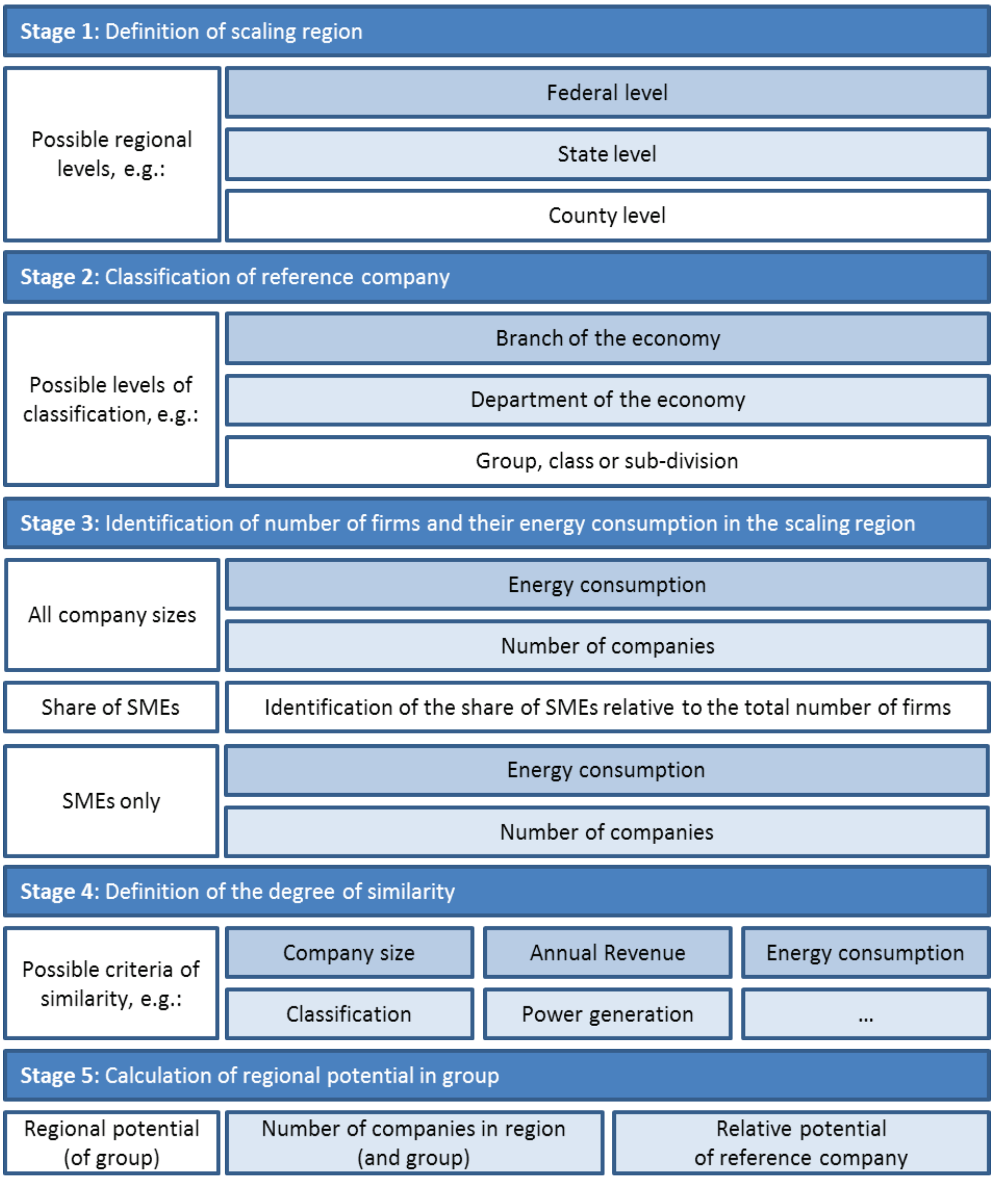


Figure 7: Load balancing potential Scale-up method for SMEs

In stage 1, the geographic region for the scaling is defined. It is suggested to tailor the region according to the accessible database, as statistical information is oftentimes only available on county-, state- or federal level.

In stage 2, the statistical data according to the classification of the reference company is identified. For that the Statistical Classification of Economic Activities in the European Community" (NACE Rev. 2), in Germany by using WZ 2008, was used (see Table 1).

Table 1 Structure and coding system of WZ 2008

Hierarchical level	Number of items	Code
Sections	21	A-U
Divisions	88	01-99
Groups	272	01.1-99.0
Classes	615	01.11-99.00
Sub-classes	839	01.11.0-99.00.0

In stage 3, the number of companies corresponding to stage 1 and 2 is identified and the average energy consumption is determined. According to industrial branch and energy consumption, the total number of companies inside the scaling region is narrowed down to the remaining quantity that is taken into account for scaling.

In stage 4, the degree of similarity is evaluated and if appropriate, the number of companies can be further reduced by choosing only those companies that closely resemble the reference company. Criteria of similarity can include staff size, revenue or other parameters.

In stage 5 the regional potential of technical load shifting is determined. The number of companies in the specified region and, if applicable, in specific statistical groups, is multiplied with the relative load shifting potential of the reference company (see 2.1.1). The relative load shifting potential is the absolute load shifting potential of the reference company divided by its power consumption.

2.3 Technical Load shifting potential for the case company

The technical load shifting potential for the manufacturing company used as a case was determined using the introduced methodology up to stage 3a.

The technical potential was determined for the entire manufacturing site, using the original energy consumption data series provided by the local energy supplier. It was assumed to shift the daily peak loads into the work break periods which have a total duration of 45 minutes per day. For each 15-minute interval during a work break, the difference between the load in that interval and the average daily peak load was calculated and then summed up to the absolute technical load shifting potential.

For May 2014, the average technical load shifting potential of a working day for the case company was:
$E_{p+}abs$= 38.8 kWh.

The average power consumption per working day was 1,10162 MWh.

The relative technical load shifting potential then accounts to:
$E_{p+}rel$ = 38,8 kWh/ 1101,62 kWh = 0,0352

For the main case company energy consumption data on a very detailed level were available through installed measuring equipment of the PREmdeK project. The technical load shifting potentials on the level of individual machines were also investigated using the measured data of the PREmdeK project. It was assumed that the production processes are arbitrarily flexible and that no impacts on the production planning are acceptable. From the daily machine load profiles, theoretical load reductions down to the idle-state of a machine can be concluded and plotted as a daily profile as well. However, since very high equipment efficiency is targeted, virtually no leeway is available to actually shut down a machine within the scope of load management. Production planning and load shifting will conflict in almost all situations, especially for the energy intensive CNC-milling and turning machines, as well as for the welding equipment. Potentials to shift their power loads are definitely there, but a sound trade-off between production scheduling and load management must be determined.

Especially with regard to the operation of a virtual power plant, the information of possible load alterations per 15-minute interval for each piece of production equipment is of particular importance.

The opportunity to apply stage 3a at the case company was not yet given. A supporting ERP-system providing the relevant production load and corresponding energy load data has been installed and data are build up.

For three additional SME companies, the power consumption data per 15 min interval were available as well. For these three companies, the methodology to determine the technical load profile was applied as well, though not as detailed as for the main case. In stage 2, the data for determining the fitness were less detailed as for the main case. For stage three, a typical working day by visual evaluation has been chosen for determining the technical load shifting potential instead of using average data of a month as with the main case. The resulting data for all four companies are displayed in Table 2.

Table 2 Quantitative results of the technical load shifting potential

	Company Case G	Company Case S	Company Case L	Company Case W
power consumption on working day W_{day} [MWh]	1,101	1,268	16,588	10,070
Yearly power consumption in a year W_{year} [MWh]	252	743	3889	1610
Absolute technical load shifting potential per day E_{p+abs} [kWh]	38,80	34,73	848	240,93
Relative technical load shifting potential $E_{p+rel} = E_{p+abs} / W_{year}$ [-]	0,15397	0,04674	0,21805	0,14965

2.4 Results of Scale-up Process

With the result of determining the technical load shifting potential of the cases, the scale-up process was carried out.

The total power consumption of the scaling regions is about 32741 GWh per year, the power consumption of the manufacturing sector is 9912 GWh and the consumption of all the companies in the four divisions of the case companies lies at 609 GWh. For detailed consumption of SME companies in the four divisions see Figure 8

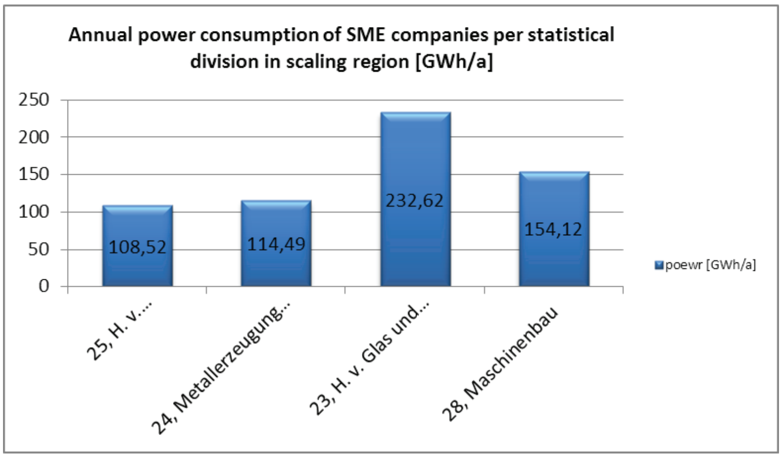


Figure 8 Annual power consumption of SME companies per statistical division

In Table 3 the results of stage 2 and 3, determining the statistical classification for the companies and their relevant data for the process are given.

Table 3 Results of the scale-up process

	Company Case G	Company Case S	Company Case L	Company Case W
Statistical section (WZ 2008)	C	C	C	C
Statistical division (WZ 2008)	25	23	24	28
Statistical group (WZ 2008)	25.99	23.11	24.5	28.99
Number of companies in division and region	295	197	24	293
Average power consumption per year in division and region [MWh]	390	1230	6050	630

Merging the results of the technical load shifting analysis and the scale up process in stage 5 of the scale-up process the technical load shifting potential of the industry divisions emerges. The results are presented in Table 4.

Table 4 Technical load shifting potential in certain industry division in North-Western Germany

	Company Case G	Company Case S	Company Case L	Company Case W
Statistical division	25	23	24	28
Absolute technical load shifting potential per day in region [kWh]	16.753,29	10.866,33	25.064,95	23.852,07

3 Conclusions

The high intake of renewable energies in the grids of energy systems transitioning to post-carbon systems challenges power grid operators; they have to keep the power grids stable. The grids have to be in balance of power supplied to the grid and power taken off the grid for consumer's usage. In traditional grids, the balance is controlled by switching power plants on and off depending on the demand. In addition different forms of storage are used. With the change of the energy system the storage volume capacities need to increase drastically to cope with future balancing needs. To keep the balance, the loss in control of the supply side - due to the fluctuating nature of the renewable power plants – needs to be made up for by control possibilities on the demand side. Though the concept of Demand Side Management is applied partially in energy intensive companies, its application has not penetrated to industry consumers. First studies have been conducted but not in the field of manufacturing. Therefore, the potential for load shifting in this industry - and furthermore at small and medium companies is not known. Without this knowledge, it is impossible to estimate the benefits for different stakeholders in the energy system to engage in Demand Side Management.

The results presented in this article help to build up knowledge regarding the potential load balancing actions could have. By estimating the technical load shifting potential for single companies and scaling it up to a region for certain industry sections, different stakeholders in the energy system should be able to estimate a possible benefit for them. The idea for this case study originated in relation to a feasibility study on operating an autarkic, small energy system with a manufacturing company as main consumer and a virtual power plant with multiple, renewable power plants and storage facilities. Due to high costs for electrical storage, Demand Side Management seems like an attractive option in such a system. Now it will be better possible to investigate whether Demand Side Management with the given technical load shifting potential could be worthwhile. The same goes for system operators. To engage in activities for stipulating Demand Side Management at the consumers' side, the potential benefit for the overall system needs to be known - either technically speaking for mid- to long-term options or financially for short-term.

In the article the technical load balancing potential of four single case companies as well as the potential of a whole region for certain industry divisions are given. The results are based on real data and include an evaluation of the companies' feasibility to exploit the technical potential. The regional data are based on a very few single case examples. With this circumstance, the results must be seen as a first estimation. It is advisable to increase the number of companies in the industry section to minimize possible deviations of the technical absolute potential to an industry average. It is further advisable to add further data of companies in additional industry sectors to estimate the regions full potential that can be drawn from Demand Side Management.

Acknowledgments

The authors would like to acknowledge the contributions of two Federal Ministries of Germany (BMBF, BMWI) for funding the research projects REN ProV and PREmdeK. Furthermore the authors want express their gratitude to Annika Menzel for editing.

References

Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen: Monitoringbericht 2013. Stand Juni 2014. Online available at: http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2013/131217_Monitoringbericht2013.pdf

Bünger, Ulrich; Crotogo, Fritz; Donadei, Sabine (Dezember/2008): Energiespeicher im Stromversorgungssystem mit hohem Anteil erneuerbarer Energieträge. Bedeutung, Stand der Technik, Handlungsbedarf. Hg. v. Energietechnische Gesellschaft im VDE (ETG). ETG. o. O. Online available at http://www.vde.com/de/fg/ETG/Arbeitsgebiete/V1/Aktuelles/Oeffentlich/Seiten/Studie-Energiespeicher.aspx

Chonin, Max; Steenhusen, Nanke (2014): Analyse von Potentialen zur Lastverschiebung in Klein- und mittelständischen Unternehmen. Technisches Projekt, Hochschule Emden/Leer.

eTelligence EWE AG (2012): Abschlussbericht eTelligence. Neue Energien brauchen neues Denken. Online available at: http://www.e-energy.de/documents/eTelligence_Projektbericht_2012.pdf.

Focken, Ulrich; Bümmerstede, Jens; Klobasa, Maria (Mai/2011): Kurz- bis Mittelfristig realisierbare Marktpotenziale für die Anwendung von Demand Response im gewerblichen Sektor. Öffentlicher Abschlussbericht. Hg. v. energy & meteo systems GmbH [u.a.] und Technische Informationsbibliothek u. Universitätsbibliothek. Fraunhofer-Institut für System- und Innovationsforschung; und energy&meteo systems GmbH. Oldenburg. Online available at http://edok01.tib.uni-hannover.de/edoks/e01fb12/726677981l.pdf (last checked 24 Jul 2014).

Statistisches Bundesamt: German Classification of Economic Activities (2008). https://www.destatis.de/DE/Methoden/Klassifikationen/GueterWirtschaftklassifikationen/klassifikationWZ08englisch.xls

Karg, Ludwig; Jagwitz, Alexander von; Baumgartner, Georg (November 2013): Lastverschiebungspotenziale in kleinen und mittleren Unternehmen und Erfolgsfaktoren zur Hebung dieser Potenziale. Hg. v. Bundesministerium für Verkehr, Innovation und Technologie. München/Salzburg (8/2014).

Klobasa, Marian (2009): Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz. Stuttgart: Fraunhofer-IRB-Verl. (ISI-Schriftenreihe \"Innovationspotenziale\"). http://publica.fraunhofer.de/documents/N-93747.html (last checked 09 Sep 2014)

Kröcher, Uwe; Scheele, Ulrich; Brandt, Arno; Voßen, Georg Daniel (May 2013): Potentialstudie Energieregion Nordwest. Studie im Rahmen des Projektes Hansa Energy Corridor (HEC). Hg. V. Oldenburger Energiecluster OLEC e.V. Oldenburg/Hannover.

Lünsdorf, Ontje (2012): Selbstorganisation virtueller Geräte für das Lastmanagement von Kleinverbrauchern. Universität Oldenburg. http://oops.uni-oldenburg.de/id/eprint/1380.

Müller, Ernst. A.; Graf, Eliane; Kobel, Beat (Juni/2013): Potential der Schweizer Infrastrukturanlagen zur Lastverschiebung - Schlussbericht 2013. Bundesamt für Energie BFE. o. J. Online available at http://www.bfe.admin.ch/php/modules/enet/streamfile.php (last checked 24 Jul 2014).

Facilitating multi-stakeholder discussions on eco-innovation for process upgrading

Les Levidow, Development Policy and Practice, Open University, Milton Keynes MK7 6AA, UK, L.Levidow@open.ac.uk
Michiel Blind, Deltares, The Hague, www.deltares.nl
Åsa Nilsson and Sara Alongi Skenhall, IVL Swedish Environmental Research Institute, Stockholm, www.ivl.se
Irina Ribarova, Albena Popova and Peyo Stanchev, University of Architecture, Civil Engineering and Geodezy (UACEG), Sofia, http://uacg.bg

Abstract

Industry has been investing in eco-innovation, combining environmental and economic benefits, in pursuit of various aims. Improvement options have been sometimes evaluated through eco-efficiency assessments, a ratio between economic benefits and resource burdens, focusing on a company site. Looking more broadly, some companies have shown interest in eco-efficiency assessment at the whole-system (meso level) of a production process.

For such assessments, the EcoWater project gained cooperation from companies which already had invested in eco-innovation upgrading a production process; they have strong prospects for further improvements. The assessment method facilitated multi-stakeholder discussion on potential futures, including a PESTLE analysis of factors influencing eco-innovation. At case-study workshops, stakeholders learned more about each others' perspectives, improvement options and future scenarios.

Eco-innovation is meant to combine ecological-resource and economic benefits as a win-win strategy, but the assessments identified tensions – among various aims, resource burdens, process stages, system levels, economic beneficiaries and timescales. The question arises: benefits for whom, what, where? By opening up such questions, the EcoWater method can help to assess better options, identify their tensions, reach joint responsibilities and pursue more conducive policy frameworks for eco-innovation.

Key words: resource efficiency, process upgrading, whole-system (meso level) assessment, eco-efficiency, scenario exercises

Introduction

For many years, industry has sought to enhance sustainability through strategies such as lean manufacturing, waste minimization or reuse, more efficient material or energy yields, and substitution of renewable energy. Such changes have been conceptualised as eco-innovation, combining ecological and economic benefits as a win-win strategy. To compare benefits of eco-innovation, the eco-efficiency concept has helped to anticipate or measure improvements in resource efficiency alongside economic advantage. But most assessments have narrowly focused on a production site within a company. Recently some companies have shown interest in whole-system analysis, i.e. encompassing the value chain of an entire production process, as a basis to assess options and develop better strategy.

Such efforts could contribute to EU policy aims, which promote eco-innovation for enhance resource efficiency. The Europe 2020 strategy promotes 'resource efficient technologies' to decouple economic growth from the use of resources (CEC, 2010: 4; also CEC, 2011a, 2011b). For the current decade, the shift towards a resource-efficient and low-carbon economy 'will help us to boost economic performance while reducing resource use'. In particular, 'stricter environmental targets and standards which establish challenging objectives and ensure long-term predictability, provide a major boost for eco-innovation' (CEC, 2011a: 2, 6).

In the EU policy context promoting those aims, this paper discusses the following questions:

- Looking beyond a production site, what are options for eco-innovation to enhance resource efficiency within an entire process across the whole-system value-chain?
- What are drivers, barriers and trade-offs for specific options?
- How can multi-stakeholder discussions clarify those issues, towards better decision-making?

After surveying analytical perspectives, this paper links those concepts through an EC-funded research project which had multi-stakeholder involvement in assessing improvement options. Each case study analyses the company context and focuses on one or two options (see Table 1), as a basis to address the above questions.

1 Analytical perspectives: eco-innovation issues

This section surveys perspectives on eco-innovation and multi-stakeholder scenario analysis, as a basis for linking them at the level of a production process, as explained in the subsequent section on Research Methods.

1.1 Eco-innovation evaluated as eco-efficiency

The term eco-innovation gives 'eco' a double meaning. This encompasses various innovations offering greater economic value and lower resource burdens, i.e. inputs and emissions. As a high-profile definition:

> Eco-innovation is the introduction of any new or significantly improved product (good or service), process, organisational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle (EIO, 2011a: 2).

Eco-innovation has been defined more broadly as 'a change in economic activities that improves both the economic performance and the environmental performance of society' (Huppes et al. 2008: 29). In the 1990s many discussions emphasised dematerialisation, i.e. reducing material inputs and thus gaining 'more for less'.

But important distinctions are warranted. Eco-innovation has various forms, e.g. merely incremental change, or radical change in a production system. Associated with eco-efficiency improvements, 'Incremental changes refer to gradual and continuous competence-enhancing modifications that preserve existing production systems and sustain the existing networks, creating added value'. By contrast, radical innovation offers greater societal benefit but may conflict with previous investment: they ‘are competence-destroying, discontinuous changes that seek the replacement of existing components’ (Carrillo-Hermosilla et al., 2010: 1075).

Incremental change is often conceptualised as a process-upgrading which increases eco-efficiency, also potentially generating new functions. In particular:

> A firm can transform its internal processes by redesigning them on the basis of new environmental standards or goals. The strategy defined as ‘beyond compliance leadership’ can also refer to the process-upgrading framework, but it may also induce the firm to develop new functions and play a new role in its VC [value chain], therefore pointing to a functional upgrading. In the first case, this process will result in improved efficiency; in the second in a competitive advantage based on differentiation, that is, a better corporate image (De Marchi, 2013: 66).

Beyond a better overall image, companies have linked eco-innovation with specific products offering consumer benefits, which could increase the company’s income through greater sales or price. Such an advantage depends on aligning product characteristics with green consumer behaviour (Jansson, 2011). According to a survey of German companies, process innovations corresponded to lower profit margins than did product innovations (Rennings and Rammer, 2011). Thus innovation in process upgrading may have weaker incentives than in ‘green products’, whose sales may turn out to expand material consumption. Indeed ‘ecoefficiency must fit within the growth-paradigm and, in fact, it is subtly designed to re-enforce it’ (Welford, 1998: 4).

Eco-innovation design entails tensions among objectives: ‘Like any innovator, an eco-innovator must deal with trade-offs. The trade-offs depend on the state of technology and contextual factors such as prices and infrastructure’ (Kemp and Oltra, 2011: 250). As a related obstacle to eco-innovation, decision-making responsibilities are often fragmented – between economic and environmental criteria, between energy and water burdens, and between value-chain stages, especially across companies. Such fragmentation misses opportunities for eco-innovation. ‘Establishing framework conditions which foster innovation and transparency and which allow sharing responsibility among stakeholders will amplify eco-efficiency for the entire economy and deliver progress toward sustainability’ (WBCSD, 2000: 6-7).

Environmental sustainability improvements were once seen mainly as costs. According to a survey of numerous Europe-based large companies, many have integrated sustainability into their innovation strategies: ‘integration is achieved through formal consideration of sustainability topics with regard to innovation in pre-development or stage-gate processes and related guidelines’. They have developed greater capacity for such integration, especially in response to more stringent regulation of resource burdens. Such responses depend on company knowledge-bases which ‘are path dependent and often determined by irreversible historic processes’ (Wagner and Llerena, 2011: 756, 759), thus generally favouring incremental change.

For moves towards a radical sustainability transition, environmental innovations generally save input factors (energy and/or materials) rather than improve quality in ways which could increase consumer price or sales. Towards reducing GHG emissions, for example, eco-innovation may depend on environmental regulation forcibly internalizing costs of environmental harm by adopting available technologies (van den Bergh et al., 2011: 4).

Indeed, the EU’s relatively more stringent regulation has stimulated some eco-innovation, especially in water-use systems. According to a survey of European companies, major drivers for eco-innovation include: future prospect of full-cost water pricing, water scarcity, regulatory pressures and expected regulatory changes. But regulatory pressures can have contradictory effects on whether or how companies adopt water eco-innovation. Specific regulatory criteria may favour currently available technologies and so hinder more resource-efficient ones: regulations ‘do not support radical innovation and may unintentionally support the existing technological regime’ (EIO, 2011b: 53).

Eco-innovation improvements have been generally evaluated at a specific site within a company or at most within its overall internal processes (e.g. van Caneghem, 2010). Even when a company carries out a life-cycle analysis of wider environmental effects, the economic analysis generally focuses on the company only. A wider scope for both parameters is necessary to evaluate alternative options for supply chains (Michelsen et al., 2006).

As a widespread assessment method, eco-efficiency is a ratio between the economic value and ecological-resource burdens of a process. By comparing options for improvement, eco-efficiency can be 'a strategy or an approach aimed at de-coupling resource use and pollutant release from economic activity' (Mol and Gee, 1999: 24). But eco-efficiency assessments often neglect wider economic aspects, especially changes in value chains (VCs).

> Conversely, business studies lack the more comprehensive analysis of VCs which extend the focus to external stakeholders, including customers and suppliers other than regulators, demonstrated to be, in many contributions, the key players in encouraging environmental strategies… the point is to understand how firms may reduce the impact of all the activities performed to realize their products, including those of suppliers and sub-suppliers, therefore moving the focus from firm-level strategies to VC-level strategies (De Marchi, 2013: 64).

There has been some recognition that potential benefits vary according to the choice of system boundary, as well as the choice of eco-innovation, so that company strategy should take a broader perspective. Looking beyond a production site, some companies have shown interest in a whole-system analysis, also called the meso level. This encompasses all inputs, valuable products, waste, its treatment, etc. According to one study, 'the meso level is the most challenging from the point of view of gathering evidence, as it requires information from many agents' (Reid and Miedzinski, 2008: 22). This methodological gap has been addressed in the EcoWater project (section 2 on methods).

1.2 Multi-stakeholder discussion and scenarios

Beyond information-gathering, meso-level (whole-system) assessments stimulate extra options which depend on multi-stakeholder discussion and new interactions. This intervention role relates to the sociological theory of re-structuration: actors position themselves somewhere between current and future structures – by obeying, neglecting, bypassing and/or transforming the current structure. In dealing with current structures, an actor needs knowledge of other actors – their interpretive schemas, capacities, normative expectations, etc. An external agent such as a researcher can facilitate actors' development of such mutual knowledge (Grin et al., 2010: 273). In this way, research can facilitate new strategies, perhaps even common strategies among actors.

In particular, technology scenarios can play a facilitation role. According to socio-technical perspectives, future-visioning exercises have become a commonplace means to express good intentions for environmental sustainability. Such exercises can also provide conditions for change – more so if linked to demonstration projects of environmental improvement. Transition scenarios are meant to be inspiring, especially if developed by front-runners operating independently of the dominant regime. Socio-technical scenarios can shape stakeholders' expectations, formulate transition routes and develop strategies to realise them (Grin et al., 2010: 84, 273).

As a well-known method, a scenario-analysis identifies PESTLE parameters (Political, Economic, Social, Technical. Legal and Environmental) likely to influence future decisions. A similar schema is called STEEEPA: social, technical, economic, environmental, educational, political and aesthetic (Van der Heijden, 2005: 183). The PESTLE method identifies factors likely to be most important in the time-scale relevant to decision-making.

What roles do drivers and barriers play in actors' strategies? Their roles differ according to two explanatory frameworks – variance versus process theory. Variance theory looks for stochastic causes from independent variables such as drivers and barriers, which are seen as the main forces or actors; organisational decision-making becomes a dependent variable. By contrast, process theory looks for narratives and processes of action-patterns by the main actors, whose character may change through interactions. Also the wider context has various turning points, e.g. crises or policy pressures, which may open up opportunities for actors to stimulate change (Grin et al., 2010: 93).

From a process perspective, PESTLE exercises can explore how stakeholders anticipate future trends. How do their strategies prioritise forms of eco-innovation accordingly? How do/can they try to cooperate across the value chain? How do/can they try to strengthen drivers and weaken or overcome barriers of eco-innovation?

2 EcoWater project: research methods and focus

Our EU-funded research project, EcoWater, has developed a methodology and framework for assessing eco-efficiency on the meso level, also known as the whole-system level. This level is defined as interactions and interdependencies among heterogeneous actors in a production process (Schenk, 2007), e.g. among water suppliers, water users and wastewater treatment providers (EcoWater, 2012a, 2012b). Assessments follow resource burdens and total value-added across a product and water-service value chain (see Figure 1).

The project develops eco-efficiency indicators as a basis to compare options for innovative practices within a specific water-service system. Broader than water use, the latter concept means

> a system which includes the entire range of water services required to render water suitable for a specific water-use purpose, and safely discharging it to the water environment; this system also includes water-using processes and economic activities (EcoWater, 2012b: 45).

By operationalizing those concepts, the EcoWater project aims: to assess the eco-efficiency of various options for innovative practices (including technologies), to compare their relative benefits, to analyse factors influencing decisions to adopt such practices, to inform better decision-making, and to inform policy frameworks which could promote such decisions.

The cases were chosen to provide diverse contexts for refining the EcoWater method, and to ensure that adequate relevant data would be available to calculate eco-efficiency effects of several options. The project focuses on companies which already have invested in process eco-innovation and have relatively strong prospects for improvement. Any competitive advantage comes symbolically for its overall brand: these companies seek a public reputation for environmental sustainability through resource-efficiency measures (e.g. Arla, 2011; NUON, 2013, Volvo, 2011, Sofiyska Voda, 2014). Perhaps not by coincidence, such companies were most willing and able to cooperate with the project.

Within a meso-level value chain, innovative practices can have several stages and roles:

- Water or production chain, as shown in Figure 1: An innovation can upgrade the water-service chain, e.g. the water supply or sewerage system at stages in the horizontal axis. Or it can upgrade the production chain – e.g. through lower resource-inputs, lower emissions (to water, air or soil) or less harmful by-products – at stages in the vertical axis. In the diagram, ‘technologies’ is short-hand for innovative practices which depend on more than technologies.
- Process or product: Within the production chain, process upgrading uses resources in more efficient ways, while production-chain upgrading increases the market value of products.

Such improvements can have synergies. For example process upgrading can reduce emissions in wastewater, in turn facilitating improvements in the water-supply chain, e.g. through in-house wastewater treatment (henceforth abbreviated as WWT), reuse, recycling, etc.

Figure 1: Whole-system (meso-level) value chain
Credit: EcoWater project

Eco-efficiency is usually assessed as a ratio: total value-added (income minus costs) is divided by resource burdens. A baseline eco-efficiency assessment identified the processes or stages which have the greatest resource burdens in each case study, e.g. in a production plant. Each site was the focus for comparing improvement options with the baseline situation and with each other. Each case study considered many options for process upgrading and then emphasised one or two in a multi-stakeholder workshop.

In the Arla dairy case study, a plant was paying a WWT company and was considering investment to bring this stage in-house through an anaerobic WW pre-treatment facility. The biogas yield would substitute for fossil-fuel inputs, thus significantly increasing resource efficiency at the micro level. But the renewable energy would be merely shifted from outside to inside the main company, so this option would bring little improvement at the meso level (Levidow et al., 2014). This assessment stimulated and informed multi-stakeholder discussion of other options which may have greater meso-level benefits (Lindgaard-Jørgensen, 2014).

Each case study also carried out a PESTLE exercise on one or more options, resulting in a detailed Table. Just a few aspects are selected below for relevance to multi-stakeholder cooperation.

In the next three sections, each case study describes the industry-wide context for a company, its environmental perspective, and then one or two eco-innovative options which were discussed in a multi-stakeholder workshop.

3 Truck-body corrosion-resistance

The automobile sector has generally directed eco-innovation at vehicle use and users, especially for greater fuel efficiency as a competitive advantage, as well as CO2 reductions as a regulatory criterion (e.g. Oltra and Maïder, 1999). The sector has incrementally improved the energy efficiency of the internal combustion engine. Since the 1990s some manufacturers have also developed alternative-fuel vehicles (Sierzchula et al., 2012; Köhler et al., 2013).

Such redesign has responded partly to market competition; vehicles can generally gain a higher price or sales through fuel efficiency, but not through improvements in the production process. In the European context a key driver has been legislation requiring that by 2015 CO2 emissions from all new EU-registered cars should not exceed an average of 130g CO2/km across the range of each manufacturer; this limit was around one fifth below 2007 levels (EC, 2009). Moreover, car manufacturers receive official recognition and carbon credits if they fit their new cars with approved 'eco-innovations' (EC, 2011).

As an atypical priority within the industry, Volvo's agenda for resource efficiency has driven improvements within the production process. According to the Volvo Group's sustainability report, 'a resource-efficiency approach is well integrated in our culture and is an important priority ahead' (Volvo, 2011: 38). Operations attempt to minimise energy use and recycle materials, especially by installing closed-process water systems (ibid: 58).

At each Volvo site, different units have responsibility for economic and environmental evaluation, with some discussion between them. There has been no systematic discussion between Volvo and WWT companies about improvement options. So fragmented responsibilities impede or complicate whole-system improvements.

In the corrosion-protection process, Volvo Trucks has already made an environmental improvement by replacing a hazardous chromium process with zinc-phosphating technology. But the latter still has several environmental disadvantages: it requires heating of process baths, uses heavy metals (Zn, Ni, Mn) which end up in wastewater, and produces hazardous sludge (e.g. metal hydroxides). Relative to those problems, a new silane-based polymer has several advantages. It features: process at room temperature; total energy use ~40% less than the Business As Usual (BAU) process; water use 50-90% less than BAU; no use of heavy metals or P; no hazardous sludge and very little other sludge. Wastewater pollutants (Zr, silane, fluoride) can be reduced to ~0 mg/l by ion exchange.

Silane-based technology has been considered at Volvo's Tuve site, which applies the corrosion-protection process to cabins received from Volvo's Umeå site. The option has been evaluated at the meso level by encompassing both sites, their respective water supplier and Stena Recycling, which charges the Tuve site for WWT services. At the multi-stakeholder workshop held in March 2013, the case-study team presented the following results of meso-level eco-efficiency.

As regards environmental improvement, the silane-based option would reduce water use, as well as the wastewater quantity and emissions content; overall improvement in resource burdens would be 5-10%. Specific indicators are shown in Figure 2, comparing the silane-based option (diamond-shaped nodes) with the baseline situation (circle-shaped nodes). Improvements appear mainly in aquatic ecotoxicity and eutrophication, due to reduced emissions to water of heavy metals and phosphorus. Although the silane process significantly reduces the water input, the overall improvement appears negligible because the Umeå site uses relatively much more water and the abundant freshwater sources have a low exploitation index.

Figure 2: Silane-based option compared with baseline indicators
Credit: IVL, Goteborg/EcoWater project

As regards the total value added (TVA), the lower quantity of both water use and WWT mean a lower electricity demand for pumps and less use of chemicals. The total costs of water and water-related inputs would be somewhat reduced for the Tuve site, its water supplier and Stena Recycling. So the TVA slightly rises. More significantly, the TVA would be redistributed across the meso-level value chain. Each company's changes in net economic performance is shown in Table 2. So the silane-based option involves a trade-off between overall systemic improvement versus lower income for two actors.

Table 2: Distribution of economic and environmental changes in the silane-based option
Credit: IVL, Goteborg/EcoWater project

The workshop discussed stakeholder interactions and potential cooperation around the silane-based option. The WWT company commented: 'If Volvo improved its environmental performance and generated effluents of better quality, it would be easier for Stena Recycling to comply with the regulations.' (EcoWater, 2013: 35).

Thinking about innovative technology implementation in general, the workshop carried out a PESTLE analysis, identifying many drivers and barriers of improvement options (see section 1.2). One point had special relevance to any change in effluent, namely, standards for Best Available Technology (BAT). Several years ago the latest Bref document mentioned silane-based alternatives for the corrosion protection process without evaluating them (CEC, 2006). Companies face uncertainty about whether the authorities will accept such alternative as 'best available' technology. Although BAT standards have provided a common minimum, future uncertainty potentially limits or deters investment in eco-innovation.

Workshop participants agreed that cooperation could help avoid sub-optimal solutions:

> Sub-optimisation can be more easily avoided through stakeholder cooperation in evaluating the overall system. Organization of the different 'players' towards a common goal can increase cooperation among actors that perhaps unknowingly share a mutual interest in environmental protection (EcoWater, 2013: 37-38).

Stena Recycling expressed interest in further collaboration with Volvo (and all Stena's customers) towards finding the best solutions for wastewater treatment at an early stage, before manufacturers select a new technology.

Held in May 2014, a follow-up workshop discussed more improvement options and cooperation on investment decisions. The EcoWater case-study team presented spider-diagrams of environmental impact and eco-efficiency, showing a small improvement in most indicators but also a slight deterioration in some indicators. Stena Recycling asked Volvo for early information about test runs of any new technology and for WW samples, in order to plan well in advance before a change happens (IVL, 2014).

At that workshop an interactive exercise explored barriers and drivers of potential improvements by discussing the six standard PESTLE factors (see section 1.2). The results identified three of the most important factors as follows: Economic: electricity price, Environmental: use and regulation of persistent chemicals, Political: policy on scarce resources (phosphorous, metals). The exercise anticipated plausible variations in their future states and how these may drive or impede Volvo's implementation of eco-innovative technologies. A follow-up exercise could analyse the need for specific policies to promote eco-innovation across the various potential futures.

The multi-stakeholder workshops have served as a good starting point for further discussions. The meso-level evaluation of technologies served as a tangible way to stimulate discussion. It also gave stakeholders greater insight into where the largest improvements can be made, both environmentally and economically, and how they may influence each other within a common meso-level system. Conducting a PESTLE analysis in a multi-stakeholder group is a method tool to ensure discussion of all factors (see section 1.2).

4 Cogeneration of heat and electricity

Energy cogeneration, also known as CHP (Combined Heat & Power), has higher energy efficiency than separate production of each component, provided that there is adequate demand for both power and heat. CHP plants have been established mainly in markets with large heat demand, especially in energy-intensive industries, greenhouse horticulture, services in large buildings and residential areas. The latter use depends on a large-scale, long-term expensive investment in district heating systems.

The first key factor in useable heat is the use time, i.e. the time-period when thermal energy is consumed. Domestic heat demand varies over the day and with the seasons; demand exists only during 30-50% of the year, and peak demand occurs only a few days per year. During the rest of the year, most of the produced heat remains waste heat, typically discharged to surface water. Given this constraint, greater resource-efficiency depends on a flexible distribution network and/or peak-shaving capacity to lower the maximum demand.

A second key factor in useable heat is its temperature. Industrial purposes, which are often year-round businesses, requires very high temperatures. District heating typically uses distribution temperatures of about 100-120°C, while some developments use a lower temperature, such as greenhouse farming.

Cogeneration involves trade-offs between electricity and heat: Maximizing power production requires the lowest possible temperature at the condensing site of the generator, but this depends on greater water-tapping (cooling), thus generating more excess heat (Verbruggen et al., 2013: 578). Conversely, tapping water at higher temperatures yields hotter heat and reduces heat in cooling water, though it somewhat reduces the useful electrical power and thus the related income (EcoWater, 2014).

The latter option has extra disadvantages. Investment in different equipment would be necessary to tap electricity at a higher temperature, as well as to transmit the hotter heat. These difficulties compound the lower income through lower electricity generation.

From a micro-level perspective, e.g. an energy plant per se, the priority is to maximise income (or profit), which comes mainly from electricity as the most lucrative product. From a meso-level (whole-system) eco-efficiency perspective, by contrast, priorities are to maximise usable energy and consequent income while also minimising resource burdens, especially fossil-fuel demand, GHG emissions, cooling-water emissions, etc. Any mis-match between heat demand and production can be mitigated by various strategies, for example: Buffer basins and additional heat-only boilers can shave daily peaks, and the system can include other heat users with a more constant demand. If high-temperature heat is required, then in principle this can be produced by a CHP plant.

Improvement options intersect with wider strategic issues for cogeneration. Energy production is caught between pressures of lower electricity prices and imperatives to reduce GHG emissions, especially to comply with EU targets. According to the main cogeneration company in the Netherlands, recently

> it became even clearer that the traditional business model, based on large-scale electricity generation in conventional power plants, is being challenged… Costs must be lowered along the entire value chain, the production portfolio must be restructured and flexibility must be increased where technically possible (NUON, 2013: 4, 6)

In particular the company plans to expand heat supply to district heating, alongside heat-storage facilities to provide peak-shaving amidst intermittent demand:

> Expanding further in district heating projects also provides valuable opportunities to expand further in renewable energy, as district heating provides a significant reduction of CO2 emissions in comparison with conventional gas-heated boilers…. District heating fits well with Nuon's strategy, since it offers a 50% to 80% reduction of CO2 emissions compared to conventional gas-heated boilers, depending on the source of the heat (NUON, 2013: 7, 11).

In that company-wide context the EcoWater study investigated options at the Diemen 33 cogeneration plant supplying mainly residential areas in Amsterdam and Almere. Since 2012 the cooling-water abstraction and discharge points have been swapped; water is now taken from the water body originally serving as receiving water and vice-versa. This adjustment had two drivers: Residential areas were developed on artificial islands near the discharge point, thus increasing public health risks. Prevalent water volumes and temperatures posed a risk of a cooling-water shortage. More recently, Amsterdam municipality has made a commitment to increase district heating (Gemeente Amsterdam, 2013), though specific support measures remain unclear.

The EcoWater study's multi-stakeholder workshop discussed the necessary conditions for establishing a thermal network in the local context. District heating systems had been installed in a newly built neighbourhoods in the Netherlands (and elsewhere), but there was little residential building activity near the plant; so this solution would replace and/or jeopardise previous investment in heating systems.

The workshop also discussed drivers and barriers, whose interactions were depicted in an influence diagram (Figure 3). Some key points from the discussion: The company's commitment to extend district heating would need political confidence in future favourable conditions, especially through 'consistent governance for a 30-50 year period'. Amongst such conditions for such investment: a thermal network needs a price equal to gas-based heat; and CO2 emission credits need to be made more expensive, so that low-carbon energy becomes more competitive (Goossens & Meijer, 2014).

Figure 3: Influence diagram for establishing a thermal network
Arrows indicate inter-related influences: positive sign = driver, negative sign = barrier.
Credit: Deltares

Stakeholders face a circular dilemma: If there is no heat network, then there will be no demand for district heating; but without demand, there will not be investment in a heat network. The workshop discussed two visions for a transition:

(1) A thermal network is a private initiative: private-sector parties finance and realise a network, and then provide exploitation and maintenance. Here governments can promote the transition only through legislation, governance and facilitation.

(2) A thermal network is a public-service utility like the electricity or roads, connecting various sources and many users. Here the government has a strong role in organizing the network, providing opportunities to its users, and exploiting and maintaining it (Goossens & Meijer, 2014).

These two scenarios provided a basis for multi-stakeholder discussion on possible ways forward.

Under foreseeable circumstances, the company will not make a priority of reducing the electricity-heat ratio to yield higher-temperature heat, nor of linking the plant with a district-heating system. More modest options have been pursued. Year-round demand for heat would help, especially from industrial users, so these have been sought. Peak-shaving of daily peaks (via a heat buffer or storage facility) would reduce the temporal mis-match between demand and supply of electricity. This modest investment offers a relatively modest improvement in resource efficiency and GHG savings, while also significantly lowering costs. When it becomes operational at the Diemen 33 plant, the peak-shaving facility will reduce use of the CCCT or heat-only boilers during the daily peak-demand for heat.

The above options reveal tensions between resource efficiency at the micro-level (company) and meso-level (whole-system). From the latter perspective, resource-efficiency would be greatly improved by a thermal network using all the waste heat, but this would depend on expensive long-term investment and elusive heat-users, as well as less income from electricity production. Informed by a whole-system analysis, a multi-stakeholder workshop highlighted those tensions and identified areas for policy attention.

5 Sofia urban water system

Sofia's urban water system is sourced mainly from the Iskar reservoir at a higher altitude than the city. Water is transported by pressurized water mains to the water treatment plant (WTP) Bistritsa, situated around 60m lower than the Iskar reservoir. Thus there is a huge potential for hydro-energy at the plant's inlet. The sewage is driven through pressure and gravity. Wastewater is treated at the Sofia WWTP before discharge into the Iskar River.

Investigating the urban water-service value chain, the EcoWater case-study team compared the various stages and found greatest resource burdens in householders' water use stage. Reducing water use there would most reduce energy demand in heating-water as well as for water-dependent electrical appliances, thus also reducing GHG emissions because nearly all the energy comes from fossil fuels. The team explored ways to achieve those goals, especially through various domestic water and energy-saving technologies which would maintain the previous water-service value to householders. They would make assumptions about future water prices when deciding whether to buy and install such technologies. To the extent that householders reduce water demand, the company would lose income unless prices rise.

In addition to the water use stage, the team identified other weak stages where eco-innovative technologies would increase the entire eco-efficiency performance. Pressure-reducing turbines, which convert the hydro-potential energy to electricity, were suggested for the water-supply stage. An innovative solar sludge-drying system was suggested for the WWTP stage.

The stakeholder-mapping identified three main groups: state authorities, municipal authorities-agencies and citizens, potentially represented by NGOs. For Bulgaria's national water policy, major state stakeholders are: Ministry of Environment and Water (setting overall water policy), Ministry of Regional Development (setting policy on urban water supply, and sewerage systems and water operators) and the State Energy and Water Regulatory Commission (regulating water, sewerage and energy services) and the Ministry of Economics and Energy (setting energy policy, relevant to water supply).

Sofia's entire water system is managed by Sofiyska Voda (a subsidiary of Veolia) by concession from the municipality, which holds a 22.9% stake. The company promotes its reputation as 'an environmentally responsible company'. This involves several aims: to use natural resources efficiently in order to preserve them; to save energy and other resources; and to restrict the continuously growing water consumption (Sofiyska Voda, 2014).

Held in February 2014, the Sofia multi-stakeholder workshop had 12 participants representing all those national and local institutions (except the State Energy and Water Regulatory Commission). The case-study team presented several innovative options (as listed above), aiming to obtain stakeholders' views on: i) those options and any other relevant ones, and ii) the main drivers and barriers of those options.

To achieve the first aim, stakeholders were asked to prioritise the innovative options for discussion. Stakeholders proposed three additional options:
1) Extending one of the above technologies, a pressure-reduction turbine, through a small hydropower plant along the pipe feeding the water treatment plant (WTP).
2) Extending another of the above technologies, heat recovery from households, through pumps recovering heat from the sewerage system.
3) Replacing the technology for solar sludge-drying with a technology for sludge incineration.

Participants prioritised the first two of those three options for further discussion, rather than the options originally suggested by the case-study team. Their priorities could be explained by participants' institutional responsibility or stakes in the two options. As another reason why domestic appliances were not given priority, no workshop participants represented citizens or householders.

To identify the drivers and barriers of the above two options, they were discussed in parallel in break-out groups. Group members were selected so that stakeholders from the same institution would join different groups and so that participants would be familiar with the technology or relevant part of the system. Participants individually wrote down their thoughts about drivers (D) and barriers (B) for all PESTLE factors on post-it notes. Afterwards they put their notes in the group's PESTLE table, factor by factor, while discussing each factor within the group.

In general, each participant identified different D and B factors, thus bringing extra value to the exercise and confirming its usefulness. For the technology option, 'Energy generation through hydropower plant on the feeding pipe of the WTP', two barriers were mentioned by more than one participant: high initial investment, and unsatisfactory condition or lack of infrastructure.
The group dealing with the other technology option, 'Heat recovery from the sewerage system', showed more homogeneous opinions. Participants mentioned three common drivers and three common barriers, as listed here in the standard PESTLE order:

- Political: Reducing taxes for users of 'green' energy is a political driver.
- Economic: Producing energy is an economic driver. High investment for the technology itself and the necessary infrastructure is a serious barrier
- Social: Reducing the service cost is a social driver.
- Technical: Little experience in maintaining such technology is a technical barrier.
- Legal: Absent legislation about planning, exploitation and maintenance is a legal barrier.

The latter barrier was seen as jointly political-legal, i.e. an unclear legal framework for water management and long-term strategies to improve eco-efficiency of urban water systems.

The discussions on the other option, 'Energy generation through hydropower plant on the feeding pipe of the WTP', revealed potential stakeholder conflicts over the distribution of costs and benefits. Who would benefit from the extra energy or income – only Sofiyska Voda? or also citizens through lower water tariffs? The stakes of the two main stakeholders – Sofiyska Voda, and Ministry of Economics and Energy – appeared unclear for the option to create a new energy source from the water supply system. If these institutional issues are not clarified, then the improvement potential will be lost, according to participants.

As an omission from the standard PESTLE categories, environmental factors were mentioned by few workshop participants. Renewable-energy benefits would enhance the company's environmental reputation but perhaps are not a strong driver for the necessary investment. And environmental benefits do not straightforwardly become policy drivers in the current context.

Looking beyond the above two options, participants felt that the multi-stakeholder meeting was a good opportunity to exchange information, discuss common problems and share ideas for joint ways forward (UACEG, 2014).

6 Conclusions

Industry has been investing in eco-innovation as a win-win strategy, combining environmental and economic benefits, in pursuit of various aims. Some production processes have been upgraded in ways which enhance a company's environmental reputation. Process improvements lower resource burdens (input demands and/or emissions) but lack a competitive advantage through higher-quality products or greater sales. As investigated in our four case studies, such investment has multiple incentives – environmental objectives, 'green' reputation and lower energy costs, even renewable-energy generation (see again Table 1). Company strategies go beyond current regulatory requirements, sometimes anticipating more stringent future ones.

Improvement options have been sometimes evaluated through eco-efficiency assessments, a ratio between economic benefits and resource burdens. Such assessments have generally focused on a company site. Looking more broadly, some companies have shown interest in eco-efficiency assessment at the whole-system (meso level) of a production process. The EcoWater project conceptualised this level as interactions and interdependencies among heterogeneous actors. The project gained cooperation from companies which already had invested in eco-innovation upgrading a production process. These case-study companies have strong prospects for further improvements, relative to their respective industrial sector.

For an eco-efficiency assessment of improvement options, the EcoWater method anticipated changes in resource burdens and total value-added across a meso-level value chain, e.g. encompassing water suppliers, water users and wastewater treatment (WWT) providers. Some options would depend on extra resource-usages and/or extra stakeholders, thus expanding the meso-level value chain. Relevant stakeholders provided essential information on the baseline context and on investment options that they were considering, so that the case-study team could assess and compare their whole-system eco-efficiency.

Through those assessments, the EcoWater method facilitated multi-stakeholder discussion on potential futures. Prior discussion encouraged attendance at case-study workshops where stakeholders learned more about each others' perspectives, improvement options and future scenarios. Through a PESTLE analysis of specific options, participants identified drivers and barriers. Rather than accept such factors as independent variables, participants discussed possible ways to deal with them. Thus workshops helped participants to envisage ways of sharing knowledge and greater responsibility towards better options (cf. Grin et al., 2010).

Eco-innovation is meant to combine ecological and economic benefits, yet the assessments identified tensions – among various aims, resource burdens, process stages, system levels, economic beneficiaries and timescales. Such tensions took various forms amongst the options (Sections 2 and 3, as well as Table 1):

1. In the Arla dairy case study, the WW pre-treatment option would shift renewable energy from outside to inside the main company, thus increasing micro-level resource efficiency but bringing little improvement at the meso level.
2. In the Volvo silane-based option, more advance information and cooperation would help the WWT company to benefit from a technology change. The TVA increases but would be redistributed in favour of the investor company, at the expense of other value-chain actors. Benefits-redistribution was potentially conflictual, as an internal matter within the private sector.
3. In the cogeneration case, resource efficiency would be greatly improved by a larger thermal network, especially through district heating, but its realisation is complicated by several factors, e.g. the market-demand conditions for power and heat, the high investment costs, the heterogeneous stakeholders and need for a long-term policy commitment.
4. In the Sofia options for renewable-energy production, potentially substituting for fossil fuels, there is an absent legal-political basis for distributing the economic benefits,

thus potentially impeding investment. Environmental benefits could enhance the company's reputation but do not straightforwardly become a policy driver.

In the latter two cases, the improvement option depends on expanding the meso-level system, while also clarifying the policy-legal framework and key actors' responsibilities (cf. WBCSD, 2000). The current institutional context poses difficulties for investment.

Eco-innovation has been meant as a win-win strategy combining ecological and economic benefits. But the above tensions lead us to ask: benefits for whom, what, where? For improvement options in the four case studies:

1. A micro-level resource-efficiency assessment would be deceptive regarding meso-level effects (dairy WW pre-treatment).
2. The dominant stakeholder gains economically more than others (vehicle corrosion-protection).
3. There is insufficient incentive for a single stakeholder or for multi-stakeholder joint responsibility to invest in more resource-efficient options (district heating from cogeneration). As a separate option, higher-temperature waste-heat for greater industry usage requires different equipment and somewhat lowers electricity generation.
4. Stakeholders' entitlement to the economic benefits remains ambiguous (renewable energy from urban water).

Such tensions complicate the concept of eco-innovation, as in earlier insights on trade-offs (cf. Kemp and Oltra, 2011). These have been revealed through meso-level eco-efficiency assessments and multi-stakeholder discussions in EcoWater case studies. In such ways, the project's method can help to assess better options, identify their tensions, reach joint responsibilities and pursue more conducive policy frameworks for eco-innovation.

Acknowledgements

'EcoWater: Meso-level eco-efficiency indicators to assess technologies & their uptake in water use sectors' is a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA), http://environ.chemeng.ntua.gr/EcoWater/

References

Albino, V., Balice, A., Dangelico, R.M. 2009. Environmental strategies and green product development: an overview on sustainability-driven companies, *Business Strategy and the Environment* 18: 83–96.

Carrillo-Hermosilla, J., del Río, P., Könnölä, T. 2010. Diversity of eco-innovations: Reflections from selected case studies, *Journal of Cleaner Production* 18: 1073-83.

Bönte, W. and Dienes, C. 2013. Environmental innovations and strategies for the development of new production technologies: empirical evidence from Europe, *Business Strategy and the Environment* 22: 501–516.

CEC. 2006. Integrated Pollution Prevention and Control Reference Document [Bref] on Best Available Techniques for the Surface Treatment of Metals and Plastics. Brussels: Commission of the European Communities.

CEC. 2010. *Europe 2020: A strategy for smart, sustainable and inclusive growth*. Brussels: Commission of European Communities.

CEC. 2011a. *A Resource-Efficient Europe: Flagship initiative under the Europe 2020 Strategy*, Brussels: Commission of European Communities.

CEC. 2011b. *Innovation for a Sustainable Future: The Eco-innovation Action Plan (Eco-AP*).

De Marchi, V., Di Maria, E. and Micelli, S. 2013. Environmental strategies, upgrading and competitive advantage in global value chains, *Business Strategy and the Environment* 22: 62–72.

EC. 2009. Regulation 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles.

EC. 2011. Commission Implementing Regulation (EU) No 725/2011 of 25 July 2011 establishing a procedure for the approval and certification of innovative technologies for reducing CO2

emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council Text with EEA relevance.
EcoWater. 2012a. Deliverable 1.1: Review and selection of eco-efficiency indicators to be used in the EcoWater Case Studies, http://environ.chemeng.ntua.gr/ecowater/UserFiles/files/D1_1_Review_and_selection_of_eco-efficiency_indicators.pdf [last accessed on 26.03.2014]
EcoWater. 2012b. Deliverable 1.8: Roadmap for Case Study Development.
EcoWater. 2012c. Deliverable 1.7: Methodology and scenario frameworks for elaboration in the EcoWater Case Studies, http://environ.chemeng.ntua.gr/ecoWater
EcoWater. 2013. Deliverable 6.1: Synthesis report from the 1st Round of Case Study events, http://environ.chemeng.ntua.gr/ecoWater/UserFiles/files/D6_1_Final(1).pdf [last accessed on 26.03.2014],
EcoWater. 2014. Deliverable D 4.3: Innovative technologies for enhancing the eco-efficiency of water use in industries: Case Study 5, 6, 7 and 8.
EEA. 2012. *Towards Efficient Use of Water Resources in Europe*. Copenhagen: European Environmental Agency.
EIO. 2011a. *Eco-innovation Challenge: Pathways to a resource efficient Europe*. Brussels: Eco-Innovation Observatory (EIO). Funded by the European Commission, DG Environment.
EIO. 2011b. *Water Innovation: How eco-innovation can contribute to the sustainability of Europe's water resources*, Brussels: Eco-Innovation Observatory (EIO). Funded by the European Commission, DG Environment.
EIP-Water. 2012. *Strategic Implementation Plan*, Brussels: European Innovation Partnership on Water, ec.europa.eu/environment/water/innovationpartnership/pdf/sip.pdf
Gemeente Amsterdam. 2013. Kennisnemen van de voorgenomen uitbreiding van het Amsterdamse stadswarmtenet naar de bestaande bouw [Proposed expansion of Amsterdam's district heating to existing buildings], 2 July, http://zoeken.amsterdam.raadsinformatie.nl/cgi-bin/showdoc.cgi/action=view/id=206750/type=pdf/raadsbesluit.189.663.3a.13.pdf
Goossens, H. & Meijer, K. 2014. Causal Loop and Group Model-Building Session: summary, EcoWater Case Study 6: Cogeneration of Heat and Power, held on 7 November 2013, Amsterdam: Deltares.
Grin, J., Rotmans, J., Schot, J.W., eds. 2010. *Transitions to Sustainable Development New Directions in the Study of Long Term Transformative Change*. London: Routledge.
Huppes, G. and Ishikawa, M. 2009. Eco-efficiency guiding micro-level actions towards sustainability: Ten basic steps for analysis, *Ecological Economics* 68: 1687–1700.
IVL. 2014. Outcomes and discussions of the second Automotive Industry (Volvo) Workshop, Gothenburg, held on 6 May 2014.
JRC. 2011. *International Reference Life Cycle Data system (ILCD) Handbook: Recommendations for Life Cycle Impact Assessment in the European Context*. First Edition. Luxembourg: Publication Office of the European Union. European Commission, Joint Research Centre, Institute for Environment and Sustainability.
Jansson, J. 2011. Consumer eco-innovation adoption: Assessing attitudinal factors and perceived product characteristics, *Business Strategy and the Environment* 20: 192–210.
Kemp, K. and Oltra, V. 2011. Research insights and challenges on eco-innovation dynamics, *Industry and Innovation* 18(3): 249-253.
Köhler, J., Wolfgang Schade, Guillaume Leduc, Tobias Wiesenthal, Burkhard Schade, Espinoza, L.T. 2013. Leaving fossil fuels behind? An innovation system analysis of low carbon cars, *Journal of Cleaner Production* 48: 176-186.
Levidow, L., Lindgaard-Jørgensen, P., Nilsson, Å., Skenhall, S.A., Assimacopoulos, D. 2014. Eco-efficiency improvements in industrial water-service systems: Assessing options with stakeholders, *Water Science and Technology* 69(10): 2113-21, doi: 10.2166/wst.2014.131, IWA Publishing, http://www.iwaponline.com/wst/06910/wst069102113.htm
Lindgaard-Jørgensen, P. 2014. Technology options in a dairy plant: assessing whole-system eco-efficiency, paper for European Round Table on Sustainable Consumption and Production (ERSCP), 14-16 October.
Lindskog, N. 2013. Volvo Trucks water-consuming processes. Volvo Technology, ATR, Sweden (VTEC), PPt presentation at EcoWater workshop, Gothenburg.
Michelsen, O., Fet, A., M., & Dahlsrud, A. 2006. Eco-efficiency in extended supply chains: A case study of furniture production, *Journal of Environmental Management* 79 (3): 290-297.
Mol, S. and Gee, D. 1999. *Making Sustainability Accountable: Eco-efficiency, resource productivity and innovation*. Topic report No.11. Copenhagen: European Environment Agency.
Nuon. 2014. *N.V. Nuon Energy Annual Report 2013: Continued positioning for tomorrow's energy market*,

http://www.nuon.com/Global/Nederlands/Financials/Jaarverslagen/Nuon%20Jaarverslag%202013.pdf

Oltra, V. and Maïder, S-J. 2009. Sectoral systems of environmental innovation: An application to the French automotive industry, *Technological Forecasting and Social Change* 76(4): 567–583.

Reid, A. and Miedzinski, M. 2008. *Eco-Innovation: Final Report for Sectoral Innovation Watch*, Brussels: Technopolis.

Rennings, K. and Rammer, C. 2011. The impact of regulation-driven environmental innovation on innovation success and firm performance, *Industry and Innovation* 18(3): 255-283.

Schenk, N.J., Moll, H.C. and Uiterkamp, A. 2007. Meso-level analysis, the missing link in energy strategies, *Energy Policy* 35: 1505-16.

Sierzchula, W., Bakker, S., Maat, K., van Wee, B. 2012. Technological diversity of emerging eco-innovations: a case study of the automobile industry, *Journal of Cleaner Production* 37: 211-220

Sofiyska Voda. 2014. Environmental Protection Policy of Sofiyska Voda, Sofia, http://www.sofiyskavoda.bg/SVDocuments%20English/Environmental_Policy2014ENG.pdf;
also Environment, http://www.sofiyskavoda.bg/en/environment.aspx

UACEG. 2014. Outcomes and discussions of the Sofia Case Study Workshop, held in Sofia, 25.02.2014, EcoWater project. Sofia: University of Architecture, Civil Engineering and Geodezy (UACEG).

van den Bergh, J., Truffer, B. and Kallis, G. 2011. Environmental innovation and societal transitions: Introduction and overview, *Environ mental Innovation and Societal Transitions* 1(1): 1‐23.

van der Vooren, A., Alkemade, F., Hekkert, M.P. 2012. Effective public resource allocation to escape lock-in: The case of infrastructure-dependent vehicle technologies, *Environmental Innovation and Societal Transitions* 2 (1): 98– 117.

van Caneghem, J., Block, C., Cramm, P., Mortier, R., Vandecasteele, C. 2010. Improving eco-efficiency in the steel industry: The ArcelorMittal Gent case, *Journal of Cleaner Production* 18(8): 807-814.

Van der Heijden, K. A. 2005. *Scenarios: the Art of Strategic Conversation*, 2nd edition. Chichester: Wiley.

Verbruggen, A., Dewallef , P., Quoilin, S., Wiggin, M. 2013. Unveiling the mystery of Combined Heat & Power (cogeneration), *Energy* 61: 575-582.

Volvo. 2011. *Sustainability Report 2010*. Göteborg: Volvo Group.

Wagner, M. and Llerena, P. 2011. Eco-innovation through integration, regulation and cooperation: comparative insights from case studies in three manufacturing sectors, *Industry and Innovation* 18(8): 747-764.

WBCSD. 2000. *Eco-efficiency: Creating More Value with Less Impact.* Geneva: World Business Council for Sustainable Development.

Welford, R. 1998. Editorial. Corporate environmental management, technology and sustainable development. Postmodern perspectives and the need for a critical research agenda, *Business Strategy and the Environment* 7(1): 1–12.

Two Tables

Resource burdens and potential improvement	Energy input in production process	Energy necessary to manage hazards	**Eco-innovation** option and tensions (example)
Water-service roles in each case study	in main company	in main and/or WWT company	in main company
1. **Dairy:** Milk-powder prodn extracts milky water needing disposal	Water removal from milk	Treating WW residues to avoid eutrophication	In-house anaerobic WWT would substitute renewable energy and reduce the dairy's GHG emissions. But would bring minimal whole-system benefits, by shifting biogas from the outside to the dairy.
2. **Trucks**: Corrosion-protection needs water to carry inputs, to heat the process baths and to remove wastes.	Water abstraction, purification and circulation. Hot water for high-temperature chemical process.	Treating organic materials which would cause eutrophication. Removing heavy metals.	Silane-based room-temperature process would reduce water and energy use; also would replace heavy metals and so avoid hazardous sludge. But lower-volume WW would lower the value-added for WWT plant.
3. **Cogeneration** (electricity + heat): Requires cooling-water to remove heat.	Water abstraction to cool the electricity-condensing point	Pumping to remove cooling-water, whose emissions can cause a public health hazard.	Higher-temperature condensing-point would need less energy for water pumps and produce more flexibly useful heat for industry, but would somewhat increase costs and reduce electricity income. District-heating system could use lower-temperature heat but depends on expensive investment in a heat network and a long-term policy commitment.
4. **Municipal water system** Requires energy for WWT, water purification and heating	Water purification and heating	Treating WW and sludge	Hydropower plant (along the pipe feeding the WT plant) would substitute renewable energy for fossil fuel. But the benefits-distribution remain legally ambiguous.

Table 1**: Resource efficiency through eco-innovation**
Columns emphasise energy use because its reduction is a major resource burden and driver for eco-innovation.

Value-chain stage	Kretslopp & Vatten: Water supply	Volvo Trucks: Water supply, use and WWT	Stena Recycling: WWT	Eco-efficiency of total value chain
Economic/ Environmental parameters	Econ. - Env. +	Econ. + Env. +	Econ. - Env. +	Increase

Table 2: **Redistribution of economic value in the silane-based option**

Three Figures

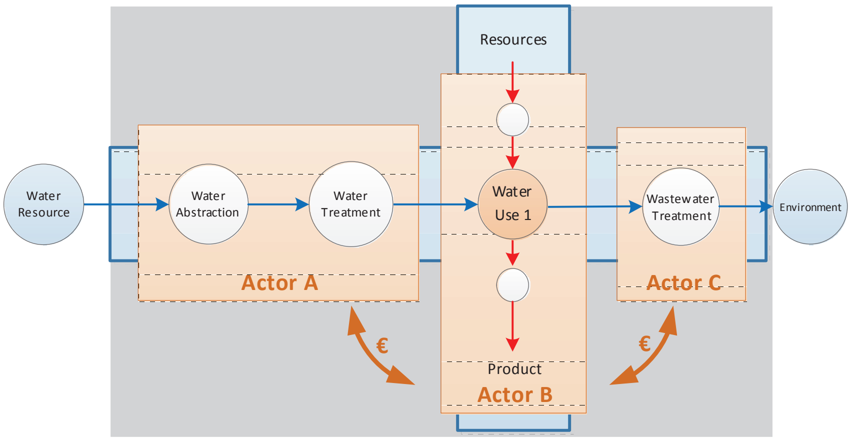


Figure 1: Whole-system (meso-level) value chain

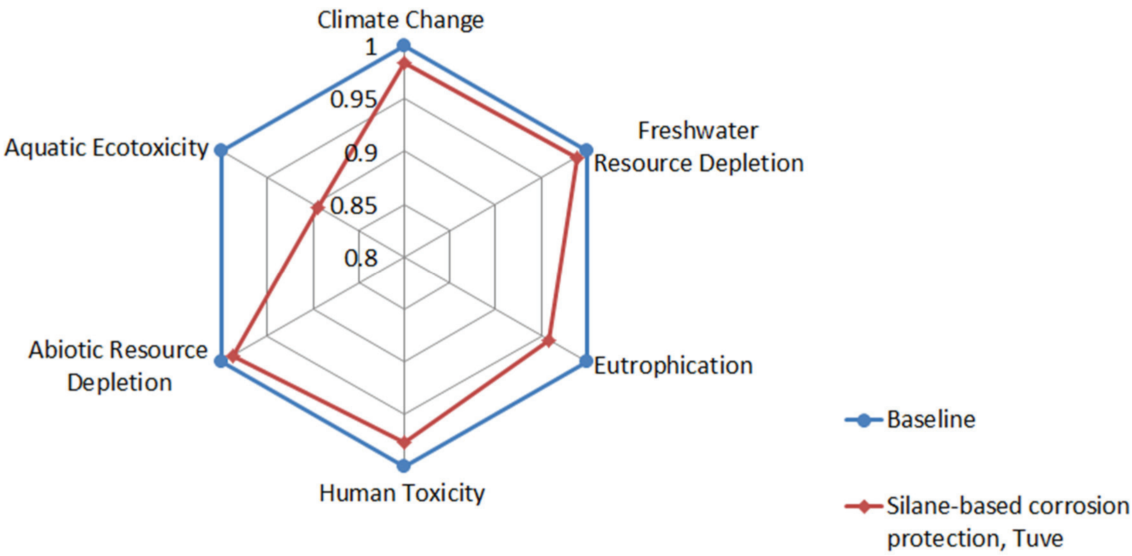
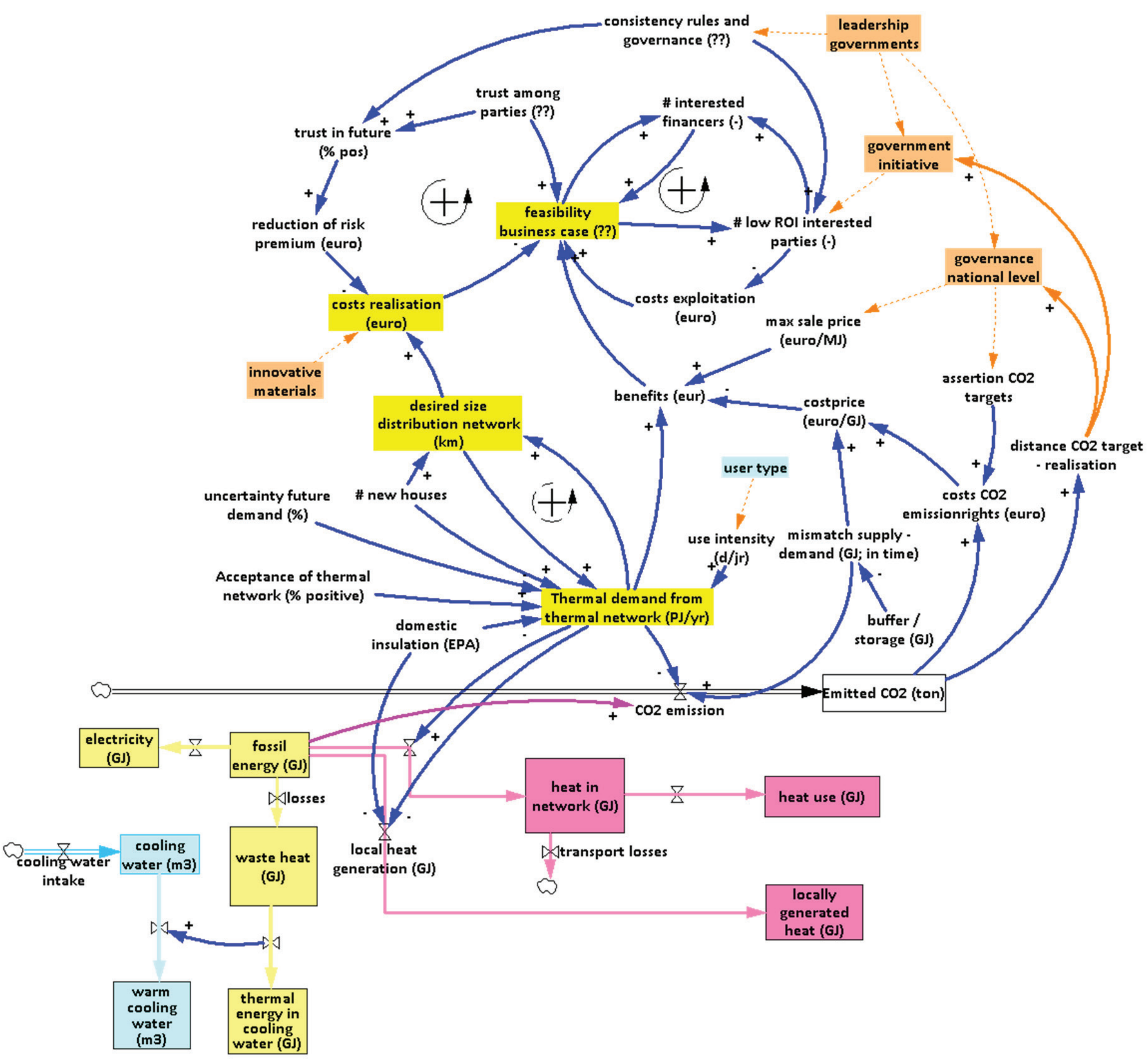


Figure 2: Silane-based option compared with baseline indicators

Figure 3: Influence diagram for establishing a thermal network
Arrows indicate inter-related influences: positive sign = driver, negative sign = barrier.
Credit: Deltares



Eco-efficiency assessment in the agricultural sector: the Monte Novo irrigation perimeter, Portugal

Rodrigo Maia, Cristina Silva and Emanuel Costa, Faculty of Engineering of the University of Porto, Rua Dr. Roberto Frias, s.n., 4200-465 Porto, Portugal, rmaia@fe.up.pt, (+351)225081916.

Keywords: Eco-efficiency assessment, economic performance, value chain optimization

Abstract

The Monte Novo public irrigation perimeter with 7.700 ha, located in the southern region of Portugal is part of the Alqueva Multi-purpose Project, with represents more than 115.000ha of benefited area. Besides being the most important investment ever did in the Alentejo region, it is also a challenge for the regional renewal and necessary social and economic development. In a region dedicated, for decades, to rainfed agriculture, the new challenge created by the Alqueva reservoir, the largest artificial surface mass of water in Europe, creates a completely different setting for the future. In fact, for the last 15 years, the Alentejo region has been experiencing a complete change in the agricultural patterns going from low to highly water demanding crops like maize and pastures.

In the context of an increasing commitment to water efficiency in the EU policy and in the current research framework, the EcoWater project has been focusing on eco-efficiency assessment, which goals are (i) to attain economic and environmental improvement and (ii) to promote the comparison between different case studies in the different economic sectors. As one of the case studies chosen for the agricultural sector, the Monte Novo case study targets the new agricultural paradigm being implemented in the Alentejo region, focusing on the assessment of eco-efficiency for both the baseline scenario and a set of potential new technologies that would be (i) resource efficient or (ii) pollution preventing.

Taking into account the performed evaluation of the baseline scenario, potential new technologies / innovations were selected and assessed based on stakeholders' involvement and perceptions (e.g. drip irrigation and biological production). The results to be presented will focus on the comparison between each of the proposed innovative technologies' performance and the baseline scenario. The methodology will highlight the impacts of the application of each of the technologies and the potential needed investments, in order to facilitate stakeholders' decisions. The set of eco-efficiency indicators evaluated will be complemented with an economic performance, leading to some policy recommendations on technology uptake.

1. Introduction

In the context of an increasing commitment to water efficiency in the EU policy and in the current research framework, the EcoWater project focuses on the integrated assessment of the environmental impacts and the value added to a specific product or service from the use of water. The analysis performed covers both the water supply and water use chains and considers the interrelations among different actors (EcoWater, 2013a). The project aims at the assessment of eco-efficiency, promoting a more efficient use of resources and lower environmental impacts in case studies from different economic sectors. In that context, a specific methodology and a set of tools (SEAT – Systemic Environmental Analysis Tool, EVAT - Economic Value Chain Analysis and the EcoWater Toolbox, http://environ.chemeng.ntua.gr/ecoWater/Default.aspx?t=299) to facilitate the evaluation of both the environmental impacts and the economic performance of the different case studies were developed. To comply with the purposes of the project, in each case study, a baseline scenario was defined as representative of the current situation and was used for comparison with some basic scenarios, each corresponding to the application of a technology for the improvement of the eco-efficiency of the case study area. Similarly to the baseline scenario, these basic proposed scenarios with potential application were evaluated regarding their specific environmental impacts, relevant costs, and the corresponding added value of implementation. The different tools available and referred above allowed to estimate/evaluate the intermediate flows/results concerning, resources, energy, water and costs, facilitating the evaluation of the scenarios and policy recommendations formulation.

Located in the southern region of Portugal, the Alqueva reservoir is the largest artificial lake in Europe with 250 km² of surface area. The implementation of the Alqueva Multipurpose Project, which is an important source of water for several uses, had, as main purpose to supply water for with a total benefited area of more than 115,000 ha. One of Alqueva Project sub-systems is the Monte Novo irrigation perimeter, which embraces more than 7,800 ha and has been chosen as the Portuguese case study in the EcoWater project and is the purpose of this paper.

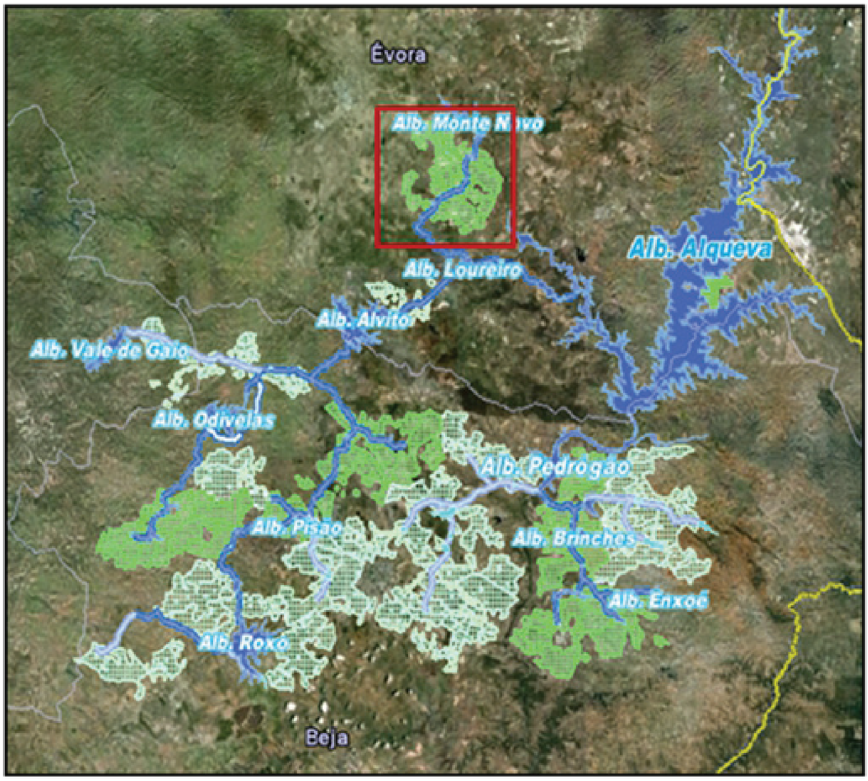


Figure 1. Location of the Monte Novo Irrigation Area in Alqueva's multipurpose project (EDIA, 2011)

It should be highlighted that the Alqueva Multipurpose Project is a main paradigm shift in the region, fostering the transition from rainfed agricultural practices to irrigation. In order to encourage the development of irrigated agriculture, the current water prices are subsidized. The low water tariffs, fixed by Law, are nonetheless decreasing gradually until 2017, when water will be charged at the total price. The subsidized water pricing policy aimed at fomenting the transition from rainfed agricultural practices to irrigation.

The Monte Novo irrigation perimeter is part of that new paradigm set for the Alentejo region, which focuses on new economic activities, embracing new standards in innovation and technology. The perimeter only began operating in 2009, with, as main crops, maize, olives and pastures, those representing approximately 80% of the irrigated area in 2012. The water volume necessary for irrigation in the Monte Novo irrigation perimeter is directly abstracted from Alqueva's reservoir and transported by a network of channels and ducts, going through different reservoirs, to the benefited area. This irrigation network can be subdivided in:

- the primary network, which corresponds to water abstraction in the Alqueva reservoir, elevation and water transport to the secondary network;
- the secondary network, which allows the water distribution (under low or high pressure) to the different irrigated farms considered by means of several reservoirs for regulating storage.

The primary network is the responsibility of EDIA – "Empresa para o Desenvolvimento das Infraestruturas de Alqueva" (the entity responsible for Alqueva's project development and exploitation) that sells the water to the farmers' Association - ABMonte Novo - responsible for the secondary network. ABMonte Novo, on the other hand, sells the water to the different farmers supplied with water from the secondary irrigation network. Currently, during a transitional period, EDIA is undertaking the role allocated, by law, to the AB Monte Novo. At the farmers' level, the water supply is provided at low or high levels of pressure head, depending on the characteristics of the irrigation area considered. According to that, the Monte Novo irrigation perimeter is sub-divided in two different types of blocks:

- low pressure blocks (approximately 1 bar of pressure head at the hydrants), with lower water tariffs. The water supply for the low pressure sub-blocks is provided by gravity, without need of any elevation.
- high pressure blocks (about 4 bar of pressure head at the hydrants), requiring lower investments from the farmers on own pumping stations but with higher water tariffs.

The main goal defined for the Monte Novo irrigation perimeter was the assessment of the environmental and economic impacts and the eco-efficiency performance associated with the water value chain in the Monte Novo case study. The assessment of the eco-efficiency was carried out by means of an indicator approach. The innovative technologies evaluated were grouped in two distinct categories for further comparison: technologies focusing on resource efficiency and technologies focusing on pollution prevention. An additional scenario focusing specifically on an energy price change was also evaluated.

2. Methodology for eco-efficiency assessment

The eco-efficiency assessment is a quantitative tool which enables the study of the environmental impacts of, in this case, agricultural products (maize, olive and pastures) along with its economic value. The eco-efficiency assessment was performed taking into account the five phases of an eco-efficiency assessment (ISO, 2006): (i) Goal and Scope Definition, (ii) Environment Assessment, (iii) Value Assessment, (iv) Quantification of Eco-efficiency and, (v) Interpretation.

The environmental impacts were evaluated using the Life Cycle Assessment (LCA) tool. This is based on a life cycle approach and consists of the Life Cycle Inventory (LCI) analysis: an inventory of relevant energy, resource inputs and environmental releases that allows the Life Cycle Impact Assessment (LCIA): identification and evaluation of the potential environmental impacts associated with identified inputs (water, electricity, nitrogen fertilizer and phosphorus fertilizer, in the case of the Monte Novo case study) and releases/outputs (EcoWater, 2013a).

The value assessment was performed considering the full life cycle of the product system. The values were calculated in monetary terms (€) and expressed through costs, price, willingness to pay, added value, profit, etc. The Total Value Added (TVA) was the economic performance indicator used (EcoWater, 2013a). Finally, the quantification of the eco-efficiency was determined by inter-relating the results of the environmental assessment with the results of the value assessment: the eco-efficiency is estimated as the ratio between the value of the product/service and the environmental impacts identified.

More specifically for the Monte Novo case study, the eco-efficiency assessment was performed for the areas of land occupied by maize, olives and pastures, the three most relevant crops in the case study area. As before referred, a baseline scenario was developed taking into account the current (2012) agricultural reality of the Monte Novo irrigation perimeter, by means of the data obtained primarily from local stakeholders, namely:

- EDIA – "Empresa de Desenvolvimento e Infra-Estruturas do Alqueva S.A.", responsible for the management and development of the Alqueva multipurpose project, including the operation of the primary and secondary irrigation networks where the Monte Novo irrigation perimeter is included.

- AB Monte Novo - "Associação de Beneficiários de Monte-Novo (AB Monte Novo)", responsible for providing water to the farmers of the Monte Novo irrigation perimeter connected to the Alqueva water distribution system from EDIA, and, ensures the operation and maintenance of hydro-agricultural development works, setting the watering schedule, ensuring the collection of taxes for operation and maintenance, and managing the revenues (as previously referred, EDIA is assuming these responsibilities during a transitional period), and

- some of the most important/representative farmers (users) of the Monte Novo irrigation perimeter and dedicated to the most representative crops in the area: maize, olives (intensive and super intensive production) and pastures, namely, e.g. FEA ("Fundação Eugénio de Almeida", main crops vineyards and olives) and ODS ("Olivais do Sul", olives and olive oil production).

For each of these actors, the annual O&M cost, annual gross income and the revenues from water services were calculated, by that obtaining the net cash flow. It should be noted that the (annual) amortization of investment costs are included in the annual OM costs. The total value added for the area of the Monte Novo irrigation perimeter evaluated in this study (which corresponds to the maize, lives and pastures areas in 2012, representing almost 80% of the total irrigated area that year) corresponds to the addition of the net cash flow of the different actors considered. The methodology followed for the economic assessment is summarized in Figure 2.

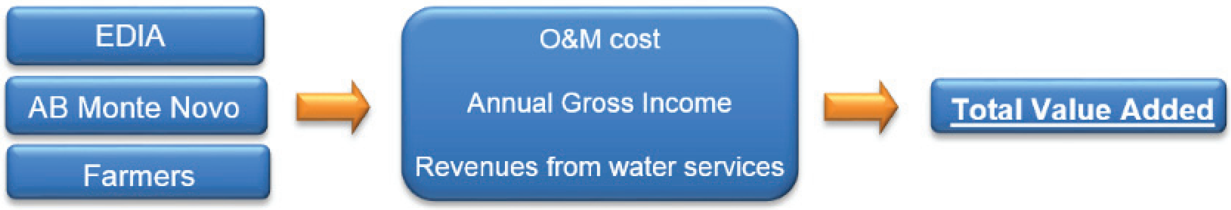


Figure 2. The economic assessment for the Monte Novo case study.

On the other end, the environmental performance assessment allows to quantify the environmental impacts caused by agricultural activities. The approach adopted in this study considers the environmental impacts of: the input resources and materials and the energy use. Regarding the system boundaries used for the LCA, a "cradle-to-gate" analysis was considered, that corresponding to an assessment of a partial product life cycle, starting from the extraction of primary resources (cradle) to the point the products leave the agricultural system boundaries (before being provided to the consumer). However, no use or end life was taken into account. Two different levels/systems were considered: (i) the foreground system, which focused on all the stages along the water value chain where supplementary resources (agro-chemicals and energy) are used, and; (ii) the background system, which included the raw materials and energy production processes (fertilizers production and electricity production), used in the foreground system (EcoWater, 2013a). More specifically, the environmental performance is evaluated according to eleven categories of environmental impacts presented in Table 1 and to their respective characterization factors.

Table 1. Characterization factors of foreground/background elementary flows (EcoWater, 2014)

		Background			Foreground		
Impact category	Unit	Electricity Production (per kWh)	N Fertilizer Production (per kg)	P Fertilizer Production (per kg)	N Fertilizer to water (per kg)	P Fertilizer to water (per kg)	Water (per m3)
Climate change	kg CO2, eq	0.80139	1.93006	0.39097	-	-	-
Eutrophication	kg PO4-3, eq	0.0003	0.00035	0.06724	0.42	3.06	-
Acidification	kg SO2-, eq	0.00606	0.02339	0.02197	-	-	-
Human toxicity	kg 1,4-DB, eq	0.06648	0.64951	0.16316	-	-	-
Respiratory inorganics	kgPM10, eq	0.00095	0.00314	0.00300	-	-	-
Fresh water aquatic ecotoxicity	kg DB	0.00311	0.22896	0.08853	-	-	-
Ecotoxicity Terrestrial	kg DB	0.00154	0.00022	0.00063	-	-	-
Photochemical ozone formation	kgC2H4, eq	0.00025	0.00100	0.00093	-	-	-
Minerals depletion	kg Fe, eq	0.00018	-	-	-	-	-
Fossil fuels depletion	kg oil, eq	0.20155	0.97804	0.14833	-	-	-
Freshwater depletion	m^3	-	-	-	-	-	0.15

The environmental impact for each material/resource used is calculated by multiplying the total amount of material/resource used in the irrigation perimeter by the respective characterization factor, for each of the 11 categories of environmental impact.

3. Baseline scenario

The baseline scenario assessment, which included an economic and environmental inventory system, is the starting point for the study to be undertaken. As referred before, this scenario is used in order to evaluate, at a later stage, the potential effect/impact of different technologies that could potentially be applied to the Monte Novo case study. It should be noted that the economic inventory presented here compiles different categories of agricultural production costs (water, energy, fertilizers, seeds, labour and equipment and other costs), per crop, for the year 2012, as presented in Table 2

Table 2. Annual (2012) costs considered in the Monte Novo case study (baseline scenario)

Cost (€/ha)	Maize (LP)	Maize (HP)	Olives I. (LP)	Olives I. (HP)	Olives S.I. (LP)	Olives S.I. (HP)	Pastures (LP)	Pastures (HP)
Fertilizers/pesticides	522	522	69	69	150	150	63	87
Seeds	220	220	0	0	0	0	0	0
Labour/equipment	93	93	780	780	1169	1169	65	65
Other costs	989	989	804	804	1005	1005	121	121

*LP - Low Pressure (secondary network); HP - High Pressure (secondary network); S.I.-Super Intensive; I.-Intensive

Table 3 presents the economic performance assessment for the baseline scenario, specifying the results for each of the actors previously considered, following the methodology described in section 2. The estimation of the Operational and Maintenance (O&M) costs was based on the data provided in Table 2, the Annual Gross Income resulted from the sale of agricultural goods produced by the farmers and the Revenues from Water Services are calculated according to the water selling price.

Table 3. Financial summary per actor (baseline scenario)

Actor	Annual O&M Cost (€/yr)	Annual Gross Income (€/yr)	Revenues from Water Services (€/yr)	Net Cash Flow (€/yr)
EDIA	684,709.65	0.00	395,196.55	-289,513.10
AB MonteNovo	265,224.07	0.00	278,416.37	13,192.29
Farmers	6,446,884.00	9,395,490.00	-673,612.92	2,274,993.08
Total	7,396,817.73	9,395,490.00	0.00	**1,998,672.27**

The Total Value Added obtained from the water use results from adding the net cash flow of the actors considered. According to this estimation, the irrigated agricultural activity (corresponding to maize, olives and pastures) in the Monte Novo case study area generates (Table 3) a Total Value Added of about Million euros.

The environmental inventory allowed to quantify the emissions caused by the use of water (foreground), electricity (background), nitrogen fertilizer (foreground and background) and phosphorous fertilizer (foreground and background) according to the 11 selected impact categories. Table 4 presents the environmental impacts from background and foreground systems for the baseline scenario.

Table 4. Environmental impacts from foreground and background systems.

Indicator (Unit)	Total Value	Foreground Value	Background Value
Climate Change (tCO2eq)	10,761.65	0	10,761.65
Fossil Fuels Depletion (MJ)	124,668,758.19	0	124,668,758.19
Freshwater Resource Depletion (m3)	3,189,641.23	3,189,641.23	0
Eutrophication (kgPO4eq)	129,621.29	105,703.29	23,918.00
Human Toxicity (kg1,4-DBeq)	1,186,343.42	0	1,186,343.42
Acidification (kgSO2eq)	91,680.89	0	91,680.89
Aquatic Ecotoxicity (kg1,4-DBeq)	182,956.92	0	182,956.92
Terrestrial Ecotoxicity (kg1,4-DBeq)	18,786.18	0	18,786.18
Respiratory Inorganics (kgPM10,eq)	13,961.50	0	13,961.50
Photochemical Ozone Formation (kgC2H4,eq)	3,854.12	0	3,854.12
Mineral Depletion (kgFe-eq)	2,165.45	0	2,165.45

4. New technologies/innovations selected and basic scenarios

After the assessment of the baseline scenario, and according to the know-how, interest and feedback from stakeholders of the region, a set of scenarios were defined considering the application of individual technologies to the baseline scenario for the improvement of the eco-efficiency of the Monte Novo case study. Five different scenarios were defined and hereafter presented. It should be noted that the scenarios 1 to 4 here defined are refined through the introduction of sub-scenarios that intend to cope with the specificities of each of the three studied crops (maize, olives and pastures).

4.1. Scenario 1: regulated deficit irrigation

Scenario 1 focuses on the improvement of water saving using Regulated Deficit Irrigation (RDI) for olives, maize and pastures which consists in the application of lower amounts of water comparatively to the currently defined water needs of the plant.

For maize, the RDI is applied during the eight weeks after sowing, with only 70% - 80% of the water required for the crop being provided. In the ninth and tenth weeks, as required by the phenological stage of maize, water needs are fully satisfied (100%). After this period, again, only 70%-80% of the water required by the crop is applied until the last phenological stage is reached (Toureiro et al., 2007).

For olives, a more specific monthly schedule is proposed, in accordance with the dependence of the irrigation needs on the cultural evapotranspiration (ETc) as defined in Table 5.

Table 5. RDI strategy for olives. (Adapted from Fernández, 2012)

Month	Irrigation
March	Provide 0% ETc
April	Provide 100% ETc
May	Provide 0% ETc
June	Provide 80% ETc
July	Provide 20% ETc
August (24 days)	Provide 20% ETc
August (remaining 6 days)	Provide 100% ETc
September	Provide 100% ETc
October	Provide 100% ETc

Finally, in what concerns pastures, those can tolerate a 35% deficit in irrigation without a noticeable reduction in production (Gomes, 1997). In this case, as no critical phenological stages are considered, the water reduction shall be constant during the entire life cycle of the crop. However, according to farmers' information, this technology is not aimed at being used for this crop and so it will not be considered in the study.

4.2. Scenario 2: substitution of fertilizer by sludge

In this second scenario, a different approach was considered by means of the introduction of sludge from waste water treatment (WWT) plants in the area to allow the decrease of fertilizer´s use in agriculture. The introduction of sludge from waste water treatment has two direct associated benefits: (i) it will allow a decrease in the amount of fertilizers used in Monte Novo case study and (ii) it will prevent the deposition of sludge in landfill, causing a decrease in the environmental impacts and waste of resources.

More specifically, the application of sludge may be associated with the production of various crops, as for example, maize and pastures. In several studies, the application of sludge showed an increase in dry matter production on pastures (Serrão et al., 2009 and 2010). In the study developed by Melo (2012), the use of sludge is shown to have increased the yield production of maize, with the increase depending directly on the amount of sludge used. The amount of sludge to be used for each crop was determined taking into account the nutritional needs of nitrogen and phosphorus versus the levels of nitrogen and phosphorus existing in the sludge. These levels were considered as corresponding, on average, to the ones of the sludge produced in Portugal. Moreover, this scenario also takes into account the real availability of sludge in the Monte Novo area.

4.3. Scenario 3: decrease of chemical fertilizers' use

This third scenario analyses the decrease in chemical fertilizers´ use through the introduction of organic compounds appropriate for biological agriculture. Organic fertilizers consist of a mixture produced from natural organic waste trough natural processes such as composting or vermicomposting. This kind of fertilization allows re-allocating nutrients to crops, for example, from green waste, manure or municipal solid waste. The use of this type of fertilization can simultaneously provide nutrients and improve soil quality (structure, water retention capacity, microbiological activity) (Alcobia & Ribeiro, 2001).

However, as main disadvantage, the use of organic fertilizer is usually related with an increase in costs. For maize, according to the information of a Portuguese supplier, it is advisable to use 700 kg/ha of organic fertilizer, which corresponds to an approximate cost of 420€/ha. In the case of olives, the amount recommended is around 600 kg/ha, corresponding to a cost of 360€/ha. For pastures, no values were provided. However, based on the content of phosphorus that may be present in the organic fertilizer and the phosphorus requirements of pastures, it was possible to estimate the amount of organic fertilizer to be used: 467 kg/ha corresponding to a cost of 280€/ha.

The main interest in the use of organic fertilizers combined with other environmentally favourable farming techniques is that it allows the production of, for example, organic olive oil and that, in this case (olives), the change from traditional agriculture to organic agriculture allows a 20% increase in the price to be paid to the farmer (Ferreira, 2010). For maize, the organic production selling price is between 300 and 330 €/ton against 260 €/ton on average for the conventional crop (EC, 2013). Finally, for pastures, due to the difficulty in achieving a consensual value of the increase in the price to be paid, only a 10% increase was considered in this study.

4.4. Scenario 4: improvement of irrigation efficiency

Another approach considered in this study is the improvement of the irrigation efficiency through the adoption of subsurface drip irrigation instead of drip irrigation for maize and olives. Subsurface drip irrigation (SDI) consists in the application of water below the soil surface though emitters (ASAE, 2005) with discharge rates similar to drip irrigation. This method of irrigation has been used all over the world in a wide variety of crops: woody crops and others such as maize, tomato, etc. As an example, studies conducted in Kansas enabled to conclude that it is possible to reduce in 25% the net irrigation needs with SDI, maintaining same levels of productivity (Lamm & Trooien, 2000). In parallel, the reduction in water needs leads to an energy saving of the same magnitude.

The adoption of subsurface drip irrigation instead of drip irrigation increases the overall on-farm irrigation efficiency from 90% to 95%. If a change from sprinkler to SDI is considered, the irrigation efficiency increases from 80% to 95%. The investment cost associated with a subsurface drip irrigation system is considered to be around 5000 €/ha, and the corresponding operation and maintenance costs around 600 €/ha/year (12% of the investment cost), for a 15 years' lifetime (EcoWater, 2013b).

4.5. Scenario 5: new energy price

The last scenario here presented considers an improvement in irrigation costs by means of a new scheduling of irrigation, during periods of lower energy price, which could be achieved by means of the celebration of different possible contracts for the purchase of electricity.

In fact, in general terms, in Portugal, the energy user can choose between three different energy contracts with different prices for energy according to specific time periods. For the contract "Tarifa Simples" ("Simple tariff") the price of the KWh is the same throughout the day, 0.115€/kWh. For the "Tarifa bi-horária" ("bi-hourly tariff") contract, the price of the KWh varies according to two scheduled periods. Finally the third type of contract, "Tarifa tri-horária" ("tri-hourly tariff") sets the price of energy according to three different time periods and has the lowest price per kWh but only during a specific time period, between the 10:00 PM and 08:00 AM.

Energy costs associated with agriculture in the Monte Novo irrigation perimeter are mainly due to the use water pumps to supply water to the crops in the low pressure blocks. After several contacts made with farmers associations producing olives and/or maize, no disadvantages associated with the irrigation during the specific low cost energy period referred above were identified. Thus, in accordance, the energy price could be considered to decrease from 0.115€/kWh to 0.0831€/kWh, corresponding to a 28% reduction. Based on the gathered information, this scenario only takes into account olives and maize as no confirmation could be obtained for pastures regarding the applicability of this technology.

5. Eco-efficiency assessment: main results

According to the methodology presented in section 2, the first step towards eco-efficiency assessment according to the EcoWater approach was the evaluation of the baseline scenario regarding the eco-efficiency indicators selected. In a second stage, the assessment of the innovative technologies envisaged to be used to improve the eco-efficiency of the Monte Novo irrigation perimeter (scenarios 1 to 5, section 4) was carried out, comparing the values obtained for the different indicators with the baseline scenario's results: a higher value of an indicator obtained with the implementation of a technology translates an improvement in eco-efficiency.

5.1. Baseline scenario

The eco-efficiency assessment of the baseline scenario, was performed, for the year 2012, as described in section 2, using the EcoWater approach (EcoWater, 2013a). The eco-efficiency indicators' values presented in Table 6 were obtained by dividing the Total Value Added presented in Table 3 by the corresponding total environmental impact of each indicator, presented in Table 4.

Table 61. Eco-efficiency indicators (baseline scenario)

Indicator	Value (€/Unit)
Climate Change (€/tCO2eq)	185.72
Fossil fuels depletion (€/MJ)	0.02
Freshwater resource depletion (€/m^3)	0.63
Eutrophication (€/kgPO4-3,eq)	15.42
Human toxicity (€/kg1,4-Dbeq)	1.68
Acidification (€/kgSO2-,eq)	21.80
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.39
Respiratory inorganics (€/kgPM10,eq)	143.16
Ozone formation (€/kgC2H4,eq)	518.58
Minerals depletion (€/kg Fe-eq)	922.98

5.2. New Technologies/innovations selected and basic scenarios

As referred in section 1, the results for the various technologies/innovations are mostly grouped and compared according to their main focus: (i) technologies promoting resource efficiency and, (ii) technologies preventing pollution, allowing an easier evaluation and comparison of results.

5.2.1. Technology scenarios promoting resource efficiency

Among the technologies evaluated for the Monte Novo case study the Regulated Deficit Irrigation (RDI) and the Subsurface Drip Irrigation (SDI) technologies are the ones considered as mostly promoting resource efficiency.

For the RDI technology, four sub-scenarios were considered, based on the water requirement reduction considered: 21% and 35% for maize, 64% for olives in intensive production and 44% for olives in super intensive production. For pastures, the RDI technology was not considered since its use is considered as unusual for this crop.

Therefore, the RDI technology was only applied to maize and olives in the Monte Novo case study. According to SEAT intermediate results, in the case of maize, the application of the RDI technology leads to a reduction in water consumption, in the Monte Novo case study, between 11% and 17% (for the 21% and 35% scenarios respectively, referred as RDI (21%) and RDI (35%)). For olives, the reduction verified is between 4% (for super intensive production, RDI (64%)) and 7% (for intensive production, RDI (44%)). With regard to energy savings, the application of the RDI technology for maize allows energy savings between 8% and 12%. For olives, the reduction achieved is between 2% and 5% (for intensive production).

The SDI technology allows to decrease both water and energy consumptions. For maize, water and energy savings are around 18% and 15%, respectively. For olives, water savings are around 5% while energy savings reach approximately 6%. Although the SDI application allows an improvement of the environmental performance, the associated costs are higher, leading to lower values of the eco-efficiency indicators when compared with the baseline scenario. On the contrary, the increase in eco-efficiency is clear when using the Regulated Deficit Irrigation technology (Table 7).

Table 7. Eco-efficiency indicators for resource use efficiency technologies (€/unit)

		Maize			Olives		
Indicators	**Baseline Scen.**	**RDI (21%)**	**RDI (35%)**	**SDI**	**RDI (64%)**	**RDI (44%)**	**SDI**
Climate Change (€/tCO2eq)	185.7	210.5	225.0	110.8	199.8	192.0	153.0
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.01	0.02	0.02	0.01
Freshwater resource depletion (€/m^3)	0.63	0.75	0.82	0.39	0.69	0.66	0.51
Eutrophication (€/kgPO4-3,eq)	15.42	16.29	16.74	7.98	15.93	15.65	11.94
Human toxicity (€/kg1,4-Dbeq)	1.68	1.87	1.98	0.97	1.79	1.73	1.37
Acidification (€/kgSO2-,eq)	21.80	24.50	26.06	12.78	23.35	22.49	17.82
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.70	12.12	5.81	11.38	11.13	8.56
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.4	121.5	130.4	64.49	115.0	110.1	88.19
Respiratory inorganics (€/kgPM10,eq)	143.2	161.2	171.7	84.27	153.5	147.7	117.2
Ozone formation (€/kgC2H4,eq)	518.6	582.8	619.74	303.9	555.3	534.9	424.0
Minerals depletion (€/kg Fe-eq)	923.0	1,055.4	1,133.9	561.1	998.2	956.1	766.0

To facilitate the inter-comparison, Figure 3 presents the graphical representation of the eleven eco-efficiency indicators obtained with the application of the two referred technologies (RDI and SDI technologies) and the baseline scenario, for the two crops considered - a) maize (Figure 3a) and b) olives (Figure 3b). These graphs present dimensionless values resulting from dividing the eco-efficiency value obtained for each indicator by the eco-efficiency value of the baseline scenario. The baseline scenario is the reference, consequently corresponding to a value of 1 for each of the indicators.

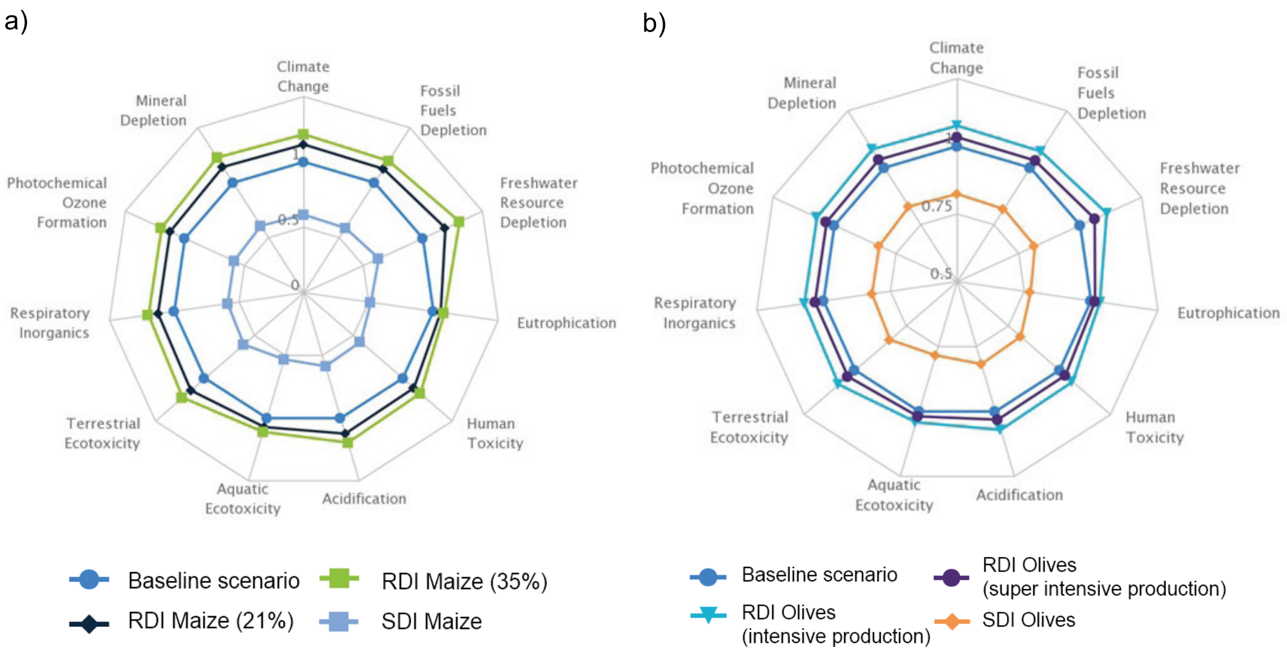


Figure 3. Comparison of the eco-efficiency indicators obtained with the application of RDI and SDI technologies with the baseline scenario for a) maize and b) olives.

Figure 3 enables to confirm that whereas the RDI technology leads to an improvement of eco-efficiency (higher values for all the indicators than in the baseline scenario, translated in Figure 4 by circles "outside" the baseline scenario), for both crops, the SDI technology leads to lower values of the selected eco-efficiency indicators.

The most relevant improvements obtained with the RDI technology implementation are related with the "freshwater resource depletion" indicator as the water consumption decreases for each crop (foreground system). The most important improvement of this environmental impact, when compared with the baseline scenario, is obtained for maize (RDI 35% sub-scenario) with a total reduction of the water supplied to the system of about 17%. This fact can be explained as maize, in this case study, requires an important amount of water per hectare. As a consequence, small changes on the water needs of this crop have great repercussions throughout the system.

The indicator "Minerals depletion" is also positively affected with the application of the RDI technology, despite on a lower scale, as this indicator is directly related with the electricity consumption. The smaller water consumption in the irrigation system directly originates a lower energy consumption and consequently a lower effect on minerals depletion.

As referred above, for the SDI technology, the eco-efficiency decreases for all the environmental indicators, for both cultures. This technology reduces the environmental impacts but its implementation originates an important increase in costs which leads to a decrease of the eco-efficiency to values below those obtained for the baseline scenario.

5.2.2. Technology scenarios focusing on pollution prevention

In what concerns pollution prevention in the case study area, the two most suitable technologies identified were (i) the use of sludge from waste water treatment plants and (ii) the use of organic fertilizers. The introduction of sludge/organic fertilizers in agriculture prevents pollution caused by the use of chemical fertilizers (nitrogen and phosphorus – foreground system).

These technologies allow a high increase of the environmental performance of the environmental indicators mainly affected by the use of chemical fertilizers as for the "eutrophication" indicator (foreground system). Additionally, changes in the indicators associated with the life cycle of nitrogen and phosphorus production ("acidification", "human toxicity", "fresh aquatic ecotoxicity" and "fossil fuel depletion" indicators – background system) are also verified.

Tables 8, 9 and 10 report the different eco-efficiency indicators by crop (Table 8 – maize, Table 9 - olives and Table 10 – pastures) obtained with the application of the both technologies (introduction and sludge and organic fertilizers) that can potentially positively affect the pollution prevention. It should be noted that different sub-scenarios were considered, according to the crop considered:

- maize in high pressure blocks (HP) and maize in low pressure blocks (LP),

- olives in intensive (I.) production in low pressure blocks (LP), olives in intensive production in high pressure blocks (HP) and olives in super intensive (S.I.) production in low pressure blocks (LP), and

- pastures in low pressure blocks (LP) and pastures in high pressure blocks (HP).

According to SEAT intermediate results, the consideration of sludge applied to maize results in a reduction in chemical fertilizers of approximately 7% for nitrogen and 7% for phosphorus. For olives, the reduction verified is between 6% for nitrogen and 5% for phosphorus. Finally, for pastures, the chemical fertilizer savings range from 5% to 6% for phosphorus.

For maize, the application of organic fertilizers results in a reduction of chemical fertilizers of around 67% for phosphorus and 77% for nitrogen. When applied to olives, organic fertilizers can reduce the consumption of chemical fertilizers in 23% for nitrogen and 21% for phosphorus. For pastures, there is a reduction of 12% for phosphorus.

Table 82. Eco-efficiency indicators for pollution prevention technologies (maize) (€/unit)

		Maize		
Indicators	**Baseline Scen.**	**Sludge (HP)**	**Sludge (LP)**	**Org. Fert.**
Climate Change (€/tCO2eq)	185.7	193.15	193.15	304.4
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.03
Freshwater resource depletion (€/m^3)	0.63	0.65	0.65	0.95
Eutrophication (€/kgPO4-3,eq)	15.42	17.07	17.06	83.00
Human toxicity (€/kg1,4-Dbeq)	1.68	1.78	1.78	3.38
Acidification (€/kgSO2-,eq)	21.80	22.83	22.83	38.72
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.93	11.93	41.11
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.4	109.98	109.97	162.5
Respiratory inorganics (€/kgPM10,eq)	143.2	149.69	149.68	249.3
Ozone formation (€/kgC2H4,eq)	518.6	543.23	543.21	923.4
Minerals depletion (€/kg Fe-eq)	923.0	953.03	953.00	1,032.8

Table 93. Eco-efficiency indicators for pollution prevention technologies (olives) (€/unit)

Indicators	Baseline Scen.	Olives			
		Sludge Ol. I. (HP)	Sludge Ol. S.I. (LP)	Sludge Ol. I. (HP)	Org. Fert.
Climate Change (€/tCO2eq)	185.7	190.17	194.46	190.5	226.24
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.02	0.02
Freshwater resource depletion (€/m^3)	0.63	0.64	0.65	0.64	0.75
Eutrophication (€/kgPO4-3,eq)	15.42	16.67	17.12	16.77	23.44
Human toxicity (€/kg1,4-Dbeq)	1.68	1.75	1.79	1.75	2.16
Acidification (€/kgSO2-,eq)	21.80	22.45	22.97	22.50	27.17
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.69	11.99	11.75	15.84
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.4	108.32	110.72	108.46	126.99
Respiratory inorganics (€/kgPM10,eq)	143.2	147.24	150.60	147.54	177.45
Ozone formation (€/kgC2H4,eq)	518.6	534.22	546.49	535.36	646.70
Minerals depletion (€/kg Fe-eq)	923.0	938.88	959.58	940.04	1,097.79

Table 104. Eco-efficiency indicators for pollution prevention technologies (pastures) (€/unit)

Indicators	Baseline Scen.	Pastures		
		Sludge (LP)	Sludge (HP)	Organic Fertilizers
Climate Change (€/tCO2eq)	185.7	187.06	187.83	182.74
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02	0.02
Freshwater resource depletion (€/m^3)	0.63	0.63	0.63	0.62
Eutrophication (€/kgPO4-3,eq)	15.42	15.75	15.86	15.71
Human toxicity (€/kg1,4-Dbeq)	1.68	1.70	1.71	1.66
Acidification (€/kgSO2-,eq)	21.80	22.02	22.13	21.61
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.08	11.13	10.92
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.4	107.15	107.59	104.67
Respiratory inorganics (€/kgPM10,eq)	143.2	144.57	145.23	141.76
Ozone formation (€/kgC2H4,eq)	518.6	523.90	526.33	514.03
Minerals depletion (€/kg Fe-eq)	923.0	929.12	932.89	907.01

Figure 4 summarizes graphically the eco-efficiency comparison between the baseline scenario and the pollution prevention technologies (sludge from waste water treatment plants and organic fertilizers) for the three crops considered: a) maize (Figure 4a), b) olives (Figure 4b) and c) pastures (Figure 4c).

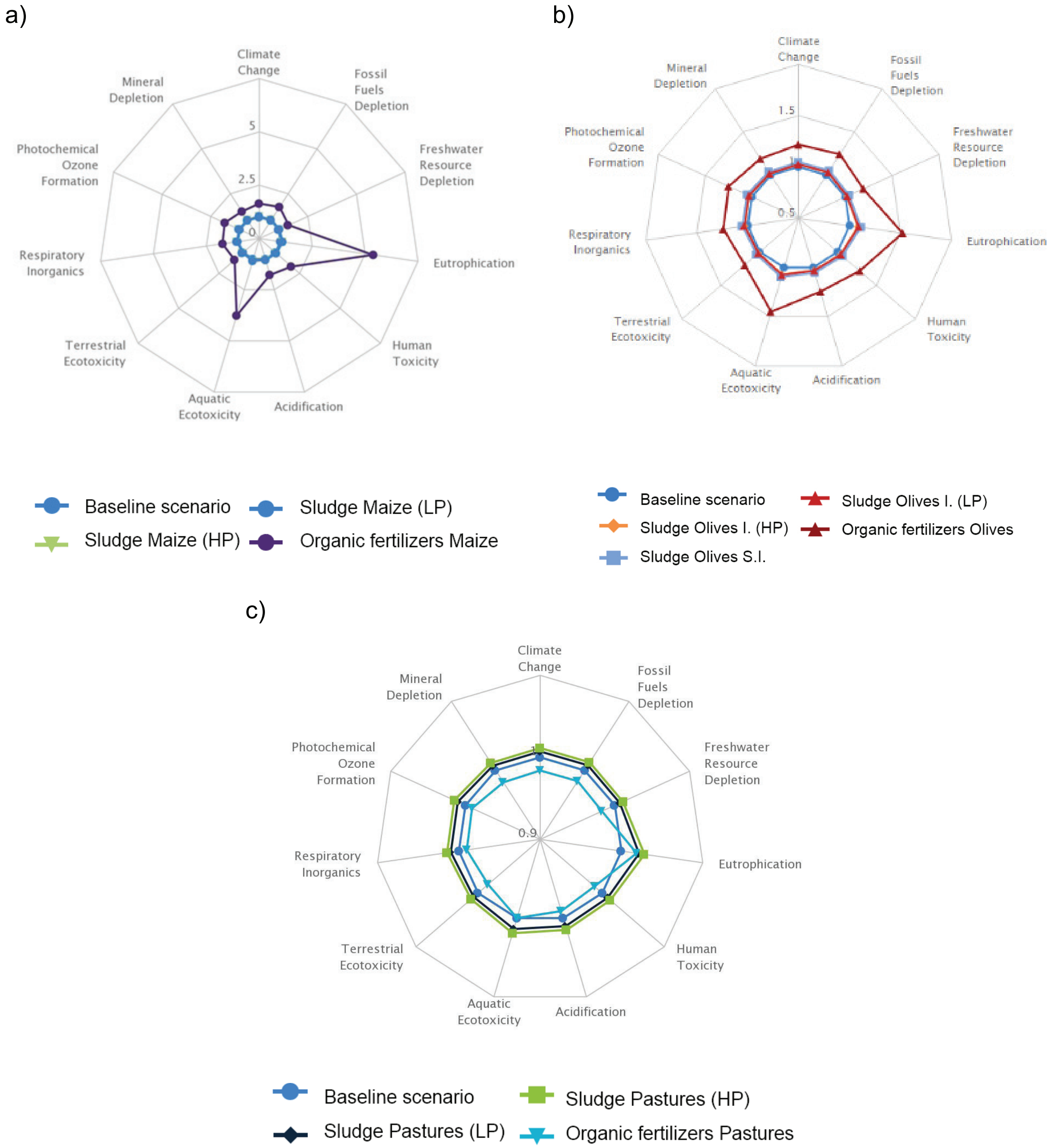


Figure 4. Comparison of the eco-efficiency indicators obtained for the baseline scenario and the pollution prevention technologies (sludge from waste water treatment plants and organic fertilizers) for the three crops considered: a) maize, b) olives and c) pastures

For maize and olives (Figures 4a and 4b), a general improvement in eco-efficiency is obtained when using organic fertilizers in agriculture, with most significant results for maize. For this culture, the introduction of organic fertilizers increases more significantly the eco-efficiency of the "Eutrophication" and "Aquatic Ecotoxicity" indicators. The increase observed for the "Eutrophication" indicator is due to the substitution of chemical fertilizer by organic fertilizers (foreground system).

For the “Aquatic Ecotoxicity” indicator, the positive effect in eco-efficiency is due to the decreased impact associated with the production of chemical fertilizers (background system). For olives, the eco-efficiency results follow a similar trend as maize.

On the opposite side, for pastures, in general terms, the eco-efficiency decreases (in comparison with the baseline scenario), when using organic fertilizers, due to the increased costs that outweigh the positive effect of reducing the environmental impact.

When using sludge, eco-efficiency is increased for the three considered crops. However, the benefits obtained with the application of this technology are much more reduced than the ones verified with the introduction of organic fertilizers, not even visible in Figure 4a (for Maize (LP) and Maze (HP)) and in Figure 4b (for Olives I. (HP)) as they almost coincide with the baseline scenario. This fact is explained by the insufficient quantity of available sludge from WWT plants in the of Monte Novo area, which does not allow meeting all the nutritional requirements of the irrigation perimeter using only sludge.

5.2.3. New energy price scenario

The scenario regarding the consideration of a new energy price is evaluated separately since it does not fit into the two above referred categories (promotion of resource efficiency and pollution prevention). The adaptation of the irrigation schedule to the low cost energy period allows a reduction in energy costs (annual O&M costs) and consequently improves the economic performance whereas the environmental performance remains the same as for the baseline scenario. Thus, the increased eco-efficiency observed for both cultures (Table 11) is only due to the increase in the economic performance.

For both selected cultures (maize and olives, as explained in section 4.5), an improvement of the eco-efficiency is obtained when compared with the baseline scenario (Figure 5). As expected, the decrease in energy costs has a positive effect on all the selected eco-efficiency indicators, for both cultures, with better global results for olives (Table 11 and Figure 5).

Table 115. Eco-efficiency indicators for the new energy price scenario (€/unit)

Indicators	Baseline	Maize (LP and HP)	Olives (LP and HP)
Climate Change (€/tCO2eq)	185.7	189.64	191.05
Fossil fuels depletion (€/MJ)	0.02	0.02	0.02
Freshwater resource depletion (€/m3)	0.63	0.64	0.64
Eutrophication (€/kgPO4-3,eq)	15.42	15.75	15.86
Human toxicity (€/kg1,4-Dbeq)	1.68	1.72	1.73
Acidification (€/kgSO2-,eq)	21.80	22.26	22.43
Aquatic Ecotoxicity (€/kg1,4-Dbeq)	10.92	11.16	11.24
Terrestrial Ecotoxicity (€/kg1,4-Dbeq)	106.4	108.64	109.44
Respiratory inorganics (€/kgPM10,eq)	143.2	146.18	147.27
Ozone formation (€/kgC2H4,eq)	518.6	529.53	533.47
Minerals depletion (€/kg Fe-eq)	923.0	942.48	949.48

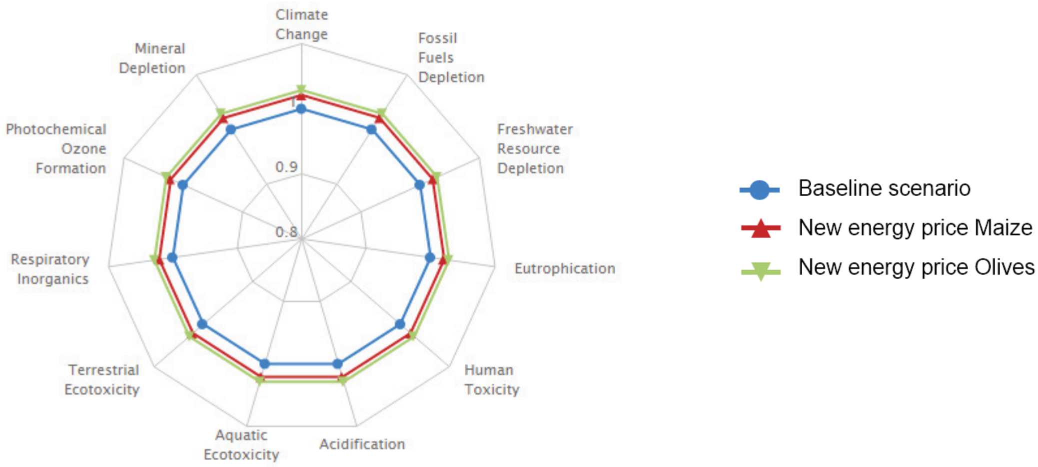


Figure 5. Comparison of the eco-efficiency indicators in the baseline scenario and the new energy price scenario

5. Conclusions and policy recommendations

The assessment of the eco-efficiency in the Monte Novo irrigation perimeter through the comparison between the baseline scenario and different technologies allowed to identify the best technologies for the maximization of economic productivity and the reduction of the environmental impacts. The various simulations carried out showed that the suggested technologies to be implemented have particular influence on water, fertilizer and energy consumption. Water and energy savings are directly related to greenhouse emissions and to production costs. The type of fertilizers used influence the composition of the soil and the water quality in the surrounding areas of the irrigation perimeter as well as the market price of the agricultural products.

Nevertheless, based on the work developed, some general recommendations to increase the eco-efficiency in the Monte Novo irrigation perimeter can be already proposed. In general terms, it came clear that the evaluation of the technologies should take into account political, economic, social and technological factors. Moreover, all stakeholders' (farmers, water user organizations, policy and decision makers, etc.) perceptions and assessments should be taken into account for adequate eco-efficient measures and/or recommendations adoption. In terms of specific actions, the following needs could already be identified:

- study on the feasibility of producing new crops economically more profitable in the current economic context in accordance with the new European agricultural policies, increasing the competitiveness,

- identification of possible barriers/weaknesses to the implementation of new technologies moving beyond quantification, saving cost and resources,

- promotion of more eco-efficient agricultural practices providing adequate information to farmers, by means of training and workshops to increase the technical capacity,

- use of new information platforms as developed during the EcoWater Project.

- promotion of the link between the production sector (difficulty in selling the product) and the marketing sector (difficulty in obtaining the product).

The approach here followed, based on the evaluation of different technologies grouped according to their main focus, promotion of resource efficiency or prevention of pollution is an important starting point for the definition of more complex scenarios combining different technologies that proved to improve the eco-efficiency of the Monte Novo case study.

References

Alcobia, M. D., Ribeiro, J. R. (2001).” Manual do Olival em Agricultura Biológica” (In Portuguese). 1st Edition, Edition Terra Sa, 111p.

ASAE - American Society of Agricultural Engineering (2005). ASAE standards engineering practices data, 43rd edition: 864, Michigan, ISBN 1892769476.

EcoWater (2013a).”Eco-efficiency assessment of meso-level water use systems − The EcoWater approach” (Internal Project Report).

EcoWater (2013b). “Innovative technologies for eco-efficiency improvement in agricultural water use“(Internal Project Report):

EcoWater (2014). Deliverable 2.4 Holistic assessment of eco-efficiency improvements & scenario analysis for the agricultural water sector (Internal Project Report).

EDIA (2011), “Map portal - Portal de mapas”, EDIA´s website: http:\\www.edia.pt.

European Commission (2013). http://www.slowfood.com/sloweurope/eng/news/175583/the-last-farmer-of-organic-corn

Fernandéz, J. E. (2012). Interview in “Fruta Legumes e Flores nº132.

Ferreira, D. (2010). “Custos e Rentabilidade na região de Moura, Alentejo” (In Portuguese), Instituto Superior de Agronomia, Universidade Técnica de Lisboa.

Gomes, H. P., (1997) “Engenharia de irrigação: hidráulica dos sistemas pressurizados, aspersão e gotejamento”, Chapter 1 (In Portuguese), 2nd ed. Campinas Grande: UFPB. 390 pp. 13 – 26.

ISO (2006). International Organization for Standardization, ISO 14044:2006 Environmental management -- Life cycle assessment – Requirements and guidelines, Genève, Switzerland.

Lamm, F., Trooien, T., (2000). “Subsurface drip irrigation for corn production: a review of 10 years of research in Kansas”, Micro-Irrigation: Advances in system design and management, Irrig Sci (2003) 22:195-200.

Melo, A., (2012). “Utilização de Lamas de ETAR Municipal na Cultura do Milho” (In Portuguese), Master Thesis at the Azores University, http://hdl.handle.net/10400.3/1342.

Serrão, M.G., Domingues, H., Fernandes, M., Martins, J., Pires, F., Saraiva, I., Fareleira, P., Matos, N., Ferreira, E., Campos, A.M., (2009) “Contribution to the improvement of degraded soils under pastures through sewage sludge application, without environmental risks”, Journal “Ciências Agrárias”, Vol. 32 No. 1, pp. 258-272.

Serrão, M.G., Domingues, H., Fernandes, M., Martins, J., Pires, F., Saraiva, I., Fareleira, P., Matos, N., Ferreira, E., Campos, A.M., (2010). “Impacto da aplicação de lama residual urbana e de fertilizantes minerais em solos sob pastagem no Alentejo” (In Portuguese). Journal “Ciências Agrárias”, Vol.33 No.1, pp. 139-149.

Toureiro, C.M., Serralheiro, R.P., Oliveira, M.R, (2007). "Maximização da Economia da Água em Regadio: Rega Deficitária Controlada" (Maximization of the water economy in irrigated agriculture: the regulated deficit irrigation - In Portuguese). II Congresso Nacional de Rega e Drenagem, Fundão.

Acknowledgements

'EcoWater: Meso-level eco-efficiency indicators to assess technologies & their uptake in water use sectors', a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA), http://environ.chemeng.ntua.gr/EcoWater/.

Available online at www.sciencedirect.com

ScienceDirect

Systems Engineering Procedia: Editor Desheng Dash WU 00 (2011) 000–000

Systems Engineering Procedia

www.elsevier.com/locate/procedia

Complexity, assumptions and solutions for eco-efficiency assessment of urban water systems

Peyo Stanchev*, Irina Ribarova, Galina Dimova

University of Architecture, Civil Engineering and Geodesy, 1404 Sofia, Bulgaria

**Corrsponding author: stanchev_fhe@uacg.bg; tel: +359 88 335 8711*

Abstract

ISO 14045 on eco-efficiency assessment was published only recently and there are few studies reporting its application. While urban water systems are not "typical" product systems, this study demonstrates that the standard could be successfully applied to them, providing valuable results for decision makers. In view of the general lack of experience in application of the standard, the paper emphasises the methodological issues.

Keywords: Background system, Eco-efficiency, Foreground system, Functional unit, ISO 14045, Urban water systems, LCIA, System boundaries

1. Introduction

The rule "doing more with more" conforms to the laws of physics – the more that is produced, the greater the resources being consumed and the greater the emissions to the environment. There is no doubt that economies based on this rule, are not sustainable and need to be modified. One of the first initiatives for application of the opposite rule - "doing more with less" was realized in the car factories of Ford at the start of the twentieth century (McDonough and Braungart, 2002). The "secret" in creating more with less lies in technological innovation. For example, with regard to urban water systems, until recently one toilet flush consumed 10 liters of water, while nowadays it is possible to do this with as little as 1 liter of water. Since its introduction by Ford the concept has been developed step by step in all economic spheres, leading to a common indicator for comparison of different systems or alternatives called "eco-efficiency". Recently this concept was enhanced by developing a standard for eco-efficiency assessment, issued in 2012 (WBCSD, 2000; Hellweg et al., 2005; Morioka et al., 2005).

Eco-efficiency quantification requires environmental performance to be related to the product system value, according to the goal and scope definition (ISO14045, 2012). The definition is based on quantitative measures of two of the pillars of the sustainability: economic and the environmental performance. Thus eco-efficiency assessment shows how sustainable a system is. The standard however defines only the general framework and requires more detailed specification for particular cases.

This paper presents the application of the eco-efficiency approach in the urban water system of Sofia, Bulgaria considering the entire water cycle from freshwater abstraction to waste water discharge into the receiving water body. The difficulties that were faced during each step of the assessment, the solutions proposed and the undertaken assumptions are discussed.

The final goal of this eco-efficiency assessment is to promote innovative technologies in urban water systems to decision makers and stakeholders (Ribarova et al., 2014). The provision of high quality water service to customers with less environmental impact is a step towards more sustainable water use.

2. Materials and methods

The eco-efficiency assessment was carried out according to ISO 14045 (ISO 14045, 2012). The environmental impact was estimated using the Life Cycle Impact Assessment (LCIA) method according to the requirements and guidelines provided in ISO14044 and ISO14040 standards, the product system value being expressed in monetary terms. The approach is tested on Sofia's urban water system which serves a population of about 1,5 million. The methodology and the system are described in more detail in Ribarova and co-authors (Ribarova et al, 2013).

3. Results and discussion

3.1. Complexity of urban water systems

Urban water systems are engineering systems, developed to serve one of the most vital social needs – provision of drinking water. Their operation and maintenance comprise a number of economic activities which, while having a primary social function can also be considered as product systems. Their characteristics make their sustainability evaluation very complex, since both environmental and economic approaches must be applied in a coherent way to an engineering system that serves different users and has various interconnected social, economic and environmental impacts. On the one hand are the domestic water users, who are often socially and culturally quite heterogeneous and whose behavior is difficult to model; on the other hand are the non-domestic users who are even more heterogeneous and the economic value from their water use is often either hidden within the lump sum of the product or is hard to calculate due to lack of a suitable metric. Furthermore the urban water system in general consists of two subsystems: the water supply and the sewerage system, which have quite different functions leading to difficulties in definition of the product and the functional unit of the system.

Lack of measurements is a common problem for many process studies, and in the context of urban water systems information is missing on direct emissions from the sewerage system to the environment, water demand in households, domestic and industrial wastewater quality, etc.

3.2. Assumptions

Given the complexity of the urban water system and the lack of essential data, some assumptions have to be made in regard to:

Pollution load discharged to the sewerage network by domestic water users

In most cases this load is not measured at source – the outlet from the house. Normally it is measured only at the WWTP inlet. Based on literature data BOD_5 was assumed to be 60 g/ca.d at source(ATV-DVWK, 2003).

Pollution load discharged to the sewerage network from non-domestic water users

There is a variety of industries in an urban water system with different flow and pollution patterns. Each of them produces specific goods or services, and it is time consuming or even impossible to assess their individual impact. To overcome this difficulty non-domestic water users are clustered into three groups depending on the BOD_5 concentration of the discharged waste water to the sewerage network (0 to 200 mg BOD_5/l; 200 to 600 mg BOD_5/l and above 600 mg BOD_5/l).

Reduced pollution load in the sewerage network

The measured pollution load at the WWTP inlet was much smaller than the sum of industrial and domestic load, estimated as described above. There are several reasons for this: 1) the settling process in the sewerage pipes in dry weather and resuspension and overflowing of pollutants through Combined Sewer Overflows during rain events; 2) the sewerage network is long, therefore it acts partly as a bioreactor and some biodegradation of pollutants occurs before they reach the WWTP; 3) exfiltration of waste water from leaky joints and cracks in the pipes; these flows cannot be directly measured, so they are considered as “reduced pollution load in the sewerage network”.

Rainwater, infiltration and exfiltration

Rainwater infiltration and exfiltration flows are considered outside the scope of the study and are aggregated into a common input to the system called “other waters”. They are assumed to be constant in all scenarios, so only the hydraulic load to the WWTP is considered.

3.3. Solutions

Defining of the system boundaries

The eco-efficiency assessment is based on LCA, which means that all processes should be estimated according to the “cradle to grave” principle (McDonough et. al, 2002). For this reason the definition of the system boundaries is one of the most crucial assessment steps. In the urban water system there is one main production chain (the water path from the natural environment and back), but there are many supplementary chains, e.g. the production of energy chemicals and the transport of supplementary resources and sludge. These chains are connected to processes from the main production chain. So, the question here is: should one consider only the water production chain or should the connected supplementary chains be included in the assessment? The supplementary chains consist of processes outside the physical boundaries of the system, which cannot be directly managed and primary data in general are not available. But these processes may also have a negative environmental impact and their simple exclusion from the assessment could give misleading conclusions. To overcome this issue the system is divided into two sub-systems: foreground (water path) and background (all supplementary production chains), thus all cumulative environmental impact is taken into account. In summary, the general principle for defining these two sub-systems was: the set of processes which can be directly managed in the product system define the foreground system, while the background system includes all other activities and processes which deliver intermediate resources (energy, materials transport) for the foreground system.

Determination of product and functional unit

According to ISO14045 the functional unit shall be measurable and clearly defined, in order to provide a reference for the environmental and value assessment (ISO14045, 2012). The identification of the product and the selection of the functional unit was not an easy task. The urban water system consists of a water use stage which connects two separate engineering subsystems with different functions – delivering drinking water in necessary quantity and quality (water supply system) and waste water collection and discharge with required quality (sewerage system). A possible easy choice for a product metric in an urban water system seems to be the amount of drinking water delivered to the customers. However, the delivered water itself has no value to the water users. The water gains value with satisfying the customers' water needs - shower, toilet, dishwashing, clothes washing, personal care etc. Depending on the efficiency of the appliances water needs could be satisfied with different amounts of water. Thus the delivered water is not the real product in the system. The solution here was to determine the service as the product of the system, e.g. product = satisfied customer's water needs. The water needs can be attributed either to a person or to a household. As the water use pattern depends mostly on the sanitary equipment of the household, the number of satisfied households was selected as a "product" in the system and "a satisfied household" as a functional unit.

Water use stage

The water use stage is divided into two main types – non-domestic and domestic water use. Data on water demand in households was absent, so a complementary study was carried out. Water accounts for individual and common water meters of representative apartment buildings were linked to the number of households and inhabitants, provided by the National Statistical Institute in order to calculate the water demand per capita and per household. This study revealed that domestic water users have different water demand depending on the type of water heating. Therefore, they are clustered further into three categories: households with local, district and alternative water heating.

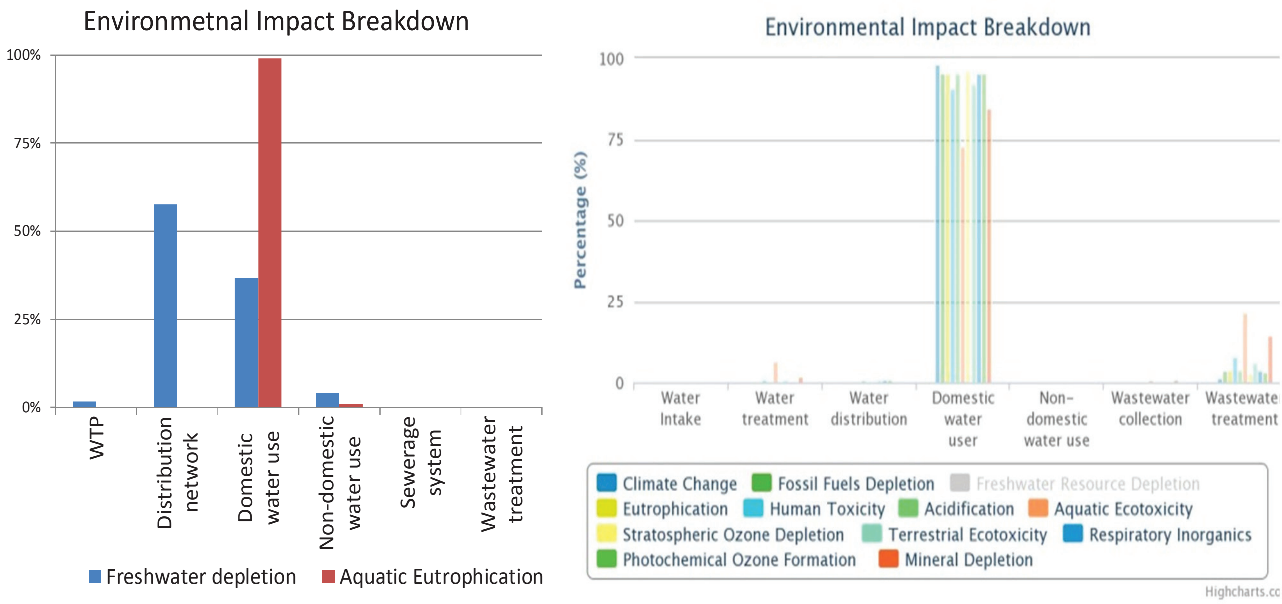
Environmental assessment

Twelve midpoint environmental categories were selected as most representative for assessment of the environmental performance of the urban water system – nine of them relate to pollution prevention and three to resource depletion (Fig.1). The environmental indicators are obtained by aggregation of the weighted impacts for each category and expressed in a common reference unit (ISO14044). The impact is further allocated to the foreground and background system. The impact from the foreground system is calculated using flows from the inventory analysis and characterization factors for the respective substances. It represents the direct pressure of the product system on the environment. The background impact shows the indirect environmental impact from processes that convert natural raw materials into supplementary materials for the product system. As the background processes could not be studied in detail, generic data obtained from LCA databases were used.

Foreground impact assessment

Another question which had to be answered was the allocation of the indicators by stages in the foreground system. The urban water system has direct connection with the environment only at its start and its end, the impact being in the categories “freshwater depletion” and “eutrophication potential”. According to the “polluter pays” principle the point at which the pollution is generated should be responsible for the environmental impact (EU Directive 91/271). So, although “eutrophication potential” is at the outlet of the final stage “wastewater treatment”, it was allocated not to this stage, but to the water use stage, where it is actually generated. Similarly, for “freshwater depletion” - the abstracted water was allocated proportionally to the stages where water is used (Fig.1).

Figure 1 shows the results for the environmental impact broken down by stages and subsystems (foreground and background).



a. Foreground system

b. Background system

Figure 1 Environmental Impact Breakdown

Fig 1 a) shows the contribution of each stage to the environmental impact (freshwater depletion and eutrophication potential) of the foreground system, while Fig 1 b) presents the global environmental impact from the background system. The environmental impact breakdown by stages revealed that the most environmentally weak stage in the urban water system is the water use stage.

4. Conclusion

A study aimed at applying the eco-efficiency approach to an urban water system has been carried out. Although the procedure for such an assessment had been standardised with ISO 14045, many stumbling blocks had to be overcome. This paper demonstrates that under a range of reasonable assumptions, good progress could be made in applying ISO14045 to urban water systems.

The paper focuses on the methodological issues which were faced during the consecutive steps of the eco-efficiency assessment. The results from baseline eco-efficiency assessment provide valuable information about the contribution of each stage of the urban water system to the total environmental impact. This enables the identification of the environmentally weak stages in the system and selection of respective technologies, which would improve the eco-efficiency performance.

The methodology developed is not case study specific. It has also been applied successfully to another urban water system with quite different characteristics, which will be described in a forthcoming paper.

Acknowledgments

This work was supported financially by the European Commission, 7th Framework program, EcoWater project, Grant agreement N 282882. The authors express their gratitude to “Sofiyska voda” for providing great assistance.

References

ATV-DVWK, (2003). Standardisation and Derivation of Dimensioning Values for Wastewater Facilities. DWA German Association for Water, Wastewater and Waste.

European Union, 1991. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment.

Hellweg, S., Doka, G., Finnveden, G. and Hungerb\"uhler, K. (2005). Assessing the Eco-efficiency of End-of-Pipe Technologies with the Environmental Cost Efficiency Indicator. Journal of Industrial Ecology, 9(4), pp.189--203.

ISO 14040: 2006. Environmental management - Life cycle assessment - Principles and framework. Second edition. International Organization for Standardization, Genève.

ISO 14044: 2006. Environmental management - Life cycle assessment - Requirements and guidelines. International Organization for Standardization, Genève.

ISO 14045: 2012. Environmental management - Eco-efficiency assessment of product systems - Principles, requirements and guidelines”, CEN.

McDonough, W. and Braungart, M. (2002). Cradle to cradle. 1st ed. New York: North Point Press.

Morioka, T., Tsunemi, K., Yamamoto, Y., Yabar, H. and Yoshida, N. (2005). Eco-efficiency of Advanced Loop-closing Systems for Vehicles and Household Appliances in Hyogo Eco-town. Journal of Industrial Ecology, 9(4), pp.205--221.

Ribarova, I., Stanchev, P., Dimova, G. and Assimacopoulos, D. (2014). A First Iteration of an Eco-efficiency Assessment of Sofia's Urban Water System. Procedia Engineering, 70, pp.1411--1420.

WBCSD, (2000). Creating more value with less impact.. Geneva, Switzerland.

Concept maps - a constructive technique for sustainable development teaching and learning

Eglė Katiliūtė
School of Economics and Business, Kaunas University of Technology,
K. Donelaicio str. 20, LT-44239, Kaunas, Lithuania
egle.katiliute@ktu.lt

Abstract

While the role of education in sustainability processes is clear, the ways to approach this issue are evolutionary. Universities are beginning to take curriculum reform very seriously as they address the need to make graduates fit for 21st century citizenship and employment. A fundamental shift in thinking, values and action by all professionals and the general population is needed and it requires a shift in university didactic system. This paper explores and compares the teaching and learning processes in specific course on sustainable development (SD course) and in quality management course (QM course). The research objective is concept mapping as a teaching and learning tool for the development of university students' SD knowledge, collaborative learning and assessment techniques in the specific SD course and QM course. This paper analyses the concept maps as a constructive technique for SD and student satisfaction with using concept mapping in courses. Summarizing research data highlighted that concept maps help and motivate students to learn, integrate prior, experiential and new knowledge, to construct their own understanding, and compare their own knowledge with other students' knowledge. These results are consistent with those reported in previous studies that examined the usefulness of concept mapping in teaching and learning. This research confirms finding that the effectiveness of this technique depends on its being part of an overall approach to learning that places great importance on conceptual understanding.

Key words:
Teaching and learning for sustainable development
Concept mapping
Higher education
Quality management
Meaningful learning process

1. Introduction

Teaching SD is rather challenging, because it's not merely transmitting knowledge, but also learning on critical thinking, complexity, values and ethics (Corcoran et al., 2002; Segalas et al., 2008). Concept maps reveal the human understanding of events and phenomena as well as the respondent's knowledge structure. In the concept map a person arranges the knowledge in the order he/she perceives it. The visual representation in an integrated, hierarchical manner of one's own understanding shows, how the learner relates concepts in a certain knowledge domain, what is still unknown to him/her or what is understood improperly. Therefore, concept maps are an excellent diagnostic tool that helps the teacher to identify the learner's knowledge and the conceptual changes in his/her understanding over a period of time (Novak, Gowin, 1984; Marchand et al., 2002; West et al., 2002). Consequently, concept map use in studies can be both instructional (as a learning tool) and diagnostic (as an assessment technique) (Taber, 1994).
Using concept mapping to evaluate knowledge on SD has already been applied by other authors in higher education (Lourdel et al., 2007; Ahlberg, 2004, 2013; Gregorio and Freire, 2006; Segalas et al., 2008).
All of the above-mentioned studies have shown the significance of using concept mapping as meaningful learning technique. But the particular determinants of students' attitudes to concept mapping using have not been discussed. This article attempts to identify the main factors that students drive to use concept mapping technique.
The main research questions will be addressed in this paper are: Is the students' understanding of target SD concepts improved by concept-mapping techniques? What factors drive students to appropriate concept mapping techniques for meaningful learning? How do students evaluate the use of concept mapping in courses?
This article aims to validate meaningful learning of students on SD and their attitude to this didactic strategy used in the specific SD course and QM course. Previous studies found concept maps to be a useful tool to represent changes in students' knowledge structure over time (Novak, 1990; Lourdel et al., 2007; Segalas et al., 2008). This study confirms change in students' knowledge, highlights concept

mapping as part of teacher didactic system and presents students perception of concept mapping technique.

2. Concept mapping for meaningful SD learning

Concept mapping can connect the learner with the content and provide a wider learner engagement with the intent of providing a learner-centered experience (Laight, 2004). Furthermore, it complements and advances self-directed learning. As articulating-, reflective- and problem-based learning focus on self-direction and tends to be mainly unstructured, the use of concept mapping can be used to structure the information/knowledge acquired during these educational approaches (Farrand et al, 2002). Concept maps as a learning strategy thus supports and fosters new trends in higher education since it allows learners to externalize their thinking in a visual/verbal outline which enables them to review, reflect and revise their thinking.

The important learning factors of motivation and persistence can also be catered for by concept mapping. Reports examining student attitudes to concept maps have indicated important non-cognitive influences such as academic workload, motivation and contextual institutional issues (Farrand et al., 2002).

A major finding of Daley's study (2002) also states that concept mapping helps adult students to understand their own learning processes and gain independence. Additionally, they were able to explain their learning processes through the use of learning strategies such as linking, developing interrelationships, creating meaning schemes, and constructing knowledge. It is reported that the maps help them to understand how they think, to think in a broader fashion, to search out complicated relationships, and to organize information so that they remember it in a much more comprehensive way (Teo, Gay, 2006).

Concept mapping by Novak (1993) was based on Ausubel's Assimilation theory ideas (Ivie, 1998):

Cognitive Structure. Ausubel emphasizes the learner's cognitive structure in the acquisition of new information. Present experience is always fitted into what the learner already knows. A cognitive structure that is clear and well organized facilitates the learning and retention of new information.

Hierarchy. The hierarchical structure of knowledge fields of inquiry are organized like pyramids. The most inclusive ideas – those located at the top of the pyramid – are the dominant and most enduring elements in the hierarchy. They possess a longer life span in memory than do particular facts or specific details, which fall at the base of the pyramid.

Subsumption. Ausubel's learning theory is built around the concept of subsumption. When a new idea enters consciousness it is processed and classified under one or more of the inclusive concepts already existing in the learner's cognitive structure. Subsumers provide a basic structure around which information is organized. They are the intellectual linchpins holding the system together.

Anchorage. The major concepts (subsumers) in cognitive structure act as anchoring posts for new information. The availability of anchoring ideas facilitates meaningful learning.

Organizers. Organizers help to bridge the gap between what is already known and what is to be learned. Organizers are particularly useful when learners do not already possess the relevant concepts needed in order to integrate new information into their cognitive systems.

Ausubel's Assimilation Theory of meaningful verbal learning underlying basis that meaningful human learning occurs when new knowledge is consciously and purposively linked to an existing framework of prior knowledge in a non-arbitrary, substantive fashion. In rote learning, new concepts are added to the learner's framework in an arbitrary and verbatim way, producing a weak and unstable structure that quickly degenerates. The result of meaningful learning is a change in the way individuals experience the world; a conceptual change.

The use of concept mapping in SD studies aims to influence meaningful learning while it is actual develop sustainability-educated students, who can make societies more sustainable. Concept map could promote meaningful learning and conceptual understanding of science content (Novak, 2002).

Presentation and discovery teaching methods can lead to highly rote or highly meaningful learning by the learner, depending on the disposition of the learner and the organization of the instructional materials (Novak and Canas, 2008)) (see Fig. 1).

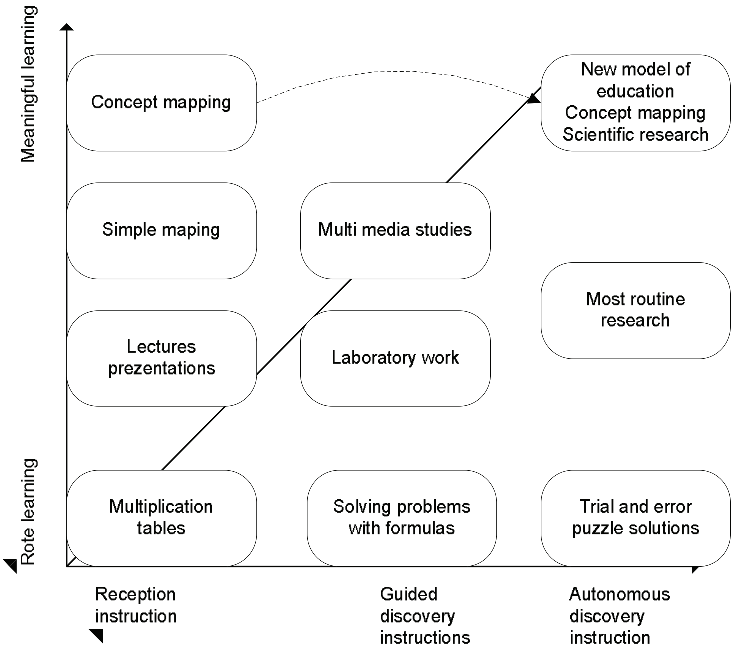


Figure 1. The Rote-Meaningful learning continuum (adapted Novak, 1998)

Concept mapping is a creative activity, in which the learner must exert effort to clarify concept meanings in specific domain knowledge, by identifying important concepts, establishing the concepts relationships, and denoting their structure (Gouli et al., 2004, Segalas et al., 2008).

3. Data analysis methods

3.1. Methodology

Using concept mapping to evaluate knowledge on sustainable development has been applied by various authors (Lourdel et al., 2007; Ahlberg, 2004, 2013; Gregorio and Freire, 2006; Segalas et al., 2008). This research aims to validate meaningful learning of students on SD and their attitude to this pedagogical strategy used in the specific SD course and QM course. The research was carried out in the Kaunas University of Technology in 2013. The research methods were the literature review, questioning survey and qualitative content analysis.

Students in both courses were asked to draw a conceptual map in each theoretical lecture. They draw 10 individual concept maps and two group concept maps per semester (one for systemizing knowledge and preparing to mid-term test, second – for preparing to final exam). Using cognitive maps as a pedagogical tool is pertinent in a metacognition process in order to check the outcomes of learning activities (Lourdel et al., 2007). In this research was no aim to make comparable analysis of students' knowledge improvement, it was important to keep meaningful learning process during course and to encourage self-reflection of students. When students were asked to draw a group concept map, the teacher helps students to analyse their maps. The student who analyses his/her own map, compares and discusses it with other students goes to deeper learning.

For the evaluation of students' perceptions regarding concept mapping as a part of teacher's pedagogic system, the 12 item questionnaire was completed by students (Karenauskaite, Katiliute, 2007; Katiliute, Daunoriene, 2011). 5 items of the questionnaire were devoted to evaluating students' attitudes to

concept mapping for the development of knowledge and its integration, 4 items – for evaluating student's attitudes to concept mapping for the development of self-directed/independent learning and reflection skills, 2 items – for evaluating student's attitudes to concept mapping for individualization and 1 item – for evaluating the appropriateness of the technique. The questions were constructed in order to clarify student's perceptions about how concept maps help and motivate them to learn, integrate prior, experiential and new knowledge, construct their own understanding, compare their own knowledge with other students' knowledge, and to clarify whether this technique is useful for them.
One open-type question was also included in the questionnaire: What do you like or dislike about concept mapping?

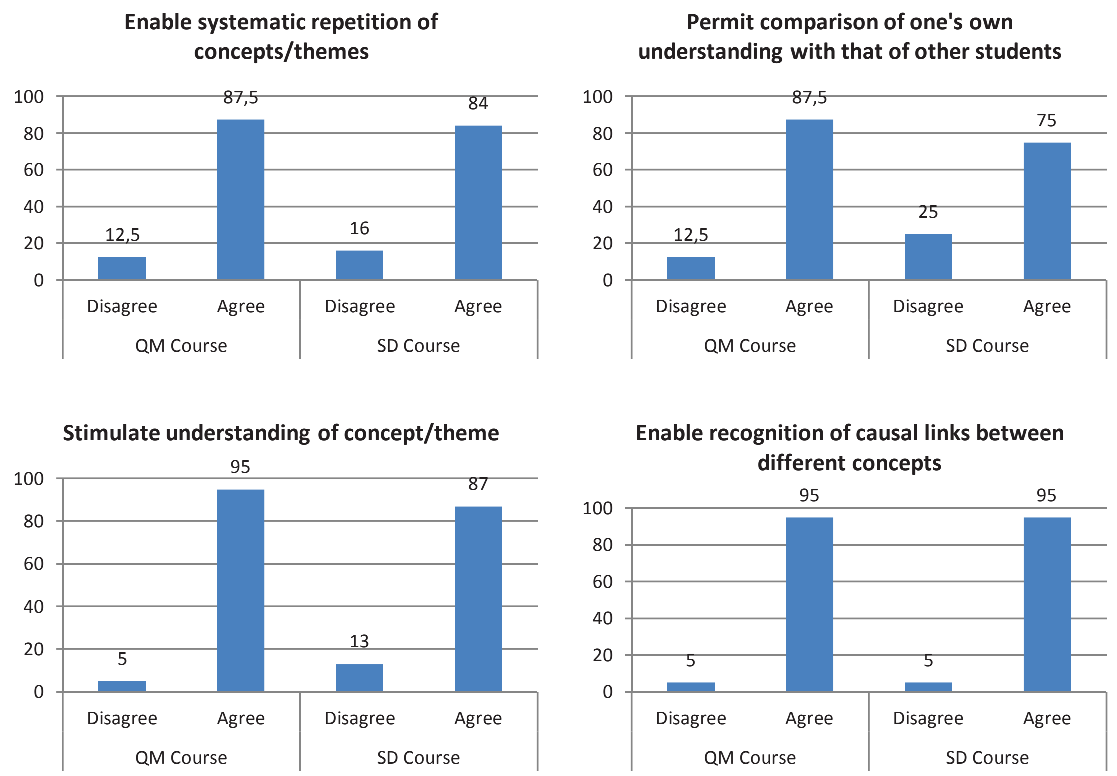
3.2. Data analysis

Statistical data analysis was based on descriptive statistics methods (mean and standard deviation). Descriptive statistics and content analysis of open-type question answers were used for the questionnaire survey evaluation.

4. Students' perception regarding concept mapping as meaningful learning tool

4.1. Quantitative analysis

As was mentioned in the methodological part of the article for evaluating students' perceptions regarding concept mapping, the 12 item questionnaire was completed by students. Students mostly evaluated concept mapping positively as regards the development of knowledge and its integration (see Fig. 2): 95% of the QM course students and 87% of the SD course students agreed that concept mapping stimulates understanding of the concept/theme; 87.5% (QM course) and 84% (SD course) – agreed that concept mapping enables systematic repetition of concepts/themes and permits the separation of more important elements of the concept/theme, to better understand their meaning (97% and 95%).



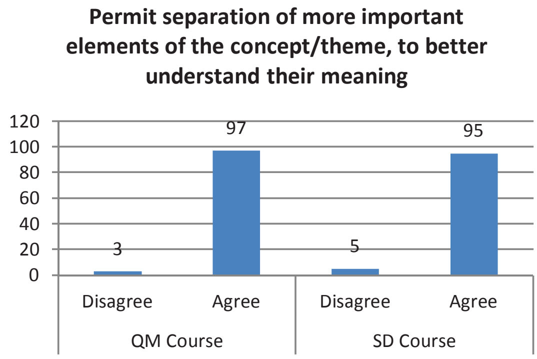


Fig. 2. Students' attitude to concept mapping as to development of knowledge and its integration (%)

Student's attitudes to concept mapping as regards the development of self-directed/independent learning and reflection skills were mostly positive in both groups (see Fig.3): 95% (QM course) and 84% (SD course) students agreed that concept mapping facilitates and stimulates independent learning, but only 75% (QM course) and 68% (SD course) – agreed that concept mapping stimulates learning motivation. 95% (QM course) and 89% (SD course) of students argued that concept mapping helps construct one's own knowledge base, less students - 89% (QM course) and 83% (SD course) – agreed that concept mapping enables the analysis of and reflection on one's own actions and understanding. It seems that some participants viewed concept mapping as too much work.

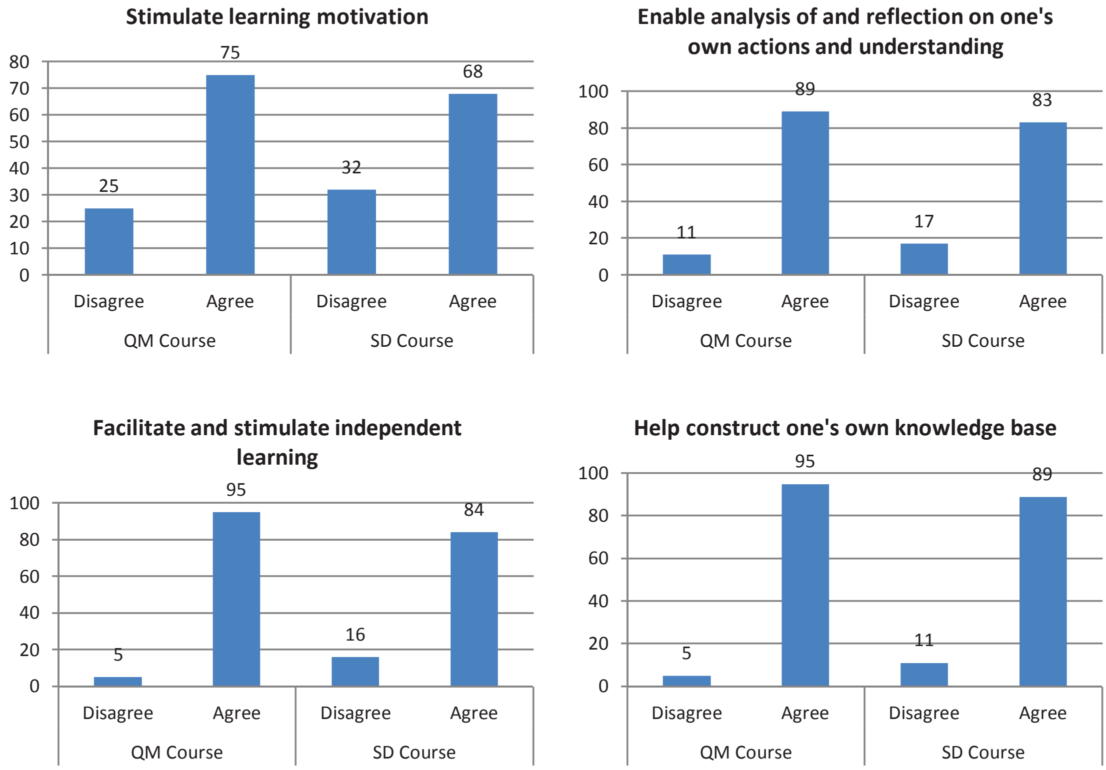
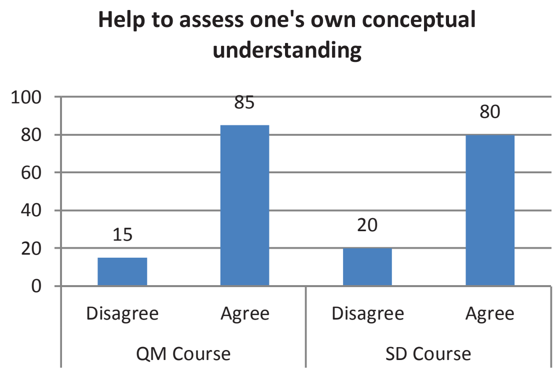


Fig.3. Students' attitude to concept mapping as to development of self-directed/independent learning and reflection skills

Most students of both groups positively evaluated concept mapping as individualization and agreed that concept mapping helped them to assess their own conceptual understanding (85% (QM course) and 80% (SD course)) and clarify gaps in their understanding (95% (QM course) and 89% (SD course)) (see Fig. 4).



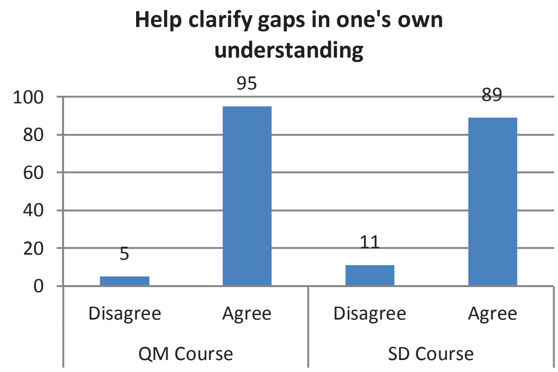


Fig.4. Students' attitude to concept mapping as to individualization

95% of the QM course and 84% of the SD course students agreed, that the concept mapping technique is appropriate (see Fig.5).

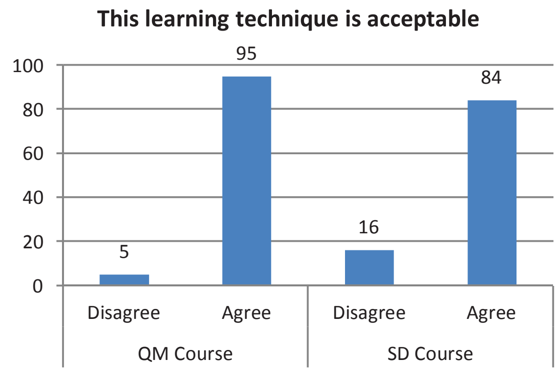


Fig. 5. Students' attitude to appropriateness of the technique

4.2. Qualitative analysis

Students' answers to the open-type question „*What do you like or dislike about concept mapping*?" showed that concept mapping was a useful learning tool in the QM and SD courses for many students in both groups. They identified some positive effects of this tool on learning.

The first item shows that concept mapping helped students '*understand main aspects*': 'About concept mapping I like that I can understand main aspect around the topic, so I can understand the argument' (student QM-5), 'The best part about using concept mapping is you can make keywords and you can link things with each other which makes things more clear and easy to understand' (SD-7), 'I invested more time in this class to fulfil the tasks (concept maps) in comparison to other lecture. But I assume I have a better understand of the issue than in other lecture' (SD-12).

The second item reflects student's perceptions of concept maps as a tool for '*remembering theory'* before coming to the final test: 'You have to work every week so when the date of exam came the concepts are fresh in your brain. You don't forget the lecture till day before exam' (QM-21), 'I prepared and revised theoretical elements by using concept maps before exam and these were very useful for preparing the final test' (QM-14).

Thirdly, students indicated that concept maps helped them '*encourage the motivation of learning*': 'The prepares of the concept maps encourage the motivation of learning already in the lecture time' (SD-8), 'Such a learning tool (concept map) is very interesting for me, I could understand the basic theme concepts and I feel motivation for learning' (QM-9).

The fifth item shows that concept mapping helped many students '*develop their understanding through different point of views*': 'Also it's a really good way to see other points of view of people from very different countries to you. I can see that what is important in my country is not enough in others' (QM-2), 'The creation of a common group map of some concepts enabled us to learn more from each other' (SD-19).

Such positive evaluations of concept mapping were founded in the answers of many students. Some of them, especially girls, were so enthusiastic about concept mapping that they coloured every map and said that colouring the maps helped them to construct correct maps and better understand them by themselves.

In addition to positive answers, students reported some difficulties in concept mapping. They had difficulty finding appropriate words to link concepts they 'knew' were related, to define the correct map hierarchy, and to understand how some concepts could be connected. It can be argued that this was due to their lack of proficiency in constructing maps at the beginning of the course. At the outset, participants' maps were mostly linear in nature, with inaccurate links, and lacking integration. Concept maps prepared toward the middle and end of the term, however, showed better hierarchical structure and more integration. The difficulties in both courses were very similar.

Students also had some special perceptions of concept mapping. One student (SD-3) wrote: 'I can say that if you want to do a clear concept map you have to spend a lot of time'. That opinion was confirmed at the end of the course.
It may be assumed that it is not easy for all students to accept new learning methods. New techniques, concept maps in this case, require considerable time and effort to master.

5. Discussion

Summarizing the quantitative and qualitative research it could be stated that it highlighted that concept maps help and motivate students to learn, integrate prior, experiential and new knowledge, to construct their own understanding, and compare their own knowledge with other students' knowledge.
These results are consistent with those reported in previous studies that examined the usefulness of concept mapping in science courses (Taber, 1994; Zienedine and Abd-El-Khalick, 2001, Karenauskaite, Katiliute, 2007). This research confirms their finding that the effectiveness of this technique depends on its being part of an overall approach to learning that places great importance on conceptual understanding.

6. Conclusions

Concept mapping allows students to analyse SD concepts and determine the relations among different concept dimensions. This enables students to work with concepts and propositions as opposed to the rote memorization of facts. Concept maps help and motivate students to learn, integrate prior, experiential and new knowledge, and construct their own understanding, compare their own knowledge with other students' knowledge and to have a better vision of sustainable development.
The use of concept maps within a both courses - SD specific course and QM course - stimulated meaningful learning and promoted the development of students' learning strategies both individually and as a group. Comparing specific SD course students' cognitive maps with those of QM course appears the same difficulties: finding appropriate words to link concepts they 'knew' were related, to define the correct map hierarchy, and to understand how some concepts could be connected.
The cognitive map method is a useful tool to improve teaching and learning. Identifying knowledge gaps allows the improvement of the training.

References

Ahlberg, M., 2004. Concept mapping for sustainable development. Concept Maps: Theory, Methodology, Technology. Proceedings of the First International Conference on Concept Mapping, Pamplona, Spain.
Ahlberg, M., 2013. Concept mapping as an empowering method to promote learning, thinking, teaching and research. Journal for Educators, Teachers and Trainers, Vol. 4 (1), 25 – 35.
Corcoran, P.B., Calder,W. and Clagston, R.M., 2002. Introduction: higher education for sustainable development. Higher Education Policy, 15(2), 99–103.
Daley, B., 2002. Facilitating Learning with Adult Students through Concept Mapping. The Journal of Continuing Higher Education, 50, 1, 21-31.

Farrand, P., Hussain, F., & Hennessy, E., 2002. The efficacy of ‘‘mind map’’ study technique. Medical Education, 36(May), 426–431.

Gouli, E., Gogoulou, A., Paanikolaou, K. and Grigoriadou, M., 2004. Compass: an adaptive web-based concept map assessment tool. Concept Maps: Theory,Methodology,Technology. Proceedings of theFirst International Conference on Concept Mapping, Pamplona, Spain.

Gregorio, R. and Freire,A., 2006. Reading and environmental education. Concept maps: Theory, methodology,Technology. Proceedings of the Second International Conference on Concept Mapping, San Jose, Costa Rica.

Ivie, .S. D., 1998. Ausubel's Learning Theory: An Approach To Teaching Higher Order Thinking Skills.(educational psychologist David Paul Ausubel). High School Journal 82.1, 35(1).

Karenauskaitė, V., Katiliūtė, E., 2007. Concept maps as a constructive technique for effective physics teaching and learning // Changes in social and business environment: proceedings of the 2nd international conference. November 8-9, 2007, Kaunas: selected papers. Kaunas: Technologija, 78-85.

Katiliūtė, E., Daunorienė, A., 2011. Toward meaningful learning in economics and management studies using concept maps in a quality management course. // Economics and management = Ekonomika ir vadyba [elektroninis išteklius] / Kaunas University of Technology. Kaunas : Technologija. ISSN 1822-6515. 2011, no. 16, p. 758-765.

Laight, D. W., 2004. Attitudes to concept maps as a teaching/learning activity in undergraduate health professional education: Influences of preferred learning styles. Medical Teacher, 26, 229–233. doi: 1080/0142159042000192064

Lourdel, N., Grondran, N., Laforest, V., Debray, B. and Brodhag, C., 2007. Sustainable Development cognitive map: a new method of evaluating student understanding. International Journal of Sustainability in Higher Education, 8 (2), 170–182.

Marchand, C. et al., 2002. An Analysis, Using Concept Mapping, of Diabetic Patients‘ Knowledge, Before and After Patient Education. Medical Teacher, XXIV, 1, 90-99.

Novak, J. D. & Canas, A. J., 2008. The Theory Underlying Concept Maps and How to Construct and Use Them. Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition, 2008, available at: [http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf]

Novak, J. D., 1993. Human constructivism: A unification of psychological and epistemological phenomena in meaning making. International Journal of Personal Construct Psychology, 6, 167-193.

Novak, J. D., 1998. Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Novak, J. D., 2002. Meaningful learning: The essential factor for conceptual change in limited or appropriate propositional hierarchies (liphs) leading to empowerment of learners. Science Education, 86(4), 548-571.

Novak, J. D., 1990. Concept mapping: a useful tool for science education. Journal of Research in Science Teaching, Vol. 27, pp. 937-49.

Novak, J. D., Gowin, D.B., 1984. Learning How to Learn. Cambridge: Cambridge University Press.

Santhanam, B., Leach, C., Dawson, C., 1998. Concept mapping: how should it be introduced, and is there a long term benefit?, Higher Education, 35, pp. 317-328.

Segalàs, J., Ferrer-Balas, D., Mulder, K. F., 2008. Conceptual maps: measuring learning processes of engineering students concerning sustainable development. European Journal of Engineering Education Vol. 33, Iss. 3, 297-306.

Taber, K. S., 1994. Student reaction on being introduced to concept mapping. Physics education (29), 276-281.

Teo, C.B., Gay, R., 2006. Concept Map Provision for E-learning. International Journal of Instructional Technology and Distance Learning. Vol. 3 No. 7., 24-31.

West, D. et al., 2002. Concept Mapping Assessment in Medical Education: A Comparison of Two Scoring Systems. Medical Education, XXVI, 9, 820-826.

Zienedine, A., Abd-El-Khalick, F., 2001. Doing the right thing versus doing the right thing right: Concept mapping in a freshmen physics laboratory. European Journal of Physics, 22, 501-511.

Address correspondence to:
Egle Katiliute
School of Economics and Business, Kaunas University of Technology
K.Donelaičio str. 20, LT- 44239 Kaunas, Lithuania
E-mail: egle.katiliute@ktu.lt
Tel: +370 612 90055

Technology options in a dairy plant: assessing whole-system eco-efficiency

Palle Lindgaard-Jørgensen*, Gert Holm Kristensen and Martin Andersen
DHI, Agern Alle 5, DK-2970 Hørsholm, www.dhigroup.com.
Tel : +45 45169200

*Corresponding author: E-mail: plj@dhigroup.com, Tel:+45 45169525

Abstract

Eco-efficiency has gained an increasing acceptance resulting a.o. in the issuance of the ISO standard ISO 14045. Eco-efficiency is a suitable measure of progress of a given system towards sustainable development, since the concept of eco-efficiency integrates both economic welfare and ecological impact of products or services throughout their lifecycle. The present paper presents an eco-efficiency assessment of a water-use system, using a life-cycle oriented approach and a set of selected eco-efficiency indicators.

The analyzed water use system comprises a dairy plant producing milk powder located in a production site in Holstebro, Denmark. The dairy uses water in its utility operation and in the dairy processes for purposes like cleaning (Cleaning in Place, CIP), rinse processes and standardization of products. Over the last decade the dairy has increased its production significantly while maintaining more or less the same water and energy use. The dairy strives to identify new technologies which are cost-effective in reducing resource burdens both within its own production site but also outside its own site in the water value chain.

The water value chain is modelled in five stages: water supply, dairy production, wastewater treatment, energy production (biogas) and transport. The study assessed how water and energy saving technology options could upgrade the whole-system eco-efficiency, measured as a ratio between total value added (TVA) and environmental impacts.

The identification of the environmentally weak stages being emissions of climate gasses resulting from energy use and water resource enables the selection of alternative actions, which could upgrade the whole value chain and improve the overall eco-efficiency. Four innovative technologies in the dairy production stage and one in the waste water treatment stage are examined and three alternative technology scenarios combining these technologies are formulated. All scenarios focus on resource efficiency, while one also focuses on reducing the emissions to water.

The eco-efficiency assessments showed that advanced oxidation and UV light treatment of the water stream separated from the milk stream had the highest eco-efficiency, showing an increase of the eco-efficiency by 130% compared to the baseline for the freshwater resource depletion indicator. Anaerobic pretreatment of the dairy waste water in the dairy plant had the highest eco-efficiency, showing an increase by 10% as compared to the baseline for the climate gas indicator. For all other technologies and combinations of technologies the increases were significantly lower.

The results of the eco-efficiency assessment provided a basis for workshops with the actors in the value chain to discuss how to anticipate distributional effects. The analysis of the economic performance clearly showed that the dairy plant had the highest economic performance due to the high value of their product and that investments in new technologies even increased the economic performance. This was mainly caused by savings on costs for water supply and waste water treatment services, which left the water utility with a reduced economic performance.

Keywords: Eco-efficiency, water-use systems, dairy industry, resource efficiency, pollution prevention

1. INTRODUCTION

Eco-efficiency assessments and Life Cycle Assessments has gained an increasing acceptance also in the dairy industry over the last decades (Mod and Gee, 1999),; OECD, 2009,; WBSCD, 2000). The UNEP Working Group for Cleaner Production in the Food Industry has developed a guidance manual for the dairy processing industry for eco-efficiency as a management tool to help dairies save money and to decrease environmental impacts (UNEP, 2004).

A recent review of the status of water utilization, energy utilization and waste water discharge provides an overview of state of the art of technologies and management systems to improve the eco-efficiency of the dairy processing industry (Rad & Lewis, 2014).The dairy industry sector has also developed its own guideline for LCA assessment (IDF, 2005).

The LCA analysis shows that 99% of the water footprint is in the primary production stage at farm level. However, the review of the status of water and energy use (Rad & Lewis, 2014) shows that there is still a potential to increase the efficiency of the water and energy use and reduce waste water emissions. Not least the potential to use water coming into the dairy with milk (about 87% of the milk is water) may replace the use of water with drinking water quality used in many dairies in Europe. This potential is largest in milk powder and cheese producing dairies as the dairy processes already comprise separation processes separating milk components and water, which still contains low concentrations of milk components (often called milk or cow water). As food safety cannot be compromised there are certain limitations to the amount of water which can be reused or recirculated. However, there has been a clear trend over the recent years that dairies use a higher percentage of water coming into the dairy with the milk.

The review also shows that the main efforts to increase eco-efficiency have been on internal measurements in the dairy processing industry, while there has been limited focus on the potential of the dairy processing industry to find solutions with other actors in the water value chain (from water supply to dairy - to waste water treatment plant and biogas production (Rad & Lewis, 2014), (UNEP, 2004).

The present study aims at assessing the water value chain of a milk-powder producing dairy and therefore complements ongoing activities in the dairy industry to study its water value chain and to look for potential solutions with other actors in the value chain. The amount of water in the milk is of the same magnitude or higher than the intake of freshwater - with a potential to close the water loop or even export water to other users. It is important to look for eco-efficient solutions in the water value chain to explore if the additional value can be created for all actors in the water value chain and emissions can be reduced.

2. METHODOLOGY

2.1 Goal and Scope Definition

The goal of the developed methodology is an integrated assessment of the eco-efficiency of a water service and water-use system. The methodology comprises a number of consecutive steps following the LCA procedure (Ecowater, 2014; JRC 2010 and 2011). The first step is an initial definition of the boundaries of the water system reflecting the special characteristics of the studied system and a determination of the functional unit

The water use system is represented as a network of unit processes. Each process corresponds to an activity, through which materials (water, raw materials, energy and other supplementary resources) are converted into products, while releasing emissions to the environment (air, land, water) or into the system's water flow. The system is divided into two subsystems: the foreground and the background. The foreground system corresponds to the set of processes, whose selection or mode of operation is affected directly by decisions based on the study, while the background includes other activities and delivers energy and raw materials to the foreground system.

The functional unit sets the scale for the comparison. It depends on the reference flow selected each time and its main purpose is to provide a reference to which results are normalized and compared

2.2 Inventory Analysis

An inventory of flows entering and leaving every process in the developed system is created and - based on that - the significance of potential environmental impacts is evaluated. Data for the inventory analysis have been based on annual averages (2012) of resource uses available in the Environmental Reports of the dairy, of the utility operating the water supply and waste water treatment system, and the biogas plant.

2.3 Eco-efficiency Assessment

2.3.1 Environmental Assessment

The assessment of the environmental performance is based on a life-cycle oriented approach using midpoint impact categories. Based on the flows entering and leaving every process in the system, the significance of potential environmental impacts is evaluated. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterisation factors.

Since water consumption is an important component of the studied system, the freshwater depletion is taken into consideration, measuring freshwater depletion as the current freshwater use to the available freshwater resources multiplied by the ratio of water withdrawal to availability ratio in the region where the dairy operation takes place (Mila i Canals, et al. 2009).

2.3.2 Value Assessment

The economic performance of a system is monitored by using the Total Value Added (TVA) to the product due to water use, expressed in monetary units per period (year 2012). The total economic value from water use is calculated by subtracting the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage from the total value of the products (Jasch, 2009).

2.3.3 Eco-efficiency Indicators

The eco-efficiency indicators of the water use systems are defined as ratios of the economic performance (TVA) to the environmental performance (environmental impacts) of the system. There is one eco-efficiency indicator for each environmental impact category.

2.4 Value Chain Upgrading

For the formulation of technology scenarios three categories of eco-efficiency measures have been considered:

- Resource Efficiency:

  Resource efficiency approach includes technological interventions targeting the optimum use of an energy and eliminating the negative impacts for which the production process is responsible.

- Pollution Prevention:

  End-of-pipe solutions incorporated into the existing manufacturing processes at the final stage and/or incorporated in the production process.

- Circular Economy:

  Technologies which constitute an integral part of the processes and have the potential to save costs by reducing the use of raw materials, energy and the costs of complying with regulations (in contrast to the end-of-pipe technologies).

3. THE DAIRY WATER VALUE CHAIN

The case study implementation area includes the total Danish dairy sector. The figure shows the distribution of dairies in Denmark. As can be seen, the dairies are located mainly in Jutland and Funen. Circles indicate co-operatively owned dairies and triangular symbols indicate privately owned dairies. The circle shows the location of the milk powder producing dairy HOCO in Holstebro which participated in the project (Arla, 2011 and 2013).

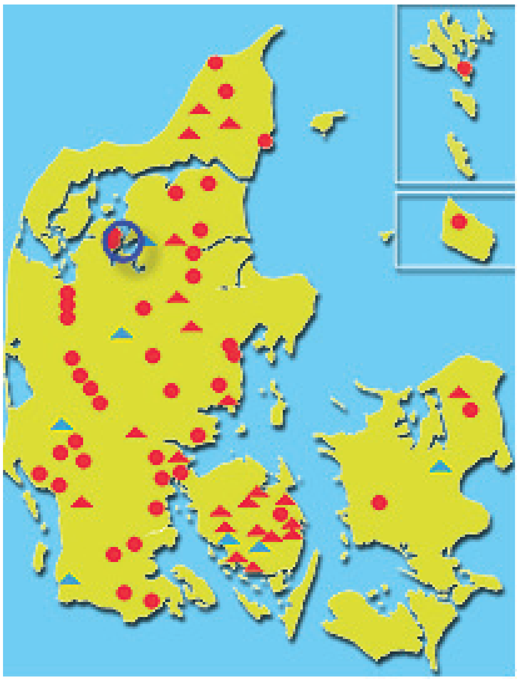


Figure 1 Location of dairies in Denmark showing also the dairy studies.

HOCO has already reduced its water and energy use significantly over the last decade and is striving to reduce it further. HOCO is part of the Arla Group which has the environmental target to reduce its emission of climate gasses and water use by 3% every year up to 2020. The Arla Group target is also a target for the individual dairies (Arla, 2010 and 2013). As can be seen, HOCO has managed to increase its production significantly and to reduce the use of water, energy and waste water discharge (Figure 2).

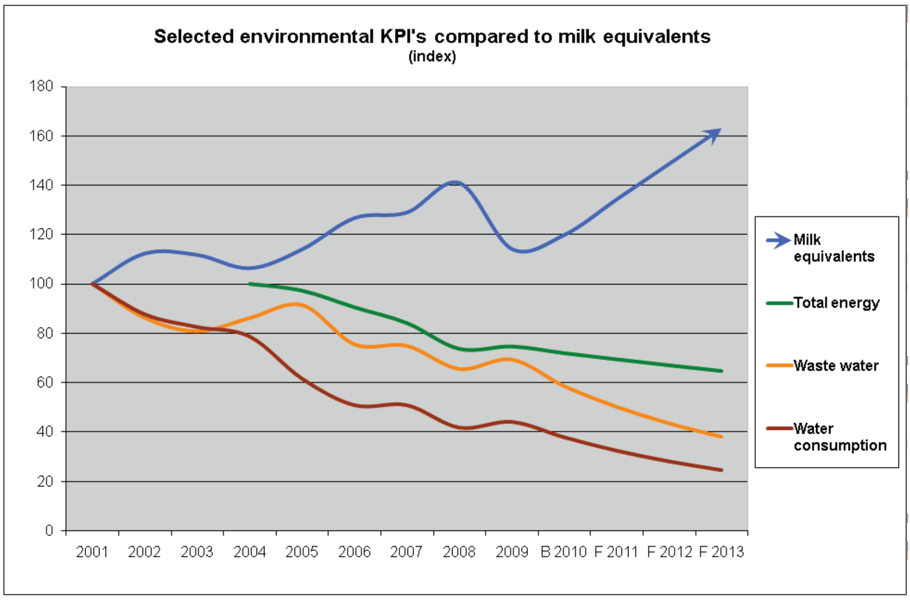


Figure 2 Water, energy and waste water discharge and milk equivalents

This has been achieved through the installation of a more efficient process technology, more efficient cleaning in place technologies and better management and lean implementation. HOCO has also installed larger tanks to which reuse water can be returned and used for a purpose which fits the quality of the reuse water. As a safeguard measure the reuse water is treated with UV light prior to its use in the dairy. The management of HOCO has also started looking at possibilities to increase efficiency by cooperating with other actors in the water value chain.

Prospects for improving the system's overall eco-efficiency are investigated. Through the identification of the environmentally weak stages of the system as well as the selection and implementation of innovative technologies that would upgrade the value chain, two alternative technology scenarios are formulated and compared to the baseline scenario. The analysis that follows is mainly focused on the study of the potential to improve water and energy efficiency through an increased use of the water in the milk, but also on reuse of water which today leaves the dairy as water vapour. Other solutions analysed are anaerobic pre-treatment of the waste water discharged to the waste water treatment.

3.1 System Boundaries & Functional Unit

The studied system is divided into the foreground and the background sub-systems. The foreground system contains the water supply, the water use chain (the dairy), the waste water treatment plant, the biogas plant and transport. These stages enclose the relevant actors involved in the system and the interactions among them. The actors of the system, both directly and indirectly involved, are the following:

- The Water Utility - Vestforsyning A/S - operating both the water supply and the waste water treatment system
- The dairy plant – HOCO - being part of Arla Foods in Denmark
- The biogas plant -Maarberg Biorefinery
- Private companies transporting milk, milk powder and other milk ingredients under contract with the dairy.

The background system consists of the production processes of the supplementary resources (electricity and natural gas), raw materials and chemicals. However, only the electricity and natural gas production processes are taken into consideration for the eco-efficiency assessment, as data on chemical uses has not been made available for the study.

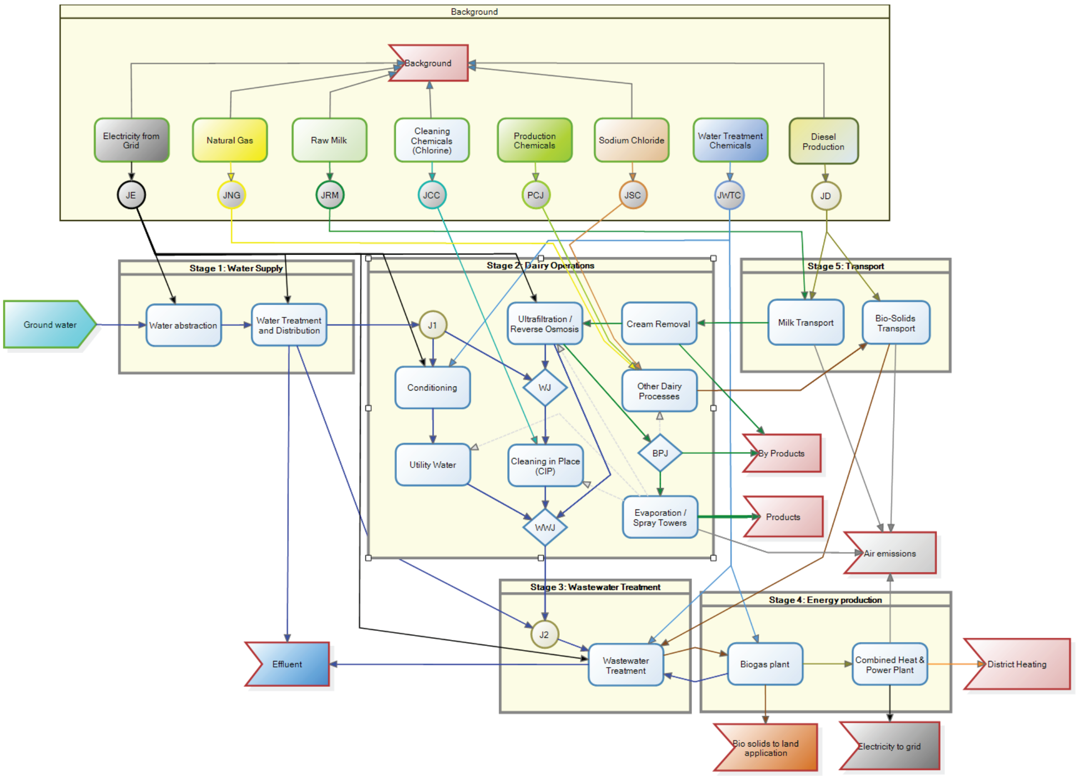


Figure 3 *Schematic representation of the foreground and background systems, including, the processes and the involved actors of the water-use system*

The functional unit used is defined as 1 kg of milk powder produced. As there is an almost fixed relation between milk powder produced and milk taken into the dairy, the results can also be expressed per kg of milk taken into the dairy.

4. RESULTS AND DISCUSSION

4.1 Baseline Scenario Assessment

The dairy had an output of 17.165 ton milk powder in 2012. For the dairy processes it is estimated that in 2012 1 kg of milk powder required 31 litre of groundwater, 2.560 kWh of electricity and energy from natural gas equivalent to 7676 kWh. The input of raw milk in 2012 was 524.236 ton giving a groundwater intake to milk ratio of about 1 litre per kg of raw milk. This is below the average 1,5 litre of water per kg of raw milk reported for milk powder production (Weeks, 2010).

In the calculations of the baseline scenario it has been taken into account that the waste water treatment plant as well as the biogas plant also receive inputs from other waste water and sludge and bio solid sources. The resource uses and emissions and value added therefore only refer to the amounts from the dairy plant.

4.1.1 Environmental Assessment

The environmental performance of the system is assessed through eight environmental midpoint indicators, representative for the specific system and relevant to the dairy industry. The background processes that are taken into account for the assessment of the environmental impacts are electricity and natural gas production, as it was not possible to collect data for the other background processes. The characterisation factors included in the CML-IA database are used for the calculation of the environmental impacts of the foreground system, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (JRC, 2011).

The environmental assessment of the baseline scenario is summarized in Table 1 Table 1 presents the normalized values of environmental indicators per kg of milk powder produced for the entire system and the contribution of the foreground and the background system separately. It is obvious that the most significant environmental problems are freshwater depletion and climate change impact.

Table 1 Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario

Midpoint Impact Category	**Environmental Performance Indicator per kg of milk powder produced**	**Foreground Contribution**	**Background Contribution**
Climate change	64 $kgCO_{2eq}$/ kg	45	55
Freshwater Resource Depletion	8.6 m^3/kg	100	0
Eutrophication	1,7 $kgPO_4{}^{3-}{}_{,eq}$/kg	0,3	99,7
Human toxicity	1,05 $kg1,4DCB_{,eq}$/kg	14	86
Acidification	0.06 $kgSO_2{}^{-}{}_{,eq}$/kg	0,8	99,2
Aquatic Ecotoxicity	0,002 $kg1,4DCB_{,eq}$/kg	0	100
Terrestrial Ecotoxicity	0,003 $kg1,4DCB_{,eq}$/kg	0	100
Photochemical Ozone Formation	0.0005 kg $C_2H_{4,eq}$/ kg	35	65

4.1.2 Value Assessment

Calculated value assessment of the value chain per actor is shown in Table 2. The total net economic output is 30.201.664 € - equivalent to 1,7 € per kg of milk powder produced. As this figure refers to the specific value chain, this figure cannot be compared with other dairy plants.

Table 2Economic evaluation of the value chain

Actor	**Annual O&M costs (€/yr)**	**Gross income (€/yr)**	**Revenues from services €/yr)**	**Net economic output €/yr)**
Water supply operator	52.731	0	953.300	882.569
Dairy industry	213.154.418	249.642.370	-9.668.941	26.819.011
WWT operator	294.049	0	2.428.019	2.133.970
Biogas plant	19.618	102.627	0	83.008
Transport companies	6.022.515	0	6.305.620	283.105

The net economic output of the value chain is completely dominated by the dairy industry and the value of the milk powder produced. For the dairy the main cost is the raw milk and the net economic output is highly influenced by this price.

4.1.3 Eco-efficiency Assessment

Table 3 presents the results of the baseline eco-efficiency assessment for the overall system. It is confirmed that the major environmental impacts of the studied system (including both foreground and background) are eutrophication, acidification, human toxicity, climate change and freshwater resource depletion which are characterised by the lowest eco-efficiency indicator value and thus the worst performance. Focussing only on the foreground climate change and freshwater resource depletion had the lowest eco-efficiency value and thus the lowest performance.

Table 3Baseline eco-efficiency assessment

Midpoint Impact Category	**Unit**	**Total for the value chain**
Climate change	€/kgCO_{2eq}	30
Freshwater Resource Depletion	€/m^3	202
Eutrophication	€/kg$PO_4{}^{3}{}_{-,eq}$	0.99
Human toxicity	€/kg1,4$DCB_{,eq}$	28,5
Acidification	€/kg$SO^{2-}{}_{,eq}$	3,14
Aquatic Ecotoxicity	€/kg1,4$DCB_{,eq}$	737
Terrestrial Ecotoxicity	€/kg1,4$DCB_{,eq}$	630
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	3271

4.2 Value Chain Upgrading

The baseline eco-efficiency assessment and the identification of the environmental weaknesses of the system can lead to the selection of innovative technologies, which can upgrade the examined value chain.

Thus, three main objectives are set for the upgrading of the studied system: (a) increase of resource efficiency, focusing on freshwater and energy optimisation, (b) energy pollution prevention, and (c) circular technologies where the water in the milk is treated to enable an increased reuse. After discussing with the actors directly involved in the system and reviewing the relevant literature, four alternative technologies were selected for implementation in the dairy and one in the waste water treatment plant. These technologies are described in the following paragraphs.

Table 4Alternative technologies to upgrade the dairy value chain

Technology Scenario	**Technologies Included**
Resource Efficiency	Anaerobic pre-treatment of dairy waste water
	Increasing the efficiency of the Cleaning in Place operation
	Condensation of water vapour from drying of milk powder
Pollution Prevention	Anaerobic pre-treatment of dairy waste water
Circular economy	Advanced oxidation and UV treatment

<u>Technologie</u>s:
Anaerobic digestion is a technology that can transform organic waste products into energy through production of biogas (methane), which can be used to substitute natural gas consumption in the dairy – or be used for power and heat production.

Anaerobic Digestion for pre-treatment of waste water from Arla HOCO aims to reduce the organic load on the municipal WWTP, while producing energy instead of using energy for aeration requirements in the WWTP.

The AD system converts organic substances in the dairy waste water (mainly fats, proteins and sugars) into mainly methane and carbon dioxide (biogas). The biogas can be burned and used to substitute natural gas or produce electricity and heat, and the methane will be converted to CO_2.

The energy consumption of the downstream WWTP will be reduced – as will the energy production from sludge treatment following the WWTP. However, the reduced biogas production from sludge treatment is more than compensated from the energy production in the pre-treatment stage.

The HOCO production process utilizes different degrees of membrane filters to separate and concentrate valuable products in the milk. Reverse Osmosis (RO) filters are used as a final step in this process to separate and concentrate different products. The permeation from the RO filters is a high quality water stream, however with some small molecular organic and nitrogen compounds still remaining, such as urea. The challenge is that these substances cause the otherwise clean water to be highly microbiologically unstable.

These compounds are very difficult to separate by physicochemical processes and the most efficient way to remove these compounds may be to use *chemical oxidation and UV treatment* to remove the organic material and also remove the growth potential in the treated “milk water”.

Cleaning-In-Place is essential in HOCO’s production for keeping a high hygienic quality of production equipment. A typical CIP sequence could be: product recovery, pre-rinse, alkaline solution wash, intermediate rinse, acid solution wash, and final rinse.

The chemical baths are of interest here, as these contain water as well as chemicals, and heat that can be recovered by installation of a nano-filtration membrane in a by-pass on the chemical CIP tanks. Water and chemicals will be able to pass through the membrane while contaminants in the CIP baths are rejected as waste water. In

this way it is possible to extend the lifetime of the chemical CIP solutions and as such save water, chemicals and products.
Large amounts of water evaporate in the spray dryers – water also containing a significant amount of bound energy. The total amount is approximately 3 kg of water per kg of product. This water comprises the most significant opportunity for separation of a very clean water stream for reuse.

The *condensation* could be achieved by using the vapor used to preheat the drying air for the spray towers. This could be done in an air-air heat exchanger or an air-liquid-air double heat exchanger with a recirculating medium in between.

Direct savings in natural gas consumption will be achieved, and significant amounts of water will be recovered and could potentially be reused. There will be an increase in electricity consumption to drive fans and pumps for this solution - however, a side effect may be better air pollution control of dust from the spray dryers.

Installation of *more efficient diffusors* and aeration systems in the waste water treatment system will improve the energy efficiency of the biological waste water treatment and thus also the total waste water treatment system (Jette Fleng Rasmussen, personal communication).

Table 5 shows an assessment of the changes of the eco-efficiency if the above mentioned technologies are installed in the water value chain - with the first four installed in the dairy and the last in the waste water treatment plant.

Table 5Eco-efficiency upgrading technologies

Midpoint Impact Category	**Base line**	**1 Anaerobic pretreat-ment**	**2 Advanced oxication UV light treatment**	**3 Upgrading CIP**	**4 Reuse of conden-sate from drying of product**	**5 More efficient blowers – diffusors**
Climate Change	30 €/kgCO_{2eq}	+10%	+6,8%	+0,8%	0%	+1%
Fresh-water Resource Depletion	202 €/m^3	+0%	+55%	+7%	+ 20%	0%
Eutrophi-cation	0,99 €/kg$PO_4{}^{3}{}_{-,eq}$	0%	+8%	+4%	+4%	0%
Human Toxicity	28,5 €/kg1,4$DCB_{,eq}$	+9%	0%	+6%	+6%	+2%
Acidifica-tion	3,1 €/kg$SO^{2-}{}_{,eq}$	+9%	+2%	+6%	+6%	0%
Aquatic Eco-toxicity	737 €/kg1,4$DCB_{,eq}$	+8%	+1%	+6%	+2%	0%
Terres-trial Eco-toxicity	630 €/kg1,4$DCB_{,eq}$	+8%	+2%	+7%	+7%	0%
Photoche mical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	+8%	+1%	+8%	+8%	0%

As can be seen, the largest improvements in eco-efficiency are for the climate change and freshwater resource depletion indicators. The advanced oxidation and UV light treatment, anaerobic pre-treatment and the reuse of condensate show the largest improvements in eco-efficiency.

Combining the technologies with the largest improvements of the eco-efficiency will improve the eco-efficiency of the water value chain further as illustrated in Figure 4.

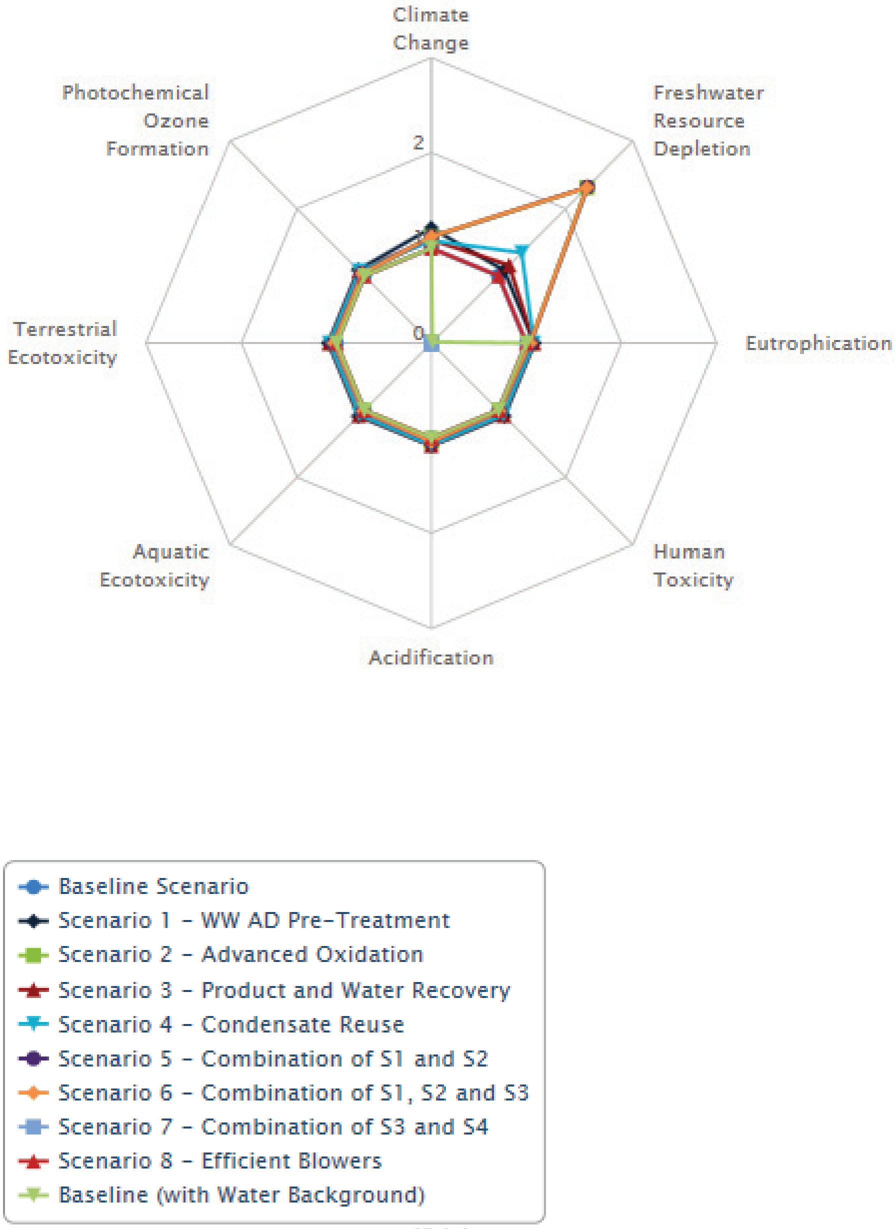


Figure 4 *Eco-efficiency assessment of the five individual technologies and combinations of technologies*

The implementation of anaerobic pre-treatment and advanced oxidation (scenario 5) and the same technologies also combined with product and water recovery (scenario 6) and more efficient blowers showed the highest improvements of eco-efficiency for climate change and water resources depletion and also either improved or left the other seven eco-efficiency indicators at the same level as the baseline. Implementing only the anaerobic pre-treatment or advanced oxidation, however, had almost a similar improvement of the indicators as the combined technologies measured as climate gas and water resources depletion.

The installation of the technologies or combination of technologies increases the total net economic output (NEO) (Table 6). For the dairy the NEO increases for all technologies and combinations of technologies- while the NEO only increases for the waste water treatment operator and is either reduced or kept constant for the other technologies and combination of technologies. In fact the increased NEO for the dairy is partly a result of the decreased cost the dairy has to pay for its water supply and waste water treatment services to the water utility.

Table 6 Net economic output all the involved actors and the total valued added of the system

Net Economic Output	Baseline	Anaerobic Pre-treatment	Advanced oxidation and UV treatment	Combined technologies scenario 5	Combined technologies scenario 6 and more efficient blowers
Water supply operator	882.569	0%	-54%	-54%	-50%
Dairy	26.819.011	+9%	+10%	+11%	+10%
WWT operator	2.133.970	+2%	-40%	-40%	-42%
Biogas plant	83.008	-25%	-17%	-18%	-20%
Transport company	283.105	0%	0%	0%	0%
Total	30.202.000	+8%	+4%	+4%	+4%

The implementation of the technologies is being considered by the actors in the value chain. The installation of more efficient blowers/diffusors by the WWT operator has already been decided. The upgrading of the CIP (part of the combined technology scenarios 5 and 6) is being considered by the dairy, as this investment has a relatively short pay-back time. For the advanced oxidation it has been decided to apply for funds to document that this technology can actually secure the microbial quality needed for the reuse of the water.

4.3 Further activities

The waste water pricing structure will be changed in Denmark from next year to also include a pollution charge. The value chain analysis made in the dairy study will provide a useful input to the discussions between the WWT operator, the biogas plant and the dairy. A follow-up workshop to discuss the results of this study is therefore planned to take place within the coming months.

Also it has been decided that an ongoing project involving cheese producing dairies in Denmark will use the eco-efficiency methodology developed for the milk powder producing dairy with the aim to establish a benchmark for eco-efficiency in cheese producing dairies.

5. CONCLUSIONS

The paper presented a methodological framework for the assessment of eco-efficiency in a dairy water value chain. The analysis of the baseline situation in the water value chain provided insight into the value created in the value chain to the environmental performance and to the weak points in the value chain which had the lowest eco-efficiencies.

The net economic output of the industrial actor (Arla HOCO) is the completely dominating factor of the complete value chain – with the price of the raw milk resource being the single factor determining the total value added of the entire system. Minor changes in the price of raw milk can completely change the TVA of the system – and as such the eco-efficiency indicators calculated.

Regarding the environmental and eco-efficiency performance of the system, the main weak points are the eutrophication and the acidification impact categories. However, both of them are mainly due to the background processes. The other two indicators with relatively low values, caused by the foreground system, are the climate change and freshwater resource depletion. Thus, technological solutions have been examined in order to reduce water and fossil fuels consumption in the dairy industry.

The implementation of anaerobic pre-treatment and advanced oxidation and more efficient blowers in the waste water treatment plant showed the highest improvements of eco-efficiency for climate change and water resources depletion and also either improved or left the other seven eco-efficiency indicators.at the same level as the baseline. Implementing only the anaerobic pre-treatment or advanced oxidation, however, had almost a similar improvement of the indicators as the combined technologies - measured as climate gas and water resources depletion.

The installation of the technologies or combination of technologies increases the total net economic output. For the dairy, the NEO increases for all technologies and combinations of technologies, while the NEO only increases for the waste water treatment operator and is either reduced or kept constant for the other technologies and combination of technologies. In fact the increased NEO for the dairy is partly a result of the decreased cost the dairy has to pay for its water supply and waste water treatment services to the water utility.

The implementation of the technologies is being considered by the actors in the value chain. The installation of more efficient blowers/diffusors by the WWT operator has already been decided. The upgrading of the CIP is being considered by the dairy as this investment has a relatively short pay-back time. For the advanced oxidation, it has also been decided to apply for funds to document that this technology can actually secure the microbial quality needed for the reuse of the water.

Furthermore, the analysis indicates that the methodology provides useful results which can make a useful contribution to decisions on installations of technologies which are eco-innovative and providing both an increased economic output and environmental performance.

Acknowledgements

The methodology presented in the paper arises from "EcoWater: Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors", a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA).

6. References

Arla Foods (2011). *Environmental Strategy 2020*, Viby, Denmark http://www.arla.com/about-us/responsibility/nature-and-environment/environmental-strategy

Arla Foods (2013). *Our Responsibility: Arla Foods' Corporate Social Responsibility Report* http://www.arla.com/Global/responsibility/pdf/csr/2013/ArlaCSR_Our%20Responsibility2013_ENG.pdf

Bulletin of the International Dairy Foundation (2005). *Guide on Life Cycle Assessment towards sustainability in the Dairy Chain*. Bulletin 398

Ecowater, http://environ.chemeng.ntua.gr/ecoWater

ISO (2006). *Environmental management – Life cycle assessment – Requirements and guidelines, ISO 14044:2006*. International Organization for Standardization, Genève, Switzerland.

ISO (2012). *Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines, ISO 14045:2012*. International Organization for Standardization, CEN.

Jasch, C. (2009). *Environmental and Material Flow Cost Accounting - Principles and Procedures*. Eco-Efficiency in Industry and Science, Vol. 25), New York: Springer.

.ISO 14044 (2006). *Environmental management - Life cycle assessment - Requirements and guidelines.* Genève: International Organisation for Standardization (ISO), 2006.

JRC (2010). European Commission – Joint Research Centre – Institute for Environment and Sustainability: *International Reference Life Cycle Data system (ILCD) Handbook – General Guide for Life Cycle Assessment – Detailed guidance*. First edition. Luxembourg: Publication Office of the European Union.

JRC (2011). European Commission – Joint Research Centre – Institute for Environment and Sustainability: *International Reference Life Cycle Data system (ILCD) Handbook: Recommendations for Life Cycle Impact Assessment in the European context.* First Edition. Luxembourg: Publication Office of the European Union

Mila I. Canals, L., J. Chenoweth, A. Chapagain, S. Orr, A. Anton, and R. Clift (2009). *Assessing freshwater use impacts in LCA: Part I - inventory modelling and* *characterisation factors for the main impact pathways.* International Journal of Life Cycle Assessment 14, no. 1 (2009): 28-42.

Mol, S., & Gee, D. (1999). *Making Sustainability Accountable: Eco-efficiency, Resource productivity and innovation*. Topic report No.11. Copenhagen: European Environment Agency (EEA).

OECD (1998). *Eco-efficiency*. Paris: OECD (Organisation for Economic Co-operation and Development),

OECD (2009). *Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement*. Synthesis Report, Paris, 2009.

Salimeh Jabbari Rad & M.J. Lewis (2014). *Water utilization, energy utilization and waste water management in the dairy industry. A review.* International Journal of Dairy Technology, Volume 67, Issue 1, page 1-20.

UNEP Working Group for Cleaner Production in the food industry (2004). *Eco-efficiency for the Dairy processing Industry.*

WBCSD (2000). *Eco-efficiency, Creating more value with less impact*. WBSCD (World Business Council for Sustainable Development).

Weeks M (2010). *Water efficient dairy processing in Australia*. Dairy Innovation Australia. http://www.wds2010.com/%5C/delegates/presentations.

Evaluation of methane production from anaerobic digestion of different agro-industrial wastes

Vitanza R., Cortesi A., Gallo V., Colussi I., Rubesa Fernandez A. S.
University of Trieste, Department of Engineering and Architecture,
Piazzale Europa 1, I-34127, Trieste, Italy

angelo.cortesi@di3.units.it
vittorino.gallo@di3.units.it
iginio.colussi@di3.units.it

Corresponding author: Rosa Vitanza
rosa.vitanza@di3.units.it
University of Trieste, Department of Engineering and Architecture, Piazzale Europa 1, I-34127, Trieste, Italy
(0039) 040 5583254

Abstract

The production of methane via anaerobic digestion of biomass, such as energy crops, agro-industrial wastes and OFMSW, would provide a clean fuel from renewable feedstock and would replace the fossil fuel derived energy. Because of this, the prediction of methane yield (as regards to gas volume and rate of production) of residual and waste materials is gaining increasing interest. The biochemical methane potential (BMP) test is widely used for anaerobic process feasibility and design purpose, providing information about the biodegradability of high solid content substrates.

In this work, methane yield coefficients and first-order disintegration rates for five different substrates (apple waste, brewery spent grain, brewery yeast waste, maize silage and red chicories waste) are evaluated. BMP tests are performed in 5 L fed-batch stirred reactors at several inoculum/substrate ratios. All runs are performed without the addition of chemicals.

Keywords: BMP test, biomethane, anaerobic digestion, anaerobic biodegradability

1. Introduction

The European Union is promoting the use of energy from renewable sources in replacement of fossil fuels. According to the Directive 2009/28/EC (EU Directive, 2009), 20 % of the final energy consumption have to be provided by renewable sources by 2020.

In this context, the biogas production via anaerobic digestion of biomass is gaining importance. Biogas is an energy carrier with several possible applications: raw biogas may be used for heating and electricity production, whereas upgraded biogas (with a content of methane of 95 – 99%) may be used as vehicle fuel or injected in a natural gas network (Olsson and Fallde, 2014). The three main biogas production routes are: direct recovery from landfill, anaerobic digestion of wasted sludge from WWTPs, and purpose-designed biogas plants (van Foreest, 2012). With respect to the latter, many feedstock can be processed to produce the collectively known "other biogas": manure, energy crops (*e.g.* maize silage) and agro-industrial waste (*e.g.* remains of breweries, fruit processing and slaughter houses).

In 2012 the estimated primary production of biogas in the EU was of 12,016 ktoe (Eurobserv'er, 2013). The sector is dominated by ~~the~~ three main countries, Germany, United Kingdom and Italy, accounting for three quarters of the installed capacity (Eurobserv'er, 2013).

In recent years, Italy is witnessing a proliferation of biogas energy plants. According to Fabbri et al. (2013), the biogas plants operating in Italy at the end of 2012 were 994, with an increase of 91% compared with 2011. The management of these plants is not trivial: it involves the achievement of the proper OLR, the balance of the C/N ratio, the maintenance of the proper pH values, and the mitigation of the inhibitory effects. Additionally, another important point is that the feedings of the agricultural biogas plant (usually managed by the farmers) are subject to the growing periodicity. In this context, it's clear that laboratory experiments and process modeling are indispensable tools for supporting the plants design and management.

In the present paper, results of biomethanization tests performed with five different substrates (apple waste, brewery spent grain, brewery yeast waste, maize silage and red chicories waste) are reported. The experiments were carried out in different time intervals. The specific methane production for each substrate was related to its own anaerobic biodegradability by merging the chemical composition data (taken from literature) with the results of laboratory BMP tests. The obtained methane production curves are then employed to calculate the CH_4 yield of each substrate and to estimate a first-order disintegration/hydrolysis rate constant.

2. Materials and methods

2.1 Substrates

Tested substrates came from farms and food processing industries located in the North-East of Italy.

Apple wastes (AW) originated from an apple juice manufacture in Friuli Venezia Giulia (FVG) region. The apple juice process production creates residuals ranging from 25% to 35% of the fresh fruit mass with a high nutritional content.

Brewery wastes were collected from a local (FVG region) brewery and consisted of spent grains and exhausted yeast. Brewer’s spent grains (BSG), the residual solid fraction of the final mash process of malting, are a main waste fraction of beer production (Mussatto et al., 2006; Thomas et al., 2006; Lorenz et al., 2013), corresponding to around 85% of total by-products generated. Brewer's yeast (BY) is produced by the well-known one-celled fungus *Saccharomyces cerevisiae*. In the brewing process, brewer's yeast is added to hops and malted barley to ferment them into alcohol. During alcoholic fermentation, the cells reproduction (gemmation) takes on and, at the end of the process, the residual yeast is about twofold – threefold of the added quantity.

The red *radicchio* (a type of chicory) wastes (RR) ,were acquired from a farm located in the Veneto region. In the Italian North-East horticulture, the production of red *radicchio* (Treviso variety) is one of the leading cultivation. The RR production involves many steps, during which several amounts of by-products are discarded and left to waste.

The maize silage (MS) was obtained from a silo after approximately six months of ensiling. The samples were tested in order to study the efficiency of a local farm plant biogas.

All substrates were analyzed in order to determine the total and volatile solids (Standard Methods, 2005) and the chemical oxygen demand (Raposo et al., 2008). The results of the substrates characterization are presented in table 1.

2.2 Experimental set – up

The biomethanization tests were carried out in the home made equipment (Colussi et al., 2014) here used in a single-stage arrangement. The anaerobic reactors are glass bottles, with 5 L of volume each, placed in a controlled temperature environment (water bath) of 35 °C (± 0.1 °C) and mixed continuously with magnetic stirrers to suspend the sludge solids. Pressure transducers were connected to the bioreactors to outline the pressure changes during the test. The volumetric method (acidic water displacement) was used to measure the biogas produced, with a composition achieved by a gas analyzer. All the data were finally recorded by a PC.

As mentioned earlier, the results originated from trials carried out in different periods. The duration of each experimentation (with single substrate) ranged from one month to two months during which several feeds were done. Each new feed took place when no appreciable biogas production was observed. A summary of the experimental feeds is reported in table 2.

3. Results and discussion

31. Specific methane production

When organic material is degraded anaerobically, the end result is carbon in its most oxidized form (CO_2) and in its most reduced form (CH_4) (Angelidaki and Sanders, 2004). If the substrate composition is known, the theoretical methane yield potential can be obtained from the Buswell's equation (Buswell and Neave, 1930):

(1)

Then the theoretical specific methane yield, usually expressed as CH_4 volume per mass volatile solids added or COD added, might be calculated as:

(2)

(3)

where 22.4 (L) is the volume of 1 mole of gas at STP conditions and 32 ($g{\cdot}mol^{-1}$) is the molar mass of O_2.

Several factors usually lower the previous theoretical yield in actual anaerobic digesters (Angelidaki and Senders, 2004), among which the un-degradability of lignin in anaerobic conditions.

The theoretical methane yield of the tested substrates was calculated according to experimental COD and chemical composition (taken from literature). The chemical oxygen demand of each component was calculated based on the reaction of organic compound oxidation (Koch et al., 2010):

(4)

The anaerobic biodegradability of each substrate was calculated by dividing the theoretical methane yield in COD units by the stoichiometric production of 0.350 $LCH_4{\cdot}gCOD^{-1}$ at STP conditions.

The results of calculations are summarized in tables 3 and 4.

As it can be seen from table 4, the anaerobic biodegradability of substrates containing lignin is lower than 100%.

Theoretical methane yield was expressed both as COD units and VS units except for brewery yeast. For this substrate, the correlation between COD and VS was impossible to calculate, because the brewery yeast slurry is rich in alcohols (mainly ethanol) derived from fermentation, which are likely to volatilize during solids determination. For this kind of wastes, containing a significant proportion of highly volatile compounds, the organic content is represented more accurately by COD (Nieto et al., 2012).

The average methane yield coefficient Y_{CH4} was estimated plotting the final cumulative methane production versus the added load (for each substance), as proposed by Raposo et al. (2006): the slope of the line represents the requested Y_{CH4} (figure 1).

Methane yield of apple waste was 0.284 LCH_4 (STP)·$gCOD_{add}^{-1}$, *i.e.* 0.309 LCH_4 (STP)·gVS_{add}^{-1}, when expressed in VS units. This value is comparable with those found by Nieto et al. (2012). Brewery spent grains revealed an average methane yield of 0.284 $LCH_4 \cdot gCOD^{-1}$ (expressing the substrate as COD) or 0.429 $LCH_4 \cdot gVS^{-1}$ (expressing the substrate as VS), in agreement with data recounted by Lorenz et al. (2010). The average methane yield of brewery yeast was of 0.255 $LCH_4 \cdot gCOD^{-1}$, a value difficult to compare with literature because previous studies considered the biomethanization of BY mixed with wastewater (Neira and Jeison, 2010; Zupančič et al., 2012). Maize silage methane yield was 0.218 $LCH_4 \cdot gCOD^{-1}$ (in COD units) or 0.327 $LCH_4 \cdot gVS^{-1}$ (in VS units), value that was within the range of methane yields typically found in literature (Herrmann et al., 2011). Red *radicchio* gave a production of 0.313 $LCH_4 \cdot gCOD^{-1}$ or 0.403 $LCH_4 \cdot gVS^{-1}$.

The efficiency of digestion process was calculated comparing the actual specific productions with the theoretical ones. Efficiency values resulted in 90.4 % for apple waste, 93,4% for brewer's spent grains, 78.3 % for brewer's yeast, 83% for maize silage and 92.6 % for red radicchio.

3.2 Disintegration and hydrolysis phase

The anaerobic digestion of a complex organic substrate is a non-linear bioprocess assumed to pass several stages, starting from complex organic material to monomers to gaseous compounds (Biernacki et al., 2013).

The extracellular breakdown of complex organic substrates to soluble substrates is expressed as disintegration and hydrolysis phase ((Biernacki et al., 2013). Several Authors agree that this starting phase is the rate limiting step of the anaerobic degradation (Biernacki et al., 2013).

Results from BMP tests can be used to obtain information on the disintegration/hydrolysis rate (Angelidaki et al., 2009): in fact, when there is no accumulation of intermediary products, methane production can be represented by a first-order kinetic for the hydrolysis of particulate organic matter (Veeken and Hamelers, 1999).

The k_h first-order hydrolysis rate (for each substrate) was evaluated using non-linear least squares curve fitting on the net cumulative specific methane production (SMP):

(5)

where $SMP_{(t)}$ is the specific methane production ($LCH_4 \cdot gCOD^{-1}$) at time t at standard conditions (STP) and SMP_0 represents the theoretical specific methane yield above calculated. In literature the same first-order rate equation was introduced, estimating the SMP_0 value as the maximum methane yield of the substrate (Veeken and Hamelers, 1999; Galì et al., 2009).

Figure 2 shows the comparison between experimental and simulated cumulative methane.

Estimated values of disintegration/hydrolysis rate constant are reported in table 5. The k_h values, ranging from 0.180 d^{-1} for brewery spent grains to 0.877 d^{-1} for apple waste, resulted of the same order of magnitude of those reported in literature (Veeken and Hamelers, 1999; Vavilin et al. 2008).

4. Conclusions

The aim of this work was to increase the database concerning the biomethanization of agro-industrial wastes and energy crops with regard to the Italian agriculture. Due to the government subsidies, in the last years Italy has witnessed a proliferation of biogas energy plants, management of which is not trivial, involving several scientific and technological aspects. The studied substrates (coming from farms and food processing industries located in the North-East of Italy) were subjected to BMP tests in order to calculate the methane yield of each waste material and to estimate their first-order disintegration/hydrolysis rates. The obtained average methane yield ranged from 0.218 $LCH_4 \cdot gCOD^{-1}$ for maize silage to 0.313 $LCH_4 \cdot gCOD^{-1}$ for red *radicchio*, achieving more than the 80% of the theoretical production. The estimated k_h values ranged from 0.180 d^{-1} for brewery spent grains to 0.877 d^{-1} for apple waste.

References

Angelidaki, I, Alves, M, Bolzonella, D, Borzacconi, L, Campos L, Guwy, A, Kalyauzhnyi, S., Jenicek, P., van Lier, J.B., 2009. Defining the biomethane potential (BMP) of solid organic wastes and energy crops. Water Science and Technology, 59,927–34.

Angelidaki, I., Sanders, W., 2004. Assessment of the anaerobic biodegradability of macropollutants. Reviews in Environmental Science and Biotechnology 3 (2), 117–129.

APHA, AWWA, WPCF, 2005. Standard methods for the examination, of water and wastewater. 17th ed. Washington, DC.

Bettio, G., 2008. Utilizzo di batteri lattici per la produzione di composti bioattivi a partire da scarti vegetali. Degree Thesis. University of Padova. Available at: http://tesi.cab.unipd.it/24236/1/bettio_giacomo_tesi.pdf (last accessed 11.08.2014)

Biernacki P.,Steinigeweg S., Borchert A., Uhlenhut F., 2013. Application of Anaerobic Digestion Model No. 1 for describing anaerobic digestion of grass, maize, green weed silage, and industrial glycerine. Bioresource Technology, 127, 188-194.

Buswell, A.M. and S.L. Neave, 1930. Laboratory studies of sludge digestion. Department of Registration and Education.

Colussi I., Cortesi A., Gallo V., Rubesa Fernandez A. S., Vitanza R. 2014. Methane Production from Solid Potatoes by a Procedure Simulating a Bench-Scale Sequencing Batch Reactor Anaerobic Process. Chemical Biochemical Enginering Quarterly, 28 (1) 119–125.

EurObserv'ER 2013. The state of renewable energies in Europe. Edition 2013. 13th EurObserv'ER Report. Available at: http://www.energies-renouvelables.org/observ-er/stat_baro/barobilan/barobilan13-gb.pdf (last accessed 08.11.2014)

European Parliament, 2009. Directive 2009/28/EC of the European Parliament and of the Council of April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC.

Fabbri, C., Labartino, N., Manfredi, S., Piccinini, S., 2013. Biogas, il settore è strutturato e continua a crescere. L'informatore Agrario 11, 11-16.

Galí A., Benabdallah T., Astals S., Mata-Alvarez J., 2009. Modified version of ADM1 model for agro-waste application. Bioresource Technology, 100, 2783-2790.

Herrmann, C., Heiermann, M., Idler, C., 2011. Effects of ensiling, silage additives and storage period on methane formation of biogas crops. Bioresource Technology, 102 (8), 5153-5161.

Kanauchi O., Mitsuyama K., Araki Y., 2001. Development of a functional germinated barley foodstuff from brewer's spent grain for the treatment of ulcerative colitis. Journal of American Society of Brewing Chemists 59, 59-62.

Koch K., Lübken M., Gehring T., Wichern M., Horn H., 2010. Biogas from grass silage – Measurements and modeling with ADM1. Bioresource Technology, 101, 8158-8165.

Lorenz H., Fischer P., Schumacher B., Adler P., 2013. Current EU-27 technical potential of organic waste streams for biogas and energy production. Waste Management 33, 2434-2448.

Mussatto S.I., Dragone G., Roberto I.C., 2006. Brewers' spent grain: generation, characteristics and potential applications. Journal of Cereal Science 43, 1-14.

Neira K., Jeison D., 2010. Anaerobic co-digestion of surplus yeast and wastewater to increase energy recovery in breweries. Water Science and Technology 61 (5), 1129-1135

Nieto, P.P., Hidalgo,, D., Irusta, R., Kraut D., 2012. Biochemical methane potential (BMP) of agro-food wastes from the Cider Region (Spain). Water Science & Technology, 66 (9), 1842-1848.

Olsson, L., Fallde, M., Waste(d) potential: a socio-technical analysis of biogas production and use in Sweden, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.02.015.

Pacheco, M.T.B., Caballero-Córdoba, G.M., Sgarbieri, V.C., 1997. Composition and nutritive value of yeast biomass and yeast protein concentrates. Journal of nutritional science and vitaminology 43 (6), 601-612.

Raposo F., de la Rubia M.A., Borja R., Alaiz M., 2008. Assessment of a modified and optimised method for determining chemical oxygen demand of solid substrates and solutions with high suspended solid content. Talanta 76, 448–453

Thomas K.R., Rahman P.K.S.M., 2006. Brewery wastes. Strategies for sustainability. A review. Aspects of Applied Biology 80, 147-153.

van Foreest, F., 2012. Perspectives for biogas in Europe. Oxford Institute for Energy Studies. Available at: http://www.oxfordenergy.org/wpcms/wp-content/uploads/2012/12/NG-70.pdf (last accessed 08.11.2014).

Vavilin, V.A., Fernandez, B., Palatsi, J., Flotats, X., 2008. Hydrolysis kinetics in anaerobic degradation of particulate organic material: an overview. Waste management, 28 (6), 939-951.

Veeken, A., Hamelers, B., 1999. Effect of temperature on hydrolysis rates of selected biowaste components. Bioresource Technology, 69, (3), 249-254.

Zupančič G., Škrjanec I., Logar R.M., 2012. Anaerobic co-digestion of excess brewery yeast in a granular biomass reactor to enhance the production of biomethane. Bioresource Technology, 124, 328-337.

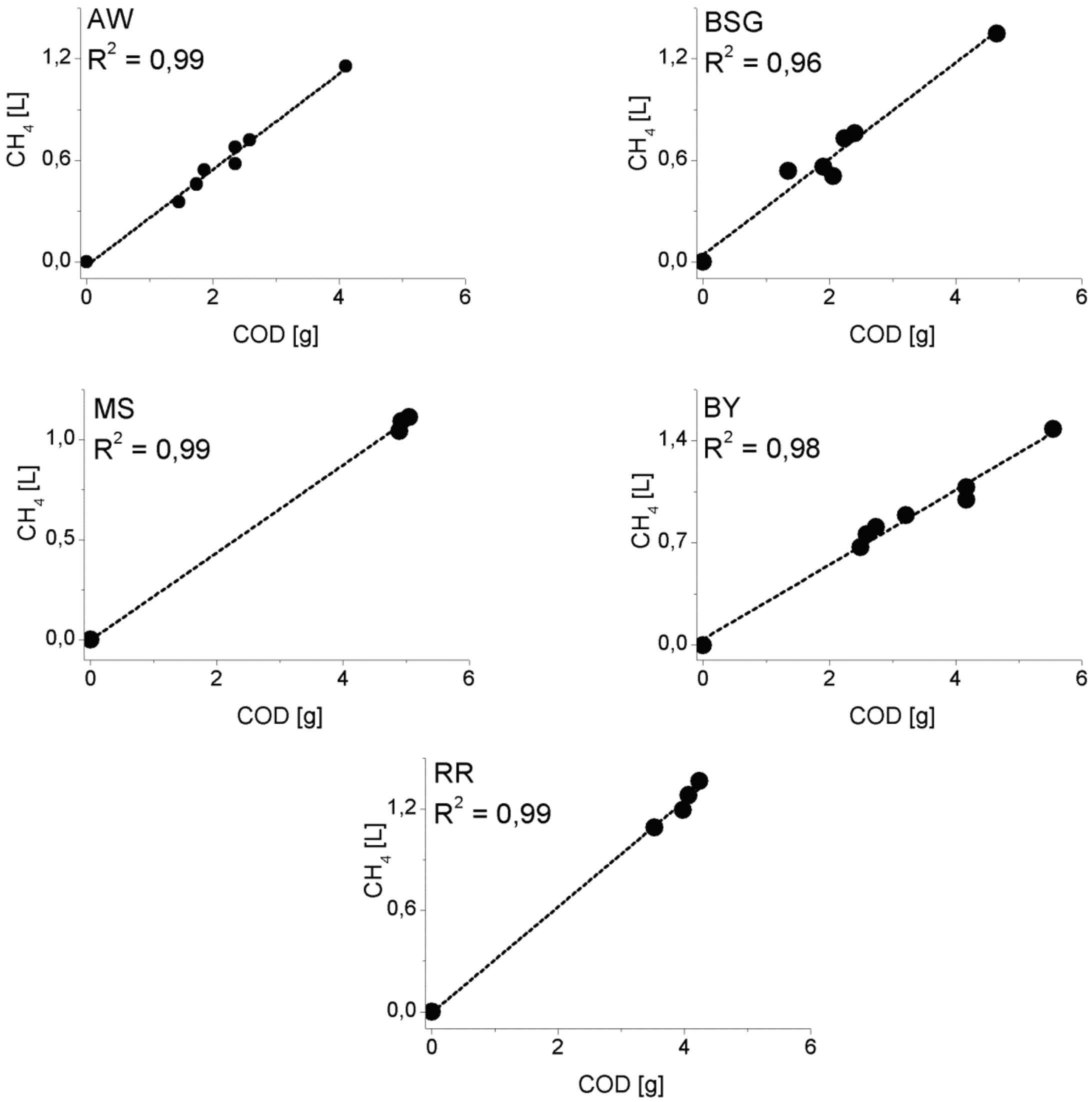


Figure 1

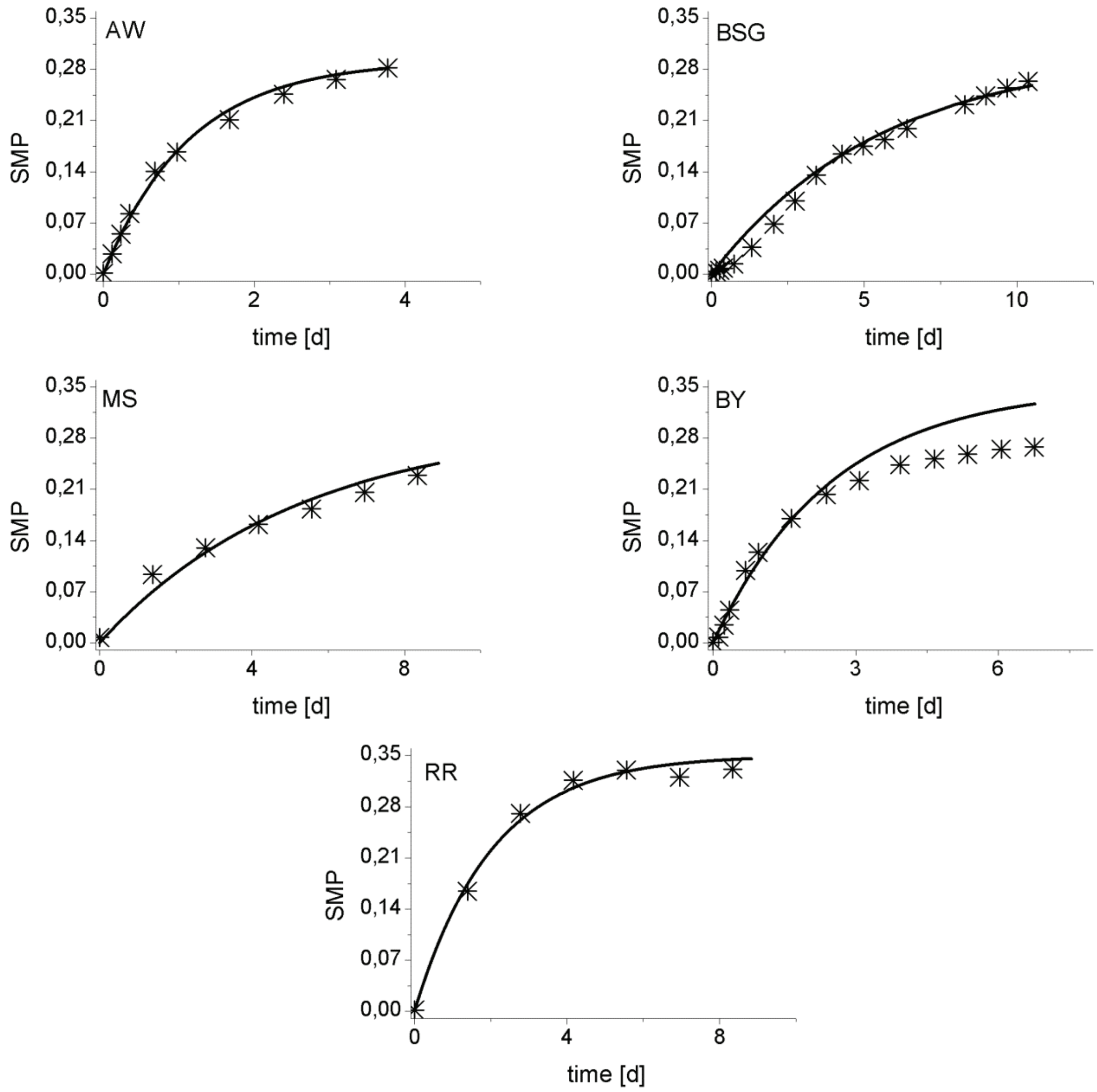


Figure 2

Figure captions:

Fig. 1. Average methane yield estimation

Fig. 2. SMP ($L\text{-}CH_4 \cdot gCOD^{-1}$) profiles (* experimental; - simulated)

Table 1

Substrates characterization

Substrate	Total Solids [mg TS· g^{-1}]	Volatile Solids [mg VS· g^{-1}]	Total COD [mg COD· g^{-1}]
Apple waste (AW)	147.1	135.2	174.0
Brewery spent grains (BSG)	187.0	180.5	276.2
Brewery yeast waste (BY)	158.9	147.8	341.5
Maize silage (MS)	333.0	325.0	493.0
Red chicory waste (RC)	53.0	47.0	65.0

Table 2

Trials summary

Substrat e	Trials duration [d]	N. of feed	S/I ratio [gCOD·$gCOD^{-1}$]
AW	60	7	0.03÷0.06
BSG	60	6	0.03÷0.08
BY	60	6	0.05÷0.08
MS	30	3	0.08
RR	30	4	0.02÷0.03

Table 3

Theoretical oxygen demand (Th OD) and methane yield of typical substrate components

Substrate Component	Composition	Th OD	CH_4 yield	
		[gO2·gVS^{-1}]	[STP LCH_4·$gCOD^{-1}$]	[STP LCH_4·gVS^{-1}]
Carbohydrat e	$(C_6H_{10}O_5)_n$	1.19	0.350	0.415
Lignin	$C_{10\cdot92}H_{14.24}O_{5.76}$	1.56	---	--
Protein	$C_5H_7O_2N$	1.42	0.350	0.496
Lipid	$C_{57}H_{104}O_6$	2.90	0.350	1.014

Table 4

Theoretical methane yield (Th CH_4 yield) of tested substrates

Parameter	Units	AW	BSG	BY	MS	RR
Carbohydrates	% dry wt	75.04 [(a)]	26.5 [(b)]	32.86 [(c)]	66.30 [(d)]	53.33 [(e)]
Lignin	% dry wt	13.16 [(a)]	22.7 [(b)]	0.00 [(c)]	11.60 [(d)]	0.00 [(e)]
Proteins	% dry wt	3.02 [(a)]	12.3 [(b)]	56.03 [(c)]	10.30 [(d)]	23.33 [(e)]
Lipids	% dry wt	3.31 [(a)]	25.0 [(b)]	3.44 [(c)]	5.10 [(d)]	1.67 [(e)]
Th. CH_4 yield	STP $LCH_4 \cdot gCOD^{-1}$	0.292	0.304	0.350	0.300	0.350
	STP $LCH_4 \cdot gVS^{-1}$	0.388	0.458	-	0.405	0.452
Anaerobic biodegradability	%	83.4	86.9	100.0	85.7	100.0

(a) Galì et al., 2009; (b) Kanauchi et al., 2001; (c) Pacheco et al., 1997; (d) Biernacki et al., 2013;

(e) Bettio, 2008

Table 5

Estimated disintegration/hydrolysis rate constants

	AW	BSG	BY	MS	RR
k_h [d^{-1}]	0.877	0.180	0.400	0.185	0.496

Seven years of Resource Efficient and Cleaner Production in Serbia: Lessons Learned and the Way Forward

Bojana Vukadinovic[a], Dr Branko Dunjic[a], Vojislavka Satric[a], Denise Reike[b] and Dr Rodrigo Lozano[b,c]
[a]University of Belgrade, Faculty of Technology and Metallurgy - Cleaner Production Centre of Serbia, Karnegijeva 4, 11000 Belgrade, Serbia
[b]Utrecht University, The Netherlands
[c] Organisational Sustainability Ltd., United Kingdom

Abstract

Cleaner Production (CP) is a preventive environmental strategy that can be applied to processes, products and services to reduce risks to humans and the environment and improve the efficiency of resource use. Numerous national, regional and international CP initiatives have since then been initiated, including the UNIDO-UNEP establishment of the National Cleaner Production Programmes (NCPPs). This paper outlines the role of the Serbian National Cleaner Production Centre (NCPCS) in the identification and implementation of efficient and cleaner production (RECP) opportunities and business cases. RECP is an extension Cleaner Production (CP), and aims at continuous application of integrated preventive environmental strategies. The NCPCS was established in 2007. One of its main objectives is to foster the implementation of RECP through workshops, and training of national experts and company employees. A key result from the NCPCS's activities is the potential saving of up to 257 MEUR for the Electrical Power Company of Serbia by developing more than 140 RECP options between 2010 and 2012 (number is an estimate based on evaluation of 50% of the options). The paper discusses the advantages of the NCPC being based at a university, such as increased credibility and client contacts. The paper provides an outlook on planned developments and NCPCs chances to become a self-sufficient entity in the near future.

1. Introduction: From Cleaner Production to Resource Efficient and Cleaner Production

Cleaner Production (CP) is a preventive environmental strategy that can be applied to processes, products and services to prevent the generation of waste and emissions, and thereby reduce risks to humans and the environment and improve the efficiency of resource use ('eco-efficiency') (DeSimone and Popoff, 2000; Robèrt et al., 2002; UNEP, 2000, 2001). The definition of CP was developed by UNEP in Paris, in 1989. The concept was first promoted at the First International Advisory Seminar on Preventive Environmental Management Strategies organized by UNEP, in 1990. Numerous national, regional and international CP initiatives have since then been initiated (Fresner and Yacooub, 2006; Mattsson et al., 2010; Van Berkel, 2007), including the UNIDO-UNEP establishment of the National Cleaner Production Programmes (NCPPs). The definition of CP has been expanded over time and a sustainable development orientation has been added (Glavic and Lukman, 2007). When compared against the analysis criteria it is possible to observe that CP focuses on processes and services, i.e. operations and production within the system. Although, meanwhile the concept has a clear sustainability orientation, CP focuses mainly on the environmental dimension, with typical positive improvements for the economic dimension (e.g. reducing costs or increasing productivity). Lozano (2012) highlighted that CP should not only be about changes in raw materials, processes, and products, but also about changing organizational systems, corporate culture and attitudes, applying know-how, and overcoming non-technical barriers, i.e. organizational changes (see Baumgartner and Zielowski, 2007; DeSimone and Popoff, 2000),

The United Nations Industrial Development Organization (UNIDO) and United Nations Environment Programme (UNEP) have been actively supporting the transition towards sustainable industrial systems by establishing National Cleaner Production Centres (UNIDO&UNEP, 2010). It should be noted that these are hosted either by national industry associations, technical research institutes or universities (UNIDO&UNEP, 2010). Since 1994, UNIDO and UNEP have extended the scope of their joint Programme to Resource Efficient and Cleaner Production (RECP) to associate CP more profoundly with today's and tomorrow's most pressing environmental and resource use challenges, at the local, national and global scales. The concept of Resource Efficient and Cleaner Production (RECP) is based on CP's principles of applying preventive environmental strategies, but it extends its scope and reach. Within the context of the Joint Programme on RECP, UNIDO and UNEP have defined RECP as follows:

"Resource efficient and cleaner production is the continuous application of an integrated preventive environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment. It specifically works to advance the three dimensions of sustainable development in an integrated manner, by catalyzing:

- ✓ Production Efficiency through optimization of the productive use of natural resources (materials, energy and water) by enterprises and other organizations;
- ✓ Environmental Management through minimization of the impact on the environment and nature, by preventing the generation of waste and emissions and improving the use of chemicals in enterprises and other organizations; and
- ✓ Human Development through minimization of risks to people and communities from enterprises and other organizations and supporting their own development."

RECP focuses on the enterprise level with the aim to reduce the intensity of natural resource use and waste and emission generation per unit of industrial output. In addition, applying RECP can result in reduction of environmental impacts, savings on materials, chemicals, and other costs savings, e.g. on energy costs. RECP also offers the potential to increase productivity and product quality (UNIDO&UNEP, 2010).

This paper describes the role of the National Cleaner Production Centre (NCPC) of Serbia in the identification and implementation of RECP opportunities and business cases.

2. The National Cleaner Production Centre of Serbia

In Serbia, the implementation of CP and RECP initiatives can be traced back to policy measures, such as the Strategy of Introducing Cleaner Production to Serbia (RS, 2008a) which aims to promote cleaner methods of production and the creation of institutional conditions for their implementation and use. Other important policies in this context include the National Programme for Environment Protection (RS, 2010), and the National Sustainable Development Strategy (RS, 2008b). In particular, the National Sustainable Development Strategy is based on three pillars: caring for the environment, an economy based on knowledge, and social inclusion. It also calls for an increase in the level of environmental expenditure to 1.5 % of GDP, in 2014, and 2.5 %, in 2017. The difference between this and the current 0.3 % of GDP shows a considerable state investment in environmental protection and sustainable development.

In 2007, the NCPC of Serbia, hereon NCPCS, was established through the UNIDO Cleaner Production Programme which has promoted and funded establishment of NCPCs across the globe since 1994.

The main source of finance for the NCPCS is funding from the UNIDO. In 2014, approximately 15% of the income came from direct services to the industry. The NCPCS also has institutional support from relevant Ministries.

The NCPCS is a small organization. The Centre has four full time employees –director, head of CP unit (project manager), ChL coordinator and CP associate (project assistant). The Centre has a strong network of 70 consultants, trained in RECP services and experts in different topics. Pool of 10 consultants work closely with the Centre and they are contracted on a project base.

The NCPCS is hosted at the Faculty of Technology and Metallurgy, at the University of Belgrade. This provides the NCPCS an office and some administrative support. The choice of the University of Belgrade as host institution brought a number of mutual benefits. The interest on side of the Faculty of Technology and Metallurgy to incorporate NCPC into its organizational structure was motivated by a hope for:

- ✓ Better contacts to the industry;
- ✓ Employees of the Faculty receiving extra income from performing RECP consultancy and education;
- ✓ Direct income - as the NCPC would pay a certain amount as overheads; and

- ✓ Being included in projects without participation of the NCPC (the Faculty lacked required references/competences to attract outsiders for collaboration).

The NCPCS has an Advisory Board that oversees the efforts of the Centre's core team. The board is composed of representatives of the main stakeholders from government, academia, industry and consulting companies. During the first years, the Advisory Board was essential for attracting clients and contracts that would increase national ownership of the NCPCS. During the last 3 years, the role of the Board diminished, as the NCPCS has become an integral part of its host institution.

The NCPC has profited from a stable environment that was a consequence of being a part of the Faculty of Technology and Metallurgy, thus having secured basic financing and client recognition. Another advantage is that companies perceive the NCPCS to be objective and impartial, as a consequence of it being located at the state-run University. It would be interesting to research whether the choice of location has an influence in the time required to become self-sufficient. However, is beyond the scope of this paper to draw comparisons to other host institutions.

The NCPC won also an open bidding procedure regarding 6 RECP projects in the region, including Croatia, Bosnia & Herzegovina, Kazakhstan and Ukraine in the period between 2010 and 2014. The Centre was also nominated by the Ministry of Agriculture and Environmental Protection to be the National Execution Agency for the GEF-funded project "Environmentally sound management and final disposal of PCB's" in January 2014.

The NCPCS is slowly becoming an important partner for other organizations, such as the International Finance Corporation (IFC) and the United States Agency for International Development (USAID), which have requested the NCPC to implement several projects. This will enable NCPCS to have stable cash flow.

3. Results from the NCPCS' activities

In general, the NCPCS' activities comprise: 1) training of national experts and company employees; 2) Chemical Leasing; 3) the RECP network; 4) and the provision of technical assistance and assessment of operations.

3.1 Training of National Experts and Company Employees

A total of 30 training workshops on UNIDO's CP toolkit for national experts and 20 workshops for companies were organized. In this period, 70 RECP national experts were trained. The training of RECP experts included 3 theoretical workshops based on the CP toolkit, a written examination, RECP assessment in the company (practical training component) and submission of the full CP assessment report carried out in a Serbian company. Around 200 employees from 69 companies attended the workshops and 400 people were members of the CP teams inside the companies and trained.

The workshops on specific topics for national experts and companies' employees, were organized and provided by the NCPC employees and experts from different institutions (university, ministries and consulting companies). Some of the covered topics include:

- ✓ Introduction to Cleaner production – CP basic, CP method, CP strategies
- ✓ Team, Environmental Policy and Motivation;
- ✓ Material and energy flow analysis;
- ✓ Environmental law in Serbia;
- ✓ Waste Management;
- ✓ Creativity and Innovation, CP option finding;
- ✓ Green procurement and hazardous materials;
- ✓ Indicators and environmental controlling; and
- ✓ CP Audit – how to perform and organize company visit.

3.2 Chemical Leasing

Since 2008, the NCPCS has actively promoted the application of Chemical Leasing (ChL) business models to the national industry.

'Product services' is a term used to describe a shift of business focusing from selling/using physical products, to selling/using a combination of products and services, which jointly fulfil specific customer needs. There is a great variety of business models for product services. In some cases suppliers offer services additional to their products. In other cases suppliers hold the ownership of their products and sell out the use to customers. The assumption is, that with product services, the profits of both the supplier and customer are coupled primarily to the quantity and quality of services delivered, and not to the volume of chemicals (EC, 2006)

ChL is a preventive and service-oriented business model that shifts away from high sales volumes of chemicals towards an integrated approach and extended producer responsibility throughout the entire life-cycle of a chemical. Unlike traditional business models, ChL is based on value-oriented pricing (for the function of the chemical) rather than on volume-based pricing (for the amount of the chemical). By de-coupling the payment from the consumption of chemicals, ChL encourages better chemicals management resulting in clear environmental advantages, as well as in economic benefits for both the suppliers and users of chemicals (Lozano et al., 2013).

Traditional mind-set of conventional business models and lack of awareness and understanding of new business models are barriers in the model implementation. NCPC Serbia organized several national workshops with more than 400 participants from government, industry and academia. In addition, 24 national chemical leasing experts were trained.

Up-to-date, the Centre has been working with a number of national companies on the introduction of ChL and facilitated the start-up and implementation of six major ChL contracts, several projects are in pipe. Model has been implemented in food and beverage, metalworking industry and in agriculture. Within its ChL work, the Centre provides technical assistance in process optimization, advises on legal matters and match making of companies. Supplier that could implement the model has to have expert knowledge on product, processes, equipment, as well as capacities to provide certain level of services around its products.

Experience has shown that Chemical Leasing business model is easier accepted by the bigger companies (with more than 250 employees) compared to small and medium-sized enterprises. These enterprises usually take into account the whole life cycle costs and are not focused only on the purchase costs. On the other hand suppliers are not interested to implement the model if they don't have a level of sales, which ensures profitability. Long-term relationship with the supplier could be considered as a risk by the user, as changing of supplier could be more difficult. However, several cases have shown that it is not a threat if supplier is fair and quality of product and service are at high level.

Model implementation is oriented to optimization of chemical(s) use, but also other improvements are achieved, like resource efficiency (savings of other resources like water, chemicals that are not a focus of a project, energy), occupational health and safety, productivity and very often better quality. In spite of all these benefits and successful case study the model is not widely established.

Serbian NCPC obtained the Gold Awards for its excellent work in consultancy and promoting ChL. Companies Knjaz Miloš, Ecolab, Henkel and Bambi received the Gold Awards for their outstanding model implementation.

3.3 The RECP network

The NCPCS is a founding member of RECPNet, the global network for promoting the adaptation and adoption of RECP in developing and transition economies (Recpnet, 2013). As patron agencies, UNIDO and UNEP, provide support for RECPnet through their joint RECP Programme. RECPnet seeks to enable and contribute to the effective and efficient development, application, adaptation and replication of RECP concepts, methods, policies, practices and technologies in developing and transition countries. Another main aim is facilitation of effective North-South and South-South collaboration and the transfer of RECP-relevant knowledge, experiences and technologies (UNIDO&UNEP, 2010). RECPnet has been formalized by a Charter and has become operational, and in November 2010, 41 founding members officially launched the network. Since its initiation, an elected Executive Committee has guided the further development of RECPnet.

NCPCS is active member of RECPnet and it has coordinating role for the region of South-East Europe. Also, it manages Knowledge Management System, developed by patron agencies.

3.4 Technical Assistance and Assessments of Operations

The NCPCS has carried out RECP Assessments in 69 organizations engaging almost 30,000 employees. The assessment consist of:

- ✓ Collection of data about raw material, water and energy consumption
- ✓ Consolidation of data
- ✓ Company visits
- ✓ Performing measurements on-site
- ✓ Data consolidation and analysis
- ✓ Elaboration of RECP options

- ✓ Evaluation of RECP options
- ✓ Presentation of list of options to company management

As it can be seen in Table 1, some of the client organizations have been public and private parties, and the covered sectors range from metal working, food and beverage, chemical industry, and power generation. Almost one third of all assessments were in food processing companies and intensive rearing sector (pig and cow farms). Next to processors, different manufacturing industries make use of the NCPC services, with chemical companies clearly leading in the number of assessments commissioned. Two municipalities have made extensive use of NCPC assessments with in total 18 assessments, and the publicly held Electrical Power Company (10).

Table 1: Parties and Sectors addressed by NCPC and number of assessments conducted (except for the municipalities and EPS, this equals the numbers of organizations worked with .

Parties and Sectors	**Number of Assessments**
Food processing companies, including beverages and tobacco	19
Pulp and paper industry	3
Manufacture of coke and refined petroleum products	2
Manufacture of chemicals and chemical products	7
Manufacture of rubber , plastic products and of other non-metallic mineral products	4
Manufacture of machines and equipment	1
Manufacture of electrical and optical equipment	1
Metal – processing companies	4
Manufacture of transport equipment	1
Municipality of Čačak, district heating, waste collection and management , different industry	7
Municipality of Pancevo: water supply, district heating, waste collection and management and sport facilities maintenance	11
Electrical Power Company of Serbia (EPS)	10

The economic savings and the environmental benefits calculated results in the following estimates (in averages):

- Savings per company: 100,000 EUR/year;
- Decrease of water consumption: 50,000 m3/year;
- Decrease in electrical power consumption: 500 MWh/year;
- Decrease in CO_2 emission: 500 t/year.

During 2010-2012, a major project focused on the “Implementation of RECP in the Integrated Pollution Prevention and Control (IPPC) facilities of the Electric Power Company of Serbia”. The NCPCS took a structured approach in order to derive a list of feasible options for RECP implementation at EPS. Six workshops were conducted with eleven lecturers from the NCPCS, the Faculty of Technology and Metallurgy, and the Mechanical and Civil Engineering (University of Belgrade). The Ministry of Mining, and Environment and Spatial Planning was also involved. In addition, 49 company visits (55 on-site days) were carried out by both, national and international experts, including on- and off-site consulting and execution of a number of measurements such as thermovision, water and steam flow and noise analyses. As a result of these processes, in total, 147 RECP options were identified for EPS, and preliminary results (50 % of options evaluated) show that with investment of € 257,000,000 the following consumption reductions could be attained:

- ✓ Lignite: 860,000 t/year;
- ✓ Water for 1,400,000 m^3/year;
- ✓ Electricity for 46 GWh/year;
- ✓ CO2 emission for 1,465 t/year; and
- ✓ Ash (waste) for 2,000,000 t/year.

In line with the assessment outcomes, an action plan was developed for each power plant. Action plans compose of RECP options, from good housekeeping and organisational measures to complex projects such as reconstruction of the turbine.

Good housekeeping options, such as insulation repair, repairing leaks in boilers, optimization of existing and installation of new soot blowers, reduction of the voltage from 6.3 kV to 6.25 kV, are options for which the investment payback period is less than one year. For instance in one of the power plants, by the installment of the scales for measuring the mass of the delivered coal and the amount of the coal being transported to the boilers, it would be possible to save 330,000 EUR if the amounts of the consumed coal are reduced by only 1 %.
The introduction of technical modifications in different segments of the production would also bring significant improvements. Installing a gas analyser on boilers, and their introduction into the managing system, would achieve optimization of the combustion process. Utilization of the heat waste water generated during boiler desalting and the reuse of this water for the production of demineralized water is a good example of the cleaner production concept.
Options which are required to implement in order to satisfy the legislation related to the emission limit values of SOx, NOx, particles in the air or water pollution are specifically singled out. Such options do not bring direct financial benefits, but from the environmental point of view they are very significant and therefore covered separately. During the Project some common problems were analyzed, the biggest being about large quantities of ash produced during coal combustion, the largest part of which is disposed in landfills. The ash disposal problem could be solved by switching to the thickened ash transport, but in order to address the issue properly, it is necessary to create a legal framework for further use of ash in the construction industry (Kurama and Kaya, 2008; Mulder, 1996). The ash sale would reduce the amount of ash disposed of in landfills by approximately 1 Mt/a, while savings only due to reduction in taxes would amount to 1.88 MEUR/a.

The plans indicate that RECP options will be implemented by 2015. A simple payback method calculation showed that return-of-investment can be expected in slightly over 4 years. By now, the companies have implemented 40% of proposed measures.

4. Conclusions

The establishment and running of the NCPCS is an important, if not essential, part in the implementation of the RECP concept for Serbian industries. It is the only organization that actively promotes RECP and helps companies to implement the concept in Serbia. Although UNIDO provides most of the funding for NCPCS, in some cases the NCPCS has been able to charge for some of its services. However, similarly as with other NCPCs, the revenue generated by selling services directly to industrial clients is still small, but increasingly important.

The commercial approach taken by the NCPCS is essential for financial stability/self-sufficiency of the Centre. Cash flow has been, at times, the determining factor in deciding project priorities. For instance, policy advice and awareness-raising-activities have mostly been neglected, especially over the past few years. These two potential sources of income will have to be further explored in order to increase chances that the NCPCS becomes a self-sufficient entity.

The activities undertaken by the NCPCS show the potential to implement RECP in Serbia, and potentially in the Balkans. This can help companies and other organizations lower their environmental impacts and increase their resource efficiency, whilst at the same time obtaining economic benefits by lowering costs.

References

Baumgartner, R., Zielowski, C., 2007. Analyzing zero emission strategies regarding impact on organizational culture and contribution to sustainable development. J. Clean. Prod. 15 (13-14), 1321-1327

Glavic, P., Lukman, R., 2007. Review of sustainability terms and their definitions. J. Clean. Prod. 15, 1875-1885.

[EC] European Commission, Institute for Prospective Technological Studies, 2006. Chemical Product Services in the European Union

Fresner, J., Yacooub, A., 2006. Half is Enough, ISBN 3-9501636-2-X, Graz.

Kurama, H., Kaya, M., 2008. Usage of coal combustion bottom ash in concrete mixture. Construction and Building Materials 22, 1922 – 1928.

Mattsson, L.T., Read, A.D., Phillips P.S., 2010. A critical review of the largest Resource Efficiency Club Programme in England (2005–2008): Key issues for designing and delivering cost effective policy instruments in the light of Defra's Delivery Landscape Review. Resources, Conservation and Recycling 55 (1), 1 – 10.

Mulder, E., 1996. A mixture of fly ashes as road base construction material. Waste Management 16, 15 – 20.

Lozano, R., Carpenter, A., Satric, V., 2013. Fostering green chemistry through a collaborative business model: A Chemical Leasing case study from Serbia. Resources, Conservation and Recycling 78, 136 – 144.

Lozano, R., 2012. Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives. J. Clean. Prod. 25, 14-26.

Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M., 2002. Strategic sustainable development — selection, design and synergies of applied tools. J. Clean. Prod. 10, 197-214.

Recpnet (2013). RECPnet: A Global Network. Retrieved September 8th, 2014 from http://recpnet.org/page/recpnet-a-global-network

[RS] Government of the Republic of Serbia, 2010. National Programme for Environment Protection. Retrieved September 9, 2014 from http://www.gs.gov.rs/english/strategije-vs.html (in Serbian)
[RS] Government of the Republic of Serbia, 2008. National Sustainable Development Strategy. Retrieved September 9, 2014 from http://www.gs.gov.rs/english/strategije-vs.html (in Serbian)
[RS] Government of the Republic of Serbia, 2008. Strategy of Introducing Cleaner Production to Serbia. Retrieved September 9, 2014 from http://www.gs.gov.rs/english/strategije-vs.html (in Serbian)
UNIDO&UNEP (2010). Taking Stock and Moving Forward. The UNIDO–UNEP National Cleaner Production Centres. Retrieved September 8th, 2014 from http://www.unido.org/fileadmin/user_media/Services/Environmental_Management/Contacts/Contacts/Taking%20stock%20and%20moving%20forward-November2010.pdf
UNIDO CP Toolkit. Retrieved September 8th, 2014 from http://www.unido.org/en/resources/publications/energy-and-environment/industrial-energy-efficiency/cp-toolkit-english.html

Cement Industry Greenhouse Gas Emissions – Management Options and Abatement Cost

Author: Raili Kajaste [a *], Markku Hurme [a]

[a] Department of Biotechnology and Chemical Technology, Aalto University, PO Box 16100, FI-00076 AALTO, Finland

[*] Corresponding author. E-mail address: raili.kajaste@aalto.fi

Abstract

Growing anthropogenic greenhouse gas emissions and increasing global demand for cement are general drivers for managing greenhouse gas emissions (GHG) in the cement industry. CO_2 dominates cement sector GHG emissions. Several regional datasets were formed and the contributors to the overall CO_2 emissions in the cement industry – clinker baseline, positive impact of clinker substitutes, fossil fuel emissions and electricity emissions – were further used in estimating total emissions for incomplete datasets using a least square fit from a matrix. Key contributors to the overall CO_2 balance are clinker substitutes, technology, geographic location, and primary source of energy. Uncertainties in assessing GHG emissions of the cement production raw material supply chain need further analysis. Regional variation of process and thermal energy use related CO_2 emissions is more significant than that of electricity emissions. Different options were analyzed by applying a climate impact management matrix on a cradle-to-gate basis. A comparative analysis of different options to improve the CO_2 balance of cement industries revealed that the highest near term potential to avoid emissions is by replacing clinker with mineral components (MIC). Increasing MIC use to the level of Brazil would save 312 Mt CO_2 annually with the 2013 level of global cement production. Similarly, a 2.7% reduction in the thermal energy use of the cement industry would save 28 Mt CO_2 annually, and a 10% decrease of emissions from electricity use would save 26 Mt CO_2. The best future options are MgO and geopolymer cements and different carbon capture technologies. In addition, the abatement cost of different investment projects were estimated using a uniform capital recovery factor. The cost of mitigation varied depending on the geographical location and on the initial level of CO_2 emissions.

Keywords: cement, climate impact, abatement cost, CO_2 emission management

1 Introduction

Growing anthropogenic greenhouse gas emissions and increasing global demand for cement are general drivers that motivate finding solutions for managing greenhouse gas emissions (GHG) in the cement industry and comparing the abatement cost of different technological or technical solutions. Globally, only few economic sectors – gas supply and distribution; refined petroleum; electricity and heat production and distribution; transport; cement; fertilizers; mining; metals, chemicals; pulp and paper; and fishing – contribute most to human activity induced GHG emissions. The OECD Environmental Outlook to 2050 estimates that the level of global anthropogenic GHG emissions would reach 80 gigatons of CO_2 equivalent (CO_2eq) in 2050 compared to the 30.6 gigatons in 2010 (OECD, 2012), when the cement sector was responsible for 2823 million metric tons (Mt) of CO_2 emissions. This corresponded to almost 9% of global CO_2 emissions from burning of fossil fuels that year. In total, cement production accounts for roughly 5-8% of global CO_2 emissions, and at the same time the sector is considered to have the largest energy saving potential (28–33%) (IEA, 2007). The United Nations Intergovernmental Panel for Climate Change (IPCC) and the International Energy Agency (IEA) estimate that the annual mitigation potential of GHG emissions in the cement industry will vary between 480 and 1700 million metric tons in 2030 (IPCC, 2007, IEA, 2006).

Global reporting on cement industries is, however, not complete: available statistics on cement industry production volumes and GHG emissions do not fully cover global emissions and vary in different sources of information. The large amount of CO_2 emissions, considerable use of energy, and depleting resources has pushed the cement industry to implement commitments like the Cement Sustainability Initiative (CSI, 2011, WBCSD, 2012). A roadmap for reducing the climate impact of cement industries gives the general framework (IEA, 2009) that is supported by other organizations (Gupta, 2011). Global cement production grew over 73% between 2005 and 2013 from 2310 Mt to 4000 Mt (Cembureau, 2014), marking the importance of reducing CO_2 emissions of cement production.

Research on the management of cement industry GHG emissions and, in particular, those of CO_2 has received considerable interest worldwide. The cement production process, energy use and related CO_2 emissions are well described (Usón et al., 2013, Benhelal et al., 2012, Mikulcic et al., 2012, Madlool et al., 2011). Traditional pathways to decrease cement production emissions are improved energy efficiency through improved technology, better process integration, and fuel switching together with the use of clinker substitutes like waste fly ash and slags from power production and minerals processing (McLellan et al., 2012, Worrell et al., 2008). Hasanbeigi et al. (2012) reviewed eighteen emerging technologies and their benefits for the cement industry. One of the conclusions was that information is still scarce and scattered regarding energy-efficiency and low-carbon technologies. Also most of the technologies have an energy penalty associated with their operation.

Cement is one of the key components in concrete. Several studies concentrate on the possibility to replace cement in concrete or mortar with recycled materials like glass, recycled tyre rubber or other aggregates (Castro and Brito, 2013, Ingrao et al., 2014, Medina et al., 2013, Mutuk and Mesci, 2014). Research on alternative binders to Portland cement that reduce the CO_2 emission is progressing (Ponikiewski and Gołaszewski, 2014, McLellan et al., 2011, Juenger et al., 2011) and e.g. the use of alkali-activated (AA) binder instead of ground granulated blast-furnace slag (GGBS) cement in concrete or in ordinary Portland cement (OPC)-based concrete reduces the CO_2 emission of concrete between 55 and 75% (Yang et al., 2013). GGBS can also be used as a soil stabilizer instead of cement in non-fired clay mixes (Kinuthia and Oti, 2012). Composite masonry bricks without Portland cement have been successfully tested (Turgut, 2012), and the latest news report on compostable bricks grown on agricultural waste frames with the help of fungi for short life time constructions (NS, 2014). Carbon capture technologies are also one of the future options to reduce the CO_2 emission of cement production since the implementation of CCS leads to life cycle GHG emission reductions of 39–78% for cement production (Volkart et al., 2013, Hasanbeigi et al., 2012). Simulation models for oxy-combustion, calcium looping and amine scrubbing reduced the flue gas CO_2 content by 63-85% but increased the specific energy consumption (Vatopoulos and Tzimas, 2012).

The promising different options to reduce the GHG of cement production and partially incomplete and scattered data motivated us to study how the overall management of GHG emissions in the cement production chain is related to clinker substitutes, technology in use, primary source of energy, electricity emissions and geographic location. In addition, we compare the found abatement costs of reducing the GHG of cement production by using a uniform capital recovery factor with a ten-year payback time. Our focus in this paper is on managing GHG emissions in cement production chains. Other environmental burdens like particulate matter formation, terrestrial acidification and freshwater eutrophication are excluded. Methods are described in section 2, and section 3 presents the results of our study. The conclusions are highlighted in section 4.

2 Methods

The cement production data from 2005-2011 was compiled, the system boundary for a single plant GHG management was described and available data on cement production GHG emissions was grouped for geographic regions, and GHG emissions in the cement industry were analyzed and recalculated in uniform unit (kgCO_2/t cement) for formation of datasets. The contributors to the overall CO_2 emissions in the cement industry in the datasets – clinker baseline, reducing the impact of clinker substitutes, fossil fuel emissions and electricity emissions – were further used in estimating accuracy of incomplete datasets using a least square fit matrix. The datasets and results of previous research on managing energy and GHG emissions were used for a comparative analysis of different options to improve the GHG balance of cement industries based on found contributors. In addition, the abatement cost of emission reductions were calculated using a uniform capital recovery factor (CRF).

2.1 Matrix for contributors

The sum of CO_2 emission (E_{Total}) is:

$$E_{Total} = E_{Clinker\ Baseline} - E_{ClinkerSubstitute} + E_{Fossil\ Fuel} + E_{Electricity} + E_{Transport} \quad (1),$$

and can be written as

$$E_{Total} = w1E_{Clinker\ baseline} – w2E_{ClinkerSubstitute} + w3E_{Fossil\ Fuel} + w4E_{Electricity} + w5E_{Transport} \quad (2),$$

where contributors to total emission are expressed as weighted (wi) components.
Contributors to total emission can be fitted from available data. There should be much more components than fitted values (wi) in order to gain reliable estimates. For the linear group contribution, a simple least squares fit can be extended in a straightforward manner to weight various components in the datasets. Formation of datasets was done for the equation:

$$E_{Total} = E_{ClinkerBaseline} – E_{Clinker\ substitutes} + E_{FossilFuel} + E_{Electricity} \quad (1a),$$

because information with enough geographical split was not found for transport emissions ($E_{Transport}$) in Eq.1.

2.2 Uniform capital recovery factor for calculation of the GHG abatement cost

Statistical data on investment costs in different regions were collected for the GHG abatement/ mitigation cost calculations in the cement industry. For a single abatement cost calculation we used a Capital Recovery Factor,

$$CRF = i(1+i)^n/(1+i)^n - 1 \quad (3),$$

where i is discount rate and n is the number of annuities received. The annual abatement cost for one ton of GHG reduction (CO_2eq) was calculated with two discount rates (5% and 10%) and a 10-year payback period.

3 Results

The object was to study how the overall management of GHG emissions in the cement production chain is related to (1) clinker substitutes, (2) primary source of energy, (3) electricity emissions, (4) technology in use and (5) geographic location. The developed datasets give the impact of the four first components for geographic regions. The impact of technology in use is directly linked to the amount of CO_2 emissions from thermal energy used in kilns. Various sustainability initiatives and recent research have already managed to reduce the CO_2 emissions of the cement industry. The specific emission level has dropped by 14.8% from the average 1000 kg CO_2/t clinker in 2006 to 852 kg CO_2/t clinker in 2011 (Hasanbeigi et al., 2012, GNR, 2011). The electric energy consumption has not dropped in similar tact; the global weighted average was 111 kWh/t cement in 2006 and 107 kWh/t cement in 2011 corresponding to a 3.6% reduction in 6 years (IEA, 2009, GNR, 2011). Despite improvements, the continuously increasing production volumes of cement mean that the magnitude of the problem is not diminishing. There is a clear geographical variation in the CO_2 emissions of the cement production that is also reflected in the comparative analysis of different options to improve the GHG balance of cement industries.

3.1 Regional distribution of cement production

The cement production is dominated by China, India and other Asian countries which in 2013 produced almost 74% of the world cement (Cembureau, 2014). The regional split of the production is shown in Fig.1 and Fig. 2.

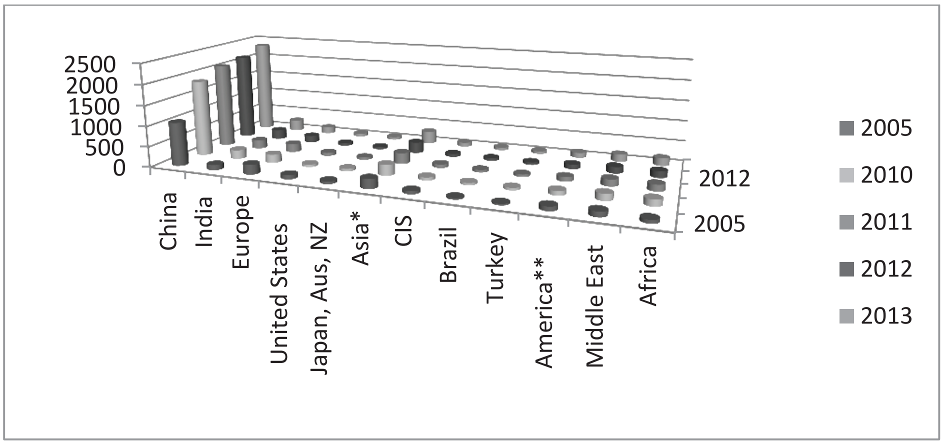


Fig. 1 World cement production volumes by region 2005-2013 in million metric tons. Notes: * excl. China, India, CIS and Japan, ** excl. Brazil and United States. Sources: GNR, 2011, Cembureau, 2014, Ke et al., 2013.

3.2 System boundary for single plant GHG management

Cement sector GHG emissions are dominated by CO_2 with 98.5% (Ingrao et al., 2014) and usually cradle-to-gate life cycle assessment (LCA) studies include only CO_2 with few exceptions (Li et al., 2014). Most of the statistics cover only process emissions and related energy emissions excluding emissions from electricity use from the assessment. Usually LCA studies of cement production report life cycle inventories (LCI) on a plant or regional scale (Li et al., 2014, Moya et al., 2011) and evaluate possibilities to reduce the environmental impact either by alternative technologies (Chen et al., 2010, Huntzinger and Eatmon, 2009) or by upgrading an existing plant (Valderrama et al., 2012). The key functional unit (FU) used is either kg or m^3 of produced clinker, cement or concrete in cases were the target is to reduce the amount of cement in concrete. The climate impact of raw material mining and quarrying including transport is generally considered to contribute about 5 percent of the overall CO_2 emissions and, therefore, has often been left out from emission evaluations. A 50% increase in transport distance has a relative impact of 3-10% on the emission for OPC concrete (McLellan et al., 2011). This means that uncertainties in assessing GHG emissions of the cement raw material supply chain remain to be clarified.

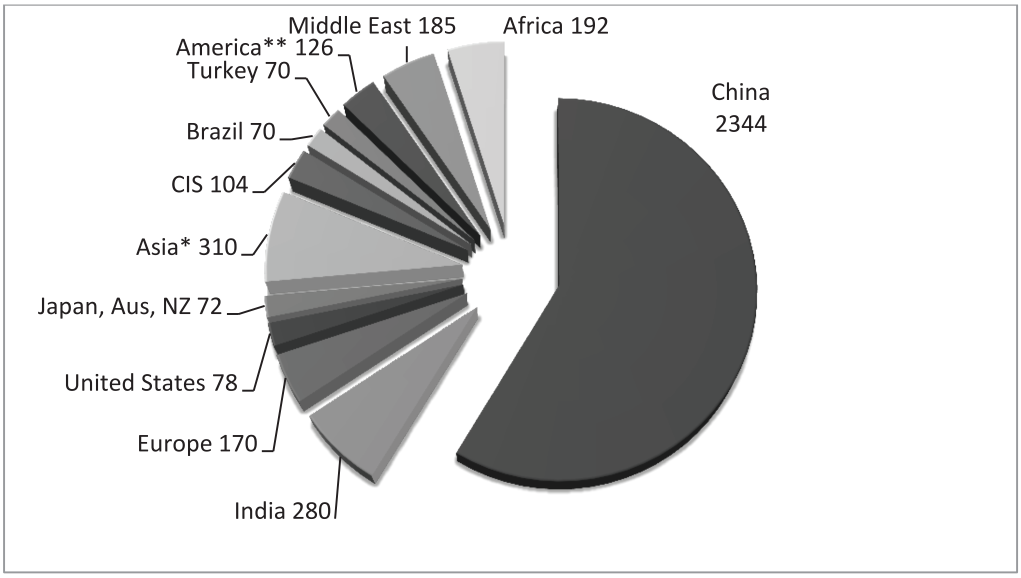


Fig. 2 World cement production in 2013 by regions in million metric tons.
Notes: * excl. China, India, CIS and Japan, ** excl. Brazil and United States. Source: Cembureau, 2014.

A typical set of boundary limits for a cradle-to-gate basis life cycle assessment (LCA) for a modern dry cement plant with pre-heaters is shown in Fig. 3.

3.2.1 Climate impact management matrix for the cement industry

A climate impact management matrix for the cement industry was developed based on a similar management matrix as for biorefinery production chains (Kajaste, 2014). The life cycle of a single cement production site, on a cradle-to-gate basis, consists of feedstock production, storage, transportation, intermediate storage, pretreatment, cement production operations, product storage, packaging and dispatching (Fig.4). The importance of reducing GHG emissions of cement comes evident also in LCAs of its end users; it was found for all US roads studied that the majority of emissions occur in year one – from cradle-to-gate materials production – primarily due to cement production (Loijos et al., 2013).

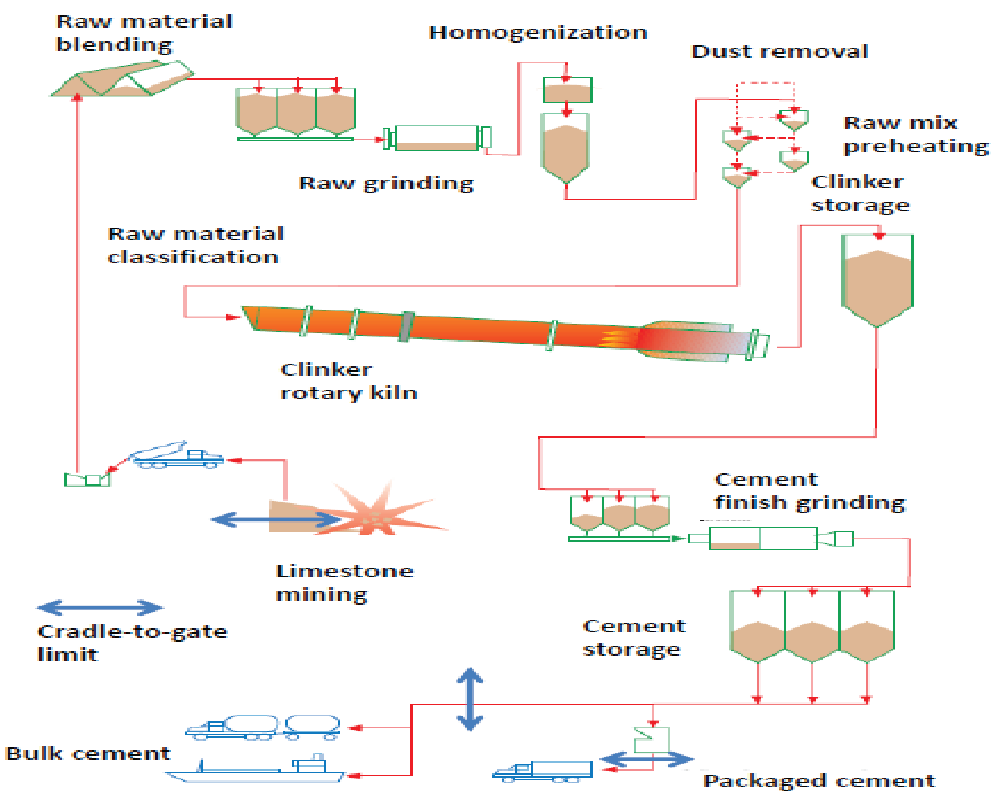


Fig. 3 System boundary for a cradle-to-gate LCA of a cement plant. Adapted from Finnsementti (2007).

3.3 Datasets developed

Geographical differences in CO_2 emissions from cement production were the reason to develop regional datasets. Formation of datasets was done for the Eq.1a. Initial data for dataset development is shown in Table 1 covering 25% of world cement production in 2011. The emissions from electricity use are not included in the specific emission of Table1. The specific emission in kg CO_2/t clinker, mineral substitute content (MIC) and fuel carbon data from Table 1 were further used to recalculate the emission for cement in Tables 7, 8 and 9. *The emission unit in all developed datasets is kg CO_2/t cement.*

Several estimates for the world cement production and corresponding CO_2 emissions for clinker (baseline minus MIC) exist, and one of them – based on satellite monitoring – reported for 2007, 2008 and 2009 gave results of 1382, 1417 and 1397 Mt CO_2, respectively (ORNL, 2010). These emissions exclude emissions from fossil fuel and electricity use in the cement industry, and taking 3000 Mt as total cement production in 2009 this gives a process emission of 466 kg CO_2/t cement that compared to the theoretical 100% clinker in cement value of 510-525 indicates a MIC% of 8.63 - 11.24 in the cement. This is lower than the World 25% of 22.55% for the same year (GNR, 2011). The difference may be explained by the fact that the companies reporting to GNR have less clinker loss in dust emissions, are more efficient in their fossil fuel use and are overall more prone to replace clinker with mineral components that reduce the overall CO_2 emission.

Cradle-to-gate Climate Impact Matrix	Feedstock production	Storage and transport	Raw mix production and clinker burning	Cement grinding, storage and dispatch	Total cement climate impact
Impact Assessment LCA	• Energy use • Production of waste • Direct land use change	• Energy use • Machninery and transport equipment use	• All process emissions inluding fuel combustion and use of chemicals	• All process emissions inluding use of chemicals and energy carriers	**Summary emissions of greenhouse gases (GHG)**
Reduction of GHG emissions	• Use of recycled residues and waste materials. • Renewable fuels • Good management practices	• Minimization of energy use • Optimization of logistics • Less emitting transport equipment	• Technology development • Process intensification • Energy optimization • Feedstock and product optimization	• Technology development • Process intensification • Energy optimization • Product development	• Optimization of the whole cement value chain • Elimination / reduction of uncertainties in the value chain
Outside Boundary System	• ILUC • Resource depletion • Alternative / recycled feedstock • Explosives and grinding media	• Emission of machinery, transport equipment & storage infrastructure production	• Emission of cement plant equipment and infrastructure production	• Emission of cement plant equipment and infrastucture production	• Changes in related energy, feedstock and product markets
BAT Reference System	Energy use 2900-3300 MJ/t clinker, Summary CO2 emission 800-810 kg CO2/ t clinker including the emissions from electricity. Additional benefits from minimization of water use, dust emissions and production losses. Usually excludes mining and transport / storage of feedstock. Other GHG's than CO2 seldom included in LCAs.				

Fig. 4 Climate impact management matrix for cement industries.

Datasets (Tables 2-8) are either based on single plant measured values or on country/region based data. In all, the datasets cover best the production in China (96%), Europe (96%), North America (76%), Brazil (72%) Central America (67%), India (55%) and Africa (51%). The percentages in brackets give the minimum coverage in the region. For the rest of the regions the coverage % is shown in Table 1. Conclusively, the datasets developed by us cover over 77% of the world cement production in 2013 assuming that no significant technological improvements have occurred since 2011. The relative uncertainty of the estimates and confidence intervals including standard deviations of datasets differ.

Datasets 1 and 2 (Table 2, Table 3) present also measured clinker baseline values including the dust loss emissions, and are valuable when comparing the three internationally recommended baseline values of 510, 525 or 540 generally used in assessing the cement production CO_2 emissions (GNR, 2011).

Table 1 Geographical distribution of 25% of the world cement production and CO_2 emissions in 2011.

Region	Production t/year	Emissions tCO2/year	Specific emission kg CO_2 /t clinker	Fuel carbon g CO_2/MJ	MIC % wt	Coverage % of production
Europe	201,000,000	129,000,000	847	82.8	25.1	96
North America	59,800,000	44,500,000	897	90.3	8.15	76
Japan Aus NZ	24,600,000	17,100,000	838	90.8	15.1	39
CIS	16,800,000	13,500,000	976	76.8	18.4	18
Central America	38,500,000	25,100,000	858	90.7	27.0	67
Brazil	46,200,000	26,800,000	850	81.8	32.3	72
South America*	32,100,000	18,900,000	848	82.1	29.3	61
China	106,000,000	75,700,000	867	96.4	25.2	5
India	123,000,000	72,200,000	837	95.9	27.3	55
Asia**	116,000,000	83,500,000	843	90.2	18.5	37
Africa	82,400,000	46,300,000	814	72.3	21.2	51
Middle East	30,700,000	21,200,000	851	91.1	16.7	11
WORLD 25%	877,100,000	573,800,000	852	87.3	23.61	25

Notes: specific emission does not include emissions from the use of electricity. MIC = mineral components, * ex. Brazil, ** excl. China, India, CIS and Japan, MIC = mineral components in Portland and blended cements. Source: GNR, 2011 (covers 25% of the world cement production).

Table 2 Dataset 1 Finland: A single cement plant data from Finland in 2006 in kgCO_2/t cement.

Dataset 1 Finland	E_{total}	$E_{clinker\ baseline}$	$E_{CSubstitute}$	$E_{fossil\ fuel}$	$E_{electricity}$
1	806	521	-68	333	20
2	823	532	-73	344	20
3	860	529	-69	380	20
4	824	525	-68	346	21
5	872	527	-70	394	21
6	848	525	-67	370	20

Source: Finnsementti, 2006, Calculations by authors.

Table 3 Dataset 2 India: A single cement plant data from India in 2006 in kgCO_2/t cement.

Dataset 2 India	E_{total}	$E_{clinker\ baseline}$	$E_{CSubstitute}$	$E_{fossil\ fuel}$	$E_{electricity}$
1	903	524	-134	396	117
2	977	551	-154	464	116
3	1103	534	-146	565	150
4	934	551	-154	464	73

Source: CDM (2014), CDM project number 0287 in India, Calculations by the authors.

The relative uncertainty of the estimates in Datasets 1 and 2 is considered to be of the normal level of laboratory and plant instrument accuracy i.e. lower than 2%. Datasets 3 and 4 (Table 4) represent incomplete data that were used to test the least square fit model for total emissions of the Eq. 2. The accuracy of estimates in these two datasets is unclear.

Table 4 Datasets 3 and 4: Incomplete single cement plant data from India in 2001-2010 in $kgCO_2$/t cement.

Dataset 3 India	$E_{clinker}$ baseline	$E_{CSubstitute}$ (fly ash)	Dataset 4 India	$E_{clinker}$ baseline	$E_{CSubstitute}$ (slag)	Slag addition %
1	621	-13	1	640	-52	8.9
2	615	-22	2	633	-98	9.6
3	602	-21	3	625	-85	6.7
4	594	-14	4	617	-80	7.9
5	598	+3	5	639	-50	8.5
6	625	+21	6	632	-97	9.2
7	621	-24	7	624	-85	6.3
8	617	-38	8	616	-77	7.5
9	613	-34	9	602	-51	5.3
10	608	-38	10	619	-53	5.3

Source: CDM (2014), CDM project number 0711 Mysore and Dalmia in India, Calculations by the authors.

The relative uncertainty of the estimates of the CO_2 emissions from China's cement production (Dataset 5, Table 5) is in the range of 10% to 18% and reflects the discrepancies between different methodologies. This uncertainty range indicates that the total estimated CO_2 emissions from China's cement industry in 2010 was lower than 1.1 Gt or higher than 1.4 Gt, a difference of more than 0.3 Gt.

Table 5 Dataset 5 China: A country specific data from China in 2007-2011 in $kgCO_2$/t cement.

Dataset 5 China	E_{total}	$E_{clinker}$ baseline	$E_{CSubstitute}$	E_{fossil} fuel	$E_{electricity}$
1	729	520	-156	291	74
2	748	547	-164	291	74
3	755	557	-167	291	74
4	863	712	-214	291	74
5	790	607	-182	291	74
6	680	532	-202	275	75
7	727	546	-162	269	74
8	664	547	-187	229	75
9	664	547	-202	243	76

Source: Ke et al., 2013, Li et al, 2014, Wang et al., 2013,1-7 data from 2007, 8 from 2009, 9 from 2011, Calculations by the authors.

Table 6 Dataset 6 Iran: Plant specific data from Iran in 2010 in $kgCO_2$/t cement.

Dataset 6 Iran	E_{total}	$E_{clinker\ baseline}$	$E_{CSubstitute}$	$E_{fossil\ fuel}$	$E_{electricity}$
1	906	510	0	293	103
2	900	510	0	287	103
3	923	510	0	318	95
4	1000	510	0	389	101
5	940	510	0	331	99

Source: Ostad-Ahmad-Ghorabi and Attari, 2013, Calculations by the authors.

Dataset 6 (Table 6) gives results of a recent emission assessment of five plants in Iran. The relative uncertainty of the estimates is considered to be higher than that of Datasets 1 and 2. Dataset 7 (Table 7) reflects best the total CO_2 emissions of the cement production in Europe. The relative uncertainty comes from the values left outside the range of 10% and 90%.

Table 7 Dataset 7: A regional dataset for Europe in 2005-2011 in $kgCO_2$/t cement.

Dataset 7 Europe	E_{total}	$E_{clinker\ baseline}$	$E_{CSubstitute}$	$E_{fossil\ fuel}$	$E_{electricity}$	Source
1	719	525	-6*	188	0	UK 2011
2	597	525	-142	160	54	Germany 2011
3	614	525	-131	166	54	Germany 2007
4	634	525	-132	241	0	Europe 2011
5	646	525	-129	250	0	Europe 2010
6	670	525	-118	263	0	Europe 2005

Note: * calculated, does not reflect the actual situation.
Source: GNR, 2011, MPA Cement, 2012, VDZ, 2014, Calculations by the authors.

Dataset 8 is derived from the data given in Table 1 which covered 967 individual facilities that reported absolute net CO_2 emission 556 $MtCO_2$ and absolute gross emission 573 $MtCO_2$ excluding emissions from electricity in 2011. Originally, the gross and net emissions per ton of clinker (Table 1) were estimated by GNR (2011) using linear regression formulas – between 10% and 90% – resulting in weighted average values of 852 kgCO2/t clinker with a standard deviation of 83 for gross emissions and correspondingly 825 kgCO2/t clinker with a standard deviation of 100 for net emissions (net CO_2 emissions = gross CO_2 emissions minus emissions from the use of alternative fossil fuels). Similarly the weighted average of electricity use was estimated at 107 kWh/ t cement with a standard deviation of 53. The emission estimate of GNR (2011) covered 651 facilities and the electricity use 254 companies.

Table 8 A global dataset excluding Europe in 2011 in $kgCO_2$/t cement.

Dataset 8 Global	E_{total}	$E_{clinker\ baseline}$	$E_{CSubstitute}$	$E_{fossil\ fuel}$	$E_{electricity}$	Source
1	824	525	-43	342	0	North America 2011
2	712	525	-79	266	0	Japan Aus NZ 2011
3	796	525	-97	368	0	CIS 2011
4	626	525	-142	243	0	Central America 2011
5	576	525	-170	221	0	Brazil 2011
6	600	525	-154	229	0	South America* 2011
7	649	525	-132	256	0	China 2011
8	609	525	-143	227	0	India 2011
9	687	525	-97	259	0	Asia**
10	641	525	-111	227	0	Africa 2011
11	709	525	-88	272	0	Middle East 2011
12	654	525	-124	253	0	WORLD 25% 2011

Notes: does not include emissions from the use of electricity, * excl. Brazil, ** excl. China, India, CIS and Japan. Source: GNR, 2011, Calculations by the authors.

3.4 A model for fitting total emissions

First the wi values (Eq. 1a) of Datasets 1, 2, 5, 6, 7 and 8 were checked for a perfect fit by using a least square matrix where all the 0 values in the datasets were replaced by 1. Then the incomplete datasets 3 and 4 (Table 4) were added to the matrix. For Datasets 1, 2, 5, 6, 7 and 8 the group contributions w1, w2, w3 and w4 all equaled to 1, confirming a perfect fit with a maximum absolute error of -2 (value for E_{total} of 652 instead of 654 in the last point of Dataset 8) i.e. an overall error of 0.31% reflecting the change of 0 values to 1 in the datasets. When adding the incomplete datasets 3 and 4 to the matrix and assuming that E_{total} equals 980 kg CO_2/t cement (average from Dataset 2 for India) we got the following weighted components:

$$E_{total} = 1.009E_{Clinker\ Baseline} - 5.69E_{ClinkerSubstitute} + 1.005E_{Fossil\ Fuel} + 0.993E_{Electricity} \quad (4)$$

Eq. 5 gives reliable results for Datasets 1, 2, 5, 6, 7 and 8, and the error margin for Dataset 3 and 4 varies from -11.8 to +9.05 percent. When we assumed that E_{total} equals to 833 kg CO_2/t cement (global India from Table 9) we got following weighted:

$$E_{total} = 1.004E_{Clinker\ Baseline} - 2.54E_{ClinkerSubstitute} + 1.002E_{Fossil\ Fuel} + 0.997E_{Electricity} \quad (5)$$

The Eq. 5 gives reliable results for Datasets 1, 2, 5, 6, 7 and 8, and the error margin for Dataset 3 and 4 varies from -7.52 to +6.38 percent. This indicates that the clinker baseline and clinker substitute values in Datasets 3 and 4 have a higher error margin than the values in other datasets. However, the total emission can be estimated with a reasonable error margin. The result also indicates the importance of correct $E_{ClinkerSubstitute}$ values when estimating total emissions of cement production.

3.5 Comparative analysis of different options

Based on the information gathered from the previous research and with the help of the datasets developed, a minimum and maximum range for the possibilities to reduce CO_2 emissions by increasing MIC in cement, by reducing the fossil fuel components and by improving the carbon balance of electricity use as well as by changing the kiln technology, were compared on the basis of the actual reduction potential.

The starting point for the comparative analysis of different mitigation options was the world cement industry emission data for 2011 estimated by the authors (Table 9). The emissions are expressed as total specific CO_2 emission and include clinker baseline emission minus clinker substitute (MIC) impact, emission from fossil fuel use and emission from electricity use. *All CO_2 emission values in Table 9 are calculated as kg CO_2/ t cement.* The emission values for the total world production in 2011 are calculated as summary emission of mass-fractional contributions of different regions.

Compared to the World 25% estimate of 2011 (Table 8, Table 1), the specific emission of the total world production (Table 9) of 2011 in kg CO_2/ t cement is 17.1% higher. The key differences are: (1) the World 25% does not include emission from electricity use; (2) the fossil fuel emission (Table 8) was just estimated by the authors as the difference of the total specific emission minus (clinker baseline – MIC impact); and (3) the World 25% has higher MIC content (23.61%) than the World total (17.52%) in Table 9. If we deduct the electricity emission from the World total specific emission (Table 9) we get a specific emission of 703 kg CO_2/ t cement that is 7.5% higher than the 654 kg CO_2/ t cement of the World 25% (Table 8).

Table 9 World cement production CO_2 emissions by geographic region in 2011 in kg CO_2/ t cement.

District	Production Mt cement /year	Emissions MtCO2/year	Specific emission kg CO_2 /t cement	Clinker with MIC kg CO_2 /t cement	Fossil Fuel kg CO_2 /t cement	Electricity Emission kg CO_2 /t cement
China	2085	1,440.74	691	365	250	76
India	210	174.93	833	387	332	114
Europe	209	143.79	688	393	241	54
United States	79	70.63	894	482	342	70
Japan, Aus, NZ	63	49.52	786	446	266	74
Asia*	270	205.47	761	428	259	74
CIS	93	81.38	875	440	385	50
Brazil	63	41.08	652	355	221	76
Turkey	64	45.31	708	392	242	74
America**	111	77.15	695	377	236	82
Middle East	168	149.04	920	502	318	100
Africa	162	134.30	829	457	272	100
WORLD	3577	2,613.34	766	433	260	73

Notes: * excl. China, India, CIS and Japan, ** excl. Brazil and United States, MIC = mineral components in Portland and blended cements. Emissions estimated from average values in Datasets 1-8.
Source: Cembureau, 2014, GNR, 2011, Calculations by the authors.

The estimate of 2613 Mt CO_2 emissions from the cement industry in 2011 (Table 9) correlates with the preliminary estimate of 2823 Mt CO_2 emissions from the cement industry in 2010 by OECD (2012) with a difference of 7.44%. A recent rough estimate for global emissions from cement production uses the following values: clinker baseline of 510 kg CO_2/ t clinker, clinker fuel emission of 353 kg CO_2/ t clinker, and for cement a process emission of 403 kg CO_2/ t cement (assumes 21% MIC content), cement fuel emission of 318 kg CO_2/ t cement and cement electricity emission of 100 kg CO_2/ t cement. The corresponding summary specific emission is 820 kg CO_2/ t cement (Gupta, 2011). This is 7.05% higher than the corresponding value in Table 9 and gives a total global emission of 2933 Mt CO_2 for the 2011 world production of cement. This is 3.9% higher than the OECD (2012) estimate for 2010.

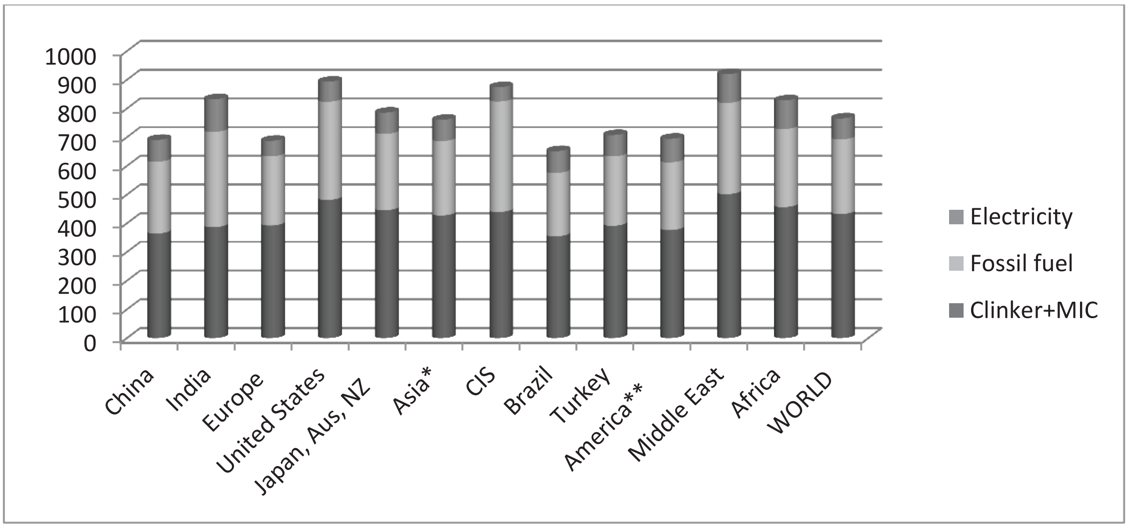


Fig. 5 Regional specific emissions in kg CO_2/t cement in 2011.

Geographically the specific emission in kg CO_2/ t cement varies from 652 in Brazil to 920 in the Middle East. Brazil has lower fossil fuel and electricity baselines than the Middle East and uses mineral components (34.2%) considerably more than is the practice in the Middle East (5%), where OPC dominates the market. The differences in fossil fuel and electricity baselines depend on several factors and are highly specific for the region. Kiln technology is one of the factors that impact the energy and electricity consumption of cement plants. The regional differences of cement production emissions are shown in Fig. 5. The total specific emission is shown as (clinker baseline – MIC impact) plus emission from fossil fuel use plus emission from electricity use as in Eq.1a.

3.5.1 Management of CO_2 emissions by increasing the MIC content in cement

Substitution of clinker with MIC reduces the CO_2 emission of calcination and is an efficient way to improve the GHG management in the cement industry. The current use of these clinker substitutes (Fig. 6) is less than the maximum allowable by current standards and national regulations (Bhushan, 2010).

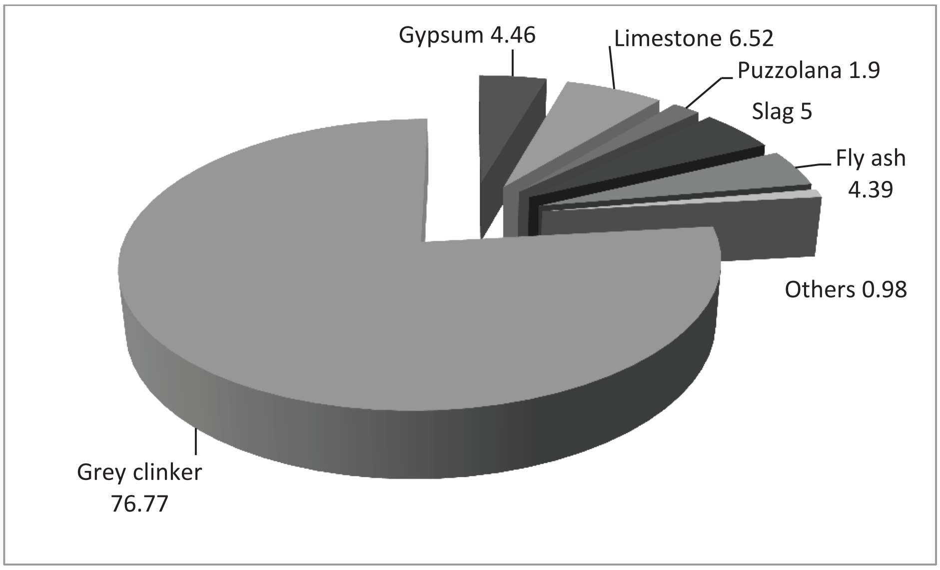


Fig. 6 Use of clinker and clinker substitutes (%) at 25% of the world cement facilities in 2011. Source: GNR, 2011.

The regional differences in replacing clinker with other mineral substitutes are significant (Fig.5) and can be assessed based on the “Clinker with MIC kg CO_2 /t cement” emission values that vary from 355 in Brazil to 502 kg CO_2 /t cement in the Middle East (Table 9). In the United States and in the Middle East the cement consumption is dominated by OPC, which explains the low clinker substitute use, and is also reflected in the high total specific emissions. Similarly the highest clinker substitute amount is in Brazil (34.2%). The minimum reduction potential could be that the world average use of clinker substitutes in 2011 (17.52%) would be increased to the level of Brazil. This would mean a reduction of 78 kg CO_2 /t cement produced, meaning a total reduction of 312 Mt CO_2/year (10.2%) with the production amount of 4000 Mt cement as in 2013 with the assumption that OPC can always be replaced with blended cement. The Cement Roadmap of IEA (2009) estimates a 27% average use of clinker substitutes in 2030 corresponding to a reduction of 50 kg CO_2 /t cement. The latter would mean a 200 Mt CO_2/year reduction with the production level of 2013. The maximum reduction potential will depend on how quickly the positive mechanical and physical test results from high substitute content in cement (>35%) will be adapted to international standards and national regulations. The availability of additional fly ash, slag, pozzolan, limestone and recycled mineral components is not considered a hindrance (Gupta, 2011).

3.5.2 Management of CO_2 emissions by reducing fossil fuel use or improving energy efficiency

The energy balance and technical solutions of cement kilns have a considerable impact on CO_2 emissions (Morrow et al., 2014). The use of high calorific municipal solid waste (MSW) and other refuse-derived fuel (RDF) as co-fired fuel in cement kilns significantly reduces the GHG emissions (Garg et al., 2009, Genon and Brizio, 2008, Kara, 2012). Sewage sludge (SS) reduces both the fossil fuel use and replaces up to 14% of the clinker in cement (Rodríguez et al., 2013). However, the use of sludge slightly increases the CH_4 and N_2O emission of the cement production (Nakakubo et al., 2012). A review on the technical, economic and environmental effects of MSW, SS, biomass, meat and bone animal meal (MBM) and end-of-life tyres (ELT) as alternative fuels and raw materials in the cement industry concluded that by coupling the cement and waste management industries, it is possible to significantly reduce the GHG emissions and natural resource consumption associated with cement production (Usón et al., 2013). Similarly, the use of charcoal from sawmill residues reduces the fossil fuel emissions by 83-91% compared to coal as fuel in a cement kiln (Sjølie, 2012). Up to 8% of the cement in mortar could be replaced by rice straw coke without a significant impact on the mechanical properties (Wang and Wu, 2013).

The CO_2 emission from fossil fuel use in the cement industry depends mainly on three factors: (1) the type of fossil fuel used; (2) the amount of biomass and waste materials replacing fossil fuels; and (3) the type of kiln used. In a specific country or region the type or mix of fossil fuels available for cement production has remained relatively unchanged for the last 10 years (GNR, 2011, IEA, 2009). Biomass and different waste materials can both be used to replace fossil fuel and as mineral substitutes for clinker (Rodríguez et al., 2013).

Dry rotary kilns with preheater and precalciner kilns dominate the facilities of cement producers (25% of the world production in 2011) that report to the Cement Sustainability Initiative (CSI) (GNR, 2011), as shown in Fig. 7. The average fossil fuel emission of these producers is 253 kg CO_2/ t cement (Table 8) and the average carbon intensity of energy is 87.3 g CO_2/MJ (Table1). From this data by calculation we get an average energy use of 2898 MJ/ t cement, which corresponds to 3793 MJ/ t clinker with the given average value of clinker substitutes (Table 1). The world average fossil fuel emission of 260 kg CO_2/ t cement (Table 9) gives with the same carbon intensity as in Table 1 an average energy use of 2978 MJ/t cement, which corresponds to 3611 MJ/ t clinker with an average value of 17.52% of clinker substitutes. The difference between the World 25% and the World total estimates is 80 MJ/t cement or 2.76%. The difference is 5.04% if calculated for MJ/t clinker. This variation reflects the uncertainty with which the amount of clinker substitutes (17.52%) is estimated in Table 9.

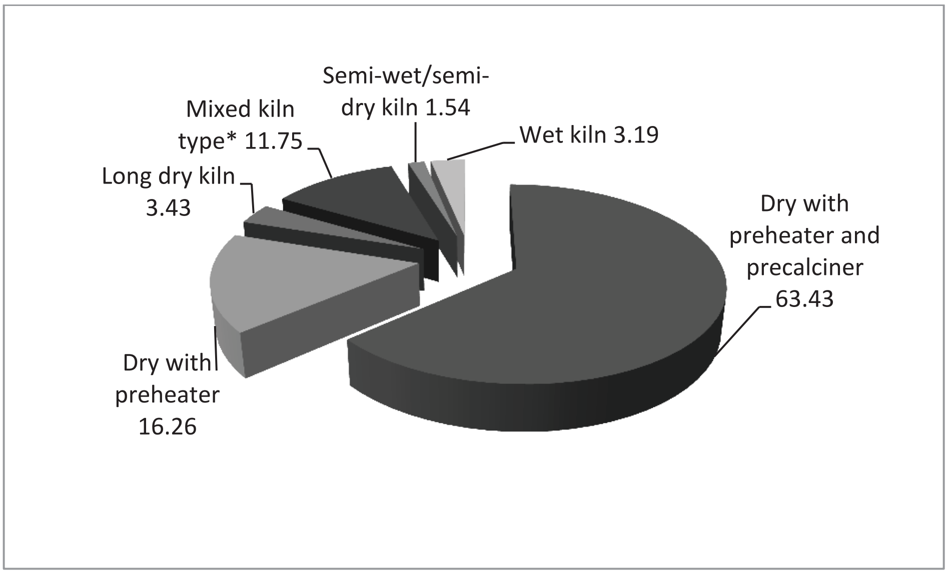


Fig. 7 Distribution of kiln technologies (%) at 25% of the world cement facilities in 2011.
Note: * facility uses several types of kilns simultaneously. Source: GNR, 2011.

The specific energy use varies between different kilns. The highest energy consumers are wet kilns with 5900 – 6700 MJ/t clinker, and vertical shaft kilns, long dry kilns, dry rotary kilns with preheater and dry rotary kilns with preheater and precalciner consume 5000, 4600, 3100 and 2900 MJ/t clinker, respectively. The theoretical endothermic minimum is considered to be 1800 MJ/t clinker (IEA, 2007) and the best observed one is 2842 MJ/t clinker. The average CO_2 emissions of different kiln types (Table 10) are based on the average fossil fuel emissions and on the average heat consumption of different kilns.

Table 10 CO_2 emissions by kiln type in kgCO_2/ t clinker in 2000 and 2011.

Kiln type	2000	2011
Dry with preheater and precalciner	847	840
Dry with preheater without precalciner	866	852
Long dry rotary kiln	965	876
Semi-wet/semi dry kiln	892	877
Wet kiln	1060	1020

Note: does not include CO_2 emissions from the electricity used at the facilities. Source: GNR, 2011.

The minimum reduction potential could be that the world average energy use of 2978 MJ/t cement in 2011 would be reduced by 2.7% to the current 2898 MJ/ t cement of the CSI member companies. This would mean a reduction of 80MJ/t cement or 7 kg CO_2 /t cement, which on a global scale means 28 Mt avoided CO_2 emissions (1%) with the production level of 2013. Conclusively, taking into account that the cement industry could reduce its average energy use by 18.5% per ton of cement from current levels by 2030 (IEA, 2009), the minimum and maximum energy saving potential of the world cement industry would be from 7 to 48 kg CO_2/ t cement, which with the 4000 Mt/ year production of 2013 would mean avoided emissions of between 28 and 112 Mt CO_2/ year on the global scale. The maximum avoided CO_2 emissions from fossil fuel use would require an increase of up to 23-24% in the use of carbon neutral fuels like biomass or expensive carbon capture technologies and a clinker to cement ratio of 73% (IEA, 2009).

3.5.3 Management of CO2 emissions by improving the carbon balance of electricity use

The electricity use in cement plants takes place dominantly in raw material preparation, grinding, homogenization and in cement finish grinding. In kilns the biggest electricity consumers are the drives of rotary kilns. The carbon balance of electricity use is defined by the consumption of electricity (usually expressed in kWh/t cement) and by the CO_2 emission of the produced electricity (usually expressed as kg CO_2/MWh). A cement plant can seldom impact the latter, and avoided emission measures are usually concentrated on the efficient use of electricity inside the facility. The weighted average of electricity use was 107 kWh/ t cement with a standard deviation of 53 in 2011 (GNR, 2011). Depending on the source of electricity and on the efficiency of the electricity use the CO_2 emission level varied from 20 to 150 kg CO_2/ t cement (Tables 2-9). A reduction target could be to level the electricity use of all facilities to the average level of 107 kWh/ t cement now used only among CSI member companies. The data available did not allow estimation of the corresponding CO_2 emission reductions that this would bring with sufficient accuracy. A recent estimate on upgrading existing cement plants proposes electricity efficiency improvements with 90 Mt CO_2/year savings – with assumed emission of 100 kg CO_2/ t cement from electricity use – on a global scale before 2020 (Gupta, 2011). One reference point could be the world average grid electricity emission of 516 g CO_2eq/kWh for mineral producing countries (IEA, 2010), which gives with 111 kWh/t cement an emission of 57 kg CO_2/ t cement instead of the 73 kg CO_2/ t cement used in Table 9. The difference is mainly explained by the fact that coal and petcoke still dominate as fossil fuel in many cement kilns with own electricity production (GNR, 2011, Gupta, 2011). A ten percent decrease in the electricity emission would improve the carbon balance with 6-7 kg CO_2/ t cement savings which with the 2013 global production level means savings from 24 to 28 Mt CO_2/year (0.9% on average).

3.5.4 Measures for the mitigation of CO2 emissions in the cement industry

The implementation of energy efficiency and CO_2 emission saving measures in the cement industry has been studied widely. A listing of possible measures to manage CO_2 emissions in the cement industry is shown in Table 11. The measures are grouped by their place in the production chain: (1) Raw material preparation, grinding, homogenization; (2) Clinker kiln; (3) Cement finish grinding; and (4) Product and fuels improvements. The magnitude of potential CO_2 reduction is shown in kg CO2/t clinker, which can be calculated to kg CO2/t cement if the MIC content of the cement is known.

Table 11 Management measures for the mitigation of CO_2 emissions in the cement industry.

MANAGEMENT MEASURE	CO_2 Reduction in kg CO_2/t clinker
Raw material preparation, grinding, homogenization	
Efficient transport systems (dry process)	0.4 – 3.2
Raw meal homogenizing (dry process)	0.3 – 2.7
Process control for vertical mills (dry process)	0.2 – 1.5
Use of roller mills (dry process)	1.2 - 10.5

High-efficiency classifiers/separators (dry process)	0.5 – 5.2
Slurry blending and homogenizing (wet process)	0.1 - 0.2
Wash mills with closed circuit classifier (wet process)	0.2 – 0.3
Roller mills for fuel preparation	0.2 – 0.3
Clinker kiln	
Improved refractoriness in all kilns	10.3 – 15.5
Energy management and process control systems	2.5 – 16.6
Adjustable speed drive for kiln fan	1.4 – 6.3
Installation or upgrading of pre-heater (rotary kilns)	4.1 – 40.7
Conversion of long dry kilns to pre-heater/precalciner kilns	20.5 – 112.6
Dry process upgrade to multi-stage pre-heater kiln	23.0 – 72.4
Increasing number of pre-heater stages (rotary kilns)	8.4 – 9.3
Conversion to reciprocating grate cooler (rotary kilns)	6.3 – 20.5
Kiln combustion system improvements (rotary kilns)	2.6 – 24.1
Indirect firing (rotary kilns)	0.4 – 0.6
Optimizing heat recovery/upgrading clinker cooler (rotary kilns)	0.8 – 40.7
Seal replacement (rotary kilns)	0.3
Low temperature heat recovery (rotary kilns)	4.6 – 31.7
High temperature heat recovery (rotary kilns)	3.7 – 9.3
Low pressure drop cyclones for pre-heaters (rotary kilns)	2.7
Efficient kiln drives (rotary kilns)	0.1 – 0.9
Replacing vertical shaft kilns with pre-heater/precalciner	62
Cement finish grinding	
Process control and management	0.9 – 4.1
Vertical roller mill	8.8 – 26.7
High pressure (hydraulic) roller press	1.3 – 25.1
Horizontal roller mill	4.3
High efficiency classifiers	0.4 – 2.1
Improved grinding media for ball mills	0.3 – 6.3
High-efficiency motors and drives	0.0 – 47
Adjustable or variable speed drives	1.0 – 9.4
Product and fuels improvements	
Blended cements	0.3 – 212.5
Use of waste-derived fuels	12.0 – 76.3
Limestone Portland cement	8.4 – 29.9
Low-alkali cement	4.6 – 12.1
Use of steel slag in kiln	4.9 – 50
Use of calcium carbide residue	Up to 374
Geopolymer cement	Up to 300
CCS from precalcination of limestone	Up to 410
Oxy-fuel technology	404 - 658
Post-combustion carbon capture (CCS)	Up to 725
MgO based cements	Up to 750

Source: Madlool et al., 2013, Madlool et al., 2011, Worrell et al., 2008, Hasanbeigi et al., 2012.

3.6 The abatement cost of reducing GHG emissions in cement production

The mitigation of GHG emissions in the cement industry is progressing slower than the growth rate of production. Cement production grew by 73% between 2005 and 2013. The CO_2 emissions calculated as kg CO_2/t clinker dropped by 14.8% and the electric energy consumption calculated as kWh/t cement was reduced by 3.6% from 2006 to 2011. Several reasons for the slow implementation of energy efficiency and CO_2 emission reduction measures exist: (1) the average lifespan of 50 years of a cement plant and the service life of key equipment is often higher than 20 years; (2) high capital expenditure requirements on new plants; (3) difficulties accessing capital for environmental investments; (4) cement market is price dominated; and (5) the quality of cement is strictly standardized and regulated. All these factors together create barriers to changing the cement composition, investing in new kiln technology, improving the energy efficiency and reducing the electricity use at cement facilities. The price of decreasing CO_2 emissions at a single facility level need to be attractive enough to overcome these barriers. We collected cost data on different measures to reduce the CO_2 emissions in the cement industry and estimated unit abatement costs using a uniform capital recovery factor (CRF) with a 10-year payback time (Eq. 3).

Table 12 Unit abatement cost of avoided CO_2 emissions with 5% and 10% discount rates.

Country	Investment cost	CO2 reduction	Abatement cost 5%	Abatement cost 10%	Reference in CDM, 2014
	US$	t CO2/year	US$/tCO2	US$/tCO2	
Indonesia	15,750,107	144,413	14	18	CDM493
Ukraine	182,000,000	755,851	31	39	JI UA01
Ukraine	3,900,000	119,436	4	5	JI UA
Ukraine	78,000,000	168,701	60	75	JI UA100
China	32,520,000	222,048	19	24	CDM3522
China	34,320,000	216,232	21	26	CDM1676
Mongolia	19,100,000	123,794	20	25	CDM1730
Colombia	24,000,000	169,565	18	23	CDM1790
TOTAL 8 projects	389,590,107	1,920,040	26.28	33.02	

Source: Calculations by the authors, CDM, 2014.

Cement companies have initiated Clean Development Mechanism (CDM) projects on clinker substitution, fuel switch, waste heat recovery and on general energy efficiency projects. Clinker substitution projects are the most common. The expected financial benefits from CDM in Brazil and India varied from US$10 to US$18/tCO_2eq in 2005 (Hultman et al., 2012). Implemented projects give an indication of the price level for the abatement cost of CO_2 reductions in the cement industry. The results (Table 12) gave a price variation from US$4 to US$75 for an avoided ton of CO_2 with an average cost of US$26.28 - US$33.02/t of avoided CO_2. The average cost for all 8 projects was calculated using Eq.3 to the summary investment cost and summary avoided emissions for a year. A voluntary GHG saving program in the Taiwan cement sector resulted in 1099 kt of avoided CO_2 emissions in 2004-2008. The corresponding investment cost was US$202.6 million and the total 5-year operational cost savings US$71 million (Chen and Hu, 2012). By dividing the savings and avoided emissions by 5 and by applying Eq. 3 we get an abatement cost of US$55 - US$85/t of avoided CO_2 originating mainly from energy and electricity savings.

The costs for avoided CO_2 emissions for the assumed construction of a new dry-process cement plant with a five-stage preheater and precalciner with either post-combustion carbon capture (CCS) or oxy-fuel combustion technologies in Europe and Asia are shown in Table 13. The oxy-combustion technology costs at a cement plant are about the same as the costs of similar technology installed at a typical coal-fired power plant. The estimated costs of post-combustion CCS are substantially higher at a cement plant (Barker et al., 2009).

Table 13 Abatement cost of avoided CO_2 emissions for CCS and oxy-fuel technologies.

Location	**Europe**	**Europe**	**Asia**	**Asia**
Capacity	1 Mt cement/year	1 Mt cement/year	3 Mt cement/year	3 Mt cement/year
Technology	oxy-combustion	CCS	oxy-combustion	CCS
Abatement cost	US$/t$CO_2$	US$/t$CO_2$	US$/t$CO_2$	US$/t$CO_2$
	56	149.8	32.2	82.6

Source: Barker et al., 2009.

Both technologies are in the development phase and several technical issues need to be solved before these technologies are ready to be utilized on a large scale in cement production. Generally the cost of CCS is considered to be too high (Table 14) for the cement industry to implement without e.g. carbon trade benefits in the form of additional revenues.

Table 14 Abatement cost of avoided CO_2 emissions for CCS in 2030 with a 10-year payback time.

IEA scenario	**Low**	**High**	**Low**	**High**
Capacity	2 Mt cement/year	2 Mt cement/year	2 Mt cement/year	2 Mt cement/year
Investment	US$ 140,000,000	US$ 420,000,000	US$ 140,000,000	US$ 420,000,000
Operational cost	US$ 20,440,000/y	US$ 102,000,000/y	US$ 20,440,000/y	US$ 102,000,000/y
CO_2 savings	380,000 tCO_2/year	380,000 tCO_2/year	380,000 tCO_2/year	380,000 tCO_2/year
Discount rate	5%	5%	10%	10%
Abatement cost	US$/t$CO_2$	US$/t$CO_2$	US$/t$CO_2$	US$/t$CO_2$
investment	47.71	143.13	59.96	179.88
with oper. cost	101.50	411.55	113.75	448.30

Source: IEA, 2009, Calculations by the authors.

The CCS costs with a 10-year payback time (Table 14) compare well with a recent estimate for retrofitting a cement plant where CCS in 2012 was of US$70/t CO_2 at a 14% discount rate with a 25-year payback time (Liang and Li, 2012). They used US$12/t$CO_2$ as an estimated income from carbon trade and included no additional operational costs.

The average fuel cost with coal and petcoke as dominant sources of thermal energy is US$11/t cement (Usón et al., 2013). This makes replacing fossil fuels sensitive to the price of alternative fuels. For example, the marginal cost of CO_2eq savings from 10% replacement of fossil fuels with refuse derived fuel (RDF) varied from €- 4.38/tCO_2eq when only the transport costs of RDF were covered to €0/tCO_2eq when the RDF price is €2.7/t and up to €84.2/tCO_2eq when the RDF price is €50/t (Schneider et al., 2012). Geopolymers are considered not competitive with OPC without carbon tax of US$20/t CO_2 (McLellan et al., 2011).

Conclusively, the cost of mitigation varies depending on the geographical location, on the plant capacity, on implemented mitigation measures and on the initial level of CO_2 emissions. Analyzing co-incineration in cement plants, Strazza et al. (2011) concluded that better utilization of resources improves competitiveness and profits, which also improve the environmental performance of a company. Even if the payback time of investments varies, the operational cost savings make the investments viable in most of the cases, especially when carbon trade benefits exist.

4 Conclusions

Different options were analyzed by applying a climate impact management matrix on a cradle-to-gate basis. Several datasets were formed and a model for estimating total emissions was developed using a least square fit from a matrix. This approach can also be used to estimate other missing parameters when there is enough data available with a low error margin to begin with. Key contributors to the overall CO_2 balance are clinker substitutes, technology, geographic location and primary source of energy. Uncertainties in assessing GHG emissions of the cement production raw material supply chain need further analysis. Regional variation of process and thermal energy use related CO_2 emissions is more significant than that of electricity emissions. A comparative analysis of different options to improve the CO_2 balance of cement industries revealed that the highest near term potential to avoid emissions is by replacing clinker with mineral components (MIC). Increasing the MIC use to the level of Brazil would save 312 Mt CO_2 annually with the 2013 level of global cement production. Similarly, a 2.7% reduction in the thermal energy use of the cement industry would save 28 Mt CO_2 and a 10% decrease of emissions from electricity use would save 26 Mt CO_2.These three emission savings would reduce the global emissions from cement production by 12.1% from the level of 2013. The best future options are MgO and geopolymer cements and different carbon capture technologies. In addition, the abatement cost of different investment projects were estimated using a uniform capital recovery factor. The cost of mitigation varied depending on the geographical location and on the initial level of CO_2 emissions.

This paper focuses on the cradle-to-gate management of cement industry CO_2 emissions. Many other factors, in addition to those covered in this paper, impact the sustainability of cement. One of them is recycling concrete, which contributes to the full life-cycle impact of cement as well. Future research on managing the sustainability of cement needs to include long term testing programs aimed at changing the existing standard requirements for cements and recycled concrete to encourage the building sector to use more MIC – like geopolymers and alternative types of waste material – in cements.

Abbreviations used:

CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CRF	Capital Recovery Factor
GHG	greenhouse gases
MIC	mineral components (other than clinker) in cement
OPC	ordinary Portland cement

5 Acknowledgements

R. Kajaste acknowledges with gratitude a research grant from Fortum Foundation, Finland.

Refererences

Barker, D. J., Turner, S. A., Napier-Moore, P. A., Clark, M., Davison, J.E., 2009. CO_2 capture in the cement industry. Energy Procedia 1, 87–94.

Benhelal, E., Zahedi, G., Hashim, H., 2012. A novel design for green and economical cement manufacturing. Journal of Cleaner Production 22, 60-66.

Bhushan, C., 2010. Challenge of the New Balance. New Delhi: Center for Science and Environment.

CDM (2014), htpps://cdm.unfccc.int/projects (accessed 12.08.2014).

Cembureau, 2014.The European Cement Association, http://www.cembureau.be/about-cement/key-facts-figures (accessed 01.06.2014).

Chen, C., Habert, G., Bouzidi, Y., Jullien, A., 2010. Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. Journal of Cleaner Production 18, 478-485.

Chen, L-T., Hu, A.H., 2012. Voluntary GHG reduction of industrial sectors in Taiwan. Chemosphere 88, 1074–1082.

CSI, 2011. The Cement CO_2 and Energy Protocol Version 3.0: CO2 Accounting and Reporting Standard for the 368 Cement Industry. Cement Sustainability Initiative (CSI), World Business Council for Sustainable Development (WBCSD). http://www.wbcsdcement.org/pdf/tf1_co2%20protocol%20v3.pdf (accessed 30.06.13.).

Finnsementti, 2007. Finnsementti Oy, Suomalainen sementti, Parainen, Finland, p.14.

Finnsementti, 2006. Environmental permit, Kaakkois-Suomen Ympäristökeskus, Finnsementti Oy Ympäristölupa, Nro A 2023, Dnro KAS2006Y101111, 21.12.2006.

Garg, A., Smith, R., Hill, D., Longhurst, P.J., Pollard, S.J.T., Simms, N.J., 2009. An integrated appraisal of energy recovery options in the United Kingdom using solid recovered fuel derived from municipal solid waste. Waste Management 29, 2289–2297.

Genon, G., Brizio, E., 2008. Perspectives and limits for cement kilns as a destination for RDF. Waste Management 28, 2375–2385.

GNR, 2011. cement data base http://www.wbcsdcement.org/index.php/gnr-database (accessed 01.06.2014).

Gupta, A. 2011. Cement Primer report, Ed. Cullinen, M. S., Carbon War Room, Washington D.C. Available from www.CarbonWarRoom.com (accessed 8.8.2014).

Hasanbeigi, A., Price, L., Lin, E., 2012. Emerging energy-efficiency and CO_2 emission-reduction technologies for cement and concrete production: A technical review. Renewable and Sustainable Energy Reviews 16, 6220–6238.

Hultman, N.E., SimonePulver, S., Guimarães, L., Deshmukh, R., Kane, J., 2012. Carbon market risks and rewards: Firm perceptions of CDM investment decisions in Brazil and India. Energy Policy 40, 90–102.

Huntzinger, D.N., Eatmon, T.D., 2009. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. Journal of Cleaner Production 17, 668-675.

IEA, 2012. Cement in India Roadmap. Available from http://www.iea.org/publications/freepublications/

IEA, 2010. International Energy Agency, CO_2 Emissions from Fuel Combustion. International Energy Agency, Paris, France, p. 512.

IEA, 2009. International Energy Agency,' Cement Technology Roadmap 2009, Carbon emissions reductions up to 2050', Paris, OECD/IEA.

IEA, 2007. International Energy Agency,' Tracking Industrial Energy Efficiency and CO2 Emissions'. Paris, OECD/IEA. Available from www. http://www.iea.org/publications/freepublications/.

IEA, 2006. International Energy Agency ,'Energy Technology Perspectives: Scenarios and Strategies to 2050' Paris, OECD/IEA.

IPCC, 2007. Climate Change 2007, Mitigation, Edited by Bert Metz et al, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change 2007, Cambridge University Press.

Ingrao, C., Giudice, A.L., Tricase, C., Mbohwa, C., Rana, R., 2014. The use of basalt aggregates in the production of concrete for the prefabrication industry: Environmental impact assessment, interpretation and improvement. Journal of Cleaner Production 75, 195-204.

Juenger, M.C.G., Winnefeld, F., Provis, J.L., Ideker, J.H., 2011. Advances in alternative cementitious binders. Cement and Concrete Research 41, 1232–1243.

Kara, M., 2012, Environmental and economic advantages associated with the use of RDF in cement kilns. Resources, Conservation and Recycling 68, 21– 28.

Kajaste, R., Chemicals from biomass - managing greenhouse gas emissions in biorefinery production chains - a review, 2014. Journal of Cleaner Production 75,1-10.

Kinuthia, J.M., Oti, J.E., Designed non-fired clay mixes for sustainable and low carbon use. Applied Clay Science 59–60, 131–139.

Li, C., Nie, Z., Cui, S., Gong, Z., Wang, Z., Meng, X., 2014. The life cycle inventory study of cement manufacture in China, 2014. Journal of Cleaner Production 72, 204-211.

Liang, X., Li, J., 2012. Assessing the value of retrofitting cement plants for carbon capture: A case study of a cement plant in Guangdong, China. Energy Conversion and Management 64, 454–465.

Loijos, A., Santero, N., Ochsendorf, J., 2013. Life cycle climate impacts of the US concrete pavement network. Resources, Conservation and Recycling 72, 76– 83.

Madlool, N.A., Saidur, R., Rahim, N.A., Kamalisarvestani, M., 2013. An overview of energy savings measures for cement industries. Renewable and Sustainable Energy Reviews 19, 18–29.

Madlool, N.A., Saidur, R., Hossain, M.S., Rahim, N.A., 2011. A critical review on energy use and savings in the cement industries. Renewable and Sustainable Energy Reviews 15, 2042–2060.

McLellan, B.C., Corder, G.D., Giurco, D.P., Ishihara, K.N., 2012. Renewable energy in the minerals industry: a review of global potential. Journal of Cleaner Production 32, 32-44.

McLellan, B.C., Williams, R.P, Lay, J., Riessen A. van, Corder, G.D., 2011. Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement. Journal of Cleaner Production 19, 1080-1090.

Medina, C., de Rojas, M.I.S., Frías, M., 2013. Freeze-thaw durability of recycled concrete containing ceramic aggregate. Journal of Cleaner Production 40, 151-160.

Mikulcic, H., Vujanovic, M., Fidaros, D.K., Priesching, P., Minic, I.,Tatschl, R., Duic, N., Stefanovic, G., 2012. The application of CFD modelling to support the reduction of CO_2 emissions in cement industry. Energy 45, 464-473.

Morrow, W.,R., Hasanbeigi, A., Sathaye, J., Xu, T., 2014. Assessment of energy efficiency improvement and CO_2 emission reduction potentials in India's cement and iron & steel industries. Journal of Cleaner Production 65, 131-141.

Moya, J.A., Pardo, N., Mercier, A., 2011. The potential for improvements in energy efficiency and CO_2 emissions in the EU27 cement industry and the relationship with the capital budgeting decision criteria. Journal of Cleaner Production 19,1207-1215.

MPA Cement, 2012. http://cement.mineralproducts.org/documents/MPA_Cement_SD_Report.pdf (accessed 18.8.2014).

Mutuk, T., Mesci, B.,2014. Analysis of mechanical properties of cement containing boron waste and rice husk ash using full factorial design. Journal of Cleaner Production 69, 128-132.

Nakakubo, T., Tokai, A., Ohno, K., 2012. Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery. Journal of Cleaner Production 32, 157-172.

NS, 2014. Urban growth: bio-bricks offer a whiff of the future. www.newscientist.com/article/dn25952-urban-growth-biobricks-offer-a-whiff-of-the-future.html#.U9fAV7Evsxt (accessed 29.07.2014).

OECD, 2012. OECD Environmental Outlook to 2050, OECD Publishing, pp.72-135. Available from http://dx.doi.org/10.1787/9789264122246-en.

ORNL, 2010. Boden, T.A., G. Marland, and R.J. Andres. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. ccsi.ornl.gov/Preliminary_CO2_emissions_2009 from 26 October 2011 (accessed 05.11.2011).

Ponikiewski,T., Gołaszewski, J., 2014. The influence of high-calcium fly ash (HCFA) on the properties of fresh and hardened self-compacting concrete and high performance self-compacting concrete. Journal of Cleaner Production 72, 212-221.

Rodríguez, N.H., Martínez-Ramírez, S., Blanco-Varela, M.T., Donatello, S., Guillem, M., et al., 2013. The effect of using thermally dried sewage sludge as an alternative fuel on Portland cement clinker production. Journal of Cleaner Production 52, 94-102.

Schneider, D.R., Kirac, M., Hublin, A., 2012. Cost-effectiveness of GHG emission reduction measures and energy recovery from municipal waste in Croatia, Energy 48, 203-211.

Sjølie, H.K., 2012. Reducing greenhouse gas emissions from households and industry by the use of charcoal from sawmill residues in Tanzania. Journal of Cleaner Production 27, 109-117.

Strazza, C., Del Borghi, A., Gallo, M., Del Borghi, M., 2011. Resource productivity enhancement as means for promoting cleaner production: analysis of coincineration in cement plants through a life cycle approach. Journal of Cleaner Production 19, 1615-1621.

Turgut, P., 2012. Manufacturing of building bricks without Portland cement. Journal of Cleaner Production 37, 361-367.

Usón, A.A., Lopez-Sabiro, A.M., Ferreira, G., Sastresa, E.L., 2013. Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options. Renewable and Sustainable Energy Reviews 23, 242–260.

Valderrama, C., Granados, R., Cortina, J.L., Gasol, C.M., Guillem, M., Josa, A., 2012.Implementation of best available techniques in cement manufacturing: a lifecycle assessment study. Journal of Cleaner Production 25, 60-67.

Vatopoulos, K., Tzimas, E., 2012.Assessment of CO_2 capture technologies in cement manufacturing process. Journal of Cleaner Production 32, 251-261.

Volkart, K., Bauer, C., Boulet, C., 2013. Life cycle assessment of carbon capture and storage in power generation and industry in Europe. International Journal of Greenhouse Gas Control 16, 91–106.

VDZ, 2014, http://www.vdz-online.de/en/publications/factsandfigures/ (accessed 18.8.2014).

Worrell, E., Galitsky, C., Price, L., 2008. Energy efficiency improvement opportunities for the cement industry. Berkeley CA, Lawrence Berkeley National Laboratory, Paper LBNL-72E. Available at http://ies.lbl.gov/publications/energy-efficiency-improvement-oppor-3 (accessed 5.8.2014)

Yang, K-H., Song, J-K., Song, K., 2013. Assessment of CO_2 reduction of alkali-activated concrete. Journal of Cleaner Production 39, 265-272.

Wang, Y., Zhu, Q., Geng Y., 2013. Trajectory and driving factors for GHG emissions in the Chinese cement industry. Journal of Cleaner Production 53, 252-260.

Wang, W-J., Wu, C-H., 2013. Benefits of adding rice straw coke powder to cement mortar and the subsequent reduction of carbon emissions. Construction and Building Materials 47, 616–622.

WBCSD, 2012.The Cement Sustainability Initiative - 10 years of progress– moving on to the next decade, World Business Council for Sustainable Development , June 2012, pp 12-19.

THE STRUCTURAL MODEL OF AUTONOMOUS SUSTAINABLE NEIGHBOURHOODS – NEW (SOCIAL) BASIS FOR SUSTAINABLE URBAN PLANNING

Primoz Medved [a]

[a] Interdisciplinary Doctoral Programme in Environmental Protection, University of Ljubljana, Slovenia

Name:	Primož
Surname:	MEDVED
Address:	Ilirska ulica 3, 1000 Ljubljana, Slovenia
Telephone number:	00386-31519717
E-mail:	primozmedved@yahoo.com

Abstract

Urban planning tools designers have recognized that today's prevailing sustainable neighbourhood models (urban design tools) do not take sufficiently into account the complexity of various social factors (integration of the community, local economy, identity of the community, etc.) in the implementation of new urban areas. In determining that the best practices of successful sustainable neighbourhoods are too little known and are not taken into account in urban design tools; from the fact that there is no such comparative analysis best practices, which would provide common guidelines for the implementation of new autonomous sustainable neighbourhoods, it follows the central objective of the article – creating an interdisciplinary structure for a holistic model of autonomous sustainable neighbourhoods. The aim of the article is to create a framework of sustainable principles, which derives from "good examples" of sustainable neighbourhoods, and that could represents a new mode of interdisciplinary urban planning, emphasizing the importance of socio-economic factors in neighbourhood modelling. The article will try to identify a concrete scheme of sustainable principles, which could facilitate the creation of new sustainable neighbourhoods in concrete urban environments (with due regard to local specifics). The structural model of autonomous sustainable neighbourhoods could be suitable as a tool for the implementation of sustainable principles and might upgrade existing sustainable urban planning tools. The proposed model, which is based on the comparative analysis of the best practices of sustainable neighbourhoods in Europe, is formed and structured by "the four pillars of urban sustainability" (Energy pillar and natural resources, Sustainable Transport, Socio-economic balance and Sustainable urban design elements). Each of the "pillar" incorporates several "sustainable principles".

Keywords: autonomous sustainable neighbourhoods, urban design model, socio-economic balance, sustainable urban principles, social ecology

Highlights:

- New basis for interdisciplinary urban planning underlining the importance of socio-economic factors is proposed.
- The proposed innovative model merges theoretical urban fundamentals with concrete sustainable variables, which derive from successfully implemented sustainable neighbourhoods.
- The concept of "social ecology" is introduced in urban planning (in addressing sustainable neighbourhoods).

1. Introduction

Rapid urbanisation is arguably the most complex and important socio-economic phenomenon of the 20th and 21st centuries (Allen, 2009). In year 2008, it was for the first time the majority of the world's population (about 3.3 billion people) lived in urban areas. The United Nations predicts that by 2050 over 70% of the world's population will live in urban areas (United Nations, 2008). Regarding the fact that cities represent the largest source of greenhouse gas emissions, and are at the same time the biggest energy consumers, it is necessary to transform and develop the urban areas in a sustainable way. As agreed by urban researchers, defective and inoperative urban development is the main cause of social and ecological imbalances (Young, 2011). According to Young (2011) sustainable urban planning with the "green infrastructure" represents an important strategic element to reduce carbon footprint and social inequalities in urban areas.

Transition to the sustainable society and culture is not possible without a radical change of our ethics, and therefore, a revision in our values scales (Plut, 2008). A harmonious development of a socially and ecologically oriented society, stand in stark contrast to the current economy, which homogenize, standardize the society, the nature and individuals (Bookchin, 1990). The environmental crisis has to be understood as a crisis of social relations (Chodorkoff, 1995; Gorz, 1994).

Obviously, a global simultaneous operational strategy that could change the world's direction towards a more sustainable development is not feasible. On the other hand, it is possible to perform and function sustainably at the micro level within low-carbon communities. Eco-villages were the first entities that addressed local rural communities in a sustainable way. In the last decades, several new local projects of sustainable urban transformation have appeared - the so-called sustainable neighbourhoods. Sustainable neighbourhoods could represent a stable durable solution for new sustainable urban balances at the local level (Rudlin and Falk, 2009).

2. Autonomous Sustainable Neighbourhood concept

Sustainable neighbourhood represents an experiment that could provide concrete solutions to the challenges of our currently unsustainable global environment. This relatively modern social formation could grow into a new metropolitan pattern, completely in line with sustainable development principles (Taylor, 2000). Harvey (1990) defines sustainable neighbourhood as an independent city within the city that preserves the symbolic richness of traditional urban form, and is based on dialogue and diversity. For Carley and Falk (2012), sustainable neighbourhood is:

• a sustainable living environment that is large enough to offer a wide selection of different residential areas and services, which could ensure a long-term balance in the local community;
• well-connected and easily accessible with efficient public transport;
• designed to preserve and maintain a sustainable usage of different natural resources;
• based on participation of neighbourhood residents, responsible local organizations, associations, who all together act in accordance with the principles of sustainable development.

The implementation of sustainable neighbourhoods and consequently the development of local urban communities necessitates setting clear environmental, social and economic goals that are in constant equilibrium (Churchill and Baetz, 1999). Sustainable neighbourhoods are located in urban areas, because the dense urban environment allows the “economy of scale” (unlike the eco-villages), to achieve a minimum level of (economic) self-sufficiency for public transport, recycling and educational system (Rudlin and Falk, 2009).

In the presented article topic, the concept of sustainable neighbourhood is upgraded with the term “autonomous” for two reasons. Firstly; self-sufficiency, self-management and independence represent essential social and political characteristics of particular “green” urban communities. According to Harvey (1990), sustainable neighbourhood is a basic, autonomous, self-sufficient cell in urban areas. The autonomy of sustainable neighbourhoods is reflected in decision-making (local governance) processes, self-management of local resources (energy, water, waste, etc.) and in organizing local socio-economic entities (initiatives, associations, cooperatives, etc.). The second reason for emphasizing the designator “autonomy” is its symbolic connotation. Autonomous sustainable neighbourhood reflects, indicates also an “autonomous zone” in the city, a “parallel urban space”[1] (Kos, 1993; Williams, 1990), a “heterotopia”[2] (Foucault, 1997) or a certain “counter-position” to the dominant unsustainable system (Foucault, 1997).

---

[1] Physical parallel worlds, spatial niches “allow a unique asylum, a retreat from a hyper complex, often too formal, repressive social control” (Kos, 1993:165). Parallel urban spaces are enclaves within the existing formal urban policy. They are in constant conflict with the system, but in certain circumstances can lead to a productive coexistence.

[2] Heterotopias are “real and effective spaces which are outlined in the very institution of society, but which constitute a sort of counter arrangement, of effectively realized utopia, in which all the real arrangements, all the other real arrangements that can be found within society, are at one and the same time represented, challenged, and overturned: a sort of place that lies outside all places and yet is actually localizable.” (Foucault, 1997: 352)

According to the mentioned definition(s) of autonomous sustainable neighbourhood, it is obvious that the concept of autonomous sustainable neighbourhoods does not cover just the environmental protection issues, but assumes new, active, participatory, egalitarian socio-existential impetuses.

2.1 The best examples of Autonomous Sustainable Neighbourhoods

Autonomous sustainable neighbourhoods are extremely vivid, organic formations, and the theoretical concept is not enough to explain this relatively new urban phenomenon. For further analysis it is necessary to highlight or (at this stage) at least mention the best practices that have been successfully implemented in different cities. As it will be shown in chapter 3, the model for future sustainable neighbourhoods has to derive from the specific solutions of already implemented "good examples", and not just from theoretical analysis. For this reason, the presented urban model framework is based on "real experience" of best practices (more in chapter 5). In this sub-chapter I am going to locate, identify and name various autonomous sustainable neighbourhoods.

To list the best sustainable neighbourhood examples, I have done a scientific literature review in order to identify which sustainable neighbourhoods are the most quoted, mentioned, analysed. From a detailed research and analysis of recent scientific articles,[3] books,[4] and sustainable neighbourhoods guides (handbooks, case studies),[5] it is possible to conclude that most of successful sustainable neighbourhoods are implemented in North and West Europe. Consequently, some researchers define sustainable neighbourhood concept as a North European sustainable model (Kyvelou et al., 2012). From the literature review is possible to determine that the most often cited "best examples" of sustainable neighbourhood implementation are located in Sweden (*Western Harbour* and *Augustenborg* in Malmö, *Hammarby Sjöstad* in Stockholm), Germany (*Vauban*, *Rieselfeld* and *Weingarten* in Freiburg, *Kronsberg* in Hannover, *Scharnhauser Park* in Ostfildern, *Französisches Viertel – Südstadt* in Tübingen), Holland (*EVA-Lanxmeer* in Culemborg; *Leidsche Rijn* in Ultrecht, *GWL Terrein* in Amsterdam), Finland (*Viikki* in Helsinki), Denmark (*Vasterbo* in

---

3 Schröpfer and Hee, 2008; Kasioumi, 2011; Marique and Reiter, 2011; Verdaguer Viana-Cárdenas, 2012; Williams, 2012; Anastasiadis and Metaxas, 2013.

4 OECD, 2010; Campagna et al, 2012; Bächtold, 2013; Fraker, 2013.

5 Energy Cities, 2008; Van Cutsem, 2010; Guarini, 2011; Royal BAM Group, 2011; Energy Cities, 2014.

Copenhagen), England (*BedZed* in Sutton, *Greenwich Millenium Village* in London), and Austria (*Solar city* in Linz – Pichling).

To balance the Northern European model it was also initiated a “South-European Eco-Quarter Design and Assessment” (Kyvelou et al., 2012) which highlights other urban sustainable criteria – the so called “determinants of the territorial capital”. *San Rocco* in Faenza (Italy), *Villaggio olimpico* in Turin (Italy), *Sarriguren* in Pamplona (Spain), *Trinitat Nova* in Barcelona (Spain), *Solar Village 3 - Pefki* in Athens (Greece), *Boavista* in Lisbon (Portugal), are just some urban plans, sustainable urban initiative (projects) and good practices that come from South Europe. South European sustainable neighbourhoods have great potential, but are rarely quoted or mentioned as “best examples” and are not often analysed in the scientific article, books and other sustainable neighbourhood guides.

3. Background – preconditions for a new sustainable urban model

Urban planning tools designers have recognized that today’s prevailing sustainable neighbourhood models (urban design models) do not take sufficiently into account the complexity of various social factors (integration of the community, local economy, identity of the community, etc.) in the implementation of new urban areas (Haapio, 2012: 168; Kyvelou et al., 2012: 570). The predominant models are focused mainly on the technical sphere and ecological parameters of the neighbourhoods (Georgiadou and Hacking, 2011: 186). This shortfall is also present in the most known neighbourhood sustainability assessment tool - “LEED for Neighbourhood development”, which ignores the influence of the local community in the process of designing sustainable neighbourhoods (Sharifi and Murayama, 2013: 78). Some other distinctive models of sustainable neighbourhoods (BREEAM, CASBEE, One Planet Living, etc.) include certain “social parameters” in the implementation process of sustainable neighbourhoods, but these factors represent only a marginal part of the models and are rarely applied in practice (Haapio, 2012; Sharifi and Murayama, 2013).

The other main shortcoming of prevailing sustainable neighbourhood assessment tools is that current models do not reproduce sustainable principles from existing “good practices”. Models do not relate to concrete, already implemented sustainable neighbourhoods (Engel - Yan et al., 2005; Marique and Reiter, 2011). Modern urban planning should be developed from the perspective of sustainable communities and at the same time should constantly refer to the best examples of sustainable neighbourhoods (Engel - Yan et al., 2005).

The aim of the article is to open a discussion about a more holistic perspective in sustainable urban design, with the development of the overlooked aspect in neighbourhood design- *the socio-economic balance*. The desired outcome of this paper is building up an interdisciplinary draft, “a skeleton”, a structure of a possible future autonomous sustainable neighbourhood model, which could overcome the two main shortcomings of current sustainable urban design tools.

4. Methodology and approach

Article research methodology is defined with a multitude of different methodological approaches. The complete research methodology composition includes scientific literature review with analysis of case studies, analysis of primary sources, analysis with personal participation, personal interviews and an international comparative analysis of the best practices of sustainable neighbourhoods in Europe. In 2013 and 2014, I visited and lived in five of most successful and advanced neighbourhoods[6] where I had the opportunity to interview the main actors,[7] who have created and significantly contributed to the development of green urban experiments.

The article’s methodological approach in constructing innovative urban model is divided in two stages. In the first phase, I created the theoretical framework of sustainable determinants for the model; also with the examination of the most known sustainable urban tools. From the initial theoretical analysis of books and scientific articles about sustainable neighbourhood, I could determine a basic network of interconnected sustainable principles, which was fundamental for the

[6] *Western Harbour* in Malmö, *Hammarby Sjöstad* in Stockholm, *Vauban* and *Rieselfeld* in Freiburg, *Französisches Viertel – Südstadt* in Tübingen.

[7] In Freiburg (Vauban and Rieselfeld) I had the opportunity to interview Andreas Delleske (the urban planner of the Freiburg municipality, who had planned Freiburg’s sustainable neighbourhoods), Wulf Daseking (the leader of the former community initiative Forum Vauban) and Sigrid Gombert (past editor of the local newspaper Vauban Actuel). In Tübingen I interviewed Marc Mausch (the editor of the local Südstadt community internet platform) and Hopfner Karin (Tübingen urban planner). In Western Harbour (Malmö) I interviewed Eva Dalman (former project manager of the district Bo01 - Western Harbour), Marial Loof and Roland Zinkernagel (both: Environmental department of the Malmö municipality) and Jan Johansson (Real estate department of the Malmö municipality). In Hammarby Sjöstad (Stockholm) I interviewed Helene Wintzel (co-planer of the community “Hammarby Sjöstad 2020”), Bjorn Cederquist (Urban planning sector of Stockholm municipality), Alan Larsson (ex European Commissioner and urban developer of the local platform “Hammarby Sjöstad 2020”).

later upgrade with factual, real-life implementation aspects from concrete sustainable urban development.

In the second phase I visited and analysed best practices of sustainable neighbourhoods (in Sweden and Germany), where I interviewed the main neighbourhood developers, urban planners and neighbourhoods' citizens. With personal involvement, scientific observations, interviews and collection of specific empirical data in each sustainable neighbourhood I was able: to identify the key urban "sustainable elements" in each district; to study the formal legal basis of the neighbourhoods; to understand unique historical conditions allowing the first implementation of sustainable neighbourhood in each city; to understand the differences between the selected neighbourhoods, etc. I could compare all common and unique sustainable factors, "sustainable principles" of the best green districts in order to create a basic structure for an interdisciplinary model of autonomous sustainable neighbourhoods.

5. The Structural model of Autonomous Sustainable Neighbourhoods

The proposed structural model is determined and formed by the "4 pillars of urban sustainability" (*Energy pillar and natural resources, Sustainable Transport, Socio-economic balance and Sustainable urban design elements*). Each of the "pillar" incorporates several "sustainable (urban) principles" (more in Table 1; p.9). *Sustainable (urban) principles* are sustainable function, green policies, sustainable features, neighbourhood's characteristics, "elementary elements" of sustainable neighbourhood design. Sustainable principles represent propositions, alternatives, solutions to current unsustainable practices in cities. They embody sustainable guidelines that are adaptable, with consideration of local spatial and social specifics, and realizable for the transformation of (currently) unsustainable urban environments.

Table 1: Configuration of the “Structural model of Autonomous Sustainable neighbourhoods”[8]

SUSTAINABLE PRINCIPLES OF AUTONOMOUS SUSTAINABLE NEIGHBOURHOODS			
ENERGY PILLAR (AND NATURAL RESOURCES)	SOCIO-ECONOMIC BALANCE	SUSTAINABLE TRANSPORT	SUSTAINABLE URBAN DESIGN ELEMENTS
Renewable Energy Co-operative	Local (organic) food Co-operative	Efficient public transport	*(heterogeneous multi-purpose community space; convergent central market, green spaces, public spaces, road closures, bike trails, clearly defined neighbourhoods’ boundaries , etc.)*
Energy-saving (passive) multi-dwelling buildings	“Social ecology” as a policy framework of the neighbourhood	The ban of cars	
Innovative solutions to stimulate recycling and to reduce natural resources (water and waste management)	Local exchange trading system (LETS)	Promoting cycling and walking	*3 sub-groups:* *“Quality of life with sustainable urban planning”* *“Protection of nature and urbanism”* *“Compactness of the buildings and the proximity of services”*
	Local economy		
	Identity of the local community and culture		

Source: Primož Medved, 2015

Each sustainable principle (presented in Table 1) encompasses several sustainable variables. For the purpose of further analysis, sustainable principles are divided into qualitative and quantitative variables (see Appendix A: Sustainable variables scheme). In that way, it is possible with qualitative variables (of sustainable principles) to focus on “unmeasurable”, descriptive aspects and “soft policies” of neighbourhoods. On the other hand, quantitative variables allow empirical comparisons of different neighbourhoods. The presented variables (Appendix A) represent the “real core” of the article, and show some very concrete focus points, that could stimulate new approaches in urban planning.

As could be seen from the Table 1 and from the model’s extended version in Appendix A, the proposed structure of sustainable principles tries to overcome the identified shortcomings (defined in chapter 3) in sustainable urbanism with emphasizing and suggesting new (social) aspects, new

[8] The structural model of autonomous sustainable neighbourhoods is based on results and interpretations of analyses from: the scientific literature review, international comparative analysis and case studies of autonomous sustainable neighborhoods, evaluation of the existing models of urban design tools (LEED, BREEAM, CASBEE, One Planet living, etc..), interviews with planners and representatives of civil initiatives of some of the most known sustainable neighborhoods in Europe (Vauban, Riesefeld, Französisches Viertel, Western Harbour, Hammarby Sjöstad).

points of references in the development of urban areas (with the innovative sustainable pillar: *Socio economic balanc*e; with the sustainable principle *Renewable energy co-operatives, etc.*). At the same time, the proposed framework preserves some “habitual”, standard sustainable principles that are typically used in common urban models (*Ban of cars, Public Transport, Public green spaces, Sustainable water management,* etc.) and puts it on an “equal level” of importance with the social variables.

The article’s model (in the “*Energy pillar*”) gives slightly more attention to the neighbourhood’s “energy aspects” compared with other natural resources. This controversial (symbolical) choice derives from the fact that “energy issues” in the urban context (in)directly condition most of the neighbourhood’s everyday activities. Neighbourhood’s energy needs include energy demand from edifices and other urban features; such are local waste and water systems, parks, public lighting as well as the energy demand from the public transport.

Sustainable Transport pillar is fundamental for the existence of a sustainable life style within the neighbourhood. An exemplary sustainable neighbourhood should have a functional, integrated public transport system. Urban green districts usually try to avoid alienated, typical suburbian single-family houses, which necessitate, because of the dispersal construction ideology, more than two cars per family.

The creation of a forth individual pillar of *Sustainable urban design elements* is also not common for traditional neighbourhoods tools, but it is essential, because represents a “physical environment” for sustainable principles’ essence and its manifestation. It symbolically embodies an “adhesive” which connects, integrates all the sustainable principles of different sustainable pillars.

For example; in the *heterogeneous multi-purpose community space (*Sustainable urban design element), which is in an energy passive building (Energy pillar), local citizens meet and discuss about local issues, about their common companies (Local economy; Socio-economic balance), like solar panels cooperatives (Energy pillar), or cooperatives of organic food (Socio-economic balance). Such community spaces, neighbourhoods’ collective buildings are important, because they enforce the local community identity (Socio-economic balance).

This is just one general example where it is possible to identify the inter-connectivity of very different sustainable variables, which forms a structure of inter-dependency between variables of autonomous sustainable neighbourhood.

The most innovative and ambiguous part of the presented structural model, represents the inclusion of the sustainable pillar “*Socio-economic balance*”. For this reason, the sub-chapter 5.1 will focus in detail on different characteristics of this innovative pillar, which proposes a new perspective in perceiving sustainable communities.

5.1 Socio-economic balance – the new key pillar for interpreting sustainable neighbourhood's context

As presented in the chapter 3, addressing autonomous sustainable neighbourhoods social issues have been mostly overlooked in urban planning tools. For this reason this article and the proposed model try to overcome this shortcoming with encouraging new planning approaches, which are concentrated in the pillar "*socio-economic balance*" (see also Appendix A). To understand better the essence of the new proposed pillar, it is primarily necessary to understand the holistic perspective of sustainable governance and social cooperation in the local urban space. The explication of the complex social interaction in a specific (sustainable) urban context lies in the fundamentals of the "social ecology" concept.[9]

Social Ecology, as a political framework, represents a radical critique of contemporary social political and environmental trends. It embodies a reconstitution of sustainable, communitarian (collective) and ethical approach to the society. The concept of social ecology is correlated with the "libertarian municipalism,"[10] which commits to the decentralization of power and its organization at the local level (Chodorkoff, 1995). Social ecology emphasizes the importance of the "moral economy" (Bookchin, 1990, 1986). The moral economy, at the level of autonomous sustainable neighbourhoods, is also enacted through egalitarian non-monetary exchange, "time bank" or local exchange trade system (LETS) scheme. LETS scheme represents a counterweight to money exchange, to monetised evaluation of work.[11] Moral, sustainable, local economy represents an alternative to destructive dynamics of today's predominant neoliberal individualistic economic activities.

---

[9] Social Ecology is a philosophical branch firstly initiated by the French anarchist and geographer Elisée Reclus, but it was Murray Bookchin, who in the sixties revitalized the concept of social ecology in theoretical and in practical terms. Social ecology epitomize a critique of current social, political, and anti-ecological global trends; it express a reconstructive, ecological, communitarian, and ethical approach to society.

[10] Libertarian municipalism is a political project to give to the politics a more ethical character with the bottom up ("grassroots") organization. It supports local urban neighborhood assemblies, and promotes a coordinated bottom-up strategy development (Chodorkoff, 1995). Libertarian municipalism strives to regain the public sphere; the public space for genuine, egalitarian, communitarian action. Libertarian municipalism is not only a political strategy, but also tries to develop democratic possibilities that are latent or in embryonic state, to form a new radical configuration of the society. The aim is a communitarian society that combines human needs with ecological necessities and develops a new ethic based on reciprocity (Bookchin, 1991).

[11] However, in practice, not many sustainable neighbourhoods have adopted the LETS scheme; some of them introduced it just partially (f.e. Vauban).

Local urban development should be focused on conserving and strengthening the local community and on an active role of its members. Local (urban) community represents the primary, central sustainable principle of any sustainable neighbourhoods. Local community with a strong identity to the local space stimulates the development of vibrant local culture activities and defines the sustainable neighbourhood's quotidian dynamism.

As already indicated, it is impossible to persist on theoretical ideals when speaking about creating vivid districts. Sustainable models, urban tools should be based on "real", already implemented good practices. Although it was inspired and formed from "real" good practices, the pillar "socio-economic balance" still represents a "desirable formula" of different sustainable social factors in an urban space. Apart from theoretical ideals, it is very interesting to understand how (to what extent) this "desirable formula" is applied in practice. If we look to some of the most successful neighbourhoods, it could be seen that socio-economic sustainable principles are interpreted, manifested, concretized in very different ways. In some sustainable neighbourhoods, like in Vauban (Freiburg), it is possible to identify the manifestation of all mentioned sustainable principles of the pillar "socio-economic balance".

Vauban has a very strong local community, which has grown gradually and has constantly consolidated the particular local identity. Over the years, with the expansion of the neighbourhood, local residents established a local grassroots community association, called "Forum Vauban", which represents a reference point and a link between all neighbourhood's associations, the municipality and local residents. Vauban's local community has created a balanced and vivid network of different social groups, local entities and associations such as (Gombert, 2013; Bächtold, 2013; Daseking, 2013; Gombert, 2013): housing co-operatives, groups of co-builders ("Baugruppen"), co-operative of organic food "Quartiersladen", associations for children, association for dementia illness, association for pedestrians, associations for the elderly, the autonomous newspaper "Vauban Actuel", Genova cooperative, self-organised association S.U.S.I. and Forum Vauban (now called "Stadtteilverein Vauban"). Vauban's community was very active in creating local economic entities with locally concentrated ownership. Local residents' ownership over local resources (particularly renewables and food distribution system) allows them to achieve a greater autonomy in decision-making and a notable degree of self-sufficiency. Some elements of Vauban's LETS scheme are manifested in the monthly "exchange market", which takes place at the neighbourhood's main plaza Alfred-Döblin-Platz (Delleske, 2013).

However, not all successful sustainable neighbourhoods have implemented such strong and equilibrated socio-economic elements. Vauban is a typical grass-root project, where involvement of citizens through various association (S.U.Z.I., Forum Vauban) was very intense. On the other hand, some top-down driven successful sustainable neighbourhoods (like the Swedish green districts Western Harbour in Malmö, and Hammarby Sjöstad in Stockholm) had different implementation processes. The community identity and the cooperation of neighbourhoods' residents in Sweden are not comparable with Vauban's (Dalman, 2014). For example, in Western Harbour the population structure is very homogenised. The district is also called "upper-middle class ghetto" (Holgersen, 2014). There is no community centre[12] for the local population and the cooperation, connection of the local community is weak. This could derived also from the fact that the whole area was designed with the top-down approach from the municipality, without the citizens involvement (Loof, 2014). From a typical top-down development of urban areas, it is more difficult to expect a strong identity or vivid citizens' initiatives in the local environment.

6. Conclusion, discussion and reflection

The proposed structural model of autonomous sustainable neighbourhoods could stimulate a new perspective, a new mode in urban planning. The presented urban tool framework could serve as a pre-structure of an interdisciplinary model for sustainable urbanism of the 21 century, which addresses sustainable neighbourhoods in a holistic way. The future model, with an adequate adaptation to local specifics of each micro urban cosmos, could transfer the main sustainable principles of the best sustainable neighbourhoods to particular urban environments in different cities.

However, despite the ambitious intent to create a framework of an experimental sustainable urban model, article opens up many unanswered questions and new subjects of discussion. Firstly, the model is very ethnocentrical, it focus on the European perspective and is based just on North-European examples. It is impossible to aggregate all the different global cultural dimensions of each city, and it is probably impossible to create a true global universal model. From that point of view, it maybe be more suitable for the model to be called (North) European model of autonomous sustainable neighbourhood. Secondly, despite the fact that the article tries to join theoretical and practical aspects (determinant) from different methodological approaches, the model (in Appendix A) will always be somehow unfinished. There would always be one factor, one variable that is fundamental, and is not mentioned in the model. Creating a sustainable urban model is a constant work in progress, and the proposed model is just a starting point, an upgradable scheme. Thirdly, at

[12] In the interview Eva Dalman, the initial developer of Bo01 (in Western Harbour, Malmö), mentioned that the community centre was not introduced also because the resident were not interested in that kind of common areas (Dalman, 2014).

this point in 2014, is maybe still too soon, too utopian, to introduce the concept of social ecology into the model, because is not entirely implemented, expressed even in the most advanced sustainable neighbourhoods (f.e. in the mentioned Swedish sustainable neighbourhoods). Realistically, from a detailed analysis of all successful neighbourhoods in chapter 2.1, just a few neighbourhoods could entirely cover all sustainable factors, mentioned in the model.

Despite some obvious deficits of the model, the suggested framework of the proposed model, could still implicate an another dimension, an alternative perspective in urban planning, which is in contrast with the well-established methods. The principal aim of this article is to open up a discussion for a new vision in sustainable urban planning and to suggest some new, concrete sustainable variables for (sustainable) urban planning tools. The pillar "Socio-economic balance" introduces a new paradigm of egalitarianism based on direct democracy in urban communities. Autonomous sustainable neighbourhoods (in theory; not always in practice) could act as a social, economic cultural contra-position against the dominant (neoliberal) order. Autonomous sustainable neighbourhood is not a utopian vision but a real transition to a new, unnamed social order that fragmentally already exists.

APPENDIXES; Appendix A: Sustainable variables scheme – The structural model of Autonomous Sustainable Neighbourhoods

1. "ENERGY PILLAR" (and natural resources)

SUSTAINABLE PRINCIPLES	*Points of interest - urban modelling focus points (qualitative research variables)*	*Determinants for the comparative analysis (quantitative research variables)*
Renewable Energy Co-operative	- establishment and organizational structure of RES[13] cooperatives - typology of implemented RES - co-operation between municipalities and civil initiatives →for the creation of cooperatives	- local population's ownership share of RES - share of local RES in regard with the total energy consumption - energy autonomy (%) - energy consumption (per capita) regarding: 1.electricity, 2. heating, 3.transportation
Energy-saving (passive) multi-dwelling buildings	- method of setting mandatory standards - exerting pressure of the civil initiative or the county for the restoration of wasteful buildings - usage of ecological materials for the construction of neighbourhoods (wood, glass, wool, etc.) - economic aspect of constructions and maintenance; WLC criterion ("whole life costing") - impact of constructions on the environment; CO2 emissions - health effects depending on the materials used - position of buildings with the consideration of "solar geometry" - *Energy efficient buildings*: ventilation; position; insulation; use of water; use of renewable energy for the electricity and heating; recycled materials; concept of smart homes, which adapts to external weather conditions; maximization of the exploitation of energy and water, passive solar energy utilization; acoustic comfort	- proportion of passive or "plus energy" buildings, - mandatory energy standards established at the level of municipalities or neighbourhoods - energy consumption for heating and electricity (per capita) - proportion of neighbourhoods buildings built with "natural materials"
Innovative solutions to stimulate recycling and to reduce natural resources (water and waste management)	- introduction of innovative concepts to reduce the consumption of natural resources (bio-gas from compost, vacuum toilets, etc.) - particular recycling methods - methods of reducing the water consumption - re-use of rainwater - water-saving modes (three treatment categories: black water, grey water and rainwater) - initiatives to reduce the amount of garbage - organic garbage for gardens - "green roof"	- recycling rate (kg / capita) - general -recycling rate (kg / capita) - which is carried out in the neighbourhood - usage of recycled material in the neighbourhood - water consumption per capita - capture rate of rainwater - kg of produced trash per capita

[13] RES: Renewable Energy Sources

2. "SUSTAINABLE TRANSPORT"

SUSTAINABLE PRINCIPLES	*Points of interest - urban modelling focus points (qualitative research variables)*	*Determinants for the comparative analysis (quantitative research variables)*
Efficient public transport	- initial establishment process of the public transport - diversity, development and availability of public transport system - pollution of public transport - actual fluidity-connectedness with the rest of the city - "car sharing" initiative - initiatives to reduce the need for vehicles - public transport-links with the regional hub of public transport / metro to the train station, to the airport - reducing the "need" for cars - proximity of essential services / urban density - multimodality of the sustainable transportation	- closeness to the railway, bus, metro or tram station (measured from the centre and the extremities of a neighbourhoods) - level of development of public transport system (ramifications, the frequency of arrivals) - proximity to crucial services (market, school, etc.). - time of the construction of public transportation in the neighbourhood: before the buildings in the neighbourhoods / or progressive construction / or the introduction of public transport after the neighbourhood completion - time needed (using public transport) to the city centre; the time required to train station; the time required to the first airport (for all, measured at different times)
Ban of cars	- methods of reducing car flow or a complete ban of cars in the neighbourhood - initiatives from local community or municipality - parking lots outside the neighbourhood / in the neighbourhood / restricted parking areas / under the blocks - "fee" for driving in the neighbourhood / town?	- no. car ownership per capita - no. garage places outside the neighbourhood or within the neighbourhood - size (proportion) of roads intended for cars in the neighbourhood
Promoting cycling and walking	- cycling and walking routes in the neighbourhood; accessibility to the city centre from the neighbourhood - parking spaces for bicycles and other initiatives -"walkability"- safety, aesthetic	- no. of bike roads, routes - amount of walking paths

3. "SOCIO-ECONOMIC BALANCE"		
SUSTAINABLE PRINCIPLES	***Points of interest - urban modelling focus points (qualitative research variables)***	***Determinants for the comparative analysis (quantitative research variables)***
Local exchange trading system (LETS)	- methods of organizing LETS schemes - typology of organizing time banks (or LETS schemes) - "exchange markets" - "initial form" of LETS (exchange of goods, vouchers- "goods for goods")	- number of people involved in LETS - growth trend of LETS
"Social ecology" as a policy framework of the neighbourhood	- level of direct democracy - "bottom up" (or "top down") approach in creating neighbourhoods - degree of self-management and autonomy in decision-making - caring for unprivileged groups - associations for the elderly, children, handicap people - solidarity between people (initiative, laws, etc.) - (symbolic) importance of the first sustainable neighbourhoods in the city- implication for vicinity (town, region,..)	- proportion of people involved in decision making processes - number and typology of topics discussed through direct democracy - number of self-managed initiatives, cooperatives - number of initiatives aimed for integrating marginalized groups
Local (organic) food Co-operative	- urban gardens - synergy with local farmers - local (organic) market and the location of marketplaces - local food cooperative characteristics - regional "food chain" integration	- number of urban gardens - proportion of people involved in the local food co-operative - frequency, variety and size of the local market
Identity of the local community and culture	- participation level in the neighbourhood - solidarity within the community - diversity of local civil initiatives and associations - intergenerational solidarity - events to strengthen the identity (f.e. neighbourhood festival etc.). - "individuality" (against the standardization) of buildings - preservation of local culture, cultural heritage - concern for the preservation of local traditions - preservation of certain historic buildings - development of neighbourhood cultural activity	- existence of the local newspaper and community internet platform - number of associations, initiatives - level of crime in relation to the other parts (relative / absolute) - number and range of networking events for the community
Local economy	- organization and promotion of local economic activities - balance in "economical exchange" between the neighbourhood and the city and the wider region - diversification of services - local craft activities - initiatives to prevent commercial food (and other) chains in the neighbourhood - diversity and variety of economic activities in the neighbourhood	- proportion (number) of people who work in their own neighbourhood - number of local businesses (how many of local business are owned locally) - proportion of people using local services

4. ***"SUSTAINABLE URBAN DESIGN ELEMENTS"***

SUSTAINABLE PRINCIPLES	***Points of interest - urban modelling focus points (qualitative research variables)***	***Determinants for the comparative analysis (quantitative research variables)***
"Quality of life with sustainable urban planning"	- heterogeneous multi-purpose community space (as a central facility of the neighbourhood) for strengthening the local community identity - convergent central market (as a community focal point) - green areas and public spaces - ban of automobiles - clear boundaries of the neighbourhood (which strengthen the adherence of the citizens) - mixed housing typology (mixed use and also personalized buildings' "form design") - public street lighting (to revitalize the public space; to prevent micro criminality) - designing neighbourhoods to reduce crime rates; CPTED (Crime Prevention Through Environmental Design) - concept of "healthy neighbourhoods" with a design that encourage walking / bicycle use (aesthetics, connectivity, permeability, lighting, bike trails, proximity to services)	- proportion, area (ha) and number of public spaces - no. of structures / buildings of public institutions (for public interest) - no. of community centres (and size) - no. of parks, squares, playgrounds - average distance to the first the neighbourhood park - share of "green roads" with trees - diversity of construction, heterogeneous aesthetics
"Protection of nature and urbanism"	- determination of green areas - biodiversity / diversity of vegetation - taking into account the wind flow as a "natural ventilation" - integration of the natural landscape in the neighbourhood (strategy at the neighbourhood level, city, region) - existence of so-called "natural corridors" - "wildlife corridors" - typology of vegetation in the neighbourhood - protection of natural habitat and rare species of plants and animals	-proportion, area (ha) and number of parks and green spaces - number of norms to protect the local natural environment
"Compactness of the buildings and the proximity of services"	- urban design in the direction of compact multi dwelling construction or single sub-urban (suburbia) family houses - stimulating the creation of services in the neighbourhood - density of buildings, constructions - services in the ground floors of the buildings	- no. population per hectare - no. service per hectare - presence of banks, post offices, shops, markets elementary and secondary schools in the neighbourhood - distance to the first ambulance and fire stations - number of building and floors/ per hectare

Source: Primož Medved, 2014

References

1. Allen, A., 2009. Sustainable cities or sustainable urbanisation? Palette UCL's journal of sustainable cities. URL: http://www.ucl.ac.uk/sustainable-cities/results/gcsc-reports/allen.pdf .
2. Anastasiadis, P., Metaxas G., 2013. Formulating the principles of an eco-city. World Transactions on Engineering and Technology Education 11 (4), 394–399
3. Bächtold, P., 2013. The Space-Economic Transformation of the City. Springer, Heidelberg.
4. Bookchin, M., 1990. Remaking Society – Pathways to a green future. South End Press, Boston.
5. Bookchin, M., 1986. Municipalization: Community Ownership of the Economy. Green Perspectives 2, 1–3.
6. Bookchin, M., 1991 Libertarian Municipalism: An Overview. Green Perspectives 24, 1–6.
7. Campagna M., De Montis A., Isola F., Lai, S., Pira, C., Zoppi, C., 2012. Planning Support Tools: Policy Analysis, Implementation and Evaluation. FrancoAngeli, Milano.
8. Carley, M., Falk, N., 2012. Sustainable urban neighbourhoods – Building communities that last. Joseph Rowntree Foundation, York. URL: http://www.jrf.org.uk/.
9. Chodorkoff, D., 1995. Redefining Development. Society and Nature 3 (1), 117–128.
10. Churchill, C., Baetz, B., 1999. Development of decision support system for sustainable community design. ASCE Journal of Urban Planning and Development 125, 17–35.
11. Dalman, E., 2014. Personal interview. Lund.
12. Daseking, W., 2013. Personal interview. Freiburg.
13. Delleske, A., 2013. Personal interview. Freiburg.
14. Energy Cities, 2008. Guide book of Sustainable Neighbourhoods in Europe. URL: http://www.energy-cities.eu/ .
15. Engel-Yan, J., Kennedy, C., Saiz, S., Pressnail, K., 2005. Toward sustainable neighbourhoods: the need to consider infrastructure interactions. Canadian Journal of Civil Engineering 32 (1), 45–57.
16. Fraker, H., 2013. The Hidden Potential of Sustainable Neighborhoods. Island Press, Washington.
17. Foucault, M., 1997. Of Other Spaces: Utopias and Heterotopias, in: Leach, N. (Ed.), Rethinking Architecture: A Reader in Cultural Theory. Routledge, New York, pp. 330–336.
18. Georgiadou, M. C., Theophilus, H., 2011. Future-Proofed Design for Sustainable Communities. Sustainability in Energy and Buildings - Smart Innovation, Systems and Technologies 7, 179–188.
19. Gombert, S., 2013. Personal interview. Freiburg.
20. Guarini, S. M., 2011. Quartieri Ecosostenibili in Europa. URL: http://www.ocs.polito.it/ .
21. Gorz, A., 1994. Capitalism, socialism, ecology. Verso, New York.
22. Haapio, A., 2012. Towards sustainable urban communities. Environmental Impact Assessment Review 32, 165–169.

23. Harvey, D., 1990. The Condition of Postmodernity. Blackwell, Cambridge.
24. Holgersen, S, 2014. The Rise (and Fall?) of Post-Industrial Malmö Investigations of city-crisis dialectics. Lund University, Lund.
25. Kasioumi, E., 2010. Sustainable Urbanism: Vision and Planning process through an examination of two model neighbourhood developments. Berkley Planning Journal, 91–
26. Kyvelou, S., Sinou, M., Baer, I., Papadopoulos, T., 2012. Developing a South-European Eco-Quarter Design and Assessment Tool Based on the Concept of Territorial Capital, in: Curkovic, S. (Ed.), Sustainable Development – Authoritative and Leading Edge Content for Environmental Management. Intech, Rijeka, pp. 561–588.
27. Kos, D., 1993. Racionalnost neformalnih prostorov. FDV, Ljubljana.
28. Loof., M., 2014. Personal interview. Malmö.
29. Marique, A. F., Reiter, S., 2011. Towards more sustainable neighbourhoods: are goods practice reproducible and extensible? A review of a few existing sustainable neighbourhoods, in: Evrard, A., Bodart, M. (Eds.), Proceedings of International Conference PLEA 2011: Architecture & Sustainable Development. Presses Universitaires de Louvian, Louvian, pp. 27–32.
30. OECD, 2010. Cities and Climate Change. OECD Publishing, Paris.
31. Plut, D., 2008. Vrednotenje geografskega okolja in okoljska etika. Dela 29, 63–75.
32. Royal BAM Group, Eindhoven University of Technology, 2011. Strategic priorities for the new framework programme for research and innovation covering the period 2014 – 2020. URL: http://ec.europa.eu/information_society/activities/sustainable_growth/cities/index_en.htm .
33. Rudlin, D., Falk, N., 2009. Sustainable Urban Neighbourhood: Buliding the 21st Century Home. Architectural Press, Oxford.
34. Schroepfer. T., Hee L., 2008. Emerging Forms of Sustainable Urbanism: Case Studies of Vauban Freiburg and solarCity Linz. Journal of Green Building 3 (2), 65–76.
35. Sharifi, A., Murayama, A., 2013. A critical review of seven selected neighbourhood sustainability assessment tools. Environmental Impact Assessment Review 38, 73–87.
36. Taylor, N., 2000. Eco-Villages: Dream and Reality, in: Barton, H. (Ed.), Sustainable Communities: The Potential for Eco-Neighbourhood. Eartscan Publication, London, pp. 20–45.
37. United Nations, 2008. World Urbanization Prospects: The 2007 Revisions. United nation, New York.
38. Van Cutsem, M., 2010. Cities of tomorrow. URL: http://ec.europa.eu/ .
39. Verdaguer Viana-Cárdenas, C., 2012. Integrated planning for ecological urban regeneration. Planning Theory and Practice, 13 (1), 168–170.
40. Williams, J., 2012. Regulative, facilitative and strategic contributions of planning to achieving low carbon development. Planning Theory and Practice 13 (1) , 131–144.
41. Williams, O. P., 1971. Metropolitan Political Analysis: A Social Access Approach. The Free Press, New York.
42. Young, R., 2011. Planting the Living City. Journal of the American Planning Association 77 (4), 368–381.

Drivers for the introduction of clean energy products and technologies: differences and similarities among key industry sectors in the EU and Japan

Masachika Suzuki
Graduate School of Global Environmental Studies, Sophia University
7-1 Kioi-cho, Chiyoda-ku, Tokyo, 102-8554 JAPAN

Abstract

Keywords: Clean energy, corporate strategy, sustainable reporting, isomorphism, country of origin effect

Corresponding author: Masachika Suzuki
Address: Graduate School of Global Environmental Studies, Sophia University
7-1 Kioi-cho, Chiyoda-ku, Tokyo, 102-8554 JAPAN
Email: suzuki@genv.sophia.ac.jp

Introduction[1]

Introduction of clean energy products and technologies has increasingly become a key strategic and managerial issue for firms in various industry sectors. Many firms report their initiative and performance of clean energy in their corporate sustainability reports. There are substantial research suggesting both tangible and intangible benefits for the firms that have successfully adopted clean energy technologies including reduction of operational cost, mitigation of regulatory risk, successful marketing products and technologies among energy cost conscious customers and enhancing their corporate brand.

This paper addresses corporate strategy on the introduction of clean energy products and technologies. Clean energy products and technologies discussed in this paper include both renewable energy technologies and energy efficiency improvement products and technologies. In particular, the paper suggests investigating whether or not there are differences and

[1] Some parts of the paper (mainly, Section 3 through Section 5) were presented at the 16th Conference of the European Roundtable on Sustainable Production and Consumption (ERSCP) in June 2013.

similarities between the EU and Japan with respect to the drivers for the introduction of clean energy products and technologies. Some companies recognize clean energy as attractive industry opportunities, while other companies promote them as part of their corporate social responsibility initiatives. The result of this study contributes to the theoretical discussion whether we can observe isomorphism or "country of origin effect" in reported corporate strategy in the introduction of clean energy products and technologies.

1. Focus of this study: clean energy products and technologies

Clean energy products and technologies include both renewable energy and energy efficiency improvement products and technologies. The IEA (International Energy Agency) report entitled "Tracking Clean Energy Progress 2013" addresses key clean energy technologies such as renewable energy, gas-fired power generation, electric and hybrid-electric vehicles as well as energy efficiency improvement technologies in buildings and technologies use for the smart grid system (IEA 2013). According to the report, carbon capture and storage technologies are also recognized as clean energy technologies (IEA 2013).

The ways that firms utilize clean energy products and technologies vary among different industry sectors. For the energy-intensive industry sectors such as oil and gas, chemical, steel, cement and pulp and paper productions, manufacturing is the main process where firms tend to introduce clean energy products and technologies since there are large potentials in reducing the use of fossil-fuel based energy in this process. For the firms in the consumer product industry sectors such as automobiles and electronics, addressing clean energy products and technologies for their end-users is more relevant since the energy use at the consumption stage is much larger than the manufacturing process. For the retail industry sector, the integration of clean energy technologies into the supply chain management is essential in reducing energy use and cost in the logistics or transportation process.

As the introduction of clean energy products and technologies has increasingly become a key strategic and management issue for firms, there have been substantial research on the utilization of clean energy products and technologies. However, in the study of business management, corporate strategy on clean energy products and technologies has not received much attention, especially, compared to environmental strategies such as climate change strategy. Climate change, in fact, has attracted a significant level of interests among business management scholars since the 1990s. On the other hand, the corporate strategy on clean energy products and technologies has only discussed until now as part of company's climate change strategy.

2. Structure of this paper

The first part of this paper illustrates theoretical discussions on corporate strategy. This will help us to understand how and why firms introduce clean energy products and technologies. Section 3 demonstrates that according to previous research in business management, there are internal and external factors leading to the formulation of corporate strategy. One important internal factor is the level of firm's resources and capabilities. Some scholar argues that the firms with larger resources and capabilities tend to address environmental (or clean energy) issues more proactively.

While the internal factors are often classified as "firm-specific factors", the external factors can be called as "home country factors." Sections 4 and 5 elaborate discussions among researchers on the consequences of receiving the external pressures upon firms. Based on the discussions, some scholars might argue that between European and Japanese firms, for example, there are convergent trends on the corporate clean energy strategy since there is the pressure to handle clean energy issue in the global scale. On the other hand, some scholars might claim that as long as there are different sets of regulations as well as social expectations for clean energy in the EU and Japan, corporate strategy on the topic would remain divergent between the two regions.

On the basis of the theoretical discussions from Section 3 through 5, Section 6 elaborates the drivers for the introduction of clean energy products and technologies. It attempts to classify different drivers discussed among previous research. The drivers include possibility for cost reductions and profit making opportunities, mitigation of regulatory risk, successful marketing products and technologies among energy cost conscious customers and enhancing their corporate brand. Some firms promote clean energy products and technologies as new products that have not launched yet in new markets. In this case, these firms recognize clean energy technologies as attractive business opportunities, while other companies promote them as part of their corporate social responsibility initiatives.

Section 7 summarizes discussions from Section 3 to 6. In addition, it suggests a design of an empirical study that examines similarities and differences in the drivers for the introduction of clean energy between the EU and Japan. The study investigates whether or not there are convergent or divergent trends in corporate clean energy strategy between the EU and Japan. The result of the study may contribute to the discussion whether or not we can observe isomorphism or “country of origin effect” between the EU and Japan with respect to corporate clean energy strategy.

The last part of this paper suggests a possibility of further study. It discusses a relationship between the introduction of clean energy products and technologies and the improvement of financial performance. It argues that there may be a positive relationship between the introduction of clean energy and financial performance. If this is the case, it may become a clear business case for firms to work on clean energy products and technologies.

3. How do the firms make a decision on the introduction of clean energy technologies?

If the introduction of clean energy products and technologies is perceived as a key strategic issue in business operations, how do firms make a decision about it? While corporate energy strategy is relatively a new research area, there are two groups of research initiatives in environmental business and management useful in exploring this question. One group addresses internal factors such as the level of firm’s resources and capabilities, while the other, including institutional scholars, looks into the influences from the external environment such as government regulations and pressures from non-governmental organizations (NGOs) and the civil society. Those who look into firms’ resources and capabilities often associate the level of environmental initiatives with the size of the resources of a firm. According to their argument, the firms with more resources and capabilities tend to address environmental issues more proactively. According to Rivera and Delmas (2004), the other group of scholars who look into internal factors highlights how top managers’ environmental beliefs, values, and attitudes play a critical role in determining corporate environmental management choices (Cordano and Frieze 2000; Egri and Herman 2000; Anderson and Bateman 2000; Winn and Angel 2000). Some studies in this group of scholars also indicate that pro-environmental attitudes and commitment by top managers positively affect the environmental behavior of middle and lower-level employees (Ramus and Steger 2000; Egri and Herman 2000).

On the other hand, the institutional scholars recognizing the influences from the external environment in business decision-making heed attention to stakeholders surrounding the firms. Sharma and Henriques (2005) describe, as a common view of the institutional scholars, that "stakeholders who are important, primary, or considered salient by managers in terms of their power, legitimacy, and urgency influence organizational strategies" (Sharma and Henriques, 2005). In particular, these scholars have extensively researched the relationship between government regulations and corporate responses to the environmental regulations (Kolk 2000; Pinkse 2006). Henriques and Sadorsky (1996) conducted an empirical study to test their hypothesis that environmental regulation represents a main determinant of managerial action to deal with environmental concerns among Canadian firms (Henriques and Sadorsky 1996). They found that government regulations are the most significant source of pressure on firms in the development of environmental strategy.

Apart from the pressures from the government, there is an empirical sign that firms attach importance to other stakeholders in formulating their environmental strategy (Buysse and Verbeke 2003; Neu et al., 1998; Fineman and Clarke 1996; Christmann, 2004). The above-mentioned empirical study conducted by Henriques and Sadorsky (2006), for example, demonstrates that in addition to government regulations, pressures from different stakeholder groups are playing an important role in the formation of environmental strategy among the Canadian firms that they analyzed (Henriques and Sadorsky 1996).

4. What are the consequences of receiving external pressures? : Convergent trends

Section 3 illustrates that institutional scholars pay an attention to the influences from the external environment in business decision-making. What are the consequences of receiving external pressures? Some institutional scholars consider that the firms in the same "organizational field" begin to adopt similar structures and strategies, yielding to common pressures for change (Hoffman 2001). This is so-called "isomorphism". The above-mentioned DiMaggio and Powell paper (1983) introduced the concept of isomorphism in 1983 (DiMaggio and Powell 1983).

The analysis of convergent trends among organizational strategies and structures is subsequently expanded to the corporate environmental arena. An example of such analysis is Kolk's research to examine the environmental reporting by multinational firms among the United States, Europe and Japan. It investigates whether any convergence in environmental report is observed in the triad region. She concludes that considering Europe as a whole, there is a convergence between Europe and Japan, while the differences between the United States and Europe and within Europe have increased (Kolk 2005). Kolk's research also indicates that the existence and degree of convergence hinge upon a subject area in corporate environmental strategy.

There are industry-specific researches examining whether or not there is convergence among corporate responses to climate change. The industry sectors with a particular research focus in research are oil and automotive industry sectors. Kolk, Levy and Rothenberg conducted a series of research to highlight strategic similarities and differences between the US and European firms in the sectors (Kolk and Levy 2004; Levy and Rothenberg 1999; Levy and Kolk 2002; Levy and Rothenberg 2002). In the case of the oil industry, Kolk and Levy (2002 and 2004) found that while there are remarkable differences between the US and European firms in the initial corporate reactions to the climate change issues, convergent pressures predominates as the issues mature (Kolk and Levy 2004; Levy and Kolk 2002).

5. The other trend in corporate environmental strategy: Divergent trends

Albeit with the convergent pressures, there is a great degree of differences among firms in corporate environmental strategy. What are the sources of the heterogeneity? Indeed, the existence of the heterogeneity is normal, as every firm has different corporate history, culture and philosophy as well as business operations and marketing positioning. According to the institutional scholars, firms are also subject to divergent pressures from the external environment. For example, the regulatory pressures from the government tend to be formulated in the unique local regulatory culture and history. The characteristics of regulatory pressures and the way firms respond to such pressures are often country-specific (or region-specific). The fashions that stakeholders influence firms also seemingly vary from one country to another. The natures of the roles and powers that stakeholders exercise are closely connected to the social and cultural contexts of the country or the region.

Sethi and Elango (1999) label the home country factors as "country of origin effects" (Sethi and Elango 1999). According to Sethi and Elango, the home country factors consist of 1) economic and physical resources and industrial capabilities, 2) cultural values and institutional norms; and 3) national government's economic and industrial policies. Sethi and Elango (1999) contend that those home country factors provide a powerful influence on firm's capabilities and strategies and create divergent pressures on firms in the formation of their corporate strategy (Sethi and Elango 1999).

Some scholars challenge the notion of "globalization" and contend that firm's operations and strategies are attributable to the local environment (Kolk and Levy 2004). They dismiss the idea that economic globalization is contributing to an emergence of "stateless" firms (Kolk and Levy 2004). They maintain that few multinational firms are truly global and most of the firms are regionally-oriented, and therefore strategic management of the firms should be regional-focused (Rugman and Brain 2003). In the publication titled "Global or Stateless Corporations Are National Firms with International Operations", Hu (1992) examines the level of internationalization among the US, European and Japanese firms in terms of their ownership and control, nationalities of the executive managers and legal nationality (Hu 1992). He concludes that with a few exceptions, all firms that he analyzed are regarded as "national firms with international operations." According to Hu, corporate strategies and operations are deeply rooted in the home country environment.

Baron and others contend that the business environment is composed of market and non-market components. According to Baron (1995 and 1997), the non-market components include interactions intermediated by the public, stakeholders, government, the media and public institutions. Baron argues that non-market environment is to an important degree nation-specific and it depends on the institutions and cultures of individual countries as well as on the organization of interests in the countries (Baron, 1995; Baron 1997). The non-market components that Baron discusses seem to be pointing out the second and third home country factors that Sethi and Elango (1999) demonstrate: cultural values and institutional norms and national government's economic and industrial policies. The differences between the US and European institutional norms is an example of the former. The Japanese METI's (Ministry of Economy, Trade and Industry) industrial policy is an example of the latter.

These arguments suggest that there are remarkable local pressures that lead to heterogeneity among corporate strategies. Kolk and Levy (2004) examined the home country factors in the formation of corporate climate change strategy (Kolk and Levy 2004). They analyzed a significance of the factors in the automobile and oil industry sectors in the United States and Europe. The home country factors that they identified include 1) societal concerns about climate change, 2) societal views on corporate responsibilities, 3) regulatory culture, 4) ability of firms to influence regulation, 5) national environmental policies and 6) national industrial promotion strategies (Kolk and Levy 2004).

6. Key drivers for the introduction of clean energy technologies

The discussions from Section 3 through 5 indicate that there are both internal factors and external pressures for firms to work on clean energy products and technologies. This section elaborates the drivers (internal and external) more specifically for corporate managers to consider in making strategic or managerial decisions on clean energy.

One common driver identified among previous research relates to regulatory support. Many studies demonstrate results showing that firms often take advantage of economic benefits associated with an introduction of regulations such as feed-in-tariff program, tax incentives, renewable energy portfolios and clean energy funds (Bird et al. 2005; Foxon et al. 2005; Geller et al. 2004 Menz 2005; Painuly 2001; Shrimali and Kniefe 2011; Wang and Chen 2010; Wiser and Mark Bolinger 2005). For example, Burer and Wustenhagen (2009) illustrate that "all other things being equal, investors in our sample perceived feed-in tariffs to be the most effective renewable energy policy (Burer and Wustenhagen 2009)." Moreover, de la Tour et al. (2010), looking at the successful adoption of the on-grid PV system, argues that the system has been entirely driven by incentive policies initially implemented in a limited number of industrialized countries (de la Tour et al. 2010). Another example is a wide diffusion of wind power generation in the US. Kaldellis and Zafirakis (2011) state that economic instruments including feed-in-tariffs and investment and production tax incentives are the primary drivers for the growth of wind energy market (Kaldellis and Zafirakis 2011)."

Another key driver relates to the fact that, with the improvement of the technologies, the cost for the introduction of the technologies falls down sometimes to the level where corporate managers perceive significant cost reductions of purchasing electricity. In addition, the corporate managers sometimes recognize an opportunity even to make profit through it. Many researchers have observed this trend among firms (Dinica 2006; Gross et al. 2003; Kaldellis and Zafirakis 2011). Gross et al. argues that the market growth take place if costs are to fall to levels that will ensure competitiveness with the lowest cost fossil fuel alternatives (Gross et al. 2003). Kaldellis and Zafirakis (1011) found this trend in reality that the wind energy production cost is found to be comparable with the respective of conventional fossil fueled generation methods, even without internalizing the externalities (Kaldellis and Zafirakis 2011). Dinica (2006) states that "although some developers may be mainly interested in self generations, others will invest motivated by some strategic considerations—such as new technological designs testing, green image considerations, local business opportunity or ideology. Overall, commercial motivation will be the main driver to invest (Dinica 2006)."

In contrast, some scholars argue that even when firms do not expect immediate financial returns, they sometimes pursue clean energy projects. This is particularly the case when they project a long-term intangible benefits through it (Byrne et al. 2007; Ginsberg and Bloom 2004; Menz 2005; Zeng et al. 2010). An example of prime importance is strong interests among customers for the clean energy products and technologies. Zeng et al. (2010) demonstrates that "the high-cost scheme activities, for example, using energy efficient and clean technologies or using renewable resources as raw materials, require significant financial investment but may not result in immediate economic benefit. However, these activities are often more visible and easily communicated to stakeholders, therefore conductive to improve corporate reputation, shareholder confidence and market share (Zeng et al. 2010)." A study conducted by Byrne et al. (2007) observe this trend among power generation firms in the US where firms provide options to purchase green power for customers and the firms are responding to the needs (Byrne et al. 2007). Based on a result of survey study, Ginsberg and Bloom (2004) recognize that overall there are demand by consumers for ethical and green products in recent years (Ginsberg and Bloom, 2004).

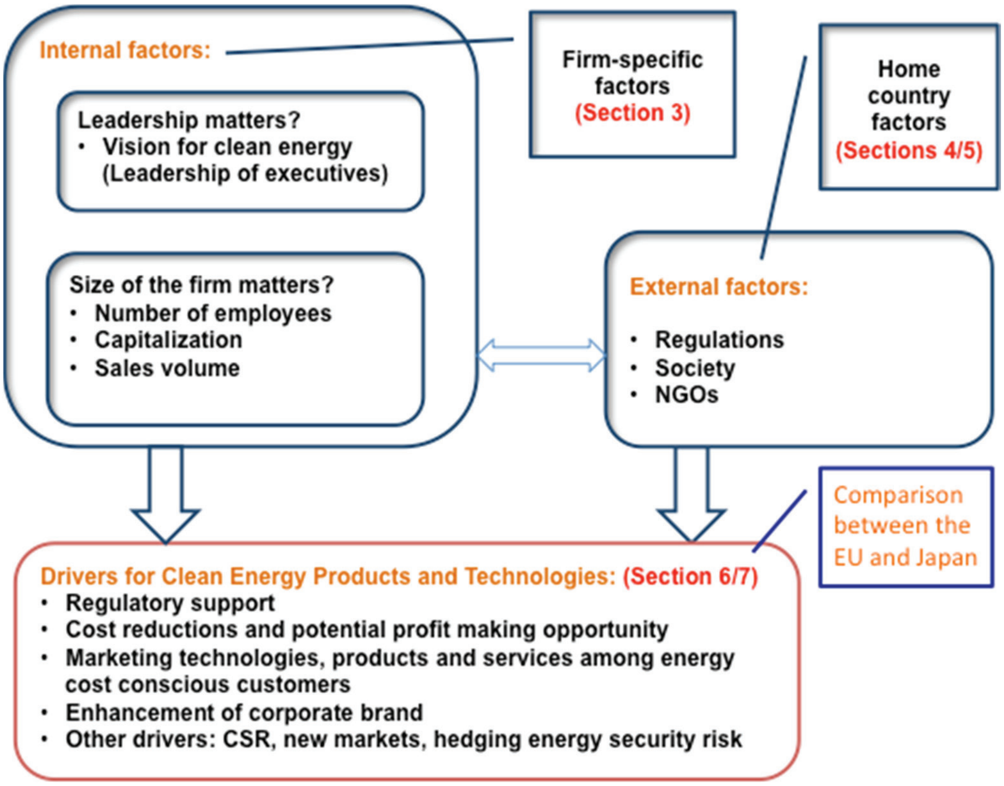
Beyond customer responses, some firms consider the impacts of adoption of clean energy products and technologies upon their brand image (González 2005; Paladino and Pandit 2012). González (2005) examined the pulp and paper industry to analyze factors influencing clean technology adoption and found that a better corporate image is the main reason for adoption, together with regulatory pressures (González 2005). Paladino and Pandit (2012) argue that "a firm can differentiate the brand on the basis of its environmental attributes by positioning the brand on its green attributes. A firm can increase its image and a consumer's connectedness with a brand and their affinity to it by branding itself as green (Paladino and Pandit 2012)."

Apart from the drivers described above, scholars observe other drivers for firms to incorporate clean energy products and technologies into their business strategy. Some firms may do it as part of their CSR initiatives (Prahalad and Brugmann, 2007). Some firms recognize the potential to enter new markets through clean energy products and technologies (Prahalad and Brugmann, 2007; Southworth 2009). Some firms address energy and environmental concerns associated with fossil-fuel based technologies and adopt clean energy products and technologies with less concerns in this area (Lloyd and Subbarao 2009; Moore and Wüstenhagen 2004). At this point, Lloyd and Subbarao (2009) argue that global energy and environmental security concerns are currently driving penetration of renewable energy alternatives.

7. Research framework for the analysis of the key drivers for the introduction of clean energy products and technologies

Section 2 through 6 illustrated theoretical discussions on corporate strategy for the introduction of clean energy products and technologies. Figure 1 summarizes those discussions below:

Figure 1: Corporate strategy for the introduction of clean energy products and technologies



Based on the theories discussed above, this paper proposes an empirical study to examine similarities and differences with respect to the drivers for the introduction of clean energy between the EU and Japan. The study is designed to test whether there are convergent or divergent trends in corporate clean energy strategy between the EU and Japan. The result of the study contributes to the discussions presented in Section 4 and 5 whether or not we can observe isomorphism or "country of origin effect" in reported corporate strategy in the introduction of clean energy products and technologies.

The analysis is based on the publicly available data reported by firms including corporate sustainability reports as well as data submitted to the Carbon Disclosure Project (CDP). As for European firms, the coverage of the analysis are the firms included in the FTSE 100 in England, the CAC 40 in France, the DAX in Germany, the Swiss Market Index in Switzerland, and the Euronext 100 in Europe. As for Japanese firms, the firms listed under the Nikkei 225 are the targets of the analysis. Many firms in both regions publish a sustainability report and provide data to the CDP. While the CDP is designed to ask firms about their climate change strategy, it also addresses some questions about their clean energy strategy in its questionnaire to the firms.

8. Further research: relationship between the introduction of clean energy technologies and improvement of financial performance

As described in Section 6, there is a growing understanding that the introduction of clean energy brings both tangible and intangible values to firms. Harmon addresses that green energy adoption may become a key element of strategies to ensure long-term economic growth (Harmon and Cowan 2009). If this is the case, there may be strong demand for further research to investigate the possible positive link between the introduction of clean energy products and technologies and the improvement of financial performance.

In reality, however, the research examining the positive link between the introduction of clean energy technologies and improvement of financial performance tends to focus on the cash flow analysis at the project specific level. There have been a number of studies, on the other hand, that attempt to examine a positive relationship between the introduction of environmental management and financial performance at the corporate strategy level. An example is a study conducted by Porter and Vandelinde exploring the link between environmental regulations and environmental as well as financial performance. They contend appropriately designed environmental regulations can stimulate technological innovation and provide a basis for "first mover advantage" in the international market (Porter 1990; Porter 1991; Porter and Vanderlinde 1995a; Porter and Vanderlinde 1995b). According to their argument, early adoption of strict environmental standards may lead to "innovation offsets" that lower costs or improve quality and ultimately lead to net benefits for firms. While some empirical studies have shown conflicting evidence on the relationship, some empirical studies indicate the positive relationship between environmental performance and financial performance (Hart, S. and G. Ahuja, 1996; Russo, M. and P. Fouts. 1997). Furthermore, some studies address that green strategies could enhance firms' competitive advantage by attracting environmentally aware consumers (Hart 1995; Sharma and Vredenburg 1998; Reinhardt 1998; Rivera, J. and Delmas, M. 2004). There have been studies indicating good environmental performance lead to better corporate image and brand as well.

Another direction of further research is to explore the linkage between the types of drivers discussed in Section 4 and better financial performance for firms. If it is possible to identify the types of the drivers leading to better financial performance, it may provide the rational basis for firms to invest resources into the area of the drivers.

ACKNOWLEDGEMENT

This work was supported by the Grant-in-Aid for Young Scientist (B) from Japan Society for the Promotion of Science (24730355). The authors wish to thank for the support.

REFERENCES

Baron, D. P. (1995). Integrated strategy - market and nonmarket components. California Management Review, 37, 47-65.

Baron, D. P. (1997). Integrated strategy, trade policy, and global competition. California Management Review, 39.

Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., and Parsons, B. (2005). Policies and market factors driving wind power development in the United States. Energy Policy, 33(11), 1397–1407.

Bürer, M. J., and Wüstenhagen, R. (2009). Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. Energy Policy, 37(12), 4997–5006.

Buysse, K. and Verbeke, A. (2003). Proactive environmental strategies: A stakeholder management perspective. Strategic Management Journal, 24, 453-470.

Byrne, J., Hughes, K., Rickerson, W., and Kurdgelashvili, L. (2007). American policy conflict in the greenhouse: Divergent trends in federal, regional, state, and local green energy and climate change policy. Energy Policy, 35(9), 4555–4573.

Christmann, P. (2004). Multinational companies and the natural environment: Determinants of global environmental policy standardization. Academy of Management Journal, 47, 747-760.

Cordano, M. and Frieze I. (2000). Pollution reduction preferences of U.S. environmental managers: Applying Ajzen's theory of planned behavior. Academy of Management Journal 43, 4, 627-641.

De la Tour, A., Glachant, M., & Ménière, Y. (2011). Innovation and international technology transfer: The case of the Chinese photovoltaic industry. Energy Policy, 39(2), 761–770.

Dimaggio, P. J. and Powell, W. W. (1983). The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. American Sociological Review, 48, 147-160.

Dinica, V. (2006). Support systems for the diffusion of renewable energy technologies—an investor perspective. Energy Policy, 34(4), 461–480.

Egri, C. and Herman, S. (2000). Leadership in the North American environmental sector: Values, leadership styles, and contexts of environmental leaders and their organizations. Academy of Management Journal 43, 571-604.

Fineman, S. and Clarke, K. (1996). Green stakeholders: Industry interpretations and response. Journal of Management Studies, 33, 715-730.

Foxon, T. J., Gross, R., Chase, a., Howes, J., Arnall, a., & Anderson, D. (2005). UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy, 33(16), 2123–2137.

Geller, H., Schaeffer, R., Szklo, A., & Tolmasquim, M. (2004). Policies for advancing energy efficiency and renewable energy use in Brazil. Energy Policy, 32(12), 1437–1450.

Ginsberg, J.M. and Bloom, P.N. (2004). Choosing the Right Green Marketing Strategy, MIT

Sloane Management Review.

González, R. (2005). Analysing the Factors Influencing Clean Technology Adoption: A Study of the Spanish Pulp and Paper Industry. Business Strategy and the Environment, 37(1), 20–37.

Gross, R., Leach, M., & Bauen, A. (2003). Progress in renewable energy. Environment International, 29(1), 105–22.

Harmon, R. R., & Cowan, K. R. (2009). A multiple perspectives view of the market case for green energy. Technological Forecasting & Social Change, 76(1), 204–213.

Hart, S. (1995). A natural resource based view of the firm. Academy of Management Review 20, 986-1014.

Hart, S. and Ahuja G. (1996). Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. Business Strategy and the Environment 5, 30-37.

Henriques, I. and Sadorsky, P. (1996). The Determinants of an Environmentally Responsive Firm: An Empirical Approach. Journal of Environmental Economics and Management, 30, 381-395.

Hu, Y. S. (1992). Global or Stateless Corporations Are National Firms with International Operations. California Management Review, 34, 107-126.

IEA (2013), Tracking Clean Energy Progress 2013 IEA Input to the Clean Energy Ministerial.

Kaldellis, J. K., & Zafirakis, D. (2011). The wind energy (r)evolution: A short review of a long history. Renewable Energy, 36(7), 1887–1901.

Kolk, A. (2000). Economics of Environmental Management, Harlow, Financial Times Prentice Hall.

Kolk, A. and Levy, L. (2004). Multinationals and global climate change: Issue for the automotive and oil industries. Multinationals, Environment and Global Competition, 9, 171-193.

Levy, L. and Kolk, A. (2002). Strategic responses to global climate change: Conflicting pressures on multinationals in the oil industry. Business and Politics, 4, 275-300.

Levy, L. and Rothenberg, S. (1999). Corporate Strategy and Climate Change: Heterogeneity and Change in the Global Automobile Industry. Belfer Center for Science and International Affairs (BCSIA) Discussion Paper E-99-13. Cambridge, MA, Environment and Natural Resources Program, Kennedy School of Government, Harvard University.

Levy, D. L. and Rothenberg, S. (2002). Heterogeneity and change in environmental strategy: Technological and political responses to climate change in the automobile industry. IN A., H. & M., V. (Eds.) Organizations, Policy and the Natural Environment: Institutional and Strategic Perspectives. Stanford, Stanford: Stanford University Press.

Lloyd, B., & Subbarao, S. (2009). Development challenges under the Clean Development Mechanism (CDM)—Can renewable energy initiatives be put in place before peak oil? Energy Policy, 37(1), 237–245.

Menz, F. C. (2005). Green electricity policies in the United States: case study. Energy Policy, 33(18), 2398–2410.

Moore, B., & Wüstenhagen, R. (2004). Innovative and Sustainable Energy Technologies: The Role of Venture Capital. Business Strategy and the Environment, 13(4), 235–245.

Neu, D., Warsame, H. and Pedwell, K. (1998). Managing public impressions: Environmental disclosures in annual reports. Accounting Organizations and Society, 23, 265-282.

Painuly, J. . (2001). Barriers to renewable energy penetration; a framework for analysis. Renewable Energy, 24(1), 73–89.

Paladino, A., & Pandit, A. P. (2012). Competing on service and branding in the renewable electricity sector. Energy Policy, 45(2012), 378–388.

Prahalad, C. K., & Brugmann, J. (2007). Cocreating Business ' s New Social Compact. Harvard Business Review, (0702), 1–14.

Pinkse, J. (2006). Business Responses to Global Climate Change. Amsterdam Graduate Business School. Amsterdam, University of Amsterdam.

Porter, M. E. (1990). The competitive advantage of nations. Harvard Business Review, 68, 73-93.

Porter, M. E. (1991). America green strategy. Scientific American, 264, 168-168.

Porter, M. E. and Vanderlinde, C. (1995a). Green and competitive - ending the stalemate. Harvard Business Review, 73, 120-134.

Porter, M. E. and Vanderlinde, C. (1995b). Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspectives, 9, 97-118.

Ramus, C. and Steger, U. (2000). The roles of supervisory support behaviors and environmental policy in employee 'eco-initiatives' at leading edge European companies. Academy of Management Journal 43, 605-626.

Reinhardt, F.L. (1998). Environmental product differentiation: implications for corporate strategy. California Management Review 40, 4, 43-73

Rivera, J., and Delmas, M. (2004). Business and environmental policy: An introduction. Human Ecology Review, Vol. 11, No. 3, winter 2004, 230-234.

Rugman, A. M. and Brain, C. (2003). multinational Enterprises are regional, not global. Multinational Business Review, 11, 3-12.

Russo, M. and Fouts, P. (1997). A resource-based perspective on corporate environmental performance and profitability. Academy of Management Journal 40, 534-559.

Sethi, S. P. and Elango, B. (1999). The influence of "country of origin" on multinational corporation global strategy: A conceptual framework. Journal of International Management, 5, 285-298.

Sharma, S. and Vredenburg, H. (1998). Proactive corporate environmental strategy and the development of competitively valuable organizational capabilities. Strategic Management Journal 19,729-753.

Sharma, S. and Henriques, I. (2005). Stakeholder influences on sustainability practices in the Canadian forest products industry. Strategic Management Journal, 26, 159-180.

Shrimali, G., & Kniefel, J. (2011). Are government policies effective in promoting deployment of renewable electricity resources? Energy Policy, 39(9), 4726–4741.

Southworth, K. (2009). Corporate voluntary action: A valuable but incomplete solution to climate change and energy security challenges. Policy and Society, 27(4), 329–350.

Wang, Q., & Chen, Y. (2010). Barriers and opportunities of using the clean development mechanism to advance renewable energy development in China. Renewable and Sustainable Energy Reviews, 14(7), 1989–1998.

Winn, M. I. and Angel, L. C. (2000). Toward a process model of corporate greening, Organization Studies 21, 6, 1119-1147.

Wiser, R., & Bolinger, M. (2005). Balancing Cost and Risk : The Treatment of Renewable Energy in Western Utility Resource. The Electricity Journal.

Zeng, S. X., Meng, X. H., Yin, H. T., Tam, C. M., & Sun, L. (2010). Impact of cleaner production on business performance. Journal of Cleaner Production, 18(10-11), 975–983.

Education, training, tools and services to enhance sustainable household consumption

Authors: Marja Salo[a*], Ari Nissinen[a], Raimo Lilja[b], Emilia Olkanen[c], Mia O'Neill[d], Martina Uotinen[e],

[a]Finnish Environment Institute, SYKE, P.O. Box 140, FI-00251 Helsinki, Finland
[b]Ecolabel Partnership, Jussintie 27, FI-50670 Otava, Finland
[c]EcoFellows Ltd, PL 487, FI-33101 Tampere, Finland
[d]Sykli Environmental School of Finland, PL 72, FI-11101 Riihimäki, Finland
[e]Valonia – Service Centre for Sustainable Development and Energy of Southwest Finland, Vanha Suurtori 7, FI-20500 Turku, Finland

*corresponding author: marja.salo@ymparisto.fi, tel. +358 400 148 572

Keywords: household, energy, carbon footprint, sustainability, consumption

Abstract

Household consumption (housing, mobility, food, goods and services) accounts for about 70% of the carbon footprint of Finland (i.e. greenhouse gas emissions caused by the domestic final use of products). The Final Draft of the IPCC 2014 report on climate change mitigation emphasises the need for diverse actions across sectors that are required to limit global warming to 2 degrees Celsius. Changes in human behaviour and consumption patterns are recognised as important parts of the mitigation acts to cut emissions. These changes in consumption are essential also because of the possible rebound effect, i.e. that the technical improvements can be offset by increased consumption.

Ecological sustainability of consumption, and especially housing, was the focus of the Finnish Ecohome project. The aim of this project was to help households decrease their energy consumption and carbon footprint. The project consortium identified four main target groups to work with. Professionals and small and medium-sized enterprises (SMEs) providing maintenance and renovation services for households and housing corporations, teachers of general education, regional advisory centres for energy and environmental issues, and non-governmental organisations (NGOs) that guide ordinary people towards more sustainable consumption. The target groups were seen as important intermediaries to support households in increasing energy efficiency and reducing their carbon footprint.

Practical outcomes of the pilots include the following: educational tools and programmes for the professional audience and young people (in schools), support for SMEs to develop business models related to energy-efficient maintenance and renovations of residential buildings, energy expert activities and interventions in blocks of flats, carbon footprint calculation tools for ordinary people, tool-supported action models for discussing carbon footprint and mitigation measures with people, and cooperation to advocate sustainable lifestyles. SMEs gain knowledge and tools to develop their business models and better respond to the need to increase the energy and cost efficiency of housing. NGOs and teachers of general education acquire tools, data and support to strengthen sustainability and carbon footprint perspectives in their work. These activities were also designed to support and supplement Finnish program for sustainable consumption and production, aimed at decreasing climate and other environmental impacts of consumption.

This article summarises the results of the pilots and experiments and it discusses the learning and potential for further application and spreading these kinds of educational approaches, tools and action models.

1 Introduction

Household consumption (housing, mobility, food, goods and services) accounts for about 70% of the carbon footprint of Finland (i.e. greenhouse gas emissions caused by the domestic final use of products (Seppälä et. al., 2011)). The Final Draft of the IPCC 2014 report on climate change mitigation (IPCC, 2014) emphasises the need for diverse actions across sectors that are required to limit global warming to 2 degrees Celsius. Changes in human behaviour and consumption patterns are recognised as parts of the mitigation acts to cut emissions. Girod et al. (2014) have reviewed carbon footprints of products in five consumption categories (food, shelter, travel, goods and services) and conclude that changes in consumption have the potential to significantly contribute to reach the climate target limiting global warming to 2 º C. Changes in consumption patterns are essential also because of the possible rebound effect, i.e. that the technical improvements can be offset by increased consumption (see e.g. Adato energia, 2013; Chitnis et al., 2013; Ajanovic et al., 2012). The change in consumption patterns may also have (positive) spill-over effects (Hertwich, 2005).

Housing typically accounts for roughly one-third of all greenhouse gas emissions from Finnish households (Seppälä et al., 2011). Therefore, housing and energy consumption, and especially heating, typically offers the highest potential for reducing a household's carbon footprint. In addition to regulations related to energy and material efficiency, behavioural aspects and the energy efficiency of appliances have a role in the reduction of housing's carbon footprint (Ministry of Environment, 2012). Food and car travel are the other two major contributors to citizens' environmental impacts when several environmental impact categories are considered (Seppälä et al., 2011; Saarinen et al., 2011; Ministry of Environment, 2012). The composition of average per capita greenhouse gas emissions in terms of private consumption per capita in Finland is presented in Figure 1.

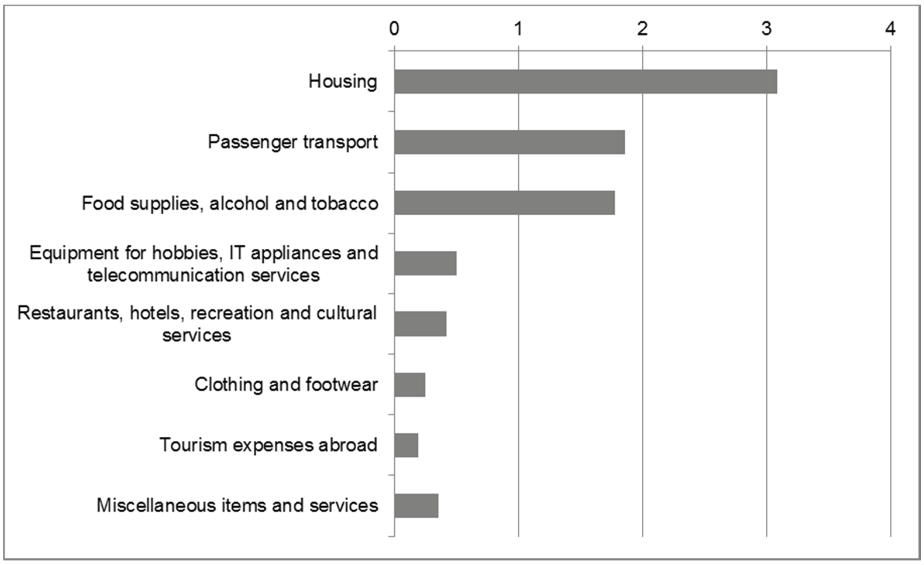


Fig. 1. Greenhouse gas emissions from private consumption in tonnes CO2 equivalent per person in Finland in 2005. Based on data from Seppälä et al., 2009.

According to an EU-wide survey (Eurobarometer, 2013), 84% of the Finnish population considered climate change to be a fairly or very serious problem. This represents an increase of three percentage points compared to 2011 (Eurobarometer, 2011). In 2013, 57% of the Finnish population indicated that they had personally taken action to tackle climate change. The respective figure for 2011 was 65%. In a Finnish study on housing choices, the environment seemed to be the least important factor affecting decisions on location and the type of a residence (Strandell, 2011). Eurobarometer results indicate that Finnish citizens are worried about environmental issues and are at least in some way ready to change their consumption patterns and lifestyles. The question is how to convert the willingness to take action into changes in everyday life.

The role of intermediaries or middle actors (Parag and Janda, 2014) is considered to be important in relation to household consumption. In this paper NGOs, municipal energy offices, private enterprises (e.g. retail stores and SMEs) are considered as potential intermediaries or middle actors. The listed agents are all involved in the everyday lives of households or decisions on consumption and housing.

This article looks into the experiences of the Finnish Ecohome project. Its aim was to help households to decrease their energy consumption, and reduce the carbon footprint through less carbon-intensive consumption patterns, changes in lifestyles, and renovations improving the energy efficiency at home.

2 Context of the study

There are 2.1 million households in Finland. The means to reduce households' energy consumption and carbon footprint are, at a general level, widely applicable for all households: reducing heating energy and electricity consumption at home, reducing the demand for travel and switching to low carbon modes of transport (active travel, public transport and low emission vehicles), decreasing the amount of meat and dairy products in one's diet, and minimising food waste. The relevance of consumption categories and the applicable tools and solutions to make changes in the consumption patterns varies between households, however. For instance, 44% of Finnish households live in flats, 40% in detached houses, and 14% in attached houses, and the rest (approximately 2%) in other types of housing (Statistics Finland, 2014). The share of housing stock built before 1990 is 73% for detached houses and 77% for blocks of flats (Statistics Finland, 2014). Consequently, measures to tackle the energy consumption of existing housing stock are important in order to achieve reductions in the carbon footprint of the Finnish housing sector.

When developing energy saving concepts for detached houses and blocks of flats, there are certain housing type-specific technical and administrational characteristics that need to be taken into account. Households living in detached houses are typically responsible for taking care of their house, while for flats and attached houses the housing companies are responsible for arranging maintenance and major renovations. Blocks of flats are typically managed by a housing board and a professional house manager. The housing board consists of elected representatives of the flat owners. The role of the board and the manager are essential when major renovations are prepared and the guidelines for the maintenance work are set. The flat owners are collectively responsible for the costs of major renovations and maintenance. Space heating energy (typically also including centrally heated water) in the whole building and the electricity used in common areas are usually collectively paid for by the owners. The electricity used in the flats is paid by the users. The owners of detached houses are exclusively responsible for the maintenance and renovations of their premises. Knowledge and skills among house owners vary. When major renovations are needed, there is a need for unbiased information, independent from any single technical solution, to find the best solution for the house.

Citizens and relevant stakeholders need relevant information and motivation to take action to be able to make informed decisions and choices. The effectiveness of the information distribution alone can be questioned, because environmental action is affected by the personal and shared values of the community, situational factors and the type of motivation (Ahonen, 2011; Barr, 2003). When designing interventions to encourage pro-environmental behaviour, the following questions can be helpful (Steg and Vlek, 2009):

1. Which behaviours should be changed to improve environmental quality?
2. Which factors determine the relevant behaviour?
3. Which interventions could best be applied to encourage pro-environmental behaviour?
4. What are the effects of the interventions?

Information and advice about sustainable choices are already provided by municipal energy offices, NGOs, and the energy and waste management companies in Finland. The information is available on the internet, by phone and in person. The challenge is to provide the right information when decisions and choices are made, in a format that the citizens find interesting, useful and trustworthy.

3 Design of the project

In this chapter, the design of the project and expected outcomes are described. First, the more specific scopes and preliminary targets of each pilot are described. Then, an overview of the process developing and improving the action models during the process is provided. The word "pilot" refers here to the activities taken to test new tools, educational programmes and business concepts, for example. The phrase "action model" describes reproducible concepts based on the learnings of the pilots.

3.1 Defining the scopes of the pilots

To meet the general aim of the project, partners of the project defined a more specific scope, based on their specific area of expertise (i.e. training; advice and support for households; energy-efficient construction, renovation and maintenance; web-based tools). The action models need to tackle significant elements of a household's carbon footprint and develop measures included in proposed policy instruments to decrease the carbon footprint of households (Nissinen et al., 2014), and the action models must have the potential to be further used or developed by either the project partners or other stakeholders following the end of the project. Three of the pilot projects focused on housing issues. The other two had a broader focus on everyday consumption patterns and behaviour related to energy use. In total, the project focuses on both everyday consumption patterns and more effective but much less frequent actions, e.g. the changing of a heating system. The following working titles and questions for pilots were used as a starting point for the four pilots.

- Training programme for professionals for supporting house owners and managers in major renovations and maintenance and related business models

  How can homeowners facing the need for major (energy) renovation access unbiased information on the potential and suitable options? How can home owners be made more aware of the costs of different choices when the whole lifespan of the system is taken into account?

- Energy management of housing companies

  How inhabitants in blocks of flats and attached houses and key persons of housing boards could be encouraged actively save energy through better maintenance and behaviour changes?

- Tailored advice for households based on the measured consumption data and tailored advice by eco-trainers

  Can household-specific and real-time measurement systems, together with tailored advice, help households change their consumption patterns and reduce their carbon footprint? How can various professionals that visit homes, like cleaning and other service providers advice also for sustainability at home?

- Web-based tools and face-to-face communication to improve the sustainability of everyday lifestyle choices

  How can a web-based carbon footprint calculator and related activities be used to raise awareness of one's carbon footprint and actions to reduce it? How to use calculator in discussion with ordinary people about carbon footprint and mitigation measures?

The business-related pilots focused on SMEs. The potential role of SMEs in energy efficiency improvements in the existing housing stock is recognised in the literature, as well as the challenges related to the fragmented nature of the sector and the markets (e.g. Killip, 2013; Heiskanen et al., 2011).

In order to provide meaningful and understandable information for households, the project team needed to choose key concepts to be used when communicating with the households. The concepts of carbon emissions and footprints, as well as direct energy consumption at home, were the most commonly used units of measurement in the project. A person's carbon footprint connects personal consumption with global environmental change. A carbon footprint also allows for the comparison of the relevance of different consumption sectors with each other. Direct energy consumption and the costs of energy were also important where the energy efficiency and costs of renovation options were concerned. Indoor air quality, general quality of housing and the value of the house can be used as motivational factors. Other aspects of sustainable consumption (i.e. eutrophication related to food items, social aspects) were also discussed in relation to everyday sustainability issues.

3.2 Process of planning the pilots and developing the action models

The approach used in the Ecohome project took ideas from action research (Ottosson, 2003). The project team took part in the activities in roles such as developer, participant and observer. The advantages of participation action research include rapid feedback from the field. Working with the target groups in person may help to understand unspoken needs and demands.

In the early phase of the project, the preliminary versions of action models were presented in a stakeholder workshop before starting the fieldwork. The idea was that the concepts were to be further developed during the project based on the experiences and feedback. There were three main sources of feedback to be taken into account: (1) two expert and stakeholder workshops, to review the action models and experiences so far; (2) practices to develop the concept together with participants, and the constant spontaneous and written feedback until then; and (3) the project advisory board consisting of experts from various fields related to the project, and the network of the Finnish Programme to Promote Sustainable Consumption and Production (KULTU).

The first expert and stakeholder workshop, which hosted 44 participants, was organised at the beginning of the project. The preliminary action models were presented, and sessions for separate working groups were held to get feedback and identify possible missing stakeholders who should be involved. The second workshop, with 33 participants, was organised after the majority of the fieldwork had already been conducted, but the action models could still be further developed during the project. A third meeting, a panel discussion, will be organised at the end of the project. The action models and the preconditions for the more extensive use of the results will be discussed with relevant policy-makers and other stakeholders.

The viable future demand and supply of the services and actions developed during the project depend on how relevant and useful the target groups consider them to be. This means that the pro-environmental behaviour needs to be considered as meaningful from the households' point of view, as a viable business for entrepreneurs, and that it supports NGOs in raising sustainability aspects on their agendas. A critical aspect to be studied during the project is the funding of the action models. In other words, is there a willingness among entrepreneurs to pay for the training and among households for the services? What kind of service concept is cost efficient yet still provides meaningful information for customers? Are there policy instruments that the public sector should introduce to enhance the demand for the services?

The role of participants in the pilots was twofold: they tested the actions but they also took part in the development. Understanding the energy end-user's perspective is essential (Heiskanen et al., 2013), because all action models are based on voluntary changes in everyday practices, and for business models it is essential that the people and companies are engaged from the very beginning. Communication activities to raise public awareness of the availability and advantages of developed tools, services and actions are important. In addition to communicating to the general public, cooperation with the key stakeholders to spread the word within their own networks is crucially important. Cooperation with stakeholders provides an opportunity to better specify the message for a certain audience, and increase the credibility of the message.

4 Results and discussion: The action models

In this chapter, a more detailed description and key findings of the pilots along with the related action models is given. We also present the challenges faced during the pilots and a discussion on the prerequisites, and the incentives to further spread the action models.

4.1 New training and business models for energy efficiency improvements

The potential of retrofitting in reducing greenhouse gas emissions of housing is recognised in the literature (e.g. Girod et al., 2014). The starting point for this particular action model was the challenge faced by homeowners of detached houses: how do you find unbiased information and support when replacing an old heating system or preparing for some other major renovation on the premises (Nissinen et al. 2014)? On the other hand, SMEs working in the field of construction, renovation and maintenance would benefit from the increased business opportunities and new service models related to energy-efficient and low carbon solutions.

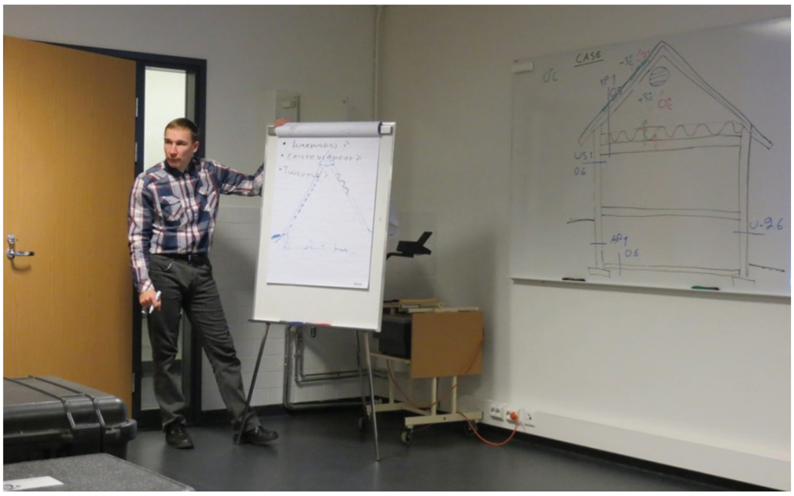


Fig. 2. The lack of reliable and competent third party information on energy renovations was identified as a challenge from detached house owners' perspective. In this figure technical details are being explained by one of the experts in energy efficiency training programme.

The development of a new training programme and service concept was started with a group of 15 professionals from the previously mentioned fields. The preliminary training programme was developed in cooperation with the Environmental School of Finland (SYKLI) project team and the participants. It consisted of 12 days of contact lessons, as well as project work to be completed mainly at home. The contact lessons consisted of theory and practical examples of construction physics, heating and ventilation technologies, including hybrid solutions and air quality, practical aspects of a field survey and calculations on energy efficiency, as well as marketing and the implementation of a new service model. The themes discussed were divided (where necessary) into detached houses and housing companies, as several professionals concentrated on only one of these housing types, and the characteristics of the buildings can be quite different. After the pilot, the length of the training was reduced to 10 days by eliminating overlaps and concentrating on more in-depth theoretical knowledge. The attendants will receive an Excel-based tool for calculating the present state energy consumption, and for calculating and optimising the energy-saving potential and payback times. This tool is applied to a real case as part of the training.

There are three aims for the training programme: (1) participants increase their current knowledge; (2) a network of experts is established; and (3) participants are provided with tools and a concept to conduct energy efficiency surveys of residential buildings. Project work, where an energy efficiency (EE) survey is conducted at a chosen location, is part of the completion of the training. After refining the programme based on feedback from the pilot training, it will be offered as a training product by SYKLI and/or other providers. The above-mentioned aims respond to typical challenges SMEs face in the renovation sector (see e.g. Killip, 2013).

From a customer point of view, the advantages the training provides is threefold: (1) it provides unbiased support to a variety of technical solutions to help identify required renovation measures and potential options, as at least three options are always given for any location; (2) the service concept is cost efficient, taking into account the limited financial resources of the detached house owners (and housing complexes); and (3) it offers a reliable network of professionals with a wide range of expertise. The first experiences from customers are that the energy efficiency survey did help them to make an educated choice for both new heating system as well as other necessary renovations. It was helpful to notice that it is not necessary to tear down a functioning system, but sometimes a supportive system can be installed. By adding some extra insulation, the energy requirement may be dramatically reduced. Most importantly, the customer learns of the price, the potential savings, the required maintenance and other practical information on various solutions.

The importance of the expert network was emphasised by the participants of the pilot training. In addition, the participants welcomed the idea of compiling an online case database, which would contain the information of the conducted energy efficiency surveys and would be available to all the members of the network. The database would offer experts (and with a wider audience, laymen of housing boards as well) insight on what types of solutions were chosen in different locations, and this gives added value and new ideas to the people working on such surveys. The specifications of the database are yet to be defined.

During the pilot, three main challenges for this action model were recognised. (1) What should the minimum level and type of education and experience for the participants of the training programme be? It is clear that a certain level of prior knowledge and expertise is required. (2) How can we ascertain and communicate to the clients the high quality of the service provided by the members of the network? Setting up a certification system would be expensive, and it is crucial to keep the costs of the service low. (3) How much are the clients willing to pay? Especially in those households living in detached houses, it might be challenging to find paying customers for planning, instead of the installation of products and technical systems. Incentives, i.e. extending the tax reduction from installation to planning, could encourage house owners to use the service. A Danish study (Mortensen et al., 2014) suggests that comfort, indoor environment and architecture are important motivational factors for retrofits, as energy saving may not be enough. These motivational aspects were recognised in this project. Further development of the training programme and service concept should continue to take the variety of motivational factors into account.

Potential demand for the service was studied by SYKLI and Ecolabel Partnership in cooperation with the Finnish House Owners' Association. A web-based survey was sent to members of the association, residing in the provinces of Uusimaa, Häme, Pirkanmaa and Etelä-Savo. A total of 1,051 responses were received. The main outcome of the survey was that nearly half of the respondents were willing to pay for this type of service, whereas the other half did the work themselves or were otherwise uninterested. The results also indicated that proper planning is important to house owners, but the extra costs are unwelcome. Nevertheless, by supporting energy-efficient planning and allowing incentives for the consumers, it is possible to improve the existing building stock as well as standards of living and limit the energy costs of housing. Furthermore, the service providers could successfully offer a planning service as a package, with other more desirable services.

Services also exist which could be supplemented with the proposed energy efficiency plan. Currently an energy performance certificate is mandatory when a detached house or a flat is sold or rented. The mandatory document must be prepared by an authorised consultant. The purpose of the document is to provide information about the energy performance of the building (see also Brounen and Kok, 2011). The document also includes suggestions about energy efficiency improvements. These suggestions are typically very general, however. A description of the physical state of the building is not a compulsory document, but it can be bought by either the seller or buyer of a detached house. The energy efficiency plan would supplement the description of the physical state by proposing actions based on the current state of the building. In addition to the above-mentioned service concept, the further development of the existing electronic housing maintenance record book concept (e.g. Stata Oy, 2014; Omakotiliitto, 2014; HuoltoOptimi, 2014) could be one option to encourage more systematic maintenance of detached houses.

4.2 Model for energy management and 'energy experts' in housing companies

This action model focuses on the energy efficiency of housing companies with their specific features related to managing renovations and maintenance, as well as the allocation of energy costs. Most of the participating companies own real estates constructed in the 1960s and 1970s building boom. Energy efficiency can be improved and the related carbon footprint can be reduced in three ways: 1) through major energy renovations (e.g. roof and wall insulation, replacing windows or installing heat recovery system). Energy efficiency improvements are compulsory when conducting a renovation that requires permission (Ministry of Environment, 2013); (2) ensuring the best possible energy efficiency of the current HVAC system through check-ups and adjustments; (3) encouraging energy savings through behaviour changes.

Knowledge related to the energy efficiency, energy efficiency renovations, and operations and maintenance of HVAC systems are included in the training programme described in section 4.1. In the programme, there was specifically-planned content for professionals working with housing companies. The action model described in this section takes into account the previously mentioned elements and in addition the potential of behaviour changes of the residents by using the energy expert concept. The concept of an energy expert was originally developed by Motiva Ltd, a state-owned company offering services in consulting, training and communications, especially in the field of energy efficiency. Energy experts are trained members of the housing company board who are familiar with energy- and water-saving potential. Energy experts have a role in communicating with other residents, the housing manager and the housing board. This helps coordinate activities in large housing companies. Depending on the level of adjustments and maintenance, consumption can be 20% higher or 10% lower than the baseline. Behaviour changes may increase or decrease energy consumption by 5% (Virta and Pylsy, 2011, according to Talokeskus).

One challenge for housing companies, compared to detached houses, is that typically residents do not pay for space heating and water consumption according to their real consumption, because there are no separate meters for each flat. This metering practice might be one reason why in the Helsinki region, for example, water consumption per capita is higher in flats than in detached houses (HSY, 2014). According to the current regulations, installing water meters for each household is compulsory in new buildings and in the older housing stock when renewing the piping system.

This particular action model aims to activate members of the housing board, the housing managers and the residents of the house to decrease energy consumption, while maintaining or increasing the perceived comfort of living. The action model consists of three elements: (1) training voluntary energy experts on the company boards with the understanding of energy and water usage and consumption reduction possibilities; (2) conducting energy efficiency studies to locate deficiencies and define the energy-saving potential; (3) supporting the housing companies in implementing the measures defined based on the energy efficiency study, systematic maintenance, and long-term plans.

Fig. 3. Energy experts were trained to enhance energy saving activities in housing companies. This figure shows a practical lessons in heating systems and their operation.

Energy efficiency studies were conducted in 15 housing companies and 150 energy experts were trained during the project. In addition, videos about conducting check-ups in different parts of the HVAC system were produced and distributed via the internet. Long-term follow-up will show how these measures affected energy and water consumption.

The complicated decision-making process in the housing companies often hinders the progress of energy efficiency. The role of the housing manager is essential. A Finnish study based on interviews with housing managers and the energy performance of buildings managed by them suggests that attitudes and practices of the managers have an impact on the energy performance of the buildings (Kyrö et al., 2012). According to experiences in the Ecohome project, the value of the energy efficiency study is not always fully appreciated by the board members. The lay board members therefore require education, explicit examples with life cycle calculations and consultation support. This would help to communicate to and convince board members about the potential benefits of the energy efficiency study and energy expert activity.

4.3 Policy instruments for promoting energy efficiency improvements in detached houses and housing companies

Girod et al (2014) list policies that can support the shift in consumption patterns. Especially the financial incentives, standards and consumers' capacity to weight future savings with initial investment are discussed in relation to experiences from the Ecohome project. The fieldwork and trials related to the energy efficiency renovations and other service concepts aiming at increasing energy efficiency and quality of housing underlined the need to further develop existing policy instruments promoting energy efficiency improvements. House owners are reluctant to pay for consulting services, despite the opportunities to save in the life cycle cost. There are not many small consultant companies or individual experts that can cover the essential aspects of an energy efficiency improvement: housing technology, renovation construction and the prevention of moisture and mould risks. Furthermore, the consultants do not always have the skills for properly communicating the technical alternatives to the average house owner and family members. Therefore, the training of experts and support in development of networks is essential.

In housing companies, renovations are extensive projects where consultancy services are used throughout the projects. The existing regulatory framework also sets guidelines on energy efficiency improvements. Carrying out ambitious energy efficiency improvements exceeding the minimum level set by the regulations would require advocacy from a board member or a consultant to motivate the board and flat owners concerning the advantages of the energy efficiency improvements.

The key points for housing renovation interventions in detached houses are: situations where a new owner purchases an old house or situations faced by a present owner where an urgent need for repair arises because of moisture/mould damage, the end-of-life phase of building parts such as the roof, floor or bathroom, or a life phase that reduces the capabilities of the residents, etc. Another point of intervention is the phase where the owner applies for permission for significant renovations or where the owner needs an energy efficiency certificate for selling or renting the house. These points of intervention for public actors are also opportunities for those offering private consultancy services to the house owner, seller or buyer.

The policy instruments to support the demand and supply of the proposed energy efficiency study and renovation services can be divided into three groups (see also CORPUS 2014; Nissinen et al., 2014).

Regulatory instruments

Recently stipulated regulations require house owners to prove that their renovation project (e.g. renewal of roof) will also improve the energy efficiency of the building (Ministry of Environment, 2013). To prove this, the applicant of a construction permit must provide appropriate energy calculations or other verification. The energy efficiency study described in section 3.1 could provide the required data for this verification. The implementation of these regulations in case of detached houses is facing problems, because of the very limited resources in municipal offices.

A more radical policy instrument which has provoked some discussion is a mandatory regular “inspection” of buildings by some authorised service provider covering fire safety, moisture and mould risks and an energy efficiency audit.

Economic instruments

Household service tax deductions are regarded as a significant incentive for energy efficiency improvements in detached houses. Taxpayers can currently deduct from their taxes 45% of the value of household service or maintenance work conducted at the taxpayer’s or his/her parent’s home, up to a maximum value of €2,000 per year (€4,000 for a couple) (Suomen yrittäjät, 2014). The deduction is an excellent example of green tax policy. Vendors of energy technology have utilised this incentive by pricing their work high and equipment low. The energy efficiency study has not been eligible for this deduction so far, because it is only partly work done at the residence. Interpretation of the guidelines might be changed to make this eligible.

Families on lower incomes or retired residents cannot utilise this deduction to its full extent. Some policy experts have proposed that in such cases, income tax should be negative, i.e. a compensation could be paid. Social grants can be applied for house renovations, but the budget allocated for this is scarce and restricted mainly to older people and those with limited mobility. Subsidies for energy renovations are also available for housing companies.

Informational instruments

Information about solutions, exemplar cases and calculations of saving potential assist in preparations for major renovation projects as well as raising knowledge about potential behaviour changes. There are many web-based and personal advisory services promoting energy efficiency and sustainable consumption. The budget for these services is usually project-based and this poses a question about continuity. The public and free information services can rarely go into detail for an individual house owner. This is why there is a niche for commercial advisory and consulting services, even for individual house owners.

Municipal authorities or public advisory services cannot officially recommend named companies or consultants, unless there is a public list of authorised experts. Such a list on certain public websites would act as a meeting point for service users and providers. What building permit authorities in municipalities could do is to generally advise the permit applicants to use a qualified consultant for conducting the energy efficiency study – without naming anyone specifically. The same applies to relevant NGOs in this field.

One option for financing public advisory services is to encourage power companies to outsource their obligation for providing energy efficiency information to their clients. EcoFellows Ltd in Tampere, Finland, is an example of such a public agency with financing coming from the municipal power company and the municipalities. This model could be replicated to other regions.

The project has identified the need for one or two interactive websites for transferring know-how on energy renovations. One site would serve as a “case bank” for small energy consultants: the energy efficiency plans and feasibility calculations for typical cases would be accumulated here. It would provide quality control through peer review and it would improve the cost efficiency of preparing the plans. The site would also facilitate networking between experts, each with specific skills. Similarly, house owners could have a site for peer support where simplified case studies could be posted. In the future, the site could also promote the pooling of service users who could pool together to hire an energy expert or call for tenders of specific energy-related equipment and installation work, for example. Stakeholders are needed to coordinate such pooling of house owners. Model agreements and calls for tenders could also be published on this site.

4.4 Household-specific metering and tailored advice by eco-trainers

A total of 18 households volunteered to participate in the project. The households were different in terms of type of housing, family size and background. During the first visit, real-time energy monitors were installed to measure electricity consumption and provide information about the related greenhouse gas emissions. The families’ cars were provided with a real-time tracking device to collect information on driving habits. The families were also instructed on how to perform the measurements concerning their use of other means of transportation, water use and waste amounts. The data was fed into a web interface that enabled the families to follow their consumption patterns in all areas. During the first or second visit, the families were interviewed about their consumption habits. Based on the data, tailored expert advice was provided and discussed in private meetings with the households. With some families, different subjects were discussed in great depth, and as much time as necessary was allocated for each visit. Each home was provided with two or three visits. The visits lasted approximately two hours, depending on the family’s ability to provide the information needed, the time it took to install the energy monitors and the amount of advice given. The measurements were conducted twice during the pilot over a minimum of four weeks, at the beginning and before any activities or advice was given. The second period of measurements took place after the households had met with the expert and had been given some time to change their behaviour and consumption patterns.

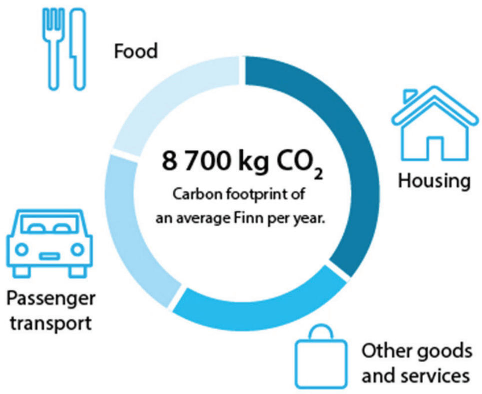


Fig 4. Illustrative information was produced to communicate about household carbon footprint. E.g. this figure shows the relevance of different consumption categories on an average carbon footprint of a Finn.

Throughout the project, the households were provided with information about the energy efficiency and other environmental aspects through newsletters and a Facebook group, as well as personal e-mails. In addition, meetings for the whole group of 18 households taking part in the pilot were arranged, to create a sense of community and peer support.

The analysis of the results is still ongoing. In the current development stage, the measurement system being used is too expensive and unreliable to be installed for the sole purpose of providing data for sustainability advice. The potential of measured household-specific data is, however, important. The amount of data collected on personal consumption patterns (e.g. electricity consumption, transport choices, shopping, etc.) is increasing, and holds the potential to also be used as a basis for personalised advice. It should be kept in mind that because of the limited number of measuring devices, the period of measurements in this project was limited to four weeks for most households.

The preliminary analysis shows that the role of the expert in interpreting the consumption data and highlighting the most important actions to be taken is crucial to achieving changes in behaviour. The data collected through the measurements was in many cases quite insignificant to the households without the interpretation and in-depth explanations of the advisor. For example, collecting data about a family's driving, consumption and eating habits has no relevance, unless it can be put into perspective through comparison with other households, by calculating possible savings and explaining the environmental effects of the actions. Energy use is usually more interesting in itself, because of its high cost and a wish for financial savings.

Earlier research suggests that computerised monitoring and feedback on energy use has the potential to reduce households' energy consumption (Abrahamse et al., 2007; Brandon and Lewis, 1999). But according to Hunter et al. (2006), calculators and tracking consumption may not be enough to encourage behaviour change. The advantage of real-time measurements is that it provides a feedback mechanism to be very close to real life actions. The pilot shows, however, that it is quite difficult to achieve changes in behaviour by merely installing monitors and measuring consumption. From the advisors' point of view, the interviews with the families provided a real insight into the possibilities for change and made it possible to give relevant advice.

In London, a study into a home energy visit programme designed to encourage reductions in household carbon emissions and water consumption was criticised for having visiting times that were too short, and for the level of expertise of energy advisors working on short-term contacts (Revell, 2014). Both of these issues were taken into account in the Ecohome project and the time allocated for each visit was about two hours, double that of the London case. The visitors were also the project workers of the Ecohome project and were motivated to achieve high quality and development from the visits.

The energy advisors of Valonia, a regional energy and sustainability office, were responsible for conducting visits during the pilot. Another aim of the Ecohome project was to pilot a new eco-trainer action in which entrepreneurs who are already in contact with households (e.g. cleaning, house maintenance and professional organising services) provide environmental advice to create added value to their services. The entrepreneurs can integrate sustainability services into their existing business idea or offer eco advice as a separate service to their customers. The above-mentioned entrepreneurs who already provide their services are potential middle actors in the field of sustainable consumption patterns and energy efficiency.

4.5 Web-based carbon footprint calculator and its use in discussions with ordinary people

The goal of this particular pilot was twofold: First, to use a web-based carbon footprint calculator to communicate the difference that households can make with their consumption and life-style choices; and second, to develop tool-supported action models for discussing carbon footprint and mitigation measures with ordinary people in different occasions. Cooperation with NGOs, companies and other stakeholders was an important part of the work, in order to raise the knowledge about the calculator among households and connect the calculator and related activities with stakeholders' own agendas and activities.

The carbon calculator Ilmastodieetti ("Climate diet") was the main tool in this action model. The calculator was first published in 2010, and there have been more than 50,000 users since the launch. The calculator takes into account different aspects of housing (especially energy use at home), personal transport, food and consumption of goods and services, and it calculates an individual's personal carbon footprint for one year. During 2013 the calculator was updated, and improvements were made to provide more detailed information about the result of each consumption section as well as the input by the user.

Inputs by users and their results are saved in a database. This dataset can be used for research purposes to understand what kind of people use the calculator, and also the level of their knowledge. One can insert quite detailed data about energy consumption and features of cars and its usage into the calculator. The calculator also provides estimates, e.g. in cases where the user does not know about their heating and electricity consumption at home. According to the preliminary analysis of the data, the median carbon footprint of Ilmastodieetti users was 6.5 tonnes of CO2 equivalent per person per annum. This is lower than the average of 8.7 tonnes in Finland (Seppälä et al., 2011). Around 60% of the users so far have been women. The dataset indicates the knowledge of the users in terms of how much people are aware of their energy consumption and heating types, as this data can be either inserted in a detailed manner, or one can use estimates provided by the calculator.

One of the advantages of tools like Ilmastodieetti is that they provide results and advice based on one's real consumption and lifestyle patterns instead of information about average figures (Whitmarsh et al., 2011). In addition, the relevance of different consumption categories is visualised and this enables users to focus on the most important sectors in their consumption to reduce the carbon footprint (Chatterton et al., 2009; Hunter et al., 2006).

Free to use web-based tools have a potential to reach large audiences. The importance of partners in spreading the word about the calculator and motivating the users was considered important. The role of partners is also essential in linking the carbon footprint concept to their own work related to e.g. energy saving at home or food choices. Important stakeholders in this respect were partners that provide activities, support, education, and goods or services for households. These include NGOs working with households, companies providing goods and services for households, municipal energy and sustainability advisors, and teachers. No special event for marketing the calculator was arranged, but activities took place at locations where people go for other reasons, i.e. grocery stores, shopping centres, fairs, family café meetings, and seminars for teachers. The motivation for this was to ensure contacts with people, who are not already particularly environmentally aware.

During the pilot, activities were introduced together with two NGOs, two municipal energy and sustainability agencies, one retail chain and three teachers' federations. Methods used in developing activities included: workshops with members and key persons of the organisations, surveys for members of the organisations, and observations and feedback from various events. The activities included events in grocery stores and shopping centres, discussions in meetings with families with small children, and workshops for teachers. The number of people contacted was not limited to face-to-face contacts since the events were in many cases presented on the news in radio, newspapers, web and television.

Fig. 5. Material and calculation tools were used in several contexts with ordinary people to gain experience and feedback for further development. The picture presents an example of "weighting" the carbon footprint of the contents of a shopping bag in Kamppi shopping centre.

The strength of the calculator is its comprehensiveness. It is also a challenge, however. For audiences already motivated to take a closer look at their lifestyle and carbon footprint, comprehensiveness is highly valuable. Teachers have also found the calculator useful to demonstrate and provide exercises for their students related to the carbon footprint issues. But in situations where people are busy (i.e. shopping centres), it was more easy to approach people with a simple message of i.e. asking to take part in a short sustainability quiz, but to continue with fulfilling the calculator together was more of a challenge. Often people were just asked to continue with the calculator at home. Thus it was important to give a card or a brochure to remind later about the calculator.

Another recognised challenge was the carbon capability (Whitmarsh et al., 2011) of the target group. The whole concept of a carbon footprint calculator is meaningful only for audiences with certain existing knowledge of climate change, and its linkages to the carbon footprint of consumption choices.

There are many web-based carbon and other calculators available. The challenge is to make people aware of them and motivate usage. In addition, the mere calculation results may not be enough to bring about changes in consumption patterns (e.g. Chatterton et al., 2009). Therefore, personal communication and interpretation of results are important. Also stakeholders who could use the tool in their own work would benefit from advice and tips, on how they can use the calculator to help communicate issues and choices related to carbon footprint. Approaching ordinary people with their busy everyday life has its challenges, however. How to get a contact and sustain it? In the long run, what could be the most efficient way or media to raise awareness of the carbon calculator?

Learnings from cooperation and campaigns with NGOs and companies include: (1) the importance of partners who have close contacts with households and share an interest in sustainability but who are not environmental experts themselves and would benefit from tools and advice on how to use them; (2) the need to carefully take into account the capability of the audience and the type of situation to receive the message. Who and in what kind of situation has the capacity to look into a tool like a carbon footprint calculator?; and (3) What kind of other, more simple materials and methods can raise the interest to use web-based tools later on at home.

5 Conclusions

This paper focused on the potential role of intermediaries and middle actors to support change in consumption patterns and to increase energy efficiency in households. The country- and context-specific aspects as well as some of the potential actors may vary but the action models and learning from this study can be applied and further developed in other countries too.

The approach of developing the action models together with the target groups was considered beneficial for learning about the practical conditions, constraints and expectations in the field. The experiences and feedback were used during the project, and these can be taken into account for further development.

Ambitious targets, regulations and supporting policy instruments set the framework for available options and economically viable practices to improve energy efficiency and affect consumption patterns. Public awareness and recognition of the relationships between consumption patterns and environmental impacts is needed. The regulatory framework together with a decent level of awareness is a prerequisite for the demand for more sustainable products and services, as well as interest in sustainable practices. To meet and create the supply of these kinds of services and practices, enterprises need to have expertise, proper technical solutions, good communicational skills and a viable business model.

This paper compiled the experiences, potential and challenges of action models to increase energy efficiency and quality of housing, and change consumption patterns. The long-term implications remain to be seen and would be an interesting topic for further studies.

Acknowledgements

This study was based on funding received from the Finnish Ministry of Environment, and belongs to the pilot projects of the Finnish Programme to Promote Sustainable Consumption and Production (KULTU).

References

Abrahamse, W., Steg L., Vlek, C., Rothengatter, T. 2007. The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviours, and behavioural antecedents. Journal of Environmental Psychology 12, 265–276.

Adato energia, 2013. Kotitalouksien sähkönkäyttö 2011. (Household electricity consumption in 2011, in Finnish) Online: http://www.tem.fi/files/35856/Kotitalouksien_sahkonkaytto_2011_raportti.pdf (accessed 5.8.14).

Ahonen, S., 2011. Experiences on projects promoting sustainable lifestyles in Nordic countries. TemaNord 2011:507 Online: http://www.norden.org/en/publications/publikationer/2011-507/at_download/publicationfile (accessed 5.8.14).

Ajanovic, A., Schipper, L., Haas, R., 2012. The impact of more efficient but larger new passenger cars on energy consumption in EU-15 countries. Energy 48, 346–355.

Barr, S., 2003. Strategies for sustainability: citizens and responsible environmental behaviour. Area 35, 227–240.

Brandon, G., Lewis, A., 1999. Reducing Household Energy Consumption: A Qualitative and Quantitative Field Study. Environmental Psychology 19, 75–85.

Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market. Journal of Environmental Economics and Management 62, 166–179.

Chatterton, T.J., Coulter, A., Musselwhite, C., Lyons, G., Clegg, S., 2009. Understanding how transport choices are affected by the environment and health: Views expressed in a study on the use of carbon calculators. Public Health 123, e45–e49.

Chitnis, M., Sorrel, S., Druckman, A., Firth, S.K., Jackson, T., 2013. Turning lights into flights: Estimating direct and indirect rebound effects for the UK households. Energy Policy 55, 234–250.

CORPUS, 2014. The SCP-knowledge hub. Online http://www.scp-knowledge.eu/ (accessed 24.9.2014)
Eurobarometer. 2013. Climate change. Special Eurobarometer 409. Online: http://ec.europa.eu/public_opinion/archives/ebs/ebs_409_en.pdf (accessed 5.8.14).

Eurobarometer. 2011. Climate change. Special Eurobarometer 372. Online: http://ec.europa.eu/public_opinion/archives/ebs/ebs_372_en.pdf (accessed 5.8.14).

Girod, B., van Vuuren, D.P., Hertwich, E.G., 2014. Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions. Global Environmental Change 25, 5–15.

Heiskanen, E., Johnson, M., Vadovics, E. 2013. Learning about and involving users in energy saving on the local level. Journal of Cleaner Production 48, 241–249.

Heiskanen, E., Lovio, R., Jalas, M., 2011. Path creation for sustainable consumption: promoting alternative heating systems in Finland. Journal of Cleaner Production 19, 1892–1900.

Heiskanen, E., Perrels, A., Nissinen, A., Berghäll, E., Liesimaa, V., Mattinen, M., 2012. Ohjauskeinoja asumisen, henkilöliikenteen ja ruoan ilmastovaikutusten hillintään. Yksityiskohtaiset ohjauskeinokuvaukset. (Policy instruments to decrease the climate impact of housing, personal transport and food - Detailed instrument descriptions, in Finnish abstract in English). The Finnish Environment 8/2012. Online: https://helda.helsinki.fi/bitstream/handle/10138/39836/SYKEra_8_2012.pdf?sequence=1 (accessed 5.8.14).

Hertwich, E.G., 2005. Consumption and the Rebound Effect An Industrial Ecology Perspective. Journal of Industrial Ecology 9, 85–98.

HSY, 2014. Kuinka paljon kulutat vettä? (How much do you consume water?) Online: http://www.hsy.fi/vesi/kodinvesiasiat/Vedenkulutus/Sivut/default.aspx (accessed 11.8.14).

Hunter, C., Carmichael, K., Pangbourne, K., 2006. Household Ecological Footprinting Using a New Diary-Based Data-Gathering Approach. Local Environment 11, 307–327.

HuoltoOptimi, 2014. Electronic house maintenance record book (in Finnish). Online: http://www.rakentaja.fi/indexfr.aspx?s=/suorakanava/huoltooptimi/ (accessed 18.8.14).

Ilmastodieetti, 2014. Carbon footprint calculator for public use. (in Finnish). Online: http://www.ilmastodieetti.fi/Ilmastolaskuri.html (accessed 18.8.14).

IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Final Draft available online: http://www.ipcc.ch/report/ar5/wg3/ (accessed 18.8.14).

Killip, G., 2013. Products, practices and processes: exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry. Energy Policy 62, 522–530.

Kyrö, R., Heinonen, J., Junnilla, S., 2012. Housing managers key to reducing the greenhouse gas emissions of multi-family housing companies? A mixed method approach. Building and Environment 56, 203–2010.

Mortensen, A., Heiselberg, P., Knudstrup, M., 2014. Economy controls energy retrofits of Danish single-family houses. Comfort, indoor environment and architecture increase the budget. Energy and Buildings 72, 465–475.

Nissinen, A., Heiskanen, E., Perrels, A., Berghall, E., Liesimaa, V., Mattinen M 2014. Combinations of policy instruments to decrease the climate impacts of housing, passenger transport and food in Finland. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2014.08.095

Omakotiliitto, 2014. Electronic house maintenance record book (in Finnish).Online: http://www.omakotiliitto.fi/pientalon_huoltokonsepti (accessed 18.8.14).

Ottosson, S., 2003. Participation action research - A key to improved knowledge of management. Technovation 23, 87–94.

Parag, Y., Janda, K.B., 2014. More than filler: Middle actors and socio-technical change in the energy system from the “middle-out”. Energy Research & Social Science 3, 102–112.

Revell, K., 2014. Estimating the environmental impact of home energy visits and extent of behaviour change. Energy Policy 73, 461–470.

Saarinen, M., Kurppa, S., Nissinen, A., Mäkelä, J., 2011. Aterioiden ja asumisen valinnat kulutuksen ja ympäristövaikutusten ytimessä. ConsEnv-hankkeen loppuraportti. (Environmental impacts of consumers’ choice of food products and housing. Final report of the ConsEnv project, in Finnish, abstract in English) The Finnish Environment 14/2011. Online: https://helda.helsinki.fi/bitstream/handle/10138/37037/SY_14_2011.pdf?sequence=3 (accessed 18.8.14).

Seppälä, J., Mäenpää, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri, J-M., Härmä, T., Korhonen, M-R., Saarinen, M., Virtanen, Y., 2011. An assessment of greenhouse gas emissions and material flows caused by the Finnish economy using the ENVIMAT model. Journal of Cleaner Production 19, 1833–1841.

Seppälä, J., Mäenpää, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri, J-M., Härmä, T., Korhonen, M-R., Saarinen, M., Virtanen, Y., 2009. Environmental impacts of material flows caused by the Finnish economy - ENVIMAT. (In Finnish, abstract in English). The Finnish Environment 20/2009, 134 p. Available online: https://helda.helsinki.fi/bitstream/handle/10138/38010/SY20_2009_Suomen_kansantalouden_materiaalivirtojen.pdf?sequence=1 (accessed 15.5.14).

Stata Oy, 2014. Electronic house maintenance record book (in Finnish). Online: www.stata.fi/talon_huoltokirja/ (accessed 18.8.14).

Statistics Finland, 2014. Dwellings and housing conditions. Online: http://pxweb2.stat.fi/Database/StatFin/databasetree_en.asp (accessed 5.8.14).

Steg, L., Vlek, C., 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. Journal of Environmental Psychology 29, 309–317.

Strandell, A., 2011. Asukasbarometri 2010 – Asukaskysely suomalaisista asuinympäristöistä. (Residents’ barometer 2010 – Residents’ Survey on Residential Environments in Finland, in Finnish, abstract in English) The Finnish Environment 31/2011. Online: https://helda.helsinki.fi/bitstream/handle/10138/37042/SY_31_2011.pdf?sequence=5 (accessed 5.8.14).

Suomen yrittäjät, 2014. Kotitalousvähennys (household tax deduction). Online (in Finnish): http://www.yrittajat.fi/fi-FI/verotjarahat/verotus/kotitalousvahennys/ (accessed 5.9.14).

Virta, J., Pylsy, P., 2011 Taloyhtiön energiakirja (Energy book for housing companies, in Finnish) Online: http://www.taloyhtio.net/ajassa/energiakirja/ (accessed 9.9.14).

Whitmarsh, L., Seyfang, G., O’Neill, S., 2011. Public engagement with carbon and climate change: To what extent is the public ‘carbon capable’? Global Environmental Change 21, 56–65.

Ministry of Environment 2013. Ministry of Environmentn asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöissä 4/13 (Ministry of the environment decree on improving the energy performance of buildings undergoing renovation or alteration) Online (in Finnish): www.ym.fi/download/noname/%7B6E3BE53C-0C24-485B-A6C4-2F6F7D7030B4%7D/57171 (accessed 5.9.14).

Ministry of Environment, 2012. Vähemmästä viisaammin. Kestävän kulutuksen ja tuotannon ohjelman uudistus 2012. (More from Less – Wisely, updated programme for sustainable consumption and production, in Finnish) Online http://www.ym.fi/download/noname/%7B8B5DC698-70AE-4547-83E1-7F5D49F8F205%7D/30375 (accessed 5.8.14).

Is Western European Textile and Clothing Consumption Sustainable? Trends in Capital, Labour and Carbon from a Global Multi-Region Input-Output Model

Simon Mair*[1], Angela Druckman[1] and Tim Jackson[1]

[1] Centre for Environmental Strategy, Faculty of Physical and Engineering Science, University of Surrey, Guildford, GU2 7JG

*Corresponding author: s.mair@surrey.ac.uk; +447706785676

Abstract

Rising demand for cheaper textiles and clothing in Western Europe is well documented, as are changes in the Textiles and Clothing industry's globalised production structure. We apply Multivariate Production Footprint (MPF) accounting to examine the sustainability implications of meeting Western European consumption of textiles and clothing between 1995 and 2009. MPF accounting estimates various environmental and socio-economic impacts of consumption and shows where these occur both geographically and in the value chain. Our results show that the carbon production footprint of Western European textile and clothing consumption remained fairly steady throughout a majority of this period, as efficiency gains were outpaced by increases in consumption. The largest single source of carbon dioxide was the Energy and Resource sector in Brazil, Russia, India and China (BRIC). We also find that Western European textile and clothing consumption remains dependent on low-cost labour from BRIC. Moreover, we show that increases in hours worked in these countries did not always correspond to increases in compensation of that labour. Conversely, in Western Europe labour income rose during periods when hours worked fell. We conclude by discussing the implications of these results for a more sustainable future for Western European textile and clothing consumption.

1 Introduction

In recent years, the sustainability of the Textile and Clothing sector has come under close scrutiny (e.g. Allwood, Laursen, Russell, Rodriguez, & Bocken, 2008; Allwood, Laursen, Rodriguez, & Brocken, 2006; Ekström & Salomonson, 2014). Consequently the sector is known to be important for all three pillars of sustainability: environment, economy and society. In environmental terms, textiles and clothing production and consumption is a substantial contributor to greenhouse gas emissions (Carbon Trust, 2011), solid waste (Claudio, 2007), chemical toxicity (Chen & Burns, 2006) and water use (Muthu, Li, Hu, & Mok, 2012). Economically, textile and clothing production is a major source of revenue for many developing and emerging economies, in some cases accounting for up to 15% of GDP and 80% of export revenue (Keane & Willem te Velde, 2008).

Socially, the sector is important in terms of job creation, directly supplying some 60 million jobs worldwide (ILO, 2014). However, there are concerns over the work conditions. For example, in 2013 the collapse of the Rana Plaza clothing factory complex in Bangladesh killed 1100 workers, predominantly young women, and more than 2000 were injured (Butler, 2013; Motlagh, 2014; Poulton, Panetta, Burke, Levene, & Guardian Interactive team, 2014; Taplin, 2014). Unfortunately, the Rana Plaza collapse was not an isolated event but a high profile example of the dangers of the Textile and Clothing sector for workers: Taplin (2014) and the British Parliaments' All Party Parliamentary Group on Bangladesh (BAPPG, 2013) recount several smaller fatal accidents in apparel factories immediately before and after Rana Plaza. "*Three people died and six were injured when a floor piled with material collapsed in a sneaker factory in Cambodia"* (P.72 Taplin, 2014), *"just months [before the Rana Plaza collapse]a fire in the Tazreen Fashions factory killed an estimated 112 workers"*(P. 6 BAPPG, 2013). In light of these reports the BAPPG (P. 15 2013) state that "hazardous conditions of varying severity are systemic to the industry."

In this paper we consider how the sustainability of Western European textile and clothing consumption changed between 1995 and 2009. During this period the Textile and Clothing value chain underwent substantial structural change in the form of globalisation. Since 1990, globalisation has been characterised by an increase in the trade of intermediate[1] goods as production has specialised and been distributed across global production networks (Feenstra & Hanson, 1996). This process is known as fragmentation of production and is common to all manufacturing industries (Los, Timmer, & de Vries, 2014; Timmer, Los, Stehrer, & de Vries, 2013). However, the Textile and Clothing sector is especially amenable to fragmentation as at nearly every stage of the production process products can be exported (Morris and Barnes 2008). Largely due to the high labour intensity of production and relatively low barriers to entry, globalisation in the Textile and Clothing sector has seen a reduction in production in affluent countries and a rise in production in developing and emerging countries (Dicken, 2011; Morris & Barnes, 2008) . Moreover, this trend was exaggerated by the Multi-Fibre Arrangement (MFA) which regulated the majority of global Textile and Clothing trade between 1972 and 2005 (OECD, 2004a). A key mechanism of the MFA was trade quotas restricting imports of particular goods. Reactions to the quota system drove further fragmentation of production as producers switched production to countries with no or unfulfilled quotas, in the case of some small developing countries actually creating new Textile and Clothing Industries (Dicken, 2011) . 1995 marked the beginning of the phasing out of the MFA, leaving some smaller countries unsure of their ability to compete with Chinese operations (Adhikari & Yamamoto, 2007; Dicken, 2011; Spinanger, 1999).

One result of globalisation is that although large amounts of globally produced Textile and Clothing goods are destined for Western European consumers, very little production occurs within Western European territorial borders (Allwood et al., 2006; Gardetti & Torres,

[1] Intermediate goods are those manufactured and sold as inputs to other production processes ending up as final product only after multiple stages of production, distribution and marketing.

2013). This means that the impacts of producing Textile and Clothing goods for Western European consumers are now spread throughout the world.

Linked to globalisation are changes in consumer preferences. Consumers now dispose of and replace textile and clothing products much more rapidly (Doyle, Moore, & Morgan, 2006; Niinimaki & Hassi, 2011). Retailers have both responded to and encouraged this change by shifting from a biannual mode of production to a continuous mode of production. This has required retailers to supply a steady stream of cheap goods, arguably facilitating the fragmentation process (Morris & Barnes, 2008; Tokatli, 2008; Tokatli, Kizilgun, & Cho, 2011). This changing trend in consumption/production is particularly prevalent amongst clothing retailers and consumers in Western Europe (Crofton & Dopio, 2007; Sull & Turconi, 2008).

Both the tendency toward more fragmented production and changed consumer preferences are thought to have changed the sustainability implications of producing textiles and clothing goods for Western European consumers. It is argued that the increasingly rapid consumption of textiles and clothing has exacerbated the fragmentation of production to low wage, low worker rights countries as affluent country retailers look to reduce costs and lead times, passing risk and pressure to their developing country manufacturers (Morris & Barnes, 2008; Taplin, 2006). Additionally, official UK Government documents refer to the “Primark” effect when describing the rise in textile waste sent to landfill in the UK, Primark being a large retailer of cheap disposable clothing (Clift, Sim, & Sinclair, 2013).

Therefore, the aim of this study is to provide a systematic, empirical sustainability assessment of textile and clothing consumption by Western Europe from 1995 until 2009. To achieve this we apply Multivariate Production Footprint (MPF) accounting to assess how the changing dynamics of the sector have effected its environmental, social and economic impacts. Our MPF analysis provides a novel insight into the sustainability of recent trends Western European textile and clothing consumption by generating empirical estimates of an environmental indicator (the carbon dioxide emitted during production), and socio-economic indicators (labour inputs to the production processes, compensation of this labour, and financial returns to capital). Moreover, the MPF accounting framework allows examination of each of these indicators in geographical and sectoral terms.

We consider the ease and speed with which MPF accounting allows multiple indicators to be studied one of its chief benefits. With the advent of databases like the World Input-Output Database (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013) (used here) making multiple indicators available in a consistent framework available we anticipate seeing more MPF analyses. This kind of comprehensive analysis is important given that a focus on one indicator can lead to unexpected consequences in other areas. For instance, recent work suggests that a shift to low greenhouse gas consumption patterns could lead to disproportionately high economic losses for low income countries (Erickson, Owen, & Dawkins, 2012). Given the interlinked nature of the environment, society and the economy, sustainability impacts are typically spread across all of these areas and sustainability assessments should consider environmental, economic and social effects to begin to build a holistic picture. Ideally, this should be done in a consistent way with a common conceptual framework so as to ensure compatibility and consistency when comparing differing indicators. The MPF accounting framework we apply achieves this consistency by constructing production footprints built from global value chain indicators.

The primary contribution of this paper is the application of the MPF accounting framework to a timeseries of Western European Textile and Clothing consumption. The rest of the paper is structured as follows. In the next section we introduce two key concepts, global value chains and production footprints. Following this we outline the MPF accounting framework (section 3) before applying it to Western European textile and clothing consumption (section 4). Based on this analysis, we make suggestions for a more sustainable future for Western European Consumption of textiles and clothing consumption (section 5).

2 Global Value Chains and Production Footprints

2.1 Global Value Chains

Value chains describe the full set of activities in the production of a good (Gereffi & Fernandez-Stark, 2011). It is important to note that here production is used in its broadest sense, encompassing every activity that adds economic value between conception and delivery of a product including design, marketing and financial services (Feenstra & Hanson, 1996; Timmer, Los, et al., 2013). In this way global value chains are more complete than supply chains which are typically more focused on physical production stages (Timmer, Erumban, Los, Stehrer, & de Vries, 2013). The prefix "global" implies that a particular value chain crosses multiple geographical borders. In all industries most value chains are now global (Los et al., 2014), and this is the case for the Textiles and Clothing value chain (e.g. Dicken, 2011).

An intuitive understanding of a global value chain can be illustrated by considering the French Textile and Clothing sector. An increase in demand for French textiles and clothing will in the first instance stimulate an increase in production in the French Textile and Clothing sector. However, the increase production will require additional inputs from other sectors, for example the German Chemical sector (e.g. chemicals used to treat the cloth), the Chinese Textile and Clothing sector (e.g imports of intermediate textiles to be finished in France) and the French Business Services sector (e.g. insurance). Likewise, each of these suppliers will increase their own production, further stimulating production by their suppliers and so on *ad infinitum*. The French Textile and Clothing global value chain is this international network of production.

Timmer, Los, et al., (2013) propose two new indicators based on the global value chain concept; global value chain income (GVC Income) and global value chain jobs (GVC Jobs). GVC Income is defined as the sum of all gross value added generated along a given global value chain while GVC Jobs is the total employment across the global value chain. Timmer, Los, et al (2013) use GVC Income and GVC Jobs to analyse fragmentation and competitiveness of European manufactures industries. Their analysis confirms that the role of European nations is increasingly shifting to service industries and that manufacturing is increasingly globally distributed. Their GVC indicators are of interest to us because they reveal aggregate, geographical and sectoral patterns in global income and job creation. This has clear sustainability implications, particularly if the GVC Income and GVC Jobs indicators can be linked to more usual sustainability indicators such as carbon or labour *footprints* – which are more widely applied in the environmental and social accounting literature (for example, Alsamawi, Murray, & Lenzen, 2014; Druckman, Bradley, Papathanasopoulou, & Jackson, 2008; Druckman & Jackson, 2009)

GVC Income or GVC Jobs type indicators are easily extended to environmental and social concerns: GVC Carbon would be a measure of carbon generated at every point in the GVC. In fact, we can construct a generic GVC Indicator as the sum of any given factor, for which we have data, across a global value chain. However, there remain differences between the application of the GVC Indicator and a footprint. In the next sub-section we link research on globalisation and value chains with our MPF sustainability assessment by showing that global value chain indicators are the basis for our production footprints (PFs).

2.2 Footprints

Footprints have been widely applied in the environmental and social accounting literature. At the macro-economic scale carbon footprints of entire nations have been estimated (Druckman et al., 2008; Hertwich & Peters, 2009) and global flows of labour quantified (Alsamawi et al., 2014). On the other hand, researchers have estimated the carbon footprints of hotels (Filimonau, Dickinson, Robbins, & Huijbregts, 2011), individual products (Cederberg, Persson, Neovius, Molander, & Clift, 2011) and households (Druckman & Jackson, 2009; Shirley, Jones, & Kammen, 2012).

Theoretically, a true footprint encompasses all aspects of a lifecycle; for example, a carbon footprint of a t-shirt should include all the carbon produced in the GVC of that t-shirt *plus* all the carbon produced in the maintenance, care, and disposal of the t-shirt. This is a first key distinction between GVC Income and an income footprint: a complete footprint includes processes that occur post-production. However, increasingly prominent in the literature is a constrained form of footprint that does not include post-production processes; a PF.

Sinden, et al., (2011) examine the European Union Aluminum carbon PF, finding that only about a third of the CO_2 PF of aluminum consumed in Europe is covered by the European Union Emissions Trading Scheme. More closely related to our study both the Carbon Trust (2011) and Andrew and Peters (2013) study the CO_2 emissions of the clothing sector, while the latter study also examines the Value Added PF. They both find that clothing consumption is a substantial contributor to global emissions, with the Carbon Trust recommending increasing product lifespans and Andrew and Peters identifying the Chinese electricity sector as the dominant source of emissions in the sector.

For those familiar with process-based lifecycle analysis, our term “production footprint” is analogous to a cradle-to-gate Life Cycle Assessment (LCA). PFs have a substantially reduced data requirement relative to complete footprints. However, the main difference is not an advantage or disadvantage but a change in emphasis; production footprints are useful where we are concerned with the processes upstream of consumers or retailers.

As with the generic GVC Indicator we can define a generic PF. However, there remains a key distinction: footprints are consumption based whilst the GVC Indicator is production based. Therefore, GVC Income for French Textiles and Clothing is equal to the income generated producing goods eventually *sold by* the French Textile and Clothing sector to consumers whilst the French Textiles and Clothing income production footprint is equal to the sum of all income generated producing Textiles and Clothing goods then *purchased by* French consumers.

In the highly simplified case where the French Textiles and Clothing Sector only sells its final goods to French consumers and French consumers only purchase textiles and clothing from the French Textiles and Clothing sector, the French Textiles and Clothing GVC Income is equal to the French Textiles and Clothing Income PF. Alternatively, if French consumers also purchase Italian textiles and clothing goods and the French Textiles and Clothing sector exports some goods to Italian consumers, the French Textiles and Clothing Income PF will not equal the French Textiles and Clothing GVC Income. Instead, the French Textiles and Clothing Income PF will be the sum of the French Textiles and Clothing GVC Income weighted by French consumption *plus* the Italian Textiles and Clothing sector GVC Income weighted by the French consumption. In practice, consumers purchase from many different countries, stimulating multiple GVCs. Consequently a PF is the sum of many GVC Indicators each weighted by the consumption of the region of interest. This is important for MPF analysis because it makes explicit the common conceptual, economic, framework used for each variable in the multivariate analysis.

3 Methods and Data

Here we present our MPF accounting framework. For the sake of simplicity we focus on the Western European Textiles and Clothing Carbon PF but the explanation is applicable to all indicators (see section 3.3). In section 3.1 we provide a descriptive overview of our accounting framework and in section 3.2 we outline the underlying mathematics. Section 3.2 provides a deeper insight into our method but assumes some prior knowledge of matrix algebra, it can be skipped without losing the main thread of the paper

3.1 Estimating Production Footprints

Estimating production footprints requires an accounting system able to describe global value chains and provide breakdowns of consumption by region. Therefore, we must start with an accounting framework covering multiple countries and sectors. Global multi-regional input-output (GMRIO) models link national accounts for different countries using detailed trade statistics (Tukker & Dietzenbacher, 2013) and therefore provide a good framework for estimating PFs. In GMRIO models, domestic national accounts describe the relationships between domestic sectors; trade statistics describe links between sectors in different countries; and domestic final demand figures provide detailed breakdowns of consumption by region and sector. In all cases, links are described in the form of sales and purchases.

An additional benefit of using the GMRIO framework is that recent developments mean practitioners and researchers have ready access to multiple indicators in a consistent framework. We use the World Input-Output Database (WIOD) (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013) which provides detailed labour, economic and environmental indicators, but other databases are also available (Lenzen, Moran, Kanemoto, & Geschke, 2013; Tukker et al., 2013; Tukker & Dietzenbacher, 2013).

Staying with the case of French Textiles and Clothing, all the purchases required to produce a single unit of output can be extracted from a GMRIO model. For example, in 2009 to supply $1 of textiles and clothing goods to the final consumer, the French Textile and Clothing sector required, amongst other inputs, $0.11 of purchases of French business services, $0.01 of Chinese textile and clothing products, and $0.005 of German chemicals. In turn, we can also extract the requirements for these additional inputs (for example, the German Chemicals sector requires a small amount of French Business Services etc.) and so on until we have the total sales (gross output) induced across the global value chain in producing one unit of French textiles and clothing goods. This is the French Textile and Clothing GVC Gross Output per dollar of consumption. To estimate total French Textile and Clothing GVC Gross Output we would then multiply by the total global consumption of French Textile and Clothing goods. However, as we are estimating the Western European Textiles and Clothing PF we multiply by the consumption of French textile and clothing goods in Western European countries only. This process is repeated for the global value chains for all the Textile and

Clothing sectors worldwide and the results added together to give the Western European Textiles and Clothing Gross Output PF.

To extend this to carbon dioxide emissions we multiply the Western European Textiles and Clothing Gross Output PF by the ratio of carbon dioxide emissions to gross output. This is done on a sectoral basis – so that the gross output for French Business Services in the estimated production footprint is multiplied by the carbon dioxide intensity of gross output for French Business Services. This gives the Western European Textile and Clothing Carbon PF.

Whilst process may sound laborious, this is not the case. Using the matrix algebra detailed in section 3.2, the whole process can be completed in a few minutes on a standard desktop PC or Laptop.

3.2 Technical exposition

The MPF is based on the widely applied generalised Leontief quantity input-output model (Bradley, Druckman, & Jackson, 2013; Davis & Caldeira, 2010; Druckman & Jackson, 2010; Leontief & Duchin, 1986; McBain, 2014). Consequently, here we only briefly describe the method. For a detailed discussion readers should consult Miller and Blair (2009).

Input-output analysis is a tool used to analyse the connections between the various consuming and producing sectors of an economy. It is built on input-output tables compiled as part of the system of national accounts. Consequently it has a strong empirical basis. The basic Leontief quantity input-output model is given by the following equation,

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \qquad (1)$$

where there are n sectors, $\mathbf{x}$ is the $1 \times n$ vector of gross output by sector and $\mathbf{A}$ is the $n \times n$ technology matrix describing the production processes used within the economy (i.e. the direct requirements of final demand), $\mathbf{y}$ is the $1 \times n$ vector of final demand, $\mathbf{I}$ is an $n \times n$ identity matrix (a matrix with ones on the diagonal and zeroes on the off diagonal). $(\mathbf{I} - \mathbf{A})^{-1}$ is the

Leontief inverse describing how the production processes of the economy are connected (i.e. the direct and indirect requirements, or value chains, of final demand).

In a global model, $\mathbf{A}, \mathbf{x}$ and $\mathbf{y}$ are partitioned into individual countries. So in the case of two countries (1) becomes,

$$\begin{bmatrix} \mathbf{x_1} \\ \mathbf{x_2} \end{bmatrix} = \left(\mathbf{I} - \begin{bmatrix} \mathbf{A_{1,1}} & \mathbf{A_{1,2}} \\ \mathbf{A_{2,1}} & \mathbf{A_{2,2}} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{y_1} \\ \mathbf{y_2} \end{bmatrix} \qquad (2)$$

where, the subscript denotes the region, so $\mathbf{A_{1,1}}$ represents the domestic requirements of region 1, $\mathbf{A_{1,2}}$ represents import requirements of region 2 from region 1 and $\mathbf{x_1}$ represents the gross output of region 1. This model can be extended to any number of regions – in our empirical analysis we model 41 regions.

Our aim is to examine the greenhouse gas emissions associated with consumption of textile and clothing goods in Western Europe. Following the logic of the previous section, the next step is to extract the Western European Textiles and Clothing Gross Output PF. Recall that this means the sum of global Textiles and Clothing GVC Gross Output weighted by Western European final consumption. Setting region 1 as Western Europe and region 2 as rest of the world (RoW), assume Western Europe purchases \$100 of textiles and clothing goods from Western Europe, and \$50 directly from the RoW. We enter these values into (2) and in a simplified model (the model we actually apply has 35 sectors in each of the 41 regions) with two sectors, “Textiles and Clothing” and “Other”, final demand from equation (2) becomes,

$$\begin{bmatrix} y_1^{Textiles} \\ y_2^{Other} \\ y_1^{Textiles} \\ y_2^{Other} \end{bmatrix} = \begin{bmatrix} 100 \\ 0 \\ 50 \\ 0 \end{bmatrix} \qquad (3)$$

This gives us the Western European Textile and Clothing Gross Output PF,

$$\begin{bmatrix}\mathbf{x_1}\\\mathbf{x_2}\end{bmatrix} = \begin{bmatrix}x_1^{Textiles}\\x_2^{Other}\\x_1^{Textiles}\\x_2^{Other}\end{bmatrix} \quad (4)$$

which we multiply by the carbon dioxide intensity of gross output (u) in each sector to get the Western European Textiles and Clothing Carbon PF for a given year $(\mathbf{e})$,

$$\mathbf{e} = \begin{bmatrix}e_1^{Textiles}\\e_2^{Other}\\e_1^{Textiles}\\e_2^{Other}\end{bmatrix} = \begin{bmatrix}u_1^{Textiles} & & & \\ & u_2^{Other} & & \\ & & u_1^{Textiles} & \\ & & & u_2^{Other}\end{bmatrix}\begin{bmatrix}x_1^{Textiles}\\x_2^{Other}\\x_1^{Textiles}\\x_2^{Other}\end{bmatrix} \quad (4)$$

This process is repeated for all years.

3.3 Our Indicators and Data

Gross value added is a commonly used measure of economic performance, representing the economic contribution of a producer or sector (ONS, 2010). Gross value added can be decomposed into a profit component (gross operating surplus), taxes on production (less subsidies) and employee compensation which covers wages and other expenses such as redundancies (ONS, 2010). We follow (Timmer, Erumban, et al., 2013) in splitting gross value added into two parts, employee compensation, which we refer to as Labour Income, and all other component parts which we refer to as Capital Income. Therefore, we estimate Capital Income as the residual of gross value added minus Labour Income. As (Timmer, Erumban, et al., 2013) point out, Capital Income defined in this way includes returns on intangible capital, such as R&D and Branding. However, note that unlike in other studies (e.g. Nordås, 2004) income for the self-employed is included in our Labour Income measure, not in the Capital Income measure. The Capital Income PF represents the returns to capital generated at every stage of the production process in producing the final good. Likewise, the Labour Income PF represents the compensation of labour in producing the final good. For both Income PFs we deflate the results to 1995 US dollars using sector specific price indices.

Linked to the Labour Income PF is the Labour Hours PF indicator. The Labour Hours PF is the sum of the labour used in production of the final good measured in hours of work. The Labour Hours PF complements the Labour Income PF by providing a physical indication of labour use (hours worked). This allows us to provide a more nuanced analysis of socio-economic impacts.

The Carbon PF is our environmental indicator. The Carbon PF is the sum of the carbon dioxide emitted in production of the final good. It is closely linked to energy use (Genty, Arto, & Neuwahl, 2012) and does not include other important greenhouse gases such as methane. The decision to exclude other greenhouse gases was taken to improve the robustness of our analysis. The database we use represents agriculture as on sector. Agricultural subsectors have considerable variation in their greenhouse gas intensities (Tukker & Dietzenbacher, 2013). For example, if the Chinese agricultural sector began shifting to a more meat based export industry this would cause an increase in the methane emission attributed to the Textiles and Clothing sector. It is also important to note that climate is only one environmental issue among many. However, carbon data is substantially more reliable than other metrics and received special attention in the construction process of the dataset used here (Genty et al., 2012). Future analyses should expand on our work by assessing other environmental issues. With suitably robust data, additional analyses can be readily carried out within the framework we use to provide comparable results.

All data are taken from the WIOD. For a full description readers are directed to the relevant documentation (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013; Erumban, Gouma, De Vries, De Vries, & Timmer, 2012; Genty et al., 2012; Timmer, 2012). In brief, WIOD provides multi-regional input-output tables covering 41 regions (40 countries and one rest of the world region) and corresponding socio-economic and environmental satellite accounts. All countries are available at a 35 sector level of detail.

Although other GMRIO databases cover more countries (Lenzen et al., 2013; Peters, Andrew, & Lennox, 2011), a longer timespan (Lenzen et al., 2013) or have more detailed sector coverage (Peters, Andrew, et al., 2011; Tukker et al., 2013; Wiebe, Bruckner, Giljum, & Lutz, 2012), we chose to use WIOD for several reasons. First, WIOD provides detailed socio-economic statistics, such as sector specific price indices and labour hours by sector. Second, WIOD is built from publically available, official data, meaning that tracing the construction process of WIOD is easier than for other datasets. This is especially important for sector level analyses where anomalous data points may have more influence than at the national level. Additionally, WIOD improves upon a major source of uncertainty in multi-region input-output modelling; the import proportionality assumption. A commonly applied method in global multi-regional input-output modelling used to overcome the lack of detailed import data, the import proportionality assumption assumes that intermediate and final consumption share the same proportion of imports. WIOD improves upon this by differentiating between intermediate and final imports using detailed Comtrade data (Dietzenbacher, Los, Stehrer, Timmer, & G, 2013), thus making its trade matrices more robust. Finally, WIOD is freely available[2] ensuring replication and advancement of our analysis is open to the broadest possible range of practitioners and researchers.

3.4 Assumptions and Limitations

Our analysis is subject to all the usual assumptions and limitations of input-output analysis, covered in detail elsewhere (Bullard & Sebald, 1988; Lenzen, Wood, & Wiedmann, 2010; Miller & Blair, 2009; Weber, 2008; Wilting, 2012). Most relevant to our analysis is the fact that global multi-region input-output models are typically understood to give their most robust footprints at the national level (Lenzen et al., 2010; Wilting, 2012). This is because the current understanding of input-output uncertainty/error is that much of it is stochastic. As a result, during aggregation processes errors are likely to cancel out. For this reason, we do not

[2] Eora (Lenzen et al 2013) is also freely available but this is limited to “academic (university or grant-funded) work at degree-granting institutions”.

to report results at the individual country-sector level (e.g. Turkish-Agriculture or Chinese-Mining). Rather, we confine our results to regions, such as Western European demand and BRIC (Brazil, Russia, India, China) production. We aggregate countries according to the classifications given in table 1. This means that when we refer to individual sectors it is in the context of the global economy (so, for example, if we discuss a rise in Agricultural contributions to the Carbon PF without specifying a region we mean that the contribution from all 41 agricultural sectors to the Western European Textiles and Clothing Carbon PF has risen).

Table 1 Aggregation of countries into regions

Region	Countries
Western Europe (WEU)	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom
Other Europe (OEU)	Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Malta, Poland, Romania, Slovakia, Slovenia, Turkey
BRIC	Brazil, Russia, India, China
Other Affluent Countries (OAC)	Australia, Canada, Japan, Korea, Taiwan, USA
Other Less Affluent Countries (OLAC)	Indonesia, Mexico, Rest of the World

Also important to note is that Wiod does not provide labour hours data or component breakdowns of gross value added for the Rest of the World (RoW) region. This is important in interpreting trends in these indicators. For the Capital Income and Labour Income PFs we conducted sense checks by comparing their trends to aggregate gross value added PF trends (Appendix A). This was not possible for the Labour Hours PF. A useful next step for research would be to compile a labour hours satellite account for RoW.

In the face of the limitations of our method we would note several things. First, WIOD improves a major source of GMRIO uncertainty, the import proportionality assumption. A commonly applied method in global multi-regional input-output modelling used to overcome the lack of detailed import data, the import proportionality assumption assumes that intermediate and final consumption share the same proportion of imports. WIOD improves upon this by differentiating between intermediate and final imports using detailed Comtrade data (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013), thus making its trade matrices more robust. Second, as detailed here we have taken other steps to improve the robustness of our analysis. Finally, because other methods of environmental and economic impact analysis are necessarily limited to a certain number of value chain stages (Lenzen, 2000) or rely on more simplified representations of international trade (for example only representing trade between the country of interest an the countries it imports from e.g. Nijdam, Wilting, Goedkoop, & Madsen, 2005) we believe GMRIO models represent the best method for estimating the impacts of consumption. Moreover, they allow us to do this across multiple metrics with relative speed. We are not alone in this assessment: reviewing the recent developments in global multi-region input-output models, (Tukker & Dietzenbacher, 2013 p.6) conclude that GMRIO modelling "*is probably the best tool to understand how consumption of specific product groups drives environmental and socio-economic impacts (e.g. global emissions and job creation) elsewhere in the world.*"

4 Results and Discussion

4.1 Aggregate Trends

Figure 1 shows trends in Western European consumption deflated to 1995 prices and Western European Textiles and Clothing Production Footprints (PFs) for Carbon, Labour Hours, Labour Income, and Capital Income. In line with Western European Textiles and Clothing consumption, all PFs fell after 1995. However, while the Labour Hours PF and Carbon

PF rose again after 1997 Labour and Capital Income PFs continued to fall until 2001[3]. After 2002, there is a pronounced upward trend in all indicators driven by the corresponding increase in levels of consumption. The Capital Income and Labour Income PFs continue to follow the consumption trend closely, rising with consumption expenditure but never quite recovering to 1995 levels.

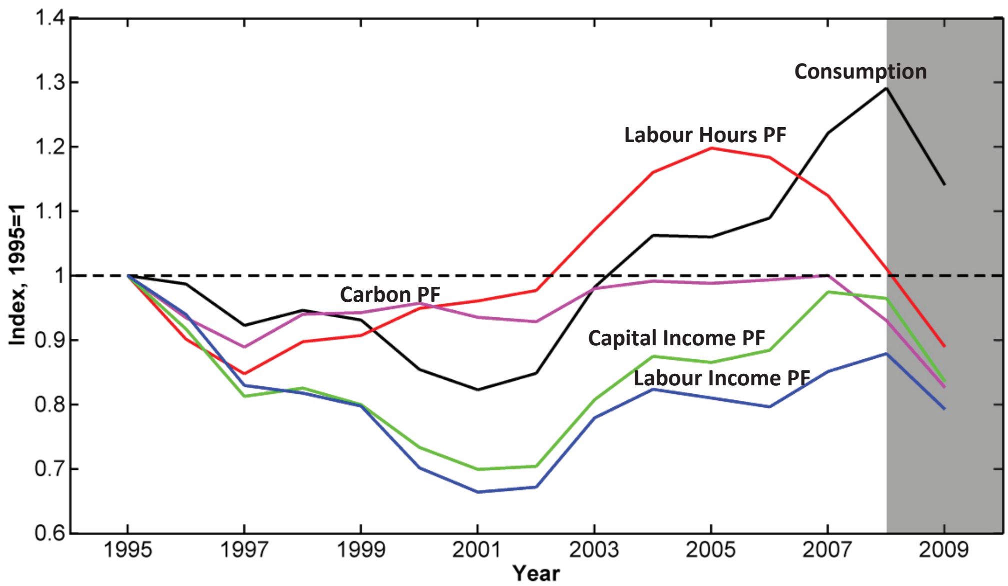


Figure 1 Trends in Western European Textiles and Clothing Carbon, Labour Hours, Labour Income, Capital Income Production Footprints (PFs) and Consumption Expenditure, 1995=1. Greyed area Indicates a recessionary period in Western Europe and the dotted line is a reference line indicating no change since 1995.

All PF's decrease again at the end of the time series. Recession caused levels of consumption to fall after 2008 and this explains much of the falls in PFs after 2008. However, falls in the Carbon and Labour Hours PFs prior to 2008 are not explained by recession or falling consumption. Rather, pre-2008 reductions in the Labour Hours PF and Carbon PF indicate production processes that have become more carbon and labour efficient with respect to consumption. This is what we would expect: capitalist economies are good at efficiency (Jackson, 2009). However, two things should be noted here. First, for the majority of the timeseries these efficiency gains were largely outstripped by rising demand, in line with other

[3] Note that Capital Income and Labour Income PFs do not include the RoW region (as detailed in section 3.4). However, the aggregate gross value added PF (which does include RoW data) does not show substantial deviation from the Labour Income and Capital Income PF trends (see appendix A).

work showing that rising consumption is a more important driver of emission profiles than efficiency (Brizga, Feng, & Hubacek, 2014; Jackson, 2009; Peters, Weber, Guan, & Hubacek, 2007). Second, whilst improved efficiency seems the most plausible explanation for the relative decoupling of the Carbon PF and levels of consumption, this is less plausible for the sharp reduction in the Labour Hours PF. Rather, we hypothesise that at least some of this sharp fall is indicative of the rising importance of countries for which we do not have labour hours data (section 3.4).

Finally, it is interesting to note that in the aggregate form presented in Figure 1 between 1997 and 2001 the Labour Income PF fell whilst the Labour Hours PF rose. This is presumably the result of increased use of labour in lower wage nations (Dunford, 2004), something we consider further in our regional analysis (section 4.2). At the aggregate level we can see that this shift to lower wage labour did not immediately correspond to an increase in the Capital Income PF. However, it remains to be seen in our regional analysis if certain regions gained from this process at the expense of others.

In summary, at the macro-level there is a mixed picture in sustainability terms. Changes in production have seen some success in decoupling the Carbon PF and levels of Western European textiles and clothing consumption. However, the Labour Income PF was highest in 1995, despite periods when the Labour Hours PF was substantially higher than in 1995. In order to form a clearer picture of the sustainability of Western European Textile and Clothing consumption we now explore the geographical spread of the PFs.

4.2 Regional Trends

Figure 2 shows the regional breakdown of the Western European Textile and Clothing Consumption PFs for Carbon (Top Left); Labour Hours (Top Right); Capital Income (Bottom Left); and Labour Income (Bottom Right). Western Europe shows declining contributions to all these PFs. This is in line with reported shifts away from developed countries in Textiles and Clothing and other manufacturing production (Dicken, 2011; Dunford, 2004; Los et al., 2014) and confirms that the production of Textiles and Clothing goods for Western Europe increasingly takes place outside of Western Europe.

The regional breakdown of the Labour hours PF (Figure 2 Top Right) reveals that BRIC has supplied a majority of labour through the entire period, confirming expectations (Kaplinsky & Morris, 2006). Likewise, we see rapid growth in BRIC labour use after 2001 which is likely due to the 2nd stage phasing out of the MFA (Adhikari & Yamamoto, 2007; Spinanger, 1999). In contrast, the regional breakdown of the Labour Income PF (Figure 2 Bottom Right) shows that Western Europe dominated the Labour Income PF throughout the timeseries; experiencing an increase in Labour Income between 2001 and 2009 despite reduced contributions to the Labour Hours PF. This fits with the suggestion that Western Europe has retained highly skilled employment in the sector, in for example, design and R&D (Nordås, 2004; Sørensen, 2008). Moreover, our analysis shows that despite being the biggest contributor to the Labour Hours PF, BRIC is still only marginal in terms of the Labour Income PF suggesting the jobs created in BRIC by Western European Textile and Clothing consumption are low skilled and badly paid by Western European Standards. This is also problematic as BRIC countries are known to have poor working conditions and restricted rights (International Trade Union Confederation, 2014; Song, 2014)

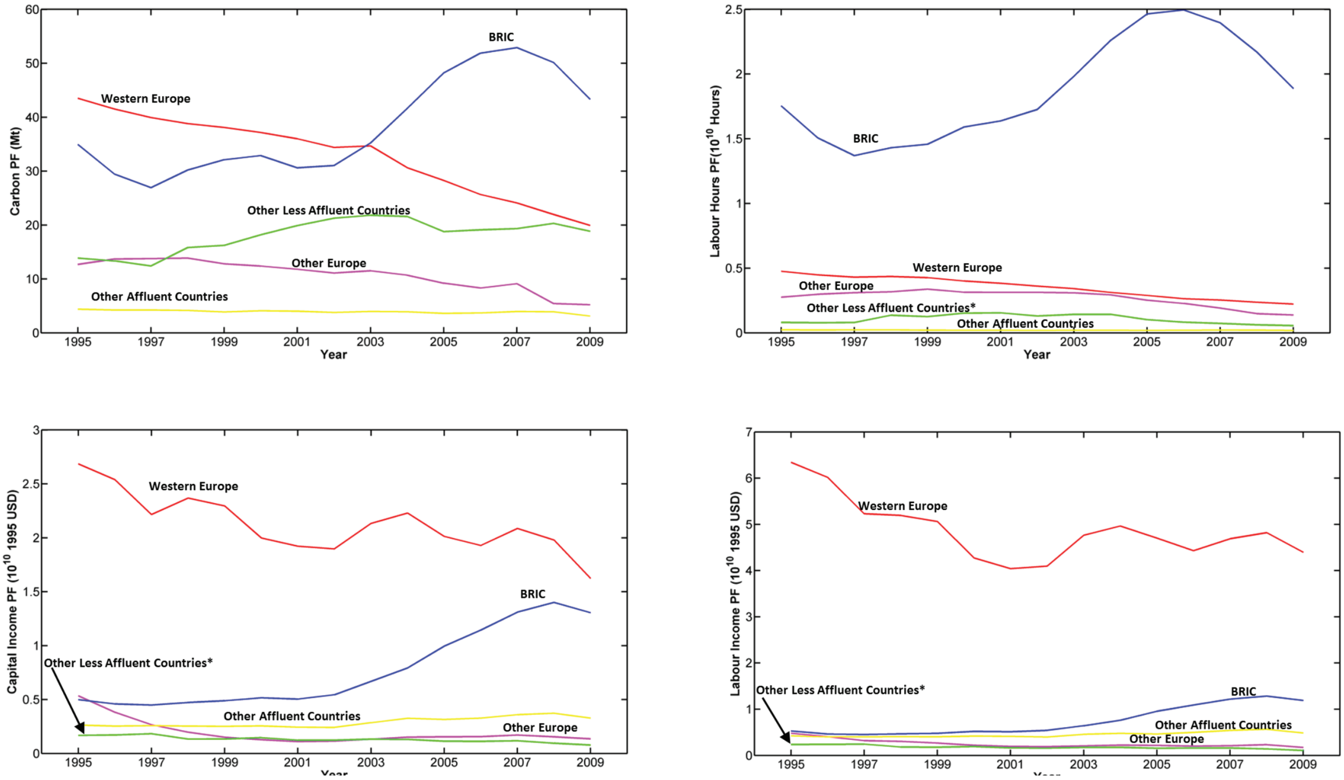


Figure 2 *Top Left* **Carbon Production Footprint by region in Megatonnes (MT)** *Top Right* **Labour Hours Production Footprint by region.** *Bottom Left* **Capital Income Production Footprint by region in USD dollars deflated to 1995 prices.** *Bottom Right* **Labour Income Production Footprint by region in USD dollars deflated to 1995 prices**
***denotes that RoW region was not included in these figures.**

Qualifying these results is that WIOD does not have Labour data for the RoW region which is included in the Other less affluent nations region (Table 1). The likely effect of this is that our estimates are conservative indicators for low wage labour use (Appendix A); others have shown that affluent nations tend to use high quantities of cheap labour (Alsamawi et al., 2014).

However, (Gereffi & Memedovic, 2003) argue that countries can ‘move up’ value chains by capturing higher value activities and our analysis suggests that BRIC is, slowly, managing this. BRIC contributions to the Labour Income PF continued to rise even after BRICs Labour Hours PF contribution fell, suggesting wages are rising as more skilled, higher value work is undertaken. This supports the long standing contention that regions outside Europe, not only have “low labour input costs to be exploited, but also an increasing availability of highly skilled labour”(P.2 Giuli, 1997) and that firms are beginning to capitalise on this (Tewari, 2006). Additionally, the bottom left panel of Figure 2 shows that after 2002 BRIC began to generate a much greater share of the Capital Income PF, in 2009 almost matching the Western European contribution. This suggests that production with greater returns to capital is also moving to BRIC. Provided this income remains in BRIC and does not subsequently flow abroad, this is a positive development for BRIC. Nonetheless, it is worth noting that Capital Income in BRIC has increased substantially faster than Labour Income and as Capital Income contains a profit component, Figure 2’s bottom left panel may provide evidence of profit seeking behaviour.

Additionally, Figure 2 Top Left shows that contributions from BRIC and the other less affluent countries became increasingly important to the Carbon PF. This is in line with other studies finding that offshore emissions constitute increasingly bigger portions of the carbon footprints of affluent nations (Peters, Minx, Weber, & Edenhofer, 2011; Wiedmann et al., 2010). There also appears to be a link between the Carbon and Labour Hours PFs as both follow similar regional patterns with BRIC contributions spiking after 2002 (about the time of the third stage removal of MFA quotas (Spinanger, 1999)). This suggests carbon and labour intensive production is relocating to similar geographical locations.

4.3 Sectoral trends

Figure 3 shows the sectoral contributions to the Western European Textile and Clothing Consumption PFs for Carbon (Top Left); Labour Hours (Top Right); Capital Income (Bottom Left); and Labour Income (Bottom Right)[4]. The Textile and Clothing sector is the biggest contributor to the Capital Income, Labour Income, and Labour Hours PFs and the second biggest contributor to the Carbon PF after the Energy and Resource Sector. In all cases, the contributions of the Textile and Clothing sector fell relative to 1995, albeit only slightly in the Labour Hours PF.

[4] Contributions by sector have been aggregated to 5 sectors in for clarity of presentation. For the full detail and correspondence to the NACE classification system see Appendix B.

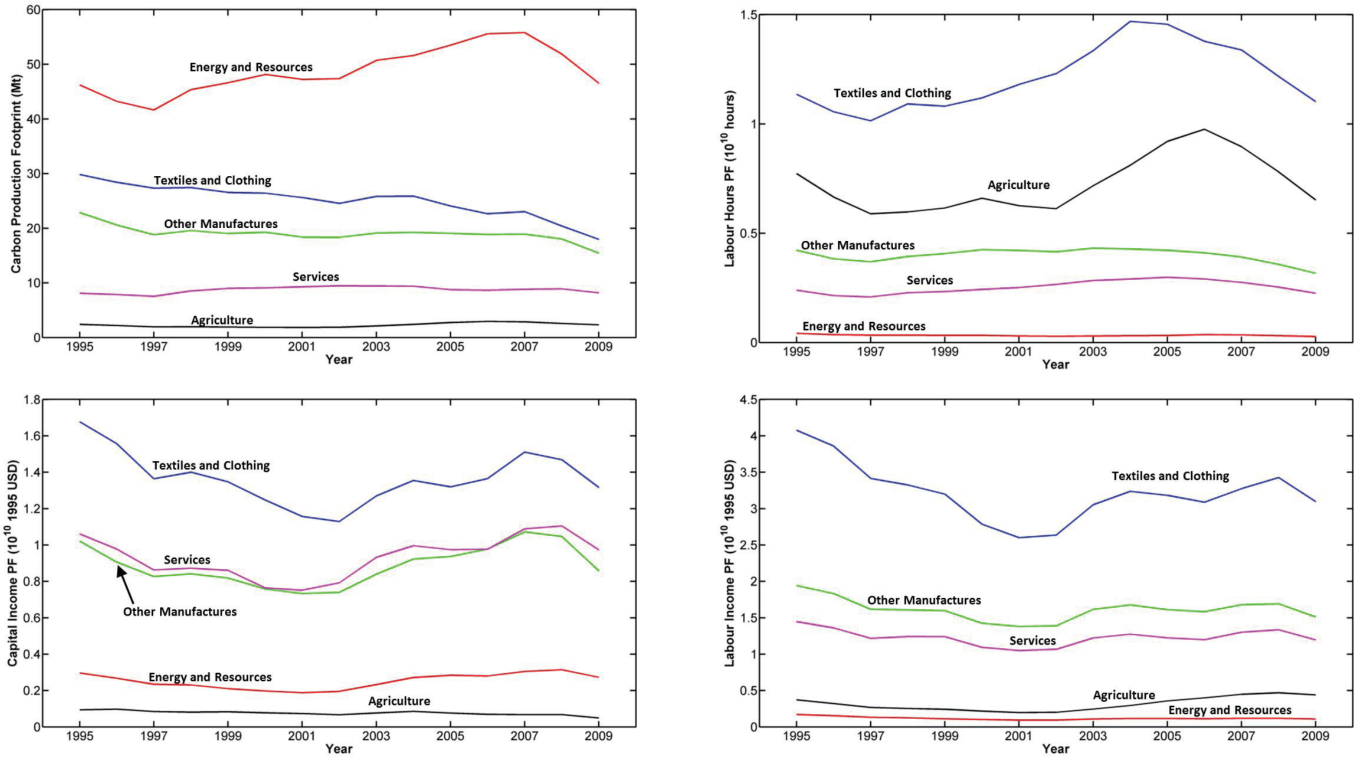


Figure 3 *Top Left* **Carbon Production Footprint (PF) by sector in Megatonnes (Mt)** *Top Right* **Labour Hours Production Footprint by sector.** *Bottom Left* **Capital Income Production Footprint by sector in USD dollars deflated to 1995 prices.** *Bottom Right* **Labour Income Production Footprint by sector in USD dollars deflated to 1995 prices**

The biggest contribution to the Labour Hours PF was the Textile and Clothing Industry. This can be explained by the highly labour intensive nature of clothing production; because cloth is soft and flexible, mechanising the process has proved difficult in clothing production (though not in textile production) (Dicken, 2011; OECD, 2004b). The Labour Income PF is also dominated by the Textile and Clothing sector. Figure 4 shows that this is the result of the high wages paid to Textile and Clothing workers in Western Europe. Figure 4 should be interpreted with care as it represents the highest level of uncertainty of our analysis. However, it corresponds to expectations in the literature regarding the geographical distribution of work in the Textile and Clothing sector (design and other skilled activities in affluent nations and low skilled manual labour in developing nations (Nordås, 2004)). Therefore we feel confident in interpreting Figure 4 as further evidence of reliance of Western European Textile and Clothing retailers and consumers on low wage labour in BRIC.

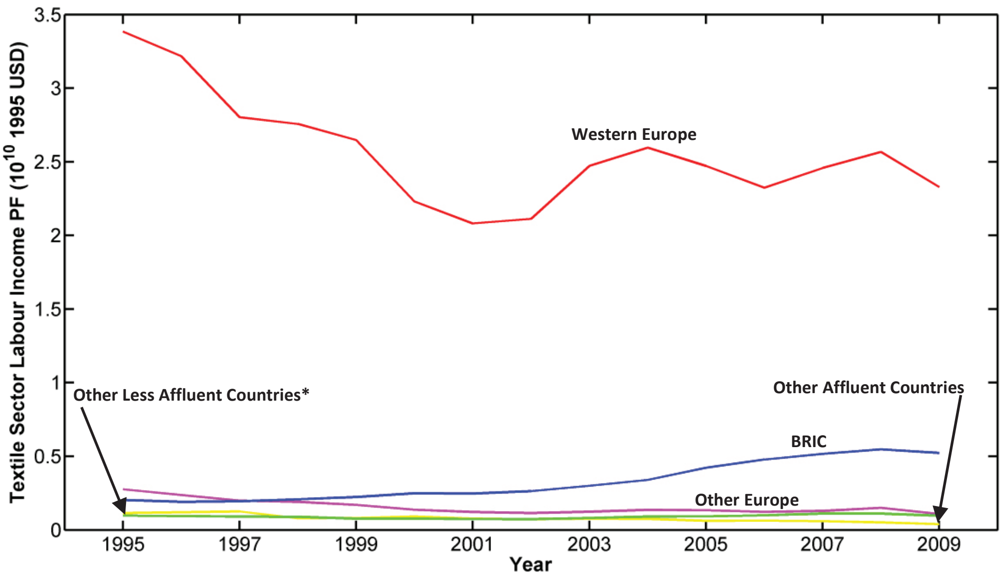


Figure 4 Contributions to the Western European Textile and Clothing Labour income PF from the Textile and Clothing sector in different regions.

A similar picture emerges for the Agricultural industry. Unlike clothing production, mechanisation of, for example, cotton production is possible and in the USA has greatly reduced labour requirements (Rivoli, 2006). However, the regional breakdown of Labour

Hours PF (figure 2 Top right) shows that the BRIC labour contribution shows very similar patterns to the Textile and Clothing and Agricultural sectors contributions to the Labour Hours PF, suggesting that most of the increase in the Labour Hours was drawn from the Textile and Clothing and Agricultural Sectors in BRIC countries. This is supported by the fact that China, Brazil, and India were consistently among the top 10 global cotton producers between 1995 and 2009 (FAOSTAT, 2014) and rely on substantial quantities of labour-intensive hand harvesting (Chaudry, 2004).

In terms of the Carbon PF, our sector level analysis shows that decarbonisation efforts in the Textile and Clothing sector itself were what kept the Carbon PF below 1995 levels despite increases in the contributions to the Carbon PF from the Energy and Resource sector. However, after rising between 1997 and 2007, the Carbon Footprint only decreased in 2008 (Figure 1) when emissions from the biggest contributor to the Carbon PF, the Energy and Resource sector, fell.

Figure 5 breaks down the contributions of the Energy and Resource sector to the Western European Textiles and Clothing Carbon PF, showing BRIC Energy and Resource sector to be the biggest contributor. As with Figure 4 this represents a high level of uncertainty. Nonetheless, the pattern is in line with the wider literature; (Andrew & Peters, 2013) report that the Chinese Electricity sector was the biggest contributor to the UK, French and Norwegian Clothing Greenhouse Gas PFs for 2007 while the Carbon Trust (2011) reported that the Chinese Electricity Sector was the biggest contributor to the UK’s Clothing Carbon PF for 2004. Therefore we conclude that the biggest source of Carbon in the Western European Textiles and Clothing Carbon PF was the BRIC Energy and Resource sector. Further, we conclude that the carbon intensity of the background energy system has been of considerable importance in determining the Western European Textile and Clothing Carbon PF.

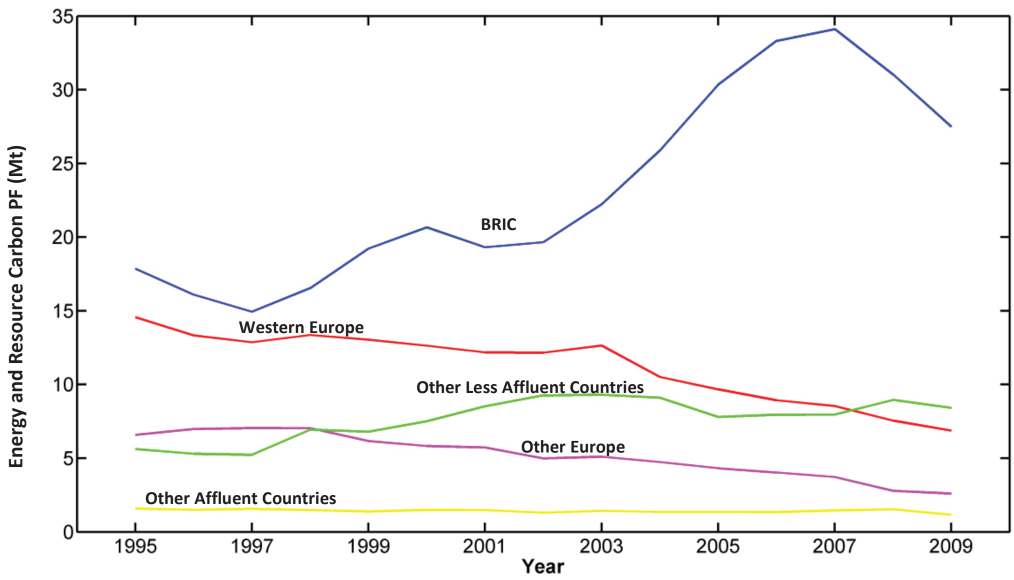


Figure 5 Contributions to the Western European Textile and Clothing Carbon PF from the Energy and Resource sector in different regions.

5 Synthesis – Sustainable Futures?

Several key findings emerge from our analysis. Firstly, Western European consumption of Textile and Clothing goods between 1995 and 2009 relied on large quantities of low paid labour principally in the Textiles and Clothing, and Agricultural sectors, whilst retaining high paid jobs for Western European workers. (Alsamawi et al., 2014) characterise this type of relationship as a “master” and “servant” relationship, the low paid servant nations supporting the lavish lifestyles of the wealthy master nations. This type of inequity does not sit easily with visions of a sustainable future where intra-generational equity is key (Brundtland, 1987; Haughton, 1999; Jackson, 2011).

Achieving intra-generational equity requires an increase in the income of the global poor sufficient to both meet their material needs and to partake in society. One way to overcome the inequity of the current situation, and to better enable BRIC workers to flourish is to raise wages. This is a strategy that curries favour with third sector groups. For example, the Asia Living Wage Floor Alliance is a group of unions and labour activists from across Asia whom advocate payment of a living wage to garment workers[5]. Moreover, McMullen et al (2014) report that New Look, the British high street chain, is already paying a living wage to some of its workers in China. However, how New Look finance this is unclear. Also unclear is the extent to which payment of a living wage affects production cost. Beyond studies examining the consumer price effects of increases in the minimum wage in developed nations (Aaronson, 2001; O'Brien-Strain & MaCurdy, 2000) we can find very limited consideration of this in the literature. Therefore we flag this as an interesting area for future research.

It is also worth noting that the Asia Living Floor Wage and the McMullen report focus on improving prospects of workers in clothing factories. By highlighting the substantial contributions to the Western European Textiles and Clothing Labour Hours PF of Agriculture, our analysis shows that a focus on garment workers alone will not be sufficient to remove dependency on low wage labour. For that, wage increases must also be made in other sectors.

Next, the biggest contributor to the Western European Textile and Clothing Carbon PF was the Energy and Resource sector in BRIC. This indicates the importance of decarbonising economies, especially those of the nations where industry is expected to relocate. Therefore a sustainable Textile and Clothing sector relies on energy companies and governments to ensure a sustainable future for manufacturing by investing in renewable energy infrastructures.

Third, the Western European Textile and Clothing Carbon PF was, for the majority of the timeseries, outstripped by rising levels of consumption. Consequently, our results suggest large scale reductions in carbon emissions from Western European Textile and Clothing will require absolute reductions in levels of consumption. Therefore, Western European retailers may need to rethink their business models, and consumers their consumption choices, in order to absolutely reduce per capita consumption levels. This recommendation is in line with

[5] http://www.cleanclothes.org/livingwage/who-are-the-asia-floor-wage-alliance

arguments that achieving a sustainable society will require substantial lifestyle changes in affluent nations away from consumerist values (Duchin & Lange, 1994; Jackson, 2009).

One way to bring together a reduction in consumption in affluent nations and increased labour income in poorer nations is the “better rather than more” strategy (Clift et al., 2013; Girod & De Haan, 2010) which advocates a reduction in the volume of consumption by purchasing “better” products at a higher price. The difficulty with such a strategy lies in defining what it means for a product to be “better”. ne interpretation of “better” in this context is “more equitable”. That is, a better product can be understood as one with a more equitable value chain – fairer wages and stronger rights for workers in all sectors and countries. Following this understanding the better rather more strategy by definition leads to increased income for workers in the value chain. Moreover, it has been argued elsewhere that low costs of consumer goods enables short lifespans (Cox, Griffith, Giorgi, & King, 2013). Consequently, passing the resultant increased cost of wage increases, better working conditions and improved rights could be enough to begin tipping consumer preferences away from high volume consumption thus reducing carbon emissions and achieving greater socio-economic and environmental sustainability for Western European textile and clothing consumption.

6 References

Aaronson, D. (2001). Price Pass-Through and the Minimum Wage *Review of Economics and Statistics, 83*(1), 158-169

Adhikari, R., & Yamamoto, Y. (2007). The textile and clothing Industry: Adjusting to the post-quota world *Industrial Development for the 21st Century: Sustainable Development Perspectives* (pp. 432). New York: United Nations, Department of Economic and Social Affairs.

Allwood, J. M., Laursen, S., Russell, S., Rodriguez, C. M., & Bocken, N. (2008). An approach to scenario analysis of the sustainability of an industrial sector applied to clothing and textiles in the UK. *Journal of Cleaner Production, 16*(12).

Allwood, J. M., Laursen, S. E., Rodriguez, C. M., & Brocken, N. M. P. (2006). Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom. Cambridge, UK, University of Cambridge Institute for Manufacturing.

Alsamawi, A., Murray, J., & Lenzen, M. (2014). The Employment Footprints of Nations. *Journal of Industrial Ecology, 18*, 59-70.

Andrew, R., & Peters, G. (2013). Optimal Carbon Policy for Supply Chain Analysis. Retrieved 22/05/2014, from http://www.rug.nl/research/ggdc/workshops/eframe/papers/session8_andrew_paper.pdf

BAPPG. (2013). (Bangladesh All Party Parliamentary Group), After Rana Plaza: A report into the readymade garment industry in Bangladesh 2013. Retrieved 18/06/2013, from http://www.annemain.com/pdf/APPG_Bangladesh_Garment_Industry_Report.pdf

Bradley, P., Druckman, A., & Jackson, T. (2013). The development of commercial local area resource and emissions modelling – navigating towards new perspectives and applications. *Journal of Cleaner Production, 42*(0), 241-253. doi: http://dx.doi.org/10.1016/j.jclepro.2012.11.009

Brizga, J., Feng, K., & Hubacek, K. (2014). Drivers of greenhouse gas emissions in the Baltic States: A structural decomposition analysis. *Ecological Economics, 98*(0), 22-28. doi: http://dx.doi.org/10.1016/j.ecolecon.2013.12.001

Brundtland, G. H. (1987). World commission on environment and development. *Our common future*, 8-9.

Bullard, C., & Sebald, A. (1988). Monte Carlo Sensitivity Analysis of Input-Output Models. *The Review of Economics and Statistics, 70*(4), 708-712.

Butler, S. (2013). Bangladeshi factory deaths spark action among high-street clothing chains. *The Observer*.

Carbon Trust. (2011). International Carbon Flows: Clothing. Retrieved 26/05/2014, from http://www.carbontrust.com/media/38358/ctc793-international-carbon-flows-clothing.pdf

Cederberg, C., Persson, U. M., Neovius, K., Molander, S., & Clift, R. (2011). Including Carbon Emissions from Deforestation in the Carbon Footprint of Brazilian Beef. *Environmental Science & Technology, 45*(5), 1773-1779. doi: 10.1021/es103240z

Chaudry, R. (2004). Harvesting and Ginning Cotton in the World. Retrieved 21/08/2014, from https://www.icac.org/cotton_info/speeches/Chaudhry/BW97.PDF

Chen, H.-L., & Burns, L. D. (2006). Environmental Analysis of Textile Products. *Clothing and Textiles Research Journal, 24*(3), 248-261. doi: 10.1177/0887302x06293065

Claudio, L. (2007). Waste Couture: Environmental Impact of the Clothing Industry. *Environmental Health Perspectives, 115*(9), A449–A454.

Clift, R., Sim, S., & Sinclair, P. (2013). Sustainable consumption and production: quality, luxury and supply chain equity. In I. Jawahir, S. Sikdar, & Y. Huang (Eds.), *Treatise on Sustainability Science and Engineering*: Springer.

Cox, J., Griffith, S., Giorgi, S., & King, G. (2013). Consumer understanding of product lifetimes. *Resources, Conservation and Recycling, 79*(0), 21-29. doi: http://dx.doi.org/10.1016/j.resconrec.2013.05.003

Crofton, S., & Dopio, L. (2007). Zara-Inditex and the Growth of Fast Fashion. *Essays in Economics and Business History, 25*, 41-54.

Davis, S. J., & Caldeira, K. (2010). Consumption-based accounting of CO2 emissions. *Proc. Natl. Acad. Sci. U. S. A., 107*(12), 5687-5692.

Dicken, P. (2011). 'Fabric-ating Fashion': The Clothing Industries. In G. S. M. t. Changing (Ed.), *Global Shift: Mapping the Changing Contours of the World Economy* (6th ed., pp. 302-330): Sage Publications.

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & de Vries, G. (2013). THE CONSTRUCTION OF WORLD INPUT–OUTPUT TABLES IN THE WIOD PROJECT. *Economic Systems Research, 25*(1).

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & G, d. V. (2013). THE CONSTRUCTION OF WORLD INPUT–OUTPUT TABLES IN THE WIOD PROJECT. *Economic Systems Research, 25*(1).

Doyle, S., Moore, C., & Morgan, L. (2006). Supplier Managament in Fast Moving Fashion Retailing. *Journal of Fashion Marketing and Management, 10*(3), 272-281.

Druckman, A., Bradley, P., Papathanasopoulou, E., & Jackson, T. (2008). Measuring progress towards carbon reduction in the UK. *Ecological Economics, 66*(4), 594-604.

Druckman, A., & Jackson, T. (2009). The carbon footprint of UK households 1990-2004: A socio- economically disaggregated, quasi- multi- regional input- output model. *Ecological Economics, 68*(7), 2066-2077.

Druckman, A., & Jackson, T. (2010). The bare necessities: How much household carbon do we really need? *Ecological Economics, 69*(9), 1794-1804. doi: http://dx.doi.org/10.1016/j.ecolecon.2010.04.018

Duchin, F., & Lange, G.-M. (1994). *The future of the environment: ecological economics and technological change*.

Dunford, M. (2004). The Changing Profile and Map of the EU Textile and Clothing Industry. In M. Faust, U. Voskamp, & V. Wittke (Eds.), *European Industrial Restructuring in a Global Economy: Fragmentation and Relocation of Value Chains*: SOFI.

Ekström, K. M., & Salomonson, N. (2014). Reuse and Recycling of Clothing and Textiles—A Network Approach. *Journal of Macromarketing*. doi: 10.1177/0276146714529658

Erickson, P., Owen, A., & Dawkins, E. (2012). Low-Greenhouse-Gas Consumption Strategies and Impacts on Developing Countries Retrieved 27/05/2014, from http://www.sei-international.org/mediamanager/documents/Publications/SEI-WP-2012-01-Low-GHG-Consumption.pdf

Erumban, A., Gouma, R., De Vries, G. J., De Vries, K., & Timmer, M. P. (2012). WIOD Socio-Economic Accounts (SEA): Sources and Methods. Retrieved 23/5/2014, from http://www.wiod.org/publications/source_docs/SEA_Sources.pdf

FAOSTAT. (2014). Cotton production statistics by country. Retrieved 28/08/2014, from http://faostat3.fao.org/

Feenstra, R., & Hanson, G. (1996). Globalization, Outsourcing, and Wage Inequality. *NBER Working Paper 5424.* Retrieved 07/08/2014, from http://www.nber.org/papers/w5424

Filimonau, V., Dickinson, J., Robbins, D., & Huijbregts, M. A. J. (2011). Reviewing the carbon footprint analysis of hotels: Life Cycle Energy Analysis (LCEA) as a holistic method for carbon impact appraisal of tourist accommodation. *Journal of Cleaner Production, 19*(17), 1917-1930.

Gardetti, M., & Torres, A. (2013). Introduction. In M. Gardetti & A. Torres (Eds.), *Sustainability in Fashion and Textiles*. Sheffield: Greenleaf Publishing.

Genty, A., Arto, I., & Neuwahl, F. (2012). Final Database of Environmental Satellite Accounts: Technical Report on Their Compilation. from http://www.wiod.org/publications/source_docs/Environmental_Sources.pdf

Gereffi, G., & Fernandez-Stark, K. (2011). Global Value Chain Analysis: A Primer. Retrieved 29/07/2014, from http://www.cggc.duke.edu/pdfs/2011-05-31_GVC_analysis_a_primer.pdf

Gereffi, G., & Memedovic, O. (2003). The Global Apparel Value Chain: What Prospects for Upgrading by Developing Countries? Retrieved 15/05/2014, from http://www.unido.org/fileadmin/import/11900_June2003_GereffiPaperGlobalApparel.4.pdf

Girod, B., & De Haan, P. (2010). More or Better? A Model for Changes in Household Greenhouse Gas Emissions due to Higher Income. *Journal of Industrial Ecology, 14*, 31-49.

Giuli, M. (1997). The competitiveness of the European textile industry. *Research Papers in International Business, No.2-97.* Retrieved 01/07/2014

Haughton, G. (1999). Environmental Justice and the Sustainable City. *Journal of Planning Education and Research, 18*(3), 233-243. doi: 10.1177/0739456x9901800305

Hertwich, E. G., & Peters, G. (2009). Carbon Footprint of Nations: A Global, Trade- Linked Analysis. *Environ. Sci. Technol., 43*(16), 6414-6420.

ILO. (2014). (International Labour Organisation), Textiles, clothing, leather and footwear sector. Retrieved 06/08/2014, from http://www.ilo.org/global/industries-and-sectors/textiles-clothing-leather-footwear/lang--en/index.htm

International Trade Union Confederation. (2014). ITUC Global Rights Index: The world's worst countries for workers. Retrieved 01/06/2014, from http://www.ituc-csi.org/IMG/pdf/survey_ra_2014_eng_v2.pdf

Jackson, T. (2009). *Prosperity without growth : economics for a finite planet*. London: London : Earthscan.

Jackson, T. (2011). Societal transformations for a sustainable economy. *Natural Resources Forum, 35*(3), 155-164. doi: 10.1111/j.1477-8947.2011.01395.x

Kaplinsky, R., & Morris, M. (2006). Dangling by a Thread: How Sharp are Chinese Scissors? Retrieved 20/5/2014, from http://asiandrivers.open.ac.uk/documents/Dangling_by_a_thread_Feb_06_%20final.pdf

Keane, J., & Willem te Velde, D. (2008). The role of clothing and textile industries in growth and development strategies. Retrieved 10/08/2014, from http://www.odi.org/publications/2493-role-clothing-textile-industries-growth-development-strategies

Lenzen, M. (2000). Errors in Conventional and Input-Output-based Life-Cycle Inventories. *Journal of Industrial Ecology, 4*(4), 127-148.

Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building Eora: A Global Multi-Region Input–Output Database at High Country and Sector Resolution. *Economic Systems Research, 25*(1), 20-49. doi: 10.1080/09535314.2013.769938

Lenzen, M., Wood, R., & Wiedmann, T. (2010). Uncertainty Analysis for Multiregion Input–Output Models – A Case Study of the UK's Carbon Footprint. *Economic Systems Research, 22*(1), 43-63.

Leontief, W., & Duchin, F. (1986). *The Future Impact of Automation on Workers*. New York: Oxford University Press.

Los, B., Timmer, M. P., & de Vries, G. J. (2014). HOW GLOBAL ARE GLOBAL VALUE CHAINS? A NEW APPROACH TO MEASURE INTERNATIONAL FRAGMENTATION. *Journal of Regional Science*, n/a-n/a. doi: 10.1111/jors.12121

McBain, D. (2014). Quantitative accounting for social economic indicators. *Natural Resources Forum*.

McMullen, A., Luginbühl, C., Nolan, K., Crabbé, C., & Ajaltouni, N. (2014). Tailored Wages. Retrieved 29/05/2014, from http://www.labourbehindthelabel.org/campaigns/itemlist/category/294-report

Miller, R., & Blair, D. (2009). *Input output analysis, foundations and extensions*. New Jersey: Prentice-Hall.

Morris, M., & Barnes, J. (2008). Globalization, the Changed Global Dynamics of the Clothing and Textile Supply Chains and the Impact on Sub-Sahran Africa. *Research and Statistics Branch Working Paper 10/2008.*

Motlagh, J. (2014). A year after Rana Plaza: What hasn't changed since the Bangladesh factory collapse. *Washington Post*.

Muthu, S. S., Li, Y., Hu, J. Y., & Mok, P. Y. (2012). Quantification of environmental impact and ecological sustainability for textile fibres. *Ecological Indicators, 13*(1), 66-74. doi: http://dx.doi.org/10.1016/j.ecolind.2011.05.008

Niinimaki, K., & Hassi, L. (2011). Emerging design strategies insustainable production and consumption of textiles and clothing. *Journal of Cleaner Production, 19*(16), 1876-1883.

Nijdam, D. S., Wilting, H. C., Goedkoop, M. J., & Madsen, J. (2005). Environmental Load from Dutch Private Consumption: How Much Damage Takes Place Abroad? *Journal of Industrial Ecology, 9*(1-2), 147-168. doi: 10.1162/1088198054084725

Nordås, H. K. (2004). The Global Textile and Clothing Industry post the Agreement on Textiles and Clothing. *Discussion Paper No.5.* Retrieved 23/08/2014, from http://www.tno.it/tecno_it/fashion4_2_05/documenti/WTO%20Discussion%20Paper%20TExtile%20and%20Clothing%20after%202005.pdf

O'Brien-Strain, M., & MaCurdy, T. (2000). Increasing the Minimum Wage: California's Winners and Losers. from http://www.ppic.org/main/publication.asp?i=88

OECD. (2004a). Market Developments and Trade Policies *A New World Map in Textiles and Clothing Adjusting to Change: Adjusting to change* (pp. 234): OECD Publishing.

OECD. (2004b). *Policy Brief, A New World Map in Textiles and Clothing: adjusting to change*. Paris: OECD.

ONS. (2010). *Measuring the economic impact of an intervention or investment, Paper One: Context & rationale*.

Peters, G., Andrew, R., & Lennox, J. (2011). Constructing an environmentally extended multi-regional input–output table using the GTAP database. *Economic Systems Research, 23*(2), 131-152.

Peters, G., Minx, J. C., Weber, C. L., & Edenhofer, O. (2011). Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the National Academy of Sciences of the United States of America, 108*(21), 8903.

Peters, G., Weber, C. L., Guan, D., & Hubacek, K. (2007). China's Growing CO2 Emissions A Race between Increasing Consumption and Efficiency Gains. *Environmental Science & Technology, 41*(17), 5939-5944.

Poulton, L., Panetta, F., Burke, J., Levene, D., & Guardian Interactive team. (2014). The Shirt on Your Back. Retrieved 02/05/2014, from http://www.theguardian.com/world/ng-interactive/2014/apr/bangladesh-shirt-on-your-back

Rivoli, P. (2006). *The Travels of a T-Shirt in the Global Economy* (Paperback Ed.). USA: Wiley.

Shirley, R., Jones, C., & Kammen, D. (2012). A household carbon footprint calculator for islands: Case study of the United States Virgin Islands. *Ecological Economics, 80*(0), 8-14. doi: http://dx.doi.org/10.1016/j.ecolecon.2012.04.027

Sinden, G. E., Peters, G. P., Minx, J., & Weber, C. L. (2011). International flows of embodied CO2 with an application to aluminium and the EU ETS. *Climate Policy, 11*(5), 1226-1245. doi: 10.1080/14693062.2011.602549

Song, Y. (2014). What should economists know about the current Chinese hukou system? *China Economic Review, 29*(0), 200-212. doi: http://dx.doi.org/10.1016/j.chieco.2014.04.012

Spinanger, D. (1999). Textiles Beyond the MFA Phase-Out. *World Economy, 22*, 455-476.

Sull, D., & Turconi, S. (2008). Fast Fashion Lessons. *Business Strategy Review, 19*, 4-11.

Sørensen, S. Y. (2008). EU textiles and clothing sector: Location decisions. Retrieved 07/08/2014, from http://www.eurofound.europa.eu/publications/htmlfiles/ef0848.htm

Taplin, I. (2006). Restructuring and reconfiguration: The EU textile and clothing industry adapts to change. *European Business Review, 18*(3), 172 - 186.

Taplin, I. (2014). Who is to blame? A re-examination of Fast Fashion after the 2013 factory disaster in Bangladesh. *critical perspectives on international business, 10*(1/2).

Tewari, M. (2006). Adjustment in India's textile and apparel industry: reworking historical legacies in a post-MFA world. *Environment and Planning A, 38*(12), 2325.

Timmer, M. P. (2012). The World Input-Output Database (WIOD): Contents, Sources and Methods, WIOD Working Paper Number 10. Retrieved 02/06/2014

Timmer, M. P., Erumban, A., Los, B., Stehrer, R., & de Vries, G. J. (2013). Slicing Up Global Value Chains. Retrieved 290/04/2014, from http://www.irs.princeton.edu/sites/irs/files/event/uploads/Slicing%20Up%20Global%20Value%20Chains%20Timmer%20and%20others%20GGDC%20RM.pdf

Timmer, M. P., Los, B., Stehrer, R., & de Vries, G. J. (2013). Fragmentation, incomes and jobs: an analysis of European competitiveness. *Economic Policy, 28*(76), 613-661. doi: 10.1111/1468-0327.12018

Tokatli, N. (2008). Global Sourcing: Insights from the Global Clothing Industry - the Case of Zara, a Fast Fashion Retailer. *Journal of Economic Geography, 8*, 21-38.

Tokatli, N., Kizilgun, O., & Cho, J. (2011). The Clothing Industry in Istanbul in the Era of Globalisation and Fast Fashion. *Urban Studies, 48*(6), 1201-1215.

Tukker, A., de Koning, A., Wood, R., Hawkins, T., Lutter, S., Acosta, J., . . . Kuenen, J. (2013). EXIOPOL – DEVELOPMENT AND ILLUSTRATIVE ANALYSES OF A DETAILED GLOBAL MR EE SUT/IOT. *Economic Systems Research, 25*(1), 50-70. doi: 10.1080/09535314.2012.761952

Tukker, A., & Dietzenbacher, E. (2013). GLOBAL MULTIREGIONAL INPUT–OUTPUT FRAMEWORKS: AN INTRODUCTION AND OUTLOOK. *Economic Systems Research, 25*(1), 1-19. doi: 10.1080/09535314.2012.761179

Weber, C. (2008). *Uncertainties in Constructing Environmental Multiregional Input-Output Models*. Paper presented at the International Input Output Meeting on Manageing the Environment, Seville, Spain. http://www.iioa.org/pdf/Intermediate-2008/Papers/5d4_Weber.pdf

Wiebe, K. S., Bruckner, M., Giljum, S., & Lutz, C. (2012). CALCULATING ENERGY-RELATED CO2 EMISSIONS EMBODIED IN INTERNATIONAL TRADE USING A GLOBAL INPUT–OUTPUT MODEL. *Economic Systems Research, 24*(2), 113-139. doi: 10.1080/09535314.2011.643293

Wiedmann, T., Wood, R., Minx, J., Lenzen, M., Guan, D., & Harris, R. (2010). A Carbon Footprint Time Series of the UK – Results From a Multiregion Input–Output Model. *Economic Systems Research, 22*(1), 19-42. doi: DOI 10.1080/09535311003612591

PII 922183656

Wilting, H. (2012). Sensitivity And Uncertainty Analysis In MRIO Modelling; Some Empirical Results With Regard To The Dutch Carbon Footprint. *Economic Systems Research, iFirst*, 1-31.

7

8 Appendix A

In section 3.3 we note that the Labour Income and Capital Income components of gross value added are not available for the Rest of the World Region. Consequently the Western Euopean Textiles and Clothing Labour Income and Capital Income PFs presented in the main text do not include contributions from the Rest of the World. Here we present the results of a sense check for the Western Euopean Textiles and Clothing Labour Income and Capital Income PFs. Our sense check takes the form of a comparison of the Western Euopean Textiles and Clothing Income PF with the Western Euopean Textiles and Clothing Income-RoW PF. The Income PF is the sum of the Labour Income and Capital Income PFs and represents gross value added generated at every stage of the value chain outside of the Rest of the World. The Income-RoW PF represents the gross value added generated at every stage of the value chain, including the Rest of the World region.

Figure 6 shows trends in the Western Euopean Textiles and Clothing Income and Income-RoW PFs at the aggregate level. Trends are identical until 1999, when the Income PF falls more quickly than the Income-RoW PF. This illustrates that value added declined less rapidly in the RoW region than in the other model regions. After 2001, the Income-RoW PF and Income PF recovered at similar rates until 2007 when growth in the Income PF was slower than growth in the Income-RoW PF. This suggests that between 2007 and 2008 value adding activities in RoW grew faster than the regional average.

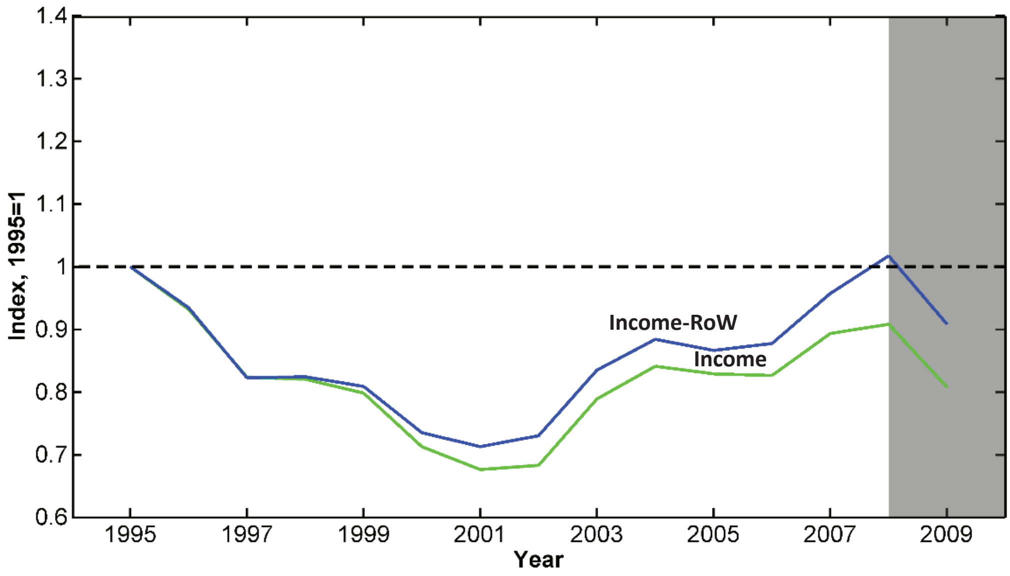


Figure 6 Comparison of Western European Income and Income-RoW PFs

Figure 7 shows the regional contributions to the Income and Income-RoW PFs. By definition, all trends are identical apart from the Other less affluent nations region, which includes the Rest of the World region. Figure 2 confirms the results of Figure 1, that relative to other regions, contributions to gross value added fell more slowly in the Rest of the World until 1999 and then began to grow before any other region. Figure 2 also highlights that gross value addition in the Rest of the World did experience relatively high growth rates in the 2007-2008 period.

Together, Figures 6 and 7 suggest that the Labour Income and Capital Income PFs are underestimated. However, it is also clear that overall trends remain relatively unaffected. That said, we would expect production in the Rest of the World region (which includes, for example, Cambodia and Bangladesh) to be Labour rather than capital intensive. Hence we would expect most of the value added in this region to be in the form of Labour Income and as a result, the sense check implies that not including contributions from the Rest of the World region had the biggest effect on the Labour Income PF.

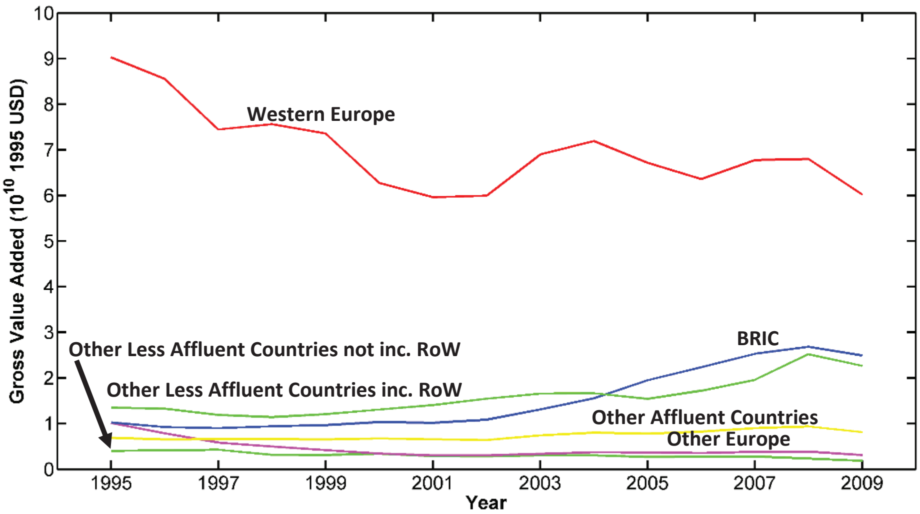


Figure 7 Regional Contributions to the Income and Income-RoW PFs. Contributions from all regions except Other Less Affluent Countries are identical.

9 Appendix B

Table 2 Sector classification system correspondence table

Mair, Druckman, Jackson 2014	**WIOD**	**NACE Codes**
Agriculture	Agriculture	AtB
Energy and Resources	Mining and Quarrying, Coke; Refined Petroleum and Nuclear Fuel; Electricity, Gas and Water Supply	C;23;E
Textiles and Clothing	Textiles and Clothing	17t18
Other Manufactures	Food, Beverages and Tobacco; Leather, Leather and Footwear; Wood and Products of Wood and Cork; Pulp, Paper, Paper , Printing and Publishing; Chemicals and Chemical Products; Rubber and Plastics; Other Non-Metallic Mineral; Basic Metals and Fabricated Metal; Machinery, Nec; Electrical and Optical Equipment; Transport Equipment; Manufacturing, Nec; Recycling; Construction; Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel; Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles; Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	15t16; 19;20; 21t22; 24; 25; 26; 27t28; 29; 30t33; 34t35 36t37;F;50; 51; 52
Services	Hotels and Restaurants; Inland Transport; Water Transport; Air Transport; Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies; Post and Telecommunications; Financial Intermediation; Real Estate Activities; Renting of M&Eq and Other Business Activities; Public Admin and Defence; Compulsory Social Security; Education; Health and Social Work; Other Community, Social and Personal Services; Private Households with Employed Persons	H; 60; 61; 62; 63; 64; J; 70; 71t74; L; M; N; O; P

Patterns and performance benefits of sustainability practices: a cross-country comparison

Matjaž Maletič[a], Damjan Maletič[a], Jens J. Dahlgaard[b], Su Mi Dahlgaard-Park[c], Boštjan Gomiščeka[a*]

[a] Faculty of Organizational Sciences, University of Maribor, Slovenia
[b] Division of Quality Technology and Management, Linköping University, Sweden
[c] Institute of Service Management, Lund University, Sweden

Abstract

This paper aims to explore the relationship between sustainability practices and organizational performance. In particular, this paper draws upon institutional theory whit the aim to enhance the understanding of sustainability-related phenomena, mainly from the perspective which has not yet been widely investigated in prior empirical studies.

Therefore, the paper addresses the research question whether sustainability practices as conceptualized within the framework of exploitation and exploration notions are characterized by organization's country of origin.

The target respondents of a large scale web-based survey were manufacturing and service industries distributed across five countries: Germany, Poland, Serbia, Slovenia and Spain. Multiple regression with categorical predictors (dummy variables) was utilized to examine country effects on each of the performance measures.

The outcome of the regression analysis provides some evidence indicating that organizations based in different countries hold substantially different perspectives:

(1) Regarding the patterns and correlations among organizational performance dimensions;

(2) Regarding the achieved levels of organizational performance as a consequence of deploying sustainability practices.

In general, results suggest that organizations in different countries show many more differences in relation to the sustainability practices and organizational performance compared to the organizations within the same country. With this respect results suggest that institutional mechanisms might be a plausible explanation for differences in the deployment of sustainability practices and the effects of sustainability practices on the organizational performance.

The paper contributes to the literature by providing a more clarity and better understanding of how organizations may effectively pursue sustainability practices to gain performance benefits.

Key words: sustainability, sustainability practices, organizational performance, country effect

1. Introduction

In recent years, the concept of sustainable development has been increasingly addressed by the business sector (Hahn and Scheermesser, 2006; Lozano, 2012). In the current business environment, more and more organizations see the need to look beyond the traditional concerns of running a business for immediate profit and to begin to deal with factors in the greater world that impinge on their medium to long-term success (Fairfield et al., 2011). It is now commonplace that without corporate support, society will never achieve sustainable development, as corporations represent the productive resources of the economy (Bansal, 2002). In the current highly competitive context, the question arises whether engaging in sustainability can bring an advantage to the organization. In response to this question, Azapagic (2003) elaborates that for many industry leaders and corporations, corporate sustainability has become an invaluable tool for exploring ways to reduce costs, manage risks, create new products, and drive fundamental internal changes in culture and structure.

Drawing on management literature on exploitation and exploration (March, 1991; Zhang et al., 2012), and prior studies (e.g. Maletič et al., 2014; Amini and Bienstock, 2014) that have developed theoretical frameworks to address the multidimensionality of corporate sustainability practices, this study distinguishes two different kinds of corporate sustainability practices with different objectives: sustainability exploitation (SEI) and sustainability exploration (SER). While sustainability exploitation is characterized by practices aimed at making an organization more efficient through incremental improvements in processes and outputs (e.g. improvements in eco-efficiency, improvements in stakeholder responsiveness), sustainability exploration is concerned with challenging existing sustainability solutions with innovative concepts and developing capabilities and competencies for sustainability-related innovation (Maletič et al., 2014).

This research investigates the patterns of SEI and SER practices across countries as well as the effects of these practices on organizational performance. Based on the institutional view (Matten and Moon, 2008), organizations facing similar institutional factors should have similar implementation pattern of SEI and SER. Further, it could also be proposed that exploration practices might differ across countries to a greater extent than exploitation practices. For example, some countries might have similar approaches in terms of formal, mandatory and codified rules or laws, while they can have substantially different approaches regarding voluntary sustainability initiatives, as well as having different attitudes or approaches towards the incentives and opportunities that are motivated by the perceived expectations of different stakeholders (Matten and Moon, 2008).

This study contributes to the corporate sustainability literature in several ways. First, this study explores the link between sustainability practices and organizational performance measures and provides empirical verification of two different sets of sustainability practices: SEI and SER. Second, the study tests the proposed model using large-scale cross-sectional data. And lastly, it investigates the patterns of sustainability practices across and within countries.

2. Methods

2.1. Sample and data collection

This research adopts a questionnaire survey as a primary source of data collection method. The questionnaire with the cover letter indicating the purpose and significance of the study was emailed to target respondents. To ensure a reasonable response rate, the survey was sent in two waves. Managers were chosen because they were considered to be familiar with the implementation of sustainability practices and performance indicators. The questionnaire was responded by organizations that are located in Germany, Poland, Serbia, Slovenia and Spain, in portion of 8.1%, 23.1%, 8.1%, 47.0% and 13.8%, respectively. The profile of the organizations and respondents is provided in Table I.

Table I. Profile of the respondents in our sample

Sample distribution		**Percentage**
Respondent profile	Middle management	34.7
	Frontline management	23.7
	Top management	17.1
	Data not available	24.5
Organization profile (employees)	0–5	4.5
	5–50	18.1
	50–250	27.5
	250–500	8.9
	over 500	25.9
	Data not available	8.9
	Total	100 (N = 247)

2.2. Analysis methods

Content, convergent, and discriminant validity was used to validate measurement models (Hair et al., 2010). The content validity of was established from the existing literature as well as by examining the measurement items by several researchers and experts. In order to assess convergent and discriminant validity, a combined exploratory–confirmatory approach was applied. First, data were subject to exploratory factor analysis. Then confirmatory factor analysis (CFA) was applied, with the aid of the AMOS software. Regression analysis (Field, 2005) was used in order to analyse the performance implications of sustainability practices, to explore the performance outcomes based on different contexts, and to examine the country of origin effects.

2.3. Measures

Sustainability exploration and sustainability exploitation. This study adopts the conceptualization of the study constructs proposed by Maletič et al. (2014) and operationalization of the variables utilized in prior studies (Maletič et al., 2014c). The scales for measuring sustainability exploitation and sustainability exploration were developed from the existing literature and discussions with several experts.

We carried out an exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to simultaneously validate the measures of sustainability exploration and sustainability exploitation. In order to confirm the latent factor structure for measured variables, an exploratory factor analysis (EFA) was first performed. The items that loaded significantly on their respective theoretical constructs were remained in the measurement model. Therefore, the results of the exploratory analysis in conjunction with a theoretical framework are taken into account in the subsequent CFA. The results of the CFA are summarized in Table II. Fit indices for SER second-order model are satisfactory ($\chi2/df < 2$, NFI > 0.90, and CFI > 0.95). All measurement variables are statistically significantly related to constructs ($p < 0.05$) while the standardised loadings range from 0.69 to 0.88. From Figure II, it can be seen GFI (0.989), AGFI (0.963) are well above 0.9, RMSEA (0.036) is below 0.05 and thus indicative of a very good model-data fit for SEI as well. Furthermore, the standardised coefficients for the three sub-constructs are 0.91 for SOEI, 0.92 for RSI, and 0.73 for PMEI, and are all statistically significant; therefore, the higher-order construct (SEI) can be considered.

The results revealed that sustainability exploration construct consists of two sub-constructs termed 'Sustainable product and process development' (SPPD) and 'Sustainability-oriented learning' (SOL). Regarding the sustainability exploitation construct, the best overall fit of the model corresponds to the following sub-constructs: Stakeholder orientation for exploitation (SOEI), Stakeholder responsiveness and integration (RSI), and Process management for exploitation (PMEI). A part of the results of the validation process are summarized in Table II.

Table II. Goodness of test results for measurement models

Second-order model	No. of items	χ^2	df	χ^2/df	p	GFI	AGFI	RMSEA
SER	8	29.34 2	19	1.544	0.061	0.969	0.942	0.048
SEI	6	7.841	6	1.307	0.250	0.989	0.963	0.036
Recommended values (Hair et al., 2010)				≤2	≥.05	≥0.9	≥0.9	≤.05

Organizational performance measures. This study has used existing scales from the previous empirical studies (Maletič et al., 2014b; Maletič et al., 2014c). Since organizational performance is recognized as a multi-dimensional concept (Chenhall and Langfield-Smith, 2007; Kaplan and Norton, 1996), this study considers a more balanced approach of measuring organizational performance in a way that includes both financial and non-financial performance measures. Study variables with their corresponding values of Cronbach's alpha are shown in Table III.

Table III. Organizational performance measures

Construct	No. of items	Cronbach's Alpha
Financial and market performance	4	0.865
Quality performance	4	0.845
Innovation performance	3	0.841
Environmental performance	4	0.798
Social performance	3	0.819

The resulting four-item scale financial and market performance captures the extent to which organizations achieve business success. A four-item scale measures quality performance and captures the extent to which organizations have improved quality of their products and services during the last 3 years and meet customer satisfaction. A three-item scale measures innovation performance in terms of product and process innovation. A four-item scale measures environmental performance and captures the extent to which organizations achieve efficiency of material and energy consumption. Finally, a three-item scale measures social performance from the employee perspective (satisfaction, motivation and turnover ratio).

An exploratory analysis of the scales was used to check for any possible cross loading problems of the measurement items. According to the results of the factor analysis, all factor-loading estimates exceeded 0.50 (ranged from 0.658 to 0.866).

3. Analysis and Results

3.1. Regression analysis

First, mean scores were calculated from the scale's items to generate the composite scores for the organizational performance, which will be used in the regression analysis. Table IV summarises the regression results for the effects of sustainability practices on the organisational performance.

Table IV. Results of regression analysis: SER, SEI, and organisational performance

Dependent: organisational performance	
	Model
SER	0.331**
SEI	0.246**
R^2	0.283
Adjusted R^2	0.277
F	43.455
P-value of overall model	0.000

*P < 0.05, **P < 0.01

The result of the regression model shows that both sustainability orientations have a significant relationship with organizational performance ($\beta = 0.331$, $p < 0.01$; $\beta = 0.246$, $p < 0.01$ respectively).

3.2. Regression analysis with interactions

Multiple regression with categorical predictors (dummy variables which take the value of 0 and 1) (Field, 2005) was utilized in order to examine country effects on each of the performance measures. When dummy coding is used in the regression analysis, the overall results indicate whether there is a relationship between the dummy variables and the dependent variables. The Slovenian subset was chosen as a baseline (i.e. a group against which all other groups are compared). Five countries are included in the research, so there are four dummy variables included in the multiple regression analysis. For example, the dummy variable 'Germany' actually means Slovenia vs. Germany.

In the following, a regression analysis with interaction effects is presented (Table V). The underlying assumption is that sustainability practices have different effects on financial and market performance regarding different groups (i.e. countries). It is important to note that the interaction terms (Model 1) are identical to the SER if dummy variables are 1; otherwise, the values are zero. Results are consistent with the interpretation that organisations within the Polish data subset gain superior financial and market benefits from sustainability practices compared to the Slovenian data subset ($\beta = 0.168$, $p < 0.05$ and $\beta = 0.175$, $p < 0.01$, respectively). In contrast, organisations within the Serbian data subset achieve significantly lower benefits from sustainability practices compared to organisations within the Slovenian data subset ($\beta = -0.141$, $p < 0.05$ and $\beta = 0.131$, $p < 0.05$, respectively). Furthermore, the results indicate that interaction effects between sustainability practices and Germany as well as between sustainability practices and Spain are not significantly different from the Slovenian data subset.

Table V. Interaction effects of sustainability practices and country of origin on financial and market performance

	Dependent: Financial and market performance	
	Model 1	**Model 2**
SER	0.255**	
SEI		0.278**
SER × Germany	0.080	
SER × Poland	0.168*	
SER × Serbia	-0.141*	

SER × Spain	-0.011	
SEI × Germany		0.050
SEI × Poland		0.175**
SEI × Serbia		-0.131*
SEI × Spain		-0.031
R^2	0.133	0.144
Adjusted R^2	0.112	0.124
F	6.543	7.177
P-value of overall model	0.000	0.000

*P < 0.05, **P < 0.01

Table VI. Summary of the main finding regarding the country effect

Regression model
Financial and market performance = $\beta_0 + \beta_1$*SER + β_2*SER × Poland – β_3*SER × Serbia
Financial and market performance = $\beta_0 + \beta_1$*SEI + β_2*SEI × Poland - β_3*SEI × Serbia
Quality performance = $\beta_0 + \beta_1$*SER + β_2*SER × Germany
Quality performance = $\beta_0 + \beta_1$*SEI + β_2*SEI × Germany
Environmental performance = $\beta_0 + \beta_1$*SER + β_2*SER × Spain
Environmental performance = $\beta_0 + \beta_1$*SEI - β_2*SEI × Germany
Social performance = $\beta_0 + \beta_1$*SEI - β_2*SEI × Germany

The findings presented in Table VI consist of nine regression equations with statistically significant slopes and intercepts. The regression models provide some empirical evidence regarding the justification of institutional perspective. For instance, the effects of sustainability practices on the financial and market performance increase if the country changes from Slovenia to Poland and decrease if country changes from Slovenia to Serbia.

Furthermore, Germany appears to be dominant in accounting for the country effect on the quality performance. However, the interaction term of Germany and SEI is negatively related to the environmental and social performance. This suggests that environmental and social performance decrease if country changes from Slovenia to Germany. In contrast, environmental performance increases if country changes from Slovenia to Spain. Additionally, findings indicate that Germany and Spain show higher levels of SEI deployment compared to the level of SER deployment.

3.3. One-way ANOVA

One-way ANOVA was utilised to analyse the country effects. The purpose of using one-way ANOVA analysis is to verify if there are significant differences of SEI and SER implementation across countries. Table VII present important descriptive statistics for the ANOVA with respect to the SER practices. From the descriptive statistics presented, there appears to be some differences in the mean of SER practices between the five levels or groups (countries). From the data, one could assume that country of origin affects organizations engagement in SER practices. However, to determine if this relationship is significant, examination of the ANOVA results needs to be applied.

Table VII. Descriptive statistics for SER across countries

Country	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Slovenia	116	3.8337	0.77286	0.07176	3.6916	3.9758
Spain	34	3.0735	0.88401	0.15161	2.7651	3.3820
Serbia	20	3.4750	1.16010	0.25941	2.9321	4.0179
Poland	57	3.8099	0.77501	0.10265	3.6043	4.0156
Germany	20	3.3167	1.09344	0.24450	2.8049	3.8284
Total	247	3.6527	0.89239	0.05678	3.5408	3.7645

The ANOVA analysis of SEI implementation across the five countries has an F value of 6.689 and a p-value of 0.000. However, Levene's test of homogeneity of variances was significant ($p < 0.05$), indicating that the equal variance assumption has been violated. In the case in which the assumption of homogeneity of variance is questionable, using adjusted F statistic is suggested. Two such types of adjustments are provided by the Welch statistic and the Brown-Forsythe statistic (Field, 2005). As such, using the Welch statistic, we find that $F(4, 60.843) = 6.028$, $p < 0.001$. We can interpret Welch's Robust ANOVA as indicating a significant mean difference among the countries in terms of sustainability exploration. The above results show that for SER implementation, organisations within the same country demonstrated significant similarity. In this regard, strong country effect is shown through ANOVA analysis.

Moreover, we use the Games-Howell post hoc test as being appropriate when the equal variances assumption has been violated. The Games-Howell post hoc testing reveals a significant difference between the Slovenian group and the Spanish group, as well as a significant difference between the Spanish and Polish group. The results, therefore, indicate that organisations within Slovenian and Polish subsets achieve significantly higher values of SER practices compared to the organisations within the Spanish subset.

In the following, descriptive statistics for SEI are presented (Table VIII). According to the results, only one mean value (Serbia) differs to a greater extent from the other values. Thus, there is no strong assumption that mean values of SEI differ across countries.

Table VIII. Descriptive statistics for SEI across countries

Country	N	Mean	Std.	Std. Error	95% Confidence

					Interval for Mean	
			Deviation		Lower Bound	Upper Bound
Slovenia	116	3.9187	0.62370	0.05791	3.8040	4.0334
Spain	34	3.7157	0.69210	0.11869	3.4742	3.9572
Serbia	20	3.5583	1.10193	0.24640	3.0426	4.0741
Poland	57	3.9181	0.63396	0.08397	3.7499	4.0863
Germany	20	3.9000	0.63614	0.14225	3.6023	4.1977
Total	247	3.8599	0.68953	0.04387	3.7735	3.9463

ANOVA test results do not show a significant difference among the countries in terms of sustainability exploitation (ANOVA statistic F(1.676), $p > 0.05$; Welch statistics $F(4, 61.939) = 1.039$, $p > 0.05$).

Difference of means (t-test)

To further investigate the effect of each country, the implementation of SER and SEI was compared within each country. T-tests were used here to examine whether there is significant difference of SER and SEI implementation within each country. The results are presented in Table IX.

Table IX. Difference between SER and SEI within countries

		SER-SEI		
Country	N	Mean	Std. Error	t
Slovenia	116	-0.08499	0.04993	-1.702
Spain	34	-0.64216	0.10297	-6.236**
Serbia	20	-0.08333	0.14932	-0.558
Poland	57	-0.10819	0.08746	-1.237
Germany	20	-0.58333	0.17791	-3.279**

*P < 0.05, **P < 0.01

The results in Table IX show that within particular countries, there are differences in deployment of SER and SEI. Two countries show significant differences of SER and SEI deployment. In Spain and Germany, more exploitative practices are implemented than explorative sustainability practices while within other countries there is no significant difference between SER and SEI. These results could to some extent support the institutional argument, which suggests that there is a significant difference between sustainability exploitation (SEI) and sustainability exploration (SER) as a function of country of origin.

4. Discussion and conclusions

An important stream of studies (e.g. Wagner, 2010) investigates the economic benefits of socially and environmentally responsible behavior. In this regard, our study underscores previous assertions that organizations can benefit from pursuing sustainability by providing empirical evidence that sustainability practices (in terms of exploration and exploitation) positively influence the organizational performance.

Despite the recent expansion of sustainability literature, the application of institutional theory to understand sustainability-related phenomena has not yet been widely investigated. As noted by Campbell (2007), most of the literature on corporate social responsibility does not explore whether institutional conditions affect the tendency for organizations to behave in socially responsible ways.

The question arises whether sustainability practices as conceptualized in this study are characterized by organization's country of origin. In particular, the study examines the effects of country of origin on the relationship between sustainability practices and organizational performance. Our study findings suggest that organizations based in different countries hold substantially different perspectives on: 1) achieved levels of organizational performance dimensions; 2) deployment of sustainability exploration practices; 4) country effects on the organizational performance. The ANOVA analysis and the post hoc tests show institutional effects when organizations implement sustainability practices. Organizations in different countries show much more differences in SER deployment than SEI deployment. It appears that the vast majority of the organizations strive to gain competitive advantage by successfully addressing the stakeholder expectations (as reflected through SEI). As argued by Asif et al. (2013), a key challenge of corporate sustainability integration is to address the diverse needs of different stakeholders. Regarding the country of origin effect, Matten and Moon (2008) suggest that European countries predominantly demonstrate elements of implicit activities that normally consist of values, norms, and rules that result in (mandatory and customary) requirements for corporations to address stakeholder issues and that define proper obligations of corporate actors in collective rather than individual terms.

Furthermore, regression analysis shows that there is certain evidence to support that there are implementation differences between SER and SEI based on organizational performance and country of origin effects. In this regard, results reveal some differences in the achieved levels of performance measures across countries. One possible explanation is perhaps that businesses can compete (and can compete effectively) in quite different ways (Zadek et al., 2003). For instance, some organisations invest in environmentally-friendly technology, raise productivity by improving their employees' work-life balance, and lower long-term supply costs by building long-term relationships with quality suppliers (Zadek et al., 2003). When trying to discuss the mechanisms why organizations behave in a similar way, one should consider institutional perspective, namely three aspects (DiMaggio and Powell, 1983; Matten and Moon, 2008): coercive isomorphism, mimetic processes and normative pressures. Coercive isomorphism consists of externally codified rules, norms, or laws that assign legitimacy to new management practices. Mimetic processes refer to behaviour which is characterized by ”copying” best management practices. Normative pressures are related to the educational and professional factors that directly and indirectly influence the organizational isomorphism.

Further, a more comprehensive picture is needed to better understand the unlikeliness of a universally valid definition of sustainability-related practices and to illustrate how the institutional environment shape and influence sustainability-related business practices (Matten and Moon, 2008; Campbell, 2007; Schultz and Wehmeier, 2010). According to the Doh and Guay (2006), organizations and their strategies are substantially influenced by the broader institutional settings in which they operate, and shaped by the institutional legacies that reflect the culture, history, and polity of the particular country or region. In this regard, Matten and Moon (2008) argued that the organisation is both embedded in its historically grown national institutional framework and its respective national business system, as well as in its organisational field.

Nevertheless, these results should be interpreted with caution, keeping in mind some main limitations of the research. First, the analysis was based on different research settings as indicated by different sample sizes and by the diversity of organisations covered by samples. In addition, several relevant control variables could be included to control for possible alternative explanations.

References

Amini, M., Bienstock, C.C., 2014, Corporate sustainability: an integrative definition and framework to evaluate corporate practice and guide academic research. J. Clean. Prod. 76, 12-19.

Asif, M., Searcy, C., Zutshi, A., Fisscher, O.A.M., 2013. An integrated management systems approach to corporate social responsibility. J. Clean. Prod. 56, 7-17.

Azapagic, A., 2003. Systems approach to corporate sustainability. A general management framework. Process. Saf. Environ. Protec. 81(5), 303-316.

Bansal, P., 2002. The corporate challenges of sustainable development. Acad. Manag. Exec. 16(2), 122–131.

Campbell, J.L., 2007. Why Would Corporations Behave In Socially Responsible Ways? An Institutional Theory of Corporate Social Responsibility. Acad. Manag. Rev. 32(3), 946–967.

Chenhall, R.H., Langfield-Smith, K., 2007. Multiple Perspectives of Performance Measures. Eur. Manag. J. 25(4), 266–282.

DiMaggio, P.J., Powell, W.W., 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. Am. Sociol. Rev. 48, 147–160.

Doh, J.P., Guay, T.R., 2006. Corporate Social Responsibility, Public Policy, and NGO Activism in Europe and the United States: An Institutional-Stakeholder Perspective. J. Manag. Stud. 43(1), 47-73.

Fairfield, K.D., Harmon, J., Behson, S.J., 2011. Influences on the organizational implementation of sustainability: an integrative model. Organ. Manag. J. 8, 4–20.

Field, A., 2005. Discovering Statistics Using SPSS (Introducing Statistical Methods series), Second Edition, Sage Publications Ltd, London.

Hahn, T., Scheermesser, M., 2006. Approaches to Corporate Sustainability among German Companies. Corp. Soc. Responsib. Environ. Manag. 13, 150–165.

Hair, J.F.Jr., Black, W.C., Babin, B.J., Anderson, R.E., 2010. Multivariate Data Analysis, 7th ed. Pearson Prentice Hall, London.

Kaplan, R.S., Norton, D.P., 1996. The Balanced Scorecard: Translating Strategy into Action. Harvard Business School, Boston.

Lozano, R., 2012. Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives. J. Clean. Prod. 25, 14-26.

Maletič, M., Maletič, D., Dahlgaard, J.J., Dahlgaard-Park, S.M., Gomišček, B., 2014. Sustainability exploration and sustainability exploitation: From a literature review towards a conceptual framework. J. Clean. Prod. 79, 15 September, 182-194.

Maletič, M., Maletič, D., Dahlgaard, J.J., Dahlgaard-Park, S.M., Gomišček, B., 2014b. The Relationship between Sustainability–Oriented Innovation Practices and Organizational Performance: Empirical Evidence from Slovenian Organizations. Organ. 47(1), 3-13.

Maletič, M., Maletič, D., Dahlgaard, J.J., Dahlgaard-Park, S.M., Gomišček, B., 2014c. Do corporate sustainability practices enhance financial and market performance? The mediating role of innovation performance. In, Dahlgaard, J.J., Dahlgaard-Park, S.M (Eds.), Proceedings of 17th QMOD conference on Quality and Service Sciences ICQSS 2014, September 3-5, Prague.

March, J.G., 1991. Exploration and exploitation in organizational learning. Organ. Sci. 2(1), 71–87.

Matten, D., Moon, J., 2008. 'Implicit' and 'Explicit' CSR: A Conceptual Framework for a Comparative Understanding of Corporate Social Responsibility. Acad. Manag. Rev. 33(2), 404–424.

Schultz, F., Wehmeier, S., 2010. Institutionalization of corporate social responsibility within corporate communications: Combining institutional, sensemaking and communication perspectives. Corp. Commun. Int. J. 15(1), 9-2.

Wagner, M., 2010. The role of corporate sustainability performance for economic performance: A firm-level analysis of moderation effects. Ecol. Econ. 69, 1553–1560.

Zadek, S., Sabapathy, J., Dossing, H., Swift, T., 2003. Responsible competitiveness. Corporate Responsibility Clusters in Action, AccountAbility/The Copenhagen Center, London.

Zhang, D, Linderman, K., Schroeder, R.G., 2012. The moderating role of contextual factors on quality management practices. J. Oper. Manag. 30(1–2), 12–23.

Value chain upgrading in a textile dyeing industry

A. Angelis-Dimakis[1*], A. Alexandratou[1], A. Balzarini[2]

[1]Environmental & Energy Management Research Unit, School of Chemical Engineering, National Technical University of Athens, Athens, Greece

[2] Geologist, Italy

*Corresponding author: E-mail: angelis@chemeng.ntua.gr, Tel +30 210 772 3303

Abstract

Eco-efficiency has been widely accepted during the last two decades as a suitable measure of progress of a given system towards a greener and sustainable development, since the concept of eco-efficiency combines the concepts of economic welfare with the ecological impact of products or services throughout their lifecycle.

The present paper briefly presents a methodological framework for the eco-efficiency assessment of water-use systems, using a life-cycle oriented approach and a set of selected eco-efficiency indicators. The proposed framework is applied to the textile industry in Biella, Italy. The environmental performance of the system is evaluated through the relevant midpoint environmental impact categories, while the economic performance is measured using the total value added to the system's final product due to water use.

The analysis reveals that the major environmental problems of the textile industry in the region are freshwater resource depletion, as well as human toxicity and ecotoxicity (both aquatic and terrestrial).

The identification of the environmentally weak stages of the system enables the selection of alternative actions, which could upgrade the whole value chain and improve the overall eco-efficiency. Six innovative technologies are examined and two alternative technology scenarios are formulated. The first scenario focuses on resource efficiency, while the second one on reducing the emissions to water.

The results show reveals that all technologies could potentially improve the majority of the environmental performance indicators of the system, without deteriorating the economic output of the involved actors, thus proving that there is plenty of room for improvement in the studied value chain. More specifically, the scenario towards resource efficiency improves the freshwater resource depletion (three times higher), while the scenario towards pollution prevention improves significantly the aquatic and terrestrial ecotoxicity indicators.

Keywords: Eco-efficiency, water-use systems, textile industry, resource efficiency, pollution prevention

1. INTRODUCTION

The concept of eco-efficiency was first introduced by Schaltegger and Sturm in 1990 and its main objective was to bring together the economic and environmental viability (Schaltegger and Sturm, 1989). According to the World Business Council for Sustainable Development (WBCSD), the term eco-efficiency combines the concepts of competitively priced goods or services, which satisfy human needs, while progressively reducing environmental impacts, and resource intensity throughout their lifecycle to a level at least in line with earth's carrying capacity (WBCSD, 2000). The Organisation for Economic Co-operation and Development (OECD) has defined eco-efficiency as the efficiency with which ecological resources are used to satisfy human needs. It is expressed as the ratio of an output (the total value of products and services produced by a firm, sector or economy) divided by an input (the sum of environmental pressures generated by the firm, sector or economy) (OECD, 1998). Since, it combines the evaluation of the environmental impacts of a product or service system with the estimation of its economic value, it can serve as a measure towards sustainability.

The present paper briefly presents a methodological framework for the eco-efficiency assessment of water-use systems. A Life-Cycle Analysis oriented approach, which includes the principles of functional unit, life-cycle inventory and life-cycle impact assessment (LCIA), is used for the evaluation of the environmental performance, while the economic performance is assessed through the total value added to the product due to water use.

The proposed framework is applied to a water use system of the industrial sector, and more specifically to the textile industry of the Biella region in Northern Italy. The textile industry was selected as a demonstrative water use system, because it represents one of the bigger industrial water consuming sectors. Large amounts of freshwater are used along the entire value chain of the textile industry. More specifically, the wet processing operations (i.e. dyeing and finishing processes) utilize a large amount of freshwater for dissolving dyes and chemicals. Furthermore, the reduction of water consumption may lead to corresponding reductions in the energy required for steam production and, to a lesser extent, in the amounts of chemicals and dyes used.

The most common method for assessing the environmental performance of a textile industry is the eco-labelling system. However, there is a plethora of studies identifying problems in eco-labelling, among which are the increasing complexity of textile production processes and the limited resources that make difficult the satisfaction of the eco-regulations (You et al., 2009). Several studies have tried to develop a framework, based on environmental performance indicators, which are applicable to the textile industries; however these indicators are not detailed enough to provide a comprehensive view on eco-friendly manufacturing (Cao, 2007). It has been considered imperative for the textile industry the development of a method, suitable for its own practices and technologies, which could manage efficiently the environmental issues along with its economic performance (You et al., 2009).

2. METHODOLOGY

2.1 Goal and Scope Definition

The objective of the developed methodology is the integrated assessment of the eco-efficiency of a water-use system. Before selecting and calculating the eco-efficiency indicators, the boundaries, the special characteristics of the studied system and the functional unit, should be identified.

A generic water use system is represented as a network of unit processes. Each process corresponds to an activity, through which generic materials (water, raw materials, energy and other supplementary resources) are converted into products, while releasing emissions to the environment (air, land, water) or into the system's water flow. The system is divided into two subsystems; the foreground and background. The foreground system corresponds to the set of processes, whose selection or mode of operation is affected directly by decisions based on the study, while the background includes other activities, which deliver energy and raw materials to the foreground system.

The boundaries of the foreground system encompass all the processes related to the water supply and the water use chains and can be grouped into four stages, as illustrated in Figure 1.

Figure 1**.** The generic water use system, divided into foreground and background sub-systems

The functional unit sets the scale for the comparison of two or more products or services delivered to the consumers. It depends on the reference flow selected each time and its main purpose is to provide a reference to which results are normalized and compared (ISO, 2006; JRC, 2010). Possible functional units for a water use system could be: (a) one unit of product or service delivered or (b) one unit (e.g. m^3) of water used.

2.2 Eco-efficiency Assessment

2.2.1 *Environmental Assessment*

The assessment of the environmental performance is based on a life-cycle oriented approach using midpoint impact categories. An inventory of flows entering and leaving every process in the system is created and, based on that, the significance of potential environmental impacts is evaluated. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterisation factors. The environmental impact for impact category c is expressed as a score (ES_c) in a unit common to all contributions within the category. It can be easily calculated using the flows from the inventory analysis and the characterisation factors, as follows:

(1)

where $cf_{r,c}$ is the characterisation factor of resource r for the impact category c, $cf_{e,c}$ the characterisation factor of emission e for the impact category c (both retrieved from LCA databases), and f_r, f_e the elementary flows of resource r and emission e respectively.

The impacts from the use of freshwater are neglected by most LCA studies and databases and as a result, there is no standardised environmental midpoint indicator for the freshwater resource depletion (JRC, 2010). However, since water consumption is an important component of the studied system, freshwater depletion is taken into consideration. Mila i Canals et al. (2009) have proposed a methodology measuring freshwater depletion which introduces the Freshwater Ecosystem Impact (FEI) indicator. FEI relates current freshwater use to the available freshwater resources and is defined as:

(2)

where $f_{w,abs}$ is the flow of freshwater abstracted and WTA is the water withdrawal to availability ratio.

2.2.2 *Value Assessment*

The economic performance of a system is monitored by using the Total Value Added (TVA) to the product due to water use, expressed in monetary units per period and per functional unit. It is estimated as:

(3)

where EVU is the total economic value from water use, VP_{BP} the income generated from any by-products of the system, TFC_{WS} the total financial cost related to water supply provision for rendering water suitable for the specific use, TFC_{WW} the total financial cost related to wastewater treatment and TIC the annual equivalent future cash flow generated by the introduction of new technologies in the system. The total economic value from water use can be calculated by subtracting the expenses for all the non-water inputs in the water use stage from the total value of the products.

2.2.3 *Eco-efficiency Indicators*

The Eco-Efficiency Indicators (*EEI*) of the water use systems are defined as ratios of the economic performance indicator (Total Value Added, *TVA*), to the environmental performance metrics (environmental impacts) of the system. There is one eco-efficiency indicator for each environmental impact category c:

(4)

2.3 Value Chain Upgrading

A general approach for the improvement of eco-efficiency along the water value chain has been based on the concept presented in the OECD framework. Based on this model, each type of technology can be classified according to the measures of pollution prevention, resource efficiency, and circular economy, which are adopted to achieve better eco-efficiency performance (OECD, 2009). Thus, three alternative technology scenarios can be formulated based on these three objectives:

- Scenario towards Pollution Prevention

  In this category, end-of-pipe solutions are mainly adopted, in order to treat effluents or wastes, handle and dispose emissions and wastes, generated from the production process. These technologies are incorporated into the existing manufacturing processes at the final stage and are usually not essential parts of the production process.

- Scenario towards Resource Efficiency

  Resource efficiency approach includes technological interventions targeting at the optimum use of materials and energy and eliminate the negative impacts for which the production process is responsible.

- Scenario towards Circular Economy

  Technologies of this category are incorporated or modify production facilities and contribute to the pollution reduction by cutting down the amount of inputs used for production and/or by substituting the inputs with resources obtained through reuse or recovery technologies. In addition, they constitute an integral part of the processes and they have the potential to save costs by reducing the use of raw materials, energy and the costs of complying with regulations.

3. THE CASE OF TEXTILE INDUSTRY IN BIELLA, ITALY

The proposed approach has been applied to the textile industry of Biella, a province of northern Italy located in Piedmont Region. The province covers an area of 930 km^2, hosts 82 communities and is one of the most significant areas for the textile industry worldwide, especially with regard to wool and cashmere products manufacturing. The Biella district has traditionally been an important wool processing and textile centre, and the first textile factory dates back to 1254. Industrial groups that are internationally known and have a long historical tradition, as well as many SMEs producing high quality products were located in the area.

During the last decade, the active textile units in Italy have decreased by 28%. More specifically in Biella, the crisis of the textile sector is much more acute since nearly half of the factories closed down and 50% of the employees lost their jobs. However, despite the economic crisis, Biella remains one of the most distinguished production centres of wool fabrics for clothing and fine fibres with more than 650 active textile industrial units (Industrial Union of Biella – Personal Communication).

Textile industry utilizes an extensive amount of freshwater, especially during wet processing operations, such as dyeing, as water is the medium in which dyes, chemicals and dyeing auxiliaries are dissolved. The textile wastewater is rated as the most polluting, considering its volume and composition, among the industrial sector. The generated wastewater includes toxic and stable pollutants, characterised by a significant amount of suspended solids, nutrients, salts, high chemical and biological oxygen demand (COD, BOD), as well as heavy metals and increased colour concentrations. The disposal of these contaminated effluents into receiving water bodies results in environmental problems, influencing the aquatic and terrestrial ecosystem, and even the human health (Chequer, et al., 2013). In the Biella region, the textile industry has a critical impact on the environment, particularly by polluting river waters through process effluents.

On the other hand, the industry has a high economic significance on textile commerce and the local workforce, and subsequently affecting quality of life and final consumer costs. However, local stakeholders have pointed out that apart from the economic crisis, EU products are competing against cheap Asian imports which have been produced in environmentally more polluting ways, since there is a lack of national and European legislation/regulation protecting the textile production of the "Made in Europe" mark as quality excellence. Thus, increasing the eco-efficiency in the textile industry can have various effects through impacts on the socio-technical dynamics and environmental sustainability.

On the basis of the above described picture the analysis that follows is mainly focused on the study of the dyeing process. Prospects for improving the system's overall eco-efficiency are investigated. Through the identification of the environmentally weak stages of the system, as well as the selection and implementation of innovative technologies that would upgrade the value chain, two alternative technology scenarios are formulated and compared to the baseline scenario. The first scenario aims at increasing resource efficiency, while the second at reducing water pollution.

3.1 System boundaries & Functional unit

For the purposes of our analysis, two representative units of the textile industry are considered (Figure 2):

- A unit with in-house wastewater treatment plant, where the dyeing process is done by using standard chemical methods (Unit A); and
- A unit which uses both standard chemical dyes and natural herbal dyes (in separate production lines) and is connected to the municipal wastewater network (Unit B).

The studied system is divided into the foreground and the background sub-systems. The foreground system contains two different chains, the water supply and the water use chain. The water supply chain is divided into four stages, namely water abstraction, distribution, use and wastewater treatment. These are defined in such way to enclose the relevant actors involved in the system and the interactions among them. The actors of the system, both directly and indirectly involved, are the following:

- The regional authorities, responsible for the water supply to industry;
- The textile industry, including the chemical and natural dyeing units; and
- The municipalities' consortium, which is responsible for the operation of the wastewater treatment plant and the sewage disposal network.

The background system consists of the production processes of the supplementary resources (electricity and natural gas) and raw materials (dyes, additives, wool). However, only the electricity and natural gas production processes are taken into consideration for the eco-efficiency assessment, due to lack of data for the other processes.

Figure 2. Schematic representation of the examined system

The functional unit depends on the reference flow selected each time and the purpose of the analysis. In the current study, two different cases are examined. When the goal is the comparison between the two units, then the flow of interest is the unit of product delivered and the functional unit is defined as 1 kg of dyed product. On the contrary, when alternative technologies are compared, the quantity of interest is the water used for the production purposes and the functional unit is 1 m^3 of water used in the dyeing process.

3.2 Baseline Scenario Assessment

Unit A, the standard chemical dyeing unit, has an annual output of 500,000 kg dyed product. For the dyeing process, it is estimated that 1kg of dyes and additives are required, while 1.02 kWh of electricity and 0.64 m^3 of natural gas are consumed per kg of wool. Furthermore, the dyeing process needs 0.15 m^3 of water per kg of wool, which is abstracted from private wells using electric groundwater pumps. The electricity consumption of the pump is estimated at 0.13 kWh per m^3 of water abstracted. Finally, the in-house wastewater treatment plant consumes 0.7 kWh of electricity per m^3 of wastewater treated.

Unit B, the unit with two separate production lines, produces annually 392,000 kg of chemically dyed product and 98,000 kg of naturally dyed product. The requirements of the chemical dyeing production line are the following: 0.32 kg of dyes and additives, 1.44 kWh of electricity, 0.59 m^3 of natural gas and 0.16 m^3 of water per kg of wool. The natural dyeing process requires less electricity (1.27 kWh per kg of wool) but higher quantities of dyes and water (0.5 kg of dyes and 0.19 m^3 of water per kg of wool), while the required amount of natural gas remains the same. In both cases, water is abstracted from Quargnasca Torrent (Cervo River Basin) and is pumped using electricity driven pumps, which consume 0.11 kWh per m^3 of water abstracted.

Unit B also performs a filtering of the wastewater before sending it to the municipality consortium owned wastewater treatment plant. The filtering process consumes electricity (0.55 kWh per m^3 of wastewater treated) and produces solid waste (0.27 kg of sludge from the natural dyeing process per m^3 of wastewater treated).

3.2.1 Environmental assessment

The environmental performance of the system is assessed through eight environmental midpoint indicators, representative for the specific system and relevant to the textile industry. The background processes that are taken into account for the assessment of the environmental impacts are electricity and natural gas production, as it was not possible to collect data for the other background processes, including wool, dyes and additives production. The characterisation factors included in the

CML-IA database are used for the calculation of the environmental impacts of the foreground system, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (Guinee, et al., 2001).

The environmental assessment of the baseline scenario is summarized in Tables 1 and 2. Table 1 presents the normalized values of environmental indicators per volume of water used, for the entire system and the contribution of the foreground and the background system separately. It is obvious that the most significant environmental problems are toxicity related issues (including human toxicity and ecotoxicity), due to chemicals used in the dyeing process, and freshwater depletion.

Table 2 displays the environmental performance of the two industrial units for the baseline scenario. The figures presented include both the foreground and the background system contribution. It is evident that Unit A has better performance in climate change, freshwater resource depletion and acidification due to less electricity and water consumption. On the contrary, Unit B has lower values in the two ecotoxicity indicators due to the natural dyeing production line which produces cleaner wastewater. However, the human toxicity indicator does not follow the same pattern, because in that case the contribution of the background electricity production counterbalances the direct environmental impact from the water effluents of the dyeing process.

Table 1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario

Midpoint Impact Category	Environmental Performance Indicator	Foreground Contribution	Background Contribution
Climate change	0.01 $kgCO_{2eq}/m^3$	51%	49%
Freshwater Resource Depletion	0.15 m^3/m^3	100%	0%
Eutrophication	0.02 $kgPO_4{}^{3}{}_{-,eq}/m^3$	90%	10%
Human toxicity	2.68 $kg1,4DCB_{,eq}/m^3$	73%	27%
Acidification	0.05 $kgSO_2{}^{-}{}_{,eq}/m^3$	28%	72%
Aquatic Ecotoxicity	22.45 $kg1,4DCB_{,eq}/m^3$	99%	1%
Terrestrial Ecotoxicity	1.94 $kg1,4DCB_{,eq}/m^3$	99%	1%
Photochemical Ozone Formation	0.003 kg $C_2H_{4,eq}/m^3$	25%	75%

Table 2. Comparison of the environmental performance between the two units for the baseline scenario

Midpoint Impact Category	Unit	Ind. Unit A	Ind. Unit B
Climate change	$kgCO_{2eq}$/kg product	0.002	0.003
Freshwater Resource Depletion	m^3/kg product	0.023	0.029
Eutrophication	$kgPO_4{}^{3}{}_{-,eq}$/kg product	0.003	0.003
Human toxicity	$kg1,4DCB_{,eq}$/kg product	0.440	0.482
Acidification	$kgSO^{2-}{}_{,eq}$/kg product	0.008	0.009
Aquatic Ecotoxicity	$kg1,4DCB_{,eq}$/kg product	3.865	3.856
Terrestrial Ecotoxicity	$kg1,4DCB_{,eq}$/kg product	0.352	0.334
Photochemical Ozone Formation	kg $C_2H_{4,eq}$/kg product	$<10^{-3}$	$<10^{-3}$

3.2.2 Value assessment

All financial costs required for the calculation of the Total Value Added are summarized in Table 3. The purchase cost for all the supplementary resources (i.e. electricity, natural gas) is the same for both units. The main difference is the price of dyes, which is assumed to be 5-6€/kg of chemical dye but in the case of natural herbal dyes it reaches 11€/kg. However, similar is also the difference in the price of the finished dyed product. In the case of chemical dyeing processes, it ranges from 5.5€ to 7€/kg whereas a naturally dyed product can be sold for as much as 15€/kg. Unit A has lower expenses for water abstraction (due to private wells) and wastewater treatment and disposal (due to in-house treatment) but has an extra expenditure for sludge treatment and disposal.

The TVA from water use to the dyed product is estimated to be 18.36 € per m^3 of water used. Furthermore, both industrial units have positive annual economic balance. The annual net economic output for Industrial Unit A is 548,946 € whereas for Industrial Unit B is 2,434,621 €.

Table 3. Financial costs of the two industrial units

Expenditure	Ind. Unit A	Ind. Unit B (Chemical)	Ind. Unit B (Natural)
Electricity	0.18 €/kWh		
Natural Gas	0.45 €/m^3		
Dyes and Additives	5.2 €/kg	6.0€/kg	11.0€/kg
Water Abstraction	2,200 €/yr	50,000 €/yr	
Wastewater Treatment and Disposal	0.35 €/m^3	0.85 €/m^3	0.85 €/m^3
Sludge Treatment and Disposal	0.85 €/kg sludge	-	-
Operation and Maintenance Cost	0.16 €/kg product	0.21 €/kg product	

3.2.3 Eco-efficiency assessment

Table 4 presents the results of the baseline eco-efficiency assessment both for the overall system and for each industrial unit separately. It is confirmed that the major environmental impacts of the studied system are toxicity related issues and freshwater resource depletion,. The results of the assessment also indicate a clear superiority of the Industrial Unit B concerning eco-efficiency, by having higher values in all eight indicators and thus better performance. Despite the similar environmental performance, Unit B is more eco-efficient due to increased profit, since the natural dyed product are sold in a much higher price.

3.3 Value chain upgrading

The baseline eco-efficiency assessment and the identification of the environmental weaknesses of the system will lead to the selection of innovative technologies, which can upgrade the examined value chain. Thus, based on the results, two main objectives are set for the upgrading of the studied system: (a) increase of resource efficiency, focusing on freshwater, and (b) pollution prevention, focusing on treatment of water effluents. After discussing with the directly involved actors in the system and reviewing the relevant literature, six alternative technologies are selected for implementation in the current system and they are described in the following paragraphs.

Table 4. Baseline eco-efficiency assessment

Midpoint Impact Category	Unit	Overall	Ind. Unit A	Ind. Unit B
Climate change	€/kgCO_{2eq}	1,350.72	515.54	2,122.05
Freshwater Resource Depletion	€/m^3	122.44	50.86	178.95
Eutrophication	€/kg$PO_4^{3-}$$_{,eq}$	1,024.68	377.11	1,666.96
Human toxicity	€/kg1,4$DCB_{,eq}$	6.85	2.60	10.80
Acidification	€/kg$SO^{2-}$$_{,eq}$	366.14	147.09	549.87
Aquatic Ecotoxicity	€/kg1,4$DCB_{,eq}$	0.82	0.30	1.35
Terrestrial Ecotoxicity	€/kg1,4$DCB_{,eq}$	9.45	3.43	15.58
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	6,958.75	2,731.69	10,659.82

Smart pumping systems are centrifugal pumps equipped with special instrumentation and a microprocessor that can be operated at variable speed. Through their application to a water abstraction process, a 30-40% reduction in energy consumption and a subsequent reduction in air emissions can be achieved. The investment cost of this technology is 15,000-20,000€ and its lifetime is estimated to be 15 years. The operation and maintenance costs are reduced due to the decreased energy consumption (Stavale, 2001). For the application in the Biella region, it is assumed that the smart pumping systems are installed in both chains.

Automatic dye and chemical dispensing consists of automatic and semi-automatic weighting, dissolving and measuring systems that enable the precise delivery of dyeing chemicals and auxiliaries. The environmental performance of the proposed technology is characterised by a reduction in the amount of water abstracted, as well as in energy and dyes consumed, by 15% each. The investment cost is 150,000-300,000€ with a lifetime of 15 years, while the operation and maintenance costs are 20,000€ (Cotton Inc., 2009). For the application in the Biella region, it is assumed that automatic dye dispensing systems are installed only in the chemical dyeing processes.

Low-liquor-ratio (LLR) jet dyeing machines are based on the principle of accelerating water through a venturi construction or nozzle to transport fabrics. The system's environmental performance is improved since abstracted water is decreased by 50%, the energy consumption (for water heating) by 40% and the quantity of dyes and additives by 20%. The investment cost of this technology is 150,000-300,000€, the operation and maintenance costs are 20,000€ and its lifetime is 10 years (Cotton Inc., 2009). For the application in the Biella region, it is assumed that LLR dyeing machines are installed only in the chemical dyeing processes.

The use of natural dyes, derived from plants, minerals and animals, can make textile processes more sustainable. A reduction by 50% in additives and 15% in energy consumption is achieved, while water used during the dyeing processes is slightly increased, by 15%. Natural dyes result in the absence of heavy metals in the wastewater effluents, having a positive impact on toxicity indicators. As already mentioned, the price of natural dyes is higher than the standard chemical ones; however, the dyed product can be sold in a much higher price. For the application in the studied system, it is assumed that Unit B increases the capacity of the natural dyeing production line, and 75% of its total production volume consists of natural dyed wool.

Advanced oxidation processes (AOPs) are used in wastewater treatment and are based on the generation of very reactive free radicals (i.e. hydroxyl radicals), which in sufficient amounts oxidise most of the chemicals present in textile wastewater. AOPs are classified into two groups; non-photochemical and photochemical AOPs. Fenton process is a non-photochemical oxidation process, used as a wastewater pre-treatment, achieving full decolourization and a 55-65% reduction in COD and heavy metals quantities present in textile effluents (Bautista, et al., 2008). It is assumed that the advanced oxidation process is installed only in Unit A. The investment cost required to upgrade the existing plant is 100,000€ and the operation and maintenance cost is 0.29€/m^3 wastewater. The technology lifetime is approximately 10 years (Yonar, 2011).

Membrane Bioreactor consists of a membrane process (i.e. microfiltration, ultrafiltration) combined with a suspended growth bioreactor and is used for industrial and municipal wastewater treatment. This technology can significantly decrease the quantities of BOD, COD and heavy metals in the effluents, improving the eutrophication and toxicity indicators. Membrane bioreactors are characterised by higher energy consumption compared to other biological treatment, but lower sludge production (Bolzonella and Fatone, 2008; Badani, et al., 2005). It is assumed that the membrane bioreactor is installed only in Unit A. The investment cost is 2,800€ per m^3 of wastewater treated, the operation and maintenance cost is 1.70€/m^3, while the lifetime of the technology, regarding the membrane, is 10 years (Cheryan and Rajagopalan 1998).

A preliminary eco-efficiency assessment of the six selected technologies is presented in Figure 3. It is apparent the smart pumping systems and LLR jet dyeing systems improve significantly three of the indicators; namely climate change, freshwater resource depletion and acidification while natural dyes and MBR show the bigger improvement in aquatic and terrestrial ecotoxicity.

As a second step in the process of upgrading the value chain, two alternative technology scenarios are examined and assessed. The first one is characterised by the application of a set of technologies focusing on resource efficiency, while the second scenario includes technologies which are oriented towards water pollution prevention. The combination of technologies used in each scenario is shown in Table 5.

More specifically, the first scenario (RE Scenario) includes the implementation of the technologies that reduce the consumption of water and supplementary resources. The smart pumping system is applied to water abstraction process, while the LLR jet dyeing machines and automatic dye and chemical dispensing system are applied to the chemical dyeing process.

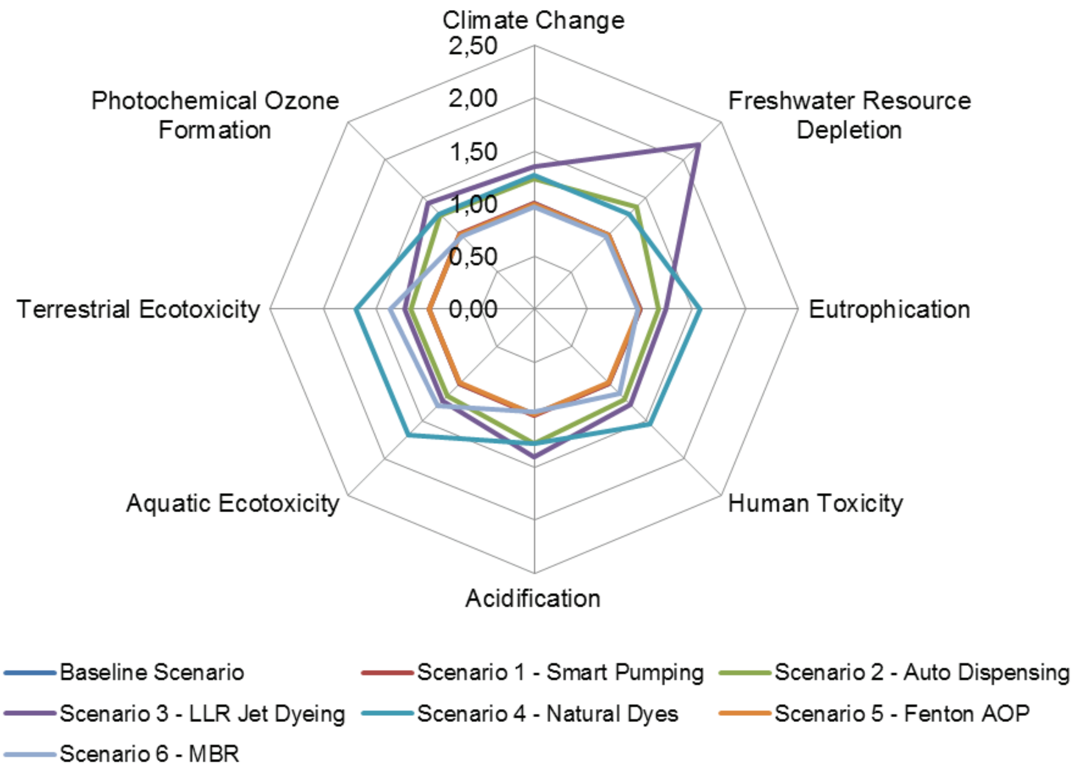


Figure 3. Eco-efficiency assessment of the six selected technologies

The second scenario (PP Scenario), which is pollution prevention oriented, investigates the implementation of two technologies at the stage of wastewater treatment; one pre-treatment process and one for the main treatment, and the partial replacement of chemical dyeing processes with natural dyeing.

Table 5. Alternative technology scenarios

Technology Scenario	Technologies Included
…towards Resource Efficiency	Smart Pumping Systems
	Automatic Dye and Chemical Dispensing
	Low-Liquor-Ratio Jet Dyeing Machines
…towards Pollution Prevention	Use of Natural Dyes
	Advanced Oxidation Process (Fenton's Reagent)
	Membrane Bioreactor

4. RESULTS

Table 6 presents the environmental performance of the two technology scenarios and more specifically the relative change in the eight environmental indicators of the upgraded system compared to the baseline scenario. The obvious observation is that the technology scenario towards resource efficiency significantly improves freshwater resource depletion (reduction by 52.8%) and slightly improves energy related indicators (acidification by 12.4%, climate change by 9.3% and photochemical ozone formation by 15.9%). On the contrary, all toxicity related indicators are significantly improved through the implementation of the technology scenario towards pollution prevention (reduction in aquatic ecotoxicity by 50.1%, terrestrial ecotoxicity by 53.4%, and human toxicity by 32.7%). Eutrophication is also slightly improved but all other indicators are not positively affected. However, it should be noted that the implementation of both scenarios does not has a negative impact to any of the indicators.

Table 6. Environmental performance assessment of the two alternative technology scenarios

Midpoint Impact Category	Baseline	RE Scenario	PP Scenario
Climate change	2,311 $kgCO_{2eq}$	−9.3%	−0.2%
Freshwater Resource Depletion	25,500 m^3	−52.8%	0.0%
Eutrophication	3,047 $kgPO_4^{3-}{}_{,eq}$	−1.9%	−20.3%
Human toxicity	455,971 $kg1,4DCB_{,eq}$	−4.2%	−32.7%
Acidification	8,527 $kgSO^{2-}{}_{,eq}$	−12.4%	−0.3%
Aquatic Ecotoxicity	3,817,041 $kg1,4DCB_{,eq}$	0.0%	−50.1%
Terrestrial Ecotoxicity	330,541 $kg1,4DCB_{,eq}$	−0.1%	−53.4%
Photochemical Ozone Formation	448 kg $C_2H_{4,eq}$	−15.9%	−0.3%

Figure 4 presents the eco-efficiency indicators for the two technology scenarios, confirming that both scenarios improve all nine eco-efficiency indicators. Furthermore, the total value added to the product due to water use is increased in both cases (49.52€/m^3 in the RE scenario, 23.12€/m^3 in the PP scenario). The net economic output (NEO) of all the actors increases or, in the worst case, remains constant, with the exception of the NEO of the Industrial Unit A in the technology towards pollution prevention (Table 7). This observation may be critical for the feasibility of the scenario, since the industrial unit A is the actor responsible for the implementation of two of the technologies. The decrease in the NEO indicates that the economic profit from the installation of an advanced oxidation process and the MBR is not high enough to counterbalance the high investment cost.

Given the economic conditions of the textile industry in Biella, this scenario may not be realistic. Thus, certain economic incentives are required to make its implementation feasible, such as environmental taxes or subsidies. Besides that, similar alternative scenarios could be examined, such as the joint implementation of the WWTP upgrade by more than one actor.

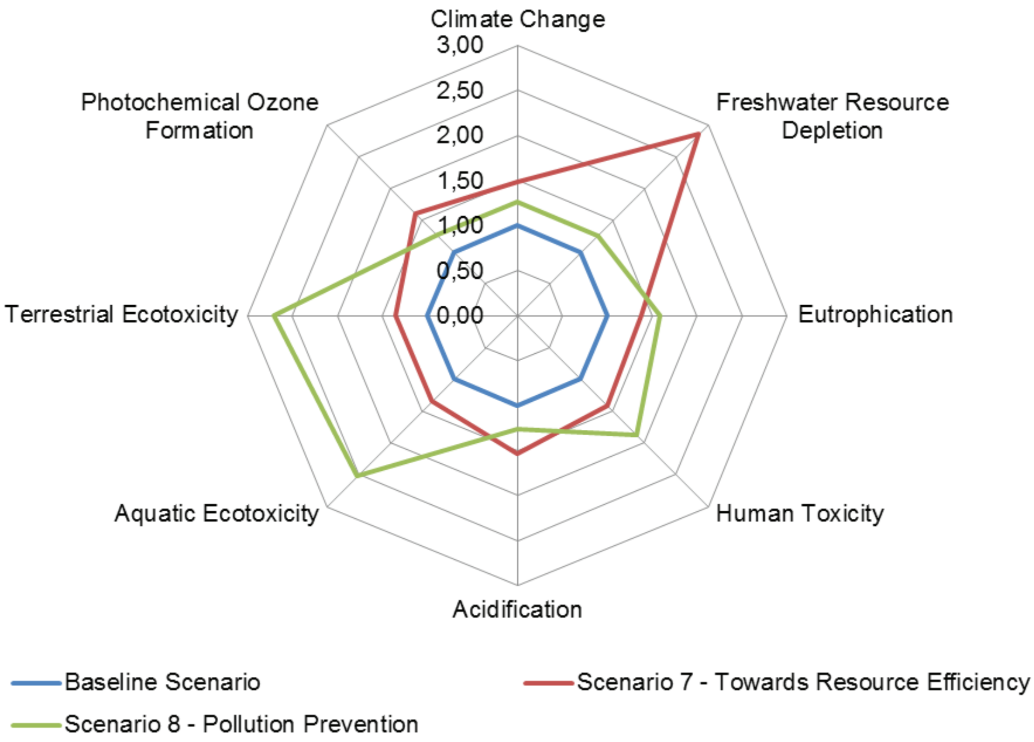


Figure 4. Eco-efficiency assessment of the alternative technology scenarios

Table 7. Net economic output all the involved actors and the total valued added of the system

Net Economic Output	Baseline	RE Scenario	PP Scenario
Industrial Unit A	548,946 €	1,365,876 €	512,832 €
Industrial Unit B	2,434,621 €	2,704,712 €	3,273,878 €
CORDAR	86,365 €	86,365 €	92,145 €
Region	52,200 €	52,200 €	52,200 €
Total Value Added	3,122,132 €	4,209,153 €	3,931,055 €

5. CONCLUSIONS

The paper presented a methodological framework for the assessment of eco-efficiency in water use systems as a measure of progress towards a more sustainable economy. The aforementioned approach was applied to the water use system of the textile industry in Biella, Italy. The baseline scenario was compared to two alternative scenarios that encompass a set of technologies focused on resource efficiency and pollution prevention.

The first technology scenario investigated the implementation of a smart pumping system at the stage of water abstraction and a combination of technologies, namely the automatic dye and chemical dispensing system and low-liquor-ratio jet dyeing, applied to the chemical dyeing process. The analysis underlined the important effect of the implementation of the aforementioned technologies on all eco-efficiency indicators, but mainly on those related to resource efficiency. More specifically, the first scenario is characterised by a significant improvement in the freshwater resource depletion, with a 3-fold increase in the respective eco-efficient indicator.

The second scenario examined the prospect of improving the effectiveness of wastewater treatment by installing innovative technologies which are suitable for treating textile effluents. More specifically, an advanced oxidation process (Fenton process) and a membrane bioreactor process were chosen as a pre- and main wastewater treatment, respectively. In addition to that, the partial replacement of chemical dyeing with natural dyeing was also implemented. In this case all eco-efficiency indicators were improves with higher impact on aquatic and terrestrial ecotoxicity.

For the specific system, the analysis has showed that there is a lot of room for improvement, concerning the main environmental problems of the area; namely the freshwater resource depletion and the toxicity of the effluents. However, given the economic conditions of the region and the economic crisis, certain policies (i.e. economic incentives) or actions (i.e. cooperation among the involved actors) are required for the uptake of the selected technologies

Furthermore, the analysis indicates that the proposed methodological framework gives reliable results and can be expanded and applied to other water use systems. The application of the framework to other alternative water use systems will help reveal its weaknesses as well as areas for further research. Finally, the application of the approach in several water use systems may lead to a definition of a range for each indicator and of reference values for normalizing them. It will also allow technology benchmarking by providing a reference value for eco-efficiency improvements and identification of the most eco-efficient options for each case study.

Acknowledgements

The methodology presented in the paper arises from "EcoWater: Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors", a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA).

References

Badani, Z., Ait-Amar, H., Si-Salah, A., Brik, M., Fuchs, W., 2005. Treatment of textile waste water by membrane bioreactor and reuse. *Desalination* 185 (1-3): 411-417. doi:10.1016/j.desal.2005.03.088.

Bautista, P., Mohedano, A.F., Casas, J.A., Zazo, J.A., Rodriguez, J.J., 2008. Review: An overview of the application of Fenton oxidation to industrial wastewaters treatment. *Journal of Chemical Technology and Biotechnology* 83 (10): 1323-1338. doi:10.1002/jctb.1988.

Bolzonella, D., Fatone, F., 2008. Application of the membrane bioreactor technology for wastewater treatment and reuse in the Mediterranean region, in Fried, J., Scherfig, J. (Eds.), *Proceedings of the International Conference on Water Scarcity, Global Changes and Groundwater Management Responses*. Irvine, USA.

Cao, J., 2007. Measuring green productivity growth for China's manufacturing sectors: 1991-2000. *Asian Economic Journal* 21 (4): 425-451. doi:10.1111/j.1467-8381.2007.00265.x.

Chequer, F.M.D., De Oliveira, G.A.R., Ferraz, E.R.A., Cardoso, J.C., Zanoni, M.V.B., De Oliveira, D.P., 2013.Textile Dyes: Dyeing Process and Environmental Impact. in Günay, M., (Ed.), *Eco-Friendly Textile Dyeing and Finishing*, InTech, pp. 151-176.. doi:10.5772/53659.

Cheryan, M., Rajagopalan, N., 1998. Membrane processing of oily streams. Wastewater treatment and waste reduction. *Journal of Membrane Science* 151 (1): 13-28. doi:10.1016/S0376-7388(98)00190-2.

Cotton Inc. 2009. *A World of Ideas: Technologies for Sustainable Cotton Textile Manufacturing*. America's Cotton Producers and Importers.

Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J., 2002. *Handbook on life cycle assessment. Operational guide to the ISO standards*. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht.

ISO, 2006. ISO 14044:2006 *Environmental management - Life cycle assessment - Requirements and guidelines*. Genève: International Organisation for Standardization.

JRC, 2010. *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Provisions and Action Steps*. Luxembourg: Publications Office of the European Union.

Mila i Canals, L., Chenoweth, J., Chapagain, A., Orr, S., Anton, A., Clift, R., 2009. Assessing freshwater use impacts in LCA: Part I - inventory modelling and characterisation factors for the main impact pathways. *International Journal of Life Cycle Assessment* 14 (1): 28-42. doi:10.1007/s11367-008-0030-z.

OECD., 1998. *Eco-efficiency*. Paris: OECD (Organisation for Economic Co-operation and Development).

OECD., 2009. *Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement*. Synthesis Report, Paris.

Schaltegger, S., Sturm, A., 1989. Ecology induced management decision support. Starting points for instrument formulation. WWZ-Discussion paper No. 8914, Wirtschaftswissenschaftliches Zentrum (WWZ), Universität Basel.

Stavale, A.E., 2001. *Smart Pumping Systems: The Time is Now*. Unpublished White Paper (ITT Industries, Fluid Technology Corporation).

WBCSD., 2000. *Eco-efficiency, Creating more value with less impact*. World Business Council for Sustainable Development.

Yonar, T., 2011. Decolorization of Textile Dyeing Effluents Using Advanced Oxidation Processes. in Hauser, P. (ed.), *Advances in Treating Textile*. InTech. doi:10.5772/18908.

You, S., Cheng, S., Yan, H., 2009. The impact of textile industry on China's environment. *International Journal of Fashion Design*, Technology and Education 2 (1): 33-34. doi:10.10810/17543260903055141.

An online suite of tools to support the systemic eco-efficiency assessment in water use systems

G. Arampatzis[1], A. Angelis-Dimakis[1], M. Blind[2] and D. Assimacopoulos[1,*]

[1]Environmental and Energy Management Research Unit, School of Chemical Engineering, National Technical University of Athens, Athens, Greece

[2]Deltares, Delft, The Netherlands

*Corresponding author: E-mail: assim@chemeng.ntua.gr, Tel +30 210 7723218

Abstract

The eco-efficiency assessment of a water use system at the meso level, as well as the estimation of the anticipated eco-efficiency improvement or deterioration as a result of innovative practices/technologies, is a conceptually and methodologically challenging issue. A systemic approach is required to capture the complexity of all interrelated aspects and the interactions among the heterogeneous actors involved in the system. This involves mapping the behaviour of the system into representative models, structuring the analysis in easy to understand procedures and developing versatile software tools for supporting the analysis.

This paper presents an integrated suite of on-line tools and resources (EcoWater Toolbox) for assessing eco-efficiency improvements from innovative technologies in water use systems at the meso-level, developed in the context of the EcoWater research project. Equipped with a continuously updated inventory of currently available technological innovations as well as a list of eco-efficiency indicators, the EcoWater Toolbox supports a comprehensive four-step eco-efficiency assessment of a water use system: (1) allows the users to frame the case study by defining system boundaries, describing the water supply chain and value chains and including all the actors; (2) helps the users to establish a baseline eco-efficiency assessment, using the integrated modelling tools; (3) supports the users in identifying both sector-specific and system-wide technologies and practices to suit their situation, through the integrated technology inventory; and (4) enables the users to assess innovative technology solutions by developing predictive technology scenarios and comparing these with baseline results.

At the core of the Toolbox are two modelling tools, which combine both economic and environmental viewpoints into a single modelling framework. The “Systemic Environmental Analysis Tool” (SEAT), assists in building a representation of the physical system, its processes and interactions and forms the basis for evaluating the environmental performance of the system. The “Economic Value chain Analysis Tool” (EVAT), addresses the value chain and focuses on the economic component of the eco-efficiency.

The methodology adopted and the operational aspects of the EcoWater Toolbox are presented and demonstrated through the assessment of the eco-efficiency performance associated with the water value chain in the case of a milk production unit of a dairy industry.

Keywords: *eco-efficiency, water use systems, value-chain, environmental assessment, eco-innovation*

1. INTRODUCTION

In a typical water use system, freshwater is abstracted from a source (surface water or groundwater), purified and distributed for different water uses. Each use consumes water of a specific quantity and quality, along with other resources (energy, raw materials, etc.), for the provision of goods or services (both of which are denoted as "products"). Wastewater from uses is collected and treated before being disposed into the environment. In order to monitor the progress of water use systems towards sustainable development, methods and tools are required, which may help quantify and compare their performance. Recent policy frameworks, such as the Europe 2020 strategy, widely promote the concepts of resource efficiency (minimizing the resources used for the provision of products) and resource productivity (the efficiency of economic activities in generating added value from the use of resources) for transforming economy into a sustainable one (O'Brien, et al., 2011). Eco-efficiency is nowadays recognized as a key instrument for promoting fundamental changes in the way societies produce and consume resources, and thus for measuring progress towards sustainability (UN-ESCAP, 2010).

The aim of the eco-efficiency assessment of a water use system is twofold; to analyze the system and its environmental and economic exchanges (attribution analysis) and/or to describe how the environmental and economic exchanges of the system can be expected to change as a result of innovative practices, including technology adoption (consequential analysis) (Rebitzer, et al., 2004). An EU-funded research project, EcoWater, has been systematising those concepts in order to develop a methodology for the assessment of eco-efficiency in water use systems at the meso-level and of the potential eco-efficiency improvements from the implementation of innovative technologies. The meso-level encompasses the water supply and water use chains and entails the consideration of the interactions among all the involved heterogeneous actors, e.g. between water service providers and users.

Interventions in a water use system at the meso-level may have synergies. For example, process upgrading can reduce the concentration of pollutants in the effluents, in turn facilitating improvements in the water use chain, e.g. through in-house waste water treatment, reuse, recycling, etc. On the other hand, they may cause tensions between economic and ecological parameters since innovative practices can incur economic costs for an actor lacking a clear incentive or responsibility to make such an investment for environmental benefits of the overall system. Due to the complexity of the interrelated aspects relevant to environmental and economic behaviour and the interactions among the actors, the eco-efficiency analysis of a meso-level water use system is not trivial. This complexity may be resolved by mapping the behaviour of the system into representative models and structuring the analysis in easy to understand procedures. Many software tools for easing this process are available (EcoWater, 2012). However, typical software tools focus on the environmental aspects of a production system (IFU Hamburg, 2012; PE International, 2013; Goedkoop, et al., 2013) and their capabilities for simultaneously analysing economic features are usually limited. By assigning costs or revenues to the energy or material flows of the water supply and use chains, monetary cost accounting can be added to the environmental assessment. In order to go one step further and include the meso-level effects of technology decisions, models and tools that combine both economic and environmental perspectives should be developed. This would help analysing more complex issues, such as the distributional effects among the actors involved in the system under study.

The scope of this paper is the presentation of an integrated suite of on-line tools and resources (EcoWater Toolbox) for assessing eco-efficiency improvements from the implementation of innovative technologies in water use systems at the meso-level, which has been developed in the context of the EcoWater research project (EcoWater, 2013). The Toolbox integrates a technology inventory, an indicators repository and a pair of modelling tools which combines both economic and environmental viewpoints into a single modelling framework.

2. CONTEXT OF THE ANALYSIS

A generic system, which models the typical meso-level water use system, is presented in Figure 1. The system combines the typical water supply chain with the corresponding water use chain and is represented as a network of unit processes grouped into stages. Each process represents an activity, implementing one or more technologies, where generic materials (water, raw materials, energy and other supplementary resources) are processed and transformed into other materials, while releasing emissions to the environment (air, land, water).

Figure 1. The water supply and water use chains of a meso-level water use system.

The economic analysis of the system also entails the consideration of the interdependencies and the economic interactions of all the heterogeneous actors involved in the water supply and use chain. It involves the sharing of resources, services and by-products among the actors in order to add value and reduce costs. As a result, the meso-level water use system has another significant component, the water value chain, as presented in Figure 2.

Figure 2. The water value chain of a meso-level water use system.

Eco-efficiency is expressed quantitatively by the “eco-efficiency equation” shown in Figure 3. In the numerator is the economic output (benefit) provided by the system and in the denominator are the environmental impacts (costs) associated with that (UN-ESCAP, 2010).

Figure 3. The eco-efficiency “equation”.

There is a wide spectrum of indicators that could measure the environmental performance of the water use system. The methodology developed in EcoWater project follows a life-cycle oriented approach (ISO 14045, 2012) using a standard list of midpoint impact categories

(JRC, 2010), which make it possible to characterize different environmental problems, such as climate change, ozone depletion, photochemical ozone formation, acidification, eutrophication and resource depletion (Guinée, et al., 2001). The most relevant economic output indicator in the meso-level water use system is the so called Total Value Added to the product due to water use, expressed in monetary units. "Total" denotes the economic value added minus various costs of water abstraction, treatment, wastewater treatment, etc. as well as other resource inputs. Hence, evaluating eco-efficiency requires information about the physical system, in terms of elementary flows as well as financial information, in terms of product prices, investment costs, cost of materials and other operational and maintenance costs.

3. ECOWATER TOOLBOX

The EcoWater Toolbox is a web-based platform, which contains the resources and tools necessary for the eco-efficiency assessment of different technologies, through their implementation in water use systems. Figure 4 illustrates the architecture of the Toolbox. It is equipped with a continuously updated inventory of currently available technological innovations as well as a list of eco-efficiency indicators. It has been designed to support a comprehensive four-step eco-efficiency assessment.

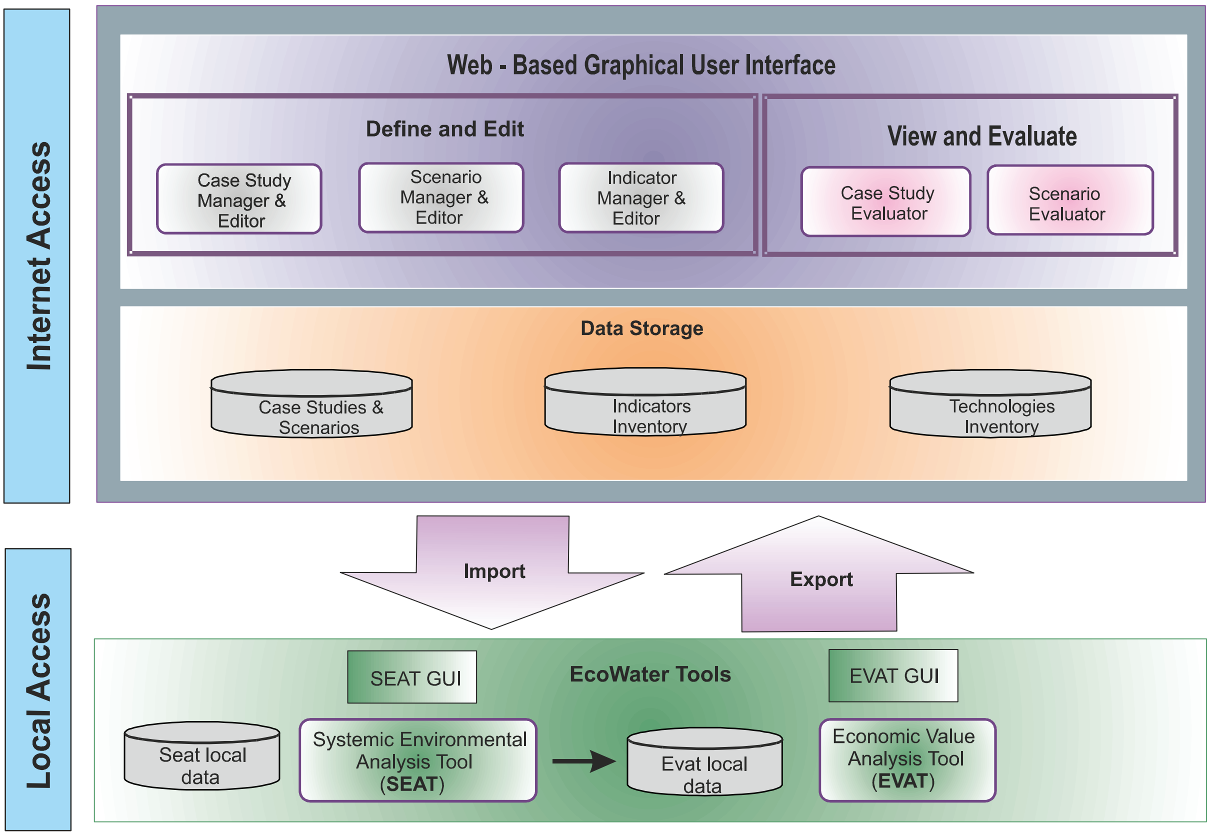


Figure 4. Architecture of the EcoWater Toolbox.

3.1 Step 1 – System Framing.

In this step, the definition of the system boundaries as well as the mapping and description of the water supply chain (stages, processes and existing technologies) and value chain (actors involved and their interrelations) take place, both through a narrative way and by uploading the relevant models of the water supply and value chain.

3.2 Step 2 – Baseline Eco-Efficiency Assessment

The environmental impact for the impact category *c* is expressed as a score (ES_c) based on the concepts of classification and characterization (Guinée, et al., 2001):

(12* MERGEFORMAT)

where ($cf_{r,c}$, $cf_{e,c}$) are the characterization factors that quantify the extent to which each resource *r* (energy, raw materials and supplementary resources) or emission *e* contributes to the impact category *c* and (f_r, f_e) are the corresponding elementary flows of resources and emissions (calculated in SEAT/see Section 4).

The Eco-Efficiency Indicators (*EEI*) of the meso-level water use systems are estimated as ratios of the economic performance indicator (Total Value Added, calculated in EVAT/see Section 5) to the environmental performance of the system (environmental impacts):

(34* MERGEFORMAT)

This step also supports the interpretation of the baseline eco-efficiency assessment results through:

- Calculation of the contribution of foreground and background systems to the environmental performance indicators, highlighting the most significant environmental impacts;
- Breakdown of the environmental impact per stage of the foreground system, indicating the environmental weaknesses of the system; and
- Estimation of the Net Economic Output for each directly involved actors.

3.3 Step 3 – Identification of Technologies

The Toolbox integrates a technology inventory (Figure 5), with detailed information on the possible technologies and practices for the eco-efficiency improvement of the water system. During this step, technologies can be selected from the inventory for implementation either throughout the water supply and wastewater treatment stages (common for all water use sectors) or within the water use processes (sector specific technologies).

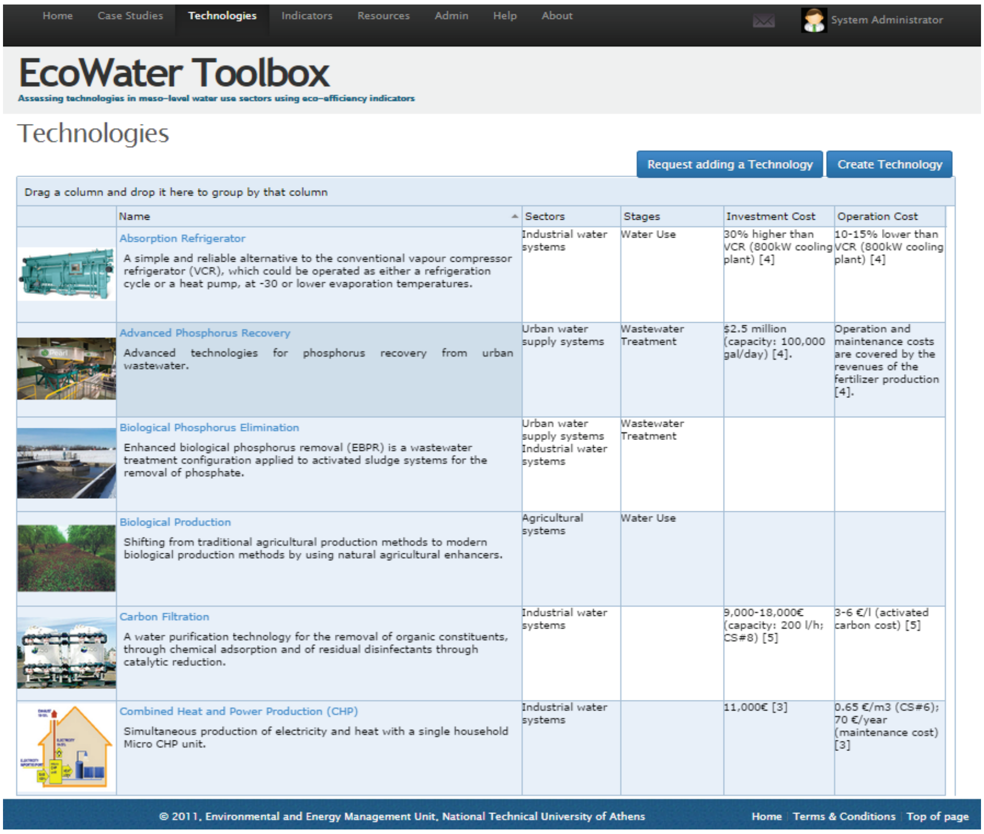


Figure 5. The Technology Inventory.

3.4 Step 4 – Technology Scenario Assessment

Each of the proposed technologies is modeled by identifying the parameters of the water supply and value chains that are affected by their implementation. The estimation of the eco-efficiency indicators can be repeated for each different technology or combination of technologies. The toolbox enables the assessment of innovative technologies by supporting the development of technology scenarios and providing tools for modeling the impacts on the water system from the technology implementation. Thus, it facilitates the comparison of technology scenarios to the baseline results both per actor and for the entire system studied.

4. SYSTEMIC ENVIRONMENTAL ANALYSIS TOOL

4.1 Scope and objectives

SEAT is the core modeling tool of the EcoWater Toolbox that assists in building a representation of a meso-level water use system, its processes and interactions. This model forms the basis for evaluating the midpoint impact indicators, used to measure the environmental performance of the system. A SEAT model provides the elementary flows of resources and emissions that are necessary for evaluating the environmental impacts. It also provides the flows of water, products and other materials that allow the estimation of the costs and incomes generated by the system and quantify the interactions among the actors. Therefore, the system's model is built in SEAT and its results are the main input to the EVAT tool.

4.2 Operational aspects

SEAT operates as an interactive graphical modelling environment (Figure 6) providing the following core functionalities:

Design of a model representation of the analysed physical system. A graphical approach is followed, where the user specifies the stages and the processes of the water use system by actually drawing the elements on a canvas.

Mapping of the stages and the production processes in the water supply and use chains. This is the core modelling step where the user specifies the flow of materials to and from processes, as well as the relationships between input and output flows.

Automatic calculation of the material flows for each process and stage, using the input-output relations defined in the previous step, when at least one reference flow is specified.

Presentation and reporting of the results. The software supports the tabular representation of the calculated flows per link, process, stage, and for the entire system. It also allows exporting the results in common format for further processing and graphing.

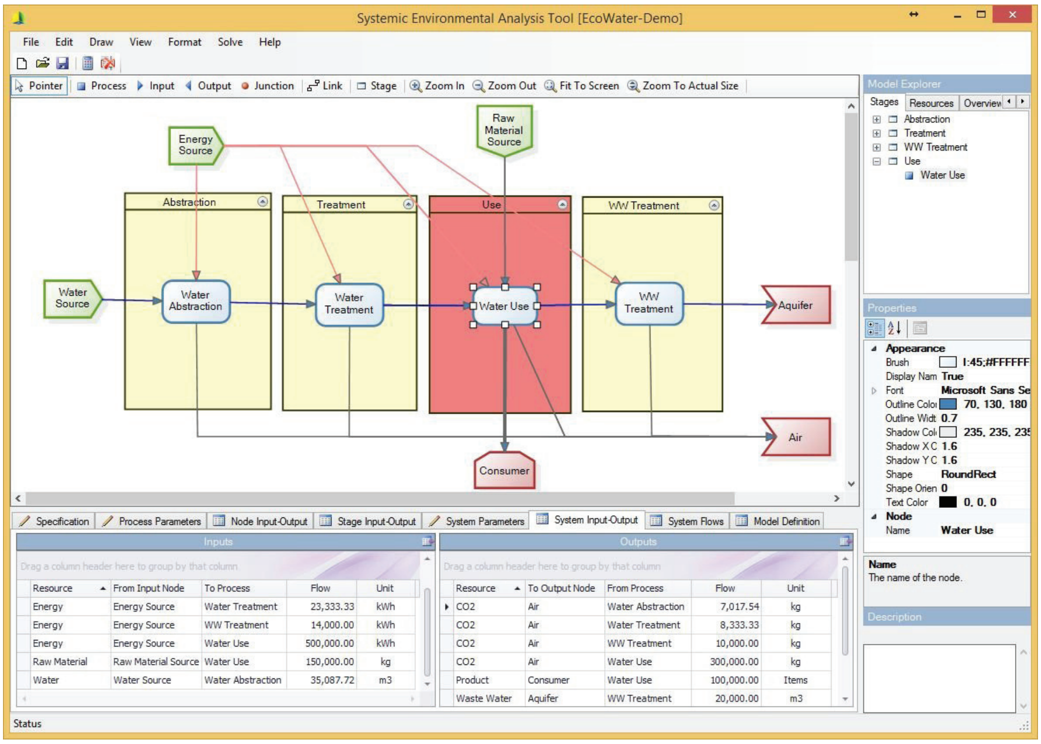


Figure 6. The SEAT modelling environment.

4.3 Methodology

The modelling approach adopted in SEAT is based on the principles of Material Flow Analysis (Huang, et al., 2012) and Material Flow Networks (MFN) (Wohlgemuth, et al., 2006) which model material and energy flows in production chains. According to this approach, SEAT networks are graphs with two different types of vertices called processes and places, connected with links. Processes represent single activities in which materials are processed and transformed to other materials. Places represent store and/or transfer nodes for materials within the network and are distinguished as input nodes (the initial sources of materials flowing towards processes) and output nodes (the target sinks of materials flowing from processes). Junctions are special type of places, connecting processes and acting as output nodes for one process and input nodes for the other process. Links represent a way by which materials can flow between nodes. Finally, processes can be grouped into stages that serve as containers for network nodes.

The principal entities of the network are the processes which describe activities that are entered by all the required materials (input) and, as a result, generate new or modified materials (output). The most important modelling step is the specification of a process. This involves the definition of the input and output materials as well as the relations between input and output flows. Two types of process specifications can be defined. The simplest is based on the use of linear scaling factors , which define linear relationships between a process' inputs and outputs. In this context the values of all process flows can be calculated from a single known flow , according to the equation:

(56* MERGEFORMAT)

A more complex but more flexible approach for process specification uses a set of expressions (script) to describe relationships between input and output flows. Using scripts to attach complex rules to a process can extend SEAT further and makes it possible to model non-linear dependencies.

The overall network solution algorithm is an iterative procedure using the following steps (Page, et al., 2008):

- One or more reference flows must be specified.
- Knowing some flows, the corresponding processes are solved, calculating the previously unknown flows.
- The known flows are propagated through junctions, triggering the calculation of flows in other processes.
- Eventually all unknown flows are calculated, unless the model is not well defined (under/over defined), in which case an error is issued by SEAT.

5. ECONOMIC VALUE CHAIN ANALYSIS TOOL

5.1 Scope and objectives

EVAT supplements the analysis of SEAT by addressing the value chain, its actors and their interactions. The value chain monitors the added value to the final product due to water use from stage to stage and can be described using monetary quantities. EVAT also provides the allocation of costs and incomes among the chain stages and actors that forms the basis for the analysis of potential distributional effects involved in the studied systems.

The main output from EVAT is the monetary flows that can be used to estimate the total value added (*TVA*) to the product from water use, defined as:

(78* MERGEFORMAT)

In Equation (8), *EVU* represents the economic value-added from water use, TFC_{WS} is the cost related to water supply provision for rendering the water suitable for the specific use, TFC_{WW} is the cost related to wastewater treatment, and *TIC* is the equivalent annual total investment cost, from upgrading the system's value chain. *EVU* refers to the total benefits from direct use of water and is estimated using the residual value approach:

(910* MERGEFORMAT)

where *TVP* is the total value of product(s) and EXP_{NW} are the non-water related expenses in the water use stage.

EVAT is also used to calculate the net economic output of each actor *i* (NEO_i), defined as:

(1112* MERGEFORMAT)

The term WS_i represents the net revenues of the actor from the water services (incomes from services provided to other actors minus expenses from services received by other actors), while VP_i, FC_i and IC_i are the value of product(s), financial costs and annual investment costs, respectively, incurred in the pertinent stages of actor.

5.2 Operational aspects

EVAT operates on a similar to SEAT interactive environment, based on the network representation of the physical model. The core functionalities provided are:

- Management of the relevant actors, e.g. the specification of the actors involved in the water system and the assignment of the relevant stages to each actor.
- Specification of financial costs incurred in the system's processes and the incomes generated from products or services.
- Analysis of economic interactions among actors by identifying and quantifying the water services between actors.
- Calculation, presentation and reporting of the results. The software calculates the total value added from water use and the net economic output per actor. All economic results are broken-down either per stage or per actor.

5.3 Methodology

The approach adopted for the development of EVAT is based on the concept of inheritance used in object oriented design patterns. EVAT builds on the model developed in SEAT, inheriting the basic elements described in Section 4.3, and extending it to include economic information, necessary for the estimation of total value added and the net economic output of actors according to Eqs. (8-12). Two complementary views (modes) of EVAT operation permit the specification of the different financial elements in the value chain in an organized manner.

The "stages view" provides the context for defining the cost elements incurred in each stage of the water supply and use stages, as well as the incomes generated from product in water use stage. On the other hand, the "actors view" permits the specification of water services between actors, necessary to calculate the net economic output of actors.

Equivalent annual investment cost (from the upgrade of the value chain) is calculated by specifying the total investment cost, the life time of the implemented action and an interest rate. Operations and maintenance cost are composed by a fixed part plus the cost of productive inputs (resources) and/or any taxes paid for the emissions. The unit costs of resources and emissions are specified in the stages view and the actual costs are calculated using the corresponding flows from the SEAT model. A similar procedure is followed for the specification of incomes.

The “actors view” mode of EVAT operation is shown in Figure 7. Any type of water tariff structure can be specified by defining a flat rate and a volumetric tariff. The latter may be a fixed volumetric rate or a more complex block tariff (increasing or decreasing). Expenses and incomes from water services are calculated by combining the tariffs defined in EVAT with the water flow calculated in SEAT model.

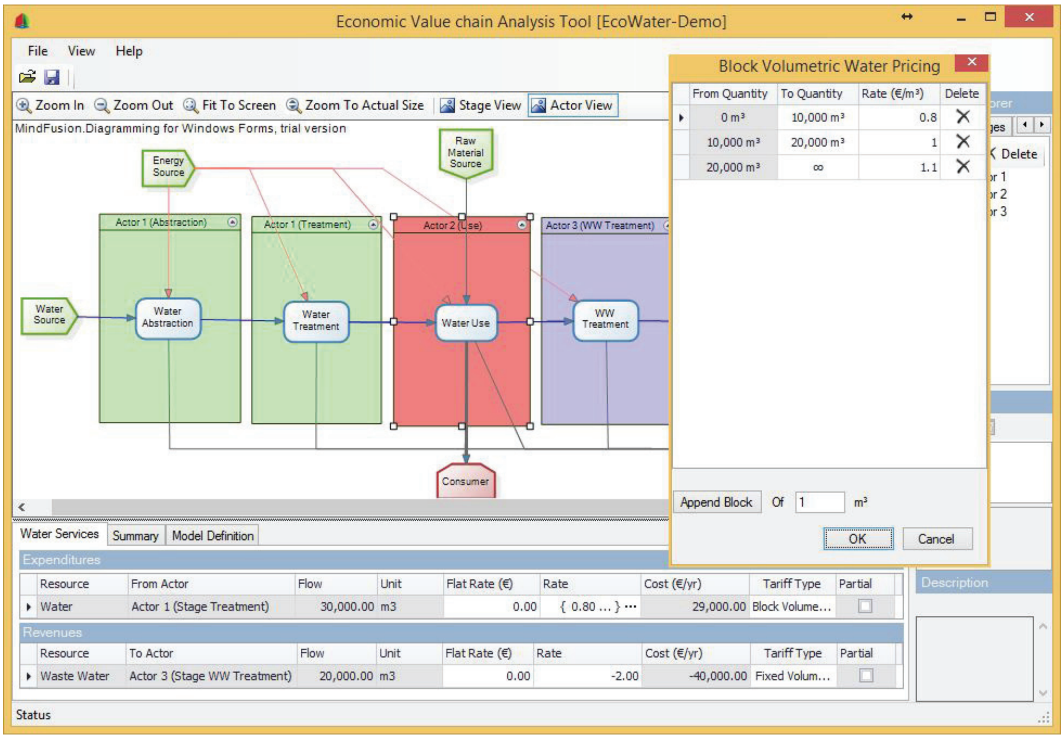


Figure 7. Actor view of the EVAT modelling environment and the specification of a block volumetric water tariff structure

6. DEMONSTRATION OF THE TOOLS

The operational aspects of the SEAT and EVAT modelling tools are illustrated through the assessment of the environmental impacts and the eco-efficiency performance associated with the water value chain in the case of a milk production unit of a dairy industry. An attempt to upgrade the value chain through the introduction of two innovative technologies is investigated and the eco-efficiency improvement of the system is evaluated.

6.1 System framing

The analysis of the dairy industry encompasses the whole water value chain starting from its origin as a natural resource and ending to a receiving water body after its environmental degradation in the production process. The main stages of the water value chain include the water supply, treatment and distribution systems, the use stage where water is used in the milk production process and the final stage were wastewater is treated before being discharged in a water body. Figure 8 presents the model of the physical system in the SEAT tool.

Each stage has been defined in such way that encloses the relevant actors involved in the system and the interactions among them. The actors involved in this case are:

- The Water Supply and Sewerage Company (OPERATOR) which has the responsibility for water supply in the industrial sector and the wastewater treatment facilities.
- The Milk Production Unit (INDUSTRY).

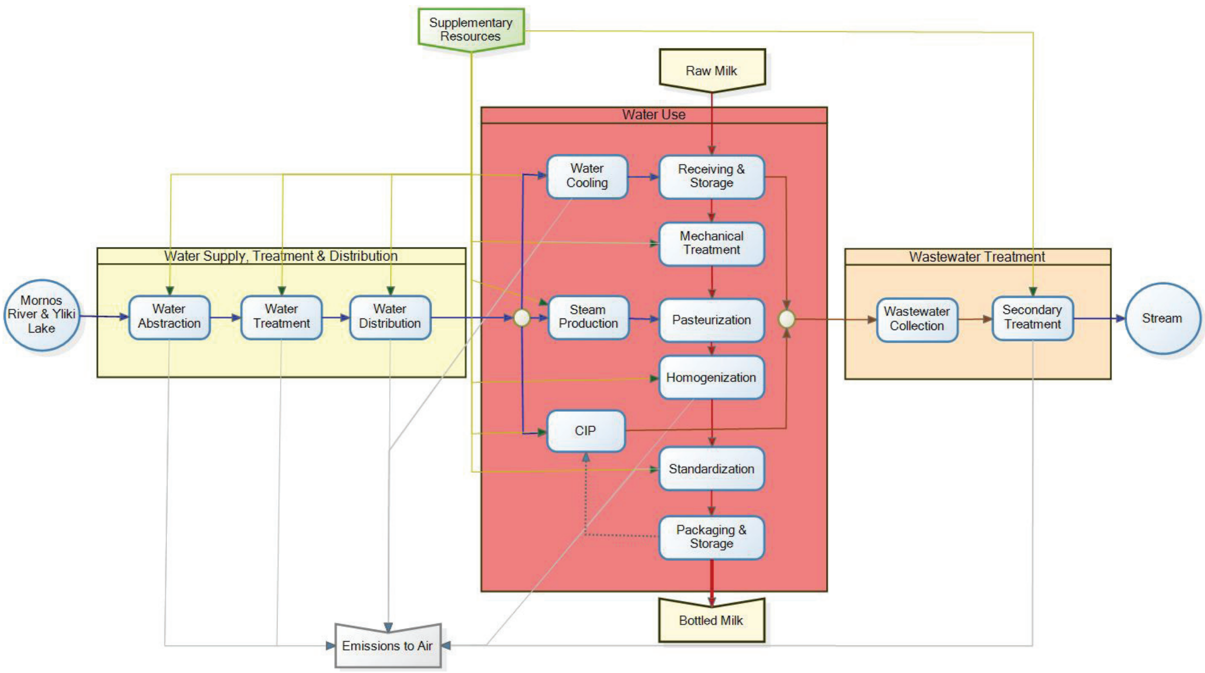


Figure 8. SEAT Model of the water use system in the dairy industry.

6.2 Baseline Eco-efficiency Assessment

6.2.1 Environmental assessment

The annual average milk production is estimated to be 190,000 m^3 of milk and the annual water requirements are assumed to be:

- 0.3 m^3 of water per m^3 of milk, for cooling;
- 1.25 m^3 of steam per m^3 of milk, for pasteurization; and

- 3.2 m^3 of water per m^3 of milk; for cleaning purposes.

Steam is produced using a natural gas fed boiler with average efficiency of 60%. All other energy requirements of the industrial unit are satisfied using electricity, bought from the grid. It is also assumed that each m^3 of milk requires 6 kg of sugar at the standardization process.

In the water supply chain, the total electricity requirements for abstraction, treatment and distribution processes are 0.29 kWh/m^3 of water abstracted and 3.5 gr of chemicals are required for treating 1 m^3 of water. Before being discharged to the water stream, wastewater is being treated in a WWTP with COD removal efficiency 97% and average electricity consumption of 25 kWh/m^3 of wastewater treated.

The environmental performance of the system is assessed through seven environmental impact categories. The characterization factors included in the CML-IA database are used for the calculation of the environmental impacts and the results are presented in Table 1.

6.2.2 Economic Assessment

The total value added to the milk from the use of water is calculated based on the unit costs of supplementary resources presented in Table 2. In addition to that it is assumed that the dairy industry sells the product (bottled milk) for 1,000 €/m^3. Regarding the revenues from water services, the dairy industry buys water from the water utility operator for 1.5 €/m^3 and pays as a fee 1 €/m^3 for wastewater collection and treatment.

Table 1. Characterization factors for the calculation of the environmental impacts

Midpoint Impact Category	Unit	ESC (Unit/L water)	ESC (Unit/L milk)	EEIC (in €/Unit)
Climate change	$tCO_{2,eq}$	44.1	266	647
Eutrophication	$kgPO_4{}^{3}{}_{-,eq}$	3.8	23	7542
Acidification	$kgSO^{2-}{}_{,eq}$	14.5	87	1965
Human toxicity	$kg1,4DCB_{,eq}$	34.8	210	819
Photochemical ozone formation	$kg\ C_2H_{4,eq}$	1.0	5,8	29379
Fossil fuels depletion	GJ	193.4	1.165	147
Freshwater depletion	m^3	150.0	904	190

Table 2. Unit costs of supplementary resources

Resource	Unit Cost
Raw milk	200 €/m^3
Sugar	400 €/kg/tonne
Cleaning Chemicals	0.32 €/kg

Electricity	86 €/MWh
Natural Gas	0.5 €/m^3

Table 3. Economic results for system actors.

Actor	Annual O&M Cost	Gross Income	Revenues from Water Services	Net Economic Output
Industry	-41,794,270	76,002,000	-2,189,750	32,017,980
Operator	-1,585,151	0	2,189,750	604,599
Total Value Added:				**32,620,579**

Table 4**:** Environmental and eco-efficiency indicators.

Midpoint Impact Category	Unit	ES_C (in Unit/L water)	ES_C (in Unit/L milk)	EEI_C (in €/Unit)
Climate change	$tCO_{2,eq}$	44.1	266	647
Eutrophication	$kgPO_4{}^{3-}{}_{,eq}$	3.8	23	7542
Acidification	$kgSO^{2-}{}_{,eq}$	14.5	87	1965
Human toxicity	$kg1,4DCB_{,eq}$	34.8	210	819
Photochemical ozone formation	$kg\ C_2H_{4,eq}$	1.0	5,8	29379
Fossil fuels depletion	GJ	193.4	1.165	147
Freshwater depletion	m^3	150.0	904	190

Table 3 summarizes the economic results for both actors involved. The total value added to the product from the water use, is the sum of the net economic output of the actors, which is equal to 32,620,579 € (or 172 €/m^3 milk produced).

6.2.3 Eco-efficiency Assessment

Based on the environmental and value assessment, the seven relevant eco-efficiency indicators are calculated and presented in Table 4. It is apparent that the three major environmental impacts of the studied system are climate change and fossil fuels depletion, due to natural gas consumption for steam production and freshwater depletion. Thus, the upgrading of the system through innovative technologies should aim at improving these three key indicators.

6.3 Identification of Technologies

To identify possible improvements in the water value chain and assess the environmental performance by applying alternative technologies, two scenarios are investigated and compared on the basis of the eco-efficiency indicators.

The technologies analysed are:

- Installation of a company owned water treatment plants with simultaneous recycling of wastewater discharged from the production process and diversion to CIP process (Scenario 1). This change in the water supply chain will result to water saving of 75%, with an extra investment cost of 500,000 €.
- Replacement of the existing gas boiler (efficiency 60%) by a more efficient (80%) in the Steam Production process (Scenario 2). The investment cost is assumed to be 100,000€ and the boiler lifetime 30 years.

6.4 Technology Scenario Assessment

Figure 9 presents the relative change in the seven eco-efficiency indicators of the upgraded system compared to those of the current situation (baseline scenario). The TVA from water use in the two alternative scenarios is:

- 32,570,472 € or 171 €/m^3 milk produced (Scenario 1)
- 33,327,977 € or 175 €/m^3 milk produced (Scenario 2)

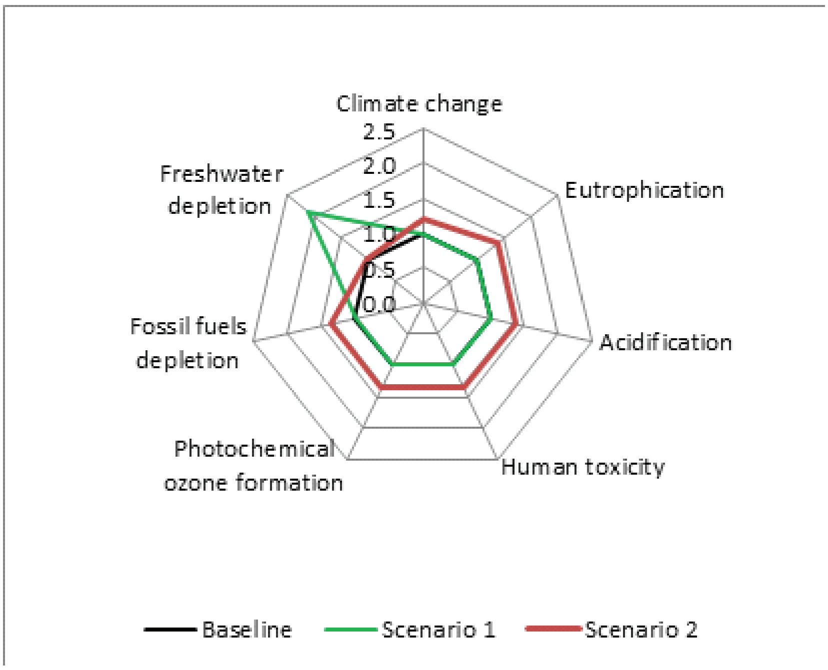


Figure 9. Comparison of eco-efficiency indicators in the three scenarios

The application of a CIP system significantly improves the freshwater resource depletion indicators, as it is expected. However, all other eco-efficiency indicators are not affected since a minor improvement is counterbalanced by the slight decrease of the TVA. On the other hand, the installation of a more efficient boiler leads to a more balanced improvement of all 7 eco-efficiency indicators, which is further enhanced by the increase on the overall TVA.

7. CONCLUSIONS

The EcoWater Toolbox, an integrated suite of on-line tools and resources for assessing eco-efficiency improvements from innovative technologies in water use systems at the meso-level, was presented in this paper. The Toolbox integrates a technology inventory, an indicators repository and a pair of modelling tools which combines both economic and environmental viewpoints into a single modelling framework. The methodological and operational aspects of the Toolbox and the integrated tools were analysed and tested through a simple case study concerning a milk production unit of a dairy industry.

The case study demonstrates the capability of the Toolbox to support four steps of eco-efficiency assessment methodology developed in the context of EcoWater project. The upgrade of the value chain through the introduction of two innovative technologies was also analysed and the eco-efficiency improvement of the system was evaluated.

Acknowledgements

This paper arises from “EcoWater: Meso-level eco-efficiency indicators to assess technologies & their uptake in water use sectors”, a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, duration: 2011-2014, coordinated by the National Technical University of Athens (NTUA), http://environ.chemeng.ntua.gr/EcoWater/.

References

EcoWater, 2012. *Deliverable 1.4 Review of existing frameworks and tools for developing eco-efficiency indicators. In: Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors.,* Athens: EcoWater.

EcoWater, 2013. *Deliverable 5.5 First toolbox prototype,* Athens: EcoWater.

Goedkoop, M. et al., 2013. *Introduction to LCA with SimaPro,* California,: PRe.

Guinée, B. J. et al., 2001. *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards.* Dordrecht: Kluwer Academic Publishers.

Huang, C.-L., Vause, J., Ma, H.-W. & Yu, C.-P., 2012. Using material/substance flow analysis to support sustainable development assessment: A literature review and outlook. *Resources, Conservation and Recycling,* Volume 68, pp. 104-116.

IFU Hamburg, 2012. *Umberto for Carbon Footprint v. 1.2: User Manual,* Hamburg: IFU Hamburg GmbH.

ISO 14045, 2012. *Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines, ISO 14045:2012,* s.l.: International Organization for Standardization, CEN.

JRC, 2010. *ILCD Handbook – General Guide for Life Cycle Assessment – Detailed Guidance,* Luxembourg: Publication Office of the European Union.

O'Brien, M., Giljum, S., Miedzinski, M. & Blei, . R., 2011. *The Eco-Innovation Challenge - Pathways to a resource-efficient Europe,* Annual Report 2010: Eco innovation objervatory.

Page, B., Wohlgemuth, V. & Raspe, M., 2008. *Material Flow Analysis for Eco-Efficiency with Material Flow Network Reference Models – Concepts and Case Study.* Barcelona, s.n., pp. 1620-1627.

PE International, 2013. *GaBi Database & Modelling Principles 2013,* Germany: PE International.

Qdais, H. A., 2003. *Water Demand Management - Security for the Mena Region.* Egypt, s.n.

Rebitzer, G. et al., 2004. Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International,* Volume 30, p. 701– 720.

UN-ESCAP, 2010. *Eco-efficiency Indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment,* Thailand: United Nations publication.

Wohlgemuth, V., Page, B. & Kreutzer, W., 2006. Combining discrete event simulation and material flow analysis in a component-based approach to industrial environmental protection. *Environmental Modelling & Software,* Volume 21, p. 1607e1617.

Systemic eco-efficiency assessment in water use systems

A. Angelis-Dimakis, G. Arampatzis and D. Assimacopoulos*

Environmental & Energy Management Research Unit, School of Chemical Engineering, National Technical University of Athens, Athens, Greece

*Corresponding author: E-mail: assim@chemeng.ntua.gr, Tel +30 210 772 3218

Abstract

Eco-efficiency has recently become an important concept of environmental decision making, serving as a policy objective and, if linked with resource efficiency, can be a measure of progress towards sustainability. The need for improving eco-efficiency leads to the challenge of identifying the most promising alternative solutions which improve both the economic and the environmental performance of a given system ("eco-innovations"). However, interventions in complex physical systems may lead to large-scale transformations and a systemic approach towards eco-innovation is required, in order to capture the complexity of all interrelated aspects and the interactions among the actors involved.

The goal of this paper is to present a methodology, developed in the context of the EcoWater research project, for the eco-efficiency assessment of a water use system at the meso level and the estimation of the anticipated eco-efficiency improvement from the introduction of innovative technologies, through a set of representative indicators. A meso-level water use system combines a typical water supply chain with the corresponding production chain. It incorporates both the physical structure of the system and the rules governing the operation, performance and interactions of the system components. In such a system, water is considered in three different ways: (i) as a resource, (ii) as a productive input, and (iii) as a waste stream.

The developed methodological framework consists of four distinct steps. The first step leads to a clear, transparent mapping of the system at hand and the respective value chain, while the second step provides the means to assess its eco-efficiency. The assessment of the environmental performance follows a life-cycle oriented approach using the midpoint impact categories (including the impacts from the background systems). The economic performance of the water use system is measured using the Total Value Added to the product due to water use. One important novelty is the distribution of economic costs/benefits and environmental pressures over different stages and stakeholders in the value chain. The third step includes the selection of innovative technologies, which are assessed in the last step and combined with mid-term scenarios in order to determine the feasibility of their implementation.

Such a systemic approach provides a concrete, comprehensive and accurate assessment of the economic and environmental performance of the system but also entails the consideration of the interdependencies and the economic interactions of

all the heterogeneous actors involved in these two chains. Furthermore, the meso-level can act as an intermediate step in technological transition; between the technological niches (in the micro-level) and the wide adoption (or rejection) of new technologies (in the macro-level). In the meso level, all involved actors are urged to cooperate in order to (a) propose and build innovative technological solutions that will improve the overall eco-efficiency of the system; and (b) provide the necessary policy framework that will facilitate and promote their uptake. This ensures that upstream decisions in the value chain are coordinated with downstream activities and all potential synergies are identified, leading to the creation of "meso-level closed resource loops" and thus the promotion of a circular economy.

Keywords: systemic eco-efficiency, water use systems, value chain, eco-innovation

1 INTRODUCTION

Water is a critical resource for all activities in a human society, with agriculture, industry, energy production and public water supply being the most important ones. It is estimated that producing enough food for one person for one day requires about 3000 liters of water (GWP, 2014). On average, 44% of total water abstraction in EU is used for energy production, 24% for agriculture, 17% for public water supply and 15% for industry. The importance of water as input to most production processes is confirmed by the fact that while the world population has tripled in the 20th century, the global water usage has increased six-fold (Abra, 2012).

Population growth, urbanization and industrialization are linked with the increasing demand for water and have serious consequences on the environment and the human health. According to the World Water Council, 23 countries will face absolute water shortage in 2025 and another 50 (with over 3,000 million total population) could suffer from water stress by the same time (Abra, 2012). Furthermore, over 80% of water used worldwide is not collected or treated, leading to more than 3 million premature deaths annually from water-related diseases in developing countries (UNWATER, 2009).

Thus, there is need for monitoring and improving water use systems by identifying the most promising alternative solutions which improve both its economic and its environmental performance ("eco-innovations"). An eco-innovation can be defined as an intervention in a given physical system that reduces the use of natural resources and decreases the release of harmful substances into the environment. The distinguishing characteristic of an eco-innovation is that its implementation results in both economic and environmental benefits, improving the overall eco-efficiency of the system.

Recent studies have shown that there is a wide range of available technical measures to save water and to improve its quality. However, the uptake of water-related innovations remains almost exclusively driven by regulations and their assessment is primarily based on water efficiency gains. Furthermore, interventions in complex physical systems (such as the water-use systems) may lead to large-scale transformations, which could affect all the heterogeneous actors involved and having conflicting interests. Hence, a systemic approach is required, which will incorporate both the physical structure of the system and the rules governing the operation, performance and interactions of the system components.

2 MESO LEVEL ECO-EFFICIENCY

In a typical water use system, freshwater is abstracted from a source, treated and then distributed to different users. Each user consumes water of a specific quantity and quality, along with other resources, for the production of one or more products/goods or/and the provision of one or more services. Wastewater from each user is collected and treated before being disposed into the environment. Various sustainability issues are linked to a water use system.

A typical issue, arising in water use systems with competitive use sectors, is the allocation of water among the uses, by fulfilling the demand in an optimal way (Figure 1). Optimization may refer to the minimization of the resource deficit (in water scarcity conditions) or the cost related to the use of the resource (e.g. the cost for water abstraction and distribution). Methodologies that are used to analyse this type of issues are based on resource balance concepts (Manoli, et al., 2005) and network optimization algorithms (Manoli, et al., 2001).

Figure 1. Water allocation to different uses

On the other hand, a common sustainability issue, arising in production systems, is the efficient use of resources for providing goods or services. Resource efficiency aims at minimizing the use of the required resources while reducing the impacts on the environment (Jonsen, 2013). Such systems are usually analysed by Life Cycle Impact Assessment (ISO, 1997; ISO, 2006; JRC, 2010; JRC, 2011) and Life Cycle Cost Analysis (Langdon, 2007) methodologies that focus on the production chain of the examined good or service, encompassing the resources required in the production processes as well as the final product. A typical example of such a system is presented in Figure 2.

The system examined under the EcoWater project, an EU-funded Research Project, is a meso-level water use system (Dopfer, et al., 2004) that combines the typical water supply chain with the corresponding water use chain (Figure 3). The meso level can be defined as an intermediate scale between the micro and the macro level and offers an additional means of interpreting the eco-efficiency indicators. The macro level represents the national framework and conditions that apply to all players and consists of the general legal, economic and environmental parameters that significantly affect the water system while the micro-level refers only to single unit and provides the basis for the evaluation of the direct effect that a specific technological option will have on it. The meso-level differs from the above described systems, as it combines a specific water use with all the processes needed to render the water suitable (both qualitatively and quantitatively) for this use, and the treatment and discharge of the generated effluents to the environment. It is not limited to the production chain of a specific enterprise or firm, but it considers the whole water cycle of the analysed system from abstraction to disposal.

Figure 2. Efficient use of resources in a water use system

It incorporates both the physical structure of the system and the rules governing the operation, performance and interactions of the system components. It provides a concrete, comprehensive and accurate assessment of the economic and environmental performance of both each actor separately and the system as a whole. The analysis on the meso-level also takes into account the interdependencies and the economic interactions of all the heterogeneous actors involved in these two chains (e.g. between water service providers and users). It also involves the sharing of resources, services and by-products among the actors (symbiosis) in order to add value and reduce costs. As a result, the meso-level water use system has a third significant component, the water value chain, as presented in Figure 3.

The aim of the EcoWater project is to develop a systemic approach for the eco-efficiency assessment of meso-level water use systems and the anticipated eco-efficiency improvement from the introduction of innovative technologies. Eco-efficiency is a concept that combines resource efficiency (minimizing the resources used in producing a unit of output) and resource productivity (the efficiency of economic activities in generating added value from the use of resources). In such an approach water should be considered in three different ways:

- As a resource, which allows assessing the resource efficiency of the system;
- As a productive input, in order to estimate the total value added from water use to the final product; and
- As a waste stream, in order to assess the environmental impacts of water use and to identify potential synergies/alternative uses for these streams

Figure 3. The meso-level water use system

The developed methodological framework consists of four distinct steps. The first step leads to a clear, transparent mapping of the system at hand and the respective value chain. The second step provides the means to assess its eco-efficiency. The assessment of the environmental performance follows a life-cycle oriented approach using the midpoint impact categories (including the impacts from the background systems). The economic performance of the water use system is measured using the Total Value Added to the product due to water use. One important novelty is the distribution of economic costs/benefits and environmental pressures over different stages and stakeholders in the value chain. The third step includes the selection of innovative technologies, which are assessed in the last step and combined with mid-term scenarios to determine the feasibility of their implementation. The four steps of the proposed methodology as well as some preliminary conclusions drawn from its application are presented in the following sections.

3. SYSTEM FRAMING

The mapping of the system under study includes the definition of its boundaries and its special characteristics as well as the functional unit. A generic system, which models the actual meso-level water use system, is presented in Figure 4. It is represented as a network of unit processes. Each process represents an activity, which implements one or more technologies. In each process materials are processed and converted into other materials, while emissions are released to the environment (air, land, water) or into the system water flow.

Figure 4. The generic meso-level water use system

An important element in a typical life cycle approach is the distinction between "foreground" and "background" systems:

- The set of processes whose selection or mode of operation is affected directly by decisions based on the study defines the foreground system.
- The background system includes all other activities and is that which delivers energy and materials to the foreground system, usually via a homogeneous market so that individual plants and operations normally cannot be identified.

As a general rule, case-specific primary data are used to describe the foreground processes, while more generic information is used for background processes (Guinée, et al., 2001). The boundaries of the foreground system encompass all the processes related to the water supply and the water use chains and can be grouped into four generic stages, presented in Table 1.

Finally, the definition of the functional unit is the foundation of an LCA approach, because it sets the scale for comparison of two or more products or services delivered to the consumers (JRC, 2010; ISO, 2006). The main purpose for a functional unit is to provide a reference to which results are normalized and compared. Possible functional units for a meso-level water use system are:

- One unit of product or one unit of service delivered; and
- One unit (e.g. m^3) of water used.

Table 1. Generic stages in a meso-level water use system

No	Name	Description
1	Water Abstraction	Processes related to the abstraction of water from the environment and the distribution to the users
2	Water Treatment	Processes related the treatment of water according to the quality standards of the users
3	Water Use	Processes related to the production of goods or services
4	Wastewater Treatment	Processes related to the treatment of wastewater before disposing to the environment

4. ECO-EFFICIENCY ASSESSMENT

A typical eco-efficiency assessment consists of the following three phases (ISO, 2012):

- Environmental assessment
- Value assessment and
- Quantification of the eco-efficiency

4.1 Environmental Assessment

The environmental assessment concerns the evaluation of the environmental impacts and follows the main stages of the typical LCA (life cycle inventory analysis and life cycle impact assessment) as described in ISO 14044 (ISO, 2006). Life cycle inventory (LCI) analysis involves creating an inventory of flows entering and leaving every process in the foreground system, i.e. the system within the defined system boundaries. Inventory flows include inputs and outputs of the generic "materials" presented in Table 2.

In a typical LCA methodology, the inventory of flows must be related to the functional unit defined in the first step. However, in the proposed approach it is preferable to express the flows on an annual basis (e.g. m^3 of water abstracted per year, tons of product produced in one year), even if the functional unit is one unit of product or one m^3 of water used. This practice facilitates the calculation of annual costs and incomes during the value assessment phase. The environmental impacts per functional unit should be calculated by dividing with the corresponding elementary flow.

Table 2**.** Material types in the meso-level water use system

Material Type	Description
Water	Water service related materials (fresh water, wastewater).
Resources	Various resources used in the processes of the water supply chain or in the production chain (energy, raw materials, chemicals, etc.)
Emissions	Emissions generated from the processes of both chains and released to the environment
Products/Services	The main outputs of the water use stage
By-products	Produced by the processes of both chains

The Life Cycle Impact Assessment (LCIA) is aimed at evaluating the significance of potential environmental impacts based on the inventory of flows. LCIA consists of the following elements:

- Selection of relevant impact categories;
- Classification and characterization; and
- Impact calculation.

The assessment of the environmental performance of the EcoWater water use system is implemented by using the midpoint impact categories presented in Table 3.

This categorization makes it possible to characterize different environmental problems and cover all aspects of different impacts on human health, natural environment, and availability of resources. (Guinée, et al., 2001). They also provide a common basis for consistent and robust environmental performance analysis.

Table 3. Midpoint impact categories

No	Impact Category	Unit of measure
1	Climate change	$tCO_{2,eq}$
2	Stratospheric ozone depletion	kgCFC-11_{eq}
3	Eutrophication	$kgPO_{4,eq}$ or $kgNO_{x,eq}$
4	Acidification	$kgSO_{2,eq}$
5	Human toxicity	kg1,$4DCB_{eq}$ or CTUh
6	Ecotoxicity 6a Aquatic 6b Terrestrial	kg1,$4DCB_{eq}$ or CTUe
7	Respiratory inorganics	$kgPM_{10,eq}$
8	Ionizing radiation	kBq U-$235_{air,eq}$
9	Photochemical ozone formation	$kgC_2H_{4,eq}$
10	Resource depletion 10a Minerals 10b Fossil fuels 10c Freshwater	 $kgSb_{eq}$ or $kgFe_{eq}$ MJ or TOE m^3

The purpose of classification is to organize and possibly combine the life cycle inventory flows into impact categories. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the ability of the resource/emission to contribute to different environmental problems. Characterization concerns the quantification of the extent to which each resource/emission contributes to different environmental impact categories and it is accomplished using standard characterization factors.

More specifically, the environmental impact for impact category c is expressed as a score (ES_c) in a unit common to all contributions within the category. The impacts from the foreground processes can be easily calculated using the flows from the inventory analysis and the characterization factors, as follows:

(1)

where $cf_{r,c}$ the characterization factors of resource r for the impact category c (e.g. water for freshwater depletion, natural gas for fossil fuel depletion and phosphorus for mineral depletion); $cf_{e,c}$ the characterization factors of emission e for the impact category c (e.g. carbon dioxide for climate change, phosphorus for eutrophication and sulphur dioxide for acidification); f_r the elementary flow of resource r; and f_e the elementary flow of emission e.

The environmental impacts from these processes are evaluated based on background or secondary data taken from LCA databases. The background data is considered to be generic, normally represented for a mix or a set of mixes of different processes. Analysing the data provided by the LCA databases, environmental impact factors ($ef_{r,c}$), representing the environmental impacts from the production and/or transportation of one unit of a resource r to each impact category c can be calculated. The contribution of background processes to the environmental impacts of category c is then calculated using these factors, as:

(2)

Background impacts are added to the foreground ones to calculate the system-wide environmental impacts.

(3)

4.2 Value Assessment

The selected economic performance indicator for the value assessment of a meso-level water use system, which takes into account the operation of both the water supply and the water use chains, is the Total Value Added (*TVA*) to the product due to water use, expressed in monetary units per period, in general per year (Euros/year). It is estimated as:

(4)

where *EVU* is the total economic value from water use, VP_{BP} the income generated from any by-products of the system, TFC_{WS} the total financial cost related to water supply provision for rendering the water suitable for the specific use purpose, TFC_{WW} the total financial cost related to wastewater treatment and *TIC* the annual equivalent future cash flow generated from the introduction of new technologies in the system.

EVU refers to the total benefits from direct use of water. The approach followed for estimating it depends on whether the water is used as a resource in a production process (e.g. water use in industrial and agricultural sectors), or delivers a service to the customers (e.g. water use in urban sector).

In the first case, *EVU* is estimated using the residual value approach:

(5)

where *TVP* is the Total Value of Products, and EXP_{NW} are the Non-Water Expenses representing the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage (stage 3), estimated as follows:

(6)

(7)

The above approach cannot be applied an urban water supply system, because the product is actually the service provided to households and to non-domestic consumers. In that case, the estimation of the economic value from water used is based on these customers' willingness to pay for the water services. Based on the assumption that the level of water services provided will not change as a result of technology implementation (i.e. the application of a technology or management practice will not result in supply interruptions or render the quality of water unsuitable for the specific purpose) and that the total utility (the overall satisfaction of wants and needs) does not change between scenarios, the economic value from water use can be estimated by:

(8)

where *WTP* consumers' willingness to pay for the services provided (defined as the maximum amount a consumer would be willing to pay in order to receive a reliable and adequate water supply) and the total quantity of water supplied to the processes of water use stage in the baseline case, as denoted by the superscript bl.

TFC_{WS} represents the expenses in the processes of water abstraction and water treatment stages (stages 1 and 2):

(9)

TFC_{WW} represents the expenses in the processes of wastewater treatment stage (stage 4):

(10)

The *TVA* can be also calculated by aggregating the Net Economic Output (*NEO*) of all the directly involved actors in the system. The NEO is estimated by the following equation:

(11)

where WS_i represents the net revenues of the actor from the water services (incomes from services provided to other actors minus expenses from services received by other actors), while VP_i, FC_i and IC_i are the value of product(s), financial costs and annual investment costs, respectively, incurred in the pertinent stages of actor.

4.3 Eco-efficiency quantification

The Eco-Efficiency Indicators (*EEI*) of the meso-level water use systems are defined as ratios of the economic performance to the environmental performance of the system. There are 14 eco-efficiency indicators, one for each environmental impact category c.

(12)

4.4 Special methodological issues

This section addresses two special methodological issues regarding: a) the handling of “recovered resources” (e.g. energy, phosphorus, etc.), generated due to the implementation of innovative technologies and b) the assessment of environmental impacts from freshwater use.

4.4.1 Recovered Resources

Recovered resources, as a result of applying an innovative technology, will affect the eco-efficiency of the water system and should be included in the analysis. The problem is more complex when the recovered resources are exported and used outside of the system boundaries. In a typical LCA analysis, this problem is handled by an expansion and substitution approach.

According to JRC (2010), when a process of a system provides more than one function, i.e. delivers several goods and/or services, it is defined as multifunctional. Multifunctionality in the analyzed meso-level water use systems occurs due to the introduction of innovative technologies, as e.g. in the following cases:

- Introduction of a hydropower generator, which functions as a pressure reduction valve, in the water distribution process. The generated electricity can be used on-site, exported to the grid or stored for future usage.
- Introduction of advanced phosphorus recovery technologies in the processes of the wastewater treatment stage. The recovered phosphorus can be sold for use to another system.

The environmental impacts of these multifunctional processes are handled as follows:

- In case of on-site use of the generated resource (closed-loop recycling) the consumption of primary energy sources is reduced affecting the environmental performance of the system; hence the amount of the recovered resources will be subtracted from the relevant elementary flow during the environmental impact assessment. The economic performance of the system is affected as well (as the costs related to resource used and the additional technology is considered for the estimation of the TVA).
- In case that the recovered resources are exported to another system (open-loop recycling) the economic and the environmental performance of the analyzed system are affected as follows:
    - The cash flow from the sale of the recovered resources will be considered for the estimation of the TVA produced, as a benefit of the relevant actor due to technology uptake.
    - The reduced amount of resources in the wastewater stream will mitigate relevant environmental impacts. The potential environmental benefits associated with the use of recovered resources (e.g. reduced amount of primary materials and energy sources) will not be considered, as they are ascribed to the system where the use of resources takes place.

4.4.2 Freshwater Resource Depletion

Impacts from the use of freshwater (resource depletion) are far from being standardized in current LCIA practice (Muñoz, et al., 2010) and there is no standardized environmental midpoint indicator for this impact category (JRC, 2011). To date, most studies have neglected this issue or reflected it as a simple indicator, expressing the volume of abstracted water by the product system (Muñoz, et al., 2008).

However, in the case of water use systems, freshwater resource depletion cannot be neglected. In the proposed approach, the methodology presented in Mila i Canals (2009) and suggested by JRC (2011) is used. It is based on the Freshwater Ecosystem Impact (FEI) indicator, defined as:

(13)

where is the freshwater abstracted and WTA is the water withdrawal to availability ratio. The latter can be defined as:

(14)

where *WU* is the total annual freshwater withdrawal in a river basin and *WR* represents the annual freshwater availability in the same basin.

5. SELECTION OF INNOVATIVE TECHNOLOGIES

The upgrading of a water use system can be achieved through one or more of the following alternative ways (Humphrey & Schmitz, 2000):

- Process upgrading, which will result in a more efficient transformation of the inputs into outputs, by rearranging the production line, by introducing new technologies or by recycling/reusing the generated wastewater/effluents;
- Product upgrading, by changing to a more profitable product line (i.e. a product with higher economic value); and
- Functional upgrading, by acquiring new functions in the value chain (i.e. marketing).

In the proposed approach, the focus is on process or product upgrading, by introducing technologies which reduce the overall environmental impact or improve the quality/quantity of the final product.

A preliminary selection of innovative technologies is formulated based on the existing lists of Best Available Techniques for each sector and the relevant literature. The final selection is guided by the eco-efficiency assessment of the system in its current state (“baseline scenario”), and the identification of its vulnerabilities and environmentally weak stages. More specifically, the breakdown analysis of environmental and eco-efficiency indicators for each Case Study per stage and the estimation of the foreground and background system contribution reveal potential areas for improvement through the implementation of new technologies. These can be classified according to the stage at which they are implemented (Figure 5):

- Technologies in the water supply chain (common in all water use systems); implemented either upstream (e.g. water treatment) or downstream (e.g. wastewater treatment) of the water use stage; and
- Technologies in the production chain (sector specific).

Figure 5. Innovative technologies implementation in different stages of water system

The technologies can be also classified in three categories, based on the three main axes of the current European research framework, according to their objective of their implementation:

- Resource efficient technologies, focusing on water, energy or material savings;
- Pollution preventing technologies, aiming to reduce the emissions to air, to water and to soil; and
- Technologies enhancing circular economy, such as reuse, recycle or recovery.

6. TECHNOLOGY SCENARIOS

The proposed technologies are assessed through the development of alternative technology scenarios and their comparison to the baseline scenario. A technology scenario can be defined as "the implementation of (at least) one innovative technology in the system under study, assuming that all other parameters remain the same".

The first step is the screening of all available technologies through an individual eco-efficiency assessment. The eco-efficient ones are then identified and then ranked based on their performance towards the three key objectives:

- Pollution Prevention
- Resource Efficiency
- Circular Economy

According to the individual assessment of technologies, alternative technology scenarios are formulated, focusing on each of the three key objectives and including all the relevant eco-efficient technological options. Finally, for each technology scenario, the distributional issues among the actors should be analyzed, in order to examine their feasibility:

- If the TVA of the system and the NEO of all actors increases, then the scenario is feasible and can be implemented
- If the NEO of certain actors decreases (especially if the affected actors are the ones who will implement the technology), then additional policies are required for managing the distributional issues

7. CONCLUSIONS AND DISCUSSION

The proposed methodological framework has been successfully applied in three different three water-use sectors (agricultural, industrial and urban water supply systems). The analysis has revealed potential eco-innovations for each one of the sectors and has led to the formulation of policy recommendations that will promote their uptake. Furthermore, the application of the approach in eight different water use systems and the cross-comparison of these case studies will lead to:

- Definition of a range for each indicator and reference values for normalizing them;
- Technology benchmarking by providing a reference value for eco-efficiency improvements;
- Identification of the most eco-efficient technological options in each case study;
- Identification of common areas for improvement, by highlighting the weak stages in the water supply chain on each case study and comparing similar stages/processes across case studies; and
- Information for prioritizing and targeting policy actions (e.g. supporting competitive sectors like industrial or agricultural with economic incentives)

Based on the application of the framework for the purposes of the EcoWater Project, it can be said that the proposed systemic approach provides a concrete, comprehensive and accurate assessment of the economic and environmental performance of a water use system and of all directly involved actors involved in the two examined chains.

Furthermore, the introduction of the meso-level can act as an intermediate step in technological transition; between the technological niches (in the micro-level) and the wide adoption (or rejection) of new technologies (in the macro-level). In the meso level, all potential actors, both directly and indirectly involved (including SMEs, research organisations, policy makers etc.) are urged to cooperate in order to:

- Propose and build innovative technological solutions that will improve the overall eco-efficiency of the system (eco-innovations); and
- Provide the necessary policy framework that will facilitate and promote their uptake.

This ensures that upstream decisions in the value chain are coordinated with downstream activities. All potential synergies are identified, leading to the creation of “closed resource loops” at a meso-level and the promotion of circular economy.

The application of the proposed approach has also revealed its weaknesses as well as areas for further research. The main open methodological issue is the suitability of the TVA (as defined for the purposes of this project) as the appropriate metric for assessing the economic performance of industrial water use systems. In addition to that, it should be clarified if and how can the results from the cross-comparison among Case Studies from different sectors be meaningful for system a cross-sectoral technology benchmarking.

Finally, a key issue is also to define the most important transition factors in enabling effective change towards systemic eco-efficiency improvement. Towards that end, the current methodological framework (both the approach proposed and the indicators list) could be upgraded from linear (value chain) to circular modeling, in order to be able to simulate an eco-industrial park. This will facilitate the transition to a more circular economy by integrating production chains through environmental partnerships and by promoting industrial symbiosis.

Acknowledgements

The methodology presented in the paper arises from "EcoWater: Meso-level eco-efficiency indicators to assess technologies and their uptake in water use sectors", a collaborative research project of the 7th Framework Programme, grant agreement no. 282882, coordinated by the National Technical University of Athens (NTUA).

References

Abra, J., 2012. Innovation for sustainable water. *Eco-Innovation Brief #2*, Eco-innovation observatory.

Dopfer, K., Foster, J. & Potts, J., 2004. Micro-meso-macro. *Journal of Evolutionary Economics, 14,* pp. 263-279.

Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J., 2002. *Handbook on life cycle assessment. Operational guide to the ISO standards*. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht.

GWP, 2014. *Global Water Partnership website– Food Security.* last accessed at 30/09/2014. http://www.gwp.org/The-Challenge/The-Urgency-of-Water-Security/food-security/

Humphrey, J., Schmitz, H., 2000. *Governance and Upgrading: Linking Industrial Cluster and Global Value Chain Research.* Working Paper 120, IDS.

ISO, 1997. *Environmental management–Life cycle assessment– Principles and Framework, ISO14040:1997,* Paris: International Organization for Standardization.

ISO, 2006. *Environmental management – Life cycle assessment – Requirements and guidelines, ISO 14044:2006,* Genève, Switzerland: International Organization for Standardization.

ISO, 2012. *Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines, ISO 14045:2012,* Genève, Switzerland: International Organization for Standardization.

Jonsen, J., 2013. *Resource efficiency: What does it mean and why is it relevant?* ECN Policy Studies.

JRC, 2010. *ILCD Handbook – General Guide for Life Cycle Assessment – Detailed Guidance,* Luxembourg: Publication Office of the European Union.

JRC, 2011. *ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European context,* Luxembourg: Publication Office of the European Union.

Langdon, D., 2007. *Life cycle costing as a contribution to sustainable construction: a common methodology.* Davis Langdon Management Consulting.

Manoli, E, Arampatzis, G., Pissia, E., Xenos, D., Assimacopoulos, D., 2001. Water demand and supply analysis using a spatial decision support system. *Global Nest Journal, 3 (3),* pp. 199-209.

Manoli, E., Katsiardi, P., Arampatzis, G., Assimacopoulos, D., 2005. Comprehensive water management scenarios for strategic planning. *Global Nest Journal, 7 (3),* pp. 369-378.

Milà i Canals, L, Chenoweth, J., Chapagain, A., Orr, S., Anton, A. and Clift, R., 2009. Assessing freshwater use impacts in LCA: Part I - inventory modelling and characterisation factors for the main impact pathways. *International Journal of Life Cycle Assessment, 14 (1),* p. 28–42.

Muñoz, I., Milà i Canals, L. & Clift, R., 2008. Consider a spherical man: A simple model to include human excretion in life cycle assessment of food products. *Journal of Industrial Ecology, 12 (4),* p. 520–538.

Muñoz, I., Milà i Canals, L. & Fernández-Alba, R. A., 2010. Life cycle assessment of water supply plans in Mediterranean Spain. *Journal of Industrial Ecology, 14 (6),* pp. 902-918.

UNWATER (2009) *The United Nations World Water Development Report vol.3, Water in a Changing World*. UNESCO Publishing.

Measuring subjective welfare – a critical review of subjective wellbeing indicators

Gabor Harangozo PhD *(gabor.harangozo@uni-corvinus.hu)*

Department of Environmental Economics and Technology, Corvinus University of Budapest

Introduction

The shortcomings of GDP as a welfare indicator have been analyzed extensively. Later on, many alternative welfare indicators have been developed to cover more or less its deficiencies by adding further aspects regarding social or environmental issues to the indicator. Such indicators include the Net Economic Welfare by Nordhaus and Tobin from 1972, the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI).

There are also many attempts for totally replacing GDP or at least substantially modify it with a set of other indicators that are considered to measure welfare more properly (for example the Human Development Index – HDI, UNDP, 2004). All these indicators are based on objective data (if at all they are available for calculating the indicators).

However, there is also another direction in measuring welfare: instead of trying to collect objective indicators that are considered to measure welfare or development, welfare or wellbeing is approached by the subjective judgment of individuals. In this paper a review on subjective welfare indicators is provided. Common is in these approaches that they intend to measure wellbeing, welfare or happiness in a subjective manner.

In this paper a critical review of eight different subjective welfare indicators – as means for measuring subjective wellbeing – is provided. Common is in these approaches that they intend to measure wellbeing, welfare or happiness in a subjective manner. This paper intends to structure and characterize the selected subjective wellbeing indicators.

In the next chapter, a short overview on the definition and measurement directions of subjective wellbeing is provided. Then, after a short chapter on the research method, the results of the literature review follows. The discussion chapter aims to provide a short comparison of the reviewed indicators and sketch the directions of further research.

Terminology and measurement of subjective wellbeing

Subjective wellbeing (SWB) or subjective welfare refers to a ‘degree to which individuals evaluate positively the quality of their life in total’ (Pacek and Radcliff, 2008). There is a huge body of literature on the concept and the determining factors of SWB (see for instance Diener and Pavot, 1993, Dolan and White, 2008, Nistor, 2011 and Selezneva, 2011).

Even if there are concerns and skepticism about the validity and reliability of the self-reported nature of SWB (Radcliff and Pacek, 2008), this concept helps us to better understand the complex nature of welfare. Furthermore, although wellbeing is subjective in that it occurs within a person’s experience, manifestations of subjective wellbeing can be measured objectively’ (Diener and Ryan, 2009).

However, there seems to be a gap in scientific literature on the measurement of SWB. The most straightforward method for measuring subjective welfare is based on direct judgment of individuals on their happiness, satisfaction with life etc. If the sample is representative, the results can be generalized to bigger groups (e.g. nations).

These methods try to capture satisfaction with life in general. Veenhoven (2011) provides an overview of numerous measurement questions and scales. A very typical question is that 'All things considered, how satisfied are you with your life as a whole these days?'' measured on a scale from 0 – dissatisfied to 10 satisfied.

World Values Survey (2011) measures happiness based on the question: 'Taking all things together, would you say you are:

1. Very happy
2. Rather happy
3. Not very happy
4. Not at all happy'

The HPI methodology (discussed later in details, Abdallah et al. 2012) uses the 'Ladder of Life' methodology for assessing wellbeing based on the Gallup World Poll Questions (2008) and Cantril (1965). Individuals are asked to respond the following questions: 'Please imagine a ladder with steps numbered from zero at the bottom to 10 at the top. Suppose we say that the top of the ladder represents the best possible life for you and the bottom of the ladder represents the worst possible life for you. On which step of the ladder would you say you personally feel you stand at this time, assuming that the higher the step the better you feel about your life, and the lower the step the worse you feel about it? Which step comes closest to the way you feel?'

Multiple component approaches are also used. The ''Satisfaction With Life Scale'' (Diener and Pavot 1993) consists five different questions, each rated on a scale from 1 to 7.

Scale of the measurements happens in these cases on a rank or ordinal scale.

Limitations of these measurements is disregarding whether certain levels of wellbeing are sustainable or not. Can high-levels of happiness or subjective wellbeing for the majority of population be sustained with the resources of this planet? These issues have to be further analyzed, maybe by using other indicators taking into account sustainability aspects.

A further potential shortcoming of these indicators based on direct questions on personal wellbeing is that positively biased answers may occur. These are based on cognitive dissonance, the individual does not want to feel dissatisfied.

Method

This study is based on a literature review of different concepts providing a framework for measuring SWB. The research process included the review of academic databases and further search engines (such as Google Scholar).

In the followings a critical review of eight different SWB indicators or sets of indicators – as means for measuring SWB – is provided. Common is in these approaches that they intend to measure wellbeing, welfare or happiness in a subjective manner. This paper intends to structure and characterize the selected subjective wellbeing indicators.

As part of future research, the review can be developed to a systematic review of the literature (Fink, 1998, Tranfield et al., 2003 and Klewitz and Hansen, 2014).

Results

Individual-based indicators

Gross National Happiness (Bhutan)

The concept of the GNH was originally suggested by Jigme Singye Wangchuck, King of Bhutan in 1972. The concept of GNH considers economic development not to be an end in itself but as one of the many means to achieve Gross National Happiness. Happiness should not be seen as a purely individual responsibility; collective happiness should be addressed directly through public policies in which happiness becomes an explicit criterion in development projects and programs. (Thinley, 2005).

The concept of GNH has become a guiding force for day-to-day economic and political decision-making in Bhutan. Its commitment to GNH has allowed Bhutan to both expand its network of roads and increase its forest cover. Furthermore, moral and ethical values were placed at the core of its economic strategies for ensuring better food, housing and health.

Practical use of the indicator: Bhutan has set up four policy bundle priority areas: sustainable and equitable socio-economic development; conservation of environment; preservation and promotion of culture; and promotion of good governance (Thinley (2005)

The underlying philosophy of the indicator that a range of minimum conditions must be met before a person can be considered to be happy. The nine dimensions of wellbeing incorporated in the index are:

- psychological wellbeing,
- time use (sufficient time for non work related activities),
- community vitality,
- culture (diversity and resilience of cultural traditions),
- health,
- education,
- environment (perceptions and ecological knowledge),
- living standards,
- governance (perceptions of equity, honesty, and quality).

The construction of the index gives greater weight to large deficits in any dimension than to small deficits or shortfalls in several dimensions. This means that a large deficit in any particular dimension has a magnified negative impact on the GNH index. The sufficiency cut-off points for particular dimensions could thus have a substantial impact on the results obtained.

Latest data available are based on the GNH Survey 2010 (Ura et al., 2012). The data collection process is much more thorough than that usually associated with happiness research. Based on the experiences of pilot studies, 33 clustered indicators and 124 variables have been developed in the 9 different domains. Data gained through a questionnaire. There are subjective and self-report indicators and indicators which are anticipated to be more objective (Ura et al. 2012).

Main shortcoming of the GNH that it is not yet clear to what extent the judgments implicit in its construction reflect the values of the people of Bhutan: whether they reflect a consensus on such matters as the dimensions of wellbeing that are important and the weighting that should be given to each dimension, as well as the determination of the cut-off points for sufficiency in each dimension. It also unclear whether there is a consensus view within Bhutan that if a greater number of people attain excellence, rather than just sufficiency, in particular dimensions of wellbeing that this makes no contribution to GNH. (Bates 2009)

The Quality of Life Index

This index has been developed by the Economist in 2004. It aims to link the results of subjective life-satisfaction surveys to the objective determinants of quality of life across countries. It predicts subjective life satisfaction by nine indicators represent a country's quality-of-life index, or the "corrected" life-satisfaction scores, based on objective cross-country determinants.

There have been many attempts to construct alternative, non-monetary indices of social and economic wellbeing by combining in a single indicator a variety of different factors. The main problem in all these measures is selection bias and arbitrariness in the factors that are chosen to assess quality of life. Furthermore, assigning weights to different indicators (measured on a comparable and meaningful scale) to come up with a single synthetic measure seems to be even more problematic (Economist, 2004).

Subjective life satisfaction survey results provide a good overview on people's judgments. However, such surveys do not exist for many countries or are out of date.

The Quality of Life Index is calculated by an estimation of available subjective wellbeing survey data through a multivariate regression model. In such a manner relevant factors are selected and their weights are calculated. The main factors of the model are:

1. Material wellbeing (GDP per person, at PPP in USD. Source: Economist Intelligence Unit).
2. Health (Life expectancy at birth, years. Source: US Census Bureau).
3. Political stability and security (Political stability and security ratings. Source: Economist Intelligence Unit).
4. Family life (Divorce rate per 1,000 population, converted into index of 1 (lowest divorce rates) to 5 (highest). Sources: UN; Euromonitor.
5. Community life (Dummy variable taking value 1 if country has either high rate of church attendance or trade-union membership; zero otherwise. Sources: ILO; World Values Survey).
6. Climate and Geography (Latitude, to distinguish between warmer and colder climes. Source: CIA World Factbook).
7. Job security (Unemployment rate, %. Sources: Economist Intelligence Unit; ILO).
8. Political freedom (Average of indices of political and civil liberties. Scale of 1 (completely free) to 7 (unfree). Source: Freedom House).
9. Gender equality (Ratio of average male and female earnings, latest available data. Source: UNDP Human Development Report).

A main shortcoming of this indicator that it does not take into account whether life in different countries is sustainable or not.

Australian Unity Wellbeing Index (Personal Wellbeing Index and National Wellbeing Index)

The Australian Unity Wellbeing Index (Cummins et al., 2003) as a subjective welfare indicator has been developed to measure satisfaction with life in different areas. It is based on the model of subjective wellbeing homeostasis. This model suggests that the subjective wellbeing of people is relatively stable (if there are no extreme good or bad events occur in the short run). There is also a 'set-point', around which the individual wellbeing varies, about 75 on a 0 to 100 scale for Western civilizations.

Although the usual "satisfaction with life as a whole" question is useful for estimating the homeostatic set-point, its high level of abstraction fails to provide information about the domains of life that also contribute, positively or negatively, to this sense of wellbeing. For approaching such information, questions need to be directed at satisfaction with certain life components.

To achieve this, the Unity Wellbeing Index is built from two sub-indices: the Personal Wellbeing Index (PWI) and the National Wellbeing Index (NWI). If evaluation also includes societal variables beyond personal ones, the overall level of homeostatically-driven satisfaction diminishes, and the evaluation process becomes more and more influenced by factors other than just the need to protect the self from negative appraisals (Cummins et al. 2003).

The Unity Wellbeing Index has more dimensions. Beyond two general questions on the abstract level (personal: 'life as a whole' and national: 'life in Australia') two indicator groups have been developed, where variables are subjective perceptions measured on 0 to 10 scales.

Personal Wellbeing Index (PWI):

1. Standard of living
2. Health
3. Achieve in life
4. Personal relationships
5. How safe you feel
6. Community connectedness
7. Future security

The PWI is based on the earlier methodology of Comprehensive Quality of Life Scale (Cummins 1997).

National Wellbeing Index (NWI):

1. Economic situation
2. State of the environment
3. Social conditions, and three additionally added sub-indicators:
4. Wealth/income distribution
5. Heath services
6. Family support

Environmental sustainability is again not included (just a general ‘state of the environment' perception).

The indicators can be refined for different groups of respondents. Special indices have been developed for example for adults, school children or intellectually disabled people (McGillivray et al., 2009, Tomyn et al., 2013).

Collective indicators

The Happy Planet Index

The Happy Planet Index (HPI) has been developed by the New Economics Foundation and Friends of the Earth (Marks et al., 2006). It is a measure of progress focusing on the sustainable wellbeing of nations. It is a ratio showing how efficiently people use the natural resources to achieve happiness. It is measuring how countries perform in providing long, happy lives for their inhabitants, whilst maintaining the opportunity for future generations to do the same. Its sub-indicators include experienced wellbeing, life expectancy and ecological footprint.

It demonstrates that high income countries with large ecological footprint do not perform that well from a global sustainability perspective.

HPI is a collective indicator, can be calculated on national (or global) level. It is based partly on objective statistical data, partly on subjective perceptions. The main domains of the indicator are:

- experienced wellbeing (based on subjective data),
- life expectancy (in years, based on statistical data) and the
- ecological footprint (based on statistical data).

On one hand, there are many strengths regarding the HPI (based on Goossens et al., 2007, p.44.):

- It considers the actual 'ends' of economic activity in the form of life satisfaction and longevity,
- It combines wellbeing and environmental aspects.
- It provides simple and easily understandable scheme for calculating the index.
- Its sub-indicators (ecological footprint and life expectancy and wellbeing) can be calculated (or even available on-line) and compared regarding different countries.
- It consists 'soft' and 'hard' criteria; takes into account people's wellbeing and resource use of countries.

On the other hand, there are many critics arise concerning HPI:

- Happiness, wellbeing or life satisfaction are very subjective and personal: cultural influences may distort these measures on an international level.
- The name is confusing: index is not a measure of happiness but rather measure of environmental efficiency of supporting wellbeing in a given country.
- Subjective wellbeing surveys (such as the World Values Survey) do not cover all nations and are carried out too rarely. As a consequence, part of the data for the HPI is estimated using regressions.

Furthermore, important issues regarding welfare like economic development, pollution, political freedom, human and civil rights etc. are not included in the concept. Further research would be needed on how to integrate the missing aspects into the model without losing its simplicity?

Welfare measurement based on the Stiglitz Report

The Stiglitz Report (Stiglitz, Sen and Fitoussi, 2009) focuses on measuring social progress from different perspectives. It highlights that standard objective socio-economic measures (economic growth, inflation, unemployment) may be not in line with subjective perceptions. It concentrates to the analysis of the gap between statistical data and subjective perceptions by highlighting the need for subjective measures beyond objective ones.

This approach suggests multidimensional measurement of welfare, based on both statistical and subjective data. The three recommended areas of measures include:

- Economic progress (how to correct GDP).
- Quality of life as a multi-dimensional issue:
    1. Material living standards (income, consumption and wealth);
    2. Health;
    3. Education;
    4. Personal activities including work;
    5. Political voice and governance;
    6. Social connections and relationships;
    7. Environment (present and future conditions);
    8. Insecurity (economic as well as a physical).
- Sustainability.

Multi-dimensional measures may contain a lot of information, but may not be easy to understand or communicate. Thus it remains an open question whether it is possible to integrate the information of the three different dimensions so that it can be easier communicated?

The Wellbeing and Progress Index

The concept of this index concentrates on the longitudinal domain of wellbeing and on the human intent and interest to increase it over time. The main idea of the Wellbeing & Progress Index (WIP) is to propose an equilibrate idea of wellbeing by linking objective and subjective elements (D'Acci, 2011).

The WIP is based on five domains, based on statistical data and subjective perceptions measured on a 0 to 1 scale:

- Health wellbeing (measured by life expectancy at birth).
- Economic wellbeing (measured by GDP per capita, the Gini-index for measuring inequalities and the unemployment rate).
- Happiness (measured by subjective wellbeing).
- Human progress (a combined measure of freedom, women's equality and intentional homicides).
- Cultural progress (measured with the same educational index as in the HDI and the number of researchers (per million people).

A major deficiency of the WPI – similarly to many other indices overviewed earlier – is that environmental sustainability is not included in the index.

The Data Quadrates and the Celestial Footprint

This concept (developed by Kocsis, 2012) adds to the debate on developing alternative measures on sustainability and subjective wellbeing. Main problem is with current concepts that they either trying to squeeze many layers of welfare into one-dimension indicators (and thus losing information) or using multi-indicator measures that are difficult to communicate.

The System of Data Quadrates helps to imagine and analyze complex relations of four different variables in a two dimensional space.

The concept of celestial footprint refers to the idea that humans need far more than just material resources to reach a state of wellbeing and enjoy a good quality of life. 'Celestial' refers to features of human existence complementary to material needs in association with the ecological footprint. Celestial footprint cannot be measured directly but can be estimated as the ratio of subjective wellbeing and calculated ecological footprint.

Variables measured in the core model may vary according to the purpose of the analysis. They may include:

- a monetary measure (gross domestic product; GDP),
- a hedonic measure (subjective wellbeing),
- a limiting measure (ecological footprint) and
- a demographic measure (human population).

The measurement units – depending on the variables included in the model – can be both objective and subjective data.

The System of Data Quadrates is a tool for simultaneous analysis of three or four variables. But causal relationships or potential correlations are not pointed out, these have to be analyzed separately.

Discussion

A review of the eight different subjective approaches for measuring welfare has been provided so far. The following table summarizes these approaches.

	Indicator/approach	Type of data	One or multi-dimensional?	Limitations, further research needs
Individual-based	Subjective welfare (direct survey)	subjective perceptions	one- or multi-dimensional	no information on the sustainability of welfare, positively biased subjective perceptions
	Gross National Happiness	subjective and objective data	one- or multi-dimensional	higher ratings regarding different sub-indicators (beyond sufficiency) does not increase GNH
	The Quality of Life Index	subjective and objective data	one-dimensional	no information on the sustainability of welfare
	Australian Unity Wellbeing Index (Personal Wellbeing Index and National Wellbeing Index)	subjective perceptions	multidimensional	sustainability is not included (just a general "state of the environment' perception)
Collective	The Happy Planet Index	partly objective statistical data, partly subjective perceptions	one-dimensional	economic development, pollution, political freedom, human and civil rights are not included in the concept, further research is needed on how to integrate the missing aspects into the model without losing simplicity
	Welfare measurement based on the Stiglitz Report	objective and subjective data	multidimensional	multi-dimensional measures may contain a lot of information, but may not be easy to understand or communicate
	The Wellbeing and Progress Index	objective and subjective data	multidimensional	no information on the sustainability of welfare
	The Data Quadrates and the Celestial Footprint	depending (can be objective and subjective)	multidimensional	it is a tool for simultaneous analysis of three or four variables, but causal relationships or potential correlations among variables are not pointed out, these have to be analyzed separately

Further research needs include a more detailed and structured analysis on the different indicators sets regarding their relationship to i) sustainability, ii) objective indicators (such as income etc.) and iii) consumption.

A further limitation of the current review and thus is a direction for the further development of this work that – even if current analysis tried to include the most important SWB indicators – a keyword based systematic review of literature can add further items to the analysis of SWB measurements.

Conclusions

On the whole, subjective wellbeing indicators can contribute significantly to the measurement of wellbeing by adding information that cannot be measured by objective indicators.

Subjective wellbeing indicators are directly or indirectly based on direct surveys on personal judgments. Some of these indicators or measurement concepts can be quantified on an individual basis as well (even though usually national averages are calculated) while some others can only be measured on a collective level.

Some of the indicators are solely rely on subjective data while others combine subjective perceptions with objective data. On one hand, one-dimensional indicators are easier to communicate; on the other hand, multidimensional ones can deliver more detailed information.

Although subjective indicators contribute significantly to measure welfare, they have several deficiencies. A frequent shortcoming of many of these indicators is that they disregard the sustainability of welfare.

References

1. Abdallah, S., Michaelson, J., Shah S., Stoll, L., Marks, N. (2012): The Happy Planet Index: 2012 report. A global index of sustainable well-being. New Economic Foundation, London. ISBN 978 1 908506 17 7
2. Bates, W. (2009). Gross National Happiness. Asian-Pacific Economic Literature, 23(2), p. 1-16.
3. Cantril, H. (1965). The pattern of human concerns. New Brunswick, NJ: Rutgers University Press.
4. Cummins R., Eckersley R., Pallant J., van Vugt J., Misajon R. (2003): Developing a National Index of Subjective Wellbeing: The Australian Unity Wellbeing Index. Social Indicators Research, 64: p.159–190, 2003.
5. Cummins, R. A. (1997): Comprehensive quality of life scale – adult. Manual: fifth edition (School of Psychology, Deakin University, Melbourne).
6. D’Acci, I. (2011): Measuring Well-Being and Progress. Social Indicators Research, 2011, 104, p.47–65.
7. Di Tella, R., MacCulloch R. (2008): Gross National Happiness as an Answer to the Easterlin Paradox? Journal Of Development Economics. April 2008, 86(1), p. 22-42.
8. Diener E, Ryan K. Subjective well-being: a general overview. South African Journal Of Psychology [serial online]. December 2009;39(4):391-406.

9. Diener, E., & Tay, L. (2014). Review of the day reconstruction method (DRM). Social Indicators Research, 116(1), 255-267.

10. Diener, E., Pavot, W. (1993): The affective and cognitive context of self-reported measures of subjective well-being. Social Indicators Research, 28(1), p. 1-20.

11. Dolan, P., Peasgood, T., & White, M. (2008). Do we really know what makes us happy? A review of the economic literature on the factors associated with subjective well-being. Journal of economic psychology, 29(1), 94-122.

12. Ericson, T., Kjønstad, B. G., & Barstad, A. (2014). Mindfulness and sustainability. Ecological Economics, 104, 73-79.

13. Fink, A. (1998): Conducting research literature reviews. From paper to the internet. Sage Publications, London.

14. Gallup World Poll Questions (2008). http://media.gallup.com/dataviz/www/WP_Questions_WHITE.pdf. *Accessed at 5th April 2013*.

15. Goossens Y, et al. (2007). Alternative progress indicators to Gross Domestic Product (GDP) as a means towards sustainable development. IP/A/ENVI/ST/2007-10. Study provided for the European Parliament's Committee on the Environment, Public Health and Food Safety.

16. King, M. F., Renó, V. F., & Novo, E. M. (2014). The concept, dimensions and methods of assessment of human well-being within a socioecological context: a literature review. Social Indicators Research, 116(3), 681-698.

17. Klewitz, J., Hansen, E. G. (2014): Sustainability-oriented innovation of SMEs: a systematic review. Journal of Cleaner Production, 65, p.57-75.

18. Kocsis, T. (2012): Looking through the dataquadrate: characterizing the human–environment relationship through economic, hedonic, ecological and demographic measures. Journal Of Cleaner Production, 35, p.1-15.

19. Marks, N., Simms, A., Thompson, S. and Abdallah, S. (2006). The Happy Planet Index: An index of human well-being and environmental impact. The New Economics Foundation & Friends of the Earth.

20. McGillivray J., Lau A., Cummins R., Davey G (2009): The Utility of the Personal Wellbeing Index Intellectual Disability Scale in an Australian Sample. Journal Of Applied Research In Intellectual Disabilities. May 2009; 22(3), p. 276-286.

21. Nistor, A. (2011). Developments on the Happiness Issue: a Review of the Research on Subjective Well-being and Flow. Scientific Journal Of Humanistic Studies, 3(4), 58-66.

22. Pacek, A. C., & Radcliff, B. (2008). Welfare policy and subjective well-being across nations: An individual-level assessment. Social Indicators Research, 89(1), 179-191.

23. Schneider, M. (1976). The "Quality of Life" and Social Indicators Research. Public Administration Review, 36(3), 297.

24. Selezneva, E. (2011). Surveying transitional experience and subjective well-being: Income, work, family. Economic Systems, 35(2), 139-157.

25. Stiglitz, J.,E., Sen, A., Fitoussi, J.P., (2009): Report by the Commission on the Measurement of Economic Performance and Social Progress. Pp. 292. www.stiglitz-sen-fitoussi.fr. *Accessed at 10th October 2011.*

26. Strumpel, B. (ed.) (1974)): Subjective Elements of Well-Being; The OECD Social Indicator Development Programme. Papers Presented at a Seminar of the Organisation for Economic Co-operation and Development. OECD Publications Center, Washington, D.C., pp.201.

27. The Economist (2004): The Economist Intelligence Unit's quality of life index, Economist Online, December 2004. http://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf. *Accessed at 2nd April 2013.*

28. Thinley, J. (2005). Keynote 'What does Gross National Happiness Mean?', by the Minister of Home and Cultural Affairs, Bhutan. Second International Conference on Gross National Happiness Rethinking Development. Local Pathways to Global Wellbeing. St. Francis Xavier University, Antigonish, Nova Scotia, Canada. 2005, June 20-24. http://www.gpiatlantic.org/conference/proceedings/thinley.htm. *Accessed at 5th April 2013*.

29. Thompson, S., Abdallah, S., Marks, N., Simms, A., Johnson, V. (2007): The European Happy Planet Index. An index of carbon efficiency and well-being in the EU. The New Economics Foundation & Friends of the Earth.

30. Tomyn A, Norrish J, Cummins R. (2013): The Subjective Wellbeing of Indigenous Australian Adolescents: Validating the Personal Wellbeing Index-School Children. Social Indicators Research. February 2013, 110(3), p.1013-1031.

31. Tranfield, D., Denyer, D., & Smart, P. (2003): Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management, 14(3), p. 207-222.

32. UNDP (2004). United Nations Development Programme. Human Development Report 2004. Technical Note 1 – Calculating the human development indices. http://hdr.undp.org/docs/statistics/indices/technote_1.pdf. *Accessed at 19th April 2013.*

33. Ura, K., Alkire, S., Zangmo, T., Wangdi, K. (2012): A Short Guide to Gross National Happiness Index. pp.104. The Centre for Bhutan Studies, Thimpu. ISBN·978-99936-14-66-1.

34. Veenhoven, R. (2011): World Database of Happiness. Continuous register of scientific research on subjective enjoyment of life. Erasmus University Rotterdam, Netherlands. http://worlddatabaseofhappiness.eur.nl. *Accessed at 4th April 2013*.

35. World Value Survey questionnaire (2011). http://www.worldvaluessurvey.org/wvs/articles/folder_published/article_base_136/files/WVS_2010-2012_REVISED_OCT_2011.pdf. *Accessed at 5th April 2013*.

Transition as a new participatory approach for achieving the sustainability of the university system

Francesca Cappellaro[a,b], Alessandra Bonoli[a]
[a] *DICAM, Department of Civil, Chemical, Environmental, and Materials Engineering, University of Bologna, Italy*
[b]*ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Via Martiri di Monte Sole 4, 40129 Bologna, Italy*

Abstract – Sustainability transitions (ST) have been recognized as promising frameworks for innovation in structures, cultures and practices towards sustainability. Applied in the university domain, ST could stimulate a successful transformation of higher education institution into place of sustainability. In order to demonstrate the potential of ST approach, this paper describes the adoption of one of Transitions instruments in the university domain. Especially the Transition Management process for the entire system of university has been investigated. In the framework of ST, the importance of implementing transition experiments have emerged. Accordingly, the paper presents a transition experiments of the University of Bologna, where both the educational and the organizational role is investigated.. The experiment has been conducted at the School of Engineering and Architecture in Bologna and Transition Management provides a valid opportunity both for successful initiation and long-term performance of university sustainability programs. As a result, a living laboratory of sustainability has been created. The living-lab not only promotes the implementation of sustainability best practices within the campus, but also enhances the engagement of staff and students in the creation of the sustainability process. Therefore Transition Management has been revealed a valid instrument to emphasize the essential role that the university plays in the improvement of sustainability culture. In conclusion, the paper encourages the adoption of ST within the university system as an engine of innovation for research, design and showcasing for sustainability.

1. Introduction

Education is one of most important drivers in order to achieve sustainable production and consumption patterns. Because universities are a model for a formal and organized education, they can define and also become models of sustainability. Actually, universities have the possibility to teach, to operate and to contribute to the global knowledge of sustainability (Rotmans, 2012). As Higher Educational Institutions (HEI), universities have the special responsibility to provide the leadership on education for sustainable development (Lozano, 2013). The university can certainly have the multiple role of being a promoter of sustainable activities, creating a place where virtuous operations can be realized. In addition, through specific teaching and learning methods, laboratories and internships the university can provide future generations with the knowledge and awareness to create a new model of life. In 2014 the United Nations Decade of Education for Sustainable Development, DESD (2005-2014) is ended. DESD has identified several elements which characterized the education for sustainability, such as: interdisciplinary, values-driven, multi-method, participatory decision-making, applicability, locally relevant, critical thinking and problem solving. Really, since 2010 the Conference of European Roundtable of Sustainable Consumption and Production (ERSCP) and the Environmental Management for Sustainable Universities (EMSU) have emerged that “formal research and interactive methods are helpful, but not sufficient for achieving changed behavior among users” (Quist and Tukker, 2013). In spite of the variety of agreements, declarations and charters among regional and international higher education associations and intergovernmental organisations have been developed (Grindsted, 2011, Lozano, 2011), several resistances to engage with sustainability still emerges (Lozano, 2013). Consequently, in order to overcome resistance and to engage university with sustainability, a new perspective is needed. Actually, university is a complex system, characterized by multi-actor and multi-process with different organisational cultures, traditions and concerns (Sharp, 2002). Therefore becoming sustainable university requires a systemic transformation which means the adoption of a whole-systems approach (Sharp,2002, Koester, 2006). This paper presents the adoption in the university domain of an emerging approach in the field of sustainable system innovation: Sustainability Transitions (ST) (Markard, Raven and Truffer, 2012).Sustainability Transitions have been recognized as promising frameworks for innovation in structures, cultures and practices towards sustainability [ref.]. In order to demonstrate the potential of sustainability transitions approach in establishing sustainability in the university domain, the paper analyses university sustainability issues through the lens of transition. According to Lozano et al. (2013), in order to ensure that sustainability involves the entire university system, several inter-linked elements are crucial: education; research; campus operations; on-campus Experiences; community outreach and collaboration; assessment and reporting. Correspondingly, the paper explains how transition perspective helps to inter-connect the different elements of the HEI system and to enhance a participative process. The final aim is to prove that applying transition in the university domain could stimulate a successful transformation of higher education institution into place of sustainability.

2. Method: Transition Theories and Experiments for systemic transformation

According to Rip and Kemp (1998) and Geels (2002), transitions can be defined as a “socio-technical” transformation in the fulfillment of social needs. Considering the recent systemic problems as systemic lock-ins, the market failure and the growing pressures on our environment, there is the growing urgency of a systemic transformation towards a Sustainable Development (SDND, 2013). In this context, Sustainability Transitions (ST) is an emerging research field provides a support to move towards more sustainable systems of production and consumption (Markard, Raven and Truffer, 2012). Thus, ST are directed to redesigning entire systems of practice and provisions. ST research aims at developing a co-evolutionary approaches that highlight the multi-dimensional inter-connection of actors and socio-technical regimes (Rotmans, 2011). In the framework of ST research, one of instruments implemented for steering transitions towards socially needed directions, is Transition Management (TM) (Kemp et al., 1998; Kemp and Loorbach, 2006, Loorbach and Rotmans, 2010). According with Loorbach and Rotmans, (2009), the Transition Management approach proposes a cyclic process with the 4 phases implemented at different levels, see Figure 1. Actually, TM is broadly applied to stimulate sustainability transitions on the scale of regions, cities and community as well as to initiate transformations in socio-technological systems (Rotmans and Loorbach, 2008).

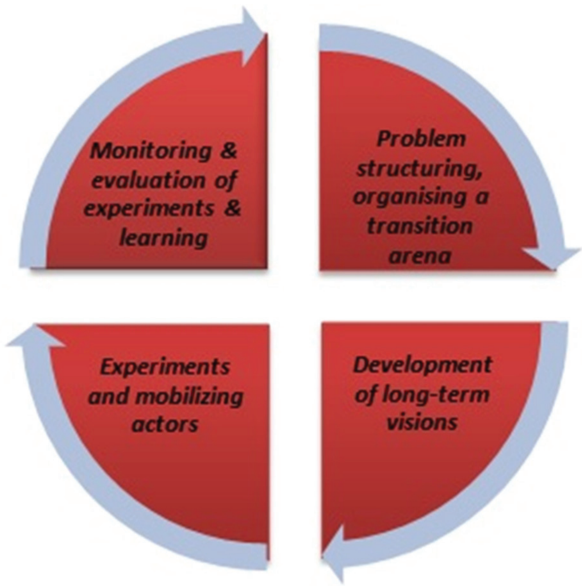


Figure 1 – Transition Management Cycle (Rotmans and Loorbach, 2008)

As Table 1 shows, TM presents different phases acting a different levels: strategic, tactical, operational and reflexive. Mainly, TM steps as Transition Team and Transition Arena are effective instruments to shape a participatory process. On one hand the Transition Team is the core team that manages and facilitates the TM process in a multifunctional and transdisciplinary way (Lang et al., 2012, Yarime et al., 2012). On the other hand, the Transition Arena is one of the main result of TM process and it provides the framework where to put into practice transition experiments. Finally, a reflexive phase is required in order to evaluate all the process, to identify new problems and challenges and to define future trajectories and actions. All the things considered, the TM processes can be adopted as a valid support for implementing transition process towards sustainability.

Level	Phase	Process step	Actions
Strategic	Problem structuring, Organizing a transition arena	Transition Team Investigating the context Community engagement	visioning, strategic discussions, long-term goal formulation
Tactical	Framing the transition challenge Development of long-term visions	negotiating, networking, coalition building	agenda-building, backcasting
Operational	Experiments and mobilizing actors	processes of experimenting, implementation	Operational activities Experiments Projects development
Reflexive	Monitoring and evaluation	Analysis and interpretation of results imagine and understand	Evaluating experiments Learning

		alternative trajectories for future action	

Table 1 – Description of the Transition Management Process

Because their potential for system innovation change, several ST research fields underline the importance of transition experiments, also called niche experiments. The concept of niche is wide-spread. In the transition perspective, niches are small-scale protected space that could be a beginning of radical innovation (Kemp et al., 1998, Raven et al., 2010). Especially, niches have specific application domains such as building, energy supply, transport, food production. Consequently, the implementation of transition experiments in a new application domain can constitute a crucial issue in order to support the emerging need to make sustainability transitions happen. In view of that, this paper has considered TM as a valid method for the definition of a concept and a roadmap of sustainable initiatives in the university domain. In order to demonstrate the effectiveness of ST in the integration of HEI elements, the role of transition experiment is investigated.

3. Experimenting Transition Management in the university domain

According with Sustainability Transitions Research Network (STRN, 2010), emerging future lines will focus on deepening the empirical basis for Sustainability Transitions research and also expanding the application domains of transitions into new problem such as education, health care, welfare state, etc. This paper shows the implementation of a ST instrument in the application domain of university. Especially with the aim to adopt an holistic approach, the Transition Management has been chosen as instrument for guiding sustainability process in the university domain. In the following, a description of the adoption of TM phases within the university domain are provided with a special focus on a TM experience implemented at the University of Bologna, Italy.

3.1 University system analysis, problem structuring

According with the sustainability issues, risks and associated challenges presented by the UNEP Greening University Toolkit (2013), HEI sustainability actions and initiatives are characterized by a structural separation of academic staff and campus management. In effect, campus structural issues is historically viewed as a distraction from the core mission of the university. Additionally, there are individual high quality initiatives, but fragmented and uncoordinated. As result, a lack of engagement of the whole university community, a lack of communication and real commitment, a lack of funding are emerging. All things considered, sustainability tends to remain a marginal part of university life. In order to structure the Strengths, Weaknesses, Opportunities and Threats within university system, a SWOT-analysis has been used. The SWOT analysis provides a support for prioritizing actions and to identify which problems can be addressed. In Figure 1, Higher Education Institutions sustainability actions and initiatives have been evaluated by means of SWOT analysis.

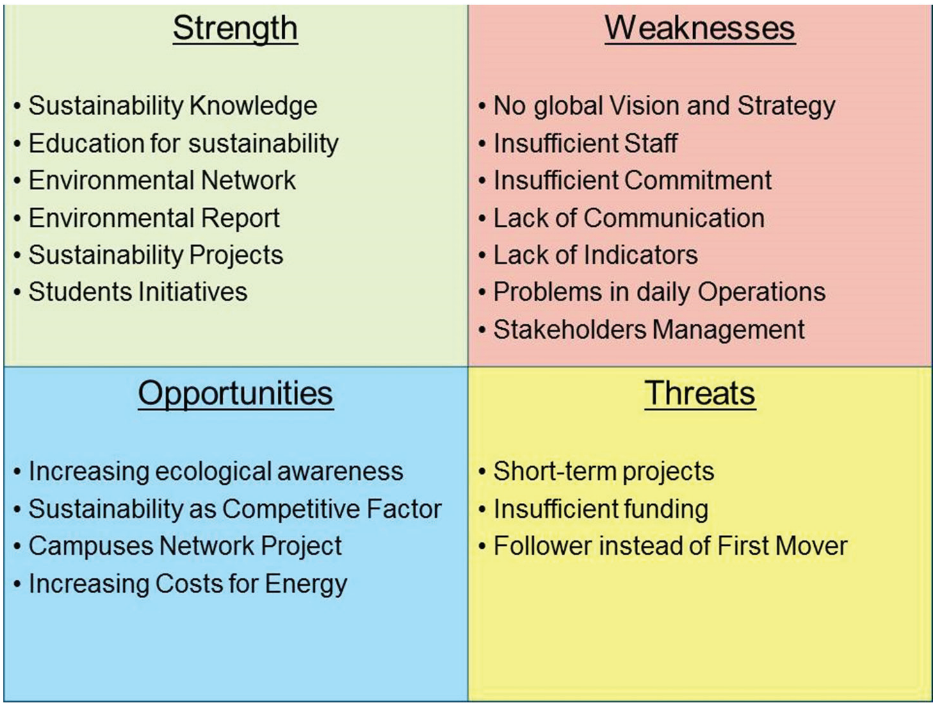


Figure 2 - SWOT analysis of university sustainability issues

3.2 University challenges and vision

The SWOT analysis has emerged that in spite of the huge number of remarkable initiatives on sustainability at university level, several lacks and weaknesses still inhibit a real transformation of university in place of sustainability. There is the necessity of re-orienting the university trajectories for a long term perspective on sustainability. According with Sharp (2002), a crucial challenge for university system can be to “achieve mission alignment between teaching, research and campus operations, harnessing the vast collective learning process that is currently underway within its walls, to benefit its own systems”. Consequently, the final vision is the transformation of the whole university system into living laboratory of sustainability. Living laboratory means to implement transitions processes in order to engage staff, students and the university stakeholders with the establishment and the co-creation of sustainability initiatives (Cappellaro et al., 2014a). In the context of university, the living-lab allows a participatory process finalized at involving the university wide-community in making a direct experience of the theory and the practice of sustainability. According to UNEP (2013), there are several examples of HEI living-lab initiatives, such as: connecting research projects affecting the campus operations, providing new resources for learning and teaching and also using real sustainability problems as a context for students to learn critical thinking and problem-solving skills. In the context of Sustainability Transitions, the living laboratory can be seen as a transition niche, also called in the TM process transition experiments.

3.3 Establishing and executing transition experiments

Due to the systemic approach, transition experiment can stimulate the implementation of living-labs of sustainability in an integrated way. In order to build coalitions, transition experiment can activate a participative processes among actors that recognize the benefit of joining forces in performing innovative experiments. A practical example of how transition experiments can work, it is offered by the experience of Terracini Campus (Cappellaro et al., 2014b). Terracini is the place of the School of Engineering and Architecture located in via Terracini, Bologna. In Table 2, the activities of the adoption of transition approach in the Terracini Campus is described.

Level	Key activities	Key Output
Strategic	- Process design - Reframing challenge - System analysis - Actor identification	Transition team (TT)
Tactical	- Transition Arena formation - Participatory context assessment - Participatory vision process - Selection of key priorities	Transition Lab for Students with the involvement of TT members.
Operational	- Translating the perspective into specific actions - Agenda formulation - Broadening the network - Influencing regular policy - Coalition forming - Implement pilots	Environmental Sustainability Plan Measures as Transition experiments Transition Network
Reflexive	- Learning - Evaluation - Reflection on vision and strategy - Adaptation of strategy	Evaluation of key initiatives and sustainability indicators. New issues and proposal for the Sustainability Plan.

Table 2 - Transition Management applied at Terracini Campus

4. Discussion

In order to prove the effectiveness of the transition approach in the achievement of systemic transformation of university system, the Transition Management process developed within Terracini has been analyzed. As shown Table 2, several activities and outputs are crucial for the implementation of a systemic transition. Firstly, the creation of the Transition Team, a multifunctional and transdisciplinary team with the participation of different members of the university community: faculty, staff, administrators, students and transition management experts. The team was established through the support of a training course dedicated on Sustainability Transitions. During the course the participants was involved in the problems identification and in the sharing of a common vision and the approach for sustainable campus. Especially, several sustainability operational issues affecting the Terracini Campus has been identified. These aspects are mostly related to natural resources and water management, energy efficiency and saving, waste reduction and recycling. Since most of these issues are part of the measures included in the Environmental Sustainability Plan of University of Bologna, the engagement of the administrative staff together with students, researchers and academia has been became crucial for the successful accomplishment of these measures. The training course has posed the basis of forming the Transition Team and of defining the Transition Arena which is the context for enhancing the involvement and the empowerment of the whole university community in the sustainability process. To achieve that, a decisive activity has been the organization of an educational course, called Transition-Lab. The Transition-Lab has been devoted to engineering students who have been directly engaged in the design of Environmental Sustainability Plan measures of the Terracini Campus. Adopting an experiential learning approach, the students have worked on “real world” problems with the support of the TT members as supervisors. In this manner, Transition-Lab has provided a context for students to learn critical thinking and problem-solving skills. Besides, the emerged solutions are strictly connected to several university research lines such as green technologies, innovative technics for water supply, water and groundwater saving, wastewater recovery, raw materials and solid waste treatment valorization and recycling. Finally, the laboratory has resulted in practical measures and actions developed for the Terracini Campus such as: experimental green roofs system, photovoltaic plant, flow controllers and timers for water consumption reduction, introduction of water drinking fountain for the reduction of plastic waste produced by bottled water, creation of Informatics Electric and Electronic Equipment Waste (IWEEE) Recovery Centre, design of some areas and spaces constructed with non-conventional building materials and for rainwater capture and reuse. On one hand, these measures have contributed to enrich the measures of Environmental Sustainability Plan. On the other hand, transition experiments has enhanced the awareness of the university community in the sustainability process. Definitely, TM has promoted the development of participatory process not only within the campus of Terracini, but also outside the campus and the whole University of Bologna. In fact, the campus has been transforming in a platform for sustainability experimentation through collaboration and networking among the university stakeholders such as the external suppliers of goods and services, the local community, public and private sector funding bodies, students’ families, etc. Other favorable initiatives that has contributed to the network creation have been collaborations with other universities. Recently, a first exchange of transition experiences has been realized in the context of the European Programme Climate-KIC, within the Project Sustainable Campuses Launching Customers (SC/LC). In addition, Unibo has also began the process of taking part in the International Sustainable Campus Network (ISCN). Similarly in Italy Unibo has been also promoted the creation of a National Network of Sustainable Universities.

5. Conclusions

Due to the urgency to adopt a systemic approach for achieving sustainability in a wider sense, this paper has presented the effectiveness of the Sustainability Transitions approach. Especially, the Transition Management instrument has been investigated and then applied in the university domain. The adoption of TM has contributed to identify an holistic approach for the transformation of the entire university system. Mainly, the TM has promoted the creation of the Transition Team and the Transition Arena which have been revealed helpful to re-connect staff, student and faculty. Moreover, through the execution of transition experiments, the living laboratory concept has been introduced as integral part of university sustainability plan. Consequently, learning and research outcomes has directly affected the campus operations and simultaneously the living laboratory experiments has provided new resources for learning and teaching into the future. As a result, transition experiments have facilitated the combination of individual buildings measures and campus-wide planning. In the end, the transition process has resulted in the creation of a Transition Network, a platform where to exchange experiences and to contaminate each other. The main consequence is the broadening and the scaling up of transition experiments through the interaction with other experiments. Correspondingly, similar transition experiments shall be initiated in other contexts and favorable conditions for scaling up are generated. In a nutshell, the TM has been useful for integrating in a systemic way the HEI elements such as campus operations, education, research, community outreach, on-campus experiences, assessment and reporting. The main conclusion of this paper is the demonstration that Sustainability Transitions can support the implementation of a new paradigm for developing sustainability as integral part of the university system.

6. Acknowledgements

The authors thank the colleagues of the DICAM, AUTC and NuTeR of University of Bologna for their contribute in the successful of Terracini Transition Project.

7. References

Cappellaro, F., Bonoli, A., 2014a, 'University in Transition. How to transform campus into living laboratory of sustainability'. Proceedings of 5th International Conference on Sustainability Transitions, Utrecht, 27-29 August.

Cappellaro, F. Bonoli, A., 2014b, 'Transition thinking supporting system innovation towards sustainable university: experiences from the European Programme Climate-KIC'. Environmental Engineering and Management Journal. (to be published)

Geels, F.W. 2002. 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study', Research Policy, Vol. 31 (8/9), pp. 1257-1274.

Grindsted, T.S., 2011, 'Sustainable universities – from declarations on sustainability in higher education to national law'. Environmental Economics, 2(2): p. 29-36.

Kemp, R., Schot, J.W., Hoogma, R., 1998, 'Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management', Technology Analysis & Strategic Management, Vol. 10, pp. 175-196.

Kemp, R., Loorbach, D., 2006 'Transition management: a reflexive governance approach', Voß, J.P., Bauknecht, D., Kemp, R. (Eds.), Reflexive Governance for Sustainable Development, Cheltenham / Northampton: Edward Elgar, pp. 57-81.

Koester, R.J. Eflin, J., and Vann, J., 2006, 'Greening of the campus: a whole-systems approach'. Journal of Cleaner Production, 14: p. 769-779.

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P,Swilling M, Thomas C, 2012, 'Transdisciplinary research in sustainability science—practice, principles and challenges'. Sustain Sci 7(Suppl). doi:10.1007/s11625-011-0149-x

Loorbach, D. and Rotmans, J., 2010. The practice of transition management: examples and lessons from four distinct cases. Futures, Vol. 42, pp.237-246.

Lozano, R., 2011, 'The state of sustainability reporting in universities', International Journal of Sustainability in Higher Education, Vol. 12 Iss: 1, pp.67 – 78.

Lozano, R., Lukman, R., Lozano, F.J., Huisingh, D., Lambrechts, W., 2013, Declarations for sustainability in higher education: becoming better leaders, through addressing the university system. Journal of Cleaner Production, 48 (2013) 10-19.

Markard, J., Raven, R., Truffer, B., 2012, 'Sustainability transitions: an emerging field of research and its prospects', Research Policy, 41(6), 955-967.

Quist, J., Tukker, A., 2013, 'Knowledge collaboration and learning for sustainable innovation and consumption: introduction to the ERSCP portion of this special volume'. J. Clean. Prod., 48 (2013), 167–175.

Raven, R.P.J.M., van den Bosch, S., Weterings, R., 2010, 'Transitions and strategic niche management. Towards a competence kit for practitioners', International Journal of Technology Management, special issue on Social Innovation, 51(1), 57-73

Rip, A., Kemp, R., 1998, 'Technological Change'. In: Rayner, S., Malone, E.L. (Eds.),Human Choice and Climate Change, Battelle Press, Columbus Ohio.

Rotmans, J. Kemp, R., Van Asselt, M., 2011, 'More evolution than revolution: Transition management in public policy'. Foresight 03 (01): 17.

Rotmans, J. and Loorbach, D., 2008, 'Transition management: reflexive governance of societal complexity through searching, learning and experimenting'. In: V.d. Bergh, J.C. J.M. and Bruinsma, F.R. (eds.), Managing the Transition to Renewable Energy, Edward Elgar, Chapter 2, 15-46, 2008.

Rotmans, J., Loorbach, D., 2009, 'Complexity and Transition Management', Journal of Industrial Ecology 13(2), 184–196.

SDSN, Sustainable Development Solutions Network, 2013, An Action Agenda for Sustainable Development report for the UN Secretary-General, 6 June 2013.

Sharp, L., 2002, 'Green campuses: the road from little victories to systemic transformation'. International Journal of Sustainability in Higher Education. 3(2): p. 128-145.

STRN, Sustainability Transitions Research Network, A mission statement and research agenda for the Sustainability Transitions Research Network, 20 August 2010.

ULSF, University Leaders for a Sustainable Future, 1990, The Talloires Declaration. Washington DC.

UNEP, United Nations Environment Programme, 2013, Greening Universities Toolkit, On line at: http://www.unep.org/training/docs/Greening_University_Toolkit.pdf

Yarime, M., Trencher, G, Mino, T., Scholz, R.W., Olsson, L., Ness, B., Frantzeskaki, N., And Rotmans, J., 2012, 'Establishing sustainability science in higher education academic development, institutionalization, and collaborations with stakeholders', Sustainability Science, Vol.7, Issue 1, pp. 101-113, DOI 10.1007/s11625-012-0157

Quality Management and sustainability initiatives: A literature review

Vanajah Siva[a], Ida Gremyr[a], Bjarne Bergquist[b], Rickard Garvare[b], Raine Isaksson[b], Thomas Zobel[b]

[a] *Division of Quality Sciences, Chalmers University of Technology, SE-41296 Sweden*
[b]*Department of Business Administration, Technology and Social Sciences, Luleå University of Technology, SE-83873 Sweden*

Abstract

Quality management is an area of expertise that has been argued fruitful as a support for integration of sustainability considerations in daily operations. The purpose of this paper is to review and elaborate on synergies and discord between Quality Management and sustainability initiatives in organizations. Additionally, an agenda for future research in further exploiting these synergies is identified. Sustainability initiatives are defined as systematic efforts to work with sustainable development and with sustainability in organizations. The literature search was done in Web of Science and Scopus databases. Relevant articles were identified based on selective review process. A total of 74 articles were included in this review. Six themes of articles have been identified: Integration of management systems in general, Quality Management as support to Environmental Management System implementation and to managing sustainability, How Environmental Management or other sustainable development initiatives affect quality performance, Integrating sustainability considerations in quality related practices, Linking of stakeholder management and customer focus, and the rest were categorized as 'Others'. There is a need for more empirical investigations to produce evidence for the synergies between Quality Management and sustainability initiatives. There is also a need for collaborative research between Quality Management and sustainability/environmental management scholars as a direction for future research.

Keywords: Quality management, sustainable development, sustainability, synergies, literature review

1. Introduction

For a long period of time the phenomenon of taking responsibility for environmental protection or to contribute to sustainable development were unknown to for-profit businesses. Some important milestones in changing this view were Rachel Carson's Silent Spring in 1962 and the Rome Club report, Limits to Growth 1972. During the 1980s, environmental regulations in the industrialized world were changing rapidly and a strategy for progressive companies was to comply with these regulations (Berry & Rondinelli, 1998). At this time the laws primarily aimed at controlling pollutants found at the "end of the pipe" (Stuart, 2000). In the late 1980s and early 1990s, the expectation from different stakeholders increased and environmental work in the private industrial sector becomes less driven by compliance and more of internal strategy (Lent & Wells, 1994). A development begins where environmental and sustainability issues receive greater and greater strategic importance to companies (Meisner Rosen, 2001).

One of the most influential forums that strongly contributed to this development were the United Nations' World Commission for Environment and Development (more popularly known as the Brundtland Commission) which in the report "Our common future" outlined the environmental situation in the world and gave us the concept of sustainable development not only limited to environmental concerns but also adding the social and economic dimensions (WCED, 1987). The report, also known as the Brundtland report, was one of several initiatives that brought about the Earth Summit in Rio de Janeiro of 1992, which placed a new global emphasis on the corporate role in environmental production and contribution to sustainable development.

One of the most important outcomes of the Earth Summit was the development by the International Organization for Standardization (ISO) of a number of environmental management standards covering areas such as environmental auditing, environmental labeling, performance evaluations, life-cycle assessment and product standards (Almgren & Brorson, 2012). These standards as well as other corporate sustainability initiatives were strongly influenced by quality management (QM) standards, foremost the ISO 9000, and the Total Quality Management (TQM) movement with the focus on external certification, systematization, small incremental improvements (Deming- cycle or the PDCA-cycle) and management by objectives.

The development and discourse in the QM field has since the creation of environmental management standards had an influence on how businesses approach the concept of sustainable development. As an example, Angell and Klassen (1999) have pointed to the QM toolbox as one being well suited for integration of sustainability considerations; one reason being that QM focuses on meeting and exceeding customer requirements and expectations (Dean and Bowen, 1994). Sustainability considerations can in this sense be seen as a customer requirement in two ways, first, environmental sustainability is becoming an explicit customer need, and second, some QM scholars argue that society is one form of stakeholder or customer per se (Garvare and Johansson, 2010). Further, Luttropp and Lagerstedt (2006) and Maxwell and Van der Vorst (2003) are examples of researchers that advocates that sustainability considerations are more likely to be taken into account in daily operations if they are integrated in existing toolboxes, rather than requiring development of new ones.

QM is in this paper seen as a philosophy consisting of principles, techniques and tools (Dean & Bowen, 1994). Hellsten and Klefsjö (2000) build on this calling the principles values; the values of QM are: customer focus, improve continuously, let everybody be committed, top management commitment, focus on processes and base decisions on fact. The purpose of this paper is to review and elaborate on synergies and discord between QM and sustainability initiatives in organizations. Additionally, an agenda for future research is identified to further exploiting these synergies and overcome the discords. We hope that the results of this review could constitute the starting point for future research aiming to utilize the knowledge in the field of QM for further development of proactive work towards sustainable development. The remainder of this paper is organized as follows. Following this introduction, the design of the review is outlined together with a description of the covered literature. In the third section the results of the review is outlined by presentation of a number of themes identified in the reviewed literature. The most important results are further discussed in a separate section; followed by a final section of conclusions and proposals for future research.

2. Method

The first step of the literature study was to select a method for making the review and to generate a literature classification sheet. All authors of this paper agreed to participating in reading and classifying the read articles. The first author created a classification sheet and distributed it to the reviewers, along with five chosen articles for a calibration review, along with directions to note if the sheet needed further instructions.

After this calibration round, a meeting was held where the review of individual articles, the review process and the classification sheet classes were discussed. At the meeting, the authors had to motivate their classifications. As a result, a few clarifications for the review were made, additional classification classes were introduced and some were elaborated on. One of the classification categories that were included was to note references from the articles that appeared noteworthy. Before the proper literature search was performed, multiple databases were checked but it was found that the Scopus and Web of Science contained the highest number of relevant hits.

The literature search was performed on January 31, 2014. The search path used in Web of Science was [(sustainable development) OR (sustainability)] AND[(quality management) AND NOT (water quality management)] in the subject fields. After performing the literature search in Web of Science, the first author scanned the abstracts. Some articles were clearly beside the scope of this study and were disregarded immediately, such as studies related to air quality management. The remaining articles were selected for the review, and this included 58 hits. The Scopus database was then searched to add articles that were in journals not covered by the Web of Science. The search path used in the Scopus database was [(sustainable development) OR (sustainability) OR (environmental management)] AND [(quality management) AND NOT (water quality management)] in the subject fields. The Scopus search did, however, generate many irrelevant hits. Most relevant SCOPUS hits were found in the following journals, the *TQM Magazine* and the successor *TQM Journal*, *Quality Progress*, *Journal of Environmental Management* and it was therefore decided to limit the Scopus search to these journals. After eliminating duplicates and reading the abstracts, 38 additional hits were added; and thus a total of 96 articles were included. This was considered sufficient for the first review round.

The selected articles were then randomly assigned to the authors of this paper for review, 16 articles per author. If a reviewer was assigned an article s/he had authored, which happened in one case, the review assignment was switched but the article was still included in the review.

After the first round of reviews, 45 articles were considered relevant. The 45 articles found in the first round, in turn contained 52 other interesting references that had not been part of the initial literature search. These references were distributed for a second round of reviews. As the added references were not limited to specific journals covered by the previously used databases, the snowballing review arguably covered a broader range. 31 of the snowballing references were considered relevant and were thus added to the original set.

Finally, the review was summarized, and 2 duplicates were found, which means that the full list of 76 reviews only contained 74 works. The duplicates inadvertently facilitated another reliability check.

When examining the duplicates, it was in one case found that both reviewers were unanimous regarding the classification of the relevance, the theme of the paper, the outcome, that the paper was conceptual, that practices were a level of focus and that a main focus was the economic perspective. In another duplicate measure, the reviewers were unanimous regarding relevance, theme, methodology units of analysis, but disagreed on if the emphasis had a quality management or environmental focus, the main focus of the triple bottom line, and if the paper focused on principles and tools beside the practices. One of the reviewers also classified the methodology as a review along with the questionnaire both reviewers had found as the main data collection method. The quality classification differed slightly too. One reviewer had classified the article as a “3” on a 2-5 scale with 5 being the top quality, and the other had classified it as “4”. The agreement was thus good on easily evaluated properties such as if the article was at least somewhat relevant, if it was conceptual or contained data collection, and general conclusions about the focus, whereas dimensions such as how many items that should be considered a focus differed. Despite these differences, the replicate measures could be considered fair, considering the subjectivity of many of the classified properties.

3. Results

Based on the review results, all the relevant articles were classified under a number of themes. The themes were formulated based on the contents of these articles, and based on the relevance to the purpose of this review. The themes are summarized in the Table 1 below, along with all references categorized under the themes. Following the table, each theme is elaborated.

Table 1. Summary of themes

Theme	Description	References
1. Integration of management systems in general	An integrated management system (IMS) is a solution to reduce redundancies and managing resources efficiently. An integrated management system is one way to identify aspects of QM system which could be supportive of sustainability in general. An integrated system is also identified as a step towards sustainable management systems.	Wilkinson, G & Dale, BG (1998), Aboulnaga, IA (1998), Karapetrovic, S & Willborn, W (1998), Wilkinson, G et al. (1999), Wilkinson G & Dale BG (1999), Seghezzi, HD (2001), von Achsen, A (2001), Matias, JCD & Coelho, DA (2002), Pun KF et al. (2002), Fresner, J & Engelhardt, G (2004), Pojasek, R (2006), Jorgensen, TH et al. (2006), Rocha, M et al. (2007), Zeng, SX et al. (2007), Salomone, R (2008), Karapetrovic, S & Casadesus, M (2009), Bernardo, M et al. (2009), Tari, JJ et al. (2009), Jabbour, CJC (2010), Simon, A et al. (2011), Zeng, SX et al. (2011), To, WM (2011), Matias JCD et al. (2011), Santos, G et al. (2011), Bernardo, M et al. (2012), Rodriguez-Anton, JM et al. (2012), de Oliveira, OJ (2013), Kuei, CH & Lu, MH (2013), Li, C (2013), and Rebelo, M et al. (2014).
2. QM as support to environmental management system (EMS) implementation and to managing sustainability	Quality management principles, practices and tools could be used for supporting the management of sustainability. A few articles propose translating the logic of principles, practices and tools to environmental management and sustainability. Most articles deal with how the QM practices can be used to support the introduction of environmental management. No articles focusing on the use of quality tools for sustainability.	Klassen and McLaughlin (1993), Borri and Boccaletti (1995), Lawrence and France (1998), Corbett and Cutler (2000), Curkovic et al. (2000), Theyel (2000), King and Lenox (2001), Zairi, M (2002), Isaksson and Garvare (2003), Ruzevicius et al. (2004), Giancarlo (2005), Rusinko (2005), Craig and Lemon (2008), Karapetrovic and Casadésus (2009), Molina - Azorin et al. (2009), Yang et al. (2010), Bergenwall et al. (2012), Wiengarten and Pagell (2012), Pereira-Moliner et al. (2012), Kuei and Lu (2013), Zhu et al. (2013).
3. How environmental management (EM) or other sustainable development (SD) initiatives affect quality performance	Only a few studies have turned things around and addressed the influence of environmental management practices on quality performances. It is not obvious that proactive environmental management and investments in pollution prevention technologies	Klassen & Whybank (1999), Narasimhan & Schoenherr (2012), Sebhatu & Enquist (2007)

	will positively influence quality performance. Both negative as well as positive impact has been reported.	
4. Integrating sustainability considerations in quality related practices	It has been argued that sustainability considerations should be integrated in existing practices and toolboxes. Within the QM area there has been one stream suggesting combinations of practices and tools from the QM area and LCA as a way to support sustainability considerations in development work. Another stream has applied tools such as the House of Quality and DoE 'as-is' and shown how it can support sustainability.	Zhou and Schoenung (2003), Zhou and Schoenung (2007), Sakao et al. (2004), Besseris (2012), Zhang et al. (1998), Rothenberg et al. (2001)
5. Linking of stakeholder management and customer focus	The concept of sustainable development may be broadening the rather narrow definition of a customer in QM to encompass more holistic views of stakeholder management.	Walker (2000), Karapetrovic & Jonker (2003), Isaksson (2006), Jörgensen (2007), Klefsjö et al. (2008), Garvare & Johansson (2010), Asif et al. (2011).

Theme 1 - Integration of management systems in general

The result of the reviews show that a total of 30 articles, out of 74, are about or based on the integration of management systems, each one arguing for integration. The management systems which are of concern here are namely the Quality Management Systems (ISO 9001), the Environmental Management Systems (ISO 14001) and the Occupational Health and Safety Management Systems (OHSAS 18001). The reasons for the integration of management systems are plenty, such as reduction of cost in implementing and maintaining standards and efficient usage of resources which reduces wasteful redundancies and create synergy effects (Karapetrovic, 2002). The discussion on integration levels and strategies appears to be an ongoing issue amongst practitioners and researchers (Karapetrovic, 2003, Jorgensen, 2006, Douglas, 2000). Based on a literature review, Bernado et al. (2009) has identified three main points of integration of management systems (MSs), which are strategies, methodologies and degrees.

The research on the integration of management systems can be categorized into a number of areas. They could be described as the ways of integration with examples (How), the need for integration (Why), the degrees of integration (Level), the outcomes or results of integration (Effect), and the reviews of studies on integration (Review). Further analysis on these categories which is of interest are the type of paper published in each category, namely conceptual or empirical, and the emphasis or main point of departure adopted in the articles, namely QM or SD. Table 2 below shows the summarized findings based on the categories.

Table 2: Categories of articles under Theme 1

Categories	Number of articles	Conceptual / Empirical	Emphasis (Main point of departure)
How	13	4 / 9	QM (8)
Why	8	5 / 3	QM (5)

Level	3	1 / 2	Not applicable
Effect	3	0 / 3	SD (2)
Review	2	Not applicable	QM (2)

The publication years of these articles are also a relevant finding in order to demonstrate the trend regarding the topic of integration of management systems in the past. The number of articles published based on the years of publication is shown in the Figure 1 below.

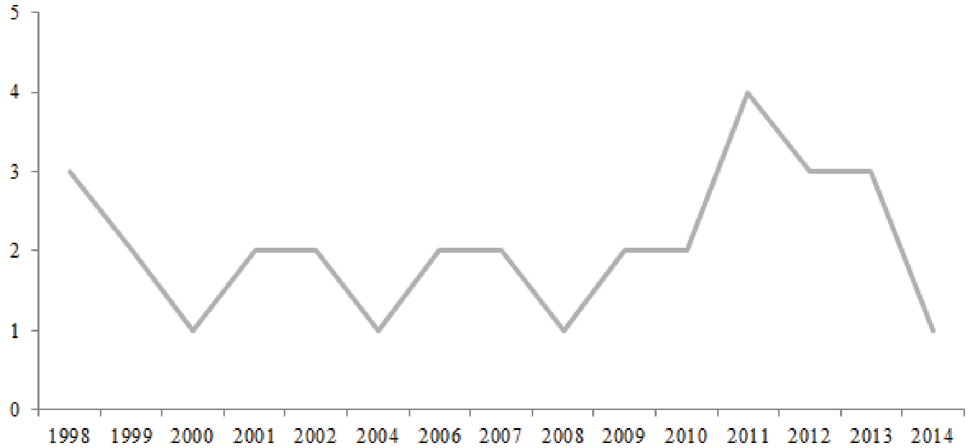


Figure 1: Publication timeline for articles under Theme 1

Theme 2 – QM as support to EMS implementation and to managing sustainability

This theme deals with how QM can be used to support environmental management and managing sustainability. This could be viewed based on the model of principles, techniques and tools described above. A total of 21 articles were categorized in Theme 2. Out of these 11 are on principles and 13 on practices. None of the articles focus on tools. Most of the articles on practices deal with how current QMS can support the introduction of EMS. A few articles deal with the similarities of principles for managing quality and managing sustainability (see Theme 5).

Even if there are 11 articles mentioning principles, there are only a few that are doing that without directly linking it to management systems. Borri and Boccaletti (1995) propose the introduction of Total Quality Environmental Management emphasising the similarities between quality and environmental improvement. Curkovic et al. (2000) carry out extensive work in establishing principles for quality management as a prerequisite for support to Environmentally Responsible Manufacturing. They conclude that the principles from MBNQA form the most solid example for describing QM. Here, the structure of working with QM is taken as the starting point. It could be argued that the difference with a starting point in ISO 9001 is not that different since QM principles are embedded in the standard as the 2000-version with the eight leadership principles essentially representing the same content as MBNQA principles.

Isaksson and Garvare (2003) propose to look at global stakeholder needs as a starting point for measuring sustainability stating that: “For true sustainable development the organization performance needs to be related to global performance”. The two main stakeholders identified are humanity and nature. The proposal is to augment QM with values relating to environmental and ethical considerations. King and Lenox (2001) find that Lean supports environmental performance. Bergenwall et al. (2012) look at how Toyota Production Systems support work with the Triple Bottom Line and conclude that this is mostly beneficial, but that there could also be some negative effects. Kuei and Lu (2013) propose integrating quality management principles into sustainability management. They propose a conceptual model for quality driven sustainability management.

The majority of practices are working with management systems. Several authors find QMS practices beneficial for the introduction of EMS, (Klassen and McLaughlin, 1993), (Borri and Boccaletti, 1995), (Lawrence and France, 1998), (Corbett and Cutler, 2000), (Theyel, 2000), (King and Lenox, 2001), (Molina-Azorin at al., 2009), (Yang et al., 2010), (Pereira-Moliner et al., 2012), (Wiengarten and Pagell, 2012), (Zhu et al. 2013). Quality Management standards predated the environmental Standards with the first ISO 9001 been launched in 1987 and the first ISO 14001 in 1996, which makes it likely to believe that QMS in many companies predates the EMS. Also, worldwide there are some 1.1 million ISO 9001 certified organizations compared to some 0.3 million with an ISO 14001 standard (ISO, 2014). It therefore is logical to find many examples of QMS paving the way for EMS.

Theme 3 - How EM or other SD initiatives affect quality performance

It becomes clear when analyzing the identified literature that focus among the authors is almost entirely on how QM can assist when developing sustainability initiatives, or how these two concepts can be integrated. However, there are a few studies in which scholars have turned things around and addressed the possible influence corporate environmental management practices might have on quality performances.

A case study in a Swedish paint manufacturer demonstrated that an EMS based on ISO 14001 is not only a system for environmental performance, but can also be used as a driving force for sustainable value creation in a change process aimed at quality improvement (Sebhatu & Enquist, 2007). These findings are supported in a recent questionnaire-based study, in which data was collected from more than 400 manufacturing companies in Australia, Europe and Asia (Narasimhan & Schoenherr, 2012). In this study the hypothesis tested was that environmental management practices (EMP) have a positive effect on actual relative competitive quality advantage (quality performance relative to competitors) and that those practices have a positive effect on perceived relative competitive quality advantage. Specifically, the influences of the practices of pollution prevention, recycling of materials and waste reduction was considered. Strong support was found for the positive influence of EMP on actual quality advantage, but in contrast only marginal support was provided for the impact of EMP on perceived quality advantage. QM practices (QMP) had significant positive impact on actual quality when looked at in isolation, but the authors were intrigued by the fact that QMP were not statistically significant in the presence of EMP; hence the impact of QMP on relative competitive quality advantage is weakened in the presence of EMP.

However, a decade before Klassen and Whybank (1999) found contrasting evidence. In their study, they explored whether, and under what conditions, investment in environmental technologies (including EM) is beneficial for environmental as well as manufacturing performance (assessed using four factors: cost, quality, speed, and flexibility). They found that significantly better manufacturing performance was found in those plants where management investment in the environmental technology portfolio was increasingly allocated toward pollution prevention technologies (cleaner alternative technology and management systems). In contrast, performance worsened as the proportion of pollution control technologies (treatment of pollutants at the end of a manufacturing process) increased. Similar results were found for cost, speed, and flexibility performance. Quality performance was negatively related to an investment portfolio increasingly allocated to pollution prevention technologies, although not statistically significant. The authors suggested two explanations for the quality performance results. First, the perceptual measure of quality had unknown reliability. Second, the implications of pollution prevention technologies may take longer to become evident for quality performance than for other measures of manufacturing performance.

Theme 4 - Integrating sustainability considerations in quality related practices

Looking at research to date Quality Function Deployment (QFD) appears to be the practice, most commonly applied as a means of addressing sustainability concerns in development. As one example Sakao et al. (2004) first elaborated on differences between QFDE, Quality Function Deployment for Environment and LCA in terms of differences in output when analyzing a pump. The conclusion from the comparison is that QFDE and LCA support different sustainability concerns and should be used in combination. QFDE is used when analyzing how functions affect environment and LCA, to quantify the environmental performance. The benefits of using QFD and LCA in combination has also been put forth by Zhou and Schoenung (2007), mainly focusing on the possibility to consider multiple constraints on a design when applying a stakeholder perspective in the tool use.

There is another stream of research on quality related tools that elaborates on how the tools 'as-is' can be used to support sustainability considerations in daily operations. As an example the use of QFD on its own, without integration with LCA, has been shown to be useful in assessing environmental impact of various design alternatives (Zhou and Schoenung, 2003). Another example is the use of Design of Experiments (DoE) to assess environmental impact of product or process alternatives, e.g. by applying an environmental indicator as the response variable (Besseris, 2012).

Theme 5 - Linking of stakeholder management and customer focus

Elaborating on the expanding quality concept and QM as a wider operational perspective of organizations Karapetrovic and Jonker (2003) describe the need for integration of function-specific management (sub)systems and a return to the more holistic approach in designing and structuring organizations to address the needs of several different stakeholders. Starting from a construction industry perspective, Walker (2000) argues that taking a wider view of the customer that also encompasses stakeholders and affected parties makes good marketing and business sense. A case study is used to illustrate how perceptions of the client/customer have shifted from satisfying the needs of a narrow 'paying customer' to ensure a balanced view of quality from the outcome perspectives of 'all major stakeholders'.

Jörgensen (2007) presents different levels of MS integration in order to promote sustainable management. She argues that companies with certified management systems should not only strengthen collaboration with stakeholders but also take a life cycle perspective and extend their focus to the entire product chain. From a case study Jörgensen (2007) finds that the integration of MS, as a basis for working towards a more sustainable management system, concerns the creation of a culture of learning, focus on stakeholders, continuous improvements, and synergies between the subject areas. She concludes that the performance of a company in relation to a sustainable management system depends on the internal willingness and capability of making improvements as well as the external forces which affect the process. Moving towards sustainable MS also demands changes in lifestyles, needs, and the organization of society.

Klefsjö et al. (2008) discuss the status of QM in terms of perspectives on customers, stakeholders and other interested parties. The authors argue that whereas top managers have to address all parts of business, there is a need to separate quality issues from other issues and to differentiate QM from business excellence. In this respect, Both Garvare and Isaksson (2001) and Asif et al. (2011) find that while sustainability considerations are addressed to some extent in business excellence models, economic prosperity remains the dominant bottom line perspective.

Garvare and Johansson (2010) present a conceptual model of stakeholder management expanding on the relationship between organizational sustainability and global sustainability. Inspired by Foley (2005) the authors consider stakeholders to be: Actors that provide essential means of support required by an organization and could withdraw their support if their wants or expectations are not met. Interested parties are all actors with any interest in the organizational activities, output, or outcome, but who do not possess the power or instruments to influence the state of the organization or its stakeholders. According to Garvare and Johansson (2010), organizational sustainability will be achieved if the organization manages to endlessly satisfy or exceed the demands of its true stakeholders. Global sustainability on the other hand will only be promoted if organizational sustainability is achieved without compromising the ability of interested parties to meet their needs, both present and future.

4. Discussion and conclusions

It is evident that much of the literature covered in this review focus on existing MS as a foundation for the organizations' contribution to sustainability. This is problematic since research has shown that the effects of MS on major improvements of more innovative nature, rather than small production and process changes, are virtually nonexistent. Könnelä and Unruh (2007) argue that the systems can potentially have positive effects initially but that the systems limit the organizational focus to the development of current production systems in many small steps instead of exploring the major innovations that are more discontinuous in nature. Therefore, they argue that new practices are needed beyond MS for the industry to help solve the complex global environmental problems faced by the world. Furthermore, research shows that the MS virtually always limit its focus to the processes within facility gates and do not include activities upstream or downstream in the supply chain (Schylander & Martinuzzi, 2008; Kautto, 2006). This indicates that the MS is not based on a holistic perspective, which is necessary in order to effectively contribute to sustainable development. It is therefore desirable that future research look beyond the existing standards and management system.

The main idea of integration found in the reviews point to the integration of management systems of quality and environment. The certification of QM systems has been a practice worldwide since the ISO 9000 was established in 1987. This was followed by the environmental management system, ISO 14000, in 1996. Today, there are over a million organizations independently certified with ISO management systems (ISO, 2014). This has created the need for organizations to explore an integrated management system (IMS) where the overlapping or similar procedures, practices and tools of various management systems could be applied more efficiently as one integrated system. A definition of the term 'integration' in this context is adopted from Pojasek (2006) (p. 96); *"a genuinely integrated system is one that combines various management systems using an employee focus, a process view, and a systems approach"*. Since managing sales, costs and investments are in management focus without being part of the IMS, the effect of the IMS on company sustainability could be limited.

It was established repeatedly that an integrated management system is beneficial to practitioners based on the commonalities found in the various standards, namely QMS and EMS. An integrated management system has been argued to support reduction of redundancies in terms of procedures and workflows (Karapetrovic, 2002). However, an integrated management system does not indicate in any way that the application of QM principles, practices or tools are supportive of the sustainability initiatives in organizations. Investigations of specific QM standards contributing to EM outputs, or vice versa, for example, are not evident but rather found to be contradictory (Narasimhan & Schoenherr, 2012, and Klassen and Whybank, 1999). In the search for synergies between QM and sustainability initiatives, the area of management systems integration is, therefore, unclear in the respect of mutual contributions.

The purpose of this paper was to review and elaborate on synergies and discord between QM and sustainability initiatives in organizations. In summary, six themes of articles have been identified: Integration of management systems in general, QM as support to EMS implementation and to managing sustainability, How EM or other SD initiatives affect quality performance , Integrating sustainability considerations in quality related practices, Linking of stakeholder management and customer focus, and the rest categorized as Others. By far the two first themes dealing with management systems have the largest number of underlying articles. In summary, there is contradictory evidence of the possible support of the QMS on the environmental management outputs, and vice versa. In the other themes, much of the research done is at a rather conceptual level pointing to ideas of synergies. Few, however, can support the potential stated by empirical evidence.

5. Future Research

It is evident from the reviews that, in the area of management systems integration, there is a lack of empirical investigations regarding specific QM standards and their contribution in the application of specific EM standards or practices. Future research on integrated management systems should be focused on such empirical investigations, in order to provide sufficient empirical evidence supporting the synergies between QM and EM systems. The evidence of such synergies will better clarify the benefits of such integration, and contribute further towards reducing redundancies.

Investigations of specific QM standards contributing to EM outputs, or vice versa, for example, are not evident but rather found to be contradictory (Narasimhan & Schoenherr, 2012, and Klassen and Whybank, 1999). In the search for synergies between QM and sustainability initiatives, the area of management systems integration is, therefore, unclear in the respect of mutual contributions. Further, a majority of the articles reviewed speak about integration, but focus on the integration of the MS per se, not about supporting managers in integrating critical areas of considerations, such as high quality versus less environmental impact. To add such a systems focus on integration is an area in need of future research. Such research could be designed to address the shortage of in-depth case studies of companies that have integrated their efforts on QM and sustainability. Hence, there is also a need to identify QM practices and tools that can aid sustainability initiatives, and to adapt (not merely apply) current practices and tools to better align with sustainability considerations.

In the literature review performed, a variety of definitions and views on sustainability have been seen. The articles are in almost all cases written by QM scholars and focus on economic sustainability alongside environmental sustainability, however the former is dominating. This might be a result of few researchers from the environmental management area studying QM as an area contributing to sustainability initiatives. This might lead to a situation where potential discords are neglected. As an example, it has been discussed that there are research on QM practices that can be seen as mere applications of standard practices and tools, rather than an adaption to further support sustainability considerations. Consequently, more joint research from researchers from various fields of expertise is advocated as a more nuanced picture of QM as a concept that is not a panacea for sustainability considerations to be integrated in daily operations, but can be one contributing field of expertise.

Acknowledgement

This work has been carried out within the Sustainable Production Initiative and the Production Area of Advance at Chalmers. The support is gratefully acknowledged.

References

Aboulnaga, I. A. (1998). Integrating quality and environmental management as competitive business strategy for 21st century. *Environmental Management and Health* Vol. 9, No. 2, pp. 65-71.

Almgren, R., Brorson, T. 2012. *Miljörevision*, 2nd edition. Breen Business, Stockholm. (In Swedish).

Angell, L.C. and Klassen R.D. 1999. Integrating environmental issues into the mainstream: and agenda for research in operations management. *Journal of Operations Management*, 17, 575-598.

Asif, M., Searcy, C., Garvare, R. and Ahmad, N. (2011), Including sustainability in business excellence models", *Total Quality Management & Business Excellence*, Vol. 22, No. 7, pp. 773-786.

Bergenwall, A. L., Chen, C., & White, R. E. (2012). TPS's process design in American automotive plants and its effects on the triple bottom line and sustainability. *International Journal of Production Economics*, 140(1), 374-384.

Bernardo, M., Casadesus, M., Karapetrovic, S. & Heras, I. (2009). How integrated are environmental, quality and other standardized management systems: An empirical study, *Journal of Cleaner Production*, Vol. 17, No. 8, pp. 742-750.

Bernardo, M., Casadesus, M., Karapetrovic, S. & Heras, I. (2012). Do integration difficulties influence management system integration levels? *Journal of Cleaner Production*, Vol. 21, No. 1, pp. 23-33.

Berry, M., Rondinelli, D., 1998. Proactive corporate environmental management: a new industrial revolution. *Academy of Management Executive* 12(2), 38-50.

Besseris, G.J. 2012. Eco-design in total environmental quality management: Design for environment in milk-products industry, *The TQM Journal*, 24 (1), 47-58.

Borri, F., & Boccaletti, G. (1995). From total quality management to total quality environmental management. *The TQM Magazine*, 7(5), 38-42.

Corbett, L. M., & Cutler, D. J. (2000). Environmental management systems in the New Zealand plastics industry. *International Journal of Operations & Production Management*, 20(2), 204-224

Craig, J. H., & Lemon, M. (2008). Perceptions and reality in quality and environmental management systems: A research survey in China and Poland. *The TQM Journal*, 20(3), 196-208.

Curkovic, S. Steven A. Melnyk, Robert B. Handfield, and Roger Calantone (2000)

De Oliveira Matias, J. C. & Coelho, D. A. (2002), The integration of the standards systems of quality management, environmental management and occupational health and safety management, *International Journal of Production Research*, Vol. 40, No. 15, pp. 3857-3866.

De Oliveira, O. J. (2013), Guidelines for the integration of certifiable management systems in industrial companies, *Journal of Cleaner Production*, Vol. 57, No., pp. 124-133.

Dean, J.W. and Bowen, D.E. 1994. Management Theory and Total Quality: Improving Research and Practice through Theory Development. *Academy of Management Review*, 19(3), 392-418.

Douglas, A. & Glen, D. (2000), Integrated management systems in small and medium enterprises, *Total Quality Management*, Vol. 11, No. 4-6, pp. 686-690.

Foley, K. (2005). Meta-management: A stakeholder/quality management approach to whole-of-enterprise management. Sydney: SAI Global.

Fresner, J. and Engelhardt, G. (2004), Experiences with integrated management systems for two small companies in Austria, *Journal of Cleaner Production*, Vol. 12, No. 6, pp. 623-631.

Garvare, R. and Isaksson, R. (2001). Sustainable Development – Extending the Scope of Business Excellence Models. *Measuring Business Excellence*, Vol. 5, No. 3, pp. 11-15.

Garvare, R. and Johansson, P. (2010). "Management for sustainability – A stakeholder theory", *Total Quality Management*, Vol. 21, No. 7, pp. 737-744.

Giancarlo, B. (2005). Matching “environmental performance” and “quality performance”: A new competitive business strategy through global efficiency improvement. *The TQM Magazine*, 17(6), 497-508.

Hellsten, U., & Klefsjö, B. (2000). TQM as a management system consisting of values, techniques and tools. *The TQM Magazine*, 12(4), 238-244.

Isaksson, R., & Garvare, R. (2003). Measuring sustainable development using process models. *Managerial Auditing Journal*, 18(8), 649-656.

Isaksson, R. (2006). Total Quality “Management for Sustainable Development – process based system models”, *Business Process Management Journal*, Vol. 12, No. 5, pp. 632-645.

ISO 2014. The ISO Survey of Management System Standard Certifications – 2013. Available: http://www.iso.org/iso/iso_survey_executive-summary.pdf. [Accessed on 2014, May 14] .

Jabbour, C. J. C. (2010), In the eye of the storm: exploring the introduction of environmental issues in the production function in Brazilian companies, *International Journal of Production Research*, Vol. 48, No. 21, pp. 6315-6339.

Jørgensen, T. H., Remmen, A. & Mellado, M. D. (2006), Integrated management systems–three different levels of integration, *Journal of Cleaner Production*, Vol. 14, No. 8, pp. 713-722.

Karapetrovic, S. & Casadesús, M. (2009), Implementing environmental with other standardized management systems: scope, sequence, time and integration, *Journal of Cleaner Production*, Vol. 17, No. 5, pp. 533-540.

Karapetrovic, S. & Jonker, J. (2003), Integration of standardized management systems: searching for a recipe and ingredients, *Total Quality Management and Business Excellence*, Vol. 14, No. 4, pp. 451-459.

Karapetrovic, S. & Willborn, W. (1998), Integration of quality and environmental management systems, *The TQM Magazine*, Vol. 10, No. 3, pp. 204-213.

Karapetrovic, S. (2002), Strategies for the integration of management systems and standards, *The TQM Magazine*, Vol. 14, No. 1, pp. 61-67.

Kautto, P., 2006. New instruments – old practices? The implications of environmental management systems and extended producer responsibility for design for the environment. *Business Strategy and the Environment* 15, 377-388.

Klefsjo, B., Bergquist, B. and Garvare, R. (2008). Quality management and business excellence, customers and stakeholders – do we agree on what we are talking about, and does it matter? *The TQM Journal*, 20(2), 120–129.

Klassen, R. D., & McLaughlin, C. P. (1993). TQM and environmental excellence in manufacturing. *Industrial Management & Data Systems*, 93(6), 14-22.

King, A. A., & Lenox, M. J. (2001). Lean and green? An empirical examination of the relationship between lean production and environmental performance. *Production and Operations Management*, 10(3), 244-256.

Kuei, C.-H. & Lu, M. H. (2013), Integrating quality management principles into sustainability management, *Total Quality Management & Business Excellence*, Vol. 24, No. 1-2, pp. 62-78.

Könnölä, T., Unruh, G.C., 2007. Really changing the course: the limitations of environmental management systems for innovations. *Business Strategy and the Environment* 16, 525-537.

Lawrence, L., Andrews, D., & France, C. (1998). Alignment and deployment of environmental strategy through total quality management. *The TQM Magazine*,10(4), 238-245.

Lent, T., Wells, R.P. 1994. Corporate environmental management survey shows shift from compliance to strategy, in: Willig, J.T. (Ed.), Environmental TQM. McGraw-Hill, New York.

Li, C. (2013), An integrated approach to evaluating the production system in closed-loop supply chains, *International Journal of Production Research*, Vol. 51, No. 13, pp. 4045-4069.

Luttropp, C. and Lagerstedt, J. 2006. EcoDesign and The Ten Golden Rules: Generic advice for merging environmental aspects into product development, *Journal of Cleaner Production*, 14(15-16), 396-1408.

Matias, J. C. D. O. & Coelho, D. A. (2011), Integrated total quality management: Beyond zero defects theory and towards innovation, *Total Quality Management & Business Excellence*, Vol. 22, No. 8, pp. 891-910.

Maxwell, D. and Van Der Vorst, R. 2003. Developing sustainable products and services. *Journal of Cleaner Production*, 11 (8), 883-895.

Meisner Rosen, C., 2001. Environmental strategy and competitive advantage. *California Management Review* 43(3), 8-15.

Molina-Azorín, J. F., Claver-Cortés, E., López-Gamero, M. D., & Tarí, J. J. (2009). Green management and financial performance: a literature review. *Management Decision*, 47(7), 1080-1100.

Pereira-Moliner, J., Claver-Cortés, E., Molina-Azorín, J. F., & José Tarí, J. (2012). Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry. *Journal of Cleaner Production*, 37, 82-92.

Pojasek, R. B. (2006), "Is your integrated management system really integrated?", *Environmental Quality Management*, Vol. 16, No. 2, pp. 89-97.

Pun, K.-F. & Hui, I.-K. (2002), Integrating the safety dimension into quality management systems: a process model, *Total Quality Management*, Vol. 13, No. 3, pp. 373-391.

Rebelo, M., Santos, G. & Silva, R. (2014), Conception of a flexible integrator and lean model for integrated management systems, *Total Quality Management & Business Excellence*, Vol. 25, No. 5-6, pp. 683-701.

Rocha, M., Searcy, C. & Karapetrovic, S. (2007), Integrating sustainable development into existing management systems, *Total Quality Management & Business Excellence*, Vol. 18, No. 1-2, pp. 83-92.

Rodríguez-Antón, J. M., Del Mar Alonso-Almeida, M., Celemín, M. S. & Rubio, L. (2012), Use of different sustainability management systems in the hospitality industry. The case of Spanish hotels, *Journal of Cleaner Production*, Vol. 22, No. 1, pp. 76-84.

Rothenberg, S., Frits, P. and Maxwell, J. 2001. Lean, green, and the quest for superior environmental performance, *Production and Operations Management*, Vol. 10, No. 3, pp. 228-243

Rusinko, C. A. (2005). Using quality management as a bridge in educating for sustainability in a business school. *International Journal of Sustainability in Higher Education*, 6(4), 340-350.

Ruzevicius, J., Adomaitiene, R., & Sirvidaite, J. (2004). Motivation and efficiency of quality management systems implementation: a study of Lithuanian organizations. *Total Quality Management and Business Excellence*, 15, 173-190.

Sakao, T., Kaneko, K., Mausi, K. and Tsubaki, H. 2004. Analysis of the Characteristics of QFDE and LCA for Ecodesign Support, Electronics Goes Green Conference, Berlin

Salomone, R. (2008), Integrated management systems: experiences in Italian organizations, *Journal of Cleaner Production*, Vol. 16, No. 16, pp. 1786-1806.

Santos, G., Mendes, F. & Barbosa, J. (2011), Certification and integration of management systems: the experience of Portuguese small and medium enterprises, *Journal of Cleaner Production*, Vol. 19, No. 17, pp. 1965-1974.

Schylander. E., Martinuzzi, A., 2008. ISO 14001 – Experiences, effects and future challenges: a national study in Austria. *Business Strategy and the Environment* 16, 133-147.

Seghezzi, H. D. (2001), Business excellence: what is to be done? *Total Quality Management*, Vol. 12, No. 7-8, pp. 861-866.

Simon, A., Bernardo, M., Karapetrovic, S. & Casadesús, M. (2011), Integration of standardized environmental and quality management systems audits, *Journal of Cleaner Production*, Vol. 19, No. 17, pp. 2057-2065.

Tarí, J. J. & Molina-Azorín, J. F. (2010), Integration of quality management and environmental management systems: similarities and the role of the EFQM model, *The TQM Journal*, Vol. 22, No. 6, pp. 687-701.

Theyel, G. (2000). Management practices for environmental innovation and performance. *International Journal of Operations & Production Management*, 20(2), 249-266.

To, W., Lee, P. K. & Billy, T. (2012), Benefits of implementing management system standards: a case study of certified companies in the Pearl River Delta, China, *The TQM Journal*, Vol. 24, No. 1, pp. 17-28.

Wiengarten, F., & Pagell, M. (2012). The importance of quality management for the success of environmental management initiatives. *International Journal of Production Economics*, 140(1), 407-415.

Wilkinson, G. & Dale, B. (1998), System integration: the views and activities of certification bodies, *The TQM Magazine*, Vol. 10, No. 4, pp. 288-292.

Wilkinson, G. & Dale, B. (1999a), Integrated management systems: an examination of the concept and theory, *The TQM Magazine*, Vol. 11, No. 2, pp. 95-104.
Wilkinson, G. & Dale, B. (1999b), Integration of quality, environmental and health and safety management systems: an examination of the key issues, Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, Vol. 213, No. 3, pp. 275-283.
Vonahsen, A. & Funck, D. (2001), Integrated management systems—opportunities and risks for corporate environmental protection, *Corporate Environmental Strategy*, Vol. 8, No. 2, pp. 165-176.
World Commission on Environment and Development (WCED), 1987. Our common future. Oxford University Press, Oxford.
Yang, C. L., Lin, S. P., Chan, Y. H., & Sheu, C. (2010). Mediated effect of environmental management on manufacturing competitiveness: an empirical study. *International Journal of Production Economics*, 123(1), 210-220.
Zairi, M. (2002). Beyond TQM implementation: the new paradigm of TQM sustainability. *Total Quality Management*, 13(8), 1161-1172.
Zeng, S., Shi, J. J. & Lou, G. (2007), A synergetic model for implementing an integrated management system: an empirical study in China, *Journal of Cleaner Production*, Vol. 15, No. 18, pp. 1760-1767.
Zeng, S., Xie, X., Tam, C. M. & Shen, L. 2011. An empirical examination of benefits from implementing integrated management systems (IMS), *Total Quality Management*, Vol. 22, No. 2, pp. 173-186.
Zhang, Y., Wang, H.P., Zhang, C.1998 Product concept evaluation using QFD-II and AHP, *International Journal of Environmentally Conscious Design & Manufacturing*, Vol. 7, No. 3, pp. 1-15.
Zhu, Q., Cordeiro, J., & Sarkis, J. (2013). Institutional pressures, dynamic capabilities and environmental management systems: investigating the ISO 9000–Environmental management system implementation linkage. *Journal of Environmental Management*, 114, 232-242.
Zhou, X. and Schoenung, J.M. 2003. Application of a Modified Production Quality Tool for Environmental Impact Assessment of Lead-free Solders. AIChE Sustainability and Life Cycle Topical Conference, San Francisco, CA, pp. 72–79

POCACITO – foresight for sustainable pathways towards liveable, affordable and prospering cities in a world context

Ingrid Kaltenegger, representing the POCACITO consortium
JOANNEUM RESEARCH Forschungsgesellschaft mbH
Resources - Department for Water, Energy and Sustainability
Energy Research Group

Abstract
The project **PO**st-**CA**rbon **CI**ties of **TO**morrow – foresight for sustainable pathways towards liveable, affordable and prospering cities in a world context (POCACITO) will develop an evidence-based 2050 roadmap for EU post-carbon cities over the period of 3 years. POCACITO facilitates the transition of EU cities to a forecasted sustainable or "post-carbon" economic model. The project focuses on towns, cities, megacities, metropolitan areas and urban clusters larger than 1 million people as well as small and medium-sized cities. The consortium consists of urban sustainability experts from thirteen countries. This paper presents an outline and overview and the results of the first eight months of the EU-project POCACITO, which is being funded under the European Union Seventh Framework Programme.

Key words: post carbon cities, foresight, scenario building, cases studies, stakeholder involvement

1 Introduction and main aims of POCACITO

The 21st century is already an increasingly urban area. Not only are cities the centre of economic and social activities, but also integral to climate change mitigation and adaptation strategies worldwide. Although accounting for merely 2% of the Earth surface [1], cities comprise over half the world's population and contribute to more than 75% of greenhouse gas emissions through energy use, waste management and land use change [2]. In the absence of a global climate agreement, the action of cities will be of critical importance. As political powers, cities may (or will) be agenda-setters in a bottom up climate architecture. The steadily increasing urban population - 95% of which will occur in developing countries - exerts enormous pressure on water supplies, sewage, the living environment, social and economic inequality and public health [3]. In addition, the transition of cities in industrialized countries towards more sustainability - comprising the three pillars environment, society and economy - requires dramatic improvements in energy and water-use efficiency; alternative transportation modes; investments in green infrastructure; waste minimization (reduced packaging and increased use of composting, waste-to-energy, and recycling); etc.

The goal of combining economic development with environmental improvement and social inclusion is framed as Green Growth by the OECD [4], as Green Economy by UNEP [5] and Sustainable Growth by the EU [6]. The European Union responded to this need with the Europe 2020 strategy for smart and inclusive growth [7]. The EU has recognised the key role that cities will have to play in achieving the goals formulated in the Europe 2020 strategy in its 2011 report on "The urban and regional dimension of Europe 2020 - Seventh progress report on economic, social and territorial cohesion" [8]. Its main conclusion is that significant effort and investment are still required to meet the smart, sustainable and inclusive objectives. The report finds that: "when designing regional growth strategies, cities should play an active role. Cities are uniquely placed to promote innovation by offering firms of all sizes the dynamic environments they need to succeed. They are at the forefront in the fight against climate change, creating new models of urban development with even higher resource efficiency." [9]

In view of these enormous challenges and significant opportunities, the **PO**st-**CA**rbon **CI**ties of **TO**morrow – foresight for sustainable pathways towards liveable, affordable and prospering cities in a world context (POCACITO) project team will develop a long-term

outlook for post-carbon cities in Europe, taking into consideration changing demographics and lifestyles, contributing to achieving the sustainable development objective of the Europe 2020 strategy and supporting the Innovation Union flagship initiative. This outlook serves to assess the long-term trends and tensions in EU cities which may have a relevant impact on urban development and to explore innovative approaches for achieving sustainable post-carbon cities in the EU. Meeting these objectives will contribute to implementing sustainable growth, defined as a target in the Europe 2020 strategy, and to support the EU Innovation Union flagship initiative.
The goal of the POCACITO project is to develop an evidence-based roadmap for EU cities to transition to post-carbon systems by 2050. This main objective will be achieved using seven components:

1. Assembling an inventory of current initiatives and best practices, which will serve to inform about potential measures and successful approaches to a post-carbon transition process.
2. Producing an initial assessment of the current situation in case study cities as an input into the scenario development.
3. Identifying win-win situations at the city level regarding CO_2 reductions and tackling other environmental problems, such as air pollution or climate change adaptation. Partner cities in the EU and in emerging economies will be informed about best practices and potential policy transfer through a dedicated 'Marketplace of Ideas' with study tours and learning opportunities. Mutual learning, exchanging visions and experiences between EU cities and internationally.
4. Developing together with stakeholders a set of three to five qualitative socio-economic scenarios for specific case study cities. This foresight will be completed by adding a post-carbon vision to each scenario in each city.
5. A quantitative analysis will measure the distance between the scenarios and the business-as-usual development and the post-carbon vision in each city. The result of the gap analysis will then inform stakeholders when choosing potential additional measures to be added to their scenarios.
6. In an iterative approach, the combination of scenarios and measures will be assessed as to their socio- economic impacts in order to adjust the choice of measures.
7. Positioning the EU as one of the first movers regarding low carbon urban solutions. Based on the results of the above six components, a set of strategic transition papers, city-specific foresights, and a generic EU 2050 roadmap with recommended pathways for a set typology of cities will be produced.

2 The concept of POCACITO - Methodology

POCACITO supports the transition process to a post-carbon economy occurring in cities and towns, ranging from megacities to metropolitan areas and urban agglomerations larger than 1 million people as well as small and medium-sized cities – with a particular focus on participatory scenario development as part of a mutual learning and living lab environment. Furthermore, the transition will need to improve the resilience of cities and regions in order to reduce existing and emerging conflicts over resources and their use in light of societal mega-trends, environmental deterioration and climate change [10].

The project team understands that developing strategies that simultaneously enhance the quality of life, promote economic prosperity and reduce impacts on the environment is a difficult task and requires a holistic approach encompassing foresight of long term trends that influence urban development and the assessment of socio-economic consequences resulting from the various pathways toward a post-carbon city. The development of innovative and pragmatic urban governance approaches will therefore be an essential element of the process.

First of all, a “Common Approach” was developed within the project partners, which enables a common understanding of key concepts, terminology and the project’s methodological approach in order to ensure coherence in the various work packages and among partners, and thus has a central role in ensuring an integrated research approach. This task also served to define key performance indicators for the quantitative analysis. After that, POCACITO will/did already identify innovative approaches for the transformation towards post-carbon cities and will develop an inventory for leading cities, an inventory for good city practices and an inventory for good national and EU practices as well as an EU cities typology (“Inventory of Urban Initiatives and Best Practices”), as there is still a lack of city typologies that help policy-makers to make appropriate policy choices.

The project will investigate more closely the current situation in ten urban case study cities, working closely with the respective local administration and relevant stakeholders, aiming for an objective and transparent baseline for the ensuing foresight exercise. An “Initial Assessment” gives a detailed assessment of the status quo in selected case study cities. Local meetings will be held to liaise with city officials in the case study cities. Findings will be compared and integrated into an integrated assessment. Together, the case study cities, respective stakeholders and the research team will co-develop local individual post-carbon scenarios for 2050 and beyond in a mutual learning process and living lab environment (“Qualitative Scenario Building”). Scenario development is a key aspect of the forward looking activity and will consider meta-trends and mega-trends in the world as well as the diversity of 'urban' contexts. These city-specific qualitative scenarios and their socio-economic impacts will be quantified using a system dynamics approach (“Quantitative Impacts” The focus will be on the analysis of the selected key performance indicators. The initial set of measures will then be assessed and refined derive specific pathways for the case study cities in ‘strategic transition papers’. Based on the results so far, and benefiting from both quantitative and qualitative approaches across disciplines, the core outcome of the project, an evidence-based 2050 Roadmap for EU post-carbon cities in a world context will be developed and presented.

Findings of the inventory, best practices as well as lessons from the case study cities will be promoted through a “Marketplace of Ideas” to other EU cities and non-EU cities in emerging economies. Involving stakeholders such as urban practitioners, representatives of civil society and decision makers both at the local and at the EU level as well as academia working on urban sciences throughout the project, as well as dissemination and communication to the wider urban community. The aim is to facilitate a reciprocal dialogue and knowledge exchange between stakeholders (such as urban planners and local government officials) from EU and non-EU cities and to export urban best-practices thereby aiding sustainable development.

“2050 Roadmap” works both at the case study city and at the EU level. Locally, it uses the results of the preceding work in the cities to develop a set of city foresights, the ‘strategic transition papers’ – validated through a last stakeholder workshop in the case study. At the EU level, an initial workshop will serve to identify expectations towards an EU roadmap for post-carbon cities. Based on the case study foresights and the “Inventory of Urban Sustainability Initiatives”, an EU level roadmap will be distilled and validated by means of another workshop. The roadmap will explore the challenges posed by the EU’s objectives as well as the policies and measures to achieve such goals. The roadmap will translate the research findings into accessible and easily understandable guidance for policy-makers and other stakeholders.

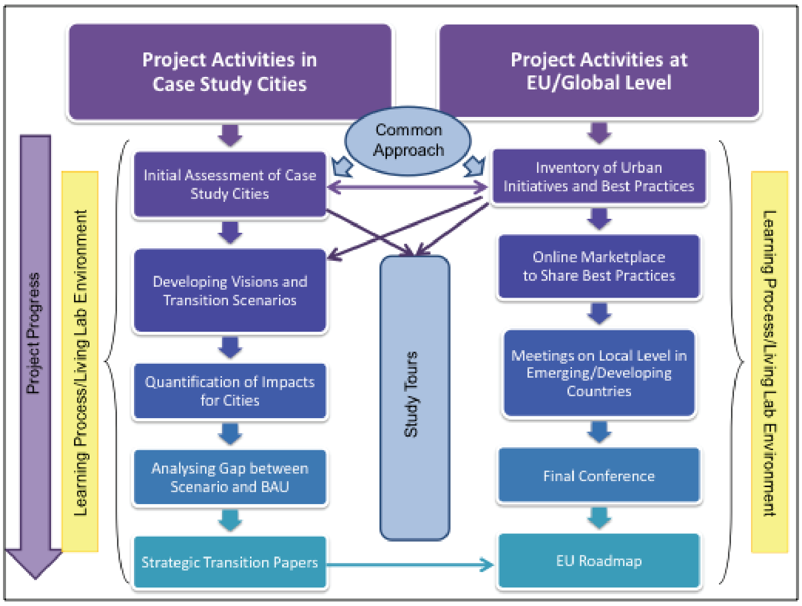


Figure 1: POCACITO approach

The project will consist of three layers:

1. Research layer

- finding a common approach for the project
- inventory of urban initiatives and best practices
- analysis of innovative post carbon cities – the initial assessment and aggregated analysis of the case study cities
- scenario development
- quantifying the social and economic impacts of the post carbon cities

2. Urban layer

- EU partner cities as case studies of successful transition approaches
- EU and non-EU partner cities for communicating innovative solutions
- city officials, stakeholders including industry representatives and urban practitioners supporting the participatory development of qualitative scenarios
- local post-carbon roadmaps

3. EU policy layer

- gathering a repository of urban transition best practices from EU and non-EU cities
- developing and presenting an evidence-based 2050 roadmap for EU post-carbon cities in a world context

2.1 The Post-Carbon City Definition

The concept of "post-carbon cities" signifies a rupture in the carbon-dependent urban system, which has led to high levels of anthropogenic greenhouse gases, and the establishment of new types of cities that are low-carbon as well as environmentally, socially and economically sustainable. The term post-carbon emphasizes the process of transformation, a shift in paradigm, which is necessary to respond to the multiple challenges of climate change, ecosystem degradation, social equity and economic pressures. Through their adaptive capacity, post-carbon cities use the threat of climate change "as an opportunity to reduce vulnerability as they restructure human–ecological and human–human relationships toward ecosystem health and a clean energy economy" [11] and [12].

2.2 Foresight and back-casting

Foresight, or the "systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint actions" [13], is the foundation of the POCACITO project. Since cities often act as innovators of governance and technology, developing foresight exercises and building scenarios is of crucial importance for strategic planning. Key actors at the city level can support transition processes by making better decisions on long-term investments in infrastructure and policies, which ultimately change the urban shape, urban carbon performance and lifestyles of inhabitants. When properly designed and implemented, foresight activities improve the quality, impact, and innovativeness of decision making.

Foresight activities within POCACITO do not aim to predict the future, but rather to create a platform to think, debate, and shape it with stakeholders at the city level. In doing so, scenarios support the learning process by examining the factors and trends that form future developments, providing insight into the long and short-term consequences of actions taken today. Unlike projections and deterministic modelling, scenarios and visions are based on assumptions and views of future developments, taking into account uncertainty, complexity, and discontinuity. Since the goal of foresight activities is to actively shape the future, the project focuses on aspects that local stakeholders are able to influence (i.e., city-level indicators

More specifically, the objectives of the POCACITO foresight activities are as follows:

- To inform policy-making so that city-level actors are aware of the longer term implications of current policy decisions.
- To build networks that bring together diverse groups of stakeholders involved in shaping the future of a city. By establishing these networks, POCACITO aims to encourage mutual understanding, to build trust, and to develop partnerships among groups that may otherwise have limited opportunities to interact with one another.
- To develop capabilities at the city level to conduct foresight activities after the completion of the POCACITO project and to integrate them into their planning processes as well as local culture.
- To build strategic visions (which can build upon existing city initiatives) about the future of cities and create a shared sense of commitment to work towards these visions among foresight participants.

POCACITO applies the planning methodology of back-casting. As an alternative to traditional forecasting, which merely extrapolates present trends into the future, back-casting allows participants to envision future desired conditions and then to define the steps needed to attain those conditions [14]. Back-casting is a particularly useful method when [15]:

- The problem to be studied is complex.
- There is a need for major change.
- Dominant trends are part of the problem.
- The problem to a great extent is a matter of externalities.
- The scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice.

As all of these features are true for the complex nature of urban systems, back-casting is deemed the appropriate tool to conduct case study workshops as it can "increase the likelihood of handling the ecologically complex issues in a systematic and coordinated way".

4 Results achieved so far

4.1 Key performance Indicators

In order to use an evidence-based approach to the development of a 2050 roadmap to support the transition of cities to a more sustainable or post-carbon future, 10 European case studies were selected: Barcelona, Copenhagen/Malmo, Istanbul, Lisbon, Litoměřice, Milan/Turin, Offenburg and Zagreb. An important step to achieve this goal is to produce an initial assessment of these case study cities. In particular, this diagnosis was done through the use of a specific methodology comprising a set of key performance indicators – the Post-Carbon City Index (PCI).

The PCI combines indicators covering environmental, social and economic dimensions. Each dimension includes a set of sub-dimensions and each sub-dimension a set of indicators. Globally, this conceptual model constitutes a holistic approach that allows the project partners to diagnose the situation of the case study cities with regard to their socioeconomic and sustainable dynamics. This tool will also allow cities to monitor the post-carbon transition process over the years. The Post-Carbon City Index is a tool oriented to measure the societal transformations occurring within the city in transition, which takes into account the interplay between different axes of diversity and the nexus between the social/spatial regimes. The index integrates a set of key performance indicators, which will allow a uniform collection of data, improve the comparison and support the identification of best practices in each case study city, covering environmental, social and economic aspects. The Post-Carbon City Index will contribute for the quantification of impacts, and for qualitative scenario building and modelling. Additionally, it will enable the comparison and monitoring of the case study cities in their realistic achievements (rather than prescriptive standards) of low-carbon targets, through the use of a specific quantitative analysis of environmental and socioeconomic metrics.

During a period of approx. 3 months, indicators in the 3 dimensions social, environmental and economic with their 25 sub-dimensions (e.g. average life expectancy, energy intensity or level of wealth) were elaborated and discussed. All the relationships, interlinkages, feedback loops and redundancies from one dimension to another, including their sub-dimension and indicators, were analysed to have an overview of the transition process without compromising the evaluation mechanism.

The assessment based on the Post-Carbon Cities Index will conduct the results from the local scenarios and visions, extract analysis and common features, and collect significant inputs that will culminate in the construction of an EU 2050 Post-Carbon City Roadmap for a common future of European cities.

4.2 Inventory of leading cities

To facilitate transitions to Post carbon cities, there is a need for a more differentiated understanding of what is possible for cities in varying contexts of action and in differing stages of post carbon transition. Thus the leading cities inventory and, later on, the good city practice inventory, need to capture as many facets of post-carbon city transition in Europe as possible. It was therefore necessary to go beyond a simple ranking of cities. There are recognised problems with rankings and award schemes, notably their lack of a sound methodology, coverage only of cities who volunteer to be included and, most damagingly, perhaps, their lack of usefulness to policymakers [16]. Rankings and awards have tended to create a sense of a high performing, wealthy elite of more sustainable cities, generally (but not only) from Western and Northern Europe. As well as geographical bias, there is little sense of how cities have advanced and how other cities might also advance and why action and performance take these forms that they do.

The aim of this part of the project is to better contextualize the notion of "leading" in relation to cities (as well as practices), to identify similarities among cities with respect to what is conducive to a transition to a "post-carbon" state. To gain such a rounded view, we looked beyond the usual cities that appear in sustainable city rankings i.e. the group of "first in class" cities and that of large, dominant cities in Europe. Hence the understanding of leading cities was not only related to measured performance (the basis for most rankings/ environmental awards), but rather the inter-relationships between context, actions and performance. The aim was to assess a wide range of cities in relation to their own potential to act and perform rather than that of other cities. Hence we aim, in a very preliminary fashion, to illuminate some of the contextual factors which shape opportunities and constraints in post carbon transitions, considering different and changing contexts. To make the analysis more inclusive "actions" were included in the analysis on the grounds that they were, at the least, indicative of willingness to change. As such they were a necessary supplement to performance, which ultimately rests on recorded or recordable data.

Research consisted of a review of the literature on cities, post-carbon and, more generally, urban environmental initiatives (e.g. transnational city networks such as Covenant of Mayors) and practices. This was supplemented by original research in the form of an expert survey, which provided fresh insights and addressed (geographical) gaps in the state of the art, particularly with regards to cities in Central and Southern Europe. After this a methodology to select leading cities/good practices according to a combination of performance and action indicators was developed. This drew on both the existing material and the expert survey city nominations.

In total, 94 leading cities have been identified and basic information and data has been gathered to show their progress with respect to their development towards post-carbon futures. A great diversity of cities has emerged. The leading cities vary markedly in size, from London (c. 8.3 million) to Großschönau (c.1,200) in Austria. There are extremely wealthy cities, such as Basel (GDP €127,365) and much poorer cities, such as Skopje (GDP €9,000). There is also a wide variation in climate and energy use in terms of heating days, from Oula in Finland (6,142 days between 2000-2009) to Oeiras and Cascais in Portugal (833 days between 2000-2009).

While they might not all be considered European leaders, every city has been selected for a reason, or more accurately a combination of reasons (rankings, expert opinion, EEA certification, Covenant of Mayors SEAP approval). This means that cities such as Jeseník (Czech Republic) or Tuzla can be seen as leading at least in their national or regional contexts, even if their performance is not comparable to European leaders. Their inclusion should assist with developing a more contextualized understanding of good practices, allowing us to see which practices have been implemented in different types of cities.

Any list of leading cities is likely to provoke plenty of discussion. The aim of this list has been to shift the focus from thinking in terms of the "number 1", the "top ten" and a competition between usual suspects, to a more inclusive reflection on the broader spectrum of urban post-carbon transitions activities found in cities, and a better consideration of the different contexts of action, the constraint and opportunity structures, in which cities find themselves.

The wider meaning of the leading cities list will be the subject of further research in the project. There is much potential to exploit the data and information contained in the inventory of leading cities. A further step would be to begin validating the results by comparing them more vigorously with particular ranking schemes, especially those with stronger and more transparent methodologies like the Siemens Green City Index. Beyond this the contextual factors present in leading cities and their link to actions, practices and performance will be the focus in the following project months, leading to the various typologies like typology of cities; typology of demonstration/pilot projects at neighbourhood level; typology of sectoral policies.

5 What is new about the project? – Beyond State of the Art

Previous work undertaken in the field of “scenario development and foresight” has identified some shortcomings, which will be taken into account by POCACITO.

A first shortcoming in foresight studies and scenario development has been identified by an analysis of 52 pieces of research on scenario planning undertaken by the European Environment Agency. It summarises that “even well-crafted scenarios can fail to have their intended policy impact if they present irrelevant information, lack support from relevant actors, are poorly embedded into relevant organisations or ignore key institutional context conditions” [17]. The participatory scenario development applied in POCACITO holds the potential to enhance the relevance of scenarios to stakeholders, and improves the preciseness of scenarios by integrating scientific and local knowledge [18]. An accurate selection of stakeholders, relying, inter alia, on stakeholder mapping exercises, supports POCACITO’s efforts to provide a representative image of stakeholders’ views and preferences. This should reduce difficulties arising from partial or biased stakeholder participation which has in the past often led to scenarios including topical issues of close concern to single groups of stakeholders. Frequently, scenario development has been approached from a narrow problem-solving angle by policy-makers, but also by other stakeholders [19]. Successfully combining long time frames with issues of direct interest of the stakeholders has been a challenge in past scenario developments and its related research.

A second shortcoming identified in the EEA report refers to limited guidance on how to optimise scenario planning [20]. POCACITO will apply a well-tailored foresight approach with a strong focus on including stakeholders. Co-developing local individual post-carbon scenarios in a mutual learning process and living lab environment will help increase the knowledge on how to optimise defining strategies towards a post- carbon city. In the context of POCACITO, quantitative modelling of future impacts of proposed strategies will provide a valuable assessment of proposed strategies and define thresholds and criteria for future monitoring of the strategies.

6 Outlook – next steps

Within the next months, the project will concentrate on the following issues:

- Different **typologies** will be developed to help to improve knowledge transfer and learning among cities. Such typologies will facilitate “matchmaking” between cities and the joint development of solutions for common problems.
- **Workshops** with the case study cities have already started: I) the purpose of the initial assessment workshop is to present the results of the initial assessment and have participants decide on key challenges for their case study city; II) the visioning workshop is an essential moment in the POCACITO case study process. The vision is the guiding star to a future – a process that is different from the one we would obtain if we remained in the present tracks. It is NOT about finding THE solution, but rather about discussing ideas and initiating a process about a post-carbon future for the city; III) The back-casting workshop is based on the visioning process and develops the pathway from the current situation towards the post-carbon vision. The back-casting workshop consists of five key steps: a) define a normative “desired” end point (the vision from the previous visioning workshop); b) consider context-scenario specific obstacles and opportunities in reaching the end point; c) identify milestones or interim projects that would signify progress in reaching the end point; d) define actions that must be taken to get to the end point and e) validate the robustness of actions in the case of other background scenarios playing out.
- In Parallel, the online **marketplace of ideas** will be established step by step, feeding into that results from the leading cities and typologies exercise.

- A **Strategy paper** on the role of EU cities for non-EU and emerging cities will be elaborated. This report will show how experiences from EU cities (based on the cases studies from WP 2) can contribute to development especially in non-EU emerging cities.
- Contract with cities in **Brazil and China** are being signed at the moment, in these cities 2-3 workshops will be held.

7 References

[1] UNEP (2011). Cities. In towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication (p. 454 – 489).

[2] World Bank 2008.

[3] UNEP (2011). Cities. In towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication (p. 454 – 489)

[4] OECD. (2011). Towards Green Growth. http://www.oecd.org/greengrowth/48012345.pdf

[5] UNEP (2011). Cities. In Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication (S. 454-489).

[6], [7] EC (2010): Europe 2020 - A strategy for smart, sustainable and inclusive growth, COM(2010) 2020.

[8], [9] EC (2011): The urban and regional dimension of Europe 2020. Seventh progress report on economic, social and territorial cohesion.

[10] EEA (2011): The European environment — state and outlook 2010: assessment of global megatrends. European Environment Agency, Copenhagen.

[11] Adger, W. Neil. 2006. “Vulnerability.” *Global Environmental Change* 16 (3): 268–81.

[12] Evans, G. 2008. “Transformation from ’Carbon Valley ’to a’ Post-Carbon Society’ in a Climate Change Hot Spot: The Coalfields of the Hunter Valley, New South Wales, Australia.” Ecology and Society 13 (1): 39.

[13] EFP. 2001. “European Communities, Foresight for Regional Development Network: A Practical Guide to Regional Foresight.” http://www.foresight-platform.eu/community/foresightguide/what-is-foresight/.

[14] Dreborg, Karl H. 1996. “Essence of Backcasting.” *Futures* 28 (9): 813–28.

[15] Holmberg, John, and K.-H. Robèrt. 2000. “Backcasting—A Framework for Strategic Planning.” *International Journal of Sustainable Development & World Ecology* 7 (4): 291–308.

[16] Mark S. Reed et al.: Participatory scenario development for environmental management: a methodological framework. Sustainable Learning Working Paper Series, No. 1, pp. 5, 24f.

[17] William Sheate et al.: Embedding Futures Thinking in Environmental Policymaking – the BLOSSOM Project, European Foresight Platform brief No. 241, 2012, p. 1.

[18] European Environment Agency: Looking back on looking forward: a review of evaluative scenario literature, EEA Technical report, no 3, 2009.

[19] Olivier da Costa et. al.: The impact of foresight on policy-making: Insights from the forlearn mutual learning process. Institute for Prospective Technological Studies Joint Research Centre / European Commission.

[20] Mark S. Reed et al.: Participatory scenario development for environmental management, p.4

Assessing the eco-efficiency of a meso-scale agricultural water system

Mladen Todorovic [1,*], Andi Mehmeti [2] and Alessandra Scardigno [3]

(1) Department of Land and Water Management, CIHEAM – Mediterranean Agronomic Institute of Bari, Italy, phone: +390804606235; e-mail: mladen@iamb.it
(2) Department of Land and Water Management, CIHEAM – Mediterranean Agronomic Institute of Bari, Italy, e-mail: ing_andi@live.com
(3) Department of Land and Water Management, CIHEAM – Mediterranean Agronomic Institute of Bari, Italy, e-mail: scardigno@iamb.it
(*) Corresponding author

Abstract:

The eco-efficiency of agricultural water sector encompasses both the ecological and economic dimensions of sustainable agriculture and promotes a simple integrated concept of achieving more agricultural outputs, in terms of income, with less inputs of land, water, energy, nutrients, labor, or capital (Keating et al., 2010). This work aims at the assessment of eco-efficiency of the irrigation district Sinistra Ofanto, located in Apulia region, South-East Italy. The study area represented a meso-scale agricultural water system which covered about 39,000 ha of agricultural land and included the relevant actors involved in the system and the interactions among them.

A model was developed through the elaboration of a case study inventory analysis which entails data about flows entering the system as well as direct and indirect emissions to the environment from the operations of the study system itself throughout the life cycle. The assessment was performed for normal and dry year, corresponding to annual precipitation of 514 and 420 mm, respectively. The on-field agronomic and water management practices, water delivery and economic data referred to year 2007. Hence, the baseline scenario adopted the application of deficit irrigation strategy for artichoke, olives, orchards and sugarbeet, and full irrigation for other crops except wheat which was grown under rainfed conditions. The eco-efficiency was estimated as a ratio between the economic performances of the system and produced environmental impacts. Economic performances were expressed in terms of Value Added of the agricultural sector , whereas the environmental performance followed a life-cycle oriented approach using 11 midpoint environmental impact categories which were selected as the most representative for the system. The analysis was performed by using the new modeling tools, Environmental Analysis Tool (SEAT) and Economic Value chain Analysis Tool (EVAT), both developed through the EcoWater project (http://environ.chemeng.ntua.gr/ecowater/). The environmental impact on a cluster (crop) level was performed on the basis of the irrigation (water) supply to crops and corresponding agronomic practices. The eco-efficiency of the system greatly depends upon the hydrological conditions, yields achieved and water use, market prices, the location and source of water (surface or ground), the hydraulic characteristics of water delivery and distribution network, landscape, cropping pattern and adopted irrigation method.

The overall results indicated that the system performances are strongly affected by a non-controlled water withdrawal from the aquifers which is particularly relevant under dry year conditions. This increases the environmental burdens and requires the uptake of new technological solutions for the enhancement of eco-efficiency of Sinistra Ofanto irrigation scheme. The system has relevant potential for the improvement of environmental performance. The most relevant solutions are the implementation of on-farm water saving technologies (drip and subsurface drip irrigation methods), the substitution of diesel engine pumps with electric pumps for groundwater abstraction and the adoption of new water pricing policies.

Keywords: water management, EcoWater project, irrigation, water saving technologies, environmental impact.

1. Introduction

In a product life-cycle framework, different processes have different environmental impacts and economic value. Eco-efficiency is a relatively new and still evolving concept which combines the environmental performance of a product system to its product system value (ISO14045:2012). The concept of eco-efficiency, introduced in 1991 by the World Business Council of Sustainable Development (WBCSD), in the last decade was applied to agriculture sector focusing on economic (productivity and profitability) and ecological (environmental sustainability) drivers of efficiency. In the simplest term, the agricultural eco-efficiency is about achieving more with less — more agricultural outputs, in terms of quantity and quality, with less inputs of land, water, nutrients, energy, labor, or capital (Keating et al., 2010).
In the Mediterranean region, natural resources are deemed to be scarce; therefore, it is important to study how to improve efficient use of these resources through the uptake of new technologies and the adoption of the best management practices. A broad literature on calculating eco-efficiency at the micro level or macro level exists (e.g., Verfaillie and Bidwell, 2000; Michelsen, 2006; Koskela, 2014). However, at these levels wider effects, for example, the interactions between different stakeholders are often neglected. The EcoWater project (EC-FP7-ENV) emphases on the eco-efficiency of meso-level water systems for different uses (agriculture, domestic and industrial) following the common methodological steps and promoting the stakeholders participation. In this work, one of eight case studies of the project is presented that focuses on the assessment of the eco-efficiency of Sinistra Ofanto (SO) irrigation scheme, located in Apulia region (Southern Italy).

2. Methodological framework

The methodology applied combines the results of previous investigations with a more direct stakeholders involvement within EcoWater project and permits a characterization of the study area that takes into account both the technical specificities (engineering and agronomic) of the water system and socio-economic and environmental issues. The methodological steps include a) analysis of the physical system; b) eco-efficiency assessment for the baseline scenario; c) identification of new technologies/innovations and practices d) technology assessment and scenario analysis.
The assessment of the environmental impacts follows the main stages of the typical life cycle inventory analysis (LCI) and life cycle impact assessment (LCIA) as described in ISO (2012). The methodology applied in this study is a system-based approach and targets to the assessment of the environmental scores of competitive market products.
The goal of the analysis is to promote innovative technology uptake in Sinistra Ofanto irrigation scheme by presenting the difference in eco-efficiencies between a baseline scenario and scenarios where new technologies are implemented. The analysis is targeted on a meso-level that encompasses the water supply and water use chains and entails the consideration of the interrelations among the heterogeneous actors. In this context, the meso-level can refer to a region, a sector, a supply chain or a product/service system.

2.1 System Boundaries

The boundaries of the system including the water supply chain and water values chain are presented in Figure 1. The system is represented as a network of several processes where each process represents an activity, implementing one or more technologies, where generic materials (water, raw materials, energy and other supplementary resources) are processed and transformed into other materials, while releasing emissions to the environment (air, land, water) or into the system water flow.

Fig. 1. A conceptual model of the Sinistra Ofanto agricultural water system

The entire study area is divided into 3 sub-schemes (districts) depending on the way water is supplied for final use (Irrigation Zones). Different stages are also defined enclosing the relevant actors involved in the system and the interactions among them. The system is divided into “foreground” and “background” subsystems. Foreground system is the product system, e.g. the system of direct interest and includes all the stages along the water value chain where resources are used and emissions are generated directly. Background system includes the production processes of the various resources entering the system which are not included in the boundaries of the study system (i.e., phosphorus based fertilizer, electricity and diesel).

2.1.1 Functional Unit

In order to relate all the data and to make the scenarios comparable, the function delivered by a product system has to be expressed by a functional unit. The functional unit of a LCA related to agricultural water systems could be 1 m^3 of water used -when the quantity of interest is the water used for the production purposes or 1 kg of yield produced when the unit of product delivered is the flow of interest. Accordingly, different environmental indicators, for each impact category, can be calculated, depending on the choice of functional unit (product or water used). Environmental indicators can also be referred to the whole study area or disaggregated on the different clusters defined as a crop cultivated in an agricultural area with common cultivation practices, climatic conditions, soil features and farmer habits..

2.2 Life Cycle Inventory

Inventory analysis is the second step in the data collection phase aimed to estimate all the inputs (resources) and outputs (emissions) in relation to the functional unit. Agronomic, engineering, economic and environmental data collected for several years from the study area were integrated in analysis in compliance with the goal and scope phase of LCA. To ensure the adequate relevant data, field visits and meetings with local stakeholders were conducted. In addition to specific data for the production process, LCA databases (e.g. ELCD, 2013) and scientific literature were used to collect information.

2.3 Indicators and Impact assessment

According to the LCIA framework that aims at evaluating the significance of potential environmental impacts based on the inventory of flows, a set of relevant environmental mid-impact indicators, was chosen (Van Vliet et al., 2012), followed by an estimation based on the derived resources consumption and generated emissions using corresponding characterization factors commonly used in LCAs. Assessment of environmental impacts from freshwater use was based on the methodology proposed in Mila i Canals (2009).

2.4 Value Assessment

The most relevant economic performance indicator in the meso-level water use system is the Total Value Added (TVA) that includes both the water supply and the water use chains. TVA is generally estimated as the water-service value minus various costs – of investment, annual operation, maintenance, inputs and waste water treatment (WWT) – across the meso-level system. The assessment of the economic performance through TVA has the advantage that the share of each actor could be easily revealed and this could be a good base in debating about new technology implementation and the burden of each actor.

2.5 Tools

The EcoWater project has developed online tools for meso-level analysis of the entire water-service value chain. The tools has been designed to support the step-by-step implementation of the EcoWater Methodological Framework. These tools are the Systemic Environmental Analysis Tool (SEAT), the Economic Value chain Analysis Tool (EVAT) and EcoWater Toolbox. SEAT addresses the supply chain, its components, processes & interactions. It provides the flows of the materials (water, resources, products, etc.) that can be used for estimating the environmental components of the eco-efficiency indicators. EVAT addresses the value chain, its actors and their interactions. It provides monetary flows that can be used for estimating the economic component of the eco-efficiency indicators. After refinement through the project's case studies, these tools were made publicly available (EcoWater, 2014).

3. Results and discussion

The eco-efficiency indicators, corresponding to the 11 relevant environmental impact categories, were estimated for the Sinistra Ofanto agricultural water system considering baseline conditions for normal and dry hydrological year (Table 1). The results revealed that the hydrological conditions play a relevant role in the eco-efficiency assessment because more precipitation usually means (at least for winter crops) lower irrigation requirements and, therefore, less consumption of resources. Accordingly, the eco-efficiency of the system is higher for a normal than for a dry year which is especially evident for the indicators related to climate change, fossil fuel depletion and freshwater depletion that in a dry year lower by 13.2, 16 and 18.6% (Table 1). In a dry year, the groundwater withdrawals are greater than recharge, which indicates a clear trend of reduction of water availability in the region and worsening of environmental conditions. Furthermore, the environmental impacts become more severe because more irrigation and related energy inputs are then required. The same applies for economic performance which, in most cases, is going to decrease due to decrease of crop water productivity.

Table 1. Eco-efficiency indicators for baseline situation under normal and dry year conditions

Eco-efficiency indicators	**Unit**	**Baseline (Normal)**	**Baseline (Dry)**
Climate Change	€/$tCO_{2,eq}$	1,081	938.79
Fossil fuels Depletion	€/toe	5	4.20
Freshwater Depletion	€/m^3	7	5.68
Eutrophication	€/$kgPO_4{}^{3-}{}_{,eq}$	109	99.00
Acidification	€/$kgSO^{2-}{}_{,eq}$	20	17.93
Respiratory Inorganics	€/$kgPM_{10,eq}$	83	74.88
Freshwater Ecotoxicity	€/$kg1,4DCB_{,eq}$	74	67.50
Terrestrial Ecotoxicity	€/$kg1,4DCB_{,eq}$	3,867	3364.56
Ozone Formation	€/$kgC_2H_{2,eq}$	3,008	2700.11
Minerals Depletion	€/$kgFe_{eq}$	8,418	7483.65

Through baseline eco-efficiency assessment, the processes with the greatest resource burdens and water-based emissions were identified. By using the EcoWater tools, the eco-efficiency of different stages of the system was determined along with the contribution of background and foreground system in the environmental impact assessment (Fig. 2). The analysis also allowed the identification of the stages (Fig. 2) environmentally weak as well as the selection of technologies to be used in the comparative scenarios.

Fig. 2.Contribution of Foreground and Background Systems in the environmental impact categories (on the left) and environmental impact breakdown per stage for a normal hydrological year (on the right).

The system under study is characterized by significant contribution of the foreground processes in climate change impact category due to direct emissions from fertilizer consumption, eutrophication of groundwater and surface water due to NO_3 and PO_4^{3-} leaching, acidification on non-agricultural soils through deposition of NH_3 and freshwater ecosystem impact due to irrigation. Hence, the foreground processes have negative environmental impact in regard to climate change, freshwater resource depletion, acidification and eutrophication (Fig. 2). The background system is mainly affected by the nitrogen production and then after by energy (electricity and diesel) production and phosphorus production.

On the farm level (considering the irrigation zones), the baseline estimation showed that the stages with the highest negative environmental impacts are those with the highest consumption of “water service related materials” and supplementary resources (as irrigation zone 3).

As for the total value added of the system, results show that it greatly depends upon the yields achieved, i.e. irrigation input, thus, the economic benefits increase with increasing irrigation water supply and its efficiency.

On the basis of a large stakeholders consultations, a list of advanced water and energy technologies and farm management practices for eco-efficiency improvement was formulated for practical application in the case study area. A technology scenario was defined as the implementation of (at least) one innovative technology in the system, assuming that all other parameters remain the same. Then, an overall technology scenario can be built, combining all eco-efficient technologies, provided that the included technologies are compatible (e.g. they are implemented in different processes). An example of the impact of implementation of drip irrigation technology instead of micro-sprinklers in a normal hydrological year is given in Figure 3. The beneficial effects of a technology are expressed through the eco-efficiency indicators which are greater than 1. Otherwise, the introduction of a technology could have negative impact.

Fig. 3. Comparison of eco-efficiency indicators for baseline scenario (blue line fixing all indicators to 1) and for scenario of drip irrigation adoption instead of micro-sprinklers

Accordingly, the adoption of drip irrigation instead of micro-sprinkler has increased the eco-efficiency for climate change, fossil fuel depletion, terrestrial eco-toxicity and mineral depletion environmental impact indicators (Fig. 3) due the highest decrease of related emissions. Seven eco-efficiency indicators were negatively affected because Total Value Added reduction (due to high investment cost) was higher than the reduction of emission for those categories. Hence, the eco-efficiency tends to decrease when the change in relative terms of environmental performance is smaller than the corresponding economic value added. The decrease of associated emission (foreground and background) with diesel and fertilizers showed relevant impact in the climate fossil fuel depletion, mineral depletion, freshwater depletion and eutrophication potential indicators. The analysis pointed out that the main environmental impacts for most investigated indicators are due to the background systems, where production of energy, fertilizer and fuels is realized.

4. Conclusions

The methodology, developed within the framework of EcoWater project, is in compliance with ISO standards on eco-efficiency and LCA and supports the quantification of eco-efficiency on meso-level. By estimating a range of proposed indicators, the assessment permitted the comparison of technology options with the baseline situation. This study promoted an innovative approach indicating that the innovation process is driven mainly by cropping pattern, water, fertilizer and energy consumption, corresponding greenhouse gas emissions, market price of agricultural products, and production costs and the level of adoption of new technologies.

Sinistra Ofanto irrigation system is already well-assessed although the potential for the improvement of eco-efficiency still exists. However, the introduction of one single technological solutions does not give relevant benefits. Hence, the solution could be the integration of different technologies as they are the on-farm water saving technologies (drip and subsurface drip irrigation methods), the substitution of diesel engine pumps with electric pumps for groundwater abstraction and the adoption of new cropping patter and water pricing policies (data are not shown).

Acknowledgement

This study has been done within the frame of EcoWater project, supported by the 7th EC Framework Programme (FP7-ENV), grant agreement n°282882, and the CIHEAM-IAM Bari Master program on “Land and Water Management: irrigated agriculture”.

References

EcoWater, 2014. EcoWater toolbox. http://environ.chemeng.ntua.gr/ewtoolbox/ [accessible after registration].

ELCD, 2013. European reference Life Cycle Database (ELCD), retrieved from ELCD website: http://elcd.jrc.ec.europa.eu/ELCD3/processList.xhtml

ISO., 2012. Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines. International Organization for Standardization.

Keating, B.A., Carberry, P.S., Bindraban, P.S., Asseng, S., Meinke, H., Dixon, J., 2010. Eco-efficient Agriculture: Concepts, Challenges, and Opportunities. Crop Sci. 50:S-109–S-119.

Koskela, M. 2014. Measuring eco-efficiency in the Finnish forest industry using public data. Journal of Cleaner Production.

Michelsen, O., Fet, A. M., Dahlsrud, A., 2006. Eco-efficiency in extended supply chains: a case study of furniture production. Journal of Environmental Management 79 (3), 290–297.

Milà i Canals, L., 2009. Assessing freshwater use impacts in LCA: Part I - inventory modelling and characterisation factors for the main impact pathways. International Journal of Life Cycle Assessment, 14 (1), p. 28–42.

Van Vliet, L., Levidow L., Alongi Skenhall S., Blind M., 2012. Review and selection of eco-efficiency indicators to be used in the Case Studies. EcoWater Project Deliverable 1.1.

Verfaillie, H.A., BidwelL, R., 2000. Measuring eco-efficiency. A guide to reporting company performance. World Business for Sustainable Development.

Biomolecules as a sustainable protection against corrosion of reinforced carbon steel in concrete

V. Shubina [a], L. Gaillet[a], T. Chaussadent[b], T. Meylheuc[c], J.Creus[d]

[a] IFSTTAR Nantes, Route de Bouaye, CS4 44344 Bouguenais Cedex, France
[b] IFSTTAR Marne-la-Vallée, 14-20 Boulevard Newton, Cité Descartes, Champs sur Marne la Vallée, Cedex 2, France
[c] INRA, UMR1319 Micalis B2HM, 25, Avenue de la République F-91300 Massy, France
[d] LaSIE, UMR7356, Université de La Rochelle, Pôle Sciences et Technologie, Bâtiment Marie Curie, 25, rue Enrico Fermi, 17000, La Rochelle, France

Summary

Actually, corrosion of steel reinforcement is an important contributor and has therefore becomes a major problem of sustainability of the infrastructure. In cases of collapse of infrastructural installations such as bridges and other concrete constructions due to corrosion damage people safety is involved. Since 1970, one of the main topics is the use of materials with high corrosion resistance or the use of protective systems combined with conventional low alloyed steels in order to increase the service life of reinforced concrete. In this way, one of the protective systems that can be developed is the use of corrosion inhibitors. Their use is more attractive because of their easy-handling ("mixed-in" or "migrate-through" the concrete) and of their lower cost. Recently, there is sufficient quantity of inhibitors available on the market, i.e. commonly used, such as nitrite salts, amino-alcohols (AMAs) and sodium monofluorophosphates (MFPs). There is always a contradiction in the opinions about the use of these inhibitors, because of their toxicity for humans and the ability to degradation in environment. The choice of the appropriate inhibitors needs to take into account their impact on the environment, and it is important to encourage the use of environmental friendly inhibitors.
Actually, there is a need to develop new so-called "green-inhibitors" to prevent corrosion in concrete. Nowadays, naturally occurring molecules with ability to prevent corrosion are the focus of studies in different corrosion fields. Regarding to the civil engineering, there is a little consideration towards the study of green inhibitors or similar materials. The aim of this study is to evaluate a new product which can be potentially used as an eco-friendly inhibitor of steel corrosion in concrete.
Biomolecules used in this study are a new class of compounds produced from renewable resources. Their efficiency as inhibitor is related to the adsorption on metal surfaces of polar functions with S, O or N atoms in the molecule. The adsorption mechanism was demonstrated using **XPS surface** analysis. **Polarization curves, Electrochemical Impedance Spectroscopy and Scanning Electron Microscopy** were used to investigate the inhibition effect. It was shown that this type of biomolecules is a film-forming and mixed type inhibitor. The decrease in corrosion current density was more pronounced using 1 g/L of product in the simulated concrete pore solution.

Keywords: *biosurfactant, corrosion inhibitor, rebar, steel in concrete, civil engineering*

1. Introduction

The deterioration of infrastructural installations such as bridges and other concrete constructions becomes very important. In case of collapses due to corrosion, the people safety is in risk. Some examples of such disasters in the history can be detailed, like Highway Mississippi Bridge collapse in Minneapolis, the collapse of a Berlin Congress Hall

roof (caused by hydrogen-induced stress corrosion cracking of pre-stressed steel) and the collapse of suspended ceilings in swimming halls in Denmark (due to chloride-induces stress corrosion cracking) (1). Although corrosion of the reinforcement is not the only one cause of deterioration in civil engineering, but one of the main contributors.
The fundamental meaning of corrosion is the return of metal to its natural state. The author (2) used a comparison of the corrosion phenomena with the action in flash battery. The body of corroding steel can be represented as a mixed electrode composed for millions of anodes and cathodes and the concrete pore water play the role of electrolyte.

$Fe^0 \rightarrow Fe^{2+} + 2\bar{e}$ (anodic partial reaction or the reaction of iron dissolution),

The oxygen diffuses into the concrete porous systeme, dissolves in the pore solution and finally reaches the surface of the steel. On this surface the oxygen will be reduced to hydroxide ion (OH^-) as in following electron reaction:

$O_2 + H_20 + 4e \rightarrow 4OH^-$ (cathodic partial reaction (I)),

This reaction could be associated with an additional cathodic reaction occurring at the steel surface in concrete in relation with the evolution of the chemical composition of the electrolyte at the steel vicinity.

$2H_20 + 2e \rightarrow H_2 + OH^-$ (cathodic partial reaction (II)),

$Fe + 2H^+ \rightarrow Fe^{2+} + 2\bar{e}$ (global reaction).

Protection of the steel rebars against the corrosion is ensured by the formation and the stability of the passive layer mainly composed of iron oxide based species in the high alkalinity media (pH=12-13 of concrete (3). The penetration of carbon dioxide and/or of chloride anions can damage the protective layer formed on the steel surface, leading to local corrosion of steel rebars (3). Then the corrosion phenomena will slowly progress up to the complete deterioration of steel reinforced concrete.

The protection methods for these systems were widely reported in literature over the last five decades (4-6). Since 1970, the use of non-corroding fusion bonded epoxy-coating for reinforcement and specially designed low-permeability concrete (low w/c ratio, latex-modified concrete, etc) was observed. Otherwise, the main topic was the development of electrochemical rehabilitation methods, their limits and their effectiveness. The well-known technique is the cathodic protection (by an impressed current using a carbon mesh anode or sacrificial cathodic protection by thermal zinc spraying). Another technique reported in the literature is the use of corrosion inhibitors for reinforced concrete (7). Their use is more attractive because of their easy-handling (“mixed-in” or “migrate-through”) and because of their low cost comparing with cathodic protection. Recently, there is sufficient variety of inhibitors available on the market, i.e. commonly used, such as nitrite salts, aminoalcohols (AMAs) and sodium monofluorophosphates (MFPs) (8).

There is always a contradiction in the opinions about the use of inhibitors that were developed, because of their toxicity for humans and the ability to degradation in environment. Actually, there is a need to develop new so-called “green-inhibitors” to prevent corrosion in concrete.

Currently, naturally occurring molecules with ability to prevent corrosion are the focus of studies in different corrosion fields (9). It is well known that efficiency of these eco-friendly corrosion inhibitors is related to the adsorption on metal surfaces of polar functions with S, O or N atoms in their biomolecules (10). It has been reported that the extracts of *Lannea coromandelica* presents a good inhibitor efficiency in sulfuric solution (0.1M) for mild steel (11); the extract of *Salvia officinalis* leaves and *Aloe vera* inhibits the corrosion of 304 stainless steel in 1M H_2SO_4 and 2 M HCl respectively (12), (13). *Azadirachta indica* proves its efficiency in sulphuric acid (1M) for copper (14) by chemisorption mechanism; *Jasminum nudiflorum* shows good properties for aluminum in 1M hydrochloric acid (15).

Regarding to civil engineering, it was found that the extract of *Bambusa arundinacea* in concrete presents a pore blocking effect and leads to a stabilization of silicate hydrates (C-S-H) ability (16). Other study has shown that *Vernonia amygdalina* has a synergetic inhibition effect with calcium nitrite in contaminated concrete exposed to a 0.5 M chlorides media (17).

However, today there is a little consideration towards the study of "green film-forming inhibitors" against corrosion dedicated for reinforced concrete. We choose to develop this subject focusing our study on the use of biomolecules (BMs) produced from renewable resources like yeast, fungi or bacteria in order to improve the corrosion resistance of steel rebars in concrete. The aim of our study was to demonstrate that BMs offer the possibility to replace conventional chemical inhibitors for concrete. Their effectiveness against corrosion was validated using accelerated corrosion tests, BMs property of "film-forming" was studied using XPS (X-ray Photoelectron Spectroscopy).

2. Materials and Methods

2.1 Samples and solutions

The samples were disks cut from real rebars kindly provided by PLBArmatures (groupe Allians-Snaam, Carquefou, France). The chemical composition of the carbon steel was in accordance with "NF EN 10080" (Carbon Steel for Reinforcement in Concrete) and is presented in Table 1. Figure 1 presents the ferritic-pearlitic microstructure deduced from nital etching of the low alloy steel, it can be observed that the density of pearlite grains is very low compared to the density of ferritic grains.

Table 1. Chemical composition of the rebar steel (wt. %)

C	S	P	N	Cu	Fe
0.24	0.055	0.055	0.014	0.85	balance

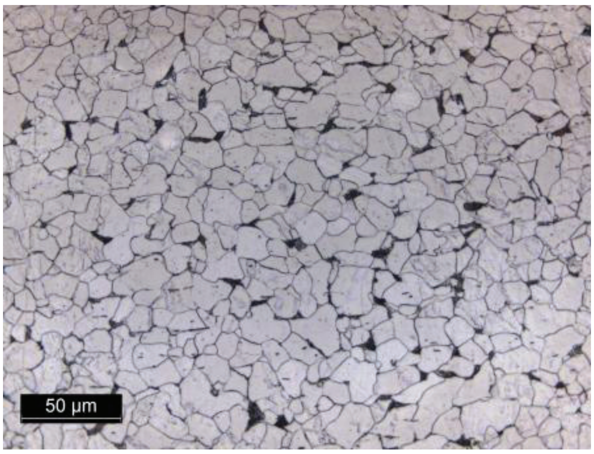


Figure 1. Microstructure of low carbon steel: the light colored ferrite region and the dark pearlite regions.

The geometrical surface area exposed to the solution was about 0.26 cm^2. Before electrochemical measurements, samples were mechanically polished with SiC papers up to grade 1200. Then they were degreased in ethanol, and three times in distilled water, and finally dried under an air flow.

The solution used for electrochemical tests was simulated concrete pore solution with addition of chlorides (SCP composition (pH=12.4) (g/L): $Ca(OH)_2$ (2.0), NaCl (29.25). This addition of chlorides was 10 times more important that real critical chloride threshold (C_{th}), to initiate the corrosion of steel in concrete (18). All electrochemical tests were carried out in stagnant conditions at room temperature.

The biomolecules (BMs) were kindly provided by Thierry Meylheuc (INRA, Massy) and was prepared as described previously (19). The 1 g/L of BMs was used in the electrochemical tests.

2.3 Electrochemical measurements

The electrochemical measurements were performed with a three-electrode cell with a volume of 0.15 L. The working electrode (WE) was carbon steel samples, the counter-electrode (CE) was a platinum wire with a large surface area, and the reference (Ref) electrode was a saturated calomel electrode (SCE: 0.241 V vs SHE).

Firstly, the corrosion potential (E_{corr}) was measured during 20 h of immersion. The linear polarization method was applied every 30 minutes, by linear polarization of ± 20 mV around the E_{corr} and with a sweep rate of 0.2 $mV.s^{-1}$. Electrochemical impedance diagrams were plotted at E_{corr} after 20h of immersion, with a frequency domain ranging from 10^5 Hz to 10^{-3} Hz, 5 points per decade, and amplitude of 10 mV peak-to-peak.

All the experiments were performed at room temperature in stagnant conditions. Electrochemical data was obtained from at least three separate experiments. Electrochemical tests and measurements were performed with a VSP potentiostat (Bio-Logic, France) and EC-Lab software v.10.37.

2.4 XPS analysis

XPS spectra were obtained on a Kratos Nova (IMN, Nantes, France) equipped with a monochromated Al kα X-Ray source (hv=1486.6 eV). Analysis was carried out using an accelerating voltage of 15 kV and a current of 10 mA. The binding energy was adjusted using a pure silver metal (Ag $3d_{5/2}$ = 0.55eV). All the survey spectra were performed at pass energy of 160 eV to identify all the elements present in the analyzed specimens. Chamber pressure before introduction of X-ray source was kept at 5 x 10^{-8} Torr and during analysis was 7 x 10^{-8} Torr. To control charging of the samples, the charge neutralizer filament was used during all experiments. The following sequences of spectra were recording: survey spectra (2 points per specimen), Fe 2p, C 1s, O 2s, N1s. Binding energies were determined by reference to the C 1s component of C-H,C set at 285 eV.

2.5 Scanning electron microscopy

After immersion in SCP solution without and with biomolecules, carbon steel specimens were coated by a thin film of gold by sputtering, and then micrographs were taken by SEM (Brucker, Gmbh). The energy of the acceleration beam employed was 10 kV and a working distance was 10mm.

3. Results and discussion

3.1 Corrosion inhibition efficiency of biomolecules deduced from electrochemical tests

From the Fig.2, the evolution of E_{corr} as the function of immersion time in corrosive solution can be seen. We can observe the same shape for both curves (with and without biomolecules) with a potential drop from -0.36 V vs SCE to 0.52 V vs SCE. In the absence of biomolecules, the stationary state is reached with the value of -0.55 V after 6 000 s. In the presence of biomolecules, the stationary state value of about -0.54 V is reached after 2000 s. No significant difference was observed between both evolutions of open circuit potential. It is well known that mixed inhibitors reduce the rate of the two partial reactions without modification of the corrosion potential (3). Linear polarization tests were carried out and polarization curve i(E) were presented on Fig. 3.

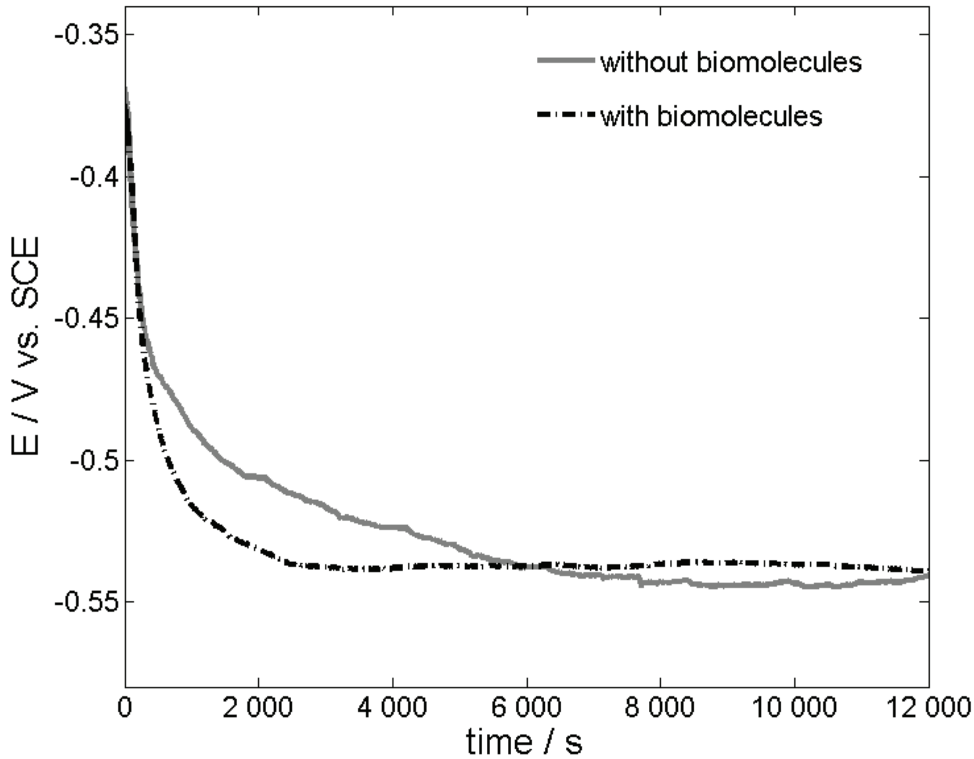


Figure 2. Corrosion potential of carbon steel (for rebars in concrete) vs. time of immersion in SCP solution without and with addition of biomolecules.

From Fig. 3, it can be seen that the cathodic branch of polarization curve as well as the anodic one are reduced by the presence of biomolecules. Thus, the BMs influence the two partial corrosion reactions and can be considered as mixed type inhibitor. Therefore, we can deduce that protection against corrosion occurred by creation of barrier on the carbon steel surface. Visual observations confirm the electrochemical data as the surface seems less attacked during the addition of inhibitor.

Moreover, the measurements of polarization resistance R_p every 1 800 s during a total immersion of 240 000 s were an important part for the evaluation of the inhibition efficiency of carbon steel surface against corrosion with time. The evaluation of R_p on carbon steel surface without and with BMs during the immersion tests is presented in Figure 4. The Fig. 4 shows that values of R_p are higher with addition of BMs. In this case, it can be seen a "little hump" at the beginning of the curve and up to 25 000 s, it was also present in the other tests (not shown here). This may be due to the reaction of the BMs with chloride ions in the test solution or to the establishment of stationary state of BMs in solution.

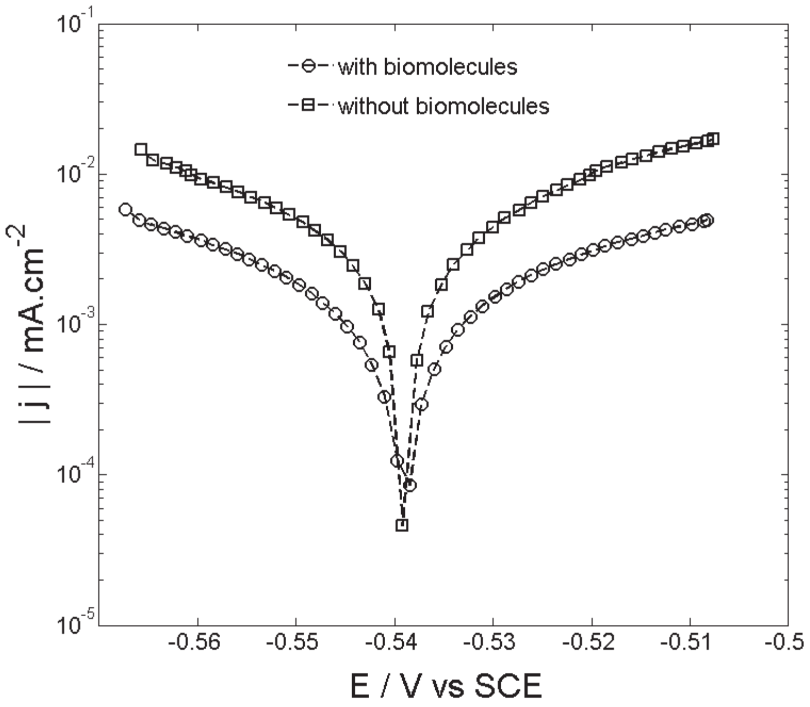


Figure 3. Polarization curves of carbon steel in aggressive SCP media without and with BMs.

As it can be seen from the Figure 4, corrosion inhibition efficiency (IE) of the biomolecules can be expressed. This parameter was calculated from the Rp values at the stationary state, using equation [1] and is equal to 58.6 %.

$$IE(\%) = \frac{Rp_{biomolecules} - Rp_{BLANK}}{Rp_{biomolecules}} \cdot 100\% \qquad [1] ,$$

where $Rp_{biomolecules}$ et Rp_{BLANK} are the values of resistance of polarization with and without biomolecules, respectively.

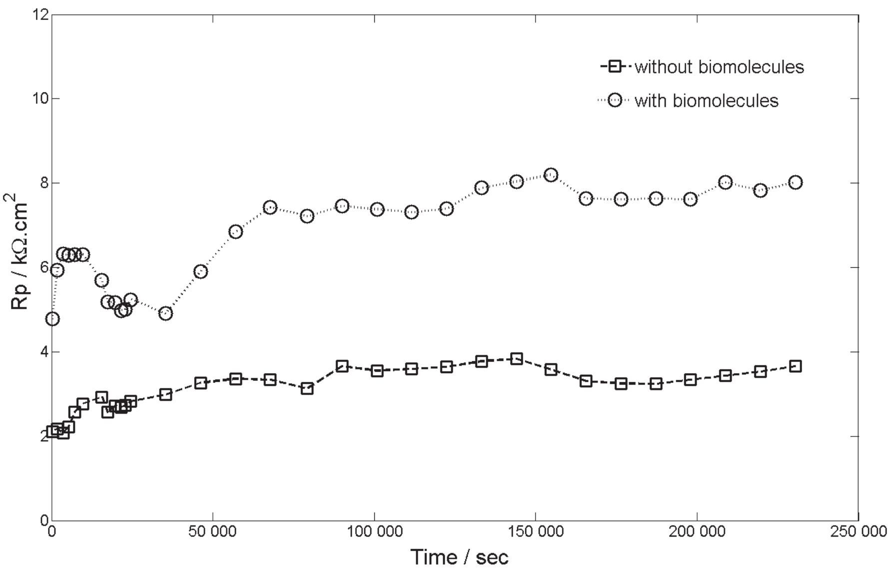


Figure 4. Evaluation of polarization resistance with time, during the immersion in aggressive solution: without and with biomolecules.

Electrochemical Impedance Spectroscopy (EIS) was also performed in order to validate the inhibition efficiency. The electrochemical impedance $\boldsymbol{Z}$ is a complex number depending of the ac-frequency.

Figure 5 shows the Nyquist diagrams in the complex plane (opposite of the imaginary part of the impedance $-\boldsymbol{Z_j}$ vs real part of the impedance $\boldsymbol{Z_r}$) plotted at $\boldsymbol{E_{corr}}$ after 20 h of immersion in corrosive media, without and with biosurfactant BMs. The diagrams present two capacitive loops at middle frequencies (MF) and very low frequencies (LF) as presented in figure 5. After 20h of immersion, we can assume that the first capacitive loop could be associated to the degradation of the low alloyed steel and the low frequency loop would give information of the formation of the corrosion product film on the electrode surface.

The size of the MF loop is significantly increased with the presence of BMs. This result, likewise XPS study (presents here below), can declare about the protection against corrosion due a previous BMs adsorption and changes in the composition of oxide layer on the carbon steel surface.

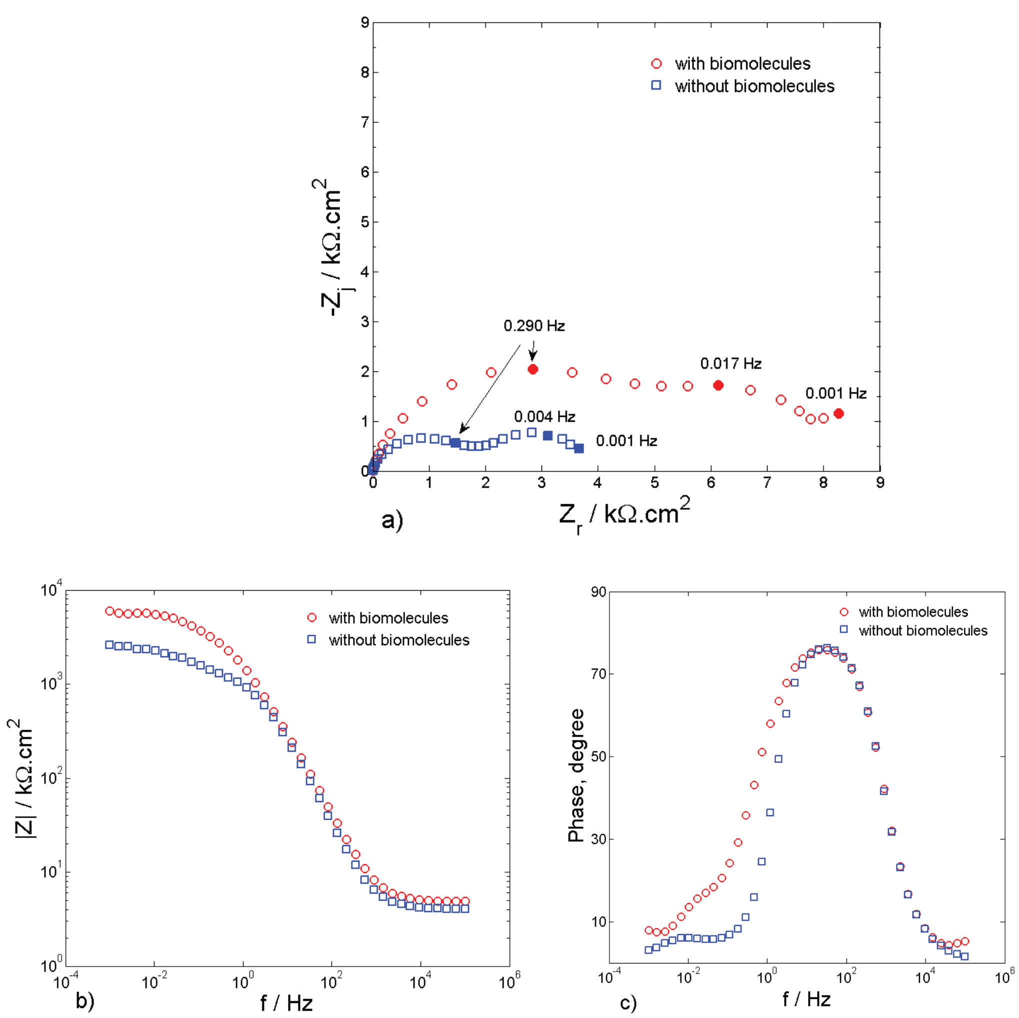


Figure 5. Experimental Electrochemical Impedance Spectroscopy Diagrams: 5 a) Nyquist diagrams and b), c) Bode representation of carbon steel samples plotted at E_{corr} after 20 h of immersion in simulated contaminated with [Cl-] concrete pore solutions, (□) without and (○) with BMs.

3.2 XPS results

The XPS measurements were carried out after electrochemical test (20 hours of immersion) to obtain the information about biomolecules adsorption on the surface. Figure 6 represents the XPS survey spectrum for the carbon steel material without and with biomolecules. For the spectrum for blank carbon steel, it is observed that the signal of iron (Fe 2p), oxygen (O 1s) and carbon (C 1s) are intensified compared to the remaining elements; and there is no nitrogen (N 1s) signal. For the survey spectrum, which represents protected against corrosion steel surface, the iron (Fe 2p) signal is less significant, and the presence of N 1s is clearly observed.

The decrease of intensity for a core level of iron indicates the adsorbed layer on the surface (20). Moreover, the important nitrogen signal is a fingerprint of the presence of BMs, as well as, an increase of oxygen and carbon peaks. It must be mentioned that the XPS survey spectra represents only qualitative information and for the further analysis the high resolution peaks must be studied.

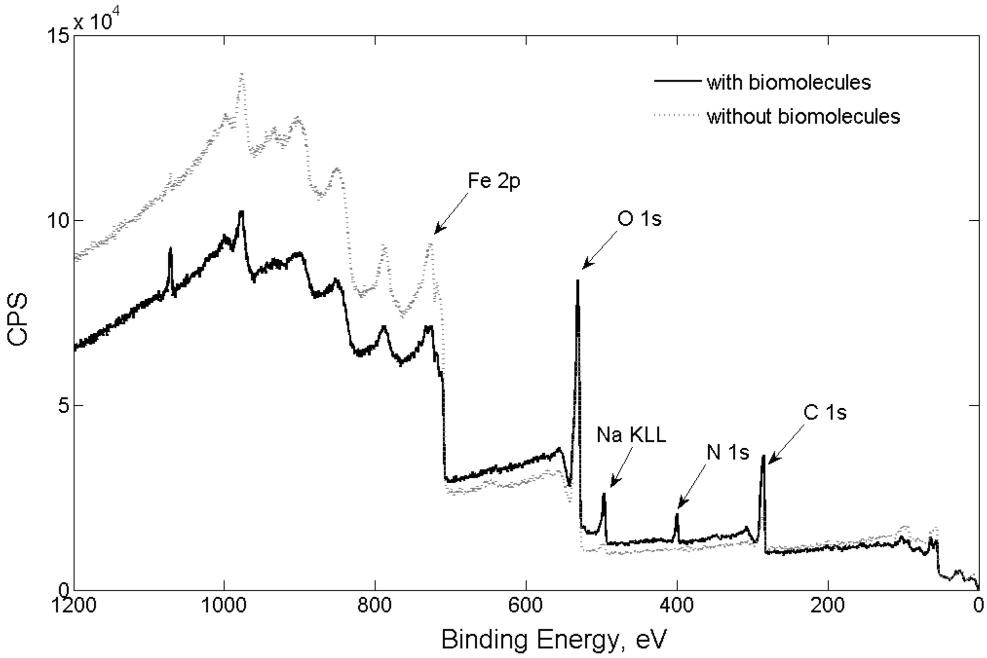
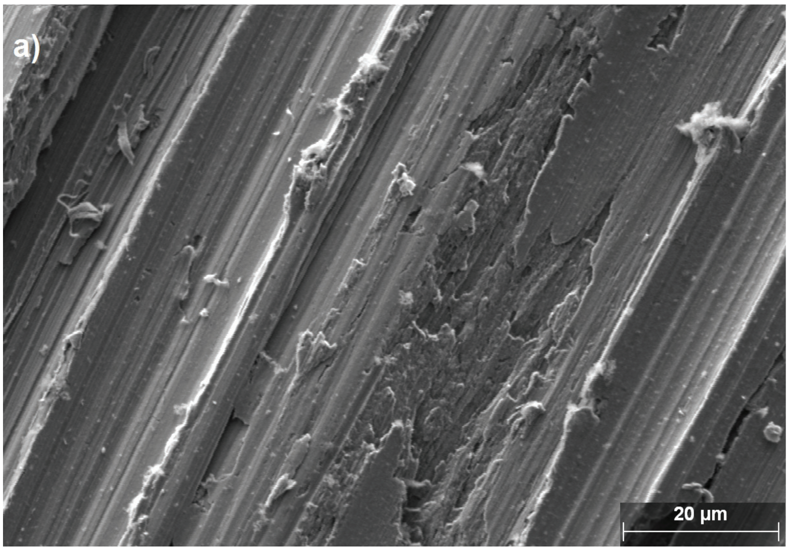


Figure 6. XPS survey spectra for the carbon steel specimens after corrosion tests: without and with biomolecules.

3.3 SEM study

The SEM images of carbon steel surfaces were carried out to establish a visual aspect of inhibition. Figure 7 shows the surface before (a) and after 20 hours of immersion in solution with an addition of BMs. The Figure 7b demonstrates that BMs have a strong tendency to adhere at the carbon steel surface and can be regarded like a good inhibitor against the steel corrosion in the presence of chloride ions.



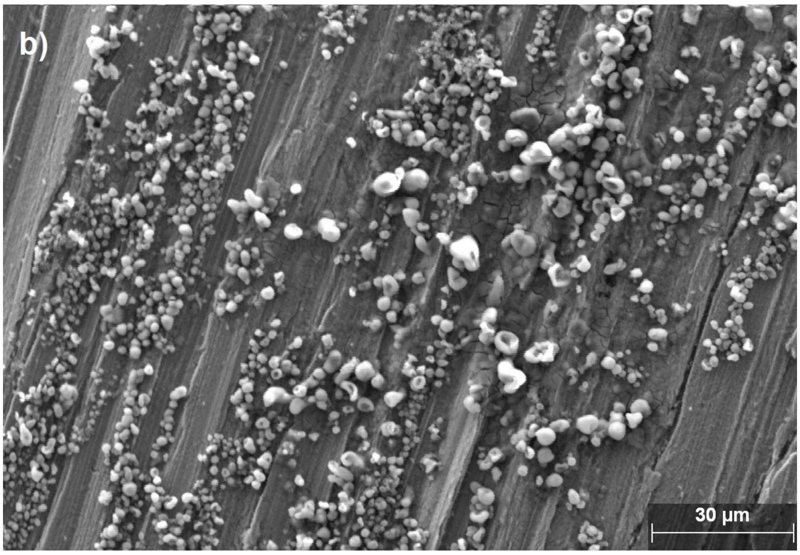


Figure 7. SEM micrographs of the carbon steel surface: a) before immersion in solution (SE MAG: x600); b) after immersion (t = 20 hours) in solution with BMs (SE MAG: x1000).

The BMs particles block both reaction sites: anodic and cathodic, by the creation of the zones of ohmic resistance between the carbon steel surface and electrolyte without changing the chemical conditions leading to the formation of corrosion products. In other words, these zones slow down galvanic reactions and the loss of electrons from the steel surface that leads to development of corrosion.

4. Conclusions

Nowadays, BMs are extremely studied molecules with multipurpose applications in biotechnology, pharmaceutical and in food industry. The demands for the “green” and sustainable products encouraged the BMs at the top of most popular research subjects.

Civil Engineering makes a part of our “everyday environment”. Buildings, bridges and other constructions can be damaged by corrosion. To reduce the corrosion rate we have to apply different methods, which could not be always environmentally friendly. The aim of the present study was to demonstrate that BMs could be a good opportunity for the civil engineering.

Following conclusions have been drawn from the present study:

- The biomolecules with the concentration of 1 g/L can be used like film-forming inhibitor of corrosion for carbon steel in concrete simulated solution;
- XPS and SEM analysis were performed, in order to obtain more information about the difference in chemical composition of surface before and after use of BMs;
- Linear Polarization tests and Electrochemical Impedance Spectroscopy showed the relatively good inhibition properties of BMs. The inhibition properties of BMs increase slightly with time. It was shown that inhibitor can be considered as the mixed type inhibitor.

Nevertheless, the validation of inhibition properties of BMs in real mortar-embedded rebars is needed and will be developed in future study.

Currently, in biotechnology attempts were made on a big emphasis of the development of cheap methodology of BMs to large-scale production. After that, chemical compounds could be successfully replaced by analogical BM.

5. References

1. Günter Schmitt, Michael Schütze, George F. Hays, Wayne Burns, En-Hou Han, Antoine Pourbaix, Gretchen Jacobson. Global Needs for Knowledge Dissemination, Research, and Development in Materials Deterioration and Corrosion Control. World Corrosion Organization. 2009.
2. Corrosion inhibitors for steel in concrete: State-of-the-art report. T.A. Söylev, M.G. Richardson. 4, 2008, Construction and Building Materials, Vol. 22, pp. 609-622.
3. Dieter Landolt. Corrosion et Chimie des Surfaces des Métaux,. Lausanne : Presses Polytechniques et Universitaires Romandes, 1993.
4. Corrosion of reinforcement in concrete: Corrosion Mechanisms and Corrosion Protection, papers from EUROCORR’99, European Federation of Corrosion Publications Number 31, London, 2000
5. Stainless Steel in Concrete: State of the Art Report, European Federation of Corrosion Publications Number 18, London, 1996
6. Corrosion of steel in reinforced concrete structures, Final report, European Cooperation in the field of scientific and technical research, R.Cigna, C.Andrade, U.Nurnberger, R.Polder, R.Weydert, E.Seitz, COST Action 521, 2003
7. Omar S. Baghabra Al-Amoudi, Mohammed Maslehuddin, A.N. Lashari, Abdullah A. Almusallam, Effectiveness of corrosion inhibitors in contaminated concrete, Cement & Concrete Composites 25 (2003), 439-449
8. Luca Bertolini, Bernhard Elsener, Pietro Pedeferri, Elena Redaelli, Rob B. Polder. Corrosion of Steel in Concrete: Prevention, Diagnosis, Repair. Weinheim : Wiley-VCH Verlag GmbH&Co, 2013.

9. Natural products as corrosion inhibitor for metals in corrosive media — A review. Pandian Bothi Raja, Mathur Gopalakrishnan Sethuraman. 15, 2008, Materials Letters, Vol. 62, pp. 113-116.
10. Anti-corrosion Ability of Surfactants: A Review. Maqsood Ahmad Malik, Mohd Ali Hashimn, Firdosa Nabi, Shaeel Ahmed AL-Thabaiti, Zaheer Khan. 2011, International Journal of Electrochemical Science, Vol. 6, pp. 1927-1948.
11. Adsorption and corrosion inhibiting behavior of Lannea coromandelica leaf extract on mild steel corrosion. P. Muthukrishnan, B. Jeyaprabha, P. Prakash, Arabian Journal of Chemistry, Available online 29 August 2013, ISSN 1878-5352.
12. Electrochemical noise investigation of Aloe plant extract as green inhibitor on the corrosion of stainless steel in 1 M H_2SO_4. M. Mehdipour, B. Ramezanzadeh, S.Y. Arman, Journal of Industrial and Engineering Chemistry, Available online 2 March 2014, ISSN 1226-086.
13. Green approach to corrosion inhibition of 304 stainless steel in hydrochloric acid solution by the extract of Salvia officinalis leaves. Nasrin Soltani, Nahid Tavakkoli, Maryam Khayatkashani, Mohammad Reza Jalali, Ahmad Mosavizade. 2012, Corrosion Science, Vol. 62, pp. 122-135.
14. Copper corrosion inhibition by Azadirachta indica leaves extract in 0.5 M sulphuric acid. L. Valek, S. Martinez. 2007, Material letters, Vol. 61, pp. 148-151.
15. Inhibition by Jasminum nudiflorum leaves extract of the corrosion of aluminium in HCl solution. Shuduan Deng, Xianghong Li. 2012, Corrosion Science, Vol. 64, pp. 253-262.
16. Green *Bambusa Arundinacea* leaves extract as a sustainable corrosion inhibitor in steel reinforced concrete. Salawu Abdulrahman Asipita, Mohammad Ismail, Muhd Zaimi Abd Majid, Zaiton Abdul Majid, CheSobry Abdullah, Jahangir Mirza. 2014, Journal of Cleaner Production, Vol. 67, pp. 139-146.
17. Inhibition Effect of *Vernonia amygdalina* extract on the corrosion of mild steel reinfocement in concrete in 0.5 M NaCl environment. C.A. Loto, O.O. Joseph, R.T. Loto, A.P.I. Popoola. 2013, International Journal of Electrochemical Science, Vol. 8, pp. 11087-11100.
18. Ahmed Elshami, Efficiency of Corrosion Inhibitors Used For Concrete Structures in Aggressive environment, phD thesis, University of Nantes, 2012.
19. Adsorption of biosurfactant on solid surfaces and consequences regarding the bioadhesion of Listeria monocytogenes LO28. Thierry Meylheuc, C.J. van Oss, M.-N. Bellon-Fontaine, Journal of Applied Microbiology 2001, 91, 822-832.
20. Enhanced corrosion resistance of mild steel in 1 M hydrochloric acid solution by alkaloids extract from Aniba rosaeodora plant: Electrochemical, phytochemical and XPS studies, Maxime Chevalier, Florent Robert, Nadine Amusant, Michel Traisnel, Christophe Roos, Mounim Lebrini, Electrochimica Acta, Volume 131, 10 June 2014, Pages 96-105.

6. Acknowledgments

The authors would like to thank The French Institute of Science and Technology for transport, development and networks (IFSTTAR) for its financial support.

The Ecodesign Directive: From Energy Efficiency to Resource Efficiency

Anja Marie Bundgaard[1] and Arne Remmen[1]

[1] Aalborg University, Department of Development and Planning, Vestre Havnepromenade 9, 9000 Aalborg, Denmark

Abstract

Resource efficiency is currently high on the European political agenda and the Ecodesign Directive has been identified as one of the instruments, which could help drive this agenda. Hence, the purpose of this study was to investigate if and how requirements for resource efficiency are currently implemented in the Ecodesign Directive? And what made it possible to include these types of requirements?

A review of the requirements in the adopted implementing measures and voluntary agreements under the Ecodesign Directive showed that requirements targeting resource efficiency were included. However, these requirements were mainly information requirements. Sixteen of the implementing measures and voluntary agreements included information requirements targeting resource efficiency. Only five product groups included specific requirements targeting resource efficiency.

Two detailed studies were made of the implementing measure covering vacuum cleaners and the voluntary agreement covering imaging equipment, since they both included resource efficiency requirements. The studies revealed that in both cases resource efficiency was regarded as a significant impact category. However, in both cases resource efficiency was considered secondary to energy efficiency, and it should be targeted at a later stage. Yet, in both cases resource efficiency requirements ended up in the final requirements. Hence, the identification of resource efficiency as a significant was not the sole reason for the uptake of the resource efficiency requirements. Other aspects were at play. Interviews with stakeholders indicated that pressure from stakeholders was a crucial aspect. In both cases, it was possible to pressure the industry by different means, which made them accept resource efficiency requirements. Furthermore, the fact that resource efficiency was on the political agenda also played a significant role. Finally, the existence of measurement and test standards and eco-labelling schemes were important for implementing the resource efficiency requirements.

1. Introduction

Resource efficiency is currently high on the European political agenda, e.g. the flagship initiative "a Resource Efficiency Europe" (European Commission 2011b) and "The Roadmap to Resource Efficiency (European Commission 2011c), and the adoption of the communication "Towards a Circular Economy a Zero Waste Program for Europe"(European Commission 2014b) in 2014.

In the European Roadmap to Resource Efficiency, the Ecodesign Directive is identified as one of the instruments that plays a vital role in the change towards increased resource efficiency, "*An approach using both voluntary and mandatory measures - as the EU's lead market Initiatives and the Ecodesign Directive - should be considered for a wider range of products and services and include more resource relevant criteria*" (European Commission 2011c, p. 5). Therefore, the Ecodesign Directive is assigned a significant role in making consumption and production more resource efficient.

The Ecodesign Directive establishes *"a framework for the setting of Community ecodesign requirements for energy-related products with the aim of ensuring the free movement of such products within the internal market."* (European Union 2009, p. 4). The generic and specific requirements are laid down in implementing measures or in voluntary agreements made with the industry. When setting these requirements, the whole life cycle of the product should be considered, and the most significant environmental aspects should be targeted. Traditionally, the requirements have target energy consumption in the use phase (Dalhammar et al. 2014, Bundgaard, Zacho & Remmen 2013, Huulgaard, Remmen 2012). However with the resource efficiency agenda high on the political agenda in the European Union, this might be changing. Therefore, the main objective of this study is to examine how resource efficiency requirements (excluding energy) are included in the implementing measures and the voluntary agreements under the Ecodesign Directive and what made it possible to include these types of requirements?

2. Material and methods

In order to examine how resource efficiency is currently implemented in the Ecodesign Directive, a review was made of all adopted implementing measures and voluntary agreements with the purpose of identifying existing resource efficiency requirements (excluding energy). When identifying resource efficiency requirements, a broad understanding of resource efficiency was applied, including improved through reduction, maintenance and repair, reuse and redistribution, remanufacturing and refurbishment and recycling of materials.

Based on the review, two product categories were selected (imaging equipment and vacuum cleaners) for further study, because they had the most ambitious resource efficiency requirements. The purpose of the two studies was to examine what made it possible to set the resource efficiency requirements through reviews of the background documents made during the process of developing the requirements, stakeholder comments from the consultation forums and qualitative research interviews with actors involved in the process. These actors are listed in table 1.

Interviewee	Organisation	Description
Karl Edsjö	Electrolux	Producer
Stephane Arditi	European Environmental Bureau	NGO
Ewout Deurwaarder	DG Energy	Policy Officer Energy Efficiency/Ecodesign and Energy Labelling
Robert Nuij	DG Energy	Head of Sector Energy Efficiency of Products
Ferenc Pekar	DG Environment	Policy Officer
Interviewee 1	Representative from EuroVAprint	Trade association
Interviewee 2	Representative from EuroVAprint	Trade association
Adrian Tan	Bio-intelligence	Consultant

Table 1: Overview of the interviewees

3. Review and Discussion of Existing Resource Efficiency Requirement in the Ecodesign Directive

The result of the review of existing resource efficiency requirements in the implementing measures and voluntary agreements is presented in table 2. The review showed that currently there are generic information requirements targeting resource efficiency in 15 implementing measures and one voluntary agreement. While, specific requirements targeting resource efficiency were only included in five implementing measures: three covering different lighting products, domestic washing machines and vacuum cleaners and one voluntary agreement covering imaging equipment.

Product groups	Resource efficiency requirements
Space and combination heaters (European Commission 2013c)	**INFORMATION REQUIREMENT** Information relevant for disassembly, recycling and/or disposal at end-of-life
Water heaters (European Commission 2013d)	**INFORMATION REQUIREMENT** Information relevant for disassembly, recycling and/ or disposal at end-of-life
PCs and servers (European Commission 2013a)	**INFORMATION REQUIREMENT** Information on the minimum number of loading cycles that the batteries can withstand. For product with an integrated display containing mercury, information on the content of mercury. If a notebook computer is operated by battery that cannot be accessed and replaced by a non-professional user, the manufacturer shall make this information available on free-access websites and on the external packaging.
Televisions (European Commission 2009f)	**INFORMATION REQUIREMENTS** Information on hazardous substances, if the television contains mercury or lead. The content of mercury as X,X mg and the presence of lead.
Fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps (European Commission 2009b)	**SPECIFIC REQUIREMENTS** Lamps: Requirements for lamp lumen maintenance factor. Requirements for lamp survival factor **INFORMATION REQUIREMENTS** Lamps: Information on rated lamp lumen maintenance factor, rated lamp survival factor, lamp mercury content as X,X mg. Luminaires: Product information requirements on luminaries should include: maintenance instructions to ensure that the luminaire maintains as far as possible its original quality throughout its lifetime, disassembly instructions.
Directional lamps, light emitting(European Commission 2012a) **diode lamps and related equipment** (European Commission 2012a)	**SPECIFIC REQUIREMENTS** Lamp survival factor, lumen maintenance, number of switching cycles before failure, premature failure rate, rated lamp lifetime. **INFORMATION REQUIREMENTS** Information on: Nominal life time of the lamp in hours, number of switching cycles before premature failure, rated lamp life time, lumen maintenance factor at the end of the nominal life. If the lamp contains mercury, then information on: Lamp mercury content as X,X mg, instructions on how to clean up the lamp debris in case of accidental lamp breakage, recommendations on how to dispose of the lamp at the end of its life for recycling.
Non-directional household lamps (European Commission 2009a)	**SPECIFIC REQUIREMENTS** Lamp survival factor, lumen maintenance, number of switching cycles before failure, premature failure rate, rated lamp lifetime **INFORMATION REQUIREMENTS** Information on the nominal lifetime of the lamp in hours, number of switching cycles before premature lamp failure, rated lamp life-time. If the lamp contains mercury then information on mercury content as X,X mg, indication which website to consult in case of accidental lamp breakage to find instructions on how to clean up lamp debris, recommendation on how to dispose of the lamp at its end of life.
Electric motors (European Commission 2009d)	**INFORMATION REQUIREMENTS** Information relevant for disassembly, recycling or disposal at end-of-life.
Ventilation fans (industrial fans)(European Commission 2011a)	**INFORMATION REQUIREMENTS** Information relevant for facilitating disassembly, recycling or disposal at end-of-life. Information relevant to minimise impact on the environment and ensure optimal life expectancy as regards installation, use and maintenance of the fan.
Circulators in buildings (European Commission 2012d, European Commission 2009e)	**INFORMATION REQUIREMENTS** Information concerning disassembly, recycling, or disposal at end-of-life of components and materials, shall be made available for treatment facilities. Manufacturers shall provide information on how to install, use and maintain the circulator in order to minimise its impact on the environment.
Water pumps (European Commission 2012c)	**INFORMATION REQUIREMENTS** Information relevant for disassembly, recycling or disposal at end-of-life

Product groups	Resource efficiency requirements
Domestic washing machines (European Commission 2010a)	**SPECIFIC REQUIREMENTS** Requirements on water consumption **INFORMATION REQUIREMENTS** Recommendation on the type of detergent suitable for the various washing temperatures.
Domestic dishwashers (European Commission 2010b)	**INFORMATION REQUIREMENTS** Information on the standard cleaning cycle referred to as "standard programme" and shall specify that it is suitable to clean normally soiled tableware and that is the most efficient programme in terms of its combined energy and water consumption for that type of tableware. Information on the indicative programme time, energy and water consumption for the main cleaning programmes.
Vacuum cleaners (European Commission 2013b)	**SPECIFIC REQUIREMENTS** The hose, if any, shall be durable so that it is still usable after 40,000 oscillations under stain. The operational motor lifetime shall be greater than or equal to 500 hours. **INFORMATION REQUIREMENTS** Information relevant for non-destructive disassembly for maintenance purpose, in particular in relation to hose, suction, inlet, motor, casing and cable. Information relevant for dismantling, in particular in relation to the motor and any batteries, recycling, recover and disposal at end-of-life.
Domestic ovens, hobs and range hoods (European Commission 2014a)	**INFORMATION REQUIREMENTS** Information relevant for non-destructive disassembly for maintenance purpose and information relevant for dismantling, in particular in relation to the motor, if applicable, and any batteries, recycling, recovery and disposal at end-of-life. DOMESTIC OVENS Mass of the appliance
Imaging equipment (EuroVAprint 2012)	**SPECIFIC REQUIREMENTS** Duplex availability, duplex-printing is set as default, availability of N-up printing Design for recycling: • Plastic parts>100 g shall be manually separable into recyclable plastic streams with commonly available tools. • Products shall utilize commonly used fasteners for joining components, subassemblies, chassis and enclosures. • Non-separable connections (e.g. glued, welded) between different materials shall be avoided unless they are technically or legally required. • Product plastics shall be marked by material type. Cartridges: • Any cartridge produced by or recommended by the OEM for use in the product shall not be designed to prevent its reuse and recycling. • The machines shall not be designed to prevent the use of a non-OEM cartridge. **INFORMATION REQUIREMENTS** Provide end-users with information regarding resource efficiency when using imaging equipment. Information that recycled as well as virgin paper certified under environmental stewardship initiatives or carrying recognised ecolabels may be suitable. For electro photography printers: indication that these can print 64 gr/m2 paper and that this paper contain less raw materials per print. Description of the benefits of printing in duplex mode Cartridge disposal and treatment Signatories shall provide end-users with information on suitable end-of-life management options for used cartridges. Information on product environmental characteristics. Information on the environmental performance of their product shall be available to customers. Information on inkjet and toner cartridge yield available to customers based on the measurement standards specified.

Table 2: Overview of the requirements targeting resource efficiency in the 21 adopted implementing measures and the two adopted voluntary agreements. The implementing measure for standby and off mode losses (European Commission 2008), battery chargers and external power supplies (European Commission 2009c), air conditioners and comfort fans (European Commission 2012b), domestic refrigerators (European Commission 2009g) and household tumble driers (European Commission 2012e) and the voluntary agreement on complex set top boxes (VA Steering Committee 2013)

did not include any resource efficiency requirements and are therefore excluded from the table. The wording in the table is the same or very similar to the one from the implementing measures or voluntary agreements.

The specific requirements targeting resource efficiency covered different aspects. For lighting it included requirements for lamp survival factor, lumen maintenance and number of switching before cycle failure. For vacuum cleaners there were requirements to the durability of the hose and requirements for the operational motor lifetime. All these requirements target a longer lifetime of the product. Moreover, in the implementing measure covering domestic washing machines there were requirements to the water consumption during the use stage. The voluntary agreement for imaging equipment included several specific requirements targeting resource efficiency. Firstly, requirements targeting the use of consumables such as the availability of N-up printing, the availability of duplex-printing and duplex-printing as default. Furthermore, the voluntary agreement set requirements for design for recycling. Only five implementing measures and one voluntary agreement included specific requirements targeting resource efficiency. Hence, there seems to be an improvement potential. For many years, energy has been the main focus in the Ecodesign Directive. However, with the energy improvements already ready gained, other issues might need our attention such as durability, reparability, reusability and recyclability.

The information requirements covered aspects such as information relevant for disassembly, recycling or disposal at end-of-life. It is important that the end-user know how to correctly dispose the product at its end-of-life, or the product may never enter a proper recycling system. It is also important that the recyclers know how to disassemble and recycle the products in the best possible way. Such information could be made more easily available, by embedding it in the product in e.g. a chip. Although, with the highly automatic and destructive methods applied today, especially by the European recyclers (Masanet et al. 2002), it can be questioned if information on disassembly will be used during the recycling process. In any case, this information can be important in order to ensure that e.g. hazardous components, precious metals and rare earths are removed and threated separately.

Information requirements on easy disassembly were included, which also can be significant in relation to maintenance. A study has shown that key obstacles for repair of fridges, dishwashers and washing machines were increased difficulties to disassemble the product for repair (RREUSE unknown). Easy disassembly can also be relevant for the end-of-life treatment. Despite the automatic and destructive processes applied today, the recyclers still have to remove certain component in accordance with the WEEE Directive. Hence, the Ecodesign Directive could potentially support the requirements in the WEEE Directive. Moreover, easy disassembly could also make it easier to remove components requiring special treatment, such as hazardous components or components containing valuable materials.

Furthermore, information requirements on hazardous substances were also included in the requirements. These types of information is important for the recycles, because it enables them to identify the components that need special treatment due to their content of hazardous substances. Again, the producers could make this information more easily available for the recyclers.

Information on the products durability was also included in the requirements. This type of information provides the end-user with necessary information to make an informed choice when selecting e.g. a computer or a lighting source. Generally, durability could be relevant to regulate, because the lifetime of certain electrical and electronic products are decreasing (Zonneveld 2014). Of course, extended durability should not result in increased energy consumption in the use phase, if newer products have significantly better energy performance. Finally, information requirements to stipulate the most efficient use of the product is also key – especially in relation to energy-related products, and it is an aspect that could be further developed.

4. The Two Case Studies: Imaging Equipment and Vacuum Cleaners

4.1. The Voluntary Agreement on Imaging Equipment

The Commission recognised the voluntary agreement on imaging equipment February 2013 (EuroVAprint 2012). The specific ecodesign requirements are presented in table 3. The voluntary agreement covers imaging equipment for household and office equipment. Sixteen signatories have signed the voluntary agreement, and they account for more than 90% of the European market for imaging equipment. The voluntary agreement expired in April 2014. A new version was drafted by the industry, but the Commission has not yet approved it (EuroVAprint 2014).

	January 2012
Energy	90% or more of the products placed on the EU market by the Signatories shall comply with the specifications of Energy Star v.1.1. (Energy consumption requirements and default delay time).
Paper	Duplex availability (depending on monochrome print speed) Duplex-printing is set as default when printing from the computer. Availability of N-up printing.
Cartridges	Shall not be designed to prevent its reuse and recycling. The machine shall not be designed to prevent the use of non-OEM cartridges.
Design for recycling	Plastic parts > 100g shall be manually separable into recyclable plastic streams with commonly available tools. Products shall utilize commonly used fasteners for joining components, subassemblies, chassis and enclosures. Non-separable connections (e.g. glues, welded) between different materials shall be avoided unless they are technically or legally required. Product plastics (>25 g or surface area > 50 cm^2) shall be marked by material type (ISO 11469 referring ISO1043).

Table 3: Specific ecodesign requirements in the voluntary agreement on imaging equipment. The information requirements are omitted. (EuroVAprint 2012)

The basis for setting resource efficiency requirements in the voluntary agreement was that resource efficiency was identified as an area for improvement along with energy efficiency in the use phase in the preparatory study (AEA Energy & Environment 2009). For resource efficiency to be included in the preparatory study, it needs to be part of the Methodology for Ecodesign of Energy-related Products (MEErP), which specifies how to conduct the preparatory study. Therefore, MEErP is important if resource efficiency requirements should be implemented in the regulation. The European Commission has already had one project on the implementation of material efficiency into MEErP (BIO Intelligence Service 2013b, BIO Intelligence Service 2013a, BIO Intelligence Service 2013c). However, the alterations to MEErP proposed in this project are minor, and this will not alone be able to ensure that material efficiency requirements are implemented – so further initiatives are needed. The recommendation in the preparatory study was firstly to focus on energy and then later to include additional requirements such as resource efficiency (AEA Energy & Environment 2009). Furthermore, the resource efficiency requirements were not included in the first draft of the voluntary agreement. This indicates that other drivers were important for the uptake of resource efficiency requirements.

A driver was that resource efficiency was on the political agenda. The voluntary agreement was finalised concurrent with the publication of the flagship and roadmap on resource efficiency. Furthermore, the implementation of the resource efficiency requirements was also an effect of pressure from stakeholders involved in the process. As expressed by one of the representatives from EuroVAprint, "*What we have witnessed is a series of requests, which came from the institutional side, the European Commission - DG Energy. At least they were channelled through the European Commission, but they came from civil society in general and stakeholders in the wider sense EPAs, ministries, consumer and environmental groups...We were at the time in the drafting phase, and we were under a lot of pressure from these stakeholder groups. Specifically, the European Consumers and Environmental NGOs. ... but my impression is that originally we* *were supposed to focus solely on Energy Star and energy consumption but then it got broader"* (EuroVAprint 2014) The industry was perhaps also more vulnerable and inclined to satisfy the stakeholders, because if they did not satisfy the stakeholders and especially the Commission, they would be facing regulation. As expressed by a representative from the EuroVAprint, *"but in the voluntary agreement my feeling is that because it is a voluntary agreement in order to somehow make the voluntary agreement to be more appealing to member states and NGOs, we had to accept more things than we would have had in an implementing measure"* (EuroVAprint 2014). Hence, the fact that the industry was keen on avoiding regulation, in the form of implementing measures, inclined them to go a bit further in the types of requirements they would include in the voluntary agreement.

Finally, it was possible to include resource efficiency requirements, because the voluntary agreement could build on existing initiatives. For instance, the requirements for default delay time and the requirement for duplex availability derived from the Energy Star version 1.1, and additional requirements were based on ecolabels such as the Blue Angel or the Electronic Environmental Assessment Tool (EPEAT) (EuroVAprint 2014).

4.2. Implementing Measure for Vacuum Cleaner

The implementing measure for vacuum cleaners was adopted in July 2013. The requirements entered into force September 2014, and the demands are further tightened in September 2017. In the implementing measure, requirements are set to energy consumption in the use phase, dust pick up, dust reemission, noise and durability see table 4.

	September 2014	September 2017
Annual energy consumption	62.0 kWh/ year	43.0 kWh/ year
Rated input power	1,600 W	900 W
Dust pick up on carpet	0.70	0.75
Dust pick up on hard floor	0.95	0.98
Dust re-emissions		1 %
Sound power level		80 dB(A)
Hose durability		40,000 oscillations under strain
Motor durability		<500 hours

Table 4: Specific ecodesign requirements for vacuum cleaners (European Commission 2013b). The information requirements are omitted.

The fact that durability was emphasised in the preparatory study laid the basis for including requirements in the implementing measure. As expressed by the policy officer currently involved, *"What is relevant for vacuum cleaners is that the preparatory study already identified that there was an issue of durability with vacuum cleaner"* (Deurwaarder 2014). As mentioned earlier, for resource efficiency to be included in the preparatory study, it needs to be attached importance to in MEErP. Hence, MEErP is an important tool if further resource efficiency requirements should be included in the implementing measures and voluntary agreements. However, it should be mentioned that durability was not proposed in the preparatory study as one of the first impact categories to set requirements to nor were the durability requirements included in the first version of the implementing measures. In other words, the fact that durability was emphasised in the preparatory study was not the sole driver for its implementation in the final version of the implementing measures.

Another driver for including the durability requirements in the final version might be that resource efficiency had come on the political agenda with the publication of the flagship and roadmap to resource efficiency. Hence, DG Environment might have seen a possibility for pushing the resource efficiency agenda in the case of vacuum cleaners. It was also emphasised by the stakeholders that DG Environment was pushing the inclusion of the durability requirements, as expressed by a policy officer from DG Environment, *"We have been pushing for the inclusion of durability requirements for the hose and the electric motor that was finally accepted…"* (Pekar 2014). According to a stakeholder (Edsjö 2014) involved in the process, the fact that the implementing measure was developed simultaneously with and linked to the Energy Labelling also had a somewhat positive impact for the implementation of the durability requirements. Because part of the industry was interested in getting the Energy Label and in exchange were willing to accept the durability requirements in the implementing measure. As expressed by the stakeholder involved *"we thought it would be damaging, if they scraped the energy labelling because of the ecodesign. It was a risk as we saw it"* (Edsjö 2014). So the fact that part of the industry was interested in getting the Energy Label made them more inclined to accept the durability requirements.

Finally, the implementation of the requirements was also made possible by the fact that an accepted industry standard existed for the durability of the motor and for the hose (Deurwaarder 2014). These standards are important in order to ensure that the requirements can be measured, verified and thereby also are enforceable.

5. Conclusion

This review of the requirements in the adopted implementing measures and voluntary agreements within the Ecodesign Directive showed that requirements targeting resource efficiency were included. Information requirements focusing on resource efficiency or end-of-life were found in 16 of the 23 implementing measures and voluntary agreements. Few specific requirements targeting resource efficiency were found. Hence, this could be further unfolded in future revisions and developments of new implementing measures and voluntary agreements.

Two case studies were made of the implementing measure on vacuum cleaners and the voluntary agreement on imaging equipment, because these two product categories had some of the most elaborated resource efficiency requirements. The two cases revealed that in both cases resource efficiency was regarded as a significant impact category in the preparatory study. It emphasises the importance of the MEErP methodology to ensure that resource efficiency is approached during the preparatory study. However, in both cases, the preparatory studies concluded that resource efficiency should be regulated at a later stage after adopting the energy requirements. Resource efficiency was considered secondary to the energy requirements. Nevertheless, in both cases they were included anyway in the final version. This indicates that other drivers were at play when resource efficiency requirements were successfully implemented in the two cases.

One driver was pressure from internal and external stakeholders in particular DG Environment, who played a significant role in both cases. Furthermore, it was possible to convince the industry to accept the resource efficiency requirements by different means. In the case of imaging equipment, the industry was to avoid regulation, and they therefore accepted the resource efficiency requirements. In the case of vacuum cleaners, part of the industry wanted the EU Energy Label, and they therefore accepted the resource efficiency requirements. Another driver for implementing resource efficiency requirements was that when the voluntary agreement and the implementing measure were developed, resource efficiency was higher up on the political agenda through. A final driver was the existence of measurement and test standards and other voluntary schemes, which were important to be able to set and enforce the requirements.

6. References:

AEA Energy & Environment 2009, *Work on Preparatory Studies for Eco-Design Requirements of EUPs Lot 17 Vacuum Cleaners TREN/D3/390-2006 Final Report*.

BIO Intelligence Service 2013a, *Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP), Part 1: Material Efficiency for Ecodesign - Draft Final Report*, Prepared for: European Commission - DG Enterprise and Industry.

BIO Intelligence Service 2013b, *Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP), Part 2 - Enhancing MEErP for Ecodesign*, Prepared for: European Commission - DG Enterprise and Industry.

BIO Intelligence Service 2013c, *Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP), Part 2 - Test Reports TV and Washing Machine*, European Commission, DG Enterprise and Industry.

Bundgaard, A.M., Zacho, K.O. & Remmen, A. 2013, *Product policies on the environmental performance of washing machines: Investigating the synergies and coherence between policy instruments*, Nordic Council of Ministers.

Dalhammar, C., Machacek, E., Bundgaard, A.M., Zacho, K.O. & Remmen, A. 2014, *Addressing ressource efficiency through the Ecodesign Directive: A review of opportunities and barriers*, Nordic Council of Ministers.

Deurwaarder, E. 2014, *Transcription of interview with Ewout Deurwaarder from DG Energy March 4. 2014*.

Edsjö, K. 2014, *Transcription of interview with Karl Edsjö from Electrolux Major Appliances Europe 28. February 2014*.

European Commission 2014a, *Commission Regulation (EU) no 66/2014 of 14 January 2014 implementing Directive 2009/125/EC of the European Parliament and of the Council with regards to ecodesign requirements for domestic ovens, hobs and range hoods.*

European Commission 2014b, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Towards a circular economy: A zero waste programme for Europe*.

European Commission 2013a, *COMMISSION REGULATION (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers*.

European Commission 2013b, *Commission regulation (EU) No 666/2013 of 6 July 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for vacuum cleaners*.

European Commission 2013c, *Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters*.

European Commission 2013d, *Commission Regulation (EU) No 814/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water heaters and hot water storage tanks*.

European Commission 2012a, *Commission regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment*.

European Commission 2012b, *Commission regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans*.

European Commission 2012c, *Commission regulation (EU) No 547/2012 of 25 June 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water pumps*.

European Commission 2012d, *Commission regulation (EU) No 622/2012 of 11 July 2012 amending Regulation (EC) No 641/2009 with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products*.

European Commission 2012e, *Commission regulation (EU) No 932/2012 of 3 October 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household tumble driers*.

European Commission 2011a, *Commission regulation (EU) No 327/2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW*.

European Commission 2011b, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A resource-efficient Europe - Flagship initiative under the Europe 2020*, European Commission, Brussels.

European Commission 2011c, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Roadmap to a Resource Efficient Europe*, European Commission, Brussels.

European Commission 2010a, *Commission regulation (EU) No 1015/2012 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines*.

European Commission 2010b, *Commission regulation (EU) No 1016/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers*.

European Commission 2009a, *Commission regulation (EC) No 244/2009 of 18 March 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps*.

European Commission 2009b, *Commission Regulation (EC) No 245/ 2009 of March 2009 implementing Directive 2005/32/EC of the European Parliament of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and the Council*.

European Commission 2009c, *Commission Regulation (EC) No 278/2009 of 6 April 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for no-load condition electric power consumption and average active efficiency of external power supplies*.

European Commission 2009d, *Commission Regulation (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors*.

European Commission 2009e, *Commission regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products*.

European Commission 2009f, *Commission regulation (EC) No 642/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for televisions*.

European Commission 2009g, *Commission regulation (EC) No 643/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigerating appliances*.

European Union 2009, *Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products*, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:EN:PDF edn, Official Journal of the European Union.

EuroVAprint 2014, *Transcription of interview with representatives from EuroVAprint March 6th 2014*.

EuroVAprint 2012, *Industry Voluntary Agreement to Improve the Environmental Performance of Imaging Equipment Placed on the European Market VA v. 4 - December 2012 (including style changes based on agreed VA 3.5. - 15 February 2011)*.

Huulgaard, R.D. & Remmen, A. 2012, *Eco-design Requirements for Televisions: How Ambitious is the Implementation of the Energy-using Product Directive? Miljøprojekt nr. 1450, 2012*, Danish Ministry of the Environment, Copenhagen, Denmark.

Masanet, E., Auer, R., Tsuda, D., Barillot, T. & Baynes, A. 2002, "An assessment and prioritization of "design for recycling" guidelines for plastic components", *IEEE International Symposium on Electronics and the Environment*, pp. 5.

Pekar, F. 2014, *Transcription of interview with Ferene Pekar from DG Environment March 28. 2014*.

RREUSE unknown, *Investigation into the reparability of Domestic Washing Machines, Dishwashers and Fridges*, The Reuse and Recycling EU Social Enterprises network (RREUSE).

Zonneveld, N. 2014, "Circular Economy: Saving resources, creating jobs: How to increase recycling rated of WEEE", European Commission, Green Week, , 3-5 June 2014.

Innovative practices in the teaching of sustainable development in life sciences

Vesna Weingerl
University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10, 2311 Hoče, Slovenia
vesna.weingerl@um.si

Abstract

The biggest problems nowadays started with our education, thus learning is not only individual, it's also a social phenomenon. Interdisciplinary and transdisciplinary approaches are the most suitable approaches in educating for sustainability. Moreover sustainable development (SD) needs disciplines to transcend their traditional boundaries and move towards a requisitely holistic concept, able to integrate regarding socio-economic, ethical, and environmental questions. The main goal nowadays isn't the solutions to theoretical questions but the changes in the values of society and in the behaviour of the people, starting from the practitioners of the education process. The teacher's mind-set is a key to the education of SD.

With our society and our world within sight of a major breakdown from resource scarcity and subsequent political conflict, it has become crucial that we face up to the need for a radical shift, beginning with a change of perception inside each one of us.

Presented work is connected with the framework of the ISLE Erasmus Thematic Network (Innovation in the teaching of the Sustainable Development of Life Sciences in Europe), which was a 36-month project that started in October 2010. Its consortium consisted of 38 partners from 32 European countries representing Higher Education Institutions (HEIs), research institutes, and enterprises that focus on life sciences. The project's objective was to implement the concept of SD within higher education. The main activities of the project were to bring together stakeholders from Europe who had already introduced the concept of SD into their curricula and wished to transfer their knowledge to the other partners of the network or wished to introduce the concept of SD into the curricula of their institutions; to acquire new knowledge on Education for Sustainable Development (ESD) and develop the necessary tools for knowledge transfer, to increase awareness in European HEIs of the urgency of ESD, and to provide the instruments for facilitating and supporting ESD.

HEIs from amongst all educational structures have an enormous impact on knowledge discovery and transfer, as well as the promotion of SD within the society and business world. Sustainability is not an individual property but is a property of an entire web of relationships. HEIs are the environment that has the chance to build the requisitely holistic point of view, and therefore the basis for SD, which is nowadays a necessity, not a fashion.

Recommendations for teaching of SD: open space principles, opinions "pro" and "contra", problem-based learning, tutoring (tutor as mediator), knowledge sharing and teachers mind-set (values/culture/ethics/norms - VCEN).

1. INTRODUCTION

We have the good fortune of inhabiting a wonderful miracle of nature. Nature, the environment in which we live, is not haphazard but has order and purpose. From the smallest single-celled organism to mankind, there is a purpose and a place for everything and everything has its place and purpose. As you gain an understanding and appreciation of life, you I discover that there is no need for mankind's intervention. Only when mankind disrupts this balance and then proceeds to circumvent and overrule natural laws, does there appear to be chaos and brutality in nature. Nature will triumph in the end whether mankind cooperates in harmony with it or plunders it away into oblivion.

However, mankind does have the capability of helping nature to regenerate. This is a marvellous wonder to observe. Nature will more than take care of mankind if he/she simply allows her to do so. She will also protect mankind if left to her own devices. Nature, the environment in which we live, is everything around us, and within us. Everything is connected with everything. Every action results in a reaction. Every cause has a consequence. This is called the law of action and reaction. When respecting nature all our actions must be sustainable.

Academic society today has the privilege that lauding and showing the sustainable path. In times of crisis, societies need universities capable of providing innovative solutions and opening up new horizons. As Einstein put it, "problems cannot be solved by the same level of thinking that created them". Therefore, effective solutions must be sought at a higher level. Universities play a key role in raising the awareness of social responsibility and that sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs.

The public data about the crisis do not show the essence of the problem, but it wisible consequences only. The problem did not grow on a tree; it results from human behaviour that lacks SR for humans to be less selfish for selfish reasons, i.e., less short-term and narrowly oriented in their behaviour so far – in order for the current human civilization to survive.The Planet Earth can live without humans, but humans cannot live without a healthy Planet Earth and hence without a healthy economy. (Mulej, 2010)

Sustainability and social responsibility incorporate economic, social and environmental goals, and require institutional, organisational and financial changes that occur under the influence of existing values/VCEN. Since universities play a key role along the path to SD and SR, their responsibilities and tasks must be precisely defined. This transition requires modified thought patterns, new values/VCEN, radical changes in politics, technologies, and management, new forms of cooperation, and especially new knowledge. SR as defined in ISO 26000, together with the principles of SD, represents the basis for sustainable and socially responsible behaviour. (Glavič et al, 2013)

In 2005, the decade of education for SD began under the auspices of UNESCO. Such an orientation requires new teaching methods, provides new opportunities for addressing social challenges, and promotes practical applications of SD. For this reason, leading European politicians prompted the discussion on promoting sustainability education (Glavič and Lukman 2006). The integration of SD into the European higher education area was also encouraged by the Bologna Process and the statement from the 2005 Bergen Ministerial Conference: "Our contribution to achieving education for all should be based on the principle of SD and be in accordance with the ongoing international work on developing guidelines for the quality provision of cross-border higher education. The 2009 Communiqué of the Conference of European Ministers Responsible for Higher Education, which took place in Leuven, states "We call upon European higher education institutions to further internationalise their activities and to engage in global collaboration for SD" (The Bologna process 2020).

A citation of F. Capra set it wisely: "Our academic disciplines have been organized in such a way that the natural sciences deal with material structures while the social sciences deal with social structures, which are understood to be, essentially, rules of behaviour. In the future, this strict division will no longer be possible, because the key challenge of this new century - for social scientists, natural scientists and everyone else - will be to build ecologically sustainable communities, designed in such a way that their technologies and social institutions-their material and social structures - do not interfere with nature's inherent ability to sustain life.'' (Capra, 2002) There are many of Capras citations included in the presented work.

Power plays a central role in the emergence of social structures. Corporations seem to be more powerful than ever; business is clearly dominating politics; and the profits and shareholder values of most companies are rising to unprecedented heights. Things seem to be going very well indeed for business, so why is there so much talk about fundamental change? Listening to the conversations among business executives it becomes clear, that the situation is not really searching for innovative solutions. Top executives are under enormous stress today. They work longer hours than ever before, and many of them complain that they have no time for personal relationships and experience little satisfaction in their lives in spite of increasing material prosperity. Their companies may look powerful from outside, but they themselves feel pushed around by global market forces and insecure in the face of turbulence they can neither predict nor fully comprehend. Understanding human organisations as living systems is one of the critical challenges of our time.

2. THEORY

2.1 Learning as a social phenomenon

Is a learning organisation a social system capable of learning or is it a community that encourages and supports the learning of its members? In other words, is learning only an individual or also a social phenomenon?

In every human organisation there is a tension between its designed structures, which embody relationships of power, and its emergent structures that represent the organisation's liveliness and creativity.

Finding the right balance between design and emergence seems to require the blending of two different kinds of leadership. The traditional idea of a leader is that of a person who is able to hold a vision, to articulate it clearly and to communicate it with passion and charisma. It is also a person whose actions embody certain values that serve as a standard for others to strive for. The ability to hold a clear vision of an ideal form, or state of affairs, is something that traditional leaders have in common with designers. The other kind of leadership consists of facilitating the emergence of novelty. This means creating conditions rather than giving directions, and using the power of authority to empower others. Both kinds of leadership have to do with creativity. (Godeman et al., 2011)

Being a leader means creating a vision; it means going where nobody has gone before. It also means enabling the community as a whole to create something new. Facilitating emergence means facilitating creativity. Since power is embodied in all social structures, the emergence of new structures will always change power relationships; the process of emergence within communities is also a process of collective empowerment. Leaders who facilitate emergence use their own power to empower others.

What is sustained in a sustainable community is not economic growth or development, but the entire web of life on which our long-term survival depends.

2.2 The biggest problems nowadays start with our education

When talking about the holistic approach we must set clear dimensions of the really holistic view. Survival of our species depends on learning the very lessons of empathy, responsibility, self-control, humbleness and humility that the vegan ideal embodies, and which our society seems so reluctant to embrace. (Campbell and Campbell, 2006)

With our society and our world within sight of a major breakdown from resource scarcity and subsequent political conflict, it has become crucial that we face up to the need for a radical shift, beginning with a change of perception inside each one of us. One of the more important innovations in the teaching of SD within life sciences in Europe seems to be the acceptance of a whole food, plant-based diet model for all programmes taught at universities. The vegan ideal represents nothing less than the next evolutionary step for humankind.

When talking about the holistic approach we should mention another point of view: our connection to the God (if this infringes upon your belief system, insert Creator, Universal Life Force, or whatever you are comfortable with). Everything is energy, whether it is soil, water, air or something else. What makes each thing different is the energy pattern and frequency at which it resonates. Some patterns and frequencies are detrimental to biological life and some are beneficial. Our goal is to minimise the detrimental ones and maximise the beneficial ones.

God has not created any nation, East nor West, Muslim nor Christian, Buddhist nor Hindu nor Sikh, nor any other religion. Got has created only one humanity. (Sant Thakar Singh, 2005)

More than ever nowadays we must be aware that all people are of the same humanity. More than ever we need to include contents of spirituality within the education system. Only this may be called a holistic approach. Mind and intellect are only meant to understand something of this way of destruction of this world, in which we are to be ruined. The human being is very, very powerful. If there is a higher power than the existence of God it is the human being. But the human beings' powers need to be directed in some direction so that they all help each other, so that no-one is to disturb anyone else and so that they may all be very useful and happy. But it is very hard, because everyone has his/her own mind, his/her own thinking, his/her own likings, his/her own disliking, and they generally collide with each other, strike against each other. This is the criterion of life in this world. Everyone is independent. And everyone thinks: "I am right, I am true. All others are false. All others know nothing. I know the best. And my will should be done. What I say should be done. Everyone should accept my authority. Everybody should consider me to be a great, wise one, a controlling one; all should be subordinate to me. I should be the ruler of everybody." So we cannot live without the help of each other and also we cannot accommodate each other. This is the great difficulty that has been in this world and will still be there. (Sant Thakar Singh, 2006)

Precisely because of man power control it is very important to speak up about spiritual topics with students and educate them to be specialists who are skilled in handling power and influence in their professional activities. Innovation in the teaching of SD would allow the younger generation to stay open-minded and to use this open-mindedness to research their environment and just to tutor them to reach their own holistic points of view. It seems to be a reasonable way of teaching this younger generation how to acquire useful knowledge and also about things that we, their teachers, don't understand, and thus to let them teach us. This seems to be the most important innovation in the teaching of SD, especially in life sciences. The time that teachers at the Universities spend with their students is the most appropriate time for realising such innovations. The best thing about innovation is that an innovation is something new. Something that you didn't realize yesterday but has today become an innovative practice and you must be aware that this means that tomorrow will also be the time for new innovative practices. This is the nature - the wheel of changes. We must not be afraid of changes.

Innovations within teaching are needed that provide participants with knowledge that could change their lives. This is urgent for the preparation of students for the future. We must take care that our students become leaders and intellectuals, who can see the light, not the twilight, or even the darkness. The twilight or the darkness doesn't exist. It is only the lack or the absence of light. Nowadays crisis is such twilight.

2.3 Motivation – inspiration – useful knowledge

The desire and motivation of the students to organise themselves within healthy and self-sufficient life, forces them to be creative. Experiential education of the individual is very important. With experiences and new knowledge students develop creative solutions. With the help of experimental work students can come to new useful knowledge, which can be transferred to their living environment. Linking experience and achieving new knowledge with experiential learning encourage people to engage in creative thinking, in particular if the new knowledge can be transferred to their home environments and with that they can improve their living environments. Living within a healthy environment, where they can achieve a natural balance and the functions of ecosystem functions and services is motivating for everyone.

Students in the natural classroom learn about these possibilities, how they can by themselves provide such an environment by preserving natural resources and producing healthy food. Eco-remediation and permaculture allow this. These are natural approaches that can affect every single person even with minimal financial resources, and have big effects. This self-independence regulation of a healthy environment raises motivation for learning and practical work. Outdoor and experiential education is happening in the classroom regarding nature. There learners learn from concrete examples. They do some tests on them and experiments. With this they learn by themselves and come alone to new skills that can be transferred to their home environments. With this experiential and experimental work they also learn to be critical and responsible at the same time. Experiential education is based on experiments and experience. It also encourages teamwork, where learners are trained how to work within a team and they can realize that a group can do more than an individual. Self-learning in the classroom in nature, which is happening at different places within different environmental or social problems, is guided and so the learners have the opportunity to learn new skills by themselves through their own work (experiment, test).In this way learners can achieved some skills for life and can see that this knowledge is useful. So they have the possibilities to transfer this knowledge and skills to their environment. (Learning regions in Slovenia with polygons regarding nature)

2.4 The teacher's mind-set is a key to the education of SD

The problem is not what we see in front of us. The problem is not the strategies of teaching on paper. The problem is not the money. The problem is always within us. We need solutions, not the mentioned problems. We need new teaching methods that make students proactive with many questions, aspirations, and consciousness. We must introduce new methods and tools of social technology that permit learning for raising future aspirations. Universities that will become sustainability leaders and change drivers, they must ensure that the needs of present and future generations are better understood and built upon, so that professionals who are well versed in SD can effectively educate students of 'all ages' to help make the transition to 'sustainable societal patterns'. In order to do so, university leaders and staff must be empowered to catalyse and implement new paradigms, and ensure that SD is the 'Golden Thread' throughout the entire university system. (Lozano et al, 2013)

The fourth pillar of sustainability/SD can no longer be ignored on the grounds of intangibility. Different approaches to this vital but missing pillar (cultural-aesthetic, religious-spiritual, and political-institutional) find common ground in the area of ethical values. Values and aspects based on them are widely assumed to be intangible and immeasurable, but it is possible to operationalise them in terms of measurable indicators when they are inter- subjectively conceptualised within clearly defined practical contexts. These processes require contextual localisation of items, which can nonetheless fit into a generalisable framework. This allows for useful measurements to be made, and removes barriers to studying, tracking, comparing, evaluating and correlating values-related dimensions of sustainability. It is advocated that those involved in operationalising sustainability (especially within the context of creating post-2015 SD goals), should explore the potential for developing indicators to capture some of its less tangible aspects, especially those concerned with ethical values. (Burford et al, 2013)

It is theoretically and practically possible to assess processes and outcomes relating to the less tangible dimensions, consisting of human values, ethics and worldviews, which conceptualise the fourth pillar of sustainability. Institutions tasked with developing SD goals, targets and indicators should take time, especially at this critical juncture, to reframe the sustainability assessment process and incorporate an explicit acknowledgement of its ethical dimensions.

Human values, ethics and worldviews are the basic and most important innovation in teaching of SD nowadays.

3. RESULTS

The ISLE - Innovation in the teaching of the Sustainable Development of Life Sciences in Europe - project's objective was to implement the concept of SD in higher education. HEIs from amongst all educational structures have an enormous impact on knowledge discovery and transfer, as well as the promotion of SD within the society and business world. The transformation of HEIs according to the principles of SD is a non-technological process requiring invention, innovation, and diffusion. By the linking educational activities, teaching, scientific research, various projects as well as examples of good practices, the discovery of new knowledge and the modernisation of values, cultures, ethics and norms would be activated.

The main activities of the project were to bring together stakeholders from Europe who had already introduced the concept of SD into their curricula and wished to transfer their knowledge to the other partners of the network or wished to introduce the concept of SD into the curricula of their institutions; to acquire new knowledge on ESD and develop the necessary tools for knowledge transfer, to increase awareness in European HEIs of the urgency of ESD, and to provide the instruments for facilitating and supporting ESD.

The final product of Work Package 6 (WP6) entitled "Innovative Practices" was the Innovative Practice Compendium. (Weingerl et al., 2013)

The objective was within the spirit of the possible and the identification of existing Innovative Practices concerned with Education for SD within HEIs. The topic was discussed with a holistic approach describing formal and informal learning experiences within HEIs and highlighting some important directions for the future vision of higher education. 18 Innovation Practices were discussed and presented in form of indicators and descriptors. The following indicators and descriptors were used:

Indicators: New technologies, Holistic approach, Collaboration, Critical thinking, Project-based learning, Creativity, Network building capacity, Internationalisation, Interdisciplinarity, Motivation aspects, Transferability, Innovation activities (present)

Descriptors: Content, Tools, Method, Outcome

The Innovative Practices were mostly selected from a Compendium of Good Practices (Chiodo et al, 2013) emerging from the previous work package WP3 analysis, carried out within the ISLE project, and from the research of the project partners. The selection was done in accordance with the criteria of innovation.

An innovative way to encourage students to actively learn the knowledge syllabus of SD was the video challenge. Within the framework of WP6 a Facebook video challenge for student groups was carried out.

The holistic and interdisciplinary approaches to ESD, the attention to achieving tangible results, the involvement of local communities and the bottom-up approaches, the importance of partnerships and networking, the capacity building, the innovation of the initiatives, and the attention given to building a framework favourable to SD was the common goal.

4. DISCUSSION

Among the innovative practices discussed during the ISLE project, emergent signs of innovative ideas in the teaching of SD within life sciences are evident in the reports dealing with the extraction of good practices published in the Compendium Good Practices (Chiodo, 2013). A number of gaps in teaching, skills, competences and useful knowledge might set a useful agenda for the further evolution of teaching sustainable development in the area of life sciences. Especially regarding the ethical and social pillars of SD, there is a huge gap for further research inquiry and intervention strategy by the politicians.

The more common barriers in SD teaching in EU universities nowadays are:

- lack of awareness/ignorance/laziness
- professors' resistance to changes

- lack of cooperation
- lack of coordination between subjects and professors
- complexity/ interdisciplinarity
- new curricula are needed

One of the biggest gaps in the teaching of SD nowadays is the demotivation of students. How to motivate them? How to even inspire them? It is very important just to listen to them, to give them power that their opinions are equal to teachers' opinions. Who is right anyway? Are teachers right with all their knowledge and experiences or the open-minded, unrestricted students? Students are trying to prove themselves, not knowing that knowledge is going to improve their existence.

Motivation leads us through at the end of the day, but inspiration leads us throughout our whole lives. We'd all like to live in prosperity. Nowadays it is obvious that the path to prosperity travels through the wisdom of respecting all pillars of SD, especially ethical -social ones. Useful knowledge of SD is going to improve our existence, that's why it is so important to attain this knowledge.

5. CONCLUSION

The biggest problems nowadays started with our education, thus learning is not only individual, it's also a social phenomenon. It is the right time for the development of systemic innovations. Interdisciplinary and transdisciplinary approaches are the most suitable approaches in educating for sustainability. Moreover SD needs disciplines to transcend their traditional boundaries and move towards a holistic concept, able to integrate regarding socio-economic, ethical, and environmental questions.

The main goal nowadays isn't the solutions to theoretical questions but the changes in the values of society and in the behaviour of the people, starting from the practitioners of the education process. The teacher's mind-set is a key to the education of SD. With our society and our world within sight of a major breakdown from resource scarcity and subsequent political conflict, it has become crucial that we face up to the need for a radical shift, beginning with a change of perception inside each one of us. Our survival depends on learning the very lessons of empathy, responsibility, self-control, and humility.

The acceptance of whole food, plant- based diet model for all programmes taught at universities seems to be one of the more important innovations in the teaching of SD within life sciences.

Today's students will be tomorrow's leaders, intellectuals, and they will handle the authority and power, so the mission of HEIs must be to give them the know-how. Precisely because of this power that it is very important to speak out regarding spiritual topics with students and educate them to be specialists who are skilled in handling power and influence in their professional activities.

HEIs teachers must grasp the significant importance of allowing the younger generation to stay open- minded and to use this open mindset to research their environment and just to tutor them into acquiring their own holistic points of view. It seems to be a reasonable way to teach this younger generation how to also acquire useful knowledge about things that we, their teachers, don't understand.

Recommendations: Open space principles, opinions "pro" and "contra", problem-based learning, tutoring (tutor as mediator), knowledge sharing.

It is time that teachers allow students, as young as they are, to also teach them - the teachers. This seems to be the most important recommendation - innovation in teaching of SD, especially within life sciences.

Teaching is needed which provides the participants with knowledge that changes their lives. We need green, generative, and researching higher education institutions for the makeover of economy and society. Useful knowledge of SD is going to improve our existence, that's why it is so important to attain this knowledge.

Nowadays it is obvious that the path to prosperity travels through the wisdom of respecting and realising all pillars of SD.

6. REFERENCES

Burford G., Hoover E., Velasco I., Janoušková S., Jimenez A., Piggot G., Podger D. and Harder M.K., 2013. Bringing the "Missing Pillar" into Sustainable Development Goals: Towards Intersubjective Values-Based Indicators, Sustainability, 5, 3035-3059.

Campbell T.C. and Campbell T.M., 2006. The China Study, BenBella Books, Dallas, USA.

Capra F., 2002. The Hidden Connections: Integrating the biological, cognitive and social dimensions of life into a science of sustainability. Doubleday, New York, USA.

Chiodo E. (ed.), 2013. Sustainable Development in Higher Education in Europe. Good Practices Compendium. ISLE Work Package 3 Final Report. Edizioni Homeless Book

Clugston R., 2011. Ethical framework for a sustainable world: Earth Charter Plus 10 conference and follow up. J. Educ. Sustain. Dev., 5, 173–176.

De Leo J., 2012. Quality Education for Sustainable Development: An Educator Handbook for Integrating Values, Knowledge, Skills and Quality Features of EDUCATION for Sustainable Development in Schooling; UNESCO APNIEVE Australia Publishing: Adelaide, Australia.

ECI Secretariat, 2010. Earth Charter Initiative Handbook; Earth Charter International Secretariat: San José, Costa Rica.

Glavic P. and Lukman R., 2006. What are the key elements of a sustainable university? In Clean Technologies and Environmental Policies, 9 103-114.

Godemann J., Herzig C., Moon J., Powell A., 2011. Integrating Sustainability into Business Schools – Analysis of 100 UN PRME Sharing Information on Progress (SIP) reports.

Hedlund-de Witt A., 2011. The rising culture and worldview of contemporary spirituality: A sociological study of potentials and pitfalls for sustainable development. Ecol. Econ., 70, 1057–1065.

Lozano R., Lukman R., Lozano F. J., Huisingh D., Lambrechts W., 2013. Declarations for sustainability in higher education: becoming better leaders, through addressing the university system. J. clean. prod., 48, 10-19.

Mulej M., 2010. [Five books review: stop hating your children and grandchildren] Syst. res. behav. sci., 27, 1. Untitled book review.

Sant Thakar Singh, 2005. The Secret of Life, Edition Naam, Augsburg, Germany.

The Bologna process 2020 – EHEA in a new decade. http://www.ond.vlaanderen.be/hogeronderwijs/bologna/conference/documents/Leuven_Louvain-la-Neuve_Communiqu%C3%A9_April_2009.pdf

UNESCO, 2011. Education for Sustainable Development. An expert review of processes and learning. http://unesdoc.unesco.org/images/0019/001914/191442e.pdf

UNESCO, 2013. Culture in the post-2015 sustainable development agenda: Why culture is key to sustainable development. Available online: http://www.unesco.org/new/en/culture/themes/culture-and-development/hangzhou-congress/ (accessed on 6 October 2014).

Weingerl V. (ed.), 2013. Sustainable Development in Higher Education in Europe. Innovative Practices Compendium. ISLE Work Package 6 Final Report. Buča, Ljubljana.

Life Cycle in Practice –

Capacity building aiming European SME's

V. PASQUET [a], A. ROY [a], N.ADIBI [a], S. COPPEE [b], P. ECHARD [b] , C. ROCHA [c], P. MARTINS [c], J. ALEXANDRE [c], E. ATIN [d]

[a] *Création et developpement d'éco-entreprises, Base 11/19 Rue de Bourgogne, 62750 Loos-en-Gohelle, France*
[b] *Greenwin, Rue Auguste Piccard 20, 6041 Gosselies, Belgium*
[c] *Laboratório Nacional de Energia e Geologia, I.P., Campus do IAPMEI, Estrada do Paço do Lumiar, 1649-038 Lisboa, Portugal*
[d] *Prospektiker, De Zubiberri Bidea, 31, 20018 Donostia, Gipuzkoa, Spain*

Keywords: Life Cycle Management, Sectorial approach, Maturity assessment, Regional, SME

Abstract

The application of life cycle approaches – including life cycle assessment, ecodesign and environmental labelling – is becoming an increasing reality for business, and a growing challenge in many economic sectors. Businesses are facing increasing legal and market requirements to enhance resource efficiency and reduce the environmental impact of their products & services. To significantly address this challenge, the Life Cycle in Practice (LCiP) project was conceived, aiming to promote the uptake of LC approaches particularly in SMEs. The LCiP project helps SMEs in France, Belgium, Portugal and Spain reduce the environmental impacts of their products and services across the entire Life Cycle in three sectors: Buildings & Construction, Waste Management and Energy Equipment. LCiP's specific objectives are to foster the widespread uptake of these approaches by SMEs beyond the duration of the project, by (i) Demonstrating the environmental and business benefits of applying LC Approaches through practical application in 32 businesses; (ii) Providing physical and online resource centres to support regional application of LC approaches; (iii) Building capacity for on-going implementation of LC approaches through a network of Life Cycle Champions and (iv) (Re)designing practical tools & methods tailored to the needs of the three industrial sectors. This paper presents the project's activities and expected results, as well as the conclusions of a maturity assessment on life cycle approaches that has been performed in the three sectors and four partner regions, as a means to identify needs and gaps that LCiP should fulfil.

1 Introduction

The adoption of a life cycle perspective in environmental management is a growing challenge in many economic sectors (UNEP/SETAC, 2009). Businesses are facing increasing legal and market requirements to enhance resource efficiency and reduce the environmental impact of their products and services. Life cycle approaches are also heavily embedded in European strategy, as can be seen in:

- **Towards a circular economy: A zero waste programme for Europe** (COM (2014) 398 final).
- The Commission's **Roadmap for moving to a competitive low carbon economy in 2050** (COM (2011) 112 final).
- The **Eco-Innovation Action Plan (Eco-AP)** (COM (2011) 899 final).

- The Commission's **Thematic Strategy on the Sustainable Use of Natural Resources** (COM (2005) 670 final).
- The **Thematic Strategy on the Prevention and Recycling of Waste** (COM (2005) 666).

Despite this, the take up of life cycle approaches in SMEs is still very low; as indeed the ability of SMEs to comply with environmental legislation in general as reflected in the need for the European Commission's Environmental Compliance Assistance Programme (ECAP). Often SMEs are unaware of the benefits of being green: new market opportunities and cost savings.

To significantly address this challenge, Cd2e created in 2009, the [avniR] platform supported by the Nord Pas de Calais (NPdC) Regional Council and the ADEME (French Environment and Energy Management Agency). [avniR] platform aims to foster mainstreaming Life Cycle Thinking in industrial sectors in North of France by using a collaborative approach with all kind of actors (Businesses, University, Research, Consultant …). To do so, a sectorial methodology have been developed and implemented in several sectors (agro-industry, mechanic, packaging, seafood, textile, wood …) supported by [avniR] resource center. The Life Cycle in Practice (LCiP) project was conceived based on those five years of feedback in north of France. It aims to promote the uptake of LC approaches particularly in SMEs in France, Belgium, Portugal and Spain to reduce the environmental impacts of their products and services across the entire Life Cycle in three sectors: Buildings & Construction, Waste Management and Energy Equipment.

This paper presents the project's activities and expected results, as well as the conclusions of a maturity assessment on life cycle approaches that has been performed in the three sectors and four partner regions, as a mean to identify needs and gaps that LCiP should fulfill.

2 LCiP Project

LCiP- Life Cycle in Practice is a project funded by the **LIFE+ Environment Policy and Governance Programme** of the EU supporting technological projects that offer significant environmental benefits. The project period is 2 September 2013 – 30 June 2016.

The application of **Life Cycle Approaches** – including Life Cycle Assessment, ecodesign and environmental labelling – is becoming an increasing reality for business, and a growing challenge in many economic sectors. Businesses are facing increasing legal and market requirements to enhance resource efficiency and reduce the environmental impact of their products & services.

LCiP's specific objectives are to foster the widespread uptake of these approaches by SMEs beyond the duration of the project, by:

- Demonstrating the environmental and business benefits of applying LC Approaches through practical application in 32 businesses,
- Providing physical and online resource centres to support regional application of LC approaches,
- Building capacity in the four project regions for on-going implementation of LC approaches through a network of Life Cycle Champions, composed of experts and organisations,
- (Re) designing practical tools & methods tailored to the needs of the three industrial sectors.

2.1 Building capacity

The LCiP project builds capacity by developing training materials for the training of both practitioners in the labour market and university, and thus contributing to build capacity in LC approaches. LCiP provides training of current and future professionals but also training of trainers, to ensure widespread and sustainable building of capacity in participating regions.
The project establishes two different types of networks which play a key role in the building of capacity. The “Life Cycle Champions” network is trained in life cycle thinking and the use of LC tools. This network remains active throughout the project and beyond and it is active in research, training and tools development, and practical application in SMEs. The network ensures as well the long term business support and dissemination of Life Cycle methodologies.
The establishment of local “LC trainers clubs” enable face-to-face exchanges between trainers to improve practices and develop collaborations at a local level. The clubs are composed of organisations dispensing LC related training and related services in the region.

2.2 Online and physical resource centres

Training materials, products and methods are made available for key stakeholders of the LCiP project through an open-access module in the online resource centre, as well as through the physical resource centres of each region.
The online resource centre brings together information on life cycle strategies (such as ecodesign, green purchasing, life cycle communication and life cycle management), available tools and information (including LCA software, LC related tools, guides, training modules, case studies, relevant sustainability information by sector, news related to LC related policies, other LC projects’ results, expert centres and consultants).
The four physical resource centres (one in each participating region) are the "hub" for SMEs seeking to integrate LC approaches into their businesses. Here they have access to selected LCA tools, reading material, expertise, training and advice.

2.3 Pilot projects

The LCiP project provides a monitoring tool tested by 32 SMEs to evaluate the environmental and socio-economic impact of the adoption of LC approaches. The activities in these 32 case studies (4 per region and sector) include coaching and direct support in LC methodologies, leading to tangible measures such as:

- Changes in raw material use and/or suppliers,
- Replacement of fossil resources (materials, energy) by renewable resources (bio-sourced or recycled from waste),
- Reduction of product weight,
- Modification/optimisation of in-house manufacturing process steps,
- Modification of product design to reduce energy/water consumption during the product use phase,
- Modification of product design to allow better end-of-life processing (e.g. product dismantling and recycling),
- Modification of packaging material or packaging system, and/or reduction of packaging weight,
- Modification of transportation methods and/or distribution channels,
- Valorisation of co-products and/or waste.

2.4 Expected results

Key to the success of LCiP is the achievement of results that will continue to spread beyond the end of the project, furthering the promotion and uptake of LC approaches among SMEs in covered sectors in participating regions but also extending to other regions.

In order to enable these further developments, the LCiP project results in the following:

- 1 online LC resource centre and 4 physical resource centres,
- Building training capacity in 4 European regions: Belgium, France, Portugal and Spain, through the training of trainers and practitioners, the establishment of trainer clubs to share and co-develop training capacity,
- Implementation of Life Cycle approaches in 32 SMEs,
- Evaluation tool adapted to the reality of SMEs to assess the environmental and socio-economic impact,
- Practical tools and methods tailored to the needs of SMEs in participating sectors,
- A network of Life Cycle Champions (influential regional players in their industrial sector) to provide guidance and training to SMEs during and after the project,
- Life Cycle Awards in each participating region,
- European and Global dissemination of LC approaches,
- A baseline analysis of the maturity of Life Cycle approaches in the 4 participating regions, including surveys and interviews of key actors, and a cartography of existing resources available to practitioners.

2.5 Partners

The project is being developed by an international partnership from France, Portugal, Belgium and Spain, adding up to 4 partners with proven expertise in the area of life cycle thinking and training. The project coordinator is CD2E- Creation Developpement des Eco-entreprises.

- **CD2E** (Framce) is the network of environment and business experts dedicated to supporting the environmental sector in Northern France and abroad.

- **GreenWin** (Belgium) is the competitiveness cluster dedicated for the economic and industrial development of Wallonia, with particular focus on eco-technologies.

- **LNEG** is the National Laboratory for Energy and Geology (Portugal) that in this project focuses on Life Cycle approaches in organizations from the building and energy equipment sectors.

- **PROSPEKTIKER** (Spain) is the European Institute for Future Studies and Strategic Planning, with particular focus on regional and local development, clean production and research related to the environment and is applying the project in the Basque Country.

2.6 Sectorial approach

The preparatory actions of the project are key to understanding the current capacity of business sectors and SMEs in each partner country to implement Life Cycle approaches. This was done through an assessment of the maturity of environmental practices, for which partners reached out to organisations representing and supporting SMEs including industry bodies such as clusters, industry associations, chambers of commerce, employers' associations, regional federations and sectorial associations (Adibi, N. et al, 2012).

The first step in the maturity assessment was the development of a common methodology based on models already in place among the partners. The Cd2e has already experimented with mapping existing life cycle activities (research, initiatives, tools...), undertaking surveys of businesses and support structures, benchmarking the maturity, and developing improvement strategies for four sectors regionally (textile, mechanic, packaging and seafood) and wishes to share and enrich its experience and methodology with contributions from the LCiP partners.

The agreed assessment methodology allowed project partners to undertake a mapping exercise of existing life cycle activities, in particular to identify research, training and business activities, with a particular focus on Life Cycle tools available to businesses, in particular SMEs: LCA software adapted to sectors, guides, case studies, training, expert centres... for each target sector in each region.

The partners undertook surveys of SMEs and SME support structures (federations, clusters…) on their knowledge and use of Life Cycle approaches. The surveys contain the same "base" questions in all regions and sectors, with a specific section for the sector/supply chain, to enable the partners to identify and account for regional and sectorial variations. A sub-group of the surveyed companies have accepted to be interviewed by project partners, in order to go more in depth on the questions asked. All in all, some 260 organisations were surveyed and 90 interviewed for the project.

Finally, these results of the maturity analysis will feed into many project activities. In particular, the mapping of LC resources in each region will help to construct the online and physical resources centers, and the challenges highlighted by companies and support structures will help us to begin to identify improvement strategies for the sector.

The maturity analysis will also be the basis for the definition of a strategic plan for large scale rollout of Life Cycle practices in business and higher education. In particular, towards the end of the project, we will undertake a strategic planning exercise, aimed at defining how to roll out life cycle practices at a large scale across the private sector. This will be achieved through our close collaboration also with support structures (through the LC Champions network), fostering the development of specialised expertise in LCA and other LC tools (consultants, research centres), and ensuring that life cycle thinking is understood by future decision makers in businesses (through higher education).

The elaboration of the strategic plan will rely on consultation of key stakeholders in each region, through workshops, discussion with project partners including LC Champions and LC Experts.

The strategic plan will include proposals for:

- Scope for the de-multiplication phase, including recommendations on in which industrial sectors and which regions (including but not necessarily limited to those sectors and regions covered by LCiP) efforts should be made to promote LC approaches.
- Recommendations as to where to find further expertise, knowledge and other relevant resources, including networks, and other relay organisations.
- Particular attention will be paid to strategies for mobilising funding for the rollout beyond the end of the project.
- Description of recommended de-multiplication processes and tools, such as the online LC platform and physical resource centres.
- Capacity building efforts, including training programmes for trainers, for individual SMEs and within higher education, coaching of individual SMEs, forums for exchange of best practices.
- Awareness-raising efforts such as Life Cycle Awards, conferences and other events.

The formal launch of the strategic plans for large-scale rollout of Life Cycle practices in business and higher education will take place during the final events to be held in each LCiP participating region. These events will bring together key stakeholders from the sectors worked on during the LCiP project, but also other sectors that are interested in the approach. Business support organisations, LC experts (consultants, researchers), higher learning institutions and local authorities will also participate. We expect at least 100 stakeholders will be present at each event, and the LCiP beneficiaries will also be invited to participate at all 4 events.

We expect that the four strategic plans (one per sector) will be of substantial use to actors in the value chain in each sector and each region, and will strongly position LC Champions and project partners as key resource partners for further development of LC practices.

3 Maturity Analysis

3.1 Method

The maturity assessment performed and improved in LCiP project, is based on the methodology that had been developed of and tested with the support of [avniR] platform in four industrial sectors (mechanic, packaging, seafood, and textile) in Nord-Pas-de-Calais region, France. It consists on the development and application of questionnaires to be filled in online by companies from the value chain of the three LCiP sectors and questionnaires (also online) targeting support organizations, i.e. institutions that provide R&D, consulting or any other type of technical support to the companies.

The questionnaires were disseminated by e-mail through the partners' Life Cycle Champions and sectorial organizations' mailing lists, in order to reach the maximum possible number of respondents per country.

A quantitative assessment methodology was used for companies of the three LCiP sectors and is described below. In table 1, the questions from the online survey that were used for the maturity assessment are presented.

		0	100
1	Environmental strategy considers the life cycle of its products/services?	No	Yes
2	Knowledge of environmental impacts activities over the life cycle ?	No	Yes
3	Tools or systems used to manage environmental impacts ?	0	10
4	Years working on LC approaches?	<1	>5
5	Internal or external human resources to implement LC approaches?	External	Internal
6	What are the internal resources to implement LC approaches?	Indefinite	Department
7	Internal communication about LC actions?	No	Yes
8	External communication about LC actions?	No	Yes

Table 1: Maturity analysis criteria

Note 1: In question 3, the scoring shown on the right hand side corresponds to the sum of the number of tools and systems, multiplied by the level of understanding of the environmental impacts over the life cycle.

Note 2: The tools or systems in the inquiry included environmental management systems, life cycle assessment, environmental product declarations, labeling and footprints, ecodesign and green purchasing.

The sum of the values obtained with the eight parameters was then normalized so that a final classification between 0 (the lowest scoring in terms of LC maturity) and 100 (the maximum scoring) was obtained.

4 Results

After collecting all the results of the different sectors in the different regions, spider web charts were produced in order to provide an overview of each region's and sector's maturity.

The results are representative of the inquired businesses and a proxy to the current maturity of the sectors and regions. Nevertheless, due to the dimension on the sample, these results must not be used out of this context.

The comparison of the different sectors is presented below.

4.1 Building sector

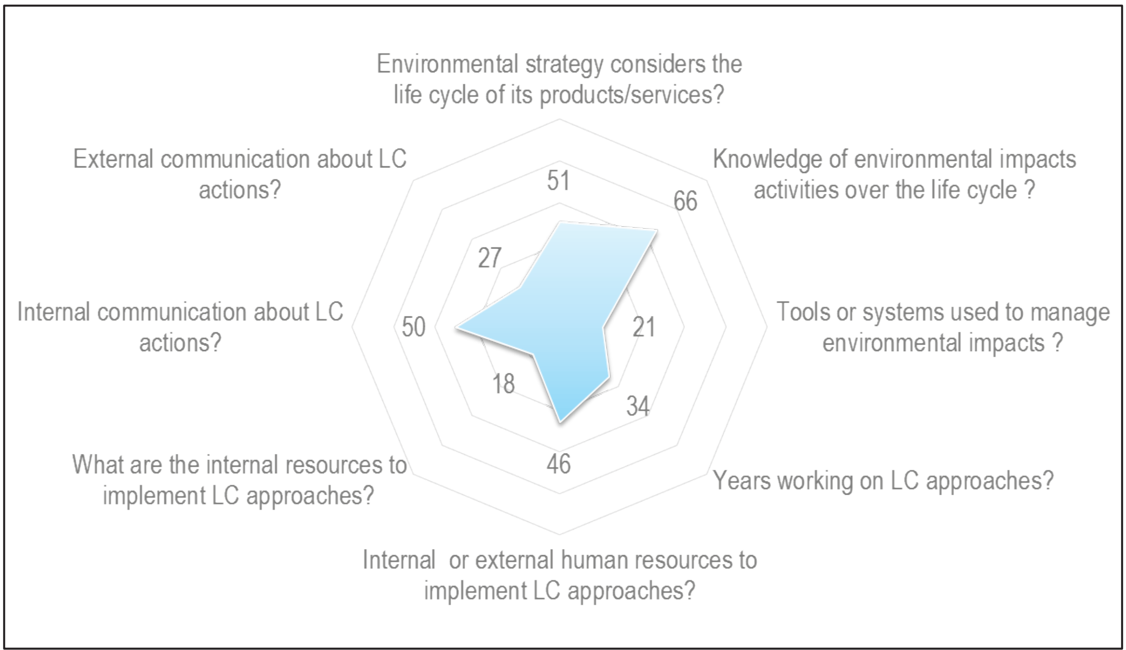


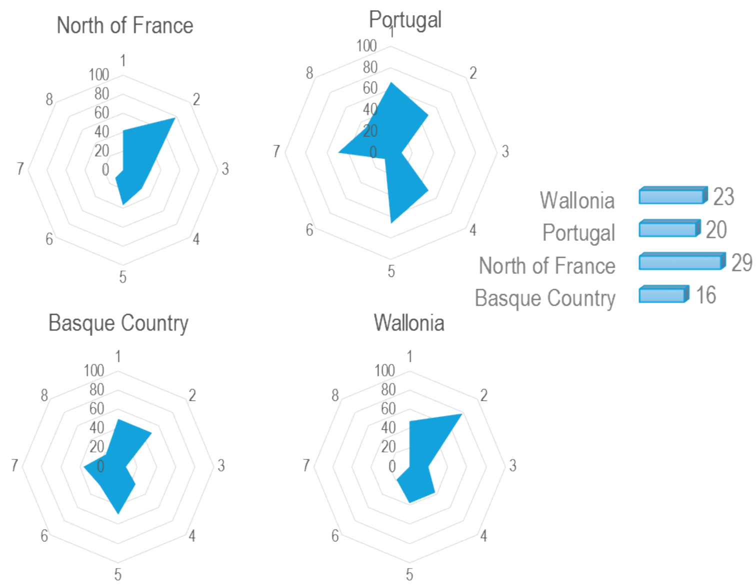
Figure 1: Global answers results of the life cycle maturity assessment in the building sector

This web chart represents the answers obtained for each of the questions in the building sector and it is not meant to represent the maturity of the sector.

As in the LCA methodology, this may be seen as a midpoint quantification of the maturity assessment, representing the results after the characterization and normalization steps. To evaluate the maturity in LC approaches, the endpoint quantification, it is necessary to apply a weighting factor to balance the significance of the different inquired areas. The weighting step is an essential step to calculate the endpoint maturity score.

- In the building sector, 50% of the companies considers the life cycle of their products in the environmental strategy.
- Over 60% of the companies claim to have knowledge of the environmental impacts of their activities over the life cycle.
- The amount of tools used to manage the life cycle environmental impacts is scored at 20%, corresponding to the use of 2 tools/strategies per company.
- In average, the activities in life cycle approaches is relatively recent, scoring 1/3 of the maximum value, corresponding to 1 to 2 years of experience.
- About half of the companies have internal human resources to work in life cycle approaches. Although most of them don´t have a specific person or department for this.
- Finally, half of the companies are communicating internally their activities of life cycle approaches, but few of them do this communication to the exterior.

1	Environmental strategy considers the life cycle of its products/services?
2	Knowledge of environmental impacts activities over the life cycle ?
3	Tools or systems used to manage environmental impacts ?
4	Years working on LC approaches?
5	Internal or external human resources to implement LC approaches?
6	What are the internal resources to implement LC approaches?
7	Internal communication about LC actions?
8	External communication about LC actions?



Building sector average LC maturity: 25%

Figure 2: Disaggregation by region of the results of the life cycle maturity assessment in the building sector

Note: North of France and Wallonia maturity do not include communication criteria. This is the reason of their zero score.

Web charts are very different from one region to another. This is mainly due to the diversity of players in this industry: public project owners, private project owners, prime contractors, architects, engineering firms, industrialists, manufacturers of building materials, etc. These actors do not address the life cycle thinking in the same way. For example, project owners pay close attention to the integration of environmental criteria in their specifications but do not use LCA tool. Instead, engineering firms may use some LCA tools: simplified ones or integrated in their sector specific software.

Regarding all the regions, the life cycle is considered in businesses strategy, (minimum average 40% of the businesses asked in each region). Indeed, the regulations in the building sector are numerous and the project owners are aware of these issues for a long time in the 4 regions.

Besides the Basque Country and Wallonia, few dedicated tools are integrated by the actors. LCA tools are new and still relatively unknown for building actors.

We note the building sector in Portugal seems to have started actions in life cycle approaches earlier than the remaining regions. And, also, there are more internal human resources working on LC approaches. Although in the final score, Portugal is only the second lowest value, because the parameter with the highest weight is related to quantity of LC tools used and here Portugal has a low score.

4.2 Energy sector

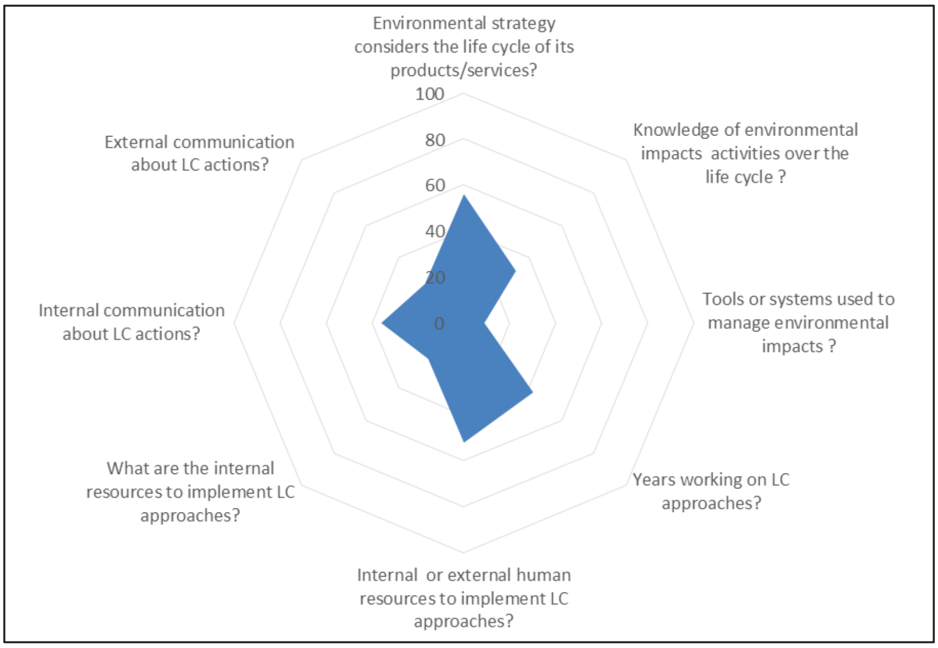


Figure 3: Global answers results of the life cycle maturity assessment in the energy sector

- In the energy sector, over 50% of the companies considers the life cycle of their products in the environmental strategy.
- Although, only 30% of the companies claim to have knowledge of the environmental impacts of their activities over the life cycle.
- The amount of tools used to manage the life cycle environmental impacts is scored at 10%, corresponding to the use of only 1 tool/strategy per company.
- In average, the performance of life cycle approaches is relatively recent, scoring over 1/3 of the maximum value, which correspond to 2 to 3 years of experience.
- About half of the companies have internal human resources to work in life cycle approaches. Although most of them don´t have a specific person or department for this.
- Finally, 36% of the companies are communicating internally their activities of life cycle approaches, and 24% of them do this communication to the exterior.

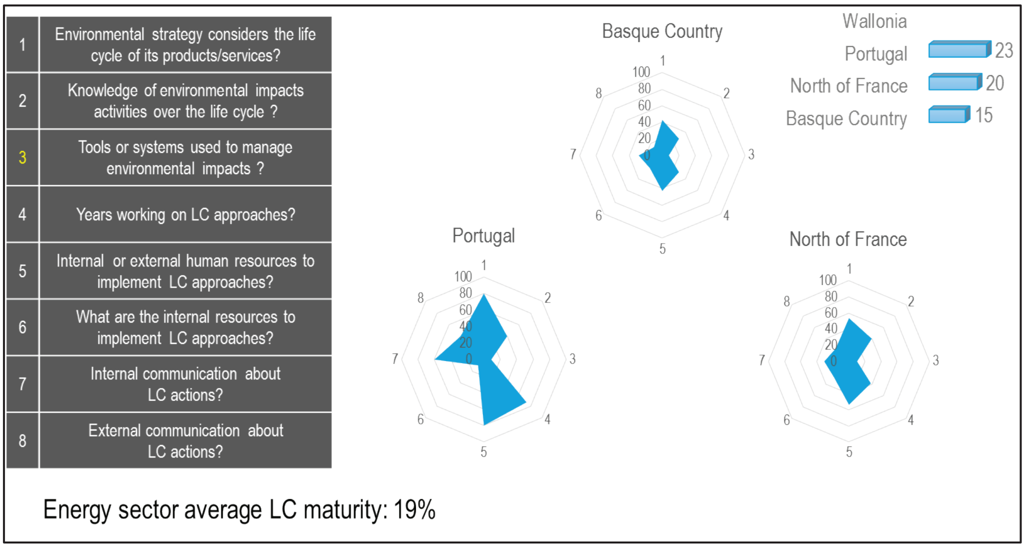


Figure 4: Disaggregation by region of the results of the life cycle maturity assessment in the energy sector

The web chart of the companies in energy sector are similar for all three regions. As in the building sector, the company global strategy considers the life cycle of products and services (minimum average 40 % of the businesses). Indeed, the energy companies, especially those specific to renewable energy have long understood the environmental challenges of energy management.

Most technologies of this sector are still in development but have not been ecodesigned in a concrete way. For example, recycling technologies for wind turbines or photovoltaic solar panels are the subject of research, but not the ecodesign of these systems as such.

For communication, as few actions were put in practice, it remains low in the four regions. As mentioned in building sector, Portuguese companies that answered have developed actions in life cycle approaches for more years than the other regions, and have a higher degree of internalization of human resources with LC approaches competences.

4.3 Recycling sector

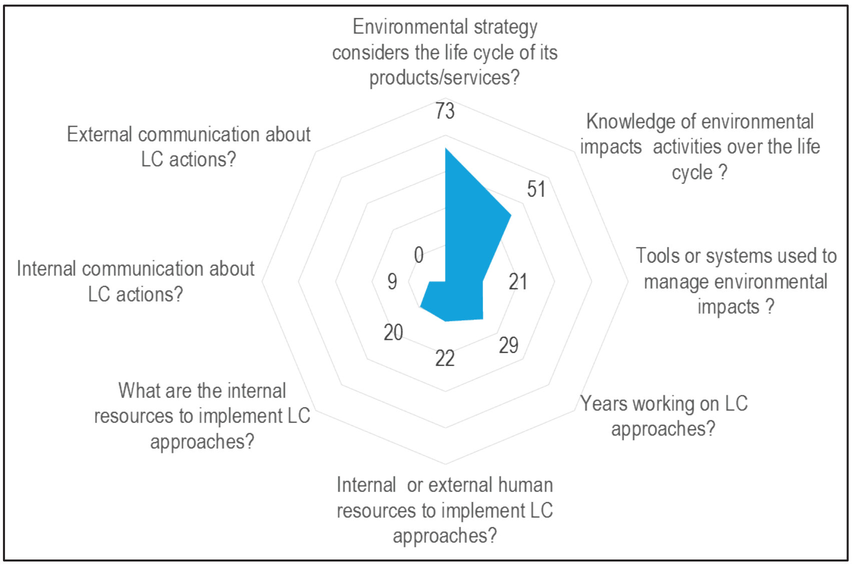
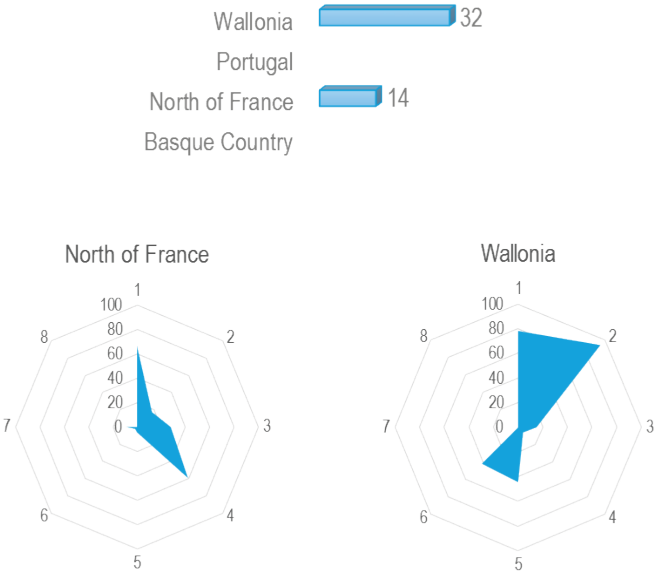


Figure 5: Global answers results of the life cycle maturity assessment in the recycling sector

- In the recycling sector, 73% of the companies considers the life cycle of their products in the environmental strategy.
- About 50% of the companies claim to have knowledge of the environmental impacts of their activities over the life cycle.
- The amount of tools used to manage the life cycle environmental impacts is scored at 20%, corresponding to the use of 2 tools/strategies per company.
- In average, the activities in life cycle approaches is relatively recent, scoring under 1/3 of the maximum value, corresponding to 1 to 2 years of experience.
- Only 20% of the companies have internal human resources to work in life cycle approaches, and generally don´t have a specific person or department for this.
- Finally, only 9% of the companies are communicating internally their activities of life cycle approaches, and none of them performed this communication to the exterior.

1	Environmental strategy considers the life cycle of its products/services?
2	Knowledge of environmental impacts activities over the life cycle ?
3	Tools or systems used to manage environmental impacts ?
4	Years working on LC approaches?
5	Internal or external human resources to implement LC approaches?
6	What are the internal resources to implement LC approaches?
7	Internal communication about LC actions?
8	External communication about LC actions?



Recycling sector average LC maturity: 22%

Figure 6: Disaggregation by region of the results of the life cycle maturity assessment in the recycling sector

Note: Wallonia's maturity does not include communication criteria. This is the reason, of their zero score.

Regarding the recycling sector, the environment is central in the business model of these companies and, as we can see in the figure, they have integrated LC in their strategies and have knowledge of the LC impacts of their products, but they don't implement or use LC tools internally. Thus, they don't have human resources with LC approaches competences, and they don't have LC related communication actions.

4.4 Maturity scoring by region and sector

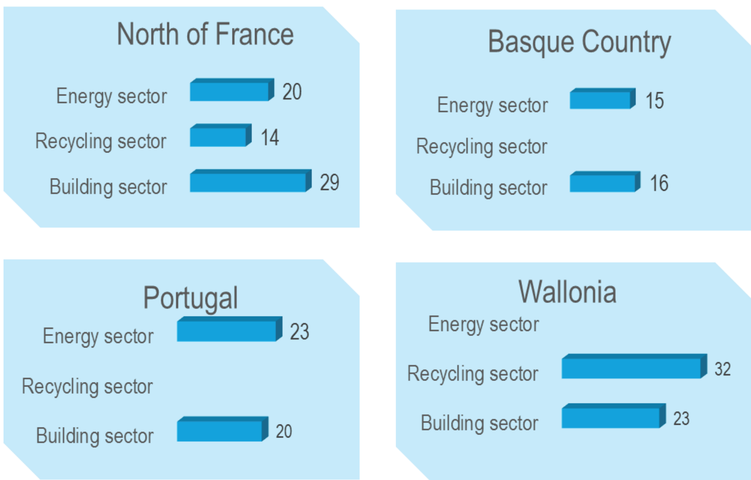


Figure 7: Sector maturity scoring by region

- When comparing the maturity of each sector by region, the results show that the building sector has the best score in the North of France and in the Basque Country (with a very similar value to the energy sector).

- In Portugal the best classified sector is the renewable energy, but close to the building sector result.
- In Wallonia region, the recycling sector has the overall bet result with a 32% score.

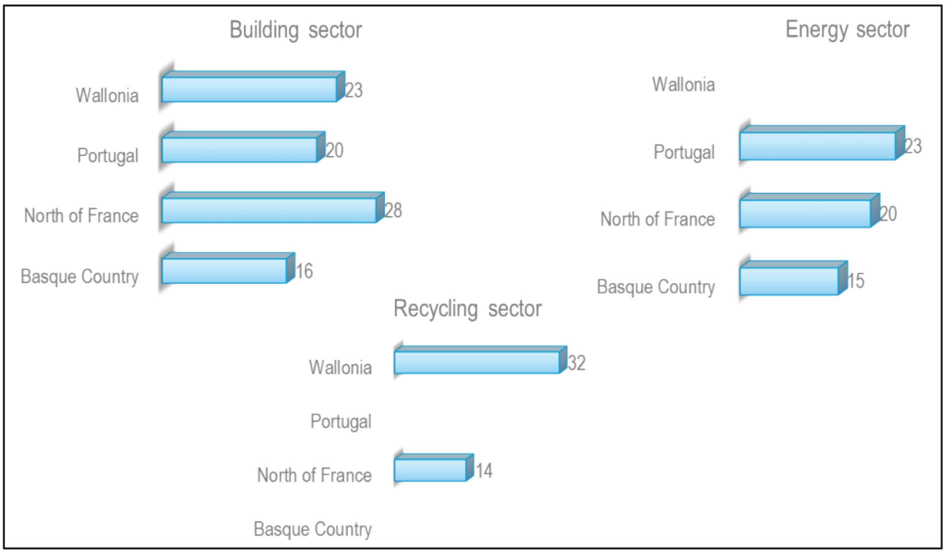


Figure 8: Regional maturity scoring by sector

- Analysing the results by sector, the results show that in the building sector the final maturity scores are between 16 and 28%, with the best score for France and the lowest to Spain. In the energy sector, the values are between 15 and 23%, and Portugal has the highest value and Spain the lowest.
- In the recycling sector, the difference between regions is significant, as Belgium has the best overall result of 32%, and France has the lowest overall result with 14%.

5 Conclusion

The maturity on life cycle approaches is low in all regions and sectors. In the endpoint evaluation, it is considered that there are no significant differences between the sectors and regions. Businesses claim to be aware of their environmental impacts through the life cycle, and that their environmental strategy include life cycle thinking. Companies have reduced and recently implemented life cycle instruments and tools. Internal human resources are typically non dedicated staff member(s). Communication actions of life cycle related issues, concerns internal dissemination activities rather than external ones.

This assessment of the maturity does not intend to be a definitive and final characterization of the maturity of the studied sectors regarding their integration of life cycle approaches, as complementary studies through stakeholders consultation is planned within LCiP project. Nevertheless, it helps to understand the advances and shortcomings of the players in each region and contribute to the development of specific action plans for each sector in the four regions.

Acknowledgements

The authors would like to thank the regional council of Nord Pas-de-Calais and the regional delegation of Agency for the Environment and Energy Management (ADEME) and the European commission for their financial support in the conduction of the present work.

References

Adibi, N., Bricout, J., Demaretz, C., Bogaert, C., 2012, Introducing a sectorial framework to better evaluate life cycle thinking maturity.

COM (2014) 398 final - Towards a circular economy_ A zero waste programme for Europe, European Commission, Brussels: 02 July 2014.

COM (2011) 112 final - A Roadmap for moving to a competitive low carbon economy in 2050, European Commission, Brussels: 25 May 2011.

COM (2011) 899 final - Innovation for a sustainable Future - The Eco-innovation Action Plan (Eco-AP), European Commission, Brussels: 15 December 2011.

COM(2005) 670 final - Thematic Strategy on the sustainable use of natural resources, European Commission, Brussels: 21 December 2005.

COM(2005) 666 final - Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste, European Commission, Brussels: 21 December 2005.

UNEP/SETAC, 2009, Life Cycle Management: How business uses it to decrease footprint, create opportunities and make value chains more sustainable.

Strategies for Education for Sustainable Development – Danish and Australian perspectives

Jette Egelund Holgaard [a,1], Roger Hadgraft [a,b], Anette Kolmos [a], Aida Guerra [a]

[a] Aalborg University, Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO, Aalborg, Denmark

[b] CQ University, School of Engineering and Technology, Melbourne, Australia.

Abstract

If we are to provide sustainable innovations for future societies, we need engineers who are able to think and act beyond pure technical competence. This is stressed in political and accreditation frameworks all over the world, and universities are trying to respond to these demand – however, Engineering Education for Sustainable Development (EESD) strategies seem to have a hard time moving from the rhetorical level to the practical level – the overview of sustainability practices and the sense of what “we” should do in terms of EESD seem fragmented and even sometimes blurred.

In this paper, we will systematically compare strategies for Engineering Education for Sustainable Development (EESD) in Denmark and in Australia, considering the similarities and differences in the institutional frameworks and not least EESD practice. Network Theory provides a platform for developing a conceptual framework for EESD, where the actors, activities and resources related to EESD are characterised at both university and national levels.

By document analysis, we provide an overview of institutional frameworks in Denmark and Australia, and we draw on literature and gather results across several studies the authors have been engaged in, including document analysis, case studies as well as action research of curricula change and EESD practice at Aalborg University, Denmark and RMIT University, Australia respectively. Based on this comparative analysis, it is concluded that by comparing these different HEI EESD networks we can get only an overview of current EESD initiatives, but we might also challenge the present understanding of the EESD profile at the university level and, by comparing with other HEI, point to potential change.

Keywords: Engineering Education, Sustainability, problem based learning, system thinking, capabilities.

1. Introduction

The overall sustainability challenge facing our post-modern society in the 21st century calls for a paradigm shift towards an ecological paradigm for education (Orr and Sterling, 2001). This ecological paradigm is characterised by development and action-orientation; critical and creative inquiry; reflective and iterative learning; an indicative and open curriculum; learning in groups, organisations and communities; and a democratic and participative environment (*ibid*).

A decade after this statement and at the end of the United Nations declared decade for Education for Sustainable Development (ESD), different approaches and integration strategies for ESD have developed slowly, and in a fragmented manner, throughout the world. The differences in strategies are not surprising due to different political and institutional frameworks, which provide different conditions for the way educational practitioners integrate sustainability into different educational programs. However, if the strategies are to develop and diffuse, more comparative research is needed to clarify potential synergies and degrees of transferability. This paper seeks to point out synergies between such strategies, even across continents, in the context of engineering education, with the intention to improve EESD.

Dowling et al. (2009) link the understanding and learning of sustainability to a new interdisciplinary approach using systems engineering. As systems engineering provides a

Corresponding author. Tel: +45 99409811 Email: jeh@plan.aau.dk

'whole systems' perspective, integrating different disciplines and requirements (Shamieh, 2011), it serves a purpose of contextualising engineering products beyond the technical problem to be solved – to include the larger complex societal systems and complex challenges such as sustainability of society, of the environment and of the economy.

At the same time, systems engineering allows for subsystems to be designed in a disciplinary fashion – with clear interfaces to other subsystems (Shamieh, 2011). Experiences from Australia shows that systems engineering, as a strategy, provides a framework for bringing sustainability cases into the classroom, and lets the students address these cases with a clear distinction and link between interdisciplinarity and the engineering discipline (electrical, mechanical, civil, etc.).

Another new approach to respond to the sustainability challenge is presented by Jamison et al. (2014) arguing for hybrid learning and an integrated mode of Engineering Education implying increasing emphasis on contextual knowledge, cultural awareness and sustainability agency as well as professional identity and scientific-technical competence. Experiences from Aalborg University, Denmark, have shown that problem based learning (PBL) can be used as a platform for this integrative mode with its focus on real-life problems and self-directed project work, as it calls for contextualisation, collaboration and agency. Students are not only getting prepared for agency, they practise agency, as they interact with surrounding stakeholders and thereby contribute to the development of society in general (Graaff and Kolmos, 2006).

Such strategic frameworks are important either to plan for EESD or to reflect on the type of response to the sustainability challenge. However, it can be difficulty to reflect on the implications of an EESD strategy without the overview of what is actually going on in the specific context. If what we could call the patchwork of EESD institutions and practices and their interrelation seems blurred, then statements in visions and missions are trapped in rhetoric without clear relation to the every day life of the university. Furthermore, the overview of what is, does not necessarily provide a picture of what could be, whereas a comparable framework for EESD institutions and practice would allow potential developments to be revealed. Based on this motivation the following research question has guided the study:

How can a conceptual framework based on network theory provide first an overview of EESD initiatives, and second be used to question current (local) standards and to seek new EESD practices based on inspiration from elsewhere?

The purpose is to emphasise the need for exploring, explicating and exploiting the synergies of different strategies across continental borders, as comparative studies will raise awareness of diverse practices.

2. Materials and methods

In this paper, we will systematically compare these strategies to Engineering Education for Sustainable Development (EESD) in Denmark and Australia considering their institutional frameworks and the type of responses from educational designers and teachers. The point of departure is a conceptual framework based on network theory.

2.1 Network Theory

Education for sustainability initiatives do not develop from out of the blue. Educational designers are prompted in some way to take the initiative to act, and they do that under the preconditions set by government, universities and faculty management. From that perspective an overview of EESD initiatives should cover the actors, their actions and the present pre-conditions for acting.

Furthermore, integrating sustainability in engineering education is, in popular terms, far from a one-man job, done overnight. The complexity of the concept of sustainability in itself, including and balancing economic, environmental as well as social concerns is challenging even at a small scale and in everyday life. Even if we commit ourselves to a path of sustainable development, the decision in designing, constructing, producing, consuming and disposal of every life product involves a net of multi-sided decision making processes involving diverse actors with diverse competencies and possibilities to act.

In other words, the path to sustainable development is in itself an ill-defined problem that calls for comprehensive, inclusive and aligned networks. Along the same lines, Gough and Scott (2008, p. 5) argue that:

"… *learning across all levels is essential for organisations and groups of organisations to adapt to major internal and external environmental shifts and challenges such as those presented by sustainable development, and that learning (however conceptualised) within and between networks of individuals, groups and organisations is likely to be an important feature of any successful initiative linking higher education and sustainable development*".

With the emphasis on networks, and following the network theory of Håkansson (1987) we characterise the EESD network in and around higher education (HE) institutions as an interplay of actors, activities and resources. This conceptual framework is chosen as the point of departure, as it provides the opportunity to develop a comprehensive framework that captures the institutional level as well as the local contexts of agency, allocated resources and type of activities that are related to the EESD strategy of the HE institution. At the same time, we recognise that this overview of who, how and by what means, do not go into depth with other yet important aspects of the network, such as the structure of the network, the type of communication flows, the mutual power relations etc.

2.2 Empirical sources

To create an overview of EESD initiatives from educational designers and teachers, university cases moving across university *and* national borders will provide the opportunity to reveal the interplay between initiatives in the universities as well as in the university context. In theory, any cross-national comparison could be of interest. The reason for the choice of Denmark and Australia, of Aalborg University and RMIT, was a shared interest in the research question, familiarity with the two universities as well as an appropriate research foundation to provide the needed overviews.

This paper is gathering a range of previous studies, which the authors have been engaged in, to collect the pieces prompted by the conceptual framework for an EESD-network. This includes:

- Studies related to capability based curricular development and EESD teaching at RMIT (Goricanec and Hadgraft, 2008), (Hadgraft and Goricanec, 2007), (Hadgraft and Muir, 2003), (Hadgraft et al., 2004a), (Hadgraft et al., 2004b) and (Jollands et al., 2005).
- Studies related to the Aalborg model of Problem based learning and EESD (Guerra, 2014), (Guerra and Holgaard, 2013), (Hansen et al., 2014) and (Holgaard et al., 2013).

Furthermore, we have added to this picture through document analysis of institutionalised documents e.g. declarations, accreditation schemes and curricula from the two universities.

3. A conceptual framework for understanding EESD

3.1 Political and institutional context for universities integrating EESD

In the context of corporate Environmental Responsibility within the education sector, Alabaster and Blair (1996) pointed to the relation between universities and the growing legal responsibilities and compliance with international policies, regulations and standards and, as well, the growing community empowerment and partnerships with "*local authorities, technical and national councils (TECs), enterprise agencies, statutory bodies and NGOs*" (Alabaster and Blair, 1996, p. 92). Jones et al. (2010) furthermore stress the role of the international declarations and charters, which offer opportunities for declared commitment to sustainability related policy and practice.

However, besides authorities, standardisation bodies and NGOs, research communities and cross-institutional knowledge networks of practitioners are important drivers for ESD initiatives.

Gough and Scott (2008, p. 122) argue that "*learning (however conceptualised) within and between networks of individuals, groups and organisations is likely to be an important feature of any successful initiative linking higher education and sustainable development*". With reference to 7 different case studies, (Gough and Scott, 2008) stress the importance of linking institutions (and individual academics) to create research communities as well as a network of ESD practitioners across institutions.

In a life-long learning perspective, such EESD community should also bring together practitioners from primary, secondary and higher (tertiary) education institutions, as well as work based learning practitioners. Likewise, the network can include local communities and civil society groups. Bawden et al., (2007) stress the critical role of civil society in fostering societal learning for a sustainable world, including civil society initiatives to interact with educational institutions. It is about using the community as a living lab to foster sustainability along with the education for sustainability – what (Orr and Sterling, 2001) would call learning *as* sustainability.

From an employability perspective, the increasing role of sustainability in the visions and missions of private as well as public companies also have an impact on the motivation, the resources as well as the possible learning environments for EESD. Environmental management, life cycle assessment, eco-design, user-driven innovation, corporate social responsibility, supply chain management and sustainability reporting are increasingly becoming a part of everyday business-discourse.

3.2 University EESD-network of actors, activities and resources

Without students, there is no education, and without students that are motivated to be educated for sustainable development, there will most likely be no useful outcomes from EESD. In this perspective, engineering students, as individuals and as student organisations, are central actors in EESD.

A Danish national wide investigation of newly enrolled engineering students and their approaches to sustainability showed that it might be a challenge to put sustainability on the agenda among math/science focused students, as their intrinsic motivation is not closely aligned to other motives to study engineering (Haase, 2013). Thereby, it is not at all given that every engineering student will welcome the emphasis on sustainability, making it more of a challenge for educational designers.

The commitment of program leaders is a considerable driver for EESD – not only in a rhetorical sense, but also by taking the lead in making the curriculum changes needed to respond to what has been termed a needed paradigm shift in HE towards an ecological paradigm. Johnston and Johnston (2012, p. 2) point to the lack of such incentive from faculty management as a considerable barrier for EESD:

"*Often times, in spite of institutional demand, faculty members seem reluctant to cede control over the curriculum to make possible more innovative curricular developments. It is their notoriously conservative and slow response to social and market needs that results in this dearth of graduates who have a vision of what a sustainable career, much less a society, looks like.*"

University management (Heads of School, Deans of Faculty, Rectors/Vice Chancellors/ Presidents) also play a leading role in "walking the talk" making comprehensive strategies for a sustainable university including environmental management, corporate social responsibility and a healthy economy as well as supporting EESD activities, including sustainable campus activities and support for EESD development projects and research.

At a more local level, the commitment from schools and program managers is necessary if EESD are to be integrated formally into curricula with or without incentives for the faculty, and make sure that the staff are sufficiently trained to cope with the integration of EESD.

Last but not least, the teachers that formally or informally educate for sustainable development and who have the direct relationships with the students, are essential gatekeepers for the realisation of EESD. However, due to the complex and integrative nature of EESD, teachers may have to move or collaborate in an interdisciplinary mode covering the field of sustainability as well as the specific engineering domain.

3.3 Overview of a conceptual framework of EESD actors, activities and resources

The conceptual framework developed concretises the conceptual framework from Håkansson to name the specific EESD actors, activities and resources (Figure 1).

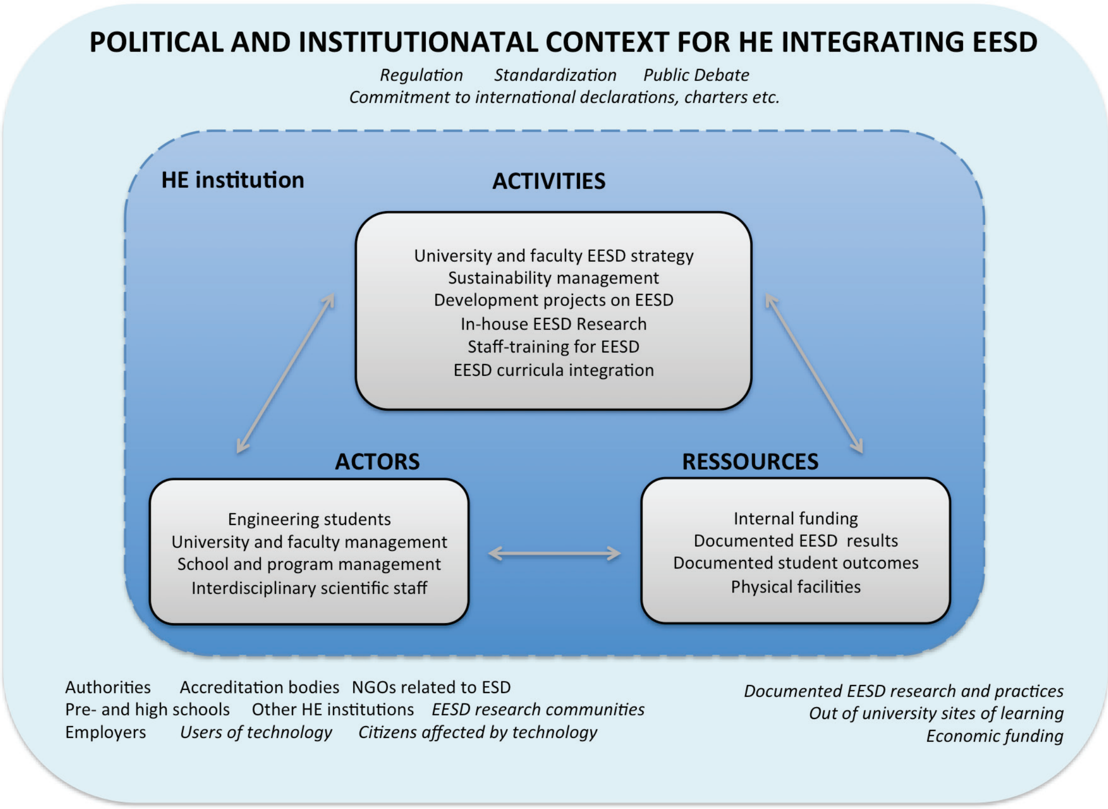


Figure 1: Political and institutional context for HE institutions integrating EESD.

4. The integrated approach to EESD – the Danish case

4.1 The institutional framework for EESD in Denmark

In Denmark, the regulatory framework and demands from accreditation bodies to integrate sustainability in HE is weak. The Ministry of Higher Education and Science have presented no specific strategies, policies or legislations for ESD in Higher Education, beyond a reference to the Copenhagen Declaration from 2002 stating the aim of "*transition towards a knowledge based economy capable of sustainable economic growth with more and better jobs and greater social cohesion brings new challenges to the development of human resources*" (Ministry of Higher Education and Science, 2013).

The Ministry of Education, having authority over primary, secondary and high school education, however, have formulated a strategy for ESD. Experiences with ESD at primary school and high school levels offers inspiration for HE institutions, and prepares students to develop knowledge, skills and competencies related to sustainability before entering HE institutions.

Some HE engineering institutions in Denmark have mentioned sustainability in their institutional profile (typically universities), but there are few guidelines to promote ESD. One example is from the student associations, e.g. Green Roskilde University Centre (GRUC), who have formulated input to the University's ESD strategy. Another example is Aalborg University, where the UNESCO Chair in PBL in Engineering and Science made a study of the ESD practices at the Faculty of Engineering and Science, and will use this as a platform to develop institutional guidelines on how to proceed with the integration of ESD.

International actors have framed the institutionalisation of ESD in Denmark. The acknowledgement from the United Nations of the Danish Regional Centre of Expertise (RCE) in Education for Sustainable Development provides a platform for collaboration for HE institutions in Denmark, where 4 out of the 16 university educators have membership (in the first three years, 10 out of 16 were members). In the first three-year period, the state funded project activities. After the three year period, the funding from the state came to an end, and on 25 February 2013, the RCE Denmark network was formally constituted as an association with the new name: Learning and Education for Sustainable Development – RCE Denmark.

Another example is UNESCO establishing Chairs and Centres related to EESD under the auspices of UNESCO. The national government has offered political and, to some extent, financial support, whereas HE institutions have also taken the initiative to allocate resources for EESD activities. Whereas the Danish Regional Centre of Expertise for Sustainable Development have focused on creating a national network including all disciplines and levels of education, the newly established (on 26 May, 2014) Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO reaches out to global communities and focuses their activities on Engineering Education for Sustainable Development.

Embedded in such collaborations are the research communities, which combine sustainability and educational research. There is a strong discourse, both in the media, in business relations and also in the research communities, related to sustainable development as well as to education, but the linking of the two is still at an early stage. There is a SD perspective on education, which has been focused on disciplines within the domain of sustainability science, and an educational perspective on sustainability, where the focus has been on integrating sustainability across disciplines by a more comprehensive view of curriculum change.

In university-business relations, which are strong in Denmark in relation to engineering education, the sustainability perspective has been strong, focusing on business processes and, to some extent, work based learning, whereas not much emphasis is put on sustainable development from an educational perspective that moves beyond disciplinary programs. Even though the sustainable development discourse represented by the users of technology can find its way to business processes in conceptual frameworks such as user centred design, the push from citizens and users of technology for EESD is limited as well as fragmented.

Furthermore, there is no tradition to provide specific staff training on ESD in Danish HE institutions moving beyond pedagogical training and courses in Human Resource Management (HRM). However, few examples have been identified, e.g. seminar activities at the Danish Technical University in 2010 and 2011, Aalborg University in 2012, 2013 and 2014, a few development projects have been carried out, providing international courses on sustainability (e.g. University College Northern Jutland, University College LilleBaelt).

What characterises these and other good examples is that it is seminars, workshops or collaborations, with the main purpose of establishing interest or mutual inspiration about ESD that works, and not formalised staff training. This does not mean that ESD is not practised, as there are examples of integration of sustainability in courses and projects. The Danish way is to create interdisciplinary staff teams. Where there is strong collaboration among those teachers, this can be very effective – however, when this is not the case, there is a risk that sustainability is seen as an add-on, which is not really related to the wider institutional strategy.

4.2 EESD at AAU – an integrative PBL approach

4.2.1 Educational model and alignment with ESD

All educational programs at Aalborg University are based on the Aalborg model of problem-oriented, project based learning, with emphasis on interdisciplinary, team-based and participant directed learning. The Aalborg model takes its point of departure as real/life authentic, practical or purely theoretical problems depending on the overall objective of the learning process (Kolmos and de Graaff, 2014). In the Faculty of Engineering and Science, problem based learning is structured as a combined 50/50 lecture courses and projects. In the projects, the students work in self-selected and self-directed groups of up to 8 persons. The courses are taught courses but, whenever possible, are in an inductive and active mode, where the students are actively engaged.

In every case the problem has to be analysed in the context in which it has evolved and is to be addressed. A problem can arise from the fact that some people consider a certain situation as unsatisfactory (aligned with a common-sense understanding of a problem), but a problem can also be to identify by the lack of attention/action to a yet unexplored potential or opportunity, a vision or a lack of knowledge (Holgaard et al., 2013).

Whatever the point of departure, the students have to analyse the problem and align the problem with possible contributions in their field of study. In this way they narrow down the problem and formulate a concrete problem related to their engineering and science field without neglecting the context in which their techno-scientific solutions are to be appropriated.

This problem based and project based learning model offers an appropriate platform for integrating ESD considering the interrelated primary requirements for education for sustainability summarised by (Sterling, 2014, pp. 22–24). This call for contextual, learning-centred, socially orientated learning and the specific reference to experiential learning cycles and democratic owner ship are directly aligned to the problem based learning principles above.

4.2.2 University and faculty ESD strategy

Aalborg University is committed to the COPERNICUS Charta whereas sustainable development has to be given fundamental status in the university strategies and promote comprehensive and integrated sustainability actions in relation to its functions (Copernicus Alliance, 2011). This is supported by Green campus initiatives and specific faculty strategies for ESD.

Although the main activities in the Green campus initiative have been related to environmental management of campus operations, initiatives have started to grow by supplementing the concept of a green campus activity with a concept of ”Green Knowledge” focusing on integrating sustainability into research and educational programs and ”Green minds” with special attention to the attitudes and behavioural patterns of employees and students in relation to environment and sustainability (Aalborg University, 2014).

At the Faculty of Engineering and Science, the Dean has allocated strategic funds to support the development and continuation of the problem based and project based learning (PBL) model in the engineering and science domain alongside an increasing focus on integrating sustainability in the educational programs. This cross-faculty organisation and global network under the UNESCO Chair of Problem based learning in Engineering was in 2014 further institutionalised into the Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO (UCPBL). The Aalborg Centre embraces and aligns Engineering Education Research (EER), PBL as well as EESD, reaching internally into the faculty as well as externally out to the global Engineering Education research community by, PhD-training, staff development activities, consultancy and network activities (UCPBL, 2014).

4.2.3 Strategy at formal school and program level

The Faculty of Engineering and Science at AAU includes three Schools, and the Heads of Schools are active players in a taskforce initiating implementation and development of sustainability in existing programs under UCPBL. The strategy has been to investigate already existing ESD initiatives in the institutions, and build on those experiences to plan for the implementation of further activities. Based on the recommendations from this analysis, the next step is to initiate concrete experiments in three programs at Aalborg University, where sustainability is not yet integrated in the formal curricula or have reported best practices.

In the study of existing ESD initiatives at AAU funded by the Faculty of Engineering and Science, a document analysis of 111 study programs showed that in more than half of the programs there was no mention of sustainability indicators extracted from the Global Report Initiative (Hansen et al., 2014, p. 24). However, a follow-up study, including in-depth interviews with chairpersons of study-boards and a questionnaire identifying good examples of teaching that integrate aspects of sustainability, revealed that even though sustainability was not integrated in the formal curricula, ESD was practised occasionally and personal interest and commitment to sustainability was one of the strongest drivers (Hansen et al., 2014).

4.2.4 Examples of EESD practice

One of the examples of the integration of sustainability in the PBL learning environment is from the Bachelor program of Media technology. Some of the characteristics from this case were that (Holgaard et al., 2013):

- The integration of sustainability was initiated by presenting a semester theme that related to sustainability, for example, sustainable lifestyles. As a part of the semester theme introduction, a workshop on sustainability was held.
- Within this theme, students themselves identified and analysed a problem and argued for different solutions that in one way or the other would foster a more sustainable lifestyle. They combined knowledge in the domain of media-technology with sustainability science facilitated by two supervisors from each of these domains.
- The students were strongly encouraged to use contextual inquiry to explore attitudes and behavioural patterns related to sustainability, and their media-technology product was targeted to make a change of these patterns.

The interdisciplinary staff-team, the open-ended thematic frame, the design methods calling for contextual inquiry and students agency to foster change is aligned with the hybrid and integrated model of engineering education and the emphasis on contextual knowledge, cultural awareness and sustainability agency (Jamison et al., 2014). However, the study of the case in Media-technology also showed that the students found it very hard to address sustainability without a defined platform of subject knowledge as the students experienced a scope which was too large for them to cope with in the learning situation. This is reinforces the call for a common understanding of sustainability that both students and teaching staff use noted in the study at the faculty level (Hansen et al., 2014).

A case-study of the integration of sustainability in the specialization Urban Planning and Management in the Master of Environmental, Energy and Urban Planning at Aalborg University (Guerra, 2014) also brought attention to the challenge students face when addressing the complex and ambiguous concept of sustainability. But even though students struggle to select an appropriate sustainability content to their profession, the self-directed way of constructing an understanding of sustainability in relation to different projects motivate students to reflect, take a stand and discover potential relations to their field of sustainability (Guerra and Holgaard, 2013). As one of the students stated:

"I've been working with sustainability at least two semesters, and I know I have a very clear and comprehensive understanding of what sustainability is, but it would be very interesting if this institution kind of have its own official understanding of sustainability. That also would have limited us in some of my project, because there was this one semester where I, myself, used a lot of time describing what sustainability could be in an urban planning context. And I would not have done that if they had an explicit explanation of what it was. Then… OK, we may have used our time in something else but however this was the way we learned what sustainability is, or at least how we see it"

As noted by Guerra and Holgaard (2013) it is a balance in the curriculum process to make the curriculum so open that the students can in fact construct their own view and select the most relevant aspects of sustainability in relation to the problem they are studying, and at the same time make sure that all students are guided through all relevant aspects of the multidimensional concept of sustainability.

5. The system engineering approach to EESD – the Australian case

5.1 The institutional framework for EESD in Australia

5.1.1 Government context

Since the election of the Liberal-National government in 2013, there has been a reduction in support for sustainability in Australia. The new government has been steadily removing support for renewable energy and other responses to climate change, such as abolishing the 'carbon tax'. The government also appears to be reducing its support for renewable energy targets, which are modest by Danish standards: 20% of Australian energy from renewables by 2020. In Denmark that figure is 50% by 2020 and 100% by 2050. So, the long-term support for ESD from this government looks bleak.

Nevertheless, good work has been done in the last decade by previous governments, particularly in encouraging the efficient use of energy (Department of Industry, 2014) and website eex.gov.au. One aspect of this work in higher education was to convene a higher education Energy Efficiency Advisory Group that would develop means to increase education around energy efficiency, particularly in engineering programs. This work eventually led to two contracts to develop resources to support teachers in universities in energy efficiency. Queensland University of Technology and the Australian National University are leading these two projects. The resources are expected to be available in late 2014 or early 2015.

The government has also been active in supporting education for sustainability across K-10 school education by providing a curriculum framework (Department of Environment, 2010). The downloadable framework for curriculum developers and policy makers establishes a national curriculum in sustainability.

State governments have also been active, for example, the New South Wales, (NSW Dept of Education and Communities, 2014). The Department has established 25 Zoo and Education Centres to help school children learn about sustainability and the environment: "learn *about* the environment, investigate and solve issues *in* the environment, acquire attitudes of care and concern *for* the environment, adopt behaviours and practices which *protect* the environment, and understand the principles of ecologically sustainable development".

In higher education, the New South Wales Government has also funded a range of training courses to help business to become more energy efficient (NSW Environment & Heritage, 2014). Another is the Energy Efficiency Training Module from The Australian Research Institute for Environment and Sustainability (ARIES, 2011).

5.1.2 Engineers Australia's accreditation framework

Engineers Australia accredits engineering programs in Australia by specifying the Stage 1 Competency Standard (Engineers Australia, 2011), which defines those outcomes that a graduate should be able to demonstrate at the end of their university education. Engineering programs must demonstrate how these outcomes are achieved in order to achieve accreditation. Australia is a signatory to the Washington Accord, which ensures international recognition for graduates of Australian programs (International Engineering Alliance, 2007).

The elements of competency relevant to EESD are elements 1.5a, 1.6c, 1.6d, 2.1g, 2.3b, 2.4e, 2.4f and 3.1c (below).

1.5 Knowledge of contextual factors impacting the engineering discipline:

a) Identifies and understands the interactions between engineering systems and people in the social, cultural, environmental, commercial, legal and political contexts in which they operate, including both the positive role of engineering in sustainable development and the potentially adverse impacts of engineering activity in the engineering discipline.

1.6 Understanding of the scope, principles, norms, accountabilities and bounds of contemporary engineering practice in the engineering discipline:

c) Appreciates the principles of safety engineering, risk management and the health and safety responsibilities of the professional engineer, including legislative requirements applicable to the engineering discipline.
d) Appreciates the social, environmental and economic principles of sustainable engineering practice.

2.1 Application of established engineering methods to complex engineering problem solving:

g) Identifies, quantifies, mitigates and manages technical, health, environmental, safety and other contextual risks associated with engineering application in the designated engineering discipline.

2.3 Application of systematic engineering synthesis and design processes:

b) Addresses broad contextual constraints such as social, cultural, environmental, commercial, legal political and human factors, as well as health, safety and sustainability imperatives as an integral part of the design process.

2.4 Application of systematic approaches to the conduct and management of engineering projects:

e) Is aware of the need to plan and quantify performance over the full lifecycle of a project, managing engineering performance within the overall implementation context.
f) Demonstrates commitment to sustainable engineering practices and the achievement of sustainable outcomes in all facets of engineering project work.

3.1 Ethical conduct and professional accountability

c) Understands the accountabilities of the professional engineer and the broader engineering team for the safety of other people and for protection of the environment.

Despite this substantial collection of required outcomes, it would be fair to say that the demonstration of the outcomes by engineering schools at accreditation time is weak, though improving. There continues to be an over-focus on technical outcomes through the four year programs with a few exceptions, e.g. (Hadgraft et al., 2004b).

One project that has attracted Engineers Australia's support over several years is the Natural Edge Project (TNEP, 2014). This group of young engineers, founded in 2002, have been resolute leaders in the field, producing 5 books and 10 sets of learning resources, including Whole System Design, which sets out a 10 step process for the design of engineering systems incorporating a whole systems approach (Stasinopoulos et al., 2011). TNEP has attracted funding from a range of national and international funding agencies.

5.1.3 ALTC/OLT funded projects

Over the last 25 years, the Australian Government has funded innovation in learning and teaching in Australian universities through a succession of agencies, the most recent of which have been the Australian Learning and Teaching Council (ALTC) and the current Office for Learning and Teaching (OLT) in the Federal Department of Education. Both of these groups have funded several projects on sustainability (Office for Learning & Teaching, 2014).

Many of these projects are also reported on the **Sustainability.edu.au** website, which has been developed through at least two projects, with the purpose of building a community of practice around the teaching of sustainability. Each academic can establish their own profile and use it to make teaching materials available to others. Each institution can also highlight the programs that they teach with a significant sustainability focus. The site can be searched to find materials and also people who can assist in the further development of teaching practices.

5.1.4 Universities themselves

The Talloires Declaration (University Leaders for a Sustainable Future, 2001) was composed in 1990. Universities around the world have become signatories, including 60% of Australian universities (University Leaders for a Sustainable Future, 2014). One tangible outcome from these efforts has been the establishment of the International Journal of Sustainability in Higher Education (Emerald Publishing, 2014).

In 2000, the Global Sustainability Institute was established at RMIT University in Melbourne, to encourage the development of sustainable practices within the University and in partner organisations. This institute has now closed though replaced by several other centres at RMIT focussed on sustainability. The National Centre for Sustainability at Swinburne University of Technology was established in 2002 and continues to work across organisations to provide education for sustainability services, including its Education for Sustainability Hub (National Centre for Sustainability, 2014).

Another initiative is the Australasian Campuses Towards Sustainability (ACTS, 2014) originating in 1990. "*ACTS aims to inspire, promote and support change towards best practice sustainability within the operations, curriculum and research of the Australasian tertiary education sector. We do this by providing resources, knowledge, developmental and networking opportunities for members and by critically challenging and supporting collaboration with stakeholders to lead sustainability innovation in the sector*." ACTS runs the Green Gowns Awards, Australasia to acknowledge good practice in the field.

In June 2013, a National Forum for Sustainability in Engineering was organised in Sydney, with the sponsorship of the Federal Department of Resources, Energy and Tourism. The intent was to bring together thought leaders from government, industry and academia to discuss the role of sustainability in educating graduates for the workforce. Industry representatives outlined current and recent projects that were transformed by a focus on sustainability.

In 2012, a new program in sustainable systems engineering was established at RMIT University to embody a new combination of systems engineering (INCOSE, 2006) and sustainability. This program draws from the mechanical engineering program, with core studies in energy, systems engineering and mathematical modelling and with options in sustainable energy systems and in sustainable transport and logistics. The program includes a project sequence that focuses on a systems approach to solving engineering problems. It begins with Engineering, Society and Sustainability in semester 1 and is followed by Engineering Design for Sustainability (semester 2), Sustainable Systems Design (semester 3), … Students undertake an additional mathematics course in Systems Dynamics and a specific Systems Engineering course.

During 2009-2011, the ALTC funded a national Academic Standards Project to develop Threshold Learning Outcomes across the nine discipline clusters represented in higher education (Discipline Scholars Network, 2013). This project is similar to the European Tuning Project (Tuning Project, 2012). Current work is addressing threshold learning outcomes for Environment and Sustainability (McBain et al., 2014). The key outcomes developed so far are: Trans-disciplinary Inquiry; Understanding Complexity; Skills for Environment and Sustainability; and Professional, Civic and Personal Responsibility. Each of these meta-skills is divided into finer grained outcomes in the draft standard at the above website.

5.2 EESD at RMIT – a capability and systems approach

5.2.1 Educational model and alignment with EESD

In 2001, RMIT University started a transformation of all engineering degree programs from traditional content-based curricula to capability-based curricula (Jollands et al., 2005). The focus shifted from a conceptual concern to teach the theory and methods within specialised technical domains, to a professional concern to provide students with the capabilities needed in their future professional practice.

RMIT has had a long tradition of Program Advisory Committees (PAC) and these committees were used as the focus for setting up industry forums in 2002 to develop the capability based curricula (Hadgraft and Muir, 2003). Through several industry meetings, the diversity and variability of views on engineering capabilities were explored. A Teaching and Learning Director from RMIT facilitated the group discussions and RMIT staff were invited to probe responses. This change from content-based to capability-based curricula had a great impact on the integration of sustainability in the engineering curricula at RMIT, as noted by (Hadgraft et al., 2004a, p. 33):

"Working with industry partners to gain a contextualised perspective of engineering for the twenty-first century, we found the traditional view of the engineer as technical problem solver with economic, social and environmental awareness was challenged in favour of a clear focus on sustainability, highlighting the need for trans-disciplinary approaches."

The call for a trans-disciplinary approach that moves beyond awareness about sustainability, led to a socio-ecological approach based on the work of Trist et al. (1997). The socio-ecological approach is "*an open system approach based on an appreciation of the levels of interdependence, measured by connectivity and dynamism) between systems and the environments in which they are embedded*" (Hadgraft and Muir, 2003, p. 3).

This open system approach has been influential both in the transformation process of the curricula as different partner perspectives on engineering capabilities have merged, but it has also been influential in terms of changes in the pedagogical approach. Together with an explicit call for capabilities related to teamwork, communication and problem-solving (Hadgraft and Muir, 2003), the pedagogical approach was adapted to capture systems thinking by a blended curriculum including process/project courses as well as technical/technology courses (Hadgraft and Goricanec, 2007).

5.2.2 University and Faculty ESD strategy

In more recent times, RMIT has established a Sustainability Committee to provide "*leadership, coordination and guidance to the University for integration of sustainability principles and practices throughout the University's core teaching and learning, research and operational activities*." (RMIT, 2014a). In part of the sustainability policy, tertiary education is required to (RMIT, 2014b):

- Engage students at all levels in learning about relevant sustainability concepts (knowledge, skills and values/attitudes), identifying issues of importance and taking actions in order to empower them as future leaders in industry and society in their chosen field.
- Embed sustainability capabilities/competencies within disciplinary and professional contexts, including where relevant challenges from beyond narrow or chosen discipline(s).
- Support academic and teaching staff to develop high levels of discipline relevant sustainability literacy so that they are able, competent and confident to facilitate sustainability learning.

However, in reality, little of this staff development occurs except within the initiative of individual academics who seek their own professional development through specialised workshops and conferences, usually related to their research interests.

In total, there are 24 courses listed as Sustainability courses on the "Think green at RMIT" website (RMIT, 2014c). The sustainability campus activities are supported by in-house research, primarily related to sustainability science although a spin-off of curricula changes also have resulted in ESD research. The Global Cities Institute, for example, embodies a range of research programs related to the sustainability of cities. ESD research is not gathered in a single cross-disciplinary Centre; rather it is a patchwork of research activities related to different disciplines across the university.

5.2.3 Strategy at formal school and program level

Out of the 23 schools at RMIT, there are 5 engineering and ICT schools: 1) Aerospace, Mechanical and Manufacturing Engineering, 2) Civil, Environmental and Chemical Engineering 3) Computer Science and Information Technology 4) Electrical and Computer Engineering and 5) the School of Engineering TAFE (Technical and Further Education – vocational engineering).

Even though the learning outcomes are aligned with the national accreditation of Engineers Australia, as explained above, the overall learning objectives from the courses that can be seen in the program handbooks of the different engineering degree programs (RMIT, 2014d) are rather broadly related to sustainability. A standard formulation in the knowledge and skill base is for example a) referring to knowledge of contextual factors impacting the engineering discipline and b) understanding the scope, principles, norms, accountabilities and bounds of contemporary engineering practice in the specific discipline.

However, when specific programs choose to elaborate on the overall Program Learning Outcomes, there *are* examples of explicit emphasis on sustainability. One example is the Bachelor of Industrial Design where it is stated that on completion of the program the student will be able to "*Demonstrate through practice-based design research an advanced knowledge of the socio-technical, environmental and economy eco-systems of industrial design both locally and globally*" (RMIT, 2014d).

The EESD strategy is strongly attached to the change from content-based to capability-based curricula. The focus on professional capabilities has on the other hand not initiated more cross-disciplinary courses. Goricanec and Hadgraft (2008, p. 123) argue that there is a lot of sustainability expertise spread across RMIT, but much is "trapped" in the disciplines and furthermore, (Hadgraft et al., 2004a, p. 47) note that engineering programs at RMIT are still trapped in the 'teach the fundamentals' model. There is, however, one compulsory cross-disciplinary course, a first year engineering practice course, in each of the three higher education engineering schools. Each of these courses uses a humanitarian engineering project designed by Engineers Without Borders – the EWB Challenge (Engineers Without Borders, 2014)

5.2.4 Examples of EESD practice

One example of a blended curriculum is the renewed Bachelor of Chemical Engineering from 2004. In the first year, new project based learning courses were introduced to develop a "*capability set made up of personal and professional development, sustainability, problem solving and decision-making, technical competences (engineering analysis), teamwork & leadership and communication*" (Jollands et al., 2005, p. 1).

One of the project based learning courses is Sustainable Engineering for first year Chemical Engineering students, which is designed to allow a stronger focus on problem based learning, including an increased focus on problem-identification, alternative applications and self-directed teamwork in smaller groups of four students (Jollands et al., 2005).

But besides developments to provide more blended curricula on the horizontal level (integrating a new type of EESD activity during a semester), the integration of sustainability was also considered in the vertical dimension to address the progression throughout the study in students' capabilities to address sustainability. For example, in the Civil and Infrastructure Engineering program, introduced in 2003, the progression of sustainability capabilities (Hadgraft et al., 2004b, p. 43) is as follows:

Year 1. Students study environmental principles for sustainability design and perform a conceptual design project to put these principles into action.
Year 2. Students focus on economic principles and project evaluation.
Year 3. Students design an eco-home, applying the full range of sustainability principles.
Year 4. Students tackle an infrastructure project (rather than a design project) extending the system view. They also study sustainability and lifecycle principles in an accompanying course called Infrastructure Management.

This way of gradually increasing students' sustainability scope provides possibilities for students to handle the complex nature of sustainability "in parts" and at the same time relate sustainability to professional practice.

Furthermore, recognising that less-recent engineering graduates will not necessarily have the same system view including not only technical and economic, but also environmental and social aspects in a life cycle perspective, RMIT has introduced a Master of Sustainable Practice, using project based learning methods (Goricanec and Hadgraft, 2006) and adult learning principles (andragogy). Besides, echoing the story of a blended curriculum with focus on continual development of capabilities, this Master's degree also exemplifies the way that academic and professional practice interact to move the focus from content to capabilities.

6. Discussion

When the two types of EESD network are compared (see figures 2 and 3) some interesting questions and potentials for further development arise.

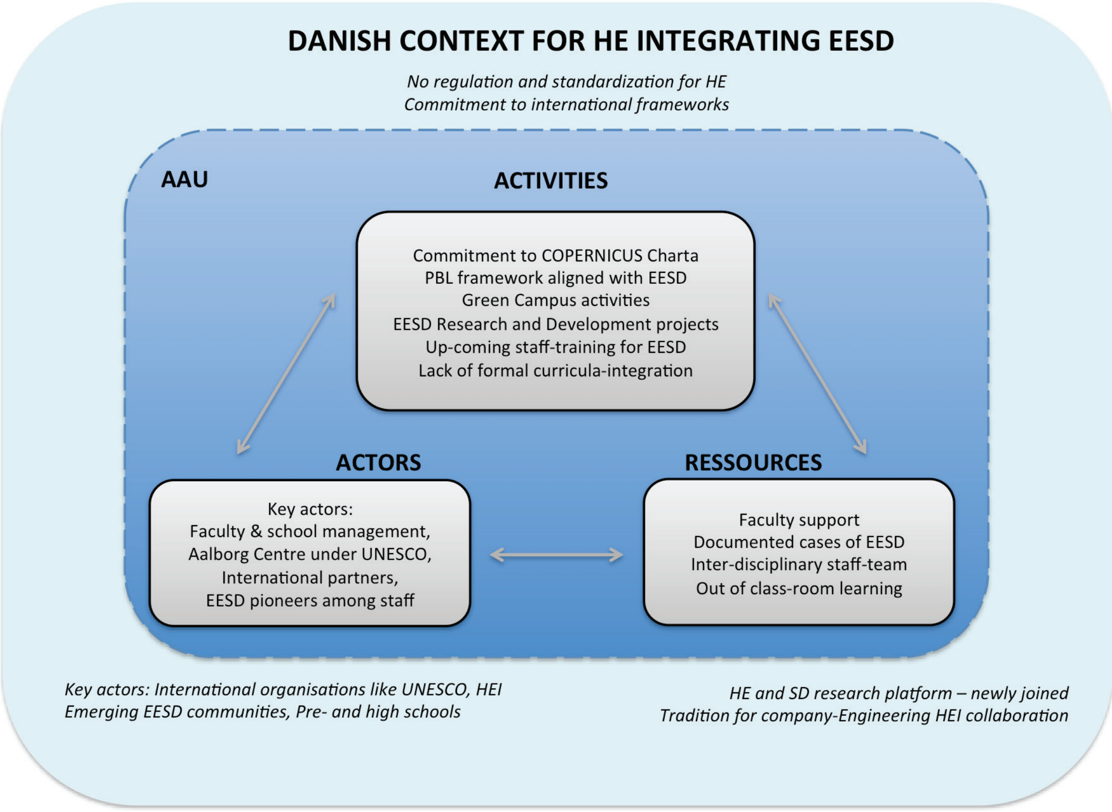


Figure 2: Danish context for HE institutions integrating EESD.

In the Danish case, a lack of focus on ESD in HE from government as well as from accreditation bodies has led to a limited push on Universities to integrate sustainability across engineering programs. The Danish government supports ESD initiatives such as the Danish Regional Centre of expertise for ESD and the Aalborg UNESCO centre for Problem Based Learning in Engineering Science and Sustainability, but economic funding is primary driven by private funds or allocated in university budgets. Thereby, the examples of integration of sustainability into the engineering curricula are mostly due to first movers among educational staff having personal commitments to SD and/or to EESD research.

In the Australian case, although there is currently little support from the Australian Government for sustainability efforts, there has been much activity over the last 15 years across government and universities. Universities themselves have often taken a leading role to champion conversations around sustainability, with a growing focus on climate change. The impact on curricula despite the focus on sustainability from accreditation bodies has, however, been slow. Although some universities list sustainability as a required graduate outcome, it is often difficult to find clear evidence of explicit sustainability outcomes in program descriptions. Like in the Danish case, the EESD-integration is fragmented and based on personal commitment rather than a comprehensive strategy.

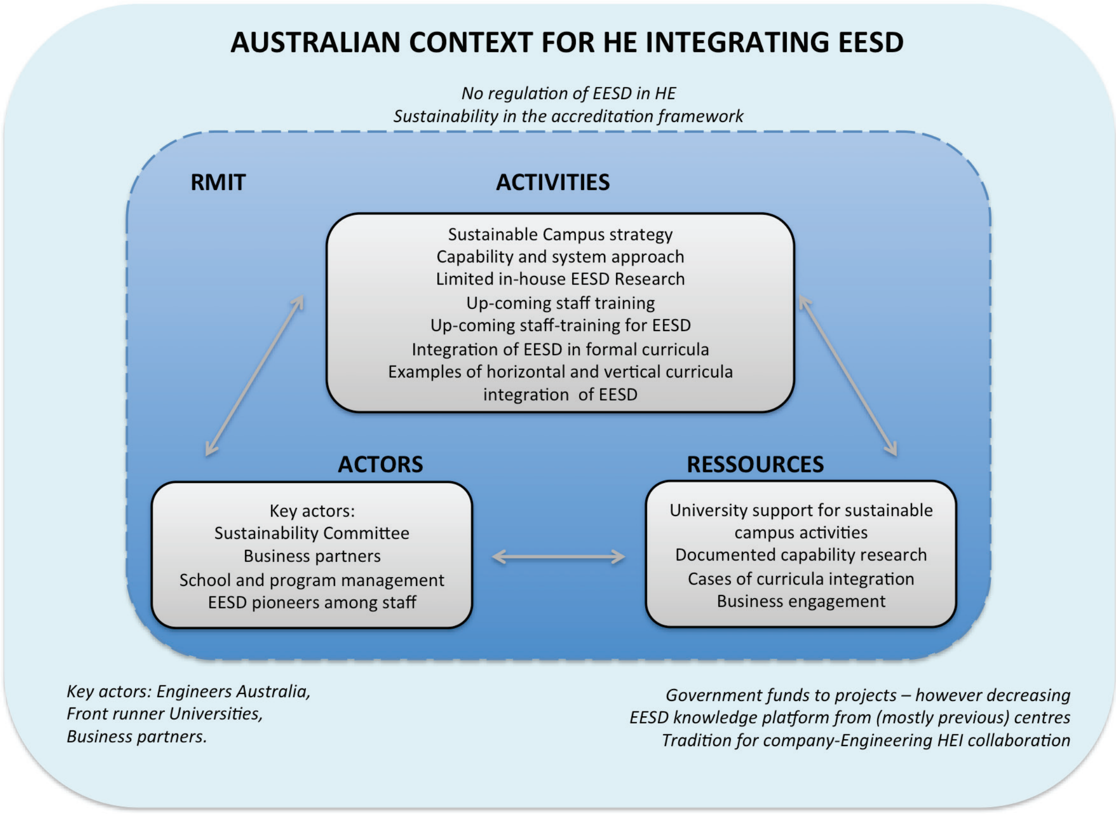


Figure 2: Danish context for HE institutions integrating EESD.

For the Danish case, one potential compared to the Australian case is to experiment with vertical integration of EESD in specific programs, and a corresponding question for reflection is, how a call for vertical integration in the curricula corresponds with the open problems and self-directed learning embedded in the Aalborg model. Another potential is to investigate whether employers in the Danish context emphasise sustainability to the same extent as has been the case in Australia, and how this can be used to motivate students to engage in sustainability in relation to their problem based learning projects. And, last but not least, the system engineering approach could be explored as a way to translate the Science, Technology and Society discourses into the engineering community.

For the Australian case the possibilities of responding to the closing down of centres for ESD in Australia could be to team up with international networks as, for example, the global network related to the Aalborg centre for PBL in Engineering Science and Sustainability. Another potential is to explore how interdisciplinary staff teams together can facilitate student learning for sustainability and ensure an integration of disciplinary and contextual knowledge.

This might even implicitly provide technical staff with training about sustainability, and staff with expertise in sustainability science with enough technical knowledge to bridge the two subjects, or rather mind-sets. And as the systems engineering approach has shown its worth as a conceptual framework for introducing sustainability as an integrated part of engineering systems, the problem based learning philosophy might be able to inspire by the focus on problem analysis as well as collaborative and self-directed learning.

7. Concluding remarks

In this paper we have introduced a conceptual framework for creating an overview of EESD initiatives, and by comparing different HEI EESD frameworks we have pointed to potential change. Because of its simplicity, the framework might also be used internally to challenge the present understanding of the EESD profile of the university. Looking for the exceptions (the black swan among the whites) can provide inspiration for further development of an EESD strategy that exemplifies the path from rhetorical statements to practical implementations.

The findings provided in this paper show that there is considerable potential for cross-fertilisation when comparing different EESD-networks and potentials for rethinking the current approach to EESD. It is a balance of creating room for different ways of relating to sustainability depending on the discipline and the professional contexts, and at the same time provides concrete guidelines so it is obvious that anything will not go.

However, if the challenge of creating a basic awareness and understanding of the pillars of sustainability and their relation to the different professions is not taken, even the most concrete statements are open for multiple interpretations – and the EESD initiatives will stay fragmented and student learning outcomes might be unpredictable.

Engineering education for sustainability is too important and engineering students future professional actions too influential for EESD to become a random activity in terms of content, integration and commitment. Coordinated action and common change strategies are needed and, to prompt this, the EESD-networks we have shown in this paper may find a purpose.

8. References

Aalborg University, 2014. Green AAU [WWW Document]. Green AAU. URL http://www.en.green.aau.dk/ (accessed 9.27.14).

ACTS, 2014. Australasian Campuses Towards Sustainability [WWW Document]. URL http://www.acts.asn.au (accessed 9.20.14).

Alabaster, T., Blair, D., 1996. Greening the University, in: Education for Sustainability, John Huckle & Stephen Sterling (Ed.). earthscan, London, UK, pp. 86–105.

ARIES, 2011. Energy Efficiency and Renewable Energy teaching module [WWW Document]. URL http://aries.mq.edu.au/projects/deewr_energy_efficiency/ (accessed 9.20.14).

Bawden, R., Guijt, I., Woodhill, J., 2007. The critical role of civil society in fostering societal learning for a sustainable world, in: Social Learning towards a Sustainable World, Arjen E.J Wals (ED.). Wageningen Academic Publishers, Wageningen, The Nederlands, pp. 133–149.

Copernicus Alliance, 2011. Copernicus Charta 2.0/2011.

Department of Environment, 2010. Sustainability Curriculum Framework: A guide for curriculum developers and policy makers.

Department of Industry, 2014. National Strategy on Energy Efficiency.

Discipline Scholars Network, 2013. Discipline Standards in Australia.

Dowling, D., Carew, A., Hadgraft, R., 2009. Engineering Your Future: An Australasian Guide, 1 edition. ed. Wiley, Milton, Qld.

Emerald Publishing, 2014. International Journal of Sustainability in Higher Education [WWW Document]. URL http://www.emeraldinsight.com/journal/ijshe (accessed 8.20.14).

Engineers Australia, 2011. Stage 1 Competency Standard for Professional Engineer.

Engineers Without Borders, 2014. EWB Challenge [WWW Document]. URL http://www.ewbchallenge.org/ (accessed 8.13.14).

Goricanec, J., Hadgraft, R., 2006. Sustainable practice in action - adult learning in a masters program, in: Proceedings of the 17th Annual Conference of the Australasia Association for Engineering Education. New Zealan: Auckland University of Technology, pp. 13–18.

Goricanec, J., Hadgraft, R., 2008. What is sustaining practice? How is it learned?, in: Global Sustainability Initiatives, J.A.F Stoner and C. Wankel. IAP-Information Age Publishing, pp. 103–137.

Gough, S., Scott, W., 2008. Higher Education and Sustainable Development: Paradox and Possibility. Routledge.

Graaff, E.D., Kolmos, A., 2006. Management of Change. Sense Publishers, Rotterdam.

Guerra, A., 2014. Problem Based Learning and Sustainable Engineering Education : Challenges for 21st Century.

Guerra, A., Holgaard, J.E., 2013. Student's perspectives on Education for Sustainable Development in a problem based learning environment, in: Proceedings EESD13. Presented at the Engineering Education for Sustainable Development, Cambridge.

Haase, S., 2013. Engineering students' sustainability approaches. Eur. J. Eng. Educ. 25.

Hadgraft, R., Goricanec, J., 2007. Engineering Sustainability?! Presented at the ASEE 2007 Annual Conference, Honolulu, Hawaii, p. 13.

Hadgraft, R., Muir, P., 2003. Defining Graduate Capabilities for Chemical Engineers at RMIT, in: Proceedings of AaeE Conference 29 September to 1 October 2003. Austral asian Association for Engineering Education, pp. 91–102.

Hadgraft, R., Muir, P., Jollands, M., Goricanec, J., Brown, A., Bunting, A., 2004a. Shifting the ground - sustainable engineering at RMIT, in: Protecting the Future, Sustainability Stories from RMIT University. CSIRO Publishing, pp. 31–51.

Hadgraft, R., Xie, M., Angeles, N., 2004b. Civil and Infrastructure Engineering for Sustainability. Presented at the ASEE annual conference, Salt Lake City.

Håkansson, H., 1987. Industrial technological development: a network approach. Croom Helm.

Hansen, K.K., Dahms, M.-L., Otrel-Cass, K., Guerra, A., 2014. Problem Based Learning and Sustainability : Practice and Potential. Faculty of Engineering and Science, Aalborg University, Aalborg.

Holgaard, J.E., Guerra, A., Knoche, H., Kolmos, A., Andersen, H.J., 2013. Information technology for sustainable development, in: Proceedings EESD13, Paper 21. Presented at the Engineering Education for Sustainable Development, Cambridge.

INCOSE, 2006. A Consensus of the INCOSE Fellows.

International Engineering Alliance, 2007. Washington Accord.

Jamison, A., Kolmos, A., Holgaard, J., 2014. Hybrid Learning: An Integrative Approach to Engineering Education. J. Eng. Educ. Volume 103, 253–273. doi:10.1002/jee.20041

Johnston, D.D., Johnston, L.F., 2012. Introduction: What's Required to Take EfS to the Next Level?, in: Higher Education for Sustainability: Cases, Challenges, and Opportunities from Across the Curriculum, Lucas F. Johnston (Ed.). Routledge, New York, NY, pp. 1–9.

Jollands, M., Hadgraft, R.G., Ward, L., Grundy, I., 2005. Student Engagement in Project-Based Courses in First Year Chemical Engineering at RMIT University, in: Proceedings of the 2005 ASEE/AaeE. Presented at the 4th Global Colloquium on Engineering Education, Austral asian Association for Engineering Education, p. 9.

Jones, P., Selby, D., Sterling, S., 2010. Sustainability Education - Perspectives and practice across higher education. earthscan.

Kolmos, A., de Graaff, E., 2014. Problem-Based and Project-Based Learning in Engineering Education: Merging Models, in: Cambridge Handbook of Engineering Education Research., A Johri & B M. Olds (Ed.). Cambridge University Press, pp. 141–161.

McBain, B., Phelam, L., Brown, Poul, Brown OA, Val, Horsfield, Richard, Taplin, Ros, Ferguson, Anna, 2014. Threshold Learning Outcomes for Environment and Sustainability.

Ministry of Higher Education and Science, 2013. The Copenhagen Declaration [WWW Document]. URL http://ufm.dk/aktuelt/pressemeddelelser/arkiv/2009/uddannelse-i-baeredygtig-udvikling-styrkes-i-nyt-netvaerk (accessed 9.27.14).

National Centre for Sustainability, 2014. National Centre for Sustainability [WWW Document]. URL http://www.swinburne.edu.au/ncs/sustainability.html (accessed 8.20.14).

NSW Dept of Education and Communities, 2014. Environmental and Sustainability Education.

NSW Environment & Heritage, 2014. Energy Efficiency Training [WWW Document]. URL http://www.environment.nsw.gov.au/business/energy-efficiency-training.htm

Office for Learning & Teaching, 2014. Sustainability [WWW Document]. URL http://www.olt.gov.au/search/apachesolr_search/sustainability (accessed 8.20.14).

Orr, D., Sterling, S.R., 2001. Sustainable Education: Revisioning Learning and Change. Green Books, Totnes.

RMIT, 2014a. Sustainability Committee [WWW Document]. URL http://www.rmit.edu.au/governance/committees/sustainability (accessed 9.25.14).

RMIT, 2014b. Sustainability Policy [WWW Document]. URL http://www.rmit.edu.au/browse;ID=wf9xrznule7c1 (accessed 9.25.14).

RMIT, 2014c. Sustainability courses [WWW Document]. URL http://sustainability.edu.au/material/courses/by-institution/rmit-university/ (accessed 9.25.14).

RMIT, 2014d. Engineering degrees at RMIT [WWW Document]. URL http://www.rmit.edu.au/browse;ID=h2ln6h2rduxe1 (accessed 9.25.14).

Shamieh, C., 2011. Systems Engineering for Dummies, IBM limited edition. ed. Wiley Publishing Inc.

Stasinopoulos, P., Smith, M.H., Karlson, “Charlie”, Desha, C., 2011. An Integrated Approach to Sustainable Engineering. earthscan, UK.

Sterling, S., 2014. Education in Change, in: Education for Sustainability, John Huckle & Stephen Sterling (Ed.). Routledge, pp. 18–40.

TNEP, 2014. The Natural Edge Project [WWW Document]. URL http://www.naturaledgeproject.net/default.aspx (accessed 9.20.14).

Trist, E., Emery, F., Murray, H., 1997. The social engagement of social science: a Tavistock anthology. University of Philadelphia, Philadelphia.

Tuning Project, 2012. Tuning Educational Structures [WWW Document]. URL http://www.unideusto.org/tuning/ (accessed 12.18.12).

UCPBL, 2014. UCPBL homepage [WWW Document]. Aalb. Cent. Probl. Based Learn. Eng. Sci. Sustain. Auspices UNESCO. URL http://www.ucpbl.net/ (accessed 9.27.14).

University Leaders for a Sustainable Future, 2001. Talloires Declaration.

University Leaders for a Sustainable Future, 2014. Talloires Declaration Institutional Signatory List [WWW Document]. URL http://www.ulsf.org/programs_talloires.html (accessed 8.20.14).

Recent impact on ancient well – the calculation of the Water Footprint of bottled natural mineral water

Maria Kalleitner-Huber*, Christian Pladerer, Austrian Institute of Ecology

Seidengasse 13, 1070 Vienna, Austria

phone: +43-699-5236115

fax: +43-1-5235843

*kalleitner-huber@ecology.at, www.ecology.at

1. Introduction

Water is the most threatened and at the same time most crucial resource for mankind. The contribution of human activity to water consumption and pollution is apparent in agriculture and industrial production as well as consumer patterns or leisure activities. Drinking water is essential for our health and fitness and the trend towards bottled mineral water is unbreakable, even in countries like Austria where most of the people are supplied with highest quality of tap water.

Vöslauer Mineralwasser AG[1] is the leading Austrian company in the sector of bottling and distributing of Mineral Water with a market share of 41 % in Austria and a 97.8 million euro turnover in the year 2013[1]. The Vöslauer Mineral Water originates from a thermal spring located in the east of Austria and is a totally pure and healthy product; it rises to the surface without pumping, because the Vöslauer spring is an artesian well, originated over 600 meters deep more than 20,000 years ago. The Vöslauer spring water is also used for the thermal bath due to its curative and healing properties.

In an effort to reduce the environmental impact of the production of bottled mineral water, Vöslauer Mineralwasser AG has implemented several measures like a reduction of weight per 20 % per product and increase of the recycling content to 66 % of the PET bottles. Special focus lies on the efficient usage of different water sources for different purposes. Thus, the artesian spring water from deeper sources is exclusively used for drinking purposes while the overflow of the source is utilized for cleaning and production processes.

The reasons for the company to implement waterfootprinting for selected products rose out of the need for gaining more information of and insight into the environmental impact of the well-known, but to date unbalanced bottling business. Although Austria is blessed with rich water resources with drinking water quality, Vöslauer takes its environmental and social responsibility seriously and looks beyond the factory gate in addition to the water consumption resulting from the on-site production activities. The company puts effort in raising awareness within the company, taking measures for optimized water management in line with other measures like reduction of losses along the pipes and ensuring sustainable usage of the ancient well.

With the following case study, the challenges and limits of calculating the Water Footprint (WF) of bottled water will be shown. Data availability and the influence of the system boundaries will be addressed as well as the comparability of different data sources (literature vs. real data from the company). Specific product improvement measures based on the results will be given. Special focus will lie on the influence of different kinds of packaging; the water footprint of a 1 litre re-usable glass bottle has been compared to a 1.5 litre PET single use bottle.

[1] http://www.voeslauer.com/web/Nachhaltigkeitsbericht?_ga=1.96794653.349004444.1400181144

2. Water Footprinting of products

2.1 Approach

Similar to other assessment or footprinting approaches like LCA or Carbonfootprint water footprinting has sought to understand and measure the invisible or virtual link between the local consumption of goods and the impacts from the production of those goods on often distant water resources. Especially if agricultural products like sugar are included, their origin has a major influence on the „outsourced" water usage.
A methodology for measuring human demands – or 'footprint '– on the biosphere was first developed in the early 1990s by Rees and Wackernagel. Allan (1998) introduced the term 'virtual water' to describe water used in the production of imported goods and hypothesised that such virtual water imports were a partial solution to problems of water scarcity in the Middle East (Chapagain and Ticker, 2012).
These ideas took on a more precise form once researchers began to quantify and calculate global virtual water flows and, from this, water footprints of specific products and of nations (e.g. Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2004; Oki et al., 2003; de Fraiture et al., 2004; Yang et al., 2006) (Chapagain and Ticker, 2012).
Water footprints of nations have been calculated on a broader basis than on individual product basis. Data on bottled drinks have been rare at the time of the waterfootprinting of bottled water.

The accounting of the water footprint of products is a method to assess the total water consumption along the whole life cycle and presents a relative young method in comparison to other indicator based methods like the carbon footprint. The rapidly growing interest of companies and governments to use water footprint accounts as a basis for formulating sustainable water strategies and policies and a shared standard and vision has been developed by the Water Footprint Network (WFN). The accounting of the water footprint of bottled mineral water has been accomplished according to this standard.

The calculation of the water footprint (WF) comprised of the following steps: setting the goal and system boundary, gathering input and output data and balancing inventory analysis, calculating the water footprint for the two products, analysis and interpretation.

2.2 Global Water Footprint Standard

The calculated water footprint (WF) follows the Global Water Footprint Standard described in detail within the Water Footprint Assessment Manual (WFN Manual) (Hoekstra et al., 2011), input and output flow table and calculations have been accomplished in excel files in order to enable the company to make adjustments easily if process parameters change. As Vöslauer is working on the fresh water reduction on a permanent basis this procedure has been selected as the most practical manner.
According to the WFN Manual the water footprint of a product is an empirical indicator of how much water is consumed over the whole supply chain of the product. The water footprint of an individual, community or business is defined as the total volume of fresh water that is used to produce the goods and services consumed by the individual or community or produced by the business.
A water footprint (WF), expressed in volumetric terms (i.e. litres or m^3 of water), is therefore a multidimensional indicator that looks at both direct and indirect water use of a consumer or

producer and which can show water consumption volumes by source and polluted volumes by type of pollution.

Figure 1 shows the schematic links between water use and the different types of water footprint in the context of the hydrological cycle (Chapagain et al., 2006 in Chapagain and Ticker, 2012).

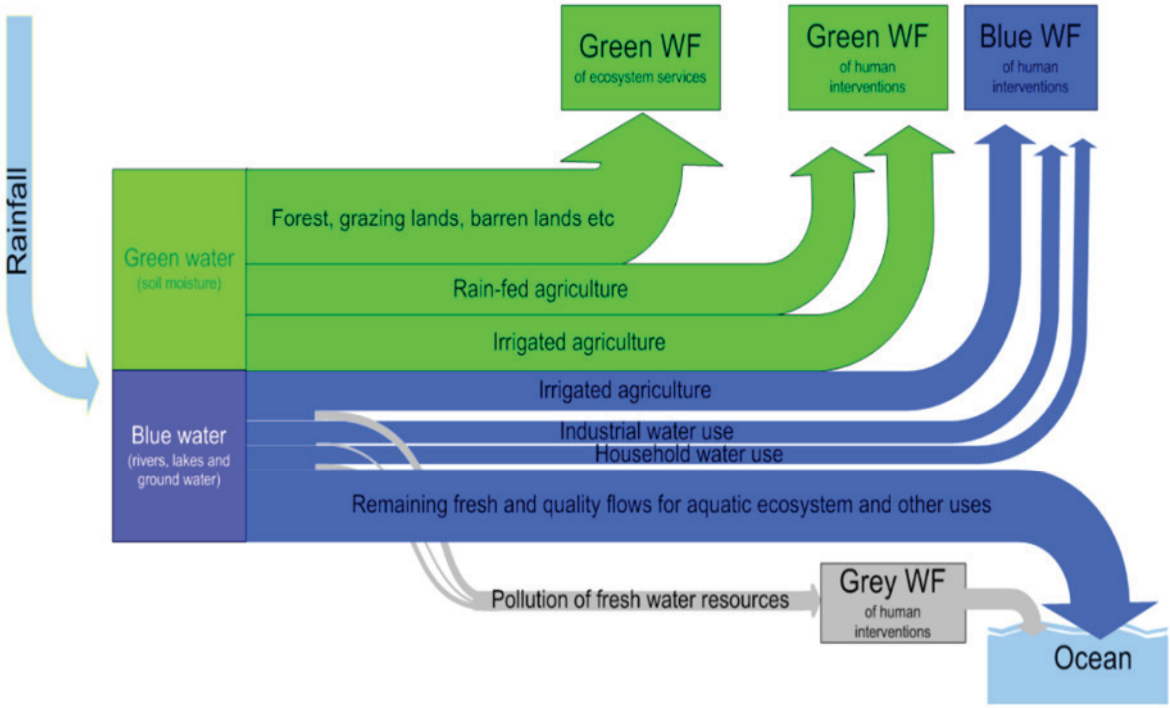


Figure 1: Components of water footprint according to Chapagain and Ticker, 2012

Green WF is the volume of rainwater consumed and expresses the volume of soil moisture used by rain-fed cropping. It is equal to the volume of water lost through evapotranspiration.

If an agricultural ingredient like sugar is used, e.g. the Green WF can have a key influence on the total WF of a beverage.

Blue WF refers to the consumption of surface water and ground water, whereby consumption refers to the volume of water that evaporates or is incorporated into a product or is transferred into another river or aquifer through the production process. The blue WF is often smaller than the volume of water withdrawal because some water may return to the ground or surface water body from which it was withdrawn.

Blue WF consists of irrigation water and/or direct water use in industry or in homes, minus return flows.

The grey WF concept reflects the notion that the impacts of water pollution can be expressed in terms of the volume of water required to dilute pollutants such that they become harmless

Grey WF is an indicator of the degree of freshwater pollution and is defined as the volume of freshwater required assimilating the load of pollutants based on existing ambient water-quality standards.

WF differs from measures of water withdrawal in that it does not include return flows, i.e. blue water withdrawal insofar as this water is returned to where it came from. Moreover, a WF normally considers green and grey water alongside blue water. A WF can also be disaggregated into direct and indirect WF components, sometimes also referred to as internal and external WF or, in the context of manufacturing and business contexts, operational and supply chain WF. The basic distinction is between water (blue, green or grey) consumed through the tap and water embedded in products or processes.

3. Water footprint of bottled mineral water

3.1 Scope and system boundary

The water footprint of the following two products has been compared:

- Carbonated mineral water in a single use 1.5 l PET bottle (household usage)
- Carbonated mineral water in a re-usable 1.0 l glass bottle (gastronomy usage)

Figure 2: Examined 1.5 l PET bottle and 1.0 l glass bottle

1000 l of natural mineral water in the selected bottles has been defined as functional unit. The system boundary comprises the extraction and bottling of the mineral water in the factory in Austria including relevant input parameters like packaging (bottles, trays, cases, euro pallets, foil) and the transport to the distribution centres and distributors. The distribution to the supermarkets and restaurants, storing and cooling before usage do not lie within the system boundary. The following figures present the two product systems with the relevant in- and output flows and sub processes at the production site. Prior to data collection it was necessary to set up a list of the individual components of the product in order to be able to depict all associated processes in the product systems.

According to literature (BEER, 2011) the following parts constitute less than 1% of the entire water consumption along the supply chain of bottled beverages and therefore have not been considered as relevant (De minimis):

- ingredients < 1 % by weight
- distribution
- retail, consumption (infrastructure, cooling)
- disposal, recycling and re-use of waste streams

The so called de minimis regulation refers to the relevancy of components and as cutting off criterion 1% of the mass of the examined final product are usually selected. Processing parts which constitute less than 1% of the mass of the examined final product are neglected because of low relevance, except for there are particularly poisonous substances and/or harmful on a long-term basis or particularly scarce resources.

As transport is considered as an impact parameter when comparing single to refillable multi

use bottles, the distribution of the bottled water to the distributors/distribution centres has been included into the calculation.
The following components are considered as relevant and have been considered for the calculation of the water footprint:

- water in the product
- ingredients > 1 % by weight
- water conditioning
- process water
- losses due to incorrect fillings
- water losses at the well/transport/infrastructure
- waste water including detergents
- energy from renewable sources and electricity
- packaging (preforms/bottles, cases/trays, euro pallets, foil)

3.2 Assumptions and adaptions for the calculation

The WF has been calculated relatively for the defined functional unit of 1000 litres of mineral water (corresponds to 666.67 pieces of PET bottles and 1000 pieces of GLASS bottles) and absolutely per a single unit (= 1 bottle). Direct and indirect WF have been depicted separately, which again consist of blue, green and grey footprint.
The Green WF has not been calculated because no agricultural products like sugar or aromatic substances are used in bottled mineral water. Thus, only the Blue and Grey WF have been calculated.
Additionally to the product itself, the mineral water from the 15,000 year old spring is used as process water, particularly for purification processes. The blue and grey WF are based on real data of actual consumption and seizable losses e.g. from reverse osmosis and rinsing losses during the CO_2 adjustment in the so called Carboniser have been considered. For the calculation of the WF the distinction of the following terms is crucial:

- Water consumption
- Water usage and
- Water pollution (wastewater).

Water consumption effects the calculation of the WFA directly and must be distinguished from water use where a certain amount of water is not consumed but remains available for the same or a different purpose. Water consumption is a measure for the spatial and temporal availability of water and contains:

- Evaporation - high influence of e.g. open water reservoirs of storage power plants
- Losses referring from storage/cooling in the water reservoir and/or water tank, transportation, evaporation from processes e.g. heating
- water which is incorporated into the product, here: bottled mineral water

For the WF of a product the consumptive water use is relevant. This refers to the quantity of water which is actually contained in the product and/or has evaporated. Local usage for the same purpose (water recycling) or an alternative purpose (water re-use) does not have any influence on the water footprint.

3.2 Preparatory steps

The inventory analysis is based on the existing data of Vöslauer and resulted into the quantification of the relevant input and output flows of the product systems. Those present the basis for further data collection and calculation of the water footprint (WF). Process and product specific data which could not be raised have been taken out of acknowledged databases and balancing software (e.g. Global Watertool, Eco-invent, Gemis) or have been estimated. Water losses were only partly quantifiable and therefore could not be considered completely. For the consideration of the upstream process steps of the packing materials data from literature were used.
With the inventory analysis all in- and output flows have been determined set aside consumption and disposal of the bottles. For this purpose flow sheets for both product systems under consideration of the system border have been provided (figure 3 and 4) as well as an input output table for the regarded processes of the selected products.
While the production steps within the company affect the direct water footprint of the products, the up- and downstream processes present the basis for the indirect WF. Data collection of upstream suppliers concerning the water consumption of the basic materials and their processing was not very fruitful. Subsequently for these process steps literature and database values were consulted and adapted if necessary.

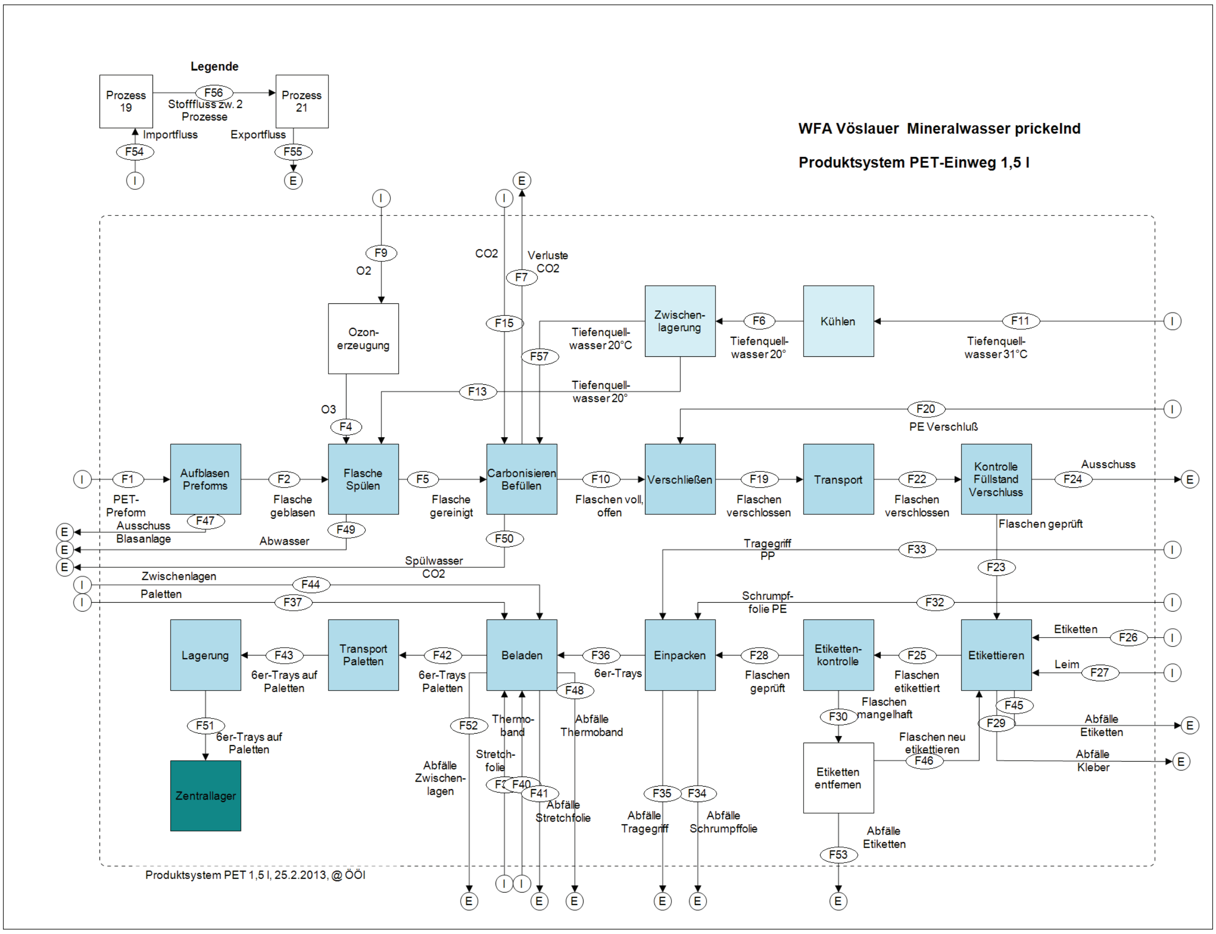


Figure 3: Product System single use 1.5 litre PET bottle

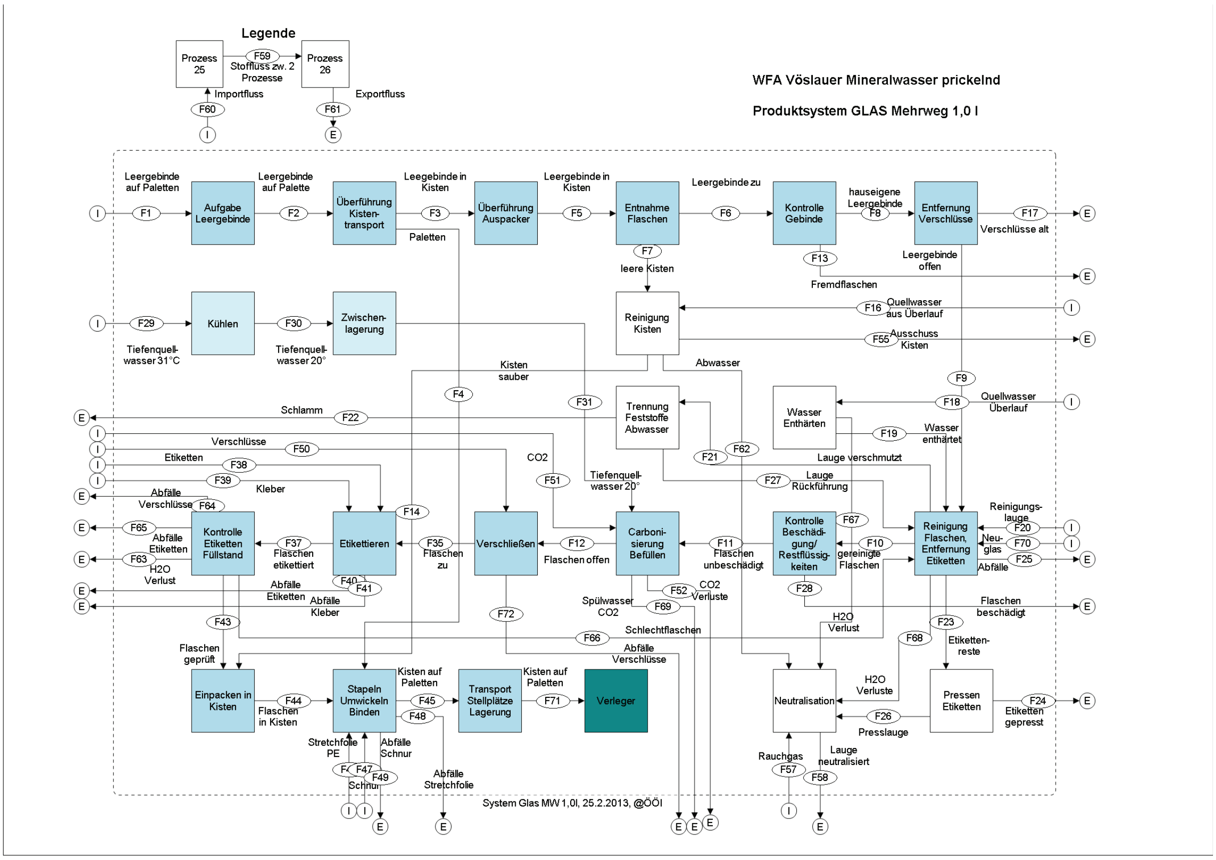


Figure 4: Product system re-usable 1.0 litre glass bottle

4. Results and Discussion

The calculation results of the two product systems have been compared and analysed; key influence factors have been identified.

4.1 Comparison of the water footprint of the two product systems

The following graphs show the percentage distribution of the blue water footprint.

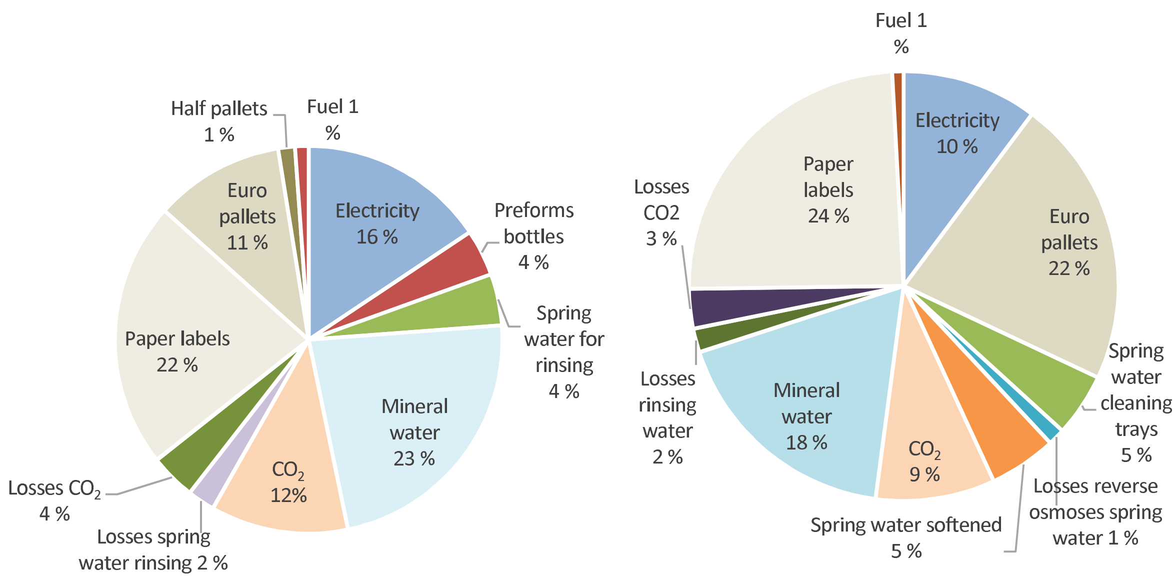


Figure 6: composition of Blue WF PET (left) in comparison to Blue WF GLASS (right

The main contribution to the blue water footprint is similar to both product systems and results from the bottled mineral water itself, the paper labels, the wood pallets, the used electricity and CO_2. The losses of CO_2 and of water from rinsing processes have the same share in both systems.
The individual contribution differs, e.g. the electricity demand for the PET system is higher due to the blow moulding process of the preforms to gain PET bottles (compare 16 % PET to 10 % GLASS).
It is also visible that for the reusable GLASS system more wood pallets are needed and additional water consumption occurs for the cleaning process of the reusable trays (5 %) and bottles (spring water softened 5 %).The pallets and paper labels of the PET system sum up to 34 % of the Blue WF PET and the product itself – the carbonised spring water to 35 %, whereas the pallets and paper labels of the GLASS system amount to 46 % of the Blue WF GLASS and the carbonised spring water to 27 %.
Figure 7 shows the results split into the indirect and direct WF depending where the consumption is allocated to. This is very important for the development of reasonable optimization strategies within reach.

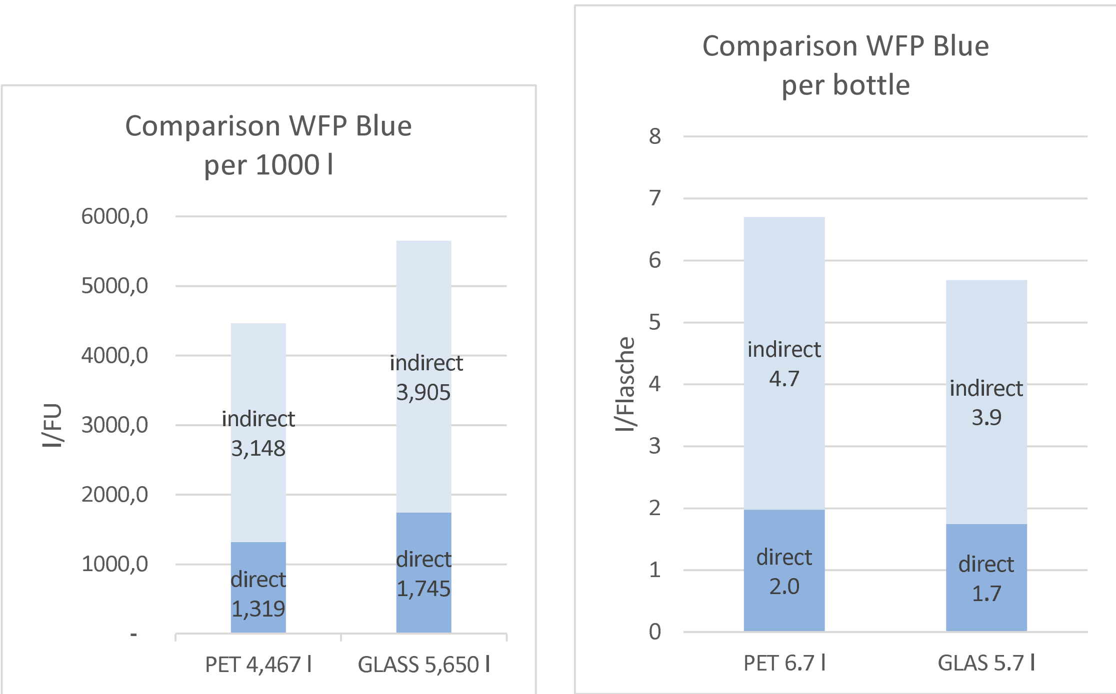
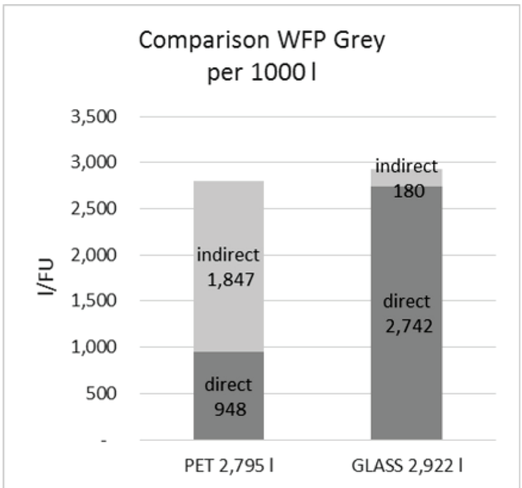


Figure 7: composition indirect and direct Blue WF per 1000 l in comparison to Blue WF per bottle

For the production of 1 l of mineral water 4.5 litres of water are needed for the bottling per 1.5 l PET bottle, whereas 5.6 litres are needed for the production of mineral water per 1.0 l Glass bottle (compare Figure 7 on the left). Figure 8 shows the results for the Grey WF which are also split into direct (internal) and indirect (external) WF contributions. Surprisingly, the Grey WF is about the same volume per functional unit, although one might assume a much higher water consumption for multi-use systems due to the cleaning processes of bottles and trays. The ratio for the amount of water necessary to dilute waste water to fulfil the local quality standards is 1 : 2.8 for PET and 1 : 2.9 for Glass.
But the share of indirect and direct WF shows very contrary results, referring from higher internal consumption for cleaning processes for the GLASS than for the PET system.



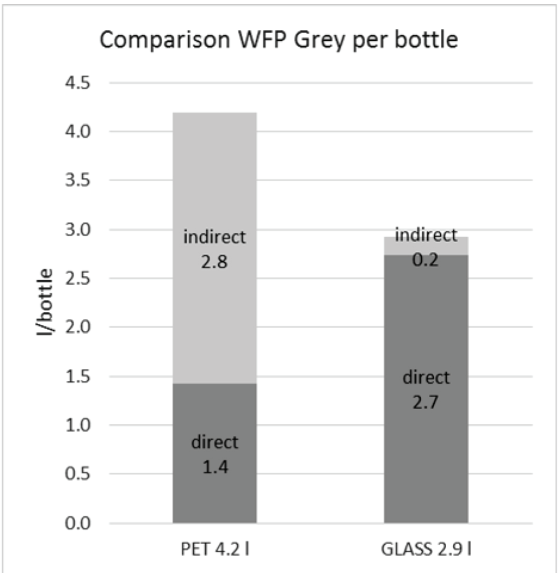


Figure 8: composition indirect and direct Grey WF per 1000 l in comparison to Grey WF per bottle

4.2 Influence factors on Blue Water Footprint and optimization

The water footprint is an indicator for the assessment of one single environmental parameter – the consumption of fresh water. The inclusion of the supply chain including packing materials and auxiliary materials shows the magnitude of the influence of water consumption along the product life cycle on the entire water footprint.
As Blue water makes the highest share of the water footprint, the following key influence factors could be elaborated as starting points for its optimization:

Key impact parameters:

- Paper labels: Paper production is water-intensive, plus raw material wood
- Wood pallets: long growth phase and corresponding water requirement
- Electricity from storage power plants: evaporation of free water surfaces
- Carbon dioxide, CO_2

Comparison product system PET to GLASS

- Absolute water consumption differs: ratio 1: 7.2 l for PET and 1: 8.6 l for glass
- Similarity: main contribution of labels, pallets, electricity, CO_2 and bottled water
- Glass: more wood pallets per functional unit
- Electricity demand for PET bottles higher due to blow moulding of preforms
- Influence of bottles lower than 1%, high glass recycling rate and multi-path usage

The calculated results of the direct WF of the systems PET and GLASS lie under those for the indirect WF resulting from the upstream processes with exception of the grey water footprint of glass, where the cleaning of the empty bottles constitutes the largest portion of the water consumption. The comparison to the already internally determined water consumption shows that the so far unconsidered up- and downstream steps have great impact on the total water footprint: “For the production of one litre of Vöslauer mineral water an average of 0.9 litre of fresh water is required which sums up to 1.9 litres per litre of bottled beverage. This leads to approximately three-quarter of a litre of waste water and a direct water consumption of 2.65

litres per litre product (ratio 1: 2.65 l)" (Vöslauer sustainability report 2011, p. 22 water protection).

Table 1 lists the main components of the total water footprint including their allocation to the direct and indirect water footprint. The paper labels, wood pallets and the electricity demand for the production of the bottles are responsible for 56 % of the WF_{total} of the system GLASS which can be assigned to the upstream processes (=indirect). The largest portion which can be related directly to the production at Vöslauer accounts for 38% of the entire water footprint and results from the water conditioning and cleaning, the carbon dioxide and the bottled mineral water itself. Regarding the largest contribution to the WF of the PET system the impact is similar and main shares can also be assigned to the upstream processes: the paper labels, the wood pallets and the electricity demand for the production of the bottles constitute 49% of fresh water need. The direct WF consists mainly of the water consumption due to cleaning and water processing, the carbon dioxide and the bottled mineral water itself and makes 45% of the entire WF.

Components/Processes with main impact	Share GLASS	Share PET	direct/ indirect
Paper labels	24 %	22 %	indirect
Euro pallets	22 %	11 %	indirect
Electricity	10 %	16 %	indirect
Total indirect	*56 %*	*49 %*	
Cleaning/ Conditioning	11%	10 %	direct
Carbon dioxide	9 %	12 %	direct
Mineral water	18 %	23 %	direct
Total direct	*38 %*	*45 %*	

Table 1: components and processes with main impact on total WF_{total}

5. Conclusions

The calculation results point out the big influence of the upstream processes and components which are considerably influenced by procurement decisions and production processes.
The ratio of the bottled product itself to the fresh water need along the supply chain is 1: 8.6 litres for glass returnable bottles and 1:7.3 litres for PET non deposit bottles. This means that for the production of 1 litre of mineral water in a refillable 1.0 l glass bottle 8.6 litres of fresh water are consumed in comparison to 1 litre in a 1.5 l PET bottle under the current conditions and made assumptions. The lever for optimization measures is accordingly high.
The water footprint is an indicator for the assessment of one single environmental parameter – the consumption of fresh water along the product life cycle. When optimizing measures are applied one should keep an eye on the fact, that one measure should not entail a major shift from one life cycle phase to another or from one impact category to the account of another like. E.g. the substitution of paper labels with plastic ones would raise the carbon dioxide equivalents of a system whereas the water footprint would show lower results. In some cases this might not be prevented, but the holistic view on the overall environmental impact should be considered. The mentioned optimization possibilities only refer to the reduction of the water footprint. A holistic optimization concept for the two product systems demands a comprehensive life cycle analysis in accordance with ISO 14040ff. A comparative confrontation with an alternative, wide-spread evaluation method like the carbon footprint, expressed in CO_2-eq is recommended.

It has to be noted that a comparative depiction of the bottle systems can be misleading, if the results for the 1 l glass bottle and 1.5 l PET bottle are confronted. In order to prevent misleading interpretations an additional conversion step to 1.0 l of bottled water is needed. This was guaranteed with the introduction of the functional unit of 1000 litres of mineral water in the respective packing.
The comparison of the water footprint of natural mineral water with that of sugar containing beverages and beverages with other ingredients from agricultural production points out the large impact of the water evaporation caused by agricultural production with large geographical differences. From this background pure mineral water should be preferred.
Data refers from the available sources at the time of the project which has been accomplished at the end 2012/beginning 2013. Due to lack of data some uncertainties still remain and comparability of results is difficult. However, with the further development and implementation of the method of WF the data situation will improve.
For a sustainable use of the pure mineral water the efficient usage of different water sources for different purposes is very important. Thus, the artesian spring water from deeper sources is exclusively used for drinking purposes while the overflow of the source is utilized for cleaning and production processes. The company puts effort in raising awareness within the company, taking measures for optimized water management in line with other measures like reducing of losses along the pipes and ensuring sustainable usage of the ancient well. The artesian well constantly delivers mineral water without pumping, not more water is used than naturally originates. The availability of the water in terms of time and space is also given for other purposes like the local thermal bath.
Water footprinting has sought to understand and measure the invisible link between the local consumption of goods and the impacts from the production of those goods on often distant water resources. In this case, the indirect water footprint is higher in both systems.

6. References

BIER 2011, A practical perspective on Water Accounting in the Beverage Sector, BIER – Beverage Industry Environmental Roundtable, 2011

Chapagain, A.K. and Tickner, D. (2012): Water footprint: Help or hindrance? In: Water Alternatives Volume 5 (Issue 3):p. 563-581, ISSN 1965-0175

Ercin, A.E., Aldaya M.M., Hoekstra, A.Y. (2009): A Pilot in corporate water footprint accounting and impact assessment: The water footprint of a sugar-containing carbonated beverage, Value of Water Research Report Series No. 39, UNESCO-IHE Institute for Water Education, Delft, the Netherlands

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011): The water footprint assessment manual: Setting the global standard, Earthscan, London, UK, ISBN 978-1-84971-279-8

Van Oel, P.R., Hoekstra, A.Y. (2012): Towards quantification of the Water footprint of paper: A first estimate of its consumptive component, in: Water Resour Manage (2012) 26: 733-749, DOI 10.1007/s1169-011-9942-7, Springer Verlag GmbH

The Coca-Cola Company: Towards sustainable sugar sourcing in Europe Water footprint sustainability assessment (WFSA), August 2011, http://www.waterfootprint.org/Reports/CocaCola-2011-WaterFootprintSustainabilityAssessment.pdf

Vöslauer Sustainability Report 2011, http://www.voeslauer.com/

Water Footprint Network http://www.waterfootprint.org/?page=files/home

A STUDY OF DUST LIFTING REDUCTION AT THE COAL AND IRON ORE STOCKPILE OF THE PORT OF KOPER

Lovrenc Novak [a,*], Benjamin Bizjan [b], Brane Širok [a], Jure Pražnikar [c], Boris Horvat [b], Alen Orbanić [b]

[a] University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia
[b] Abelium d.o.o. – Research and Development, Kajuhova 90, 1000 Ljubljana, Slovenia
[c] University of Primorska, Andrej Marušič Institute, Muzejski trg 2, 6000 Koper, Slovenia

Abstract
This paper presents investigation of local wind conditions at the coal and iron ore stockpile (European Energy Terminal) at the Port of Koper. The purpose of the study was to determine wind conditions being critical for occurrence of dust lifting from the stockpiles. A numerical (CFD) model of the stockpile site with its surroundings was built and conditions were simulated by applying realistic boundary conditions. Local wind velocity above the stockpiled material was taken as the criteria for occurrence of dusting. Results show that the current windbreak fence is inefficient mainly due to the large size of the site, which is stretched in the direction of the main winds. Modifications to the fence by replacing or/and heightening it with porous structures were simulated but were found inefficient due to the site size and due to the sharp angles of attack of the main incoming winds. Modifications in pile positions and sizes were also modeled but the main effect was redistribution and not reduction of critical spots. An efficient measure for reduction of wind velocity over the piles was found to be placement of porous barriers between the piles, oriented transverse to the main wind directions.

Key words
computational fluid dynamics; dusting; stockpile; wind protection

1. Introduction

The main environmental and safety issue related to handling and storage of loose dry materials, such as coal and iron ore presents a potential for dusting. Large open storage sites, such as those typically encountered in cargo ports, are especially problematic due to their exposure to wind. The wind-induced fugitive dust emissions result in material loss from the storage site (economic loss) and at the same time cause dust build-up on other locations, with significant environmental hazard when particles are transported to urban areas.

This paper deals with analysis of wind conditions leading to dusting at the European Energy Terminal (EET) at the port of Koper. The EET is used to handle and store coal and iron ore in both export and import directions and currently has storage areas of 108,500 m^2 with total capacity of 800,000 tons. The dusting problem at the EET is made worse by the meteorological conditions at the site. High winds from west (Tramontana) and north-east (Bora) blow intermittently throughout most of the year. Both winds occasionally reach very high velocities and can cause significant dust emissions from the EET stockpile. Transport of dust from the site to the nearby residential areas is especially sensitive; therefore reducing fugitive dust emissions remains a priority of the Port.

The Port of Koper has already invested in several dust control measures, such as watering and construction of a solid windbreaker fence around the storage site. However, the effect of the fence has been insufficient and recently a new method for suppression of dusting has

* Corresponding author. Tel.: +386 1 4771423. E-mail address: lovrenc.novak@fs.uni-lj.si

been introduced, which includes spraying of stockpiled material with a special crust-forming liquid. Application of this method gives promising results, but comes at a cost. Reduction of costs could be achieved by optimization of spraying locations, therefore knowledge of local wind distribution over the site and identification of critical spots for different wind directions is required. For this purpose Computational Fluid Dynamics (CFD) simulations of air flow over the site were conducted. The simulations were focused on analysis of the current state and on possible additional physical measures for reduction of local wind velocities.

2. Numerical method and model

Before performing the actual simulations of air flow over the coal and iron ore stockpile a geometrical model of the site and boundary conditions had to be defined. The geometric 3D model was built on the basis of a satellite image available from Geopedia [1] (figure 1). It includes an area of 1380 m length in east-west direction and 730 m length in north-south direction (figure 2). Height of the model is 200 m above terrain. Minimum extent of the storage site surroundings, included in the model was determined on the basis of guidelines from relevant literature [2]. All significant wind directions and influences of surrounding structures were also taken in consideration and the model was extended in some directions (i.e. south). Heights of included buildings and structures were either known (i.e. fence height of 11 m) or were estimated. Buildings that have no influence on conditions at the stockpile at major wind directions were not included in the model. Basic distribution of piles in the model was made on the basis of the satellite picture and represents only one of the many possibilities for distribution of the stocked material. The height of all piles was 10 m.

Figure 1: Satellite image of the coal and iron ore stockpile with surroundings [1]

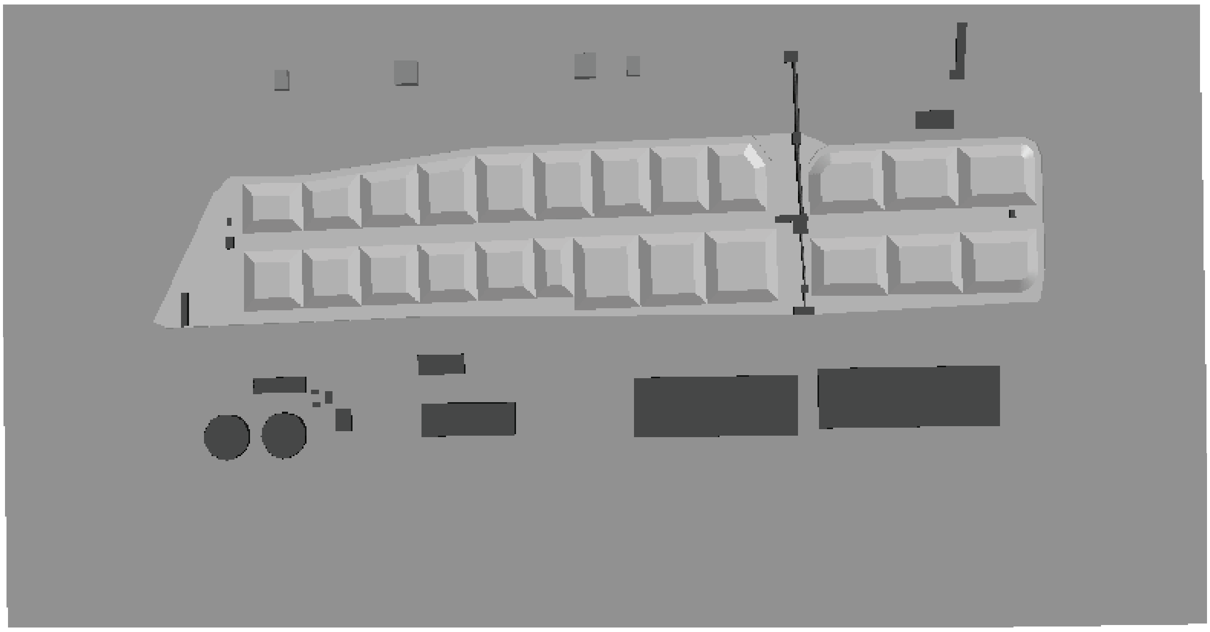


Figure 2: Top view of the geometrical model

Discretization of the geometric model into finite volumes (grid generation) was done with the Ansys ICEM CFD 14.5 software. The grid consisted of 14.5 million hexahedral, tetrahedral and prismatic elements. Prismatic elements were used on walls to enable better resolution of the boundary layer. Near wall grid density was designed for the use of wall functions, which provide sufficient accuracy for flows around buildings.

Commercial software Ansys Fluent 14.5 was used for the CFD calculations. A Reynolds Averaged Navier Stokes (RANS) method, which is an industry-standard approach for simulation of atmospheric flows around buildings, was employed. Turbulence was modeled by the k-epsilon model [3] which is a proven and robust model, often employed in similar problems. Constants of the model were adjusted to the recommended values for simulation of atmospheric flows [4]. Working fluid was set as incompressible air with constant density. Steady state conditions were simulated.

Calculation reached convergence when the maximum scaled residuals for continuity and momentum equations dropped below 5E-4 and for turbulence equations at least below 1E-3.

1.1 **Boundary conditions**

The model boundary conditions were set to represent the actual conditions at the site. The inlet and outlet boundary surfaces were set in pairs depending on the simulated wind direction. For example, in case of the north-eastern wind directions inlets were defined on the northern and eastern model boundaries while outlets were set on the southern and western boundaries. Inlets were defined as velocity inlets with velocity and turbulence quantities (k, epsilon) as functions of vertical coordinate. Standard logarithmic profiles for atmospheric boundary layers were used [5]. Terrain roughness length of 0.1 m was assumed for the profiles, meaning that the average roughness elements are 1 m high. Outlet boundaries were set as pressure outlets with average relative pressure of 0 Pa.

Walls of buildings and other structures, including the fence, were defined as hydraulically smooth walls with zero slip. Walls representing piles and terrain inside the stockpile fence were set as rough walls with equivalent sand grain roughness of 0.045 m. Terrain outside the fence (both land and sea) was treated as rough wall with equivalent sand grain roughness of

1 m, which takes into account the presence of different objects such as cars, trucks, trains, piers, sea waves etc.). Wall at the top of the model was set as a wall with zero shear stress.

Porous walls were used to represent certain structures, for example cranes located north of the stockpile that were simplified to a cuboid shape. Porous walls were also used to simulate perforated walls and barriers that were included in some of the calculated cases. The porous jump boundary condition type, which can be seen as a model for a thin membrane that has known velocity (pressure-drop) characteristics, was employed for all cases of porous walls. Only inertial resistance (quadratic function of velocity) was prescribed. For cranes and for porous fences the pressure drop at the wall equaled 0.2 times and 4 times the dynamic head of free flow, respectively.

1.2 Computed cases

Incoming wind velocity magnitude and direction were the main two parameters that were varied for the numerical simulations. The prevalent wind directions and intensities were determined on the basis of continuous field measurements at the site. The measured values are recorded in a 3-second interval and provide the complete wind velocity vector at the height of 50 m. Statistical analysis of recorded data for the period between august 2012 and august 2013 revealed dominant wind directions with corresponding velocity and gust magnitudes. Only horizontal velocity component was taken into account since the vertical velocity was significantly smaller. Initially, winds with a half-minute-average speed of more than 7 m/s were identified to blow from the north, north-east, east and west. For simulations, cases were defined at precise directions: 357°, 15°, 25°, 50°, 75°, 87°, 250°, 265° and 290°.

Most frequent wind at the site blows from the east to north-east direction and is called Burja (Bora). It was decided that the 75° heading is the most characteristic for Bora. The Bora reaches highest average velocities and especially gust intensities at the site. One minute averages of 18 m/s and gusts of 22 m/s were recorded in the observed period. The second most frequent wind direction at the site is western and in this case the wind is called Tramontana. It is generally known as a northern wind but local terrain features make it appear as a western wind. It blows from the sea inland and is more constant in direction and speed compared to Bora. Highest gusts recorded in the observed period exceeded 20 m/s and more typical gusts were around 16 m/s. Main direction for Tramontana simulations was set at 250°.

Four wind velocity magnitudes were considered for the simulations (given values are reached at a height of 50 m above terrain):

- 16 m/s – base velocity for all wind directions
- 18 m/s – velocity of frequent gusts, especially for Bora, therefore most simulations for main wind directions were done at this velocity
- 22 m/s – velocity of most powerful Bora gusts (multiple records in the observed period) and Tramontana (single record in the observed period)
- 25 m/s – highest simulated velocity for both Bora and Tramontana, not recorded in the observed period

In addition to simulating the base condition, representing currently existing structures and fully occupied storage area, additional cases with added/removed or modified structures were computed. All the modifications were done with the aim of reducing exposure of piles to high wind velocities. The cases were designated with letters:

A. basic – existing condition
B. existing fence changed into a porous fence
C. existing fence upgraded with porous sections of 4 or 8 m height
D. basic condition with piles on the south-west extended closer to the fence
E. extension or elimination of individual piles

F. additional pile in the SW area
G. closed opening in the fence in the SW corner, with/without the existing containers
H. inclusion of porous barriers between piles with heights of 11, 15, 19 or 23 m

3. Results and discussion

Erosion of fine particles from material stored in open stockpiles is a consequence of wind acting on the pile surface. Different wind erosion mechanisms can be identified depending on the ratio of wind induced aerodynamic forces (lift and drag) and gravity force, such as creep, saltation and suspension. Current study does not deal with the exact erosion modeling but rather presents local distribution of air velocities above the pile surfaces, which can be used to identify critical spots for occurrence of erosion. Determination of critical velocities for occurrence of erosion depends on several factors such as particle material, particle size distribution, moisture, etc. and was done in more detail in [6]. For the presented numerical calculations, velocities between 5 and 9 m/s were defined as potentially critical. In this respect velocity at 5 cm distance above surfaces was taken as decisive. This distance was also conditioned by the height of the first grid element at the wall.

Due to space constraints only selected results, showing most important findings for the two dominant wind directions will be displayed and discussed below. The following figures present a top view at calculated air velocity distributions above the piles' walls. Color map enables distinction between low velocities <5 m/s (green), intermediate velocities 5-7 m/s (orange), high velocities 7-9 m/s (red) and extreme velocities >9 m/s (blue).

Figures 3 and 4 present current state conditions (case D) for 2 wind speeds for both Bora and Tramontana. It is evident that intermediate and high velocities occur over most of the piles for the both wind directions and speeds. Conditions get significantly worse with increased wind speed. Wind exposure in case of Tramontana is higher than in case of the equally strong Bora. Generally, highest wind exposure is encountered on pile edges.

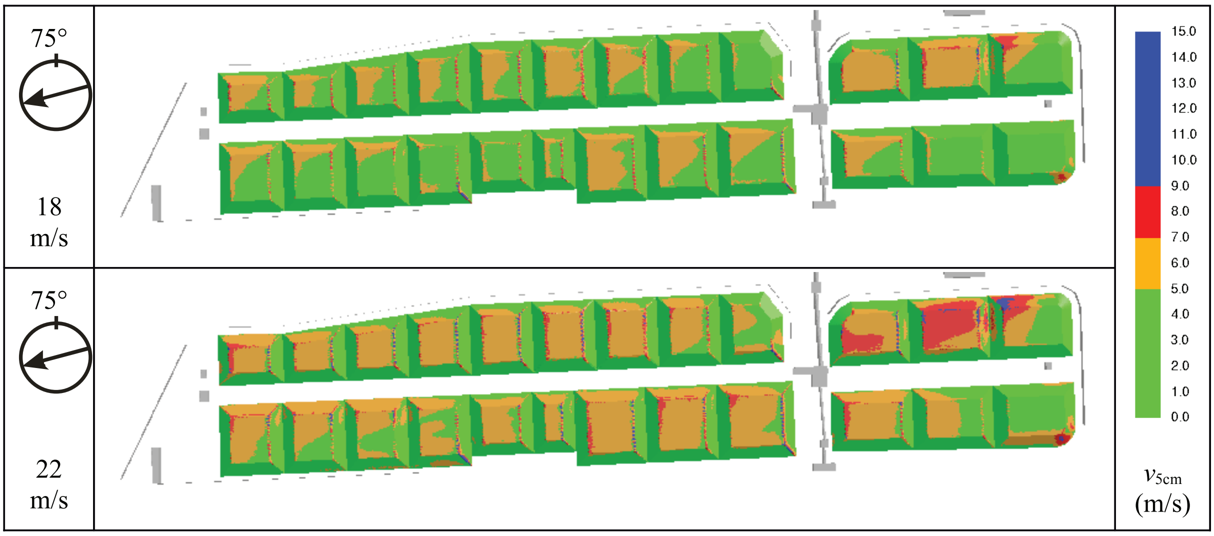


Figure 3: Velocity above piles, solid fence (case D), Bora 18 m/s (top) and 22 m/s (bottom)

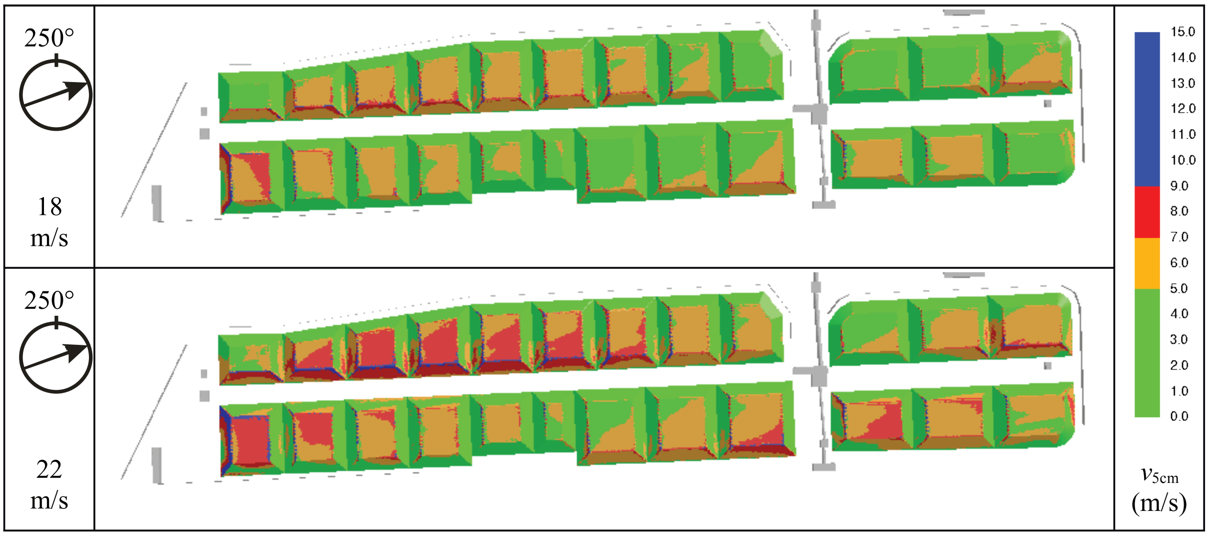


Figure 4: Velocity above piles, solid fence (case D), Tramontana 18 m/s (top) and 22 m/s (bottom)

Replacement of the solid fence with a porous one was the first simulated measure for wind exposure reduction. It is generally known that solid wind barriers have a limited local effect in wind reduction. The air flow is initially pushed over the solid barrier but then quickly lowers and continues without significant reduction in velocities. A vortex is formed leeward from the solid barrier which can additionally deteriorate local conditions. On the other side, porous barriers allow passing of fluid at a reduced velocity. This means that a region with reduced wind speed without any vortices is expected to form and stretch further downstream compared to the solid barrier case. Simulations with porous fence confirmed these expectations.

Figure 5 shows streamlines for Bora wind at 18 m/s for solid fence (case A) and porous fence (case B). The eastern part of the stockpile is shown and wind blows towards the camera position. Streamlines originate from a surface of 2 m height, located just above the fence. It is clearly seen that the existing solid fence causes many vortices that are pushed towards the stockpile edges, leaving the central part of piles exposed. The porous fence on the other side eliminates any large scale vortices and allows a uniform flow over the entire stockpile. Figure 6 shows velocity distributions above piles for both Bora and Tramontana with the porous fence. Reduced wind exposure compared to the solid fence (figures 3 and 4) can be seen on the piles located on the side of incoming wind (north-eastern side for Bora, western side for Tramontana); however, wind exposure is unaffected or even increased on other piles. Similar results were obtained when the fence was raised by 4 and 8 m – positive effects in terms of reduced wind speed did not reach piles further from the fence. Reasons for limited effects of the fence, both solid and porous, can be attributed to the large size of the stockpile, which stretches in the direction of dominant winds. Further reduction of fence effectiveness is attributed to the sharp angle of incoming winds.

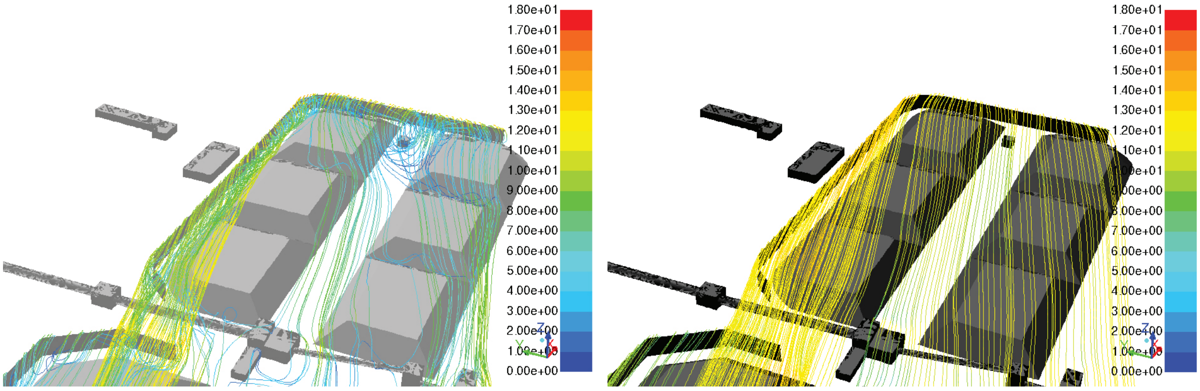


Figure 5: Streamlines for Bora at 18 m/s, solid fence (left) and porous fence (right)

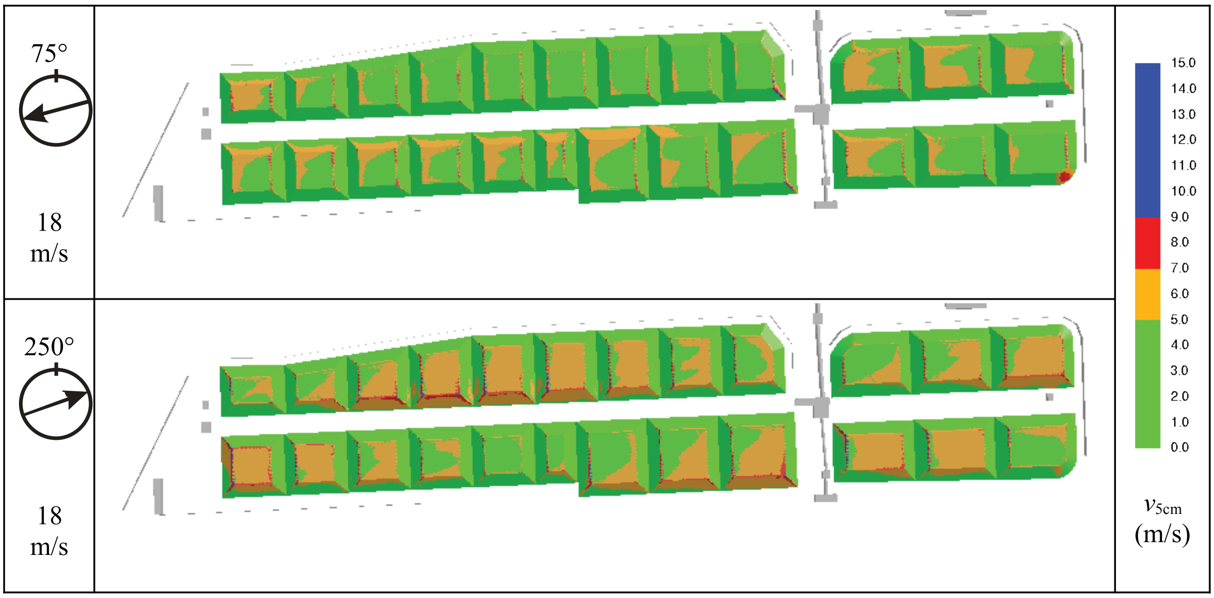


Figure 6: Velocity above piles, porous fence (case B), Bora (top) and Tramontana (bottom)

Another possible measure for wind exposure reduction at the site would be to optimize distribution and size of piles. Numerous combinations of pile locations and sizes are possible in theory but in practice they are limited by the technical possibilities of the stacking and reclaiming machinery. Furthermore, technical and logistical requirements dictate filling and emptying of the stockpile and length of individual piles. Therefore it is difficult to perform such optimization in reality, even though simulations would indicate high benefits. The effect of pile size and position was simulated by prolonging 2 piles to double length and by eliminating 2 piles. Results for Tramontana wind at 18 m/s are shown on Figure 7. It can be seen that the only benefit of having larger piles is in reduced length of edges, which are generally exposed to highest winds. Otherwise, wind exposure is similar if not higher compared to the basic pile size. Similar conclusions can be drawn for the case with 2 piles eliminated. Here, wind exposure on the piles that surround the empty area is increased, especially on the pile edges.

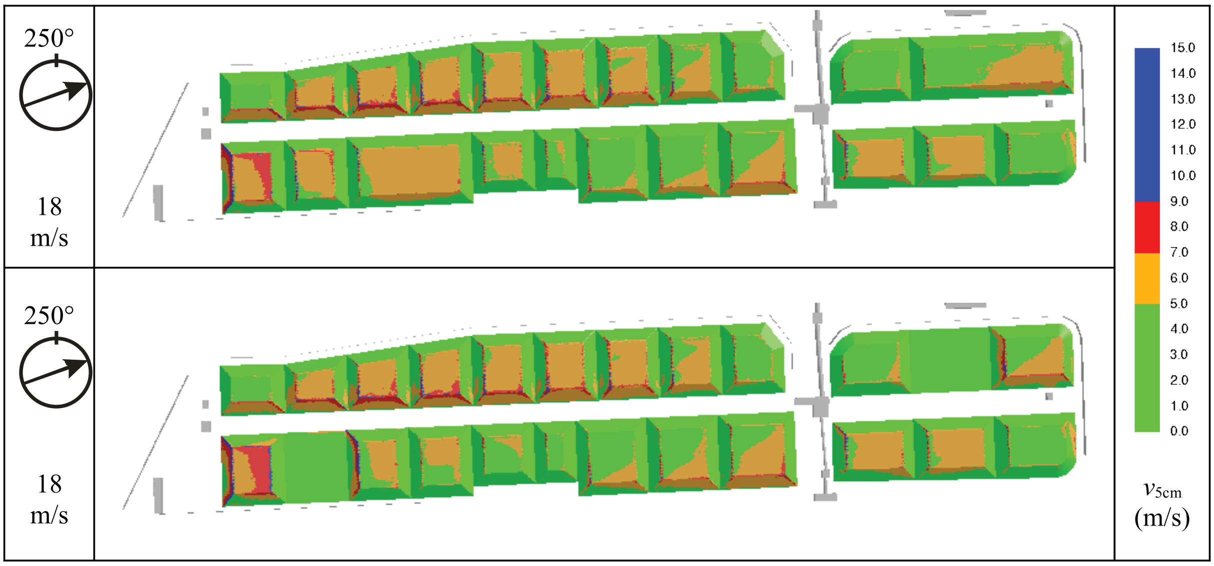


Figure 7: Velocity above piles, case E, Tramontana, two piles extended (top) and two piles removed (bottom)

As explained above, effectiveness of both solid and porous fences in reducing wind velocities above piles is greatly limited due the stretched shape and orientation of the site (and fences) relative to the incoming wind direction. Major portions of the fence are hit by wind at sharp angles and the resulting area of reduced wind velocity downstream the fence is simply too short to reach piles further away. A different approach for damping of wind was therefore proposed. Porous barriers between piles that were oriented transverse to the main winds were included into the numerical model. Two porous barriers were placed at the south-western part of the stockpile to test the method mostly for Tramontana and another barrier was placed on the eastern edge of the south-western row of piles. Cases were calculated at different barrier heights: 11 m, 15 m, 19 m and 23 m. Results for the barrier height of 19 m, which was found to be optimal, are shown on figure 8. Positive effects of the barriers are evident mostly in case of Tramontana wind. Wind exposure is significantly reduced for the first pile and partially also for the second pile downwind from the barrier. In case of Tramontana positive effects of barriers can be seen also on other piles in the wider stockpile area. Further optimization of barrier locations, their size and porosity parameters could most probably spread their influence over the entire stockpile area.

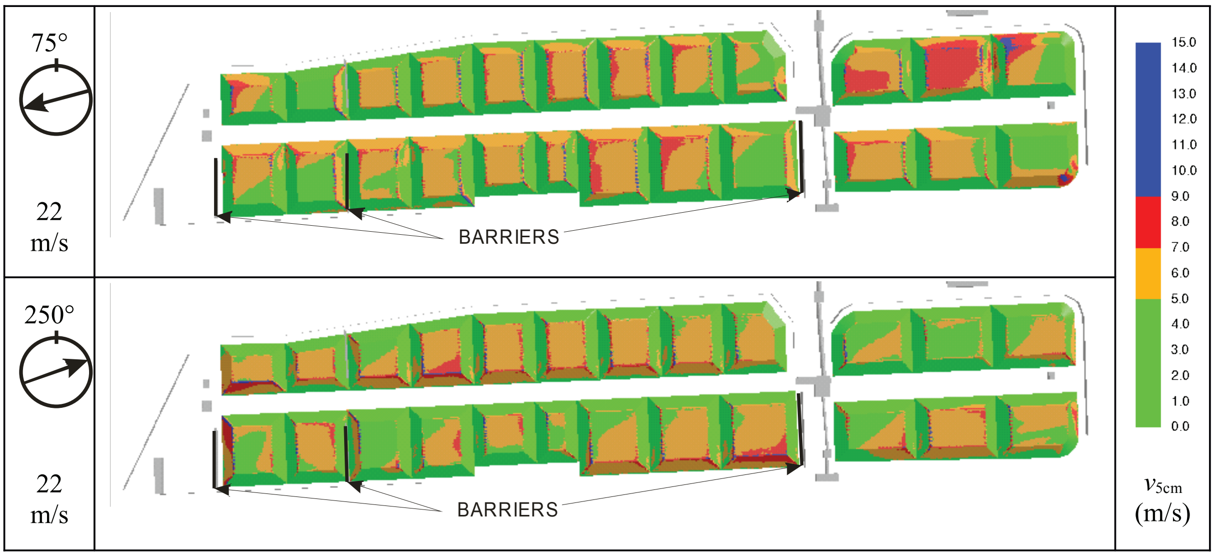


Figure 8: Velocity above piles, porous barriers between the piles (case H), Bora (top) and Tramontana (bottom)

4. Conclusions

Simulations of local wind conditions at the coal and iron ore stockpile at the Port of Koper were performed by employing state of the art CFD tools. Wind exposure of piles was analyzed for different wind conditions and by application of various physical measures for reduction of wind velocity. Results of simulations show that the existing solid fence provides a very limited protection from high winds due to the size and stretched shape of the stockpile area and its orientation relative to the main wind directions. Modifications to the fence by replacing or/and heightening it with porous structures were simulated and showed that they are inefficient due to the same reasons as in the case of solid fence.

Modifications in pile positions and sizes were also modeled but the main effect was redistribution and not reduction of critical spots. An efficient measure for reduction of wind velocity over the piles was found to be placement of porous barriers between the piles, oriented transverse to the main wind directions. However, erection of such barriers on the real stockpile could impose significant limitations for the material stacking and reclaiming machinery.

The study showed that wind reduction by physical measures such as barriers is a very challenging task when dealing with large stockpiles and strong winds. Watering and spraying with crust-forming liquids remain necessary measures for prevention of wind erosion and dusting. Nevertheless, maps of local wind velocities that were created by the simulations enable identification of critical spots for occurrence of dusting and can in this way help to optimize spraying and reduce associated costs.

4. References

[1] Geopedia, http://www.geopedia.si/#T105_F1173:6064_x402189.531_y47286.32_s17_b2, accessed September 30, 2013.

[2] Tominaga, Y., Mochida, A., Yoshie, R.,Kataoka, H., Nozu, T., Yoshikawa, M., Shirasawa, T., 2008. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of Wind Engineering and Industrial Aerodynamics 96, 1749-1761.

[3] Launder, B. E., Spalding, D. B., 1974. The numerical computation of turbulent flows. Computer Methods in Applied Mechanics and Engineering 3, 269-289.

[4] Mandas, N., Cambuli, F., Crasto, G., Cau, G., 2004. Numerical simulation of the Atmospheric Boundary Layer (ABL) over complex terrains. EWEC 2004, London, November 2004.

[5] Richards, P.J., Hoxey, R.P., 1993. Appropriate boundary conditions for computational wind engineering models using the k-e turbulence model. Journal of Wind Engineering and Industrial Aerodynamics 46&47, 145-153.

[6] Topič, N., 2009. An analysis of fugitive dust emission from coal stockpile in the port of Koper. (Master Thesis). Jožef Stefan international postgraduate school, Ljubljana.

Fostering sustainable production in Mediterranean Industrial Areas: a Mediterranean management model and a web-based toolkit

Arianna Dominici Loprieno[a], Maria Litido[a], Mario Tarantini[a], Rovena Preka[a], Maria-Anna Segreto[a], Pere Llorach[b]

[a]*ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Via Martiri di Monte Sole 4, 40129 Bologna, Italy*

[b]*Universitat Autònoma de Barcelona, Spain*

Abstract - Modern management of Industrial Areas (IAs) can give an important contribution to Sustainable Consumption and Production (SCP) policy in Mediterranean regions. It includes activities related to environmental performance and sustainability, as well as marketing and promotion of the image of the Area and can allow to identify and exploit synergies among the settled companies to improve the overall efficiency in the use of natural resources of the area. Modern management is nevertheless a complex duty which comprises several tasks and requires a remarkable expertise in several fields. To help managers in performing these new tasks, a Mediterranean model, based on several project experiences realized at European and national level has been developed. The management model consists in a series of necessary steps to be followed to progress towards a more sustainable production system. To increase its effectiveness the model has been integrated with a set of web-based tools developed in some European projects which address several aspects of IAs management: a checklist with a scoring system for evaluating and benchmarking at international level the initial status of an IAs; a database of best practices which can be adopted in Mediterranean IAs for improving their environmental, social and economic profile; a guide for designing and constructing eco-efficient industrial buildings; a software for calculating the carbon footprint of waste management in IAs; a checklist for logistic services to identify and to provide a set of practical steps that can be taken to successfully accomplish a sustainable logistic service.

In this paper, after outlining some characteristic of the production system of Mediterranean region and the weak points of the actual SCP policies, the tools developed for supporting a modern management of IAs are described and their contribution to SCP policies are discussed. Some suggestion for improving the national and local policies in Mediterranean area are then discussed in the conclusions.

1. Introduction

In several Mediterranean regions, Industrial Areas (IAs) have been considered till recent years simply a place in which confine firms trying to hide and forget the unpleasant aspects of industrial production. These areas are often endowed with the infrastructures needed to comply with the emission limits provided by law and the only aspect which is managed is the settlement of the firms. More recently, it has been understood that IAs are a fundamental element of territorial development, as they can promote growth, jobs and entrepreneurship. If suitably managed and equipped, they can provide the opportunity to optimize the use of non-renewable energy resources and increase the efficiency of the use of raw materials by identifying and exploiting environmental, economic and social synergies among the settled firms [1]. In particular, thanks to many European initiatives and projects, such as SIAM [2], MEID [3] and Ecomark [4], sustainable management of IAs is becoming one of the key elements to foster eco-innovation in the Mediterranean area, playing a significant contribution to Sustainable Consumption and Production (SCP) policy implementation, a European modern field of interest. Involving researchers and experts, development agencies, businesses, enterprises and IAs, local, national and transnational authorities as well as consumers, main aim of the SCP policy is to integrate environmental sustainability along with economic growth and welfare, to achieve an energy and resource-efficient economy.

SCP policy consists in “the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations” [5]. Mitigating the environmental effects of human activities has traditionally focused on minimizing the effects of individual goods and services through technical product improvements. The SCP approach goes one step further: it looks holistically at systems of production and consumption and explores how these systems can be changed to reduce their overall environmental impact. It recognizes the influence of consumer demand on the consumption process, and therefore its potential as a policy area that can be addressed to minimize environmental effects. For this reason, this approach has become more and more relevant in the pathway to a Green Economy [6].

In this context, modern IA management should comprise several tasks and should require a remarkable expertise in several fields. These ones are related to environment and sustainability, as well as marketing and promotion of the image of the Area, are innovative and challenging, requiring a strong involvement of both Local Authorities and settled enterprises, especially SMEs, along with the essential IA Managing Company. The awareness that a systemic approach, extended over a whole IA, can ensure a more efficient use of resources, combining the needs of the companies and improving their economic performance, has been concretely developing in the past decade at the international level, also thanks to the development of environmental management tools extended to wider contexts, such as Local Authorities and industrial districts territories. In view of these considerations, one of the keys of the success of this structure is the creation of cooperative networks among enterprises and stakeholders, which could allow for identification of environmental, economic and social synergies [7-9]. Gibbs, especially, emphasizes the importance of networking and collaboration among the co-located firms as a key factor for long-term eco-industrial development, stating that “it is this networking activity that will potentially encourage materials interchange in the long-term and distinguish eco-industrial development from other, more superficial initiatives for the greening of industry” [9] (p. 1148).

Networking, also, helps in overcoming the problem of the small dimensions of SMEs, real giant of European economy [10], typical structure of Mediterranean IAs [11] and main obstacle to their environmental and innovation investments. At European level, Mediterranean region included, in fact, a widespread problem in adopting SCP practices is the lack of significant support systems for enterprises, mainly for SMEs, besides in general for IAs. In particular, there is a general lack of financial and economic incentives, together with an overall lack of administrative simplification strategies and regulation relief [10]. There is also a common lack of integration among different environmental and research policies in business activities, along with a general lack of knowledge of how to spread SCP approach among enterprises and Local Authorities. All these settings represent a strong barrier for IAs managers and enterprises of MED regions to undertake the path towards sustainability.

With this background, to help in overcoming those hitches and to support the development of SCP initiatives and eco-innovation practices in IAs, a new approach has been developed in the framework of ECO-SCP-MED project [12]. Co-founded by MED capitalisation Programme, ECO-SCP-MED it is a 18-month project which aim at ensuring sustainability across the supply chain of the main products and services in MED area, with attention also to sustainable management of IAs.

2. Method

ECO-SCP-MED project aims at creating tools to promote SCP in the Mediterranean area through the integration of tools and methodologies implemented in different MED projects. Its major objective is the creation of synergies among projects and partners and the building of a *network of network* in order to disseminate and transfer the results and outputs, integrating experiences and recommendations. In this context a working group (WG) coordinated by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), has been organized to coordinate the work in the focus area of sustainable management of IAs. Aim of the WG has been to develop a toolkit to foster eco-innovative management of industrial areas, identifying synergies among the different outputs of previous projects conducted by partners, integrating them to make the project outputs more operational and giving in this way to users an added value.

The WG defined the main characteristics of Sustainable Industrial Areas toolkit, including its added value, the way to use it, the training needs, the actors to which the toolkit is addressed and the foreseen weaknesses. Finally the toolkit related to Sustainable Industrial Areas has been presented in an international workshop to expert of the sector to be discussed, gather suggestions and validate it.

3. Results

As introduced, modern management of IAs can give an important contribution to SCP policy and to eco-innovation development, helping the settled firms to face the increased environmental requirements of European legislation by fostering and exploiting synergies among the resident companies and helping managers to identify new marketing opportunities to make the area more competitive. To support the evolution towards an innovative IA management system a set of outputs of different projects have been integrated in an operational toolkit.

Cornerstone of the toolkit is a management model, called Mediterranean Eco Industrial Development (MEID) model, made up a series of necessary steps to be followed in order to implement sustainable management of Mediterranean IAs. The Model procedure systematizes several project experiences which have been realized at a European and local level, taking into consideration the specificities of the MED area. Since IAs of the Mediterranean have different levels of management and, most of all, have heterogeneous management, three different paths have been detected and should be followed according to the starting point of each IA [13]:

- Path 1: Planning and design of a new Industrial Area;
- Path 2:– Towards MEID Model in non-structured Industrial Areas;
- Path 3: MEID Model in structured Industrial Area.

The essential elements which have to be present and implemented at the end of the Path 3 are shown in Figure 2.

The framework created by the MEID model is essential to guarantee cohesion among companies and to provide a unique interface with Local Authorities and stakeholders, supporting the settled SMEs to improve their resource efficiency and competitiveness. In particular, the MEID model approach has contributed to identify and exploit synergies at IA level, promoting a shared industrial development policy, common infrastructures and innovative services. Figure 3 shows the key concept and elements of a sustainable IA according to MEID approach [14]. Besides, the management framework given by MEID model has shown the necessary system perspective of the structured practice.

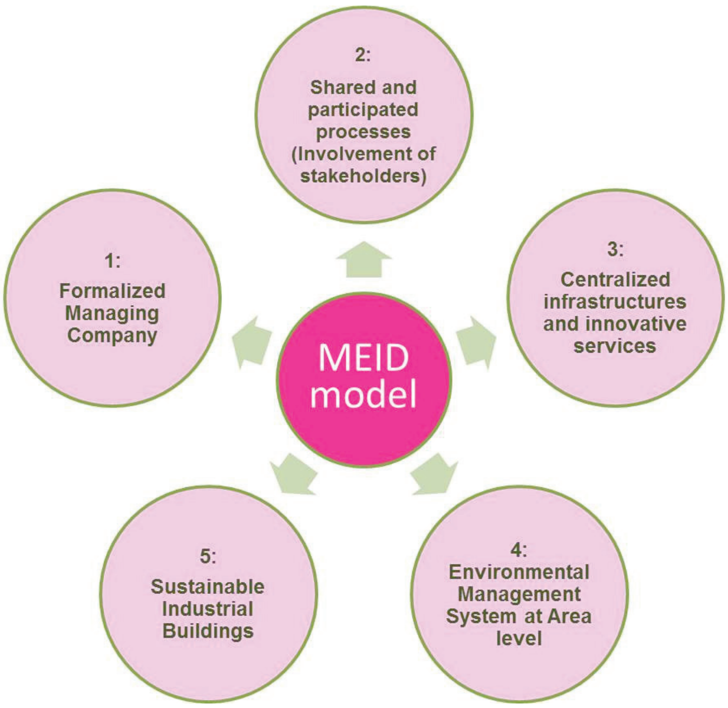


Figure 2 - MEID model

Figure 3 - Key concepts and elements of a sustainable IAs

To increase its effectiveness and to improve its implementation, the model has been integrated with a set of web-based tools developed in some European projects which address several joint aspects of IAs management:

- a check-list with a scoring system to (self) evaluate the status of an IA with regard to its most relevant aspects. The checklist is based on 13 yes/no questions divided in five main areas, considered the most relevant for IA management: management, infrastructures and centralized services, energy/environmental quality of industrial buildings, animation/participation, green marketing/external communication. According to the answer, at each question is given a score which depends by the relative importance of the related area. The scores are then summed up to have a unique score of the IA. The weighting system is based on a qualitative expert judgment and has been built on the experience gathered in several European projects as MEID, Ecomark and SIAM - Sustainable Industrial Area Model. To increase its widespread usability, the tool has been developed on excel program;
- a web database of best practices which can be adopted in MED IAs for improving their environmental, social and economic profile. It includes environmental, social and economic solutions referred to centralized established infrastructures as well as innovative services in IAs of the Mediterranean Region. To develop this tool the database of MEID project, almost 150 examples of best practices related to about 50 IAs of MEID partner countries, has been integrated with the content of Ecomark project, about 30 added IAs;
- a guide to support the different agents involved in the process of design, construction and maintenance of Eco-efficient Sustainable Industrial Buildings to evaluate and improve their environmental and energy performances. It consists in 88 good practices related to the entire building lifecycle. Each measure is scored and weighted according to the relative importance of the area of action (e.g.: material, energy, waste, ecosystem, …). The weighting system allows to reach a unique score for the entire building;
- a software for calculating the carbon footprint of waste management in IAs. It is an adaptation of CO2ZW® software of Zero Waste project [15], an excel based software created for municipality waste, to IAs context. It allows to calculate the greenhouse gas emissions (in carbon dioxide equivalents) from the management of the waste fraction of IAs assimilated to urban waste. The output can be used as a guide for driving local government policy in the context of waste sector operations;
- a check-list to present to IA managers, Local Authorities, general stakeholders (Development Agencies, businesses promoters) the steps and the phases for carrying out an innovative sustainable logistics service which includes the planning, organisation, management, execution and control of freight transport operations also by integrating information, transport, inventory, warehousing, materials handling, packaging and even security activities. It is based on the Ecomark project activities, in particular on two operative tools: software for routes and one for loads optimization.

4. Discussion

Before to develop the toolkit, a gap analysis of the focus area on Sustainable Industrial Areas has been performed. It emerged that there is a general lack of local, national and transnational policies to improve the management of industrial areas. Legislation concerning IAs, despite the common background of the European Directives, is quite different in the countries studied in the MEID project (Italy, France, Spain, Greece, Malta, Bosnia Erzegovina) and the approach to sustainability is even more heterogeneous. It should be mentioned that despite a law defines an IA in all the countries, a specific law concerning Sustainable Industrial Areas is only present in Italy. Here the concept has been introduced by Bassanini law (decree law 112/98) which delegates to the Regions the detailed regulation on the Ecologically Equipped Industrial Areas (in Italian Aree Produttive Ecologicamente Attrezzate, APEA) but still, it gives some basic reference elements such as quality infrastructures and systems and unitary management of the infrastructures and services.

Another interesting approach which has some valuable applicative experience on the environmental side is the “EMAS APO” (Ambito Produttivo Omogeneo, Homogeneous Production Areas) registration. It is ruled by a technical document of the Italian Ecolabel-Ecoaudit Committee which has the objective to promote the environmental improvement not only at a firm level but also at territorial level

In France there can be mentioned the national initiative named “Grenelle de l’Environment” which was organized in order to take long-term decisions regarding environmental issues and sustainable development, to restore biodiversity and other related issues.

Any effort to make clearer the contribution that IA management can give to European policies (such as SCP policy) is therefore positive. The toolkit has been developed having in mind Industrial Area managers which wants to improve the efficiency of their area as main users. By using the toolkit they will be able to understand and evaluate the initial status of their area, to develop specific operational paths to improve the IA performance, to access an extensive database of operational good practices and to know how to contact the related organizations, to understand how to minimize the greenhouse gas emissions from the waste management of the area and to solve specific problems such industrial building efficiency and logistic.

Nevertheless, several target users have been considered in developing the toolkit (Fig 4).

Figure 4 - Users of the practice Sustainable Management of Industrial Areas

In particular, Local Authorities can gather suggestions on the policies to set up for reaching a low-carbon economy, an efficient management of IAs and sustainable productive activities. Besides, they can act as facilitators for the development of sustainable IAs by adopting administrative and regulation relief, along with financial incentives. By a careful examination of needs and a consequently accurate IA policy, IAs can seriously consider the transition to sustainable ones, with benefits for all. SMEs can understand the benefit in settling in well-managed IAs, in sharing services and infrastructures and in gathering indications on how to improve the efficiency of their industrial buildings. Service providers (e.g., energy, waste, water management companies) and general stakeholders (e.g., Development Agencies and Businesses Promoters) can understand how to give more value to their services.

To avoid an excessive complexity, the different tools of the toolkit can be used independently as they are focused on different aspects of Industrial areas management. It is suggested anyway to start with the management model of the area which gives a correct framework for more specific actions.

With regard to the added value of the toolkit, it could allow to solve some problems encountered by IA managers which want to improve their resource efficiency and market attractiveness and competitiveness, as, e.g., the lack of:

- a system perspective in managing environmental issues;
- a single source of information, examples of good practices, case studies on sustainable IAs;
- an internationally accepted model in managing IAs to which to refer and to propose to Local Authorities;
- tools for scoring IAs and measure the progress towards resource efficiency and sustainability.

To use the toolkit a general understanding of the principles of Eco-industrial parks and innovative industrial area management, the use of common infrastructures and innovative services, elements of Environmental and Energy Management Systems is required.

Some specific tools requires an in-depth technical knowledge:

- the use of “Guide to design eco-efficient industrial buildings” requires an engineering degree or similar technical knowledge on building design and construction, and a general comprehension o the energy and resource efficient design of buildings;
- the software for calculating the greenhouse gas (GHG) emissions requires a general knowledge on the waste treatment routes and processes, on the environmental problems caused by waste management and a detailed knowledge about the quantity, merceology and treatment routes of the municipal solid waste of the IA;
- the checklist “Innovative service guidelines” requires a general knowledge of sustainable logistics related issues and, furthermore, to carry out an in-depth analysis of the local context. In case the target users decide to develop also the Broker service it is necessary to get a specific training about the software to be used.

Finally it should not be overlooked the MEID management model capability to contributing to create a cooperative climate among the resident firms which helps to identify synergies at Area level. This approach can help enterprises to face the increasing challenges of the European legislation, exploiting the opportunities of Green Economy that, in the recent years of economic crisis, stood out as one of the few sectors that can achieve high growth rate when most of the others have negative trends [15]. Moreover, a common understanding of the enterprises needs and the development of cooperation attitudes push for the creation of networks which increase the SMEs possibilities to compete on international markets.

Innovative IAs, moreover, have been confirmed as the most favorable contest to implement and test the principles and tools of Industrial Ecology due to the possibility not only of sharing infrastructures and services for increasing the production and minimizing costs, but also reducing environmental impacts caused by the industries concentration and aggregating the demand and transfer of technological innovation related to environmental, energy and water resources.

5. Conclusions and outlook

The toolkit described in the paper has been developed in order to support the sustainable management of IAs. It can help many actors, mainly IA managers and settled firms to achieve environmental and economic benefits, implementing eco-innovation activities with a cooperative approach which can help in identifying and exploiting synergies among co-located firms.

In these first months since the toolkit completion, a promising interest has been shown by IAs managers and firms on the proposed approach. Anyway, an assessment of the direct impact of the use of Sustainable Industrial Areas toolkit has not yet been produced.

Europe has prepared the ground for the transition to a more “Resource Efficient” economic model of production and consumption and this is one of the 2020 flagship initiatives coordinating actions across many policy areas to secure sustainable growth and jobs through better use of resources [16].

However, specific political, social, economic and technological barriers to wider implementation and take-up still persist:

- companies often lack awareness, knowledge or capacity to pursue circular economy solutions;
- current systems, infrastructure, business models and technology can lock the economy in a *linear* model (“take, make, dispose”);
- investment in measures to improve efficiency, or innovative business models, remains insufficient as they are perceived as risky and complex;
- demand for sustainable products and services may remain low, in particular if they involve behavioral change;
- policy signals for the transition to a model of “*circular* economy” (reuse, repair, refurbish and recycle) are not sufficiently strong and consistent.

Industrial Areas have been demonstrated the more effective for implementing sustainable models of production and all the operational tools developed to this aim [17].

A real limitation of the potential impact of the toolkit is the reluctance of IAs managers to invest in improvement actions due to a common and widespread lack of incentives, and more in general of opportunities, to support IAs to improve their resource productivity and to help the adoption of SCP policies. Usually, if provided, the environmental incentives to firms concern in fact only the theme of energy consumption, efficiency and renewable sources and do not often cover other environmental aspects. The implementation of incentives, not only of economic nature, but also as administrative simplifications strategies, should help in overcoming this problem and in supporting the enterprise’s performances.

Another important barrier for mainstreaming this tool is a lack of integration among different European policies, such as among research policies and territorial cooperation ones and a general lack of knowledge on how to spread SCP approach among enterprises and Local Authorities.

Therefore, the European projects should face these issues favoring the integration among the results of research, the innovation tools and business.

A lot of studies highlighted a greater interest in developing new on eco-design tools than on studying the use of the existing ones and to evaluate them for their improvement [18]. On the contrary, this work differs from other studies on eco-design tools and eco-innovative practices

because it is focused on identifying possible synergies among different tools. Its added value is due to the integration of different outputs and tools of European-funded projects. Therefore, rather than focusing on single solutions, new opportunities have been identified to promote SCP policy implementation, valorizing synergies of existing tools applied together.
Finally, to really implement SCP initiatives and eco-innovation in IAs and, in general, to improve sustainability of products and services and in production processes in MED area, we believe that real case studies should be developed in order to test and assess the benefits for enterprises and environment which foster the spreading of positive experiences.

6. References

[1] Tarantini M.; Preka R.; Dominici Loprieno A.; Litido M.; Segreto M.A.; Di Paolo A. Sustainable Industrial Areas in Mediterranean countries. Toolkit for SMEs and Local Authorities. MEID project, ISBN 978-88-8286-289-3, 2013, ENEA.
[2] SIAM project, http://www.life-siam.bologna.enea.it.
[3] MEID project, http://www.medmeid.eu/
[4] Ecomark project, http://www.ecomarkproject.eu
[5] Ministry of Environment Norway. Report of the Sustainable Consumption Symposium. Editor: Oslo, Norway, 1994.
[6] Lähteenoja, S. , Brüggemann, N., Tuncer, B., Sustainable Consumption and Production Policies, Editor: Claire Pascoe, Available online: http://www.action-town.eu, 2008.
[7] Gibbs, D.; Deutz, P. Implementing industrial ecology? Planning for eco-industrial parks in the USA. Geoforum 2005, 36, 452–464.
[8] Gibbs, D.; Deutz, P.; Proctor, A. Industrial Ecology and Eco-industrial Development: A potential paradigm for Local and Regional development? Reg. Stud. 2005, 39, 171–183.
[9] Gibbs, D. Industrial Symbiosis and Eco-Industrial Development: An Introduction. Geography Compass 2008, 2, 1138–1154.
[10] Buttol, P.; Buonamici, R.; Naldesi, L.; Rinaldi, C.; Zamagni, A.; Masoni, P. Integrating services and tools in an ICT platform to support eco-innovation in SMEs. Clean Technol. Environ. Policy 2012, 14, 211–221.
[11] Tarantini M.; Dominici Loprieno A.; Cucchi E.; Frenquellucci F. Life Cycle Assessment of waste management systems in Italian industrial areas: Case study of 1st Macrolotto of Prato. Energy 2009, 34, 613–622.
[12] ECO-SCP-MED project, http://www.ecoscpmed.eu
[13] Tarantini M., Preka R., Dominici Loprieno A., Litido M., Segreto M.A., Di Paolo A. Sustainable Industrial Areas in Mediterranean countries. Toolkit for SMEs and Local Authorities. MEID project, ISBN 978-88-8286-289-3, 2013, ENEA.
[14] Tarantini M., Dominici Loprieno A., Preka R., Segreto M.A. The management model of the MEID project: tools for Sustainable Industrial Areas and opportunities for SMEs, Proceedings of International Forum "Increasing the competitiveness of industrial areas. New tools and challenges: perspectives and incentives of the European policies, Bruxelles, 7 June 2012, ISBN 978-88-8286-275-6, 2012, ENEA.
[15] Zero waste project, http://co2zw.eu.sostenipra.cat.
[16] Manifesto for a Resource Efficient Europe, European Commission, December 2012.
[17] The Circular Economy. Connecting, creating and conserving value. European Commission, 2014.
[18] Baumann, H.; Boons, F.; Bragd, A., Mapping the green product development field: Engineering, policy and business perspectives. J. Clean. Prod. 2002, 10, 409–425.

Possibilities of Household Waste Electric and Electronical Equipment Reuse in Bela pod Bezdezem (Czech Republic)

Bohdan Stejskal *, **Petra Oralová**

Department of Applied and Landscape Ecology, Faculty of Agronomy, Mendel University in Brno, Zemedelska 1/1665, 61300 Brno; bohdan.stejskal@mendelu.cz, phone 00420545132468

Abstrtact

This article is focused on the problematics of municipal Waste Electric and Electronical Equipment (WEEE) reuse in Bela pod Bezdezem, the Czech Republic (4880 inhabitans).

In mentioned city, the amount of municipal solid waste (MSW) and the amount of WEEE collected by collective systems responsible for WEEE collecting was evaluated in 2012 and 2013. The amount of municipal waste was 1,425,620 kg in 2012 and 1,632,220 kg in 2013. The amount of collected WEEE was 29,551 kg in 2013 and 20,445 kg in 2013. The ratio of WEEE to MSW was 2.07 % in 2012 and 1.25 % in 2013.

The age and the functionality (possibility of use) of WEEE that citizens handed over to a junkyard observing was studied in the period from October 2013 to March 2014. 228 pieces of WEEE were collected during the mentioned period. The WEEE pieces were devided into categories by 2002/96/ES and minimal, maximal and average age and also functionality of collected WEEE for each represented category was determined.

Only 36 of 228 WEEE pieces, i.e. less than 16 % were working. This amount represents less than 0.015 pieces of WEEE per person a year. Average age of all collected WEEE was 12.3 years but average age of working WEEE was 13.3 years. Regardless of the possibility of safety and environmental risks of reuse of WEEE it is probable that in the conditions of the Czech countryside and small towns it is economically impossible to reuse collected municipal WEEE.

Key words: WEEE, reuse, municipal waste, collecting systems, waste prevention

1. Introduction

The production of electric and electronic equipment (EEE) is one of the fastest growing areas. Since the 1980s, with the development of consumer-oriented electrical and electronic technologies, countless units of electronic equipment have been sold to consumers. The useful life of these consumer electronic devices (CEDs) is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities. This development has resulted in an increase of waste electric and electronic equipment (WEEE), or electronic waste (e-waste). (Hai-Yong and Schoenung 2005).

For example, in 1994, it was estimated that approximately 20 million PCs (about 7 million tons) became obsolete. By 2004, this figure was to increase to over 100 million PCs. Cumulatively, about 500 million PCs reached the end of their service lives between 1994 and 2003. 500 million PCs contain approximately 2,872,000 t of plastics, 718,000 t of lead, 1363 t of cadmium and 287 t of mercury (Puckett and Smith 2002). This fast growing waste stream is accelerating because the global market for PCs is far from saturation and the average lifespan of a PC is decreasing rapidly — for instance for CPUs from 4–6 years in 1997 to 2 years in 2005 (Schnellmannc and Böni 2005).

PCs comprise only a fraction of all e-waste. It is estimated that in 2005 approximately 130 million mobile phones will be retired. Similar quantities of electronic waste are expected for all kinds of portable electronic devices such as PDAs, MP3 players, computer games and peripherals (O'Connell 2002).

In view of the environmental problems involved in the management of WEEE, many counties and organizations have drafted national legislation to improve the reuse, recycling and other forms of recovery of such wastes so as to reduce disposal. (Cui and Forssberg 2003).

Currently, the main options for the treatment of electronic waste are involved in reuse, remanufacturing, and recycling, as well as incineration & landfilling. In many cases, electronic equipment which is no longer useful to the original purchaser still has value for others. In this case, equipment can be resold or donated to schools or charities without any modification. Reuse of end-of-life (EOL) electronic equipment has first priority on the management of electronic waste since the usable lifespan of equipment is extended on a secondary market, resulting a reducing of the volume of treated waste stream. Remanufacturing is a production-batch process where used products or cores, are disassembled, cleaned, repaired or refurbished, reassembled and tested to produce new or like-new equipments [Cui and Zhang 2008]. Reuse is dependent on WEEE being collected and channelled to this aktivity; this is not always the case (Kahhat at al. 2008, Ongondo and Williams, 2012; Ongondo at al. 2013).

Although there are lots of articles about WEEE recyclation, there are very limited studies in the scientific literature that address the activites of WEEE/UEEE (used EEE) reuse. The aim of this paper is to study the current possibilities of WEEE/UEEE reuse in a small town Bela pod Bezdezem in the Czech Republic. The amount of municipal solid waste (MSW) and the amount of WEEE collected by collective systems responsible for WEEE collecting was evaluated in 2012 and 2013. The age and the functionality (possibility of use) of WEEE that citizens handed over to a recycling center was studied in the period from October 2013 to March 2014.

2. Material and methodology

Bela pod Bezdezem is a town of 63,2 km^2 and population is about 4880. In this town there is a junkyard for collection of dangerous waste, separately collected waste (paper, glass, plastic, metal and biodegradable waste) and also OEEZ. For OEEZ of smaller sizes people can use two bins located in the town.

There are three non-profit collecting systems. ELEKTROWIN arranging collection of big appliances, ASEKOL for smaller electrical equipment collection and EKOLAMP which collects light sources and lamps.

Data about the amount of municipal waste was taken over from the Bela pod Bezdezem register. Data about the amount of collected OEEZ was taken over from registers of the individual collecting systems. Furthermore, from October 2013 to March 2014 there was a survey at the junkyard observing:

- Kind of electrical waste
- Brand of electrical waste
- Age of the discarded equipment
- Functionality

Each discarded electrical equipment, observed by the survey, was divided into categories by 2002/96/ES and minimal, maximal and average age and also functionality of the collected WEEE for each represented category was determined. In six months, 228 questionnaires were collected. Brands of electrical equipment were not taken into the statistical processing.

3. Results

The amount of solid municipal waste and WEEE collected in Bela pod Bezdezem in 2012 and 2013 are shown in Tab 1 and Tab 2. Results of the survey is shown in Tab 3.

Tab 1. Amount of solid municipal waste and WEEE collected by Collective Systems in 2012 in Bela pod Bezdezem (town and collecting systems registers).

Months	MSW [kg]	WEEE ASEKOL [kg]	WEEE ELEKTROWIN [kg]	WEEE EKOLAMP [kg]	WEEE total [kg]
1-3	345460	616	6950	19	7585
4-6	337350	2327	7240	19	9586
7-9	347640	1122	2800	19	3941
10-12	395170	1280	7140	19	8439
Total [kg]	**1425620**	**5345**	**24130**	**76**	**29551**

Tab 2. Amount of solid municipal waste and WEEE collected by Collective Systems in 2013 in Bela pod Bezdezem (town and collecting systems registers).

Months	MSW [kg]	WEEE ASEKOL [kg]	WEEE ELEKTROWIN [kg]	WEEE EKOLAMP [kg]	WEEE total [kg]
1-3	382790	632	5130	17	5779
4-6	405180	764	4710	17	5491
7-9	422500	1744	3000	17	4761
10-12	421750	1017	3380	17	4414
Total [kg]	**1632220**	**4157**	**16220**	**68**	**20445**

Tab 3. Overview of WEEE assessed by questionnaire survey.

Category of WEEE	Type of WEEE	Number of handed EEE	Minimal EEE age	Maximal EEE age	Average EEE age	Numer of functional
1	Electric range	3	15	21	18.7	1
1	Refrigerator	27	6	25	14.8	1
1	Microwave oven	12	6	15	8.4	1
1	Dishwasher	2	7	12	9.5	0
1	Washing machine	15	6	24	11.6	2
Total (1)		**59**	**6**	**24**	**12,7**	**5**
2	Hair dryer	4	3	8	5.5	1
2	Deep fryer	2	11	14	12.5	2
2	Food processor	4	8	30	19.8	1
2	Electric kettle	2	2	5	3.5	0
2	Vacuum cleaner	13	6	25	15.6	1
Total (2)		**25**	**2**	**30**	**13.4**	**5**
3	Camera	2	15	20	17.5	1
3	Calculator	3	3	15	9.3	0
3	Keyboard	2	10	20	15	1
3	Mobile phone	5	13	20	16	2
3	Monitor	14	4	10	7.3	4
3	PC	9	4	13	8.4	3
3	Printer	19	4	15	8,7	2
Total (3)		**54**	**3**	**20**	**9.6**	**13**
4	Car radio	1	14	14	14	0
4	CD player	5	5	10	8	0
4	DVD player	3	6	7	6.7	0
4	Radio	13	8	25	16	2
4	Set top box	3	4	8	6.7	0
4	CRT TV sets	48	5	29	14.7	9
4	VCRs	13	5	15	10.9	1
Total (4)		**86**	**4**	**29**	**13.4**	**12**
6	Mower	4	9	18	13	1
Total (6)		**4**	**9**	**18**	**13**	**1**
TOTAL (ALL)		**228**	**2**	**30**	**12,3**	**36**

4. Comments and discussion

As is evident from the observed values, the amount of municipal waste was 1,425,620 kg in 2012 and 1,632,220 kg in 2013. The amount of collected WEEE was 29,551 kg in 2013 and 20,445 kg in 2013. The ratio of WEEE to MSW was 2.07 % in 2012 and 1.25 % in 2013. Collected amount of WEEE means 6.1 kg per person a year in 2012 or 4.2 kg per person a year in 2013 respectively. Relevant data of all the Czech Republic are available just for 2012; in this year there were collected 53685 tons of WEEE that means 5.1 kg per person a year (Ministry of Environment). The amount of municipal waste (in the Czech Republic) was 323264300 kg (Czech Statistical Office) so the ratio of WEEE to MSW was 1.7 %. At least in 2012 the collecting of WEEE in Bela pod

Bezdezem was higher than the average amount of the Czech Republic.

The age and the functionality of WEEE that citizens handed over to a recycling center was studied in the period from October 2013 to March 2014. 228 pieces of WEEE were collected during the mentioned period.

The youngest EEE was only two-years-old electric kettle, the oldest EEE was 30-years-old food procesor. The average age of studied EEE was 12.3 years. Compared to Japanese study of average lifespan of consumer durables (see Oguchi at al. 2008), almost every EEE collected for our study was older; relevant examples are shown in Tab 4.

Moreover, only 36 of 228 WEEE pieces, i.e. less than 16 % were working. This amount represents less than 0.015 pieces of WEEE per person a year in Bela pod Bezdezem. Average age of working WEEE was 13.3 years.

Tab 4. Comparison of average lifespan of selected EEE

Type of EEE	**Average lifespan by Oguchi at al.**	**Average age by this study**
Refrigerator	11.8	14.8
Microwave oven	13.2	8.4
Washing machine	10.1	11.6
Mobile phone	4.3	16
Monitor	6.7	7.3
PC	6.6	8.4
Printer	7.1	8,7
CRT TV sets	12.0	14.7
VCRs	8.9	10.9

It is surprising that average age of mobile phone (by this study) was 16 years. Although the numer of studied mobile phones was to small (5 pieces), such evident absurd age does not correspond to another study of end-of-life mobile phones in the Czech Republic (see Polak, Drapalova 2012). These authors found that average total lifespan of Czech mobile phones is almost 8 years (and they found it as „surprisingly long"); average usage time of mobile phones was estimated 3.6 years and average storage or reuse time was 4.4 years. This can be caused by several reasons: People want to keep an old mobile phone as a backup phone and they usually hand in only their third phone (in that case, average age would agree). Or mobile phones were collected through the junkyard (instead of a more common way when people put their phones into a bin or they leave it at the shop where they buy a new phone) together with other WEEE which was obtained for example after an inheritance claim. However, the exact cause cannot be found out by this survey.

5. Conclusion

The aim of this article was to describe the possibility of household WEEE reuse in a small town Bela pod Bezdezem. The economical possibility of WEEE reuse depends on the amount, on the age and especially on the functionality of this equipment.

The amount of collected WEEE was 29,551 kg in 2013 and 20,445 kg in 2013 (in mentioned city). The age and the functionality of WEEE that citizens handed over to a recycling center was studied by a questionnaire survey at the recycling center in the period from October 2013 to March 2014. 228 pieces of WEEE were collected during the mentioned period. The WEEE pieces were devided into categories by 2002/96/ES and minimal, maximal and average age and also functionality of collected WEEE for each represented category was determined.

Only 36 of 228 studied WEEE pieces, i.e. less than 16 % were working. This amount represents less than 0.015 pieces of WEEE per person a year in Bela pod Bezdezem. Average age of all collected WEEE was 12.3 years but average age of working WEEE was 13.3 years. Regardless of the possibility of safety and environmental risks of reuse of WEEE it is probable that in the conditions of the Czech countryside and small towns it is economically impossible to realize the reuse of collected municipal WEEE except of the ways that already exist: via second-hand stores and private classifieds.

Acknowledgement

This study was supported by project Innovative 3D Training Platform for Recyclin of Waste Electric and Electronics Devices (540527-LLP-1-2013-1-GR-LEONARDO-LMP). The authors of this paper would like to thank the anonymous reviewers for supplying their valuable comments.

Reference

Cui, J., Forssberg, E., 2003. Mechanical recycling of waste electric and electronic equipment: a review. Journal of Hazardous Materials, B99, 243–263.

Cui, J., Zhang, L., 2008. Metallurgical recovery of metals from electronic waste: A review. Journal of Hazardous Materials 158, 228–256.

Czech Statistical Office (CSO), 2013. Waste production in 2012. <http://www.czso.cz/csu/2013edicniplan.nsf/p/2001-13> (accessed 20.08.14) (in Czech)

Hai-Yong, K., Schoenung, J.M., 2005. Electronic waste recycling: A review of U.S. infrastructure and technology options. Resources, Conservation and Recycling 45, 368–400.

Kahhat, R., Kim, J., Xu, M., Allenby, B., Williams, E., Zhang, P., 2008. Exploring ewaste management systems in the United States. Resources, Conservation and Recycling 52, 955–964.

Ministry of the Environment (MŽP), 2014. Selected indicators of waste management in the area of waste electrical and electronic equipment. <http://www.mzp.cz/C1257458002F0DC7/cz/odpadni_elektronicka_zarizeni_nakladani_cr/$FILE/OODP-vybrane_ukazatele_elektrozarizeni-2014319.pdf> (accessed 20.08.14) (in Czech)

O'Connell, K.A., 2002. Computing the damage, waste Age; <http://www.wasteage.com/ar/waste_computing_damage> (accassed 10.07.14)

Oguchi, M., Kameya, T., Yagi, S., Urano, K., 2008. Product flow analysis of various consumer durables in Japan. Resources, Conservation and Recycling 52, 463-480.

Ongondo, F.O., Williams, I.D., 2012. A critical review of the UK household WEEE collection network. Proceedings of the ICE – Waste and Resource Management 165, 13–23.

Ongondo, F.O., Williams, I.D., Dietrich, J., Carroll, C., 2013. ICT reuse in socio-economic enterprises. Waste Management 33, 2600–2606

Polák, M., Drápalová, L., 2012. Estimation of end of life mobile phones generation: The case study of the Czech Republic. Waste Management 32, 1583-1591.

Puckett J, Smith T., 2002. Exporting harm: the high-tech trashing of Asia. The Basel Action Network. Seattle7 Silicon Valley Toxics Coalition.

Schnellmannc, M., Böni, H., 2005. Global perspectives on e-waste. Environmental Impact Assessment Review 25, 436– 458.

Ecodesign methodology for textile coverings used in the European construction and transport industry

A. Díaz[a,b], R. Pamminger[a], and W. Wimmer[a].
[a] ECODESIGN company GmbH, Neubaugasse 25/2/3 A-1070 Vienna, Austria.
[b] corresponding author: diaz@ecodesign-company.com, phone: +43 1 40 35 611 33.

Abstract

Ecodesign is the systematic integration of environmental requirements into product design and development, to improve its overall environmental performance. In this sense, an Ecodesign methodology has been developed for design and product development of textile coverings used in the European construction industry within the European Union project EcoMeTex, with a specific focus on recyclable textiles. The application on two textile floor covering products emphasise the importance of the materials used in the textile, and underpins the specific focus of the project on the recyclability of the textile floor coverings. As a result different new product concepts have been developed, which are being tested for their suitability and feasibility. The transferability of the Ecodesign methodology is demonstrated by its adaptation and application to a textile covering product for the transport industry [EcoMeTex, 2014] [1].

Keywords

Ecodesign, product development, textile floor covering, carpet, automotive luggage cover, close loop.

1. Introduction

The European construction and transport industry is to develop and implement an Ecodesign methodology for the production of recyclable textile coverings. This is the main objective of the EcoMeTex project, focusing on selected technical textiles. In Western Europe the consumption of technical textiles in the transport sector is about 21.2 %, and in the building sector about 15.3 % [Euratex, 2009]. Textile floor coverings in the European construction sector (for example carpets) comprise products for residential and contract applications, being this last segment the one addressed in the project. Particularly relevant is the issue of closing the material loops. The role of the Ecodesign methodology is to support the transformation from open loop life cycle to a closed loop life cycle for these products.

This is critical in light of the growing importance of environmental requirements for textile floor coverings in the context of commercial buildings.

2. Ecodesign methodology

The Ecodesign methodology for textile floor covering developed in the EcoMeTex project is structured in eight steps, according to [Wimmer, 2004]. The Ecodesign methodology aims at improving the overall environmental performance of a reference product. As shown in Napaka: vira sklicevanja ni mogoče najti, possible areas for improvement are derived from the results of the product environmental assessment (Step 2), the stakeholder analysis (Step

1 Non standard abbreviations used in this document are included as follows:
CE marking: mandatory legal conformity requirement for products sold within the European Union which fall within the scope of a CE marking directive.
GuT: The Association of Environmentally Friendly Carpets e.V.
Ü marking: conformity mark from the health and environmental related evaluation of construction products (i.e.,floor coverings) for the German market, granted by the German Centre of Competence for Construction.

3), the process analysis (Step 4), and the benchmarking of products (Step 5). Ecodesign tasks and ideas are derived from the identified possible improvement areas (in Step 6). The Ecodesign tasks are then translated into a new product concept (in Step 7).

Lastly, an environmental communication instrument is developed for the new product concept. The application of the Ecodesign methodology has been completed by means of webtools and templates, which facilitate collecting the relevant information and data on the product and processes for its analysis. These data collection instruments build the backbone of the Ecodesign methodology. The following sections describe the steps, and present the example of an illustrative woven broadloom carpet, to show the use of the methodology.

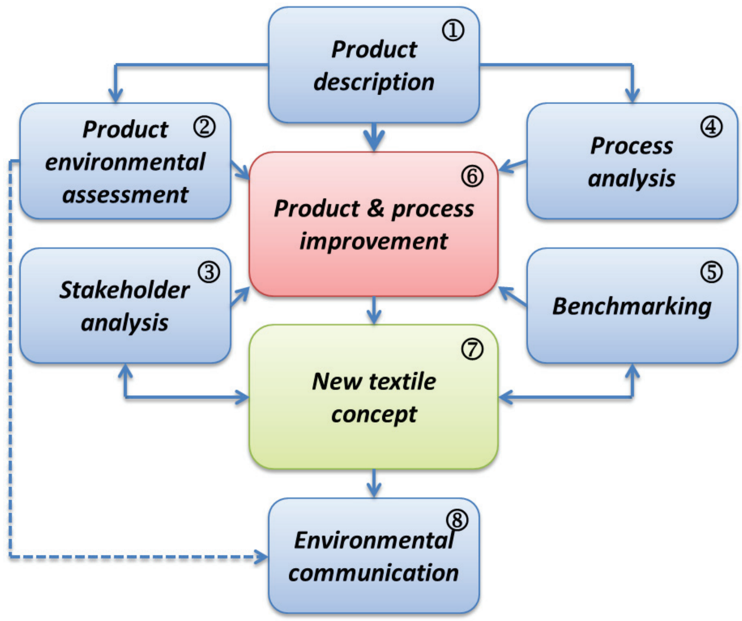


Figure 1: Eight steps of the Ecodesign methodology for textile floor coverings adapted in the EcoMeTex project.

2.1. Product description

The key leading question in this step is: What product is to be assessed/re-designed?

The Product description is the framework to support the following methodology steps with key data on the product. The application of the Ecodesign methodology in EcoMeTex refers to a product that serves as a reference. The different specifications of such product, together with an examination of industry, technical, and environmental data, build up this product description framework.

Data sources on European textile floor coverings reviewed include technical standards (e.g., classification of carpets [EN 1307, 2008], characteristics of floor coverings [EN 14041, 2008]), mandatory certifications (e.g., CE marking, Ü marking, and GuT license) and voluntary labelling schemes (e.g., EU Ecolabel [Ecolabel, 2014] and Blue Angel for textile floor coverings [Blue Angel, 2014]), economic, and environmental data (e.g., Product Category Rules for floor coverings [PCR, 2008]).

Based on the review of all these information sources, a template for a reference product was developed, aiming at collecting the data for the reference product in a structured description, with specific criteria and their corresponding references to the technical data. The template includes type of manufacturing, health and safety aspects, classification and quality, material composition, and additional product characteristics. Data gathered with this template serve as starting point for assessing the environmental performance of the reference product, and also provide the basis for the data collection of products for a comparison, as intended in the benchmarking analysis.

2.2. Environmental assessment

The key leading question in this step is: What are the significant environmental aspects of the reference product throughout its entire life cycle?

The environmental assessment deals with the description of the environmental aspects and impacts of the reference product over its entire life cycle. The goal of the environmental assessment in the Ecodesign methodology was to calculate the Global Warming Potential impact (GWP) using the new web application ECODESIGN+ [ECODESIGN+, 2014] for the assessment of the product carbon footprint in kilograms of Carbon Dioxide equivalents (kg CO2-eq). This software tool allows product developers to calculate the product carbon footprint (PCF), and identify the hot spots, with a reasonable product modelling time. The summary report of the tool presents the most important results of the PCF, as shown in Figure 2 for an illustrative woven carpet example. The results show how the PCF is distributed over the different life cycle stages (bar chart), as well as how it breaks down into the single contributions within a certain life cycle stage (pie charts).

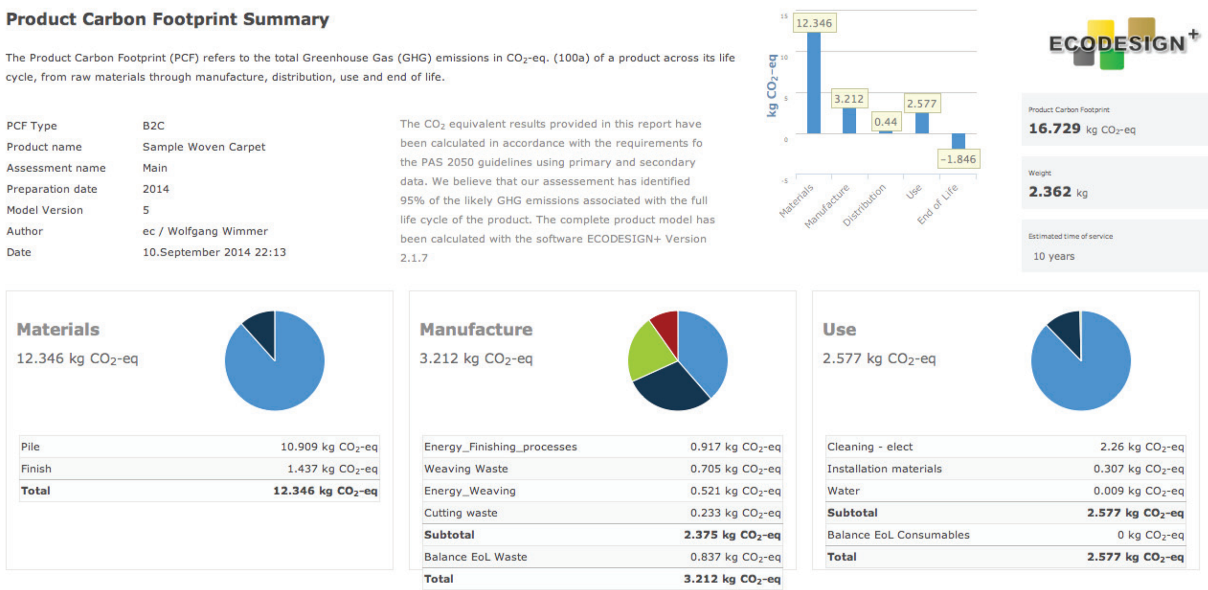


Figure 2: ECODESIGN+ summary results of the PCF for a woven broadloom floor covering.

2.3. Stakeholder analysis

Key guiding questions in this step are: What are stakeholder requirements? What is expected from the product?

The stakeholder analysis aims at identifying important stakeholders and their concrete demands to be able to understand their requirements and further translate them into concrete technical parameters. These can be understood by product developers, and should be used for product improvements later on. The outcome is a list with the most important technical parameters from the perspective of the stakeholders. In this step the relationship matrix of the method Quality Function Deployment has been used.

The list of stakeholders for textile floor coverings included the international bodies setting standards and labels, regulators, end customers, architects, contractors, carpet manufacturers, and post consumers (e.g., waste managing organizations). The requirements of relevant technical product standards and legislations form the basis for the stakeholder assessment. In addition, the requirements from end customers, architects, contractors, manufacturers, and post-consumers were identified by the product managers in the project. Twenty nine stakeholder requirements, gathered into five groups were included, ranging from general requirements, classification and quality, requirements for carpet tiles only, aesthetics and performance requirements. These requirements were weighted according to the relevance to the stakeholders.

The product experts assessed which product technical properties or parameters influence these requirements the most, and identified thirty four technical parameters, grouped in nine categories: general characteristics, surface, pile fibre, pre-coat, primary backing, secondary backing, additives, manufacturing, and use (including installation). The “relationship matrix” shows which stakeholder requirements relate to which technical parameters, and how strong this relationship is. This is completed together with company experts, by means of a numerical scale (1, 3, and 9). The values 1, 3 and 9 correspond to a “weak”, “medium” and “strong” relationship. These overall results help identify important technical design parameters. An extract of the relationship matrix, is shown in Table 1 for the illustrative woven carpet example.

Stakeholder Requirements / Technical - Parameters (9.. strong relationship; 3.. medium relationship; 1.. weak relationship)		Importance 1-5 (1=less important, 5=very important)	General characteristics: Mass per unit area of floor covering	General characteristics: Mass per unit area of use surface above substrate (SPW)	General characteristics: Total thickness of floor covering	General characteristics: Thickness of pile above the substate	General characteristics: Number of tufts per unit area	General characteristics: High thermal conductivity	General characteristics: Acoustical sound absorption	General characteristics: Acoustical impact noise reduction	General characteristics: mechanical Construction of product	Surface: Type of surface structure	Surface: Surface treatment	Surface: Surface pile density	Surface: Coefficient of friction	Pile fibre: Pile fibre material	Pile fibre: Type of pile fibre	Pile fibre: mechanical yarn construction
			1	2	3	4	5				6	7	8	9	10	11	12	
	Units		g/m2	g/m2	mm	mm	/dm2							g/cm3	1	g/m2		
General requirements	High fire resistance	5	9	3	1	1	3				9	9	1	1		1	3	3
General requirements	High slip resistance	1																1
General requirements	Low antistatic electrical behaviour	1										1	1			3		
General requirements	Electrical behaviour - low vertical/horizontal resistance	1										3	1			1		
General requirements	Suitability for use with under floor heating	1	1		1	3		9						3				1
General requirements	Absence of VOC emission	1		3	1	1							1			3		
General requirements	Absence of objectionable odours	1																1
General requirements	No Hazardous substances in the product	1											3					
Classification and quality	Suitability for Commercial heavy traffic use	5					3				9	3		3		3	1	
Classification and quality	Suitability for Continuous use of castor chairs	5				3					3	1		1			3	3
Classification and quality	Suitability for continuous use on stairs	5				1	3				3		1	3		9	3	
Classification and quality	Resistance to fraying	1									3	1						9
Classification and quality	Luxury class	1		9												9		9
Classification and quality	Light fastness	1														3		
Classification and quality	Impact noise reduction	1	9	9	1		1					1		1				9
Classification and quality	Good sound absorbtion	1	3	1	3	1	1		9	3	3	3		1				9

Table 1: Extract of the relationship matrix for a woven broadloom floor covering.

2.4. Process analysis

The key guiding question in this step is: What are the significant environmental hot-spots of the manufacturing of the reference product?

Process analysis consists of performing a systematic quantification of key parameters of the manufacturing and auxiliary activities to understand the environmental aspects and impacts. The process analysis for textile floor covering manufacturing comprises an input-output balance of the material and energy flows in the production. First the individual process steps, and how they are connected in the manufacturing line, is defined and described. Then, for each process, the input flows in terms of material (including the toxicity of materials) and energy inputs, as well as the output flows in terms of product, wastes and emissions, are defined. The data were collected in detailed tables for each process unit and for auxiliary processes such as heating and lighting of the manufacturing plant (allocated on the basis of the reference product). The result from the process analysis is the identification of hot-spots, namely processes that need to be further investigated for their improvement, in terms of material efficiency, energy consumption, and/or toxicity issues.

2.5. Benchmarking of products

The key guiding question in this step is: What are the strengths and weaknesses of the reference product compared with other products?

Benchmarking refers to the gathering of information about “other” products such as competitor products, prototypes, and best available products, to assess the degree to which these products fulfil specific stakeholder requirements compared to the reference product. The visualization of the differences between the reference textile floor covering and the other products is conducted by referring to the same technical parameters and stakeholder requirements already identified in the stakeholder analysis. The depth of the benchmarking depends on access and availability of information on these other products, and could be streamlined to include only those stakeholder requirements and/or only those technical parameters which have the highest relevance, to support discussions on specific ideas for product improvements. The example of a woven broadloom product and two other generic products (Named product 1 and 2) are presented in Table 2, with a partial evaluation of their differences.

All the instruments described so far gather the information and data on the reference product, from different perspectives (core of the analysis), and are used in the synthesis or interpretation phase of the Ecodesign methodology, namely, the identification of product and process improvements, which leads to the description of new textile concepts.

EcoMetex Step 5a Benchmarking of Technical Parameter

Date		Product category	Product ID	Editor
	Reference Product			
	Benchmark Product 1			
	Benchmark Product 2			

	Technical Parameters	Nr	Import-ance	Unit	Specific Values Reference Product	Specific Values Benchmark Product 1	Specific Values Benchmark Product 2	Fulfilment (5.. very good, 1.. poor, 0.. not fulfilled) Reference Product	Fulfilment Benchmark Product 1	Fulfilment Benchmark Product 2
General characteristics	Mass per unit area of floor covering	1	1	g/m2	550	600	660	2	1	1
	Mass per unit area of use surface above substrate	2	3	g/m2	325	350	400	3	3	4
	Total thickness of floor covering	3		mm				4	5	4
	Thickness of pile above the substate	4		mm				3	2	3
	Number of tufts per unit area	5		/dm2				3	0	4
	Construction	6		mm				3	3	4
Surface	Type of surface structure	7						4	1	3
	Surface treatment	8						3	3	3
	Surface pile density	9		g/cm3				3	3	3
	Coefficient of friction	10		1				1	2	0

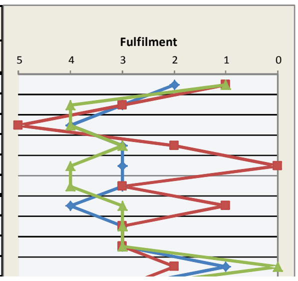


Table 2: Example of the benchmarking of products considering stakeholder requirements.

2.6. Product and process improvements

The key guiding question in this step is: How to combine stakeholder requirements and significant environmental aspects into improvement strategies?

The product and process improvements step summarizes all key results of the previous steps, to identify a range of product and process improvement opportunities through Ecodesign strategies. It is about creating a “landscape” of possible improvement directions, considering all the product life cycle stages.

These improvement directions can be generated with various different creativity techniques. Product improvement workshops were held with company and external experts, with the objective of generating a list of improvement measures for the reference products. With the list of possible measures for product and process improvements, the next step of the Ecodesign methodology is the prioritization of these measures, looking more specifically towards the development of a new textile floor covering concept.

2.7. New textile concept

The key guiding questions in this step are: Which improvement actions should be implemented for the reference product? How to generate and select the new product concept and its possible variations?

The improvement actions and strategies identified need to be assessed in greater detail and prioritized. The criteria for the evaluation are based for example on benefits, effort, and risk of the proposed improvement measures. The partners followed a qualitative approach for this evaluation, placing greater importance on their specific views in relation to their organizational capacity, and the resources to implement these measures. The consideration of the timeframe (short term, medium term and/or long term viability of the measures) is important when prioritizing. An extract of the template used to guide this discussion process, and to evaluate the measures is shown in Figure 3, for the illustrative example.

Ideally, the improvement actions with high benefit, low effort, and low risk should be taken into account. Nevertheless, not all improvement actions might be realized altogether in one product. Next to the evaluation of the improvement actions, the possibility to combine different actions is an important objective when formulating the new product concept(s). To do so, different variations of a product concepts can be proposed, and the most promising chosen for its realization.

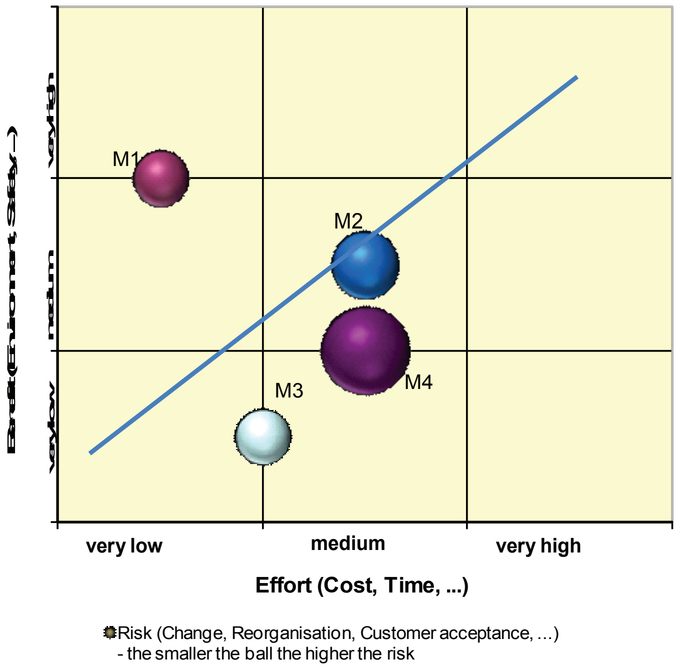


Figure 3: Extract of the template for the evaluation of improvement measures (e.g., M1 to M4).

2.8. Environmental communication

The final step of the Ecodesign methodology is to communicate the environmental performance derived from the implementation of prioritized measures for the product (and process) improvements, compared to the reference product, by using specific key environmental performance indicators. Selected textile floor covering manufacturers are already using Environmental Product Declarations (EPD) for their environmental communications. These EPDs present a status report of the environmental burdens of a specific product (or group of products), but do not provide additional information whether the product has been improved in its most recent model (or type) or not.

The communication proposed within the Ecodesign methodology serves as a complementary instrument to the textile floor covering EPDs. It considers life cycle thinking by referring to the results of the Ecodesign methodology and the particular reference products in EcoMeTex. It is also foreseen as an instrument to provide information on a possible accreditation program for recycling of carpets. It is important for project partners to communicate their efforts in developing a suitable textile covering for a closed loop system for the recycling of materials.

3. Case studies and results

Two case studies were selected for the implementation of the Ecodesign methodology. The first reference product is a woven broadloom carpet with 100% Polyamide 6.6 (PA 6.6) pile fiber, meeting the requirements for heavy contract rating. It is suitable for most commercial installations, and the product is available in 25 different colours. The product´s weight is approx. 1,5 kg/m2. The yarn, weft, and warp account together for about 73% of the product´s weight, and the finish (backing) for 27% of the weight.

The second reference product is a tufted tile of 100% Polyamide 6 (PA 6) pile fiber, also for commercial applications, with an average total weight of roughly 4,2 kg/m^2. The yarn and primary backing account for 15%, the pre-coat for 20%, and the secondary backing for 65% of the product´s total weight per m^2.

These two reference products are different from each other, especially on their structure, material composition, and weight; but both are used in the commercial (contract sector) for areas of heavy traffic. Both products are made in Europe, have a GuT license, and comply with the certifications required for the European market.

The functional unit used for the environmental assessment is one square meter of the reference product, with a service life of 10 years. This assessment was streamlined to complete the products´ carbon footprint with the software ECODESIGN+, by reporting the Global Warming Potential impact (in kg CO_2-eq). For both products, the largest impact contribution is due to the materials in the pile yarn. The second largest contribution is due to the energy consumption for cleaning the products during their entire service lives, and in third place are the contributions from their manufacturing processes. The End of Life scenarios considered the recycling of selected materials from the pile, with minor credits due to material recovery. For both products and from the environmental assessment perspective, the highest impact is associated with the material of the pile yarn, and therefore these are “raw materials intensive” products. Strategies aiming at improving these products shall particularly concentrate on the pile yarn materials.

For the stakeholder assessment the customer requirements were taken into consideration, even with specific types of customers (e.g., mainly interested in performance or in the aesthetics of the product). For the woven reference product the most important technical parameters are the pre-coat material, the mechanical yarn construction, followed by the construction of the product. For the reference tufted tile, the most important technical parameters are the additive material in the pre-coat, the pre-coat material itself, and the material of the secondary heavy backing.

The process analysis, by means of input-output assessment for both reference products, provided details into the processes involving the construction of the upper layer by weaving or tufting the supplied materials (i.e., the yarns), as well as the processes that combine this upper textile with the backing compounds into a final layered product. The energy consumption is a relevant issue, especially for the finishing of the carpets, namely the processes involving heat for drying the backing compounds.

The benchmarking for the two selected reference products includes various products in the European market, for the same commercial application, and for which publicly available information such as technical specification sheets, EPDs, and websites are available. Benchmarked products comply with mandatory requirements, but differ on parameters such as luxury class, which is related to the amount of material in the pile. For the woven reference product the comparison shows that most products are loop pile carpets with PA 6.6. The total weight and pile weight show differences (also different luxury classes), with the reference woven carpet being the lightest product in this comparison.

For tufted tiles the benchmarking shows mostly recycled PA 6 loop pile products. Products using recycled PA 6 yarns (e.g., Econyl®) show around 30% reduced PCF for the materials and production phases, when compared to products with virgin PA 6. This information was gathered from the available EPDs. The total weight, pile weight, and thickness are very similar for the products in the same luxury class.

It is plausible to state that, in both cases, the total carpet weight and pile yarn weight vary amongst products, although their expected (declared) performance remains very similar.

With all these insights from the five analysis steps of the Ecodesign methodology, the next step was the generation of ideas and measures for improving the products. This was accomplished in the context of workshops with company and external experts. The outcomes include a list of fourteen improvement measures for the reference woven broadloom, and ten measures for the reference tufted tile, ranging from new yarn compositions and mechanical properties, to different the pre-coat compositions, and alternatives for manufacturing using different technologies, including those that allow pile fiber fixation without additional components.

These measures were prioritized and combined for the description of three new product concept variations for each of the reference products. These measures were also proposed and selected to support the recyclability goals, primarily looking at the material compositions, which allow physical and chemical recycling of the carpet layers.

As part of the project´s demonstration work, the industry partners are producing prototypes, one variation per reference product. A woven mono-material commercial carpet concept is being developed, using mostly Polyamide 6 for the whole carpet construction. The woven structures are made of 70 to 80% PA 6, and the other materials in the carpet are chosen so that they have no negative impact on the chemical depolymerisation of PA 6. In this way the complete carpet can be sensibly conveyed in a chemical recycling process.

A new tufted tile concept with a recycled PA 6 pile is also being produced. It also includes a primary backing consisting of a Polyamide based non-woven textile, a coating, and a separation layer. The coating composition is adjusted to the requirements of the depolymerisation process, for the chemical recycling of the carpet. The coating dispersion allows using a separation layer for the tile, with special additives for a controllable, pre-determined breaking point of the carpet structure. This facilitates the separation of the pile thread and tufting medium and the carpet backing for recycling.

4. Summary and outlook

In the EcoMeTex project the Ecodesign methodology has been implemented to assess the environmental performance of two reference textile floor covering products, their relevant requirements and technical parameters coming from stakeholders, the important processes and flows for manufacturing, as well as comparison with competitor products in the European market. This systematic approach allowed the identification of clear areas for product improvements, followed by the prioritization and combination of the corresponding measures into new product concepts. These are being manufactured and tested for their feasibility and for their potential to close the loop of materials through recycling.

This systematic approach of the Ecodesign methodology was transferred to a textile cover used in the transport sector. The reference product in this case is a semi-finished luggage cover fabric provided to automotive original equipment manufacturers. The woven structure of Polyesther in the core is coated with layers of Polyvinyl chloride and varnish lacquer, for a resulting weight of 0,66 kg/m^2. The eight steps are adapted for the specifications of this product according to the industry standards.

Preliminary results show that potential product improvements for this “raw material intensive” coated fabric could include a new combination of materials and technologies, allowing a more efficient construction of the whole layered structure of the product, with a possible reduction on the overall weight. Prototypes are also being produced and tested for their viability and performance.

5. Acknowledgement

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) [NMP.2011.3.1-1] under grant agreement n° 280751.

6. References

[Blue Angel, 2014] Blue Angel label for textile floor coverings, http://www.blauer-engel.de/de/produktwelt/haushalt-wohnen/textile-bodenbel-ge/bodenbel-ge-textile, last accessed September 2014.

[ECODESIGN+,2014] Web application for calculating the product carbon footprint, http://ecodesignplus.com, last accessed, September 2014.

[EcoMeTex, 2014] EcoMeTex project, http://www.ecometex.eu/, last accessed September 2014

[EN 1307, 2008] DIN EN 1307:2008-08 (E) Textile floor coverings - Classification of pile carpets.

[EN 14041, 2008]: DIN EN 14041:2008-05 (E) Resilient, textile and laminate floor coverings - Essential characteristic.

[Euratex, 2009] European Apparel and Textile Confederation (Euratex); Key figures 2009.

[Ecolabel, 2014] EU Ecolabel for textile floor coverings, http://ec.europa.eu/environment/ecolabel/documents/Textile_floor_covering.pdf, last accessed September 2014.

[PCR, 2008] PCR - Product Category Rules. Environmental Product Declarations, Harmonized Rules for Textile, Laminate and Resilient Floor Coverings, 2008, http://construction-environment.com/download/CY3e2aa70X1402f0e04c8X74fe/PCR_floorcovering.pdf, last accessed September 2014.

[Wimmer, 2004] W. Wimmer, R. Züst, and K.M. Lee, ECODESIGN Implementation - A Systematic Guidance on Integrating Environmental Considerations into Product Development. Alliance for Global Sustainability bookseries, vol. 6. Springer, 2004.

A resource calculator for assessment of local production system options

Elias Martinez-Hernandez[a,b,*], Melissa Leung Pah-Hang[b], Matthew Leach[b], Aidong Yang[a]
[a]Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, UK
[b]Centre for Environmental Strategy, University of Surrey, Guildford GU2 7XH, UK

ABSTRACT

Several challenges facing the current society at global scale have been caused by unsustainable extraction, conversion and consumption of resources. The resulting environmental pollution and consequent degradation of ecosystem services threaten the continuous maintenance of human beings on the planet. Although these challenges are global, it is recognised that they result from the aggregation of local problems and that they may affect each local system differently. This calls for the engineering of man-made systems with a focus on the rational use of locally available resources. The management of resources for their sustainable use requires knowledge for the efficient balancing between demand of products and services, resources and environmental impacts within a local system. This work proposes a systematic view that supports the modelling and assessment of local systems with the aim to support the development of a Local Resource Calculator. The calculator is envisioned as a decision support tool for planning and design of local production systems based on local renewable resources as a potential pathway towards more sustainable production systems. This is shown in a case study wherein heathland ecosystem and energy production components are integrated as a symbiotic local production system within the context of an eco-town in the UK.

Keywords: sustainable local production systems, resource assessment and modelling
* Corresponding author e-mail: elias.martinezhernandez@eng.ox.ac.uk

1. Introduction

Although large scale centralised systems have been dominating the production of goods and services during the last decades, the increasing world population and the subsequent rise in energy and materials consumption have led to a resource constraint planet. Ecosystem functions are being affected due to the over-extraction of resources and the release of pollutants by human activities, threatening the continuous supply of ecosystem goods and services (Millennium Ecosystem Assessment, 2005). This drives the need to look at alternative renewable resources, such as wind, solar irradiation and biomass. The use of natural resources features prominently on the environmental policy agenda in Europe and other world regions (Giljum et al., 2008). For example, biomass has been considered in national energy strategies in Europe and around the world, so critical assessment of the local biomass resource availability is essential (Welfle et al., 2014). Resource availability varies with each locality depending on the natural environment, local practices and patterns of production-consumption. The influence of ecological processes on man-made technological processes and vice versa must be analysed at the local level in order to closely understand and select those interactions that can maintain the availability of resources and enhance the efficiency of their use in a local production system. This is different from the current approaches in other studies where systems are analysed using a top-down approach, which does not necessarily allow the particular context or situation of a specific locality to be represented (Wilbanks and Kates, 1999). Therefore, this work focuses on local production systems which can be defined as systems for synergetic provision of energy, water, food and other goods and services, based on local resources.

Turning the concept of localised production into a reality so that they can contribute to sustainable production still requires substantial engineering research to support direct stakeholders as well as planning and policy making practitioners (Curtis, 2003). The purpose of this work is to develop a conceptual and mathematical framework for the characterization and modelling of a local system to support the assessment of processes and component options that potentially form a more sustainable production system. The framework is then used as the basis for the development of a Local Resource Calculator. The calculator is a decision support tool for the selection of those production system components that allow meeting local needs while observing resource availability constraints imposed by the local ecosystem, with a view to maintain the ecosystem functions and capacities that can keep the local production system operating in a sustainable manner. The characterisation framework is presented In Section 2, followed by an application case study in Section 3.

2. Characterisation of local production systems

From the perspectives of systems engineering and industrial ecology, localised production should be in the form of a synergetic and evolving system in which heterogeneous production facilities are integrated in order to supply goods and services required to meet human needs with high resource efficiency. By-products or residues from local production processes, often classified as wastes in the current practice, together with the used products from consumption will also seek to be "looped" within the system by means of *symbiotic* arrangements, in order to reduce the need for input of virgin resources. Characterising a local production system is the first step to understand the key relationships between components and identify ways for their efficient integration.

A high level, generalised conceptualisation of a local production system is shown in **Figure 1**. Component, flow and state are the three key concepts in the conceptual framework with two different system *views*. In the *structural view*, the system is conceptualised as a collection of components and flows. Components are basic building blocks of the system and contain processes. Components and processes are interconnected by **flows**.

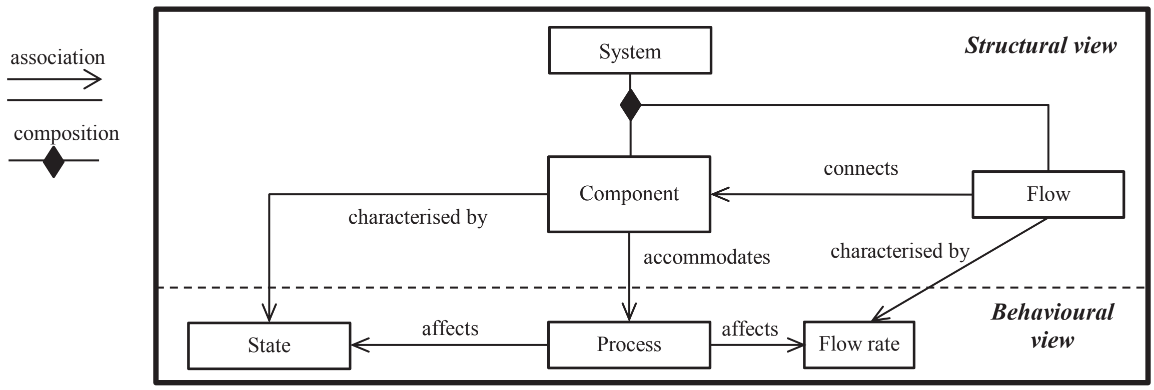


Figure 1. Conceptual model for system characterisation

Processes are at the centre of the *behavioural view*. A **process** is any transformation of flows from one condition or form to another. Processes modify the flow rates and the states within the components. The term **state** refers to the state functions that describe the attributes or conditions of the components. The ability or capacity of the system to maintain the provision of local needs within ecological constraints can be determined by analysing the states of a component. These limits depend on the rate of change produced by the processes, which can enhance or diminish such capacity as they evolve with time; hence the importance of dynamic modelling used in this work as an essential feature of the Local Resource Calculator. The results from this assessment tool can then also help to identify those elements that are essential for the system and must be maintained, those that can be removed or substituted and those that can be manipulated.

Applying the above conceptual framework, system characterisation in a particular application starts with defining the temporal and spatial scopes and then structural characterisation follows to identify the main ecosystem and man-made system components to be included in the analysis according to the objective of the study. Then, states are characterised by the resources involved and the processes and flows affecting the states are identified. This procedure is repeated for each state. It is particularly important at this point to identify those processes and flows leading to key connections that can potentially enhance (or otherwise) system resource efficiency and ecosystem health such as looping and matching between sources and demands through recycling, reuse and regeneration of resources.

The next steps are the selection of mathematical models and collection of input data before proceeding to calculations and assessment. The mathematical characterisation comprises the structured modelling of the system states within a boundary defined by system components. The generic rate of change of a system state variable *S* can be expressed as:

$$\frac{dS}{dt} = F_{in} - F_{out} - F_{cons} + F_{gen} \qquad \text{Equation 1}$$

where $\frac{dS}{dt}$ is the accumulation rate of the resource characterising a state (e.g. nitrogen in soil), F_{in} and F_{out} are the input and output flows to and from the system, respectively. Generally, there could be processes that consume (at rate F_{cons}) or generate (at rate F_{gen}) resource flows thus decreasing or increasing the accumulated value of the state. If all the processes can be expressed as rates of input (import), output (export or extraction), consumption and generation, the main processes driving the accumulation or depletion of a resource could be identified. The models for rates of consumption and generation can subsequently be introduced, depending on the physical nature of the system.. The mathematical characterisation framework thus consists of first establishing the conservation equations of the states and then introducing models (i.e. constitutive relations) for the rates of the processes involved. The characterisation framework is illustrated through a case study as follows.

3. Case study

3.1. System characterisation

A case study within the context of the Whitehill and Bordon Eco-town in the UK was undertaken. The Local Resource Calculator is used for the assessment of biomass resource availability and assessment of options for the integration of energy production components. The system and its components as analysed are shown in **Figure 2**. The system consists of energy production (electricity and heat) from heathland biomass and sewage sludge as locally available renewable resources. The dashed boundary encloses those components whose processes are directly or indirectly considered in the models. The main ecosystem component is the heathland. The man-made components include energy production, sewage treatment as municipal component and a lumped component including residential, commercial and industrial buildings. Processes in components outside the boundary (air component and water body components), were out of the scope of this case study.

In the heathland, heather (*Calluna vulgaris*) and grass species (*Deschampsia flexuosa*) compete for land and nutrients (Heil and Bobbink, 1993; Bakema et al., 1994). Whilst other nutrients are needed for plant growth, this work focuses on nitrogen due to its distinct importance to maintain heathland ecosystems. Thus, standing biomass of heather and grass and the nitrogen stock in the soil are the main states in the heathland component. Such states are affected by the growth rate, the mortality rate and harvesting rate. Growth rate has been related to nitrogen availability from atmospheric nitrogen deposition, mineralisation of litter in heathland soil, and nutrient recycling from the energy production component. The objective is to maintain the ecosystem as heathland and avoid its transition into grassland due to increased nitrogen in the system (Power et al, 2001). The potential of harvesting Calluna vulgaris as a bioenergy crop has been studied recently by Worrall and Clay, 2014).

Thus, a symbiotic relation can be created when removing nitrogen from the ecosystem by the process of harvesting, whilst plant growth process in the ecosystem provides a flow of biomass as a renewable resource for the energy production processes.

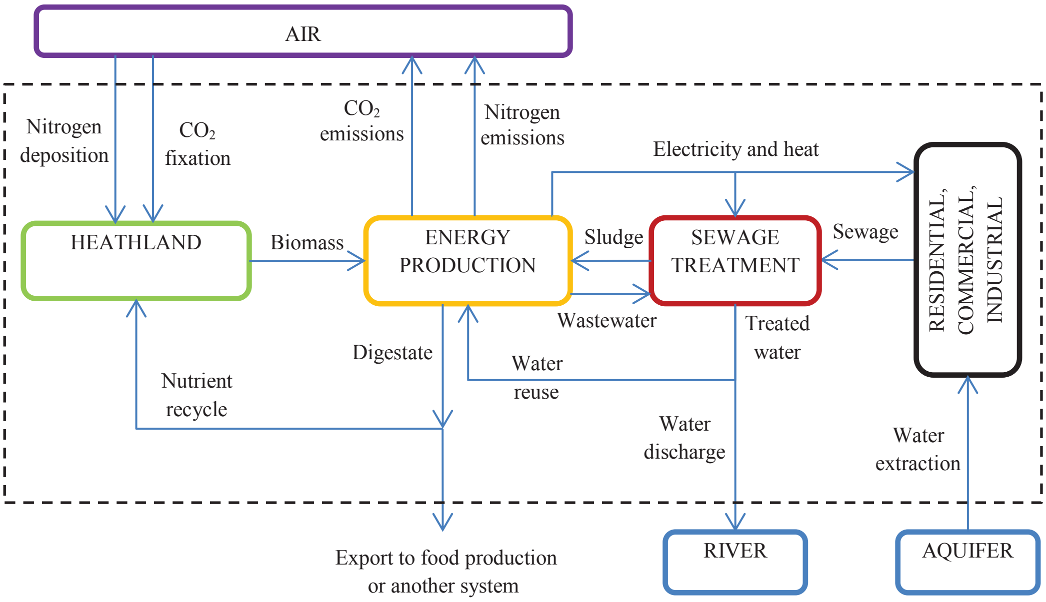


Figure 2. The local production system analysed in the case study

Three options for biomass conversion into combined heat and power (CHP) are analysed:

1) Direct combustion of whole biomass

2) Direct combustion of woody biomass and anaerobic digestion (AD) of soft biomass with subsequent biogas combustion

3) In addition to components in option 2, this option includes AD of sewage sludge to produce biogas.

The digestate from the AD process is assumed to be treated and used as fertilizer. This valorisation of residual streams contributes to maintain nutrient resources within the system or can be exported as a product to another component or local production system. Water from the sewage treatment plant can be reused for the AD of soft biomass whilst at the same time the wastewater from the dewatering of digestate can be treated in the sewage treatment. This creates another interesting symbiotic two-way relationship, saving freshwater extracted from local aquifers while producing energy to offset demands by the water management system.

Mathematical characterisation is exemplified using the ecosystem component. More detailed models will be presented in another publication (Martinez-Hernandez et al., Unpublished results). The boundary for heather and grass biomass and nitrogen in soil is the heathland ecosystem. In this case, there is no input flow but there is a generation rate due to biomass growth and a consumption rate due to mortality (litter production). The rate of change of standing biomass (B) with time can be expressed as:

$$\frac{dB}{dt} = F_{growth} - F_{mort} - F_{harv} \qquad \text{Equation 2}$$

where t is time, F_{harv} is the harvest rate (an output flow), F_{mort} is the mortality rate (consumption) and F_{growth} is the biomass growth rate (generation). In this case, the growth rate of species i ($F_{growth,i}$) can be expressed in a generic form as:

$$F_{growth,i} = \frac{dB_i^{growth}}{dt} = k(N)B_i L(B_i, B_j, N) \qquad \text{Equation 3}$$

where $k(N)$ is the growth rate constant as a function of nitrogen availability (N); $L(B_i, B_j, N)$ is land fraction available for growth as a function of both heather (i) and grass (j) biomass and nitrogen availability (Heil and Bobbink, 1993). Nitrogen availability is a triggering factor for the conversion of heathland into grassland or wooded land (Bakema et al., 1994; Power, 2001). The tracking of accumulation of N in soil can also help to assess the nitrogen use efficiency by the system. N state in soil is determined by:

$$\frac{dN}{dt} = F_{dep}^{N} + F_{fert}^{N} + F_{miner}^{N} - F_{harv}^{N} \qquad \text{Equation 4}$$

where F_{dep}^{N} is the atmospheric nitrogen deposition (input flow); F_{miner}^{N} is the N from the fraction of litter that is mineralised and is available for growth (generation); F_{harv}^{N} is the N taken out from the heathland in the biomass harvested (output flow).

Processes and states in the other system components can be modelled following a similar philosophy. Note that the slowest processes are mainly those in the ecosystem, thus the energy production and sewage treatment processes can be considered to operate in steady state. Variations in these processes are produced by variations in the supply of heathland or sewage biomass, which in turn changes with biomass yield and local human population, respectively. Thus, population dynamics was also modelled in order to capture such variability in the sewage flow and energy demands. These models will be presented in an extended version of this paper.

3.2. Results and analysis

The system models were implemented into the Local Resource Calculator to obtain the solution for annual biomass harvesting of 1600 ha of heathlands around the Whitehill and Bordon eco-town. The calculator was run for 50 years. The biomass and sewage sludge from sewage treatment are used for energy production to partially supply the demands of the eco-town. The two main states in the system are the standing heather biomass and the nitrogen content (N) in soil which are crucial for maintaining the health of the heathland ecosystem. The local N deposition is 16 kg N ha^{-1} y^{-1}.

Three options were analysed with respect to resource consumption of the system: 1) using whole biomass for CHP production via direct combustion and 2) AD of soft biomass and using the biogas and woody biomass for CHP production and 3) introduction of AD of sewage sludge to produce more biogas for CHP in addition to components in option 2. First, the nitrogen and heathland biomass dynamics and the interconnection with the energy production component were analysed. The system models were solved for different scenarios of biomass harvesting practice (setting a cut fraction as parameter). Only options 2 and 3 allow nitrogen recycling. Note that the nitrogen that is recycled is the nitrogen originally present in the soft biomass that is recovered in the digestate resulting from AD.

Figure 3a shows how both cut fraction and N recycle ratio affect the standing biomass in the heathland. Cutting of biomass to harvest is not beneficial under a cut fraction of 0.3 as the heather biomass will decline (grass might then predominate, converting heathland into a grassland). However, it was found that a cut fraction of 0.6 depletes the system faster than it can recover and both heather and grass biomass decline continuously. The N recycling digestate shows to be beneficial as this increases biomass yield. However, the influence of cut fraction is similar to the system without N recycling. **Figure 3b** shows heather biomass that can be harvested and the N in soil at steady states for different cut fractions and 50% of N recycle. Cumulative harvested biomass is also shown. If the steady-state performance is used as the criterion, a cut fraction of 0.5 optimises the system as the yield is the highest and the N in soil is the lowest, thus achieving symbiosis between ecological and technological processes. In terms of the cumulative biomass production over the considered 50 years, a cut fraction of 0.4 provides best results, however at the expense of higher N in soil, which may undermine the stability of the system. In a separate study, we show that the system becomes less resilient to an increase in nitrogen deposition as the N recycling increases (Martinez-Hernandez et al., unpublished results).

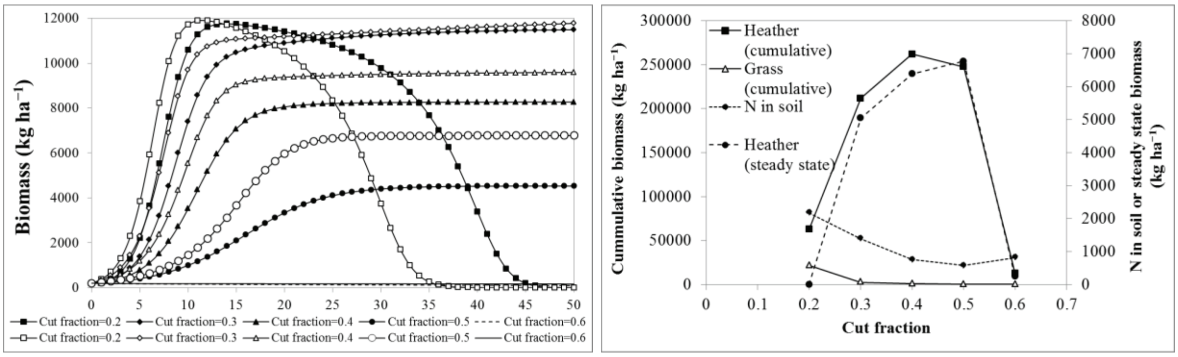


Figure 3 a) Dynamic trends of standing heather biomass under varying cut fractions and no N recycle from soft biomass (filled markers) and with 50% recycle (open markers); and b) Cumulative harvested biomass and N in soil after 50 years management and harvested biomass at steady state

Using a cutting fraction of 0.5 and recycling 50% of the N in soft biomass, the system's biomass resources at steady state were estimated using the Local Resource Calculator. The three bioenergy and water treatment design options, outlined earlier in this section, were compared in terms of percentage of demand supplied, energetic efficiency, nitrogen emissions and digestate exported as fertiliser, as shown in **Figure 4**. Whilst options 2 and 3 can supply higher amounts of the total electricity and industrial heat demands of the eco-town, option 1 is better in terms of efficiency in energy conversion. However, the nitrogen emissions (which could increase N deposition in the local ecosystem) are higher in Option 1. Furthermore, Options 2 and 3 allow the recovery of nutrients thus producing significant amounts of fertiliser for agricultural production. This could also be integrated locally or exported to another local production system. Final decision requires an economic analysis, consideration of environmental policies as well as the criteria of the decision makers.

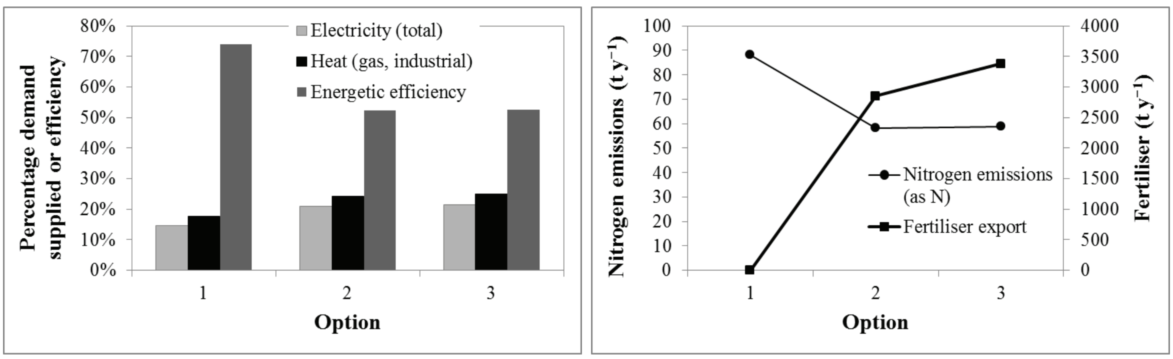


Figure 4 a) Percentage of demand that can be supplied by the three options for the local energy production system analysed; and b) Nitrogen emissions and fertiliser exported by the various options

4. Conclusions and future work

A conceptual and mathematical modelling framework for characterising local production systems has been presented in this paper. The whole characterisation framework was shown to be useful for devising options for a local energy production system which integrates both ecological and technological processes in a symbiotic way. This framework has been implemented in a Local Resource Calculator. Demonstrated through a case study, this tool allows to assess options for the establishment of a local energy production system that involves a heathland ecosystem, bioenergy production and wastewater treatment, which are inter-connected through exchange streams and loops. The tool was able to analyse the ecosystem response to the variations in management practices and the influence of technological process into ecological process and vice versa. By explicitly analysing the two-way connections between the man-made components and ecosystem components, this tool provided insight into the behaviour of the energy production system and the corresponding level of the ecosystem states that allow continuous provisioning of resources, thus leading to a more sustainable production system. With the inclusion of corresponding models of interesting components, it is envisaged that a decision maker can use the tool for scenario building to evaluate options for introducing or removing new components into a local system either to improve resource efficiency or for environmental remediation. Local food production will be especially interesting to introduce in future work as the system is currently producing considerable quantities of fertiliser. This will allow keeping the nutrient resources within the system.

REFERENCES

Bakema, A.H., Meijers, R., Aerts, R., Berendse, F., Heil, G.W., 1994. HEATHSOL: A Heathland Competition Model. Netherlands National Institute for Public Health and the Environment (RIVM).

Curtis F., 2003. Eco-localism and sustainability. Ecol. Econ. 46, 83−102.

Giljum, S., Behrens, Hinterberger, A., Lutz, C., Meyer, B., 2008. Modelling scenarios towards a sustainable use of natural resources in Europe. Environ. Sci. Policy 11(3), 204–216.

Heil, G.W. and Bobbink, R., 1993. CALLUNA a simulation model for evaluation of impacts of atmospheric nitrogen deposition on dry heathlands. Ecol. Model. 68, 161-182.

Martinez-Hernandez, E., Leach, M., Yang, A., Unpublished results. Dynamic analysis of a heathland biomass-to-energy system.

Millennium Ecosystem Assessment, 2005. Ecosystems and human wellbeing: synthesis. Island Press, Washington DC.

Power, S.A., Barker, C.G., Allchin, E.A., Ashmore, M.R., Bell, J.N.B., 2001. Habitat management: a tool to modify ecosystem impacts of nitrogen deposition? Scientific World J. 1, 714–721.

Welfle, A., Gilbert, P., Thornley, P., 2014. Securing a bioenergy future without imports. Energy Policy 68, 1–14.

Wilbanks, T.J. and Kates, R.W., 1999. Global change in local places: how scale matters. Climatic change 43(3), 601-628.

Worrall, F., Clay, GD., 2014. The potential use of heather, Calluna vulgaris, as a bioenergy crop. Biomass Bioenergy 64, 140–151.

A multi-level framework for resource accounting

Melissa Yuling Leung Pah Hang[a*], Elias Martinez-Hernandez[b], Matthew Leach[a], Aidong Yang[b]
[a] Centre for Environmental Strategy, University of Surrey, Guildford, United Kingdom
[b] Department of Engineering Science, University of Oxford, Oxford, United Kingdom

ABSTRACT

Resource accounting is an important approach that can assist decision making and system design and contribute to a more sustainable path to development through appropriate utilisation of resources along the whole value chain of a product or service. This work aims at developing a coherent framework for resource accounting to support decision making during the evaluation of alternatives for production and consumption activities. It provides a structured and holistic multi-level understanding of production and consumption of products and/or services within a defined system boundary, in which several system levels can be distinguished including unit, process, inter-process and production-consumption. This framework reveals how decisions at one level would affect other levels of the system. Based on such a multi-level view, a unique adaptation of the Cumulative Exergy Resource Accounting, 'CERA' methodology is proposed to quantify resource consumption. The scope of the proposed CERA methodology covers all types of processes, including natural ecosystem processes. This work also differentiates and accounts for the resources required for resource extraction, agriculture and manufacturing systems as well as those that provide the machinery, equipment, and buildings. The concepts and proposed analytical framework are illustrated through a case study on the production of sugarcane ethanol.

Keywords: multi-level framework, resource accounting, cumulative exergy consumption

*E-mail: ml00248@surrey.ac.uk, Ph: +44 1483 68 9559

1 Introduction

Scarcity and environmental impacts of production and processing of resources are the main considerations behind resource accounting. With growing economies, world population reaching 7 billion people (USCB, 2013) and overall standards of living rising, there is inevitably a subsequent increase in the consumption of natural resources globally. There are mounting concerns that the supply of key resources such as energy, water and materials would not be sufficient to meet the needs of a rising world population, within reasonable environmental and economic constraints. Also, inefficient use and over-exploitation of resources has led to adverse impacts on human wellbeing as well as on the natural environment and contributes to climate change (Huijbregts et al., 2010). There is thus an urgent need to improve resource efficiency by producing, processing and consuming Earth's limited resources in a sustainable manner (EC, 2013) while minimising impacts on the environment from the overall life cycle of the resource.

Previous studies by Hau and Bakshi (2004), Yi et al. (2004) and Liao et al. (2012) have recognised the need for a multilevel analysis for resource accounting, based on exergy, as adopting a narrow view by analysing only individual processes might shift the resource consumption impacts to other parts of the value chain of the product or service. However, these researchers do not offer detailed physical quantification of the processes and flows pertaining to the resource consumption at the different levels. A detailed multi-level analysis is required to unfold how a resource, before and after being processed at different stages, flows within the totality of the system, which is essential for the identification of important flows that can be either removed or improved through integration with flows associated with other products or services in the system. From existing work on multi-level resource accounting based on exergy, it can be remarked that that the system boundary is an important consideration. However, there is still a lack of a detailed and holistic quantitative study encompassing at the same time ecosystems, production as well as consumption of final product or service. In particular, the consumption side of a product or service has largely been overlooked. Also, while the most recent studies on resource accounting have attempted to include a wide range of resources, there are still some controversial aspects with regards to the admissibility of the inclusion of money and potential double counting of labour and money resources (Rocco et al., 2013). Furthermore, it can be observed that the resource burdens of constructing plant, equipment and machineries have been largely overlooked in existing resource accounting methods and that there are no detailed studies explicitly acknowledging the importance of quantitatively accounting for these resources.

Addressing the above deficiencies, this work proposes a multi-level framework for resource accounting. Conceptually it presents a multi-level structure and articulates the key aspects such as system boundary, types of flows and processes, and principles for calculating resource consumption to avoid ambiguity and double-counting. The structural depiction serves to provide a basis for assessing resource accounting quantitatively based on cumulative exergy consumption. This paper will focus on presenting the conceptual framework and illustrating it with a case study, although the quantitative framework will also be briefly mentioned.

2 A conceptual framework for resource accounting

2.1 Basic concepts of system, environment, process and flow

A system for which resource accounting is considered is defined by (i) the resource-embedded incoming *flows* that enter the *system* from its *environment*, (ii) the *process* or *processes* that convert the flows from the *environment* and (iii) the outgoing *flows* produced by the *process(es)* that leave the *system* and enter its *environment*. Resource accounting can be carried out for systems of different levels or scales. In particular, the global level and the local level can be distinguished. At the global level, the system comprises all human-driven processes as well as the processes in the natural eco-system which can potentially be affected by human-driven processes. Following this principle, this scope does not include processes which will occur in the future, or have occurred historically, independently from human intervention. Such processes essentially form the environment of the global system. In contrast with the global system, a local system comprises human-driven processes as well as natural processes that can be affected by human decisions and actions at the corresponding local level. As such, this local system exchanges flows with its environment, which typically includes both other local systems and natural processes that do not form part of the local system under study. The system boundary separates the system from the environment. This work will focus mainly on the local system as opposed to the global system. Also, in order to facilitate the subsequent discussions in this report, processes (human-driven or natural) which are affected by human activities will be referred to as Type-I processes while those that are not affected will be referred to as Type-II processes.

2.2 Resource flows and their accounting principle

This section details the potential input flows to the system from Type-I processes and Type-II processes and their accounting principle. The input flows considered for a local system include the following:

- Material and energy flows from natural processes
- Material and energy flows from technological processes
- Human labour

Material and energy flows from Type-I processes are accounted for by their cumulative exergy. Cumulative exergy is the sum of exergy; defined as the maximum available energy to do useful work, of all types of resources consumed from extraction to the point where they are used. Labour is also accounted by its cumulative exergy. A frequently adopted estimation approach is an exergy to labour conversion factor (Kotas, 1985; Sciubba, 1995; Wall, 1999).

Input flows from Type-II processes will only be accounted for by their exergy content as opposed to a cumulative exergy value. For example, the exergy content of the material fossil fuels and ores (in-situ, prior to extraction), is considered but not the cumulative exergy consumption of the ecological processes required for their original formation. This is because the resource consumed by their formation is considered historical burden and is not relevant to (or affected by) any future human activities. Similarly, the cumulative exergy consumption of the ecological processes for the formation of wind and solar radiation (sunlight) will not be taken into consideration. On the other hand, our framework does consider the resource value (in the form of exergy content) of these renewables instead of treating them as "free" resources, to recognise the fact that these resources in principle have alternative uses.

2.3 Resource consuming processes

A detailed overall depiction of the environment and the resource consuming processes occurring in the society is illustrated in Figure 1. The society refers to the system over which resource accounting is conducted. It comprises two main subsystems namely the product provision subsystem and the product consumption subsystem. A process in Figure 1 represents a sequence of processing units which can produce at least one final product or intermediate products that can be further processed by other temporally and spatially separate processes. The product provision subsystem comprises all the processes that are required to manufacture a product or service.

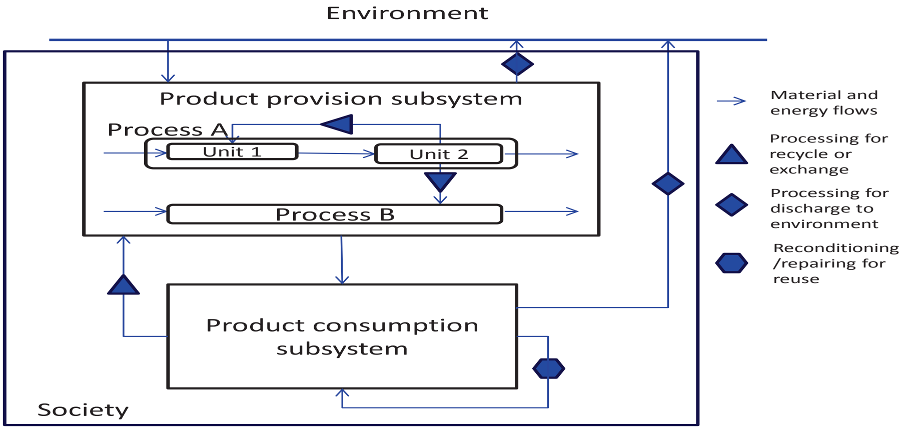


Figure 1: Overall depiction of the Environment and Societal System

The environment remediation processes for treating pollutants before they are released into the environment form part of a system and these processes can be either industrial/technological processes or natural processes, or a combination of both.

2.4 Multilevel structure of a system

In an attempt to provide a better understanding of a system and support the development of a resource accounting methodology, a system is conceptualised as a hierarchical structure with the following levels:

- *Unit level* which involves a single conversion step where input to the unit is processed to output with no recycle and reuse involved.
- *Process level* comprises one or more units where intra process (i.e. inter-unit) recycling and reuse can occur.
- *Inter-process level* with exchange of flows between two or more processes.
- *Production-consumption level* with reuse and recycle of products; this level includes consumption processes.

The physical quantification of resource consumption may be different at each system level, depending on the processes and arrangements with regard to recycling, exchange and repair. At each level, different key decisions can be made. At the unit level, decision making would involve choosing the most appropriate and resource efficient unit operation. At the process level, the focus of decision is on selecting among the best process design to adopt. At the inter-process level, resource accounting will give an indication of the industrial synergies to promote or adopt. At the production-consumption level, it could help to identify links between production processes, the ecosystem and consumption society with the aim of achieving a cradle to cradle resource model, similar to the 'circular economy concept'. Table 1 summarises briefly the main decisions at the different levels of analysis.

Table 1: Decisions making at different levels of analysis

Level	Decision
Unit	Technology development/Innovation
Process	Plant/factory design
Inter-process	Industrial symbiosis
Production-consumption	Circular economy, repair versus recycling

2.5 Resource accounting algebra

Based on the conceptual framework described previously, the resource accounting for a generalised local system can be expressed by Equation (1):

$$\mathrm{CExC_{total}} = \sum \mathrm{Ex_{Type-II}} + \sum \mathrm{CExC_{Type-I}} + \sum \mathrm{CExC_{ENV}} \quad (1)$$

Where,

$\mathrm{CExC_{total}}$ is the cumulative exergy consumption for production of a product from the system

$\sum \mathrm{Ex_{Type-II}}$ is the total exergy content of material (e.g. fossil fuels and ores before extraction) and energy (e.g. solar irradiation and wind) input flows from Type-II processes.

$\sum \mathrm{CExC_{Type-I}}$is the sum of the cumulative exergy consumption of all the input flows produced from Type-I processes.

$\sum \mathrm{CExC_{ENV}}$ is the cumulative exergy associated with environmental remediation processes.

Based on this general equation, a full resource accounting algebra has been developed for each of the levels presented above and can be found in Leung Pah Hang et al. (2014).

3 An illustrative example - bioethanol production

The conceptual framework developed for resource accounting is illustrated through a case study on the production of ethanol from sugarcane, as shown in Figure 2. The case study illustrates how natural (e.g. photosynthesis), agricultural (e.g. cane cultivation) and industrial/manufacturing (e.g. ethanol plant) processes as well as the consumption of the final product can be included in the resource accounting at different system levels. The quantitative part of this case study which demonstrates the resource accounting algebra is documented in Leung Pah Hang et al. (2014) and is not reported here.

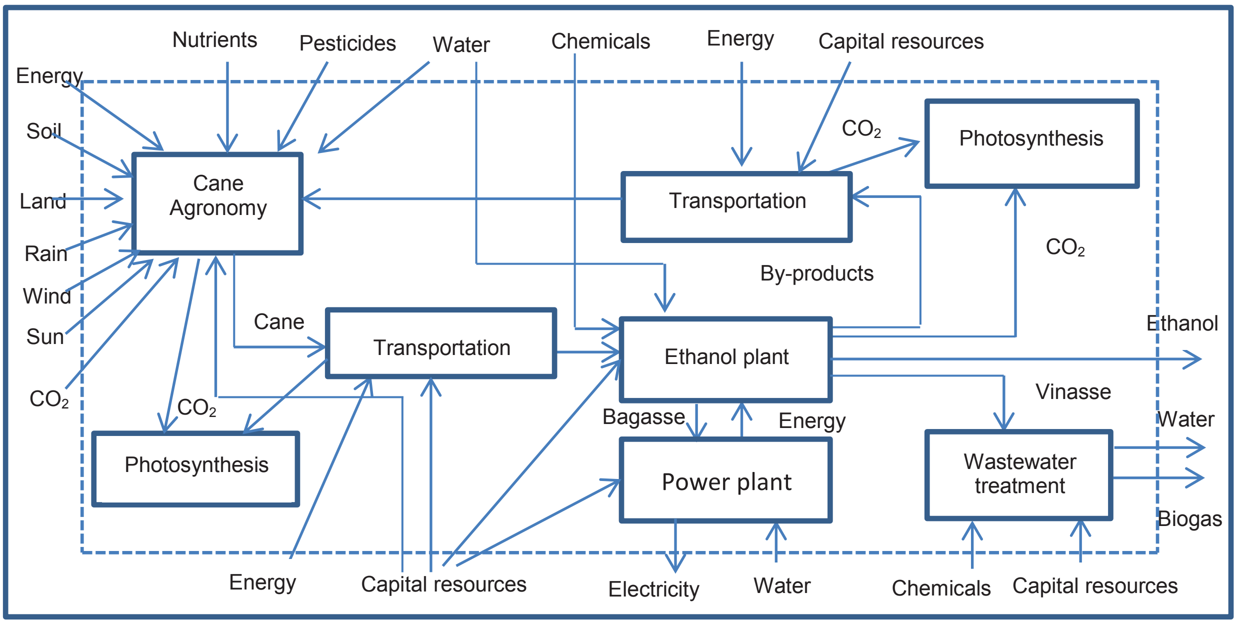


Figure 2: Ethanol production from cane

3.1 Resource accounting at unit level

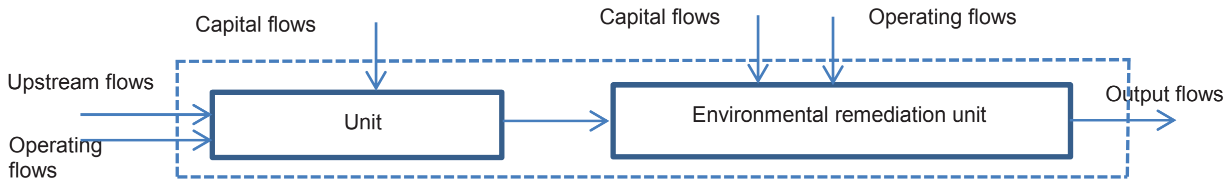


Figure 3: Resource accounting at unit level

Figure 3 represents resource accounting at the unit level. The input flows can be further categorised into operating flows and upstream flows where the upstream flows would be cumulative flows, expressed in exergy, from all the previous units. A unit could be cane agronomy, cane transportation, cane milling, cane juice clarification, fermentation, distillation, dehydration, distribution, and consumption of ethanol. At the unit level, it is possible to distinguish between the best technologies for manufacturing ethanol from a resource consumption perspective. For instance, resource accounting undertaken at the unit level for ethanol dehydration could be used to decide between two technologies namely molecular sieve and azeotropic distillation.

3.2 Resource accounting at process level

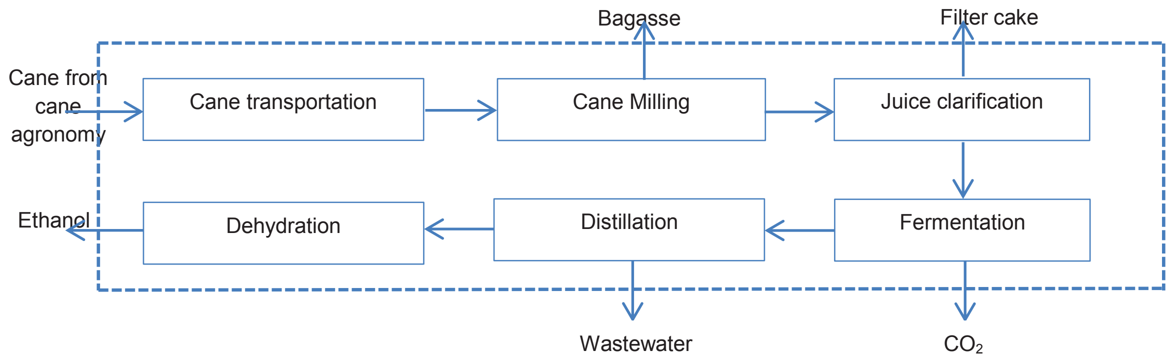


Figure 4: Ethanol production system at process level

Figure 4 illustrates the production of ethanol at the process level. Cane transportation, cane milling, juice treatment, fermentation, distillation and dehydration can be considered as units of one process for the production of ethanol from cane. Figure 4 does not show any intra-process recycling flows. One alternative could be to recycle the water flows from the distillation unit to be used as imbibition water for cane milling and to recycle the ethanol/water flows from the molecular sieve dehydration units to the distillation unit to reduce the amount of beer produced from the fermentation process. However, the recycled flows might require some processing before being pumped back as input flows to a unit. Consequently, a proper resource accounting at the process level can determine if intra recycling flows will have a positive impact overall on resource consumption.

3.3 Resource accounting at inter-process level

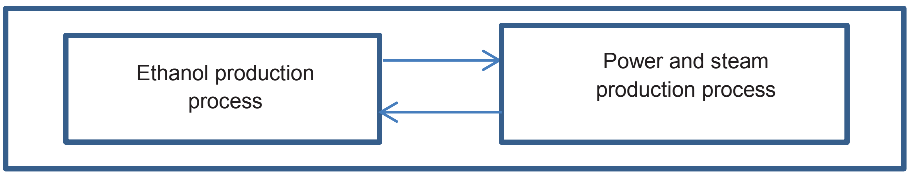


Figure 5: Production of ethanol at inter-process level

Figure 5 illustrates the production of ethanol at the inter-process level with exchange and recycled flows. At the inter-process level, synergies between different types of processes;

including heterogeneous processes like ecological and technological processes, can be investigated and their overall impact on resource consumption determined. For ethanol production, the bagasse produced as a by-product of cane milling can be considered as a useful resource and can be exchanged with the power plant so as to produce the steam and electricity required by the ethanol plant.

3.4 Resource accounting at production-consumption level

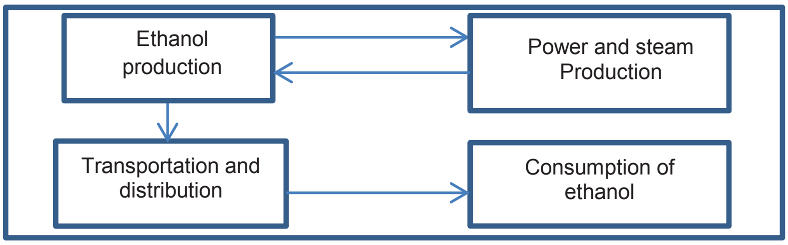


Figure 6: Interaction between production and consumption of ethanol

Figure 6 shows the overall system of production and consumption of ethanol with exchange and recycled flows. In principle, the resource benefit of practices that can potentially promote sustainable consumption such as product recycling and repair after the product has been consumed can be investigated at this level. However, ethanol is an immediate product of consumption; and as such repair or recycling of ethanol is not applicable in this case. The consumption unit for the ethanol case study would include upstream resource flows for ethanol production, resources required for the environmental remediation of harmful emissions released during the transportation of ethanol from the ethanol plant to fuelling stations and from ethanol combustion in vehicles; capital resources for manufacturing the distribution infrastructures; and operating resources such as diesel fuel used for ethanol transportation in tank cars.

4 Conclusions

The aim of this work was to develop a conceptual multi-level framework for resource accounting so as to support the evaluation of different options of human activities in consumption/production, to inform decision making. The novelty of the research lies in a structural and holistic multilevel analysis for both production as well as consumption of a product or service to render an understanding of the different scales/levels namely unit level, process level, inter-process level and production-consumption level at which resource consumption can be quantified. The conceptual framework was outlined and illustrated via a case study on ethanol production. The holistic resource accounting approach for all types of resources including capital resources, environmental remedial resource costs, labour, and renewable and non-renewable inputs was demonstrated. In the ethanol case study, the use of the multi-level framework can demonstrate how the full effects on resource efficiency can be assessed for design decisions at all levels, allowing design options to be explored to find the most efficient option. The developed resource accounting methodology can be further used to guide the design or retrofit of components in a consumption-production system by using resource efficiency/resource consumption as an objective function to be optimised.

5 References

European Commission (EC), (2013) *Online Resource Efficiency Platform (OREP)* [Online], Available from: http://ec.europa.eu/environment/resource_efficiency/ [Accessed 20 November 2013]

Hau, J and Bakshi, B (2004) Expanding Exergy Analysis to Account for Ecosystem Services and Products, *Environ. Sci. Technol*. 2004, 38, 3768-3777

Huijbregts, M.A.J., Hellweg, S., Frischknecht, R., Hendriks, H.W.M., Hungerbuhler, K., Hendriks, A.J, (2010) Cumulative energy demand as predictor for the environmental burden of commodity production. *Environ Sci Technol* 44:2189-2196

Kotas T. (1985) *The exergy method of thermal plant analysis*. London: Butterworths, 1985

Leung Pah Hang, M.Y, Martinez-Hernandez, E., Leach, M., Yang, A. (2014), *Towards a coherent framework for resource accounting*, Technical report, Centre for Environmental Strategy, University of Surrey.

Liao, W, Heijungs, R, Huppes, G (2012) Thermodynamic resource indicators in LCA: a case study on the titania produced in Panzhihua city, southwest China, *Int J Life Cycle Assess* (2012) 17:951–961

Rocco, M.V., Colombo, E. and Sciubba, E. (2013) Advances in exergy analysis: a novel assessment of the Extended Exergy Accounting Method, *Applied Energy* 113 (2014) 1405–1420

Sciubba E. (1995), Modelling the energetic and exergetic self-sustainability of societies with different structures. *J Eng Res Techn 1995*; 117(6):121–30.

United States Census Bureau (USCB) (2013), *U.S and World Population Clock* [Online], Available from: http://www.census.gov/popclock/ [Accessed 10 December 2013]

Wall G. (1999), Conditions and tools in the design of energy conversion and management systems of a sustainable society. *In: Proc ECOS'99, Tokyo. 1999*. p. 1231–8.

Yi, H.S, Lau, J.L, Ukidwe, N, Bakshi, B.R (2004) Hierarchical Thermodynamic Metrics for Evaluating the Environmental Sustainability of Industrial Processes, *Environmental Progress* Vol.23, No.4

Research Project "Simulation Wäschepflege" – Recommendations for Improving Resource Efficiency in the Laundry Washing Process in Households in Germany

K. Ellmer[1,2], M. Fuchs[1], U. Bauer[1], T. Schneider[1], P.-U. Thamsen[2], T. Morgenthal[2,4], J. Villwock[3], A. Hanau[4],

[1]*HTW Berlin, Clothing Technology/Fabric Processing, Germany.*

[2]*Technical University Berlin, Fluid System Dynamics, Germany.*

[3]*Beuth Hochschule für Technik Berlin, Mechanical Engineering, Germany.*

[4]*BSH Bosch und Siemens Hausgeräte GmbH Berlin, Germany.*

Abstract

The resource consumption of energy, water and detergents during the washing process of laundry in private households in Germany is remarkably high, with over 5.5 billion kilowatt hours of electricity (kWh) and 380 million cubic meters of water used every year.

To address this situation researchers from three different universities (Technical University Berlin, HTW Berlin, Beuth Hochschule Berlin) together with their industrial partner (BSH Bosch und Siemens Hausgeräte GmbH) are working in an interdisciplinary team to solve this resource dilemma.

The main objectives of the research program "Simulation Wäschepflege" are to identify ways to:

- Improve the resource efficiency in private washing
- Reduce the water pollution during the washing process, while sustaining high level laundry care at the same time

The work of the research team includes (1) an analysis of basic principles of the mechanical action in washing machines by using Design of Experiments, FEM simulations and physical textile testing of various textiles in the laboratory. In addition (2) a consumer survey has been conducted to gain understanding of the education level of consumers on washing principles.

In this paper the excerpts from the results of the interdisciplinary research program "Simulation Wäschepflege" will be presented together with the survey results, also giving an insight into end-consumer behavior. Furthermore, ideas for the future of washing will be discussed in reference to increased sustainability and resource efficiency of the washing process.

1 Introduction

Washing clothes is a frequent process in each household. In Germany 4 kg laundry per person and week are washed and 20 million tons of laundry are obtained yearly.[1] The resource consumption of energy, water and detergents during the washing process of laundry in private households is remarkably high. In the laundry process in private households in Germany 5.5 billion kilowatt hours of electricity (kWh) and 380 million cubic meters of water as well as 600.000 tons of detergent are used.[2] Not only in Germany but also in most industrialized countries, washing machines and tumble dryers are the two highest energy-using appliances in the average home, after refrigerators.[3] Clothes washing needs 12 % of the total water consumption

---

[1] Vgl. N.N. (2011):*Textilien richtig waschen - Werte erhalten!*; Forum Waschen c/o Industrieverband Köperpflege- und Waschmittel e.V. (Hrsg.), Frankfurt a. M., S. 2.

[2] Vgl. Pakula, C.; Stamminger, R. (2010): *Electricity and water consumption for laundry washing by washing machine worldwide; In: Energy Efficiency,* November 2010, Springer, S. 370.

[3] ACEEE (2011): American Council for an Energy-Efficient Economy, Washington, D.C

http://www.aceee.org/topics/laundry, (Accessed: 09/2014) of drinking water in private households in Germany and is therefore the third biggest item. Dishwashing in comparison requires 6 % of the water consumption.[4]

Due to this data and the high impact laundry has on a sustainable future, research into the washing process, the behavior of the consumer, and their role in the process is needed.

The main influence on resource consumption and on good cleaning performance is described in "Sinner's Circle for Laundry and Cleaning" (Figure 1) and listed below: mechanical action, time, chemistry and temperature. As the circle underlines, the segments can be changed in their size, but by reducing the size of one segment another segment size is consequently increased. For example, if temperature is reduced in order to save energy the amount of time required to complete the washing process will be increased, or more chemistry has to be used.

However, two extremely relevant aspects are missing in this view: Both 1) Textiles and 2) consumer behavior in laundry care. Both have an enormous influence on resource efficiency and on cleaning performance.

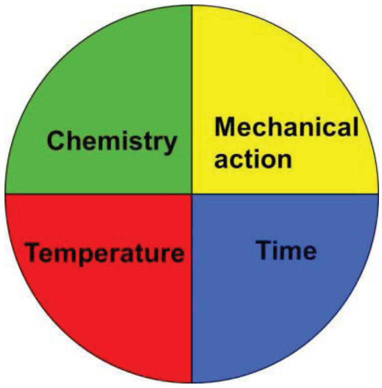


Figure 1: Sinner´s Circle for Laundry and Cleaning

Researchers from three different universities (Technical University Berlin, HTW Berlin, Beuth Hochschule Berlin) and their industrial partner (BSH Bosch und Siemens Hausgeräte GmbH) currently work in an interdisciplinary research program called "Simulation Wäschepflege". The main objective of this program is to improve resource efficiency during the washing process while achieving high-level gentle laundry care.

With the interdisciplinary team the entire washing process with all aspects involved can be researched. Different fields of the washing and drying process that influence the development of more resource and energy efficient washing machines have been identified. The research focuses on the following fields:

- The analysis and the simulation of the washing process
- The behavior of the textiles and garments in the washing process
- The impact of the consumer on the washing process

The focus areas, the current state of the teams research and its results are described in the research steps.

[4] Vgl. Erhebung des Bundesverbandes der Energie- und Wasserwirtschaft zum Thema Verwendung von Trinkwasser in deutschen Haushalten im Jahr 2013 nach Verwendungsart; URL: http://de.statista.com/statistik/daten/studie/12351/umfrage/trinkwasserverwendung-in-deutschen-haushalten/ (Accessed: 09/2014).

2 Research Program

The research program was funded by an interdisciplinary team in 2011. The idea is to work with an interdisciplinary structure to find new answers to the complex process of washing. The research network includes the Technical University Berlin – Department of Fluid System Dynamics (Prof. Dr.-Ing. Paul Uwe Thamsen), the Hochschule für Technik und Wirtschaft (HTW) Berlin – Clothing Technology/Fabric Processing (Prof. Monika Fuchs, Prof. Ulrich Bauer, Prof. Dr.-Ing. Thomas Schneider), the Beuth Hochschule für Technik Berlin – Mechanical Engineering (Prof. Dr.-Ing. Joachim Villwock) and BSH Bosch und Siemens Hausgeräte GmbH Berlin (Dr. Andreas Hanau).

Approved research projects within the program are: „DynTexTro – Ansätze zur Vorhersage der Dynamik der Wäsche in der bewegten Trommel" (time period 04/2011-03/2013), the prediction of the dynamic of laundry in the moved drum and „OptWaTro - Reduktion des Ressourcenverbrauchs durch Optimierung der Waschmechanik in der Trommel" (time period: 10/2013-09/2016). The focus is on the reduction of the resource consumption by optimizing the washing mechanics in the drum.

3 Research Steps

The work of the research program include an analysis of basic principles of the mechanical action in washing machines by using Design of Experiments, FEM simulations and physical textile testing of various textiles in the lab. In addition a consumer survey was conducted. The washing behavior of 840 consumers in Germany was analyzed in 2012. The consumers were asked questions about themselves and their households, washing machines and practices, laundry sorting and ideas for future washing. A detailed description of each research step is listed below.

Analysis of basic principles of the mechanical action in washing machines by using Design of Experiments

An important part of the interdisciplinary research program focuses on the simulation of the entire washing process by computer to enable the development of environmentally friendly washing machines. Those should need less water while reaching the same hygienic washing results with very low temperature.

Figure 2: Transparent washing machine

So far the development of washing machines depends primarily on prior physical testing. The process prediction on the basis of valid results from simulation is a new approach. The mathematical modeling and the simulation of the laundry movement in the rotating drum is a first step in that direction. A transparent washing machine was designed and developed in 2012 for this purpose. Figure 2 shows the transparent washing machine.

The transparent washing machine is used for detecting the three-dimensional movement of the laundry items and the water in the drum as well as for validating the simulation. The movement can be recorded with video cameras and the mode of motion can be evaluated by analyzing the videos. During the proceedings of the project the transparent machine will be developed further and a sensor-based method for tracking the motion of the laundry items will be added and evaluated.

The results show that the rotation of the laundry items is not evenly spread across the drum. The irregular “stops“ of the laundry have an impact on the washing performance. The knowledge of the combination of mechanical washing action and washing performance by statistical methods (Design of Experiments) means that the mathematical model is able to predict the results of the washing process, which is relevant for the development of new washing machines.

Physical textile testing of various textiles in the lab

To develop a mathematical model and a simulation of the laundry movement in the rotating drum the material parameters of the laundry must be clearly described. In a first step it was tested which parameters have an impact on the rheological behavior.

The physical textile testing of various textiles in the lab results in parameters or dimensions of the material, such as the type of fiber, the thread constructions, the construction of the fabrics, the design of the garment or the type of seams.

Referring to DIN EN 60456, woven cotton towels and bed sheets were mainly tested. The tests include e.g. mass, thickness, water absorption capacity and textile friction (Figure 3).

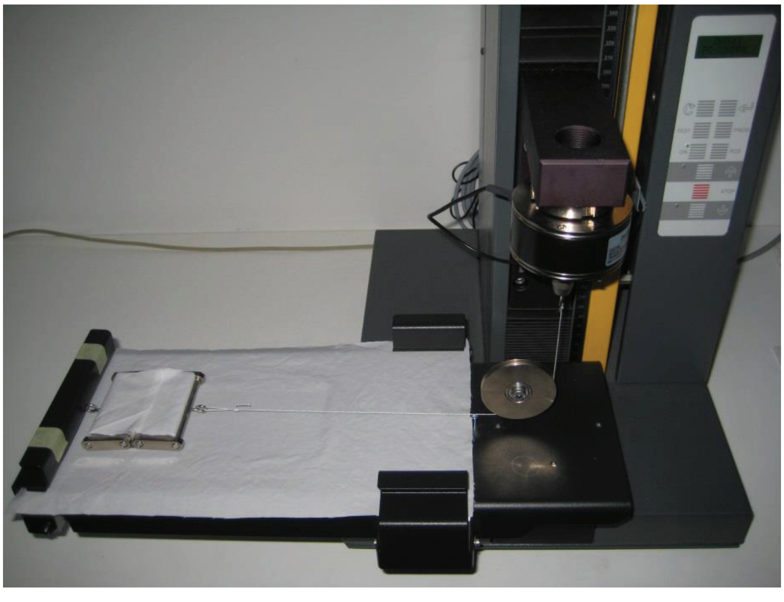


Figure 3: Testing textile friction

Depending on the test equipment and the technical realization the tests were made in three clearly defined textile conditions: dry, damp and wet. Because of adhesive forces that occur while testing damp and wet textiles the tests had to be modified or sometimes even cancelled. All material parameters are collected in a textile database and provided for the use in the simulation models.

Analysis of consumer behavior by an online-survey

As the figure (Figure 4: Consumer activities of Laundry Care) implies, the consumer has a high impact on the whole process of washing. Laundry care is not an automated process in which the washing machine operates independently. The consumer decides based on their personal understanding of cleanliness which garments should be washed in which combination (laundry load). The process of combining garments is of high interest, as laundry load should match with the washing program. After filling the machine the consumer chooses the type and the amount of detergent, the temperature, the program, the water level and the washing time. All decisions can be based on the textile material and the processing of the garment. After the laundry is sorted and put into the washing machine, the type and amount of detergent and the washing program are decided by the user, laundry washing is done automatically by the washing machines, as used in industrialized countries.

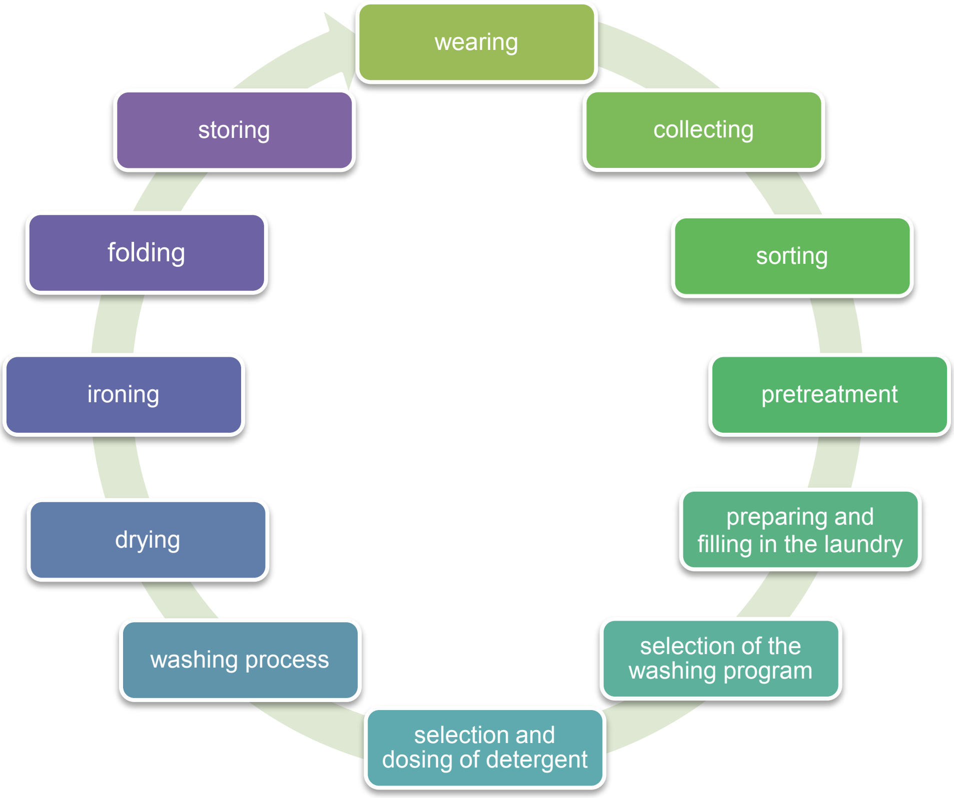


Figure 4: Consumer activities of Laundry Care

The development, implementation and evaluation of the online based consumer survey was carried out in 2012. The survey focused on how the consumer organizes the whole process, comes to decisions and which knowledge is relevant to them. Furthermore, ideas for future washing were collected. It is important to analyze consumer behavior as the improvement of the washing machine and the laundry process is based on the exact knowledge of the usage of the person who is in charge of washing in a household. One aspect of particular importance in this paper is therefore the results of the online-based consumer survey.

Online surveys are advantageous in that they offer cost-efficient and quick access to possible respondents combined with digital collection of data, which has a positive effect for further processing of the data. The main disadvantage of online surveys is that results are restricted in their representation through self-selection of respondents and the missing information on the population of Internet users and washing households in Germany. Although self-selection is considered to be a methodical weakness, it can also have a positive effect on the quality of the answers because the respondents that take part in the survey are highly motivated to answer and take interest in the survey topic.

The development of the survey consisted of the conception of the questions based on the results from secondary research, of the construction of the questionnaire layout in consultation with a marketing expert and of the implementation of the questionnaire with professional software and evaluation with pretests. The link to the survey was mailed to friends, family and colleagues and spread via networks of the cooperation partners. The respondents were also asked to invite more people to the survey. The evaluation of the survey included a check for completeness. Unfinished questionnaires were deleted while missing values were replaced by using multiple imputation techniques.

The survey consisted of 42 questions in total. Both question types (open and closed questions) were used. Closed questions were used as multiple-choice-questions with single or multiple options to answer or as matrix questions. The questions focused on the following fields: person, washing machine, washing programs, laundry and future ideas. Concerning to the given answer the respondents had to answer between 8 and 38 questions. A detailed description of the results is listed below.

In total, 840 people from all over Germany took part in the survey. Only the small number of 8,4 % left the questionnaire unfinished. The reduced sample size relates to 770 respondents. The average age is 31 and three-quarters are female. The household sizes of the respondents, specifically the frequency of single-person-households, two-person-households, three-person-households and more-person-households coincide with data from the Central Statistical Office in Germany. More than the half of the sample are employed, the others are mainly students.

The equipment level with washing machines of the households also coincides with data from the Central Statistical Office in Germany and is around 97 %. The equipment level with dryers is 29 % in the survey sample, which is 12 % lower than the data from the Central Statistical Office in Germany. This might be interpreted by the young average age of the sample. In general the equipment level of washing machines and dryers increases with the household size. The most frequently used washing programs have been “Koch-/Buntwäsche” (Cotton), followed by “Pflegeleicht” (easy care) and “Kurzwäsche” (short program). Special programs are only available for one third and mainly seldom used. The most frequently used washing temperature is 40 degrees Celsius, followed by 60 degrees Celsius and 30 degrees Celsius. Only 10 % wash cold or at 90/95 degrees Celsius.

Based on filter questions, the survey sample can be clustered into different types of persons. One detected type is the person who is not responsible for laundry washing at home. This type mainly consists of men. The other type consists of persons who mainly or sometimes do the laundry. This type is mainly made up of women. This finding clearly shows that women mainly do the laundry in German households.

More types of persons can be clustered as people who sort the laundry before the washing process and people who do not sort the laundry before the washing process. A remarkable 10 % of the survey sample does not sort the laundry at all. Of the 90 % who sort the laundry, two thirds sort by type of the textile, which means that they wash clothes and household items such as towels and bed sheets separately.

The frequency of washing loads in the households depends on the household size, the individual sorting process and the composition of the washing loads. As household size increases, as does the number of washing loads. The more exactly the laundry is sorted the more washing loads are washed per week. More than three-quarters sort by color, half separate clothing from household items, and half use the care symbols in the textile garments, which is remarkably few. Only one quarter of the survey sample pays attention to the material composition of the textile garments, the used fibers or the degree of soiling.

More than two thirds of the respondents in the survey sample wash specific garments inside out. To those garments belong mainly jeans, T-shirts and printed clothing. Zippers are closed before the washing process by half of the respondents and buttons are closed by a quarter. Half of the respondents use laundry nets for special garments like bras, tights and lingerie. More than half wash special garments in separate washing loads. To those garments mainly belong towels and bed linen. On the basis of these results two washing loads for further textile testing in the lab can be identified: One washing load consisting of towels, the other of bed linen.

Low energy and water consumption, energy-saving-washing programs and long durability are very important criteria for the respondents when thinking about buying a new washing machine. 60 % of the survey sample think that in the year 2030 the washing will change and be different from today. The ideas of the consumer vary from sharing the washing machines to digitized and communicating washing machines and laundry items to garments that will not require washing anymore.

4 Results and Discussion

Laundry washing and tasks related to laundry washing such as sorting and drying belong to daily tasks in households in Germany and raise many questions regarding the consumers. The results of the questionnaire clearly indicate that in particular, the sorting process of the laundry and the preparation of the laundry items before the washing process are time consuming and not done optimally concerning energy and water consumption or the gentle care of the garments. Some consumers sort their laundry in a very detailed and exact manner. Because of the detailed sorting, a higher number of washing loads results and therefore a higher number of wash loads per household and week. This is counterproductive concerning a sustainable washing process because energy and water consumption is higher.

The analysis clearly underlines the significance of the consumer and their influence on the process. Research results show that consumers have to undertake several tasks and come to numerous decisions concerning the washing process. Examples of which are: collecting, preparing and sorting the laundry, compose the laundry loads, decide on the type and dosing of washing detergent, temperature and washing program, line or tumble drying, ironing, folding and storing. This leads to the insight that consumers are mainly responsible for resource consumption of energy, water and detergent during the washing process.

A second insight is the finding that consumers are very interested in laundry washing. The self-selection of the survey sample was an advantage concerning the high amount of respondents who were highly motivated and answered the open questions with a lot of detail. The respondents detailed many problems and wishes about laundry washing. Furthermore consumers were asked to imagine living and washing in the year 2030. Collected ideas vary from very sustainable to high-resource demanding visions.

5 Conclusion

Finally two recommendations can be derived from the results when thinking of a sustainable future: 1) The research on consumer behavior in the laundry process needs to be improved to make an effort in influencing consumer behavior towards a sustainable lifestyle. 2) It is important that consumers learn more about textiles and the washing process so that they can act in a more sustainable manner. As an alternative, the responsibility of the consumer towards resource consumption during the washing process could be minimized.

One of the next main tasks for future research for the project team will be to intensify research on consumer behavior. Another result of the work shows the necessity to extend the research on the washing process from analyzing the mechanics and process inside the washing machine itself towards the whole washing process including upstream and downstream process phases. This will be one of the next main tasks for the research program “Simulation Wäschepflege” for its future research.

ECO-INNOVERA Systems Innovation Strategy

the way forward in research for eco-innovation

Michael Ciotkowski[1], Robbert Droop[2] and Evelyn Echeverría[3]

[1]Strategy Task Leader, Technology Strategy Board, Swindon SN2 1JF, United Kingdom

[2]Dissemination Work Package Leader, Ministry of Infrastructure and the Environment, PO Box 20901, 2500 EX The Hague, The Netherlands

[3]Coordinator, Pt-Julich, Zimmerstrasse 26-27, 10969 Berlin, Germany

Keywords: research, systemic eco-innovation, system change

Presenting author: robbert.droop@minienm.nl

1. Abstract

The present paper provides an introduction to the concept of systemic eco-innovation, primarily based on the transition theory, as a basis for developing guidance and suggestions for programming future research at the regional, national and European levels.

ECO-INNOVERA – boosting eco-innovation through cooperation in research - organized two joint calls-for-tender addressing among others paradigm change or systemic eco-innovation, prepared reports on various aspects of eco-innovation, and developed a research and innovation strategy. A number of workshops with experts from within the ECO-INNOVERA network as well as from outside, resulted in preliminary conclusions and recommendations for future research programming. The main conclusion throughout the strategy is that in order to successfully address complex challenges at a systemic level research programming needs to induce multi-phased, multi-stakeholder, cross-sectoral processes generating several competing alternative approaches and solutions in the technological and non-technological areas, which are capable to challenge vested economic processes and interests.

The conclusions and recommendations are preliminary; little practical experiences in programming research for systemic eco-innovation has been obtained so far. ECO-INNOVERA calls for integration of efforts through synchronization and cooperation between regional, national and European policy-makers, researchers and frontrunner economic actors and funders of research for further joint development of concept and implementation of systemic eco-innovation.

2. Introduction

ECO-INNOVERA[1] acts as a Europe-wide advocate for system innovation for sustainability, influencing and leveraging funding from national and EU programmes. It aims to boost eco-innovation through cooperation in research across the EU; promote an EU-wide approach for innovation with significant impact for sustainability; and identify and disseminate information on 'game changer' projects. Over the past years, ECO-INNOVERA promoted the understanding of system eco-innovation through funding projects and the development of a research agenda.

One of its tasks is to develop a Research and Innovation Strategy for ECO-INNOVERA. At this level, the ERA-Net functions as a project, intended to form a solid foundation for the better co-ordination of eco-innovation in Europe. The ambition of the consortium partners, however, goes beyond the project. The partners in ECO-INNOVERA consider that there is a unique opportunity to build a larger programme of activities, based on the intersection of interests of its partners, involving also other eco-innovation networks and platforms. The R&I strategy seeks to identify and prioritise value-adding activities for eco-innovation having faster and more significant impact in society. Moreover, it may be the start of a process by which the ERA-Net moves beyond a project into pro-active network for the European eco-innovation community.

In the framework of developing a strategy, ECO-INNOVERA identified six topics for further development:

1. Developing a common understanding of eco-innovation
2. A better understanding of national/regional programmes, leading to a research landscape for eco-innovation in Europe
3. Ex-ante assessment through common metrics for impacts
4. Value chains and business models
5. Systems thinking applied to different sectors
6. Developing a research agenda on system-innovation for advice to the European Commission

In the present paper we focus on "Systems thinking applied to different sectors". For the other topics, please refer to the website www.eco-innovare.eu.

[1] ECO-INNOVERA – boosting eco-innovation through cooperation in research and development, an ERA-net project funded through the EU 7th Framework Programme. Partners and associated partners are: Kommunalkredit (Austria), IWT and SPW (Belgium), MON (Bulgaria), MST (Denmark), Tekes (Finland), ADEME and ANR (France), Ministry BMBF, Ministry BMU and DLR (Germany), Regione Piemonte and Finpiemonte (Italy), ISERD (Israel), FNR (Luxemburg), Ministry of IenM and RVO (Netherlands), NCBiR (Poland), APA (Portugal), Ministry of Science (Slovenia), Ministry of Science and Ihobe (Spain), FORMAS (Sweden), BAFU (Switzerland), Tubitak (Turkey), and Technology Strategy Board (United-Kingdom).
Coordinator of ECO-INNOVERA is Pt-Julich (Germany). Website: www.eco-innovera.eu

Seeking to move from systems innovation as a high-level academic topic, mostly of interest to scientists for analytical purposes, to developing an understanding of the concept in specific contexts, some workshops provided the basis for conclusions and advise to the public owners of programmes for the future funding of research for eco-innovation. ECO-INNOVERA shares the results from these workshops on the concept and theoretical background of systemic eco-innovation, including a definition, and on how a systemic approach to eco-innovation could influence the expected impacts of research and policy in the complex areas of resource efficiency and the future smart city.

The conclusions and recommendations are a reflection of common insights acquired by the ECO-INNOVERA partner organizations in the course of the project. They are being presented to the benefit of European, national and regional funders of eco-innovation, and as a basis for future ongoing coordination and cooperation for effective programming of eco-innovation with faster and deeper impact in society.

3. The case for systemic eco-innovation

Eco-innovation has been defined in the Eco-Innovation Action Plan (COM(2011)899):

> *Eco-Innovation is any form of innovation resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural* resources.

The Eco-innovation Observatory (EIO) introduced a similar definition (EIO-2010):

> *"Eco-innovation is the introduction of any new or significantly improved product (good or service) process, organizational change or marketing solution that reduces the use of natural resources (including materials, energy , water and land) and decreases the release of harmful resources over the whole life-cycle".*

The definition is broad, and by implication so is the remit of ECO-INNOVERA. The sources of eco-innovation are diverse and may not require the development of new technologies. Eco-innovation can equally be the assembly or integration of a set of existing technologies employed in disparate sectors to meet a defined environmental challenge. For example, the development of carbon capture technologies draws on a set of commercially available technologies from the oil, chemical and power generation industries. (OECD 2011).

The EIO distinguishes between eco-innovation and eco-industries. Eco-industries form sector(s) originating in environmental technologies but also including "green products and technologies" and "green energy", that is serving markets for environmental goods and services. The introduction of environmental technologies is often being driven by environmental regulations. Eco-innovations are considered to be solutions that are novel to both a company and to the market, but may not be driven by an explicit requirement to reduce environmental impact (typically the driver is reducing costs of materials/energy in order to increase competitiveness). (EIO 2010) .

The terms eco-efficiency and eco-effectiveness are also sometimes used. In general terms, eco-efficiency approaches tend to work within the boundaries of an existing industrial system, and can be viewed as "doing more with less". Eco-effectiveness approaches imply change at a system level, and are associated with highly circular industrial systems based on a "waste is food" approach as introduced in the influential publication "Cradle to Cradle", referring to "industrial systems that emulate the healthy abundance of nature".

Literature approaches based on the OECD Oslo Manual definition focus on an analysis of eco-innovation in terms of its targets (the main focus of the eco-innovation), its mechanisms (how change is exerted on those targets) and its impacts (the effects of those changes on environmental conditions).

A useful typology, proposed in OECD (2009) and combining approaches of other authors, provides sub-structure to the targets and mechanisms of eco-innovation, and broadly distinguishes measures as either being primarily technological change or primarily non-technological change.

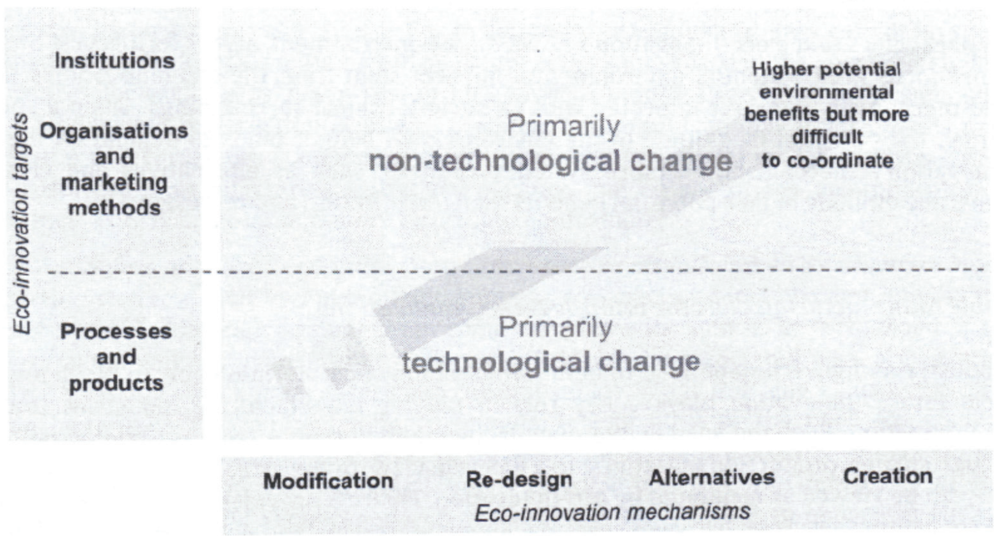


Figure 1: A typology for eco-innovation (OECD 2009)

The direction of EU environmental policy over the last 30 years broadly correlates to the direction of the arrow on this diagram, from measures focused primarily on pollution control/end-of-pipe technologies, through to cleaner manufacturing / full life cycle approaches through to measures intended to change fundamental patterns in consumption and production. Moreover, currently there is increased attention for the importance of innovation in so-called low tech sectors, creative industries, non-technological aspects of innovation and organisational innovation (Coenen & Lopez 2009).

It should be recognized that many European companies are already implementing eco-innovation: the EIO cites a recent report in which 27% of innovating companies in the EU increased their material efficiency as the result of implemented changes (EIO 2011). For the vast majority of companies, the improvements were more modest and incremental. The EIO notes that there is an "eco-innovation gap" in terms of both the scale of eco-innovation activities (there being large differences between countries, sectors and companies) and the scope of eco-innovation changes, with a tendency towards more incremental rather than radical change.

Europe, as an industrialized economy, is an intensive user of resources with consumption averaging around 16 tonnes per year person (Eurostat 2011). While there have been relative improvements in material efficiency - material consumption increased by 7.8% in absolute terms between 2000-2007 at the same time as the economy grew by 35% - as yet the efficiency gains have not been sufficient to bring about a reduction in the overall use of natural resources. European policy – as articulated in the European Commission's Roadmap to a Resource Efficient Europe and the Eco-Innovation Action Plan – requires or implies an absolute decoupling in the use of natural resources. The current trajectory for eco-innovation improvements – even if the small proportion of companies achieving near Factor 2 improvements could be massively expanded – cannot achieve this objective.

The EIO estimates that targets for absolute reduction of material consumption ranging from Factor 2 (i.e. 50%) to Factor 5 (80%) will be necessary by 2050 if absolute decoupling of economic growth from material consumption is to be achieved and European policy objectives are to be met. (EIO 2012).

Examples of global challenges include access to clean water and affordable healthcare, poverty, employment, energy scarcities, and climate change as probably the most challenging of them all. Common to challenges of this magnitude and complexity is that they cannot be addressed by any single company, sector or government but rather required broad-based collaboration and synergistic actions across organizational, sectoral and national boundaries, including private-public partnerships. Global challenges thus call for system change at various levels of the economy and society.

It is widely recognized that technological innovation alone is not sufficient to put the European economy onto a sustainable path; to meet the magnitude of this challenge will require innovations which are more systemic in nature, also involving social changes and measures to gain public acceptance. These more systemic types of eco-innovation will tend a) to be more complex, having several components on the above matrix and b) have significant components above the dotted line demarking primarily technological and non-technological change.

The types of eco-innovation necessary to achieve such a transformation in resource use extend beyond the deployment of technological solutions alone to approaches which are more systemic in nature. Bleischwitz et al (2009) considered system innovation to be one of three distinct categories of eco-innovation. By this analysis, system innovations are concerned with technological systems, disruptive technologies and system changes and associated with approaches such as life-cycle analysis, cradle to cradle, material flow analysis, closed loop, factor 4 or 10 amongst others. This implies rethinking the way the economy caters for the basic needs of society.

System innovations, according to Geels (2011) and others can be seen as "a change from one socio-technical system to another." The needs of a society in this model are met by 'socio-technical systems' – "a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks, and supply networks" providing a basic function. Examples of needs and functions include, e.g.: food and food supply; shelter and construction materials; physical protection and clean cloths; mobility and public transport. Encouraging system innovation can be seen as structuring these transitions - in the image below this is the coalescence of smaller arrows into the larger arrows. The result is that the individual elements become aligned and stabilize into a new design, creating the momentum for a system shift.

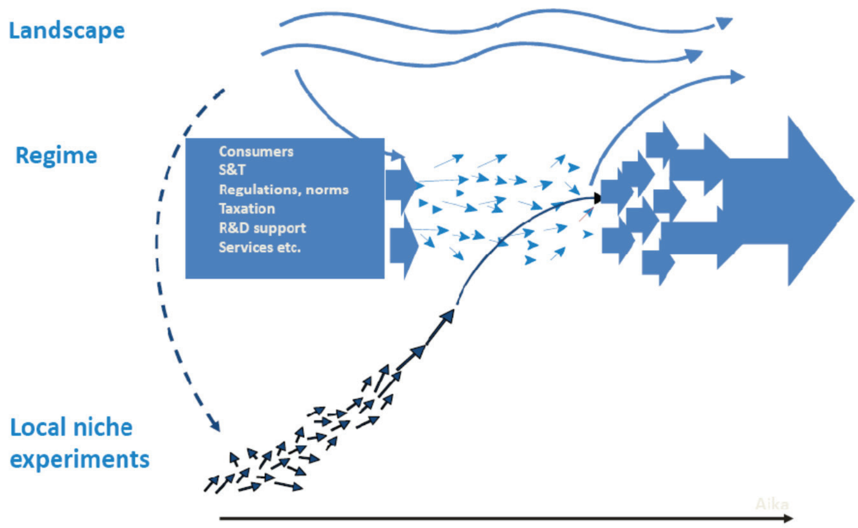


Figure 2: System level changes and innovations. Source: Finnish Tekes, after Geels (2011)

Systems innovation is a set of interventions that leads to a system-wide shift (in a sector, a city, an economy) to a more sustainable or ecologically sound path. The correct mix of policy interventions and research support - tailored to intervene at the tipping points and levers of a given system – has the potential to achieve a ***deeper*** level of innovation, ***faster*** than through a traditional, non-system approach. Furthermore, if the system is correctly defined and its potential interactions with other systems are well understood, the possibility of unintended consequences is reduced.

Process modification, product design, alternative business models and the creation of new procedures and organizational arrangements need to go hand in hand to leverage the economic and environmental benefits of such initiatives. This implies that as sustainable manufacturing initiatives advance, the nature of the eco-innovation process becomes increasingly complex and more difficult to co-ordinate. Although system innovation may have its source in technological advances, technology alone will not make a great difference. It has to be associated with organizational and social structures and with human nature and cultural values. While this may indicate the difficulty of achieving large-scale environmental improvements, it also hints at the need for manufacturing industries to adopt an approach that aims to integrate the various elements of the eco-innovation process so as to leverage the maximum environmental benefits (OECD, 2009).

4. General aspects of systemic eco-innovation

Thinking about systems innovation means embracing and understanding complexity. This means it is difficult, perhaps even counter-productive, to attempt to provide an inflexible or universal definition of system innovation. Instead, ECO-INNOVERA sought to identify some of the characteristics by which system innovation for sustainability can be identified, and which might provide some insight on the levers that can help bring about a system shift.

The key characteristics of systemic (eco)innovation were identified on the basis of a selection of case-studies that were known to ECO-INNOVERA partners (ECO-INNOVERA 2012). This resulted in the following characteristics:

1. Interdisciplinary, multi-faceted - combining behavior, technology, policy and economy;

2. Radical, transformative, providing alternative viewpoints to traditional policy thinking – thus creating significant change, using new approaches and applications

3. Collaborative - cross sector, involving different players, new entrants and new types of partnerships, including public-private partnerships;

4. Addressing whole value chains

5. Designed to work towards a shared eco or sustainability goal on complex challenges that they cannot be addressed by any single company, sector or government but rather require broad-based collaboration and synergistic actions across organizational, sectoral and national boundaries

A systemic eco-innovation also often implies significant adaptations or changes in other products or components. Increasingly complex innovations are often mutually interdependent and also have to be compatible with critical infrastructures, such as the internet or electric grids. Systemic innovations thus require much created coordination during their development, commercialization and appropriation. This coordination also entails extra costs for the innovating company, for example related to development of new competencies, new business models, creation of standards and infrastructures to ensure interoperability and compatibility. Systemic innovations can have a large impact but they are also risky due the reasons mentioned above.

As to the impacts, systemic eco-innovations aim for the best performance on both economic benefits and environmental boundaries and social values, both intrinsic as well extrinsic ("eco-effectiveness").

To achieve actual system change for sustainability, a destabilization process is a crucial step. It follows a process moving from one socio-technological system to another and towards a new stable (and dynamic) equilibrium. In this process, novel supply and novel demand challenge the current dominating supply and demand structures. The transition theory suggests means for management of the destabilization process, the transition arena (Geels 2011).

5. Systemic eco-innovation for resource efficiency

Systems innovation comprises all approaches that aim at addressing all environmental, economic and social aspects of economy in an integral manner. In the first place, that may include the choice of primary and secondary resources, the use of these resources in manufacturing and business, the provision of processes, products and services to customers, the extended ownership and responsibility for products and materials after end-of-life, and the closing of the material chain through high-level re-use and recycling while maintaining the integrity of the material characteristics. The concept requires entrepreneurs to step beyond their usual area of influence by addressing their entire supply lines, their marketing, and their business model, adapting the business strategy and enhancing internal competences to deal with challenges which are strange to entrepreneurship today. The red barrier in Figure 3 depicts the usual area of influence for entrepreneurs. That includes product and process innovation; innovation in marketing; material innovations or introducing new virgin materials; and some organisational innovations. Beyond the red barrier, we rarely find expertise, understanding and capacities among entrepreneurs or otherwise, who can actually deal with innovations that challenge the business model, substitute the use of the raw materials for recyclables or otherwise renewable resources.

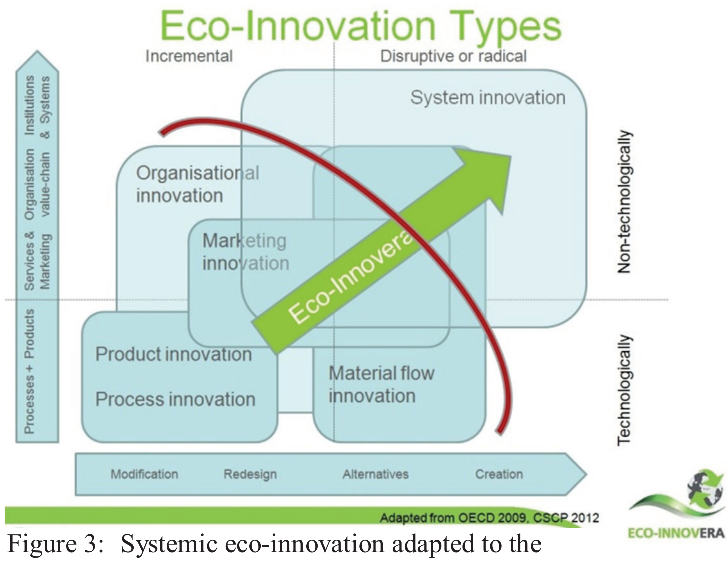


Figure 3: Systemic eco-innovation adapted to the Strategy of ECO-INNOVERA

A limited number of frontrunner entrepreneurs do so to their benefit; they develop industrial symbiosis, find new market niches for new sustainable products, services and processes, with new customers, using new sustainable resources. These frontrunners also meet many barriers of system level character: system related barriers to new approaches are all over the society, including in the education system and the user or consumer market. Experience shows that new technologies are not the main challenge. It is the way in which society values and adapts new approaches and technologies which require a change in behaviour, that poses the main challenge.

6. Systemic Eco-Innovation turned into Research and Policy

For policy-makers and research funders, such as in the ECO-INNOVERA community, Horizon2020 programming, and the EcoAP High-Level Working-Group, the questions is therefore how to identify the policy interventions necessary to connect the research agenda of systemic eco-innovation with ongoing and planned initiatives in the field of a resource efficient economy. In the course of a set of expert-facilitated workshops, ECO-INNOVERA partners identified the most significant barriers and opportunities for systemic eco-innovation (ECO-INNOVERA 2014), which can be aggregated as follows:

- Resource efficiency includes materials, energy, water and the supplying eco-system and -services.
- The EU definition of waste and resource needs streamlining, geared to the principle “there is no waste, only resource”.
- Cross-sectoral approaches and industrial symbiosis involving mutually adapted practices and performances are likely to offer major opportunities for new integrated solutions, often leading to or inducing systemic changes.
- Research is needed to enable business to re-use and recycle without significant loss of productivity, including development of new forms of entrepreneurship and business models which enable to raise funding even in cases where the innovation may lead to temporary disruption of the existing systems. Shift of profits and costs including change of social and cultural values and behaviour are inherent to system changes.
- At the level of entrepreneurship, lack of awareness and training is a barrier to change, the dominant culture within individual companies and sectors as well as entire value-chains hamper significant resource efficiency improvements; even more so in the case of systemic eco-innovation.
- Moreover, social aspects and consumer behaviour are key areas for research, challenging the current system of buy, replace, and buy more. A significant step could be made in the field of eco-design influencing from the start of the value chain having impacts also on consumer behaviour.

Key opportunities have been identified for the gearing R&D to a more radical and systemic eco-innovation and exploitation of results, including:

- Activities to involve stakeholders from different fields, during the entire process of design, innovation and innovation implementation enhance the chances for new approaches and solutions. Engagement of the design community leads to more efficient approaches to product design and use. Living labs are an example. Question remains how to tackle "big" problems with breaking them into silo's of segregate problem solving.
- The development of resource focussed communities needs research and policy-support (e.g. urban-farming, eco-industrial estates) , also building on open dialogues with all stakeholders ("participative" or "open innovation")
- The development of new networks for the exchange of products and materials will help the practical adoption at business level. Innovative marketing approaches foster awareness and motivation for new eco-innovative behaviour, practices and solutions.
- Identification of the pressure points and potential for change, including the key actors for change, and establish the right change arena for brainstorming, rethinking and redesign. Destabilisation of the dominant socio-technological regime offers niche opportunities for alternatives in the various institutional characteristics, including changes in governance, ownership, cultural implication, infrastructure, and supportive legislation.
- Learning from good and bad practices, and therefore creating an experimental space for radical novel approaches. Create case studies of systemic change, with the aim to draw conclusions for their multiple value creation potential. A dedicated experimental space could facilitate the design and development of disruptive approaches and solutions, so as to demonstrate the added societal and functional values in comparison with business-as-usual. Disruption is thus induced and managed by leadership.
- Rephrasing and enriching the currently challenge driven research programming to the effect to include the basic required functions to be delivered to society, avoiding any pre-assumptions with regard to the final form in which this function shall be delivered.
- Integrating ex-ante and ex-post assessment of value-chain impacts on all relevant domains including the social and cultural, within the programming process.
- Adapting the selection criteria for funding of research for eco-innovation in accordance with the above findings and recommendations.
- Enhancing education for future generations to take the lead in transforming current systems.
- Collaborating with eco-innovation partners and the European Commission to find best ways of triggering and supporting systemic eco-innovation, among others through public and private funding of front-runner small and medium enterprises that could induce change with their eco-innovations setting examples.
- Introducing supportive policy-mixes for redistribution of costs and benefits among value-chain actors.

The above recommendations for future research aim to trigger a different type of research, more function-based, while acquiring and exploiting new insights in social values and consumer related patterns. The connecting factor between the current and a possible future socio-technological system is the function being delivered to society, not the product or process.

7. Wrap-up

To achieve the expected impact in society and economy at a depth which is sufficient to enhance resource efficiency to the extent that European society does not overstep its rightful ecological footstep, aspects of society need to be subject of research which clearly goes beyond the realm of an individual entrepreneur, individual policy-maker, or even individual research programme. New understanding of system level barriers, including existing legislation, culture, vested interests, and the potential of new business approaches, new education and competences, and new understanding of consumer behaviour are necessary. Publicly funded research needs new language and formats to address system level barriers and trigger new system-level approaches. It may take as a starting point the economic function to be delivered to society, the system analysis surrounding that function and challenge, describing systemic barriers that tend to limit innovation to business-as-usual, among others vested interests, as well as identify possible creative partners, researchers, and frontrunner entrepreneurs, thereby creating the enabling environment to foster new system-level approaches.

The overall objective of ECO-INNOVERA is to support innovation to reduce environmental impacts/resource use at a European level. Systems innovation is in the early stages of development outside of specialised academic circles; the thinking trickles down to practitioners slowly and difficult. ECO-INNOVERA aims to share understanding, connect active practitioners, and build and sustain the community for systemic eco-innovation for high-impact change to full decoupling. As a cross-cutting network with a remit to support eco-innovation, it can reasonably expect to have influence in shaping EU-wide policy and has the opportunity to occupy a distinctive space of high policy significance. At a national/regional level, network members provide links to national funding opportunities which can translate into practice.

ECO-INNOVERA expects a great potential for growth and employment within a circular economy for which systemic eco-innovation among others will open up new business opportunities for growth in services, remanufacturing and re-use.

8. References

European Commission (2011) *Innovation for a sustainable Future – The Eco-innovation Action Plan (Eco-AP)*

EIO (2010) *Methodological Report*. Eco-innovation Observatory. www.eco-innovation.eu

OECD (2011) *Better Policies to Support Eco-innovation*. OECD studies on Environmental Innovation. OECD Paris

OECD (2009): *Sustainable Manufacturing and Eco-innovation: Framework, practices and measurement*. Synthesis report. OECD Paris.

Coenen, L. and Diaz, L. F. (2009) *Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities*. Lund University, Paper no. 2009/12, Sweden.

EIO (2011) *The Eco-Innovation Challenge: Pathways to a resource efficient Europe*, Annual Report 2010 (published May 2011)

Eurostat (2011) *Domestic material consumption per capita* http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=t2020_rl110&plugin=0

Bleischwitz R, S Giljum, M Kuhndt, FSchmidt-Bleek (2009): *Eco-Innovation: Putting the EU on the Path to a Resource and Energy Efficient Economy*, Wuppertal Insitutue for Climate Environment and Energy. Available at http://wupperinst.org/uploads/tx_wupperinst/ws38.pdf

EIO (2012). *Closing the Eco-Innovation Gap: An economic opportunity for Business*. Annual Report 2011 (published February 2012)

Geels, F. W. (2011) *The multi-level perspective on sustainability transitions: Responses to seven criticisms.* Environmental Innovation and Societal Transitions, 1**,** 24-40.

ECO-INNOVERA (2012) *Task D1.2 Research and Innovation Strategy – Interim Strategy,* Deliverable Report grant agreement number: 266538 https://www.eco-innovera.eu/lw_resource/datapool/_items/item_353/eco-innoverastrategy_and_network_development_for_sb.pdf

ECO-INNOVERA (2014) *Systemic Innovation for Resource Efficiency* https://www.eco-innovera.eu/publications?lwlt_338cmd=download&lwlt_338id=302 and *Systemic Innovation for Sustainable Cities* https://www.eco-innovera.eu/publications?lwlt_338cmd=download&lwlt_338id=293

Sustainable cities with solar energy? An automated registration of the roofs as potential space for solar energy production

Szilárd SZABÓ[1], Péter ENYEDI[2], Péter BURAI[2], György SZABÓ[3], István FAZEKAS[3], Tamás BUDAY[4], Attila KERÉNYI[3], Mónika PALÁDI[3], Gergely SZABÓ[1]

[1]Department of Physical Geography and Geoinformatics, University of Debrecen, Egyetem tér 1. 4032, Debrecen, Hungary
[2]Research Institute of Remote Sensing and Rural Development, [3]University of Debrecen, Károly Róbert College, Mátrai út 36. 3200, Gyöngyös, Hungary
[3]Department of Landscape Protection and Environmental Geography, University of Debrecen, Egyetem tér 1. 4032, Debrecen, Hungary
[4]Department of Mineralogy and Geology, University of Debrecen, Egyetem tér 1. 4032, Debrecen, Hungary

Address for correspondence:
Szilárd Szabó
Department of Physical Geography and Geoinformation Systems, University of Debrecen, Egyetem tér. 1. 4032, Debrecen, Hungary, tel.:+36 52 512900/22326 (switchboard), fax:+36 52 512945, e-mail: szabo.szilard@science.unideb.hu

Abstract

Energy production and consumption is a key element of future development that is influenced by the technical possibilities and the decision makers. Sustainability issues are in high accordance with energy policy: the increase of the proportion of renewable energy is desired. According to the Horizon 2020 climate and energy package EU member countries have to reduce the amount of greenhouse gases by 20%, to increase the proportion of renewable energy to 20% and to improve the energy efficiency by 20% until 2020. In this study we aimed to assess the possibilities of the exploitation of solar radiation on roofs. The surveyed area was in Debrecen, the second largest city in Hungary. An aerial LIDAR survey was conducted with the density of 12 points/m^2, in a 7×1.8 km wide band. We extracted the models of the buildings from the point cloud using TerraScan. Furthermore, we applied a low-cost drone (DJI Phantom with a GoPro camera) inside a smaller part of the LIDAR survey and created a 3D model, too. Buildings were identified with segmentation from the DSM and orthophoto coverages. Primarily, we focused on the roofs as these surfaces are the possible space for thermal and photovoltaic equipment. We determined the slope and aspect for roof elements, too. Building heights and building geometry was also extracted and validated field surveys. 50 buildings were chosen for geodetic survey and the results of accuracy assessment were extrapolated to other buildings; besides, 100 building heights were measured. Afterwards, models derived from aerial LiDAR and the drone surveys were compared in GIS environment (ArcGIS 10). Extracted roof geometries had varying accuracies: the research showed that LiDAR-based roof-modelling is a good possibility in residential areas, but results of the drone survey were promising, too. Generally, both approach can be applied, the calculated solar radiation values were similar. These calculations can provide valuable tool to estimate the potential solar energy production, including self-sufficient households and those ones which feeds surplus energy into the electric network.

Introduction

Renewable energy resources get more and more importance in the structure of energy production. As non-renewable sources are often considered as environment polluters (such petroleum or coal), greenhouse gas producers or those that pose high risk (nuclear energy), it is crucial to find solution to replace them with environment-friendly alternatives. Parallel, the EU introduced the Horizon 2020 Framework Program for Research and Innovation: efficiency of energy should be increased by 20%, proportion of renewable energy should be increased by 20%, and greenhouse gas emission should be reduced by 20% (European Commission, 2014). Considering the private contribution of the residents, larger spread of passive houses can mean a relevant milestone in the efficiency (Kozma et al. 2013), while local energy production can decrease the GHGs and improve the proportion of renewable energy sources (Farkas, 2010; Lázár, 2011).

In this study, we focused on solar energy, as a possible solution for private energy production. It has both advantages and disadvantages. In the current economic environment (September 2014) private properties are not supported to install photovoltaic (PV) solar systems in Hungary, but something had started, first tenders were open in this summer for local governments. Thus, high cost of the installation is a big disadvantage, but it can mean, completely or partially, continuous energy for institutions and households. Besides, there is no loss on the transportation of the energy. A limiting factor is that not all roofs can be appropriate for installing solar panels. It depends on the aspect and slope of the roof planes. Shadows generated by the roof elements, chimneys, antennas, or by the trees and pylons of the street can deteriorate the efficiency seriously.

Roofs can be detected with remote sensing techniques (e.g. Nagyváradi et al. 2013); however, the simple identification is not enough to assess the possible roofs for the installation of PV panels, those methods are appropriate that can reveal the roofs' geometry. Photogrammetry and Light Detection And Ranging (LiDAR) are the two possible methods for this purpose. While photogrammetry requires aerial photographs, and the outcome depends on the geometrical resolution of the images, LiDAR works with laser beams and the reflecting signs are recorded. Photogrammetry yields a digital surface model (DSM), while LiDAR, based on the emitted and backscattered signs with different returning time, provides a model both for the ground (digital terrain model, DTM) and the surface (digital surface, DSM). From the aspect of roof detection both techniques are suitable; we need only the surface of the objects.

LiDAR was developed in the 1960s, but became popular only in the first decade of 2000s. Nowadays, several studies deal with terrain and surface models derived from LiDAR point clouds. Highly detailed digital elevation models are the most popular application fields (e.g. Király, 2004; Liu, 2008), in natural or urban environment (Ghuffar et al. 2013; Zlinszky et al.

2014) or to extract different parts of the surface, such as geomorphic forms (Dorninger et al. 2011), trees (Király et al. 2012; Mücke et al. 2013), city buildings, or street furniture (Priestnall et al. 2000).

Numerous publications consider the detection of buildings based on LiDAR. In the research of Yu et al. (2010) the accurate detection of city buildings was the aim just like in the case of Zhou and Neumann (2013). Filtering buildings was also the goal in the works of Mongus et al (2014) and Li et al. (2013). While Alexander et al. (2009) dealt with roof structure, Lukac et al. (2014) focused especially on the potential solar radiation of built-up areas with LiDAR data. There are several researches with photogrammetric approach, too, from the digital representation of the solar panels (Shortis et al. 2008) through solar potential estimation in city-scale (Nex et al.2013) to complete survey of roof geometry (Protic et al. 2012).

Incoming solar radiation can be computed with the involvement of slope, aspect, and shadows casted by topographic features (e.g. mounts) or other surface objects (e.g. buildings, trees, chimneys, pylons etc., Boehner and Antonic, 2009). If all of these parameters are involved in a model, results can be regarded reliable. For example, ArcGIS, SAGA GIS and GRASS GIS provide solar radiation models. GRASS provides both solar irradiance ($W{\cdot}m^{-2}$) and daily sum of solar irradiation ($Wh{\cdot}m^{-2}{\cdot}day^{-1}$, Hofierka and Šuri, 2002). SAGA does not consider the shadowing effect but the computation is 2-4 time faster than GRASS (Hengl et al. 2009). ArcGIS counts with all the mentioned parameters and provides daily sum of solar irradiation ($Wh{\cdot}m^{-2}{\cdot}day^{-1}$). ArcGIS and GRASS GIS both consider the direct and diffuse solar radiation (Hofierka and Kañuk, 2009). All models have errors due to the underlying concept or lack of appropriate data, but in most cases, we do not require exact values, a good approximation of the possible maximum summed by a given time interval is sufficient.

Our aim was to investigate and compare the surface models of a LiDAR survey and an aerial imaging carried out with a drone from the aspect of roof detection. LiDAR point cloud and a photogrammetrically produced point cloud was the original data. Most of the studies deal with LiDAR point clouds, but our main goal was to introduce a low cost solution with a drone and a cheap camera. We compared the resulting roof shapes and evaluated their suitability for solar panel installation for both models.

Materials and methods

Data collection

A combined LiDAR and large resolution aerial imaging was carried out in a 7 km^2 area, in Debrecen (Eastern-Hungary). Specific details of the survey are summarized in Table 1. Accuracy assessment was carried out on the whole study area; however, we used only a smaller part in the analysis for the analysis of solar radiation, where the drone survey was possible (Fig. 1).

Table 1 approximately here

Fig. 1. approximately here

The drone survey was conducted with a DJI Phantom and a GoPro Hero III camera combined with an NDVI stress camera (XNiteCanonELPH110NDVI, LDP LLC Ltd.). The pilot area was inside the LiDAR survey, in the campus of the university (University of Debrecen).

Point cloud processing

LiDAR point cloud was classified in MicroStation's TerraScan module (Terrasolid Ltd, Helsinki) in the whole area. TIN interpolation with natural densification was carried out for the separation of ground points, then vertical outlying points were removed using filters. Next step we filtered out the buildings parameterized algorithms with TerraScan. Afterwards, we extracted the vector features of the buildings as a part of semi-automated roof identification. We aimed to find the optimal parameters to extract the minimal roof-part size to reach the most accurate and detailed building models. Cell size of the surface model was 20 cm, because it was the best resolution can be obtained from the 12 points/m^2 point cloud.

Photogrammetric analysis

We used Agisoft Photoscan demo version during the photogrammetric evaluation, its model provided a classic DSM, and also an orthophotograph was compiled from the aerial photos. The procedure yielded true orthophoto (proposed by Amhar et al. 1998); accordingly, both coverages were used in the analysis.

Image segmentation was carried out on the DSMs (LiDAR and photogrammetric) using eCognition Developer. The aim was to separate the input raster coverages into homogenous segments. We applied a roof-mask compiled from NDVI values and building heights. Procedure was repeated with the involvement of the orthophoto.

Validation

We obtained field measurements with Stonex S9 RTK GPS pair in case of 50 buildings to check the contours of the buildings. Besides, 100 measurements were carried out for 100 building with a Leica Disto D5 to control the building heights.

Solar radiation

We filtered out those segments of roof planes that suited to following conditions: slope: 20-60°; aspect: 90-270°; area: >2 m^2; compactness: >0.3. Maximum solar radiation was calculated using the Spatial Analyst module of ArcGIS9 with the Solar Radiation toolset. We calculated the potential maximum of the annual radiation considering both the direct and diffuse radiation. ArcGIS uses the algorithm developed by Fu and Rich (2002).

Statistical analysis

Solar radiation data was evaluated with statistical methods. We applied non-parametric tests due to the non-normal data distribution. Our null hypothesis (H0) was that solar radiation derived from the two surface models had the same mean rank, and the alternative hypothesis (H1) was that the mean ranks of the radiation values were different at the $p<0.05$ level. Accordingly, Wilcoxon paired test was applied in the hypothesis testing. Also, for comparison of suitable surfaces for PV panels, we applied Mann-Whitney test combined with Bonferroni correction.

In the validation process, we calculated Cohen's Kappa (Kappa Index of Agreement, KIA) to quantify the similarity of the 2 database of the contour lines. Heights were compared with Wilcoxon paired test and RMSE values were calculated. We evaluated statistical tests with p values ($p<0.05$), also with effect size as a standardized measure of the difference between groups.

Preliminary results and discussion

Roof extraction from DSMs

There were four variations of the extracted roofs and more or less, all of them showed similar picture. Roof planes derived from the LiDAR point cloud in Terrascan showed the most realistic picture compared to the orthophoto. But, accordingly to the aims, it was an important question whether the segmentation of LiDAR DSM can be an alternative in the analysis. If the answer is yes, then it worth to deal with the photogrammetric approach. Result from DSM was not as impressive as the outcome of the processing in CAD environment (with Terrascan). However, as it was not so "nice" visually, but we supposed that segmented roof planes can carry enough information to calculate solar radiation data.

Fig. 2. approximately here

Validation process justified that the automatic detection of roof planes was successful, KIA was 0.94. Considering that field surveys provided data about the contours of the buildings

and not the ground projection of the roofs, a smaller part of the errors can be attributed to eaves (i.e. the difference between the outer walls and the roofs).
Difference between LiDAR data and the measured values of heights was 0.17 m on average (including the measuring uncertainty of 6 cm of the Leica Disto device), and were controlled by roof types (Table 2). Although, Wilcoxon-test showed significant difference ($p<0.05$), effect size was very weak ($r=0.04$), showing the slight difference in data ranges.

Table 2. approximately here

Differences were acceptable, because the DSM's resolution and the interpolation itself can alter the "raw" data of the point cloud (as the largest error was experienced in case of complex shaped roofs). However, this vertical error does not bias solar date as much as horizontal inaccuracies.

We detected different number of roof planes to be considered as suitable for installing solar panels (Table 3). Differences came from the fact that various techniques detected different number of surfaces as roofs; furthermore, due to the varying characteristics (aspect and slope) of the identified roof planes, suitable items had altering extent (Table 3). Some roofs were not detected when we applied DSMs. Although, building edges were not straight, it was the consequence of the segmentation. Considering the heterogeneity of DSMs and the orthophotos, the result was good and showed the needed surfaces – with a controllable amount of errors.

Table 3 approximately here

Concerning that generally not every objects had a pair in the various solutions, we chose a building that had (at least) five roof planes being suitable for solar panels and all parts had the corresponding part in each coverage (hostel building, Fig. 3). Coefficient of variation showed that the coefficient of variation was about 10%, except in case of roof plane #31 (Table 4).

Fig. 3. approximately here
Table 4. approximately here

Solar radiation
Solar radiation for the pilot area (university campus), regarding the suitable roof planes, was between 4507 and 5614 MWh/year according to the calculations. These values was only the

sum of the values calculated for the roof planes. Next step we analyzed the differences with Mann-Whitney test and found that all solutions had similar global solar radiation compared to the classic LiDAR point cloud processing (Table 5). The only exception was the one segmented from DSM and orthophoto.

Table 5. approximately here

Frank and Mucsi (2014) applied large format aerial photographs for a similar survey and found that it can be a cost effective approach. Drones can survey only smaller parts and can raise problems according to property rights, but the results can be compared to the results of large format cameras. Barizzetti et al. (2014) also found that drone surveys with the large numbers of taken photos, we can obtain true orthophotos, without perspective distortion. Consequently, both orthophotos and DSMs carry the same spatial information, thus, both productions can be involved in the analysis.

Conclusion

LiDAR is a new and popular technology of data collection. It provides the most accurate representation of the surface, due to its high sampling density. However, the technology is expensive and needs expensive infrastructure and expertise to evaluate the raw data. Drones are getting widespread in all parts of life. Combining aerial imaging conducted with drones, we can produce ortophotos and digital surface models. In this study, we compared a LiDAR and a drone survey from the aspect of roof detection.

Result reflected that LiDAR is the best solution for extracting buildings or roofs, but processing DSMs combined with segmentation technique can be an effective tool, too. Our results showed that in smaller areas, with the right resolution, we can obtain DSMs being suitable for the analysis. Obviously, its data quality and reliability lags behind LiDAR; however, cost-benefit ratio is relevantly better.

Acknowledgement

The work is supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0041 project.
The project is co-financed by the European Union and the European Social Fund.

References

Amhar, F., Jansa, J., Ries, C. 1998. The generation of the true orthophotos using a 3D building model in conjunction with a conventional DTM. ISPRS Archives 32, 16-22.

Barrizzetti, L., Brumana, R., Oreni, D., Previtali, M., Roncoroni, F. 2014. True-orthophoto generation from UAV images: implementation of a combined photogrammetric and computer vision approach. ISPRS Archives, ISPRS Technical Commission V Symposium, Riva del Garda, Italy, II-5, 57-63.

Boehner, J., Antonic, O. 2009. Land Surface Parameters Specific to Topo-Climatology. in Hengl, T. & Reuter, H.I. : Geomorphometry - Concepts, Software, Applications

Dorninger, P., Székely, B., Zámolyi, A., Roncat, A. 2014. Automated Detection and Interpretation of Geomorphic Features in LiDAR Point Clouds. Österreichische Zeitschift Für Vermessung Und Geoinformation 99, 60-69.

European Commission 2014. Horizon 2020 in brief, The EU Framework Programme for Research and Innovation, European Union, Publications Office, 35 p.

Farkas, I. 2010. Domestic possibilities of solar energy use (in Hungarian). Magyar Tudomány 171, 937-946.

Frank, M., Mucsi, L. 2014. Automated Creation of a 3D Surface Model and Calculation of the Solar Energy Income for a Test Site Situated in City of Szeged (in Hungarian). Geodézia és Kartográfia 66, 16-22.

Fu, P., Rich, P.M. 2002. A Geometric Solar Radiation Model with Applications in Agriculture and Forestry. Comput. Electron. Agr. 37, 25–35.

Ghuffar, S., Székely, B., Roncat, A., Pfeifer, N. 2013. Landslide displacement monitoring using 3D Range Flow on airborne and terrestrial LiDAR data. Remote Sens. 5, 2720-2745.

Hengl, T., Grohmann, C.H., Bivand, R.S., Conrad, O., Lobo, A. 2009. SAGA vs GRASS: A Comparative Analysis of the Two Open Source Desktop GIS for the Automated Analysis of Elevation Data. Proc. Geomorhometry 2009, Zurich, Switzerland, 22-27.

Hofierka, J., Kaňuk, J. 2009. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. Renew. Energ. 34, 2206-2214.

Hofierka, J., Šuri, M. 2002. The solar radiation model for open source GIS: implementation and application. Proc. Open-source GIS-GRASS users conference, Trento, Italy, 19 p.

Izquierdo, S., Rodrgues, M., Fueyo, N. 2008. A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. Sol. Energ. 82, 929-939.

Jochem, A., Höfle, B., Rutzinger, M., Pfefier, N. 2009. Automatic Roof Plane Detection and Analysis in Airborne LiDAR Point Clouds for Solar Potential Assessment. Sensors 9, 5241-5262.

Kassner, R., Koppe, W., Schüttenberg, T., Bareth, G. 2008. Analysis of the solar potential of roofs by using official LiDAR data. ISPRS Archives 37 Part B4, 399-404.

Király, G. 2004. Domborzatmodellek előállításához felhasználható forrásadatok összehasonlító vizsgálata (Comparing Source Databases Generating Digital Elevation Models), HUNDEM Conference 2004, Miskolc-Hungary

Király, G., Brolly, G., Burai, P. 2012. Tree Height and Species Estimation Methods for Airborne Laser Scanning in a Forest Reserve. In: Nicholas Coops, Mike Wulder (ed.): Full Proceedings of SilviLaser 2012: 12th International Conference on LiDAR Applications for Assessing Forest Ecosystems, Vancouver, Canada, Vancouver, 260-270.

Kozma, G., Molnár, E., Czimre, K., Pénzes, J. 2013. Geographical aspect diffusion of passive houses. Int. Rev.Appl. Sci.Eng. 4, 151-156.

Lázár, I. Effects of climate change on renewable energy sources (in Hungarian), In Szabó V, Fazekas I. eds., Környezettudatos energiatermelés- és felhasználás, MTA DAB Megújuló Energetikai Munkabizottság, Debrecen, 2011, pp. 92-98.

LDP LLC Ltd. www.maxmax.com

Liu, X. 2008. Airborne LiDAR for DEM generation: some critical issues. Prog. Phys. Geog. 32, 31-49.

Lukac, N., Seme, S., Zlaus, D., Stumberger, G., Zalik, B. 2014. Buildings roofs photovoltaic potential assessment based on LiDAR (Light Detection And Ranging) data, Energy 66 (2014) 598-609.

Mongus, D., Lukac, N.,Zalik, B. 2014. Ground and building extraction from LiDAR data based on differential morphological profiles and locally fitted surfaces, ISPRS J.Photogramm. Remote Sens. 93, 145-156.

Mücke, W., Deák, B., Schroiff, A., Hollaus, M., Pfeifer, N. 2013. Detection of fallen trees in forested areas using small footprint airborne laser scanning data. Can. J. Remote Sens. 39, Paper 10.5589/m13-013.

Nagyváradi, L., Gyenizse, P., Szebényi, A. 2011. Monitoring the changes of a suburban settlement by remote sensing. Acta Geographica Debrecina Landscape Env. 5, 76-83.

Nex, F., Remondino, F., Agugiaro, G., de Filippi, R., Poletti, M., Furlanello, C., Menegon, S., Dallago, G., Fontanari, S. 2013. 3D solarweb: A solar cadaster in the Italian alpine landscape. ISPRS Archives XL-7/W2, 173-178.

Nguyen, H.T., Pearce, J.M. 2010. Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System. Sol. Energ. 84, 831-843.

Priestnall, G., Jaafar, J., Duncan, A. 2000. Extracting urban features from LiDAR digital surface models. Comput. Env.Urban Syst. 24, 31, 65–78.

Protic, D., Kilibarda, M., Vucetic, I., Nestorov, I. 2002. 3D roof modelling for accurate assessment of solar potential. Proc. EuroSun 2002 Int. Conference, Bologna, Italy, 5 p.

Shortis, M.R., Johnston, G.H.G., Pottler, K., Lüpfert, E. 2008. Photogrammetric analysis of solar collectors. ISPRS Archives 37 Part B5, 81-88.

Stevanovic, S. 2013. Optimization of passive solar design strategies: A review. Renew. Sust. Energ. Rev. 25, 177-196.

Terrasolid, Ltd., Terra Scan User's Guide, https://www.terrasolid.com/download/tscan.pdf

Yu, B., Liu, H., Wu, J., Hu, Y., Zhang, L. 2010. Automated derivation of urban building density information using airborne LIDAR data and object-based method, Landscape Urban Plan. 98, 210-219.

Zhou, Q., Neumann, U. 2013. Complete residential urban area reconstruction from dense aerial LiDAR point clouds. Graph. Models 75, 118-125.

Zlinszky, A., Schroiff, A., Kania, A., Deák, B., Mücke, W., Vári, Á., Székely, B., Pfeifer, N. 2014. Categorizing Grassland Vegetation with Full-Waveform Airborne Laser Scanning: A Feasibility Study for Detecting Natura 2000 Habitat Types. Remote Sens. 6, 8056-8087.

Table 1. The main specifications of the applied LiDAR system

LIDAR system specifications	**Leica ALS70-HP**
Flight height	1000 m
Swath	780 m
Flight speed	185 km/h
FOV	43°
Pulse rate	490 kHz
Dense of points	12 point/ m^2
Overlap	20%
Scan pattern	Sinusoid
Imaging system specifications	**RCD 30 RGBN 60 MP**
Ortho GSD	10 cm
Number of bands	4 (RGBN)

Table 2. RMSE values of the validation measurements

Roof type	RMSE (cm)
Flat	0.301
Shed	0.313
Gable	0.347
Combination	0.430

Table 3. Number and area of roof planes

Method	Number of detected planes	Sum of the area (m^2)
LiDAR point cloud processing	68	5432
DSM from LiDAR + segmentation	79	4893
DSM from aerial photographs + segmentation	78	5197
DSM from aerial photographs combined with orthophoto + segmentation	52	5239

Table 4. Statistical characteristics of roof planes of the hostel building considering the four calculation methods (N=4; unit: m^2)

	Roof plane IDs				
	16	20	23	24	31
Min	150.76	78.17	244.30	76.44	30.60
Max	182.54	100.47	284.89	96.97	70.32
Mean	160.19	90.53	257.15	88.12	52.08
Std. error	7.49	5.35	9.45	5.21	9.48
Std. dev	14.97	10.70	18.90	10.43	18.97
Median	153.72	91.74	249.69	89.53	53.70
25 percntil	151.45	79.90	244.75	77.88	33.42
75 percntil	175.39	99.95	277.00	96.94	69.13
Coeff. var	9.35	11.82	7.35	11.83	36.42

Table 5. Result of Mann-Whitney test of global solar radiation summed by roof planes (*: Bonferroni corrected significance; l: LiDAR point cloud processing; ldsm: DSM from LiDAR + segmentation; k: DSM from aerial photographs + segmentation; kso: DSM from aerial photographs combined with orthophoto + segmentation)

	l	ldsm	k	kso
l				
ldsm	0.3417			
k	0.4536	0.2285		
kso	0.21	0.00026*	0.01116	

Figure captions

Fig. 1. Location of the LiDAR and the drone survey in Debrecen

Fig. 2. Different solutions of the roof detection approaches (a: LiDAR point cloud processing; b: DSM from LiDAR + segmentation; c: DSM from aerial photographs + segmentation; d: DSM from aerial photographs combined with orthophoto + segmentation)

Fig. 3. Results of different roof detections in case of the hostel building (a: LiDAR point cloud processing; b: DSM from LiDAR + segmentation; c: DSM from aerial photographs + segmentation; d: DSM from aerial photographs combined with orthophoto + segmentation)

Fig. 1.

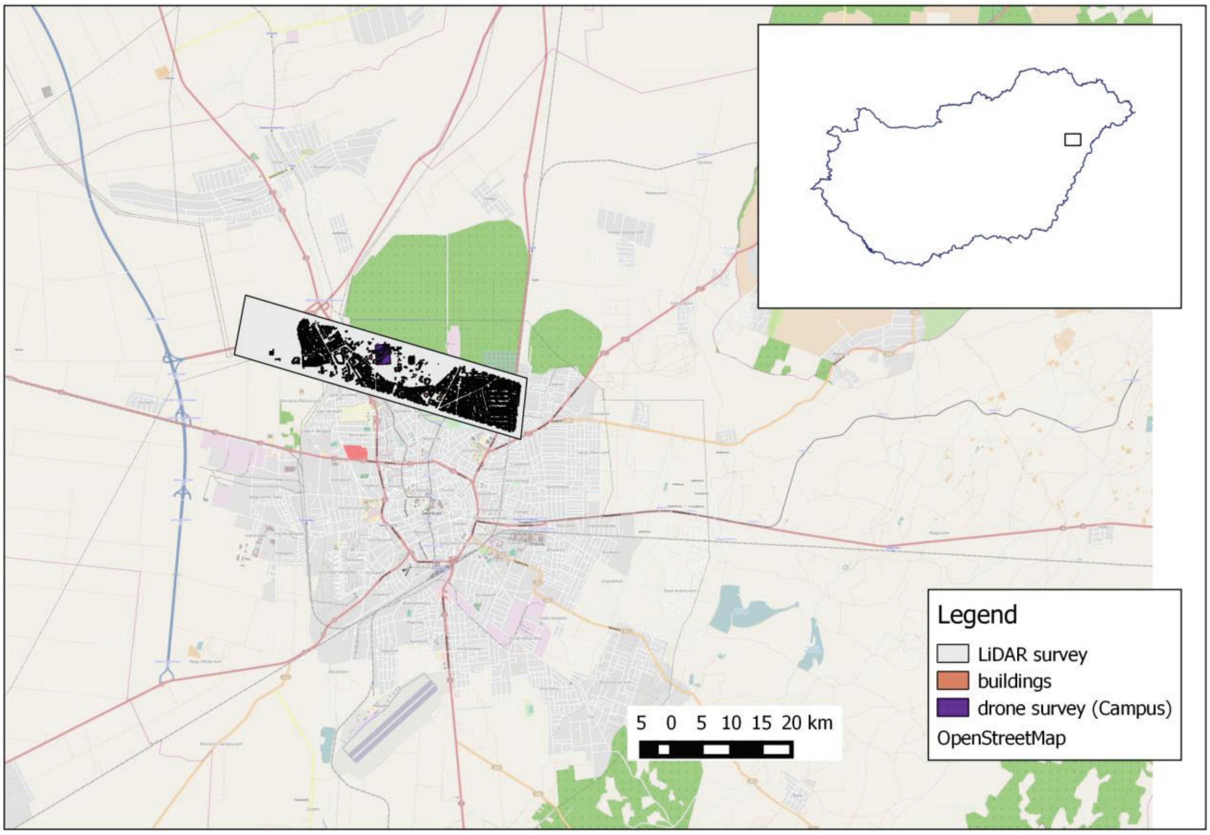


Fig. 2.

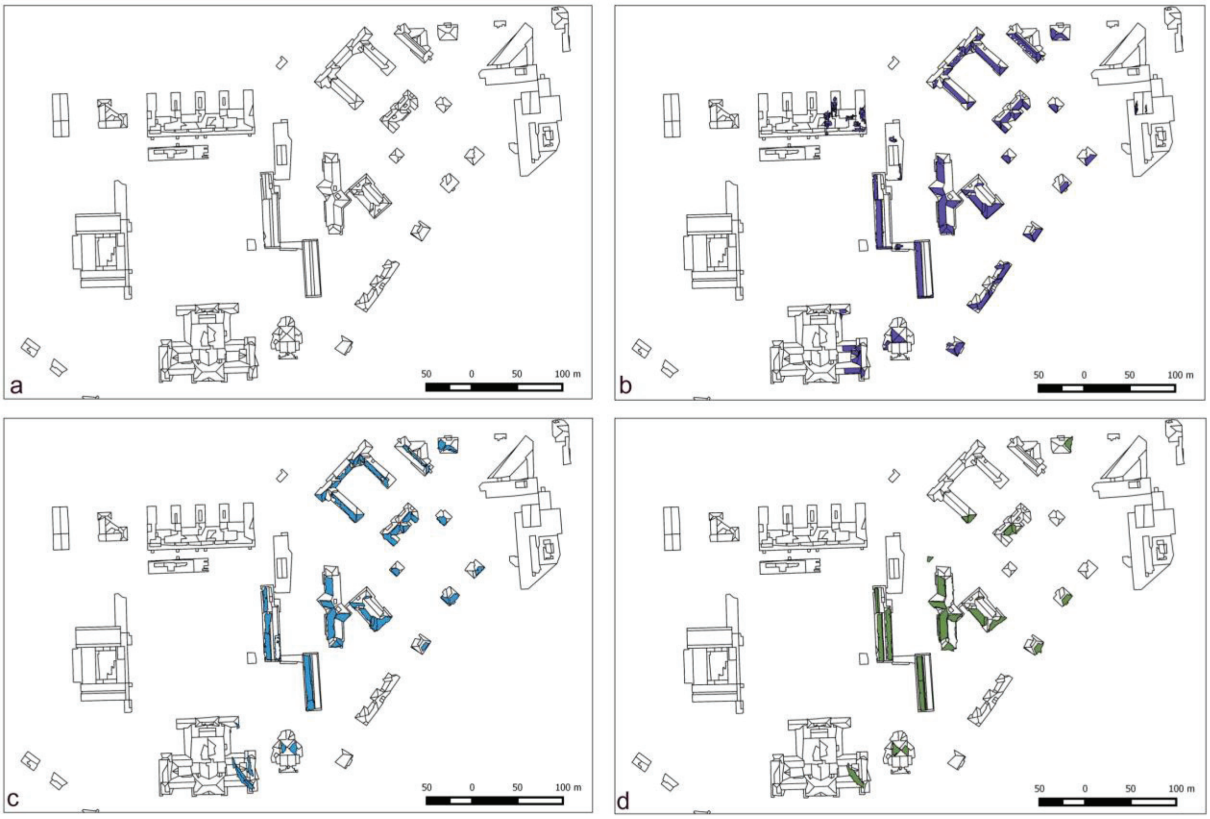
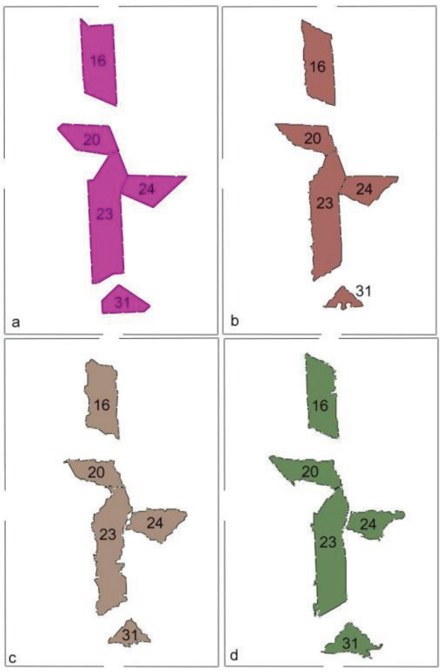

a
50 0 50 100 m
b
50 0 50 100 m
c
50 0 50 100 m
d
50 0 50 100 m

Fig. 3.


16
20
24
23
31
a
b
c
d

Solar energy and net metering in the Mediterranean area (the PV-NET project)

Peter Virtič*[1], Peter Mrak[1], Ioannis Koumparou[2], Maria Hadjipanayi[2], Grigoris Papagiannis[3], Georgios C. Christoforidis[3], Pablo de la Rosa[4], Jose Oliveira[5], Walter Martins[5], Anthi Charalambous[6], Noemie Poize[7], Rebeka Lukman[8], George E. Georghiou[2]

[1] University of Maribor, Faculty of Energy Technology, Energy Conversion Laboratory, Hočevarjev trg 1, SI–8270 Krško, Slovenia, e-mail: peter.virtic@um.si, peter.mrak@um.si.
[2] University of Cyprus, Department of Electrical Engineering, P.O. Box 20537, 1678, Nicosia, Cyprus, e-mail: koumparouy@gmail.com, m.hadjipanayi@gmail.com, geg@ucy.ac.cy.
[3] Aristotle University of Thessaloniki, Faculty of Electrical & Computer Engineering, P.O. Box 486, 54 124 Thessaloniki, Greece, e-mail: grigoris@eng.auth.gr, gchristofor@gmail.com.
[4] Andalusian Institute of Technology, Andalusia Technology Park, Marie Curie st, 4, D2, 29590 Málaga, Spain, e-mail: pdlrosa@iat.es.
[5] Regional Agency for Energy and Environment in Algarve, Building of the Center for the Study of Nature, Estrada de Albufeira, Apart. 1317, 8125 - 507 Vilamoura e-mail: joliveira@areal-energia.pt.
[6] Cyprus Energy Agency, 10-12 Lefkonos Str, CY-1011 Lefkosia, Cyprus, email: director.cea@cytanet.com.cy.
[7] Agency for Energy and Environment in Rhone-Alpes, Le Stratège - Péri, 18 rue Gabriel Péri, 69100 Villeurbanne, e-mail: noemie.poize@raee.org.
[8] Nigrad d.d., a Utility Company, Research and Development Department, Zagrebška 30, SI - 2000 Maribor, e-mail: rebeka.lukman@nigrad.si.
*Corresponding author: Peter Virtič, Faculty of Energy Technology, Energy Conversion Laboratory, Hočevarjev trg 1, 8270 Krško, Slovenia. E-mail: peter.virtic@um.si; Tel.: + 386 41 569 740

Abstract

In this paper, the research within the project 'Promotion of photovoltaic energy through net metering optimization' (PV-NET) is presented. The goal of this project is to pave the way for more efficient renewable energy sources (RES) exploitation in the Mediterranean area and support existing initiatives and EU policy on RES by promoting increased RES deployment in the most cost-efficient way and a distributed, smart-grid electricity generation environment.
Photovoltaic (PV) power plants no longer need support from Feed-in-Tariffs (FIT) and smart net metering can now allow cost-effective RES incorporation into the energy mix. The analysis of current situation in the Mediterranean area, development of technical solution with pilot net metering installations and data analysis are presented. Study pilot installations have been implemented to collect data in Cyprus, Portugal and Slovenia with remote data access which serves to provide long-term data in order to handle the energy generated by PV through smart management of supply and demand and thereby encourage an adequate and efficient use of PV. The improved access to information also improves the knowledge and competences concerning the technical aspects and public administration of more widespread adoption of PV and other RES.

Keywords: Net metering, Smart metering, Photovoltaic electricity, Mediterranean area

1 Introduction

This paper presents the research within the project PV-NET, which aims to pave the way for more efficient renewable energy sources (RES) exploitation in the Mediterranean area including the regions in Portugal, Spain, France, Slovenia, Greece and Cyprus. The PV-NET project supports existing initiatives (Smart Cities, Covenant of Mayors) and EU policy on

RES (Directive 2009/28/EC, 2009) by promoting increased RES deployment in the most cost-efficient way and distributed, smart-grid electricity generation environment. With the highest solar potential in Europe, the Mediterranean region is one of the first to reach PV grid parity. For this reason, more effort towards harmonization and re-evaluation of existing incentives is needed in order to achieve faster PV technology uptake. Smart net metering offers this possibility without compromising the interests of utilities and consumers. Despite the benefits, countries are slow to adopt legal frameworks needed for net metering. The choice of optimal net metering can be impacted by local energy pricing strategies, consumption profiles and for this reason, additional effort is needed to examine metering options in different countries. Also, it is important to demonstrate the viability and economic benefit of adopting the optimized frameworks in order to promote these advantages amongst the public, thereby creating a groundswell of support for these initiatives.

Photovoltaic (PV) power plants no longer need support from Feed-in-Tariffs (FIT). On the other hand, smart net metering can now allow cost-effective RES incorporation into the energy mix. This project addresses the design of energy policies and strategies in the Mediterranean area for cost-optimized utilization of RES and it involves smart energy management schemes, in particular net metering, to provide economically sustainable alternative to government FIT subsidies. Technical solutions of pilot smart net-metering installations with remote data access have been developed and implemented in the residential houses in Cyprus, Portugal and Slovenia. The main focus of this paper is to present the analysis of the current situation on the field of production of electrical energy from PV power plants in the Mediterranean area, the analysis of energy prices, the development of the technical solution with pilot net metering installations and the data analysis.

2 Current situation in the Mediterranean area

2.1 Solar resource and photovoltaic potential

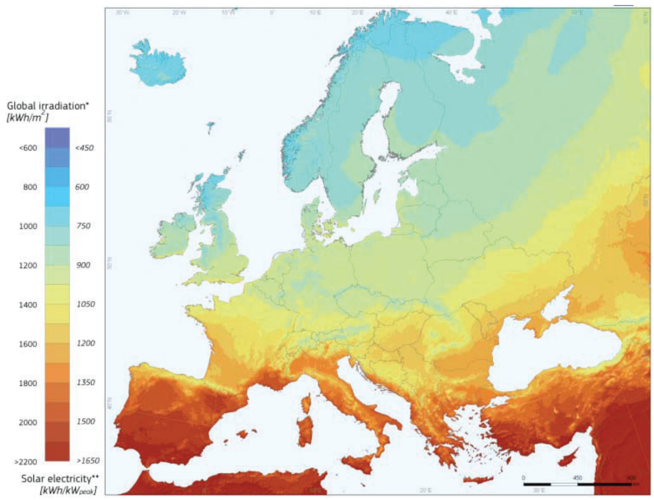


Fig. 1. Global irradiation and PV electricity potential in Europe.

The Photovoltaic geographical information system (Joint Research Centre, 2014) is an on-line tool providing the information of solar resource for the countries of Europe and Africa. The annual sum of global irradiation in kWh/m^2 and the electricity generated by solar resource in kWh/kWp (kWp is kW at peak power of PV module) for horizontally mounted PV systems for Europe is shown in Fig. 1 (PVGIS, 2012; Šúri et al., 2007; Huld et al., 2012).

Table 1 summarises the yearly global irradiation (kWh/m^2) and annual energy yield (kWh/kWp) on the AC side for an optimal placement of the photovoltaic (PV) modules (PVGIS - Interactive Maps, 2014). Participating Mediterranean regions are Cyprus, Andalucia

(Spain), Kentriki Makedonia (Greece), Slovenia, Algarve (Portugal) and Rhone-Alps (France).

Table 1
Yearly irradiation and PV power for the participating Mediterranean regions.

Country: Cyprus	
Region name: All territories	
Total area (km^2)	9360
Urban area (km^2)	98
Yearly global irradiation (kWh/m^2)	2185
Annual AC energy yield (kWh/kWp)	1720
Installed PV capacity (MW)	30.81

Country: Spain	
Region name: Andalucia	
Total area (km^2)	87593
Urban area (km^2)	890.2
Yearly global irradiation (kWh/m^2)	2150
Annual AC energy yield (kWh/kWp)	1685
Installed PV capacity (MW)	874.97

Country: Greece	
Region name: Kentriki Makedonia	
Total area (km^2)	18844
Urban area (km^2)	307.7
Yearly global irradiation (kWh/m^2)	1930
Annual AC energy yield (kWh/kWp)	1560
Installed PV capacity (MW)	318.50

Country: Slovenia	
Region name: All territories	
Total area (km^2)	20273
Urban area (km^2)	410.3
Yearly global irradiation (kWh/m^2)	1475
Annual AC energy yield (kWh/kWp)	1220
Installed PV capacity (MW)	255.60

Country: Portugal	
Region name: Algarve	
Total area (km^2)	5004
Urban area (km^2)	47
Yearly global irradiation (kWh/m^2)	2240
Annual AC energy yield (kWh/kWp)	1770
Installed PV capacity (MW)	31.50

Country: France	
Region name: Rhone-Alps	
Total area (km^2)	3252
Urban area (km^2)	312.8
Yearly global irradiation (kWh/m^2)	1580
Annual AC energy yield (kWh/kWp)	1330
Installed PV capacity (MW)	203.5

2.2 Electricity prices

With the reduction of the cost of PV systems, new opportunities arise for the widespread penetration of PV without the need for Feed-in-Tariffs and by looking at other tools such as net-metering. In order to optimise the net-metering scheme it is very important to consider the solar resource, the Levelized Cost of Electricity (LCOE) as well as the breakdown of the electricity charges which include the cost of production, network cost, standing fees and other taxes (Ossenbrink et al., 2013).

The billing schemes based on the connected power (capacity charge) in participating regions are presented. This scheme uses the connected power of the customer to determine the cost per kWh. The standing fee is, in most cases, a fixed amount that the customers get charged for being provided with electricity. The last contributions to the electricity bill are the taxes and VAT charges. All of the participating regions have VAT and other additional taxes that are based either on the consumed electricity or the connected power. Below an analysis is presented for the percentage of the VAT and the additional taxes applicable for every participating region.

Table 3
Electricity price breakdown per kWh for the participating regions.

Country: Cyprus		
Region name: All territories		
	%	€/kWh
Production Cost	67.1	0.1840
Network Cost	13.3	0.0366
Standing Fees	2.4	0.0067
Taxes & VAT	17.1	0.0469
Total	100	0.2742

Country: Spain		
Region name: Andalucia		
	%	€/kWh
Production Cost	56.0	0.1250
Network Cost	22.9	0.0511
Standing Fees	2.4	0.0054
Taxes & VAT	18.7	0.0417
Total	100	0.2232

Country: Greece		
Region name: Kentriki Makedonia		
	%	€/kWh
Production Cost	45.9	0.1025
Network Cost	13.1	0.0292
Standing Fees	1.0	0.0022
Taxes & VAT	40.0	0.0893
Total	100	0.2232

Country: Slovenia		
Region name: All territories		
	%	€/kWh
Production Cost	41.0	0.0583
Network Cost	26.3	0.0374
Standing Fees	7.0	0.0099
Taxes & VAT	25.8	0.0367
Total	100	0.1423

Country: Portugal		
Region name: Algarve		
	%	€/kWh
Production Cost	32	0.0702
Network Cost	28	0.0610
Standing Fees	17	0.0376
Taxes & VAT	23	0.0402
Total	100	0.2090

Country: France		
Region name: Rhone-Alps		
	%	€/kWh
Production Cost	39	0.0555
Network Cost	26	0.0376
Standing Fees	5	0.0066
Taxes & VAT	30	0.0430
Total	100	0.1427

3 Measurement system design

For measurement and control system (MCS) design several factors have been taken into account. The platform has to be able to: connect various types of sensors; communicate via different protocols; perform real-time and parallel processing; to be cost efficient and small enough for the final implementation. The MCS needs to interact not only with PV systems but also with household devices and web in order to obtain all the relevant data for analyzing the efficiency of the energy production and use. The main purpose of the MCS is to communicate and control different devices such as, smart meters, PV inverters, data logger, household appliances, etc. as depicted in Fig. 2. The system's primary function is to obtain numerous data (temperatures, radiation, power consumption and production, voltage, current, etc.) process them and store in different data format with a time stamp. In addition the MCS has to be able to perform administrative functions (user access control, remote access, update software, interface with web and database server, etc.), to synchronize with Network Time protocol and provide options to control devices via digital I/O or via communication protocols. Further the MCS must have self-diagnostic test in order to handle error and faults alarms and also to validate and verify the received data.

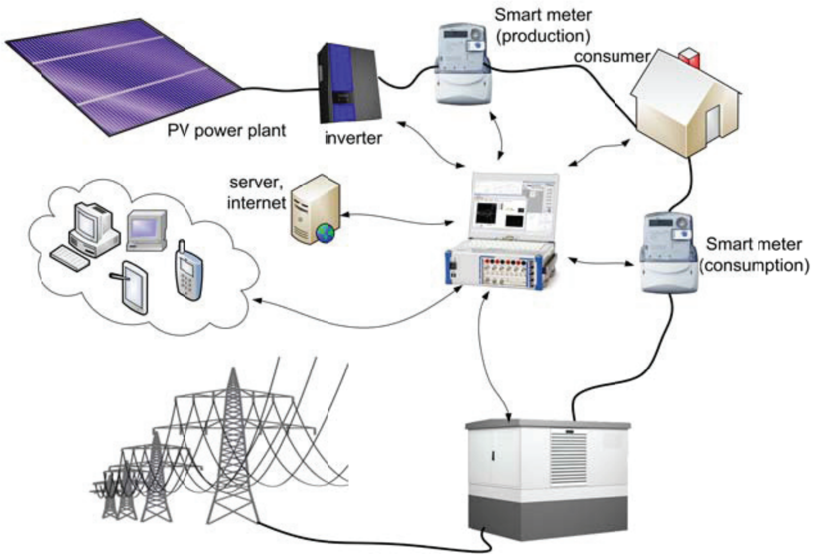


Fig. 2. Basic concept of measurement control systems for monitoring and controlling household PV system.

Different data acquisition systems (off-the-shelf) were considered for this project but none of them was able to cover all the requested specification or they were extremely expensive. Therefore we decided to develop a new customised platform which would be able to perform the desired functions and also allow expansion and upgrades. We decided to use NI Single-board RIO which employs reconfigurable embedded control and acquisition peripheral, real-time processor, a user-programmable FPGA. The NI Single-board was selected as the heart of the measurement system, which interferes with other devices.

4 Data analysis

The project PV-NET addresses the issue of implementation of PV technology in terms of smart energy schemes in net metering and their optimization with respect to the environmental and economic conditions. In Slovenia, six measurement systems at six different sites (houses) were set up in order to retrieve actual data on consumption, production and ambient conditions. The measurement systems enable storage of data every 15 minutes. Extensive data analysis has already started to be performed.

The sample rate (15 minutes) is not fast but it has to be taken into consideration that these measurements are performed on long time period which means that a lot of data is accumulated over time as shown below. Fig. 3 represents data for one day from one of measurement sites. It can be seen the impact of sun radiation on the PV production and module temperature. Sun radiation has also some influence on ambient temperature, while the consumption of energy is completely independent (depends on each individual household user). The 15 minute sample rate is enough to observe ambient changes eg. clouds (the radiation drops around 16:00) which have major impact on the PV yield.

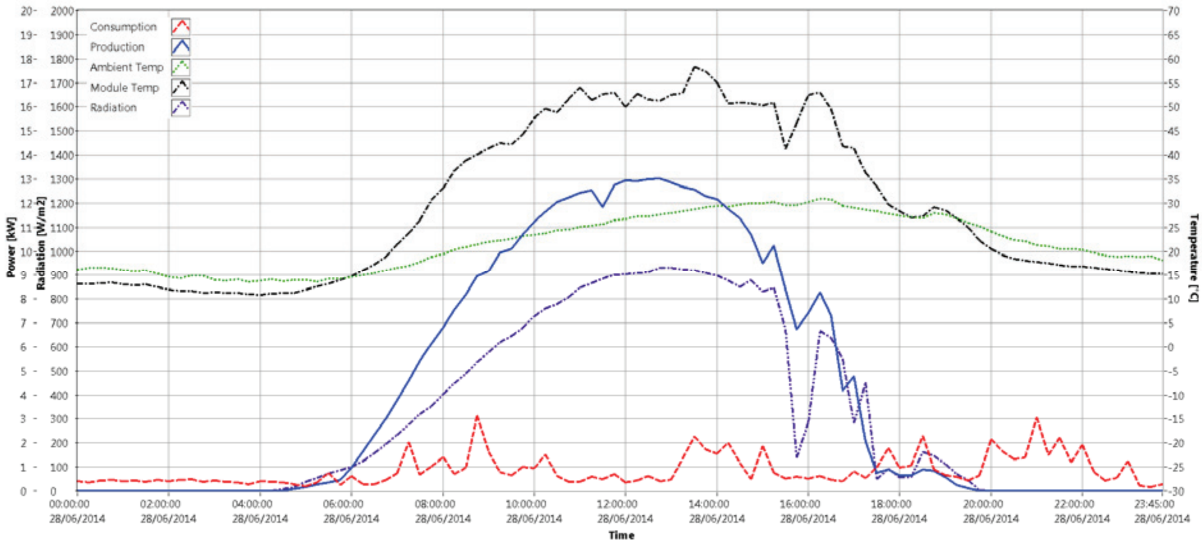


Fig. 3. Measured PV production, consumption, ambient temperature, PV module temperature and solar radiation for one day (in Slovenia).

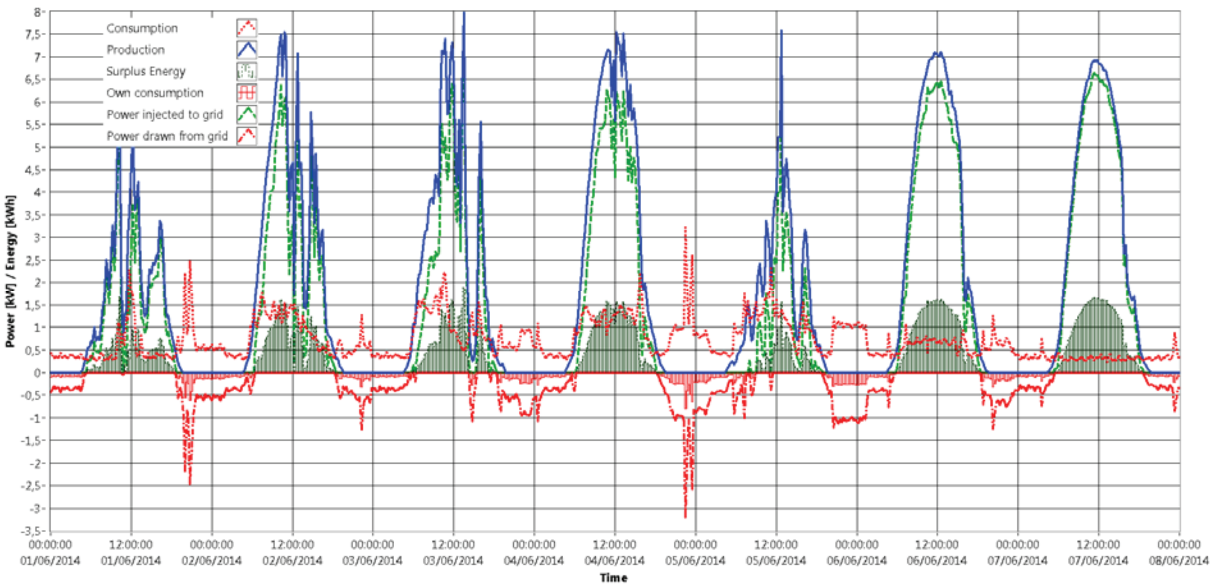


Fig. 4. Measurements including the difference between the PV production and consumption of electrical energy (in Slovenia).

The production data is monitored in kWh per day or even longer period, but we have extracted data, which are vital for the net metering and its optimization itemized down to the sample rate of MCS. Besides consumption and production power, we are analyzing also surplus energy, own consumption, power injected into grid and power drawn from the grid permanently (Fig. 4).

5 Conclusions

The obtained real time measurements confirm the good tracking of the parameters related with PV power plant production and allows optimization of PV systems in order to increase the efficiency and reduce the bills. A series of pilot smart net-metering installations serves to provide long-term data. With these data the further analysis can be done by means of classical statistics (mean value, standard deviation, variance, skewness) and even more important clustering data into different time frames (hourly, daily, monthly) with the goal of discovering all possible optimized metering schemes. Pilot installations show that it is possible to handle the energy generated by PV through smart management of electrical energy supply and demand and thereby encourage an adequate and efficient use of PV. Expected long-term impact of this project is improved access to information which improves the knowledge and competences concerning the technical aspects and public administration of more widespread adoption of PV and other RES.

References

Directive 2009/28/EC on the promotion of the use of energy from renewable sources, 2009. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN (accessed 25.09.2014).

Joint Research Centre, Photovoltaic Geographical Information System, 2014. http://re.jrc.ec.europa.eu/pvgis/ (accessed 09.09.2014).

PVGIS, Photovoltaic Solar Electricity Potential in European Countries, Joint Research Centre, European Union, 2012 (accessed 09.09.2014). http://re.jrc.ec.europa.eu/pvgis/cmaps/eu_cmsaf_opt/PVGIS_EU_201204_publication.png.

Šúri, M., Huld, T.A., Dunlop, E.D., Ossenbrink, H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Sol. Energy 81, 1295–1305.

Huld, T., Müller, R., Gambardella, A., 2012. A new solar radiation database for estimating PV performance in Europe and Africa. Sol. Energy 86, 1803-1815.

PVGIS - Interactive Maps, 2014. http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php (accessed 09.09.2014).

http://www.lagie.gr/fileadmin/groups/EDRETH/RES/2014_01_GR_MONTHLY_RES_final.pdf.

Ossenbrink, H., Huld, T., Jäger Waldau, A., Taylor, N., 2013. JRC Scientific and Policy Reports: Photovoltaic Electricity Cost Maps. European Commission Joint Research Centre Institute for Energy and Transport, Italy, JRC 83366 .

Title:

The Organizational Capability of Sensing Wicked Problems:

Implications on Stakeholder Engagement for Sustainable Development

Authors:

Dr. Domenico Dentoni[1]

Dr. Verena Bitzer[2]

[1] Assistant Professor, Management Studies Group, School of Social Sciences

Wageningen University

[2] Postdoctoral Research Fellow, Graduate School of Business

University of Cape Town

Corresponding author:

Dr. Domenico Dentoni, Management Studies Group, Wageningen University

P.O. Box 8130, 6700 EW Wageningen, The Netherlands

Tel: +31 3174 82180. Email: domenico.dentoni@wur.nl.

The Organizational Capability of Sensing Wicked Problems:

Implications on Stakeholder Engagement for Sustainable Development

1. Introduction

Given the relevance, entity and urgency of the global environmental and social issues at stake, many disciplines have progressively undertaken the study of how private sector actors deal with wicked problems. Wicked problems such as climate change and deforestation, food insecurity, and violation of human rights are ill structured, impossible to disentangle in a coherent set of cause-effect relationships, raise value conflicts among stakeholders and cannot be considered univocally solved (Rittel and Webber 1973). Given the nature of wicked problems, companies are either considered part of the problem or part of their solution, or both, by different stakeholders (Levin et al. 2012). In order to deal with wicked problems, private actors have developed institutions to effectively manage relationships with stakeholders that include networks, alliances, or a complex combination of the two.

Public policy, economics, sociology and business management theories focus on the nature of institutions responding to the problem. Moreover, various strands of life sciences assess the nature of problems influenced by institutions, or some specific aspects of these problems. Since wicked problems and institutions are inexorably entangled with each other, trans-disciplinary research has attempted to understand when and how this relationship could generate positive outcomes for the involved stakeholders and for society. Despite these trans-disciplinary knowledge advancements, a serious gap still remains across business management and wicked problems theories. On the one hand, studies on wicked problems recognize that the private sector plays a paramount role in the problems and in their possible resolution (Weber and Khademian 2008; Levin et al. 2012; Head and Alford 2013), but they do not analyse firm behaviour related to this category of problems. On the other hand, studies on business management recognize that firms face complex societal problems (Camillus 2008; Scherer and Palazzo 2011; Battilana and Dorado 2011), but do not assess strategies dealing with the "wicked nature" of these issues. This knowledge gap in between business management and wicked problems theories is serious, because all societal actors would benefit from understanding *why*, *when* and *how* firms choose to cooperate with stakeholders to effectively deal with wicked problems.

Given the existing gap in between business management and wicked problems theory, this research aims to contribute to existing knowledge by first re-conceptualizing and recognizing wicked problems from the point of view of business managers; and, second, by assessing *why* and *how* firms choose to deal with the wicked problems in a specific and rapidly emerging institutional setting, namely multi-stakeholder initiatives (MSIs) (WEF, 2011; CDP, 2013). The study is inductive and follows a grounded theory approach based on evidence from a qualitative database of secondary and primary data on the world largest corporations in the agricultural and food sector. The agricultural and food sector provides a vivid setting for this investigation because there are several wicked problems at stake; almost all the corporations in the sector have undertaken some strategies to deal with problems through inter-organizational institutions such as MSIs; yet, these companies have been undertaking different strategies, providing ample heterogeneity of observations that suits the inductive nature of the analysis. Deforestation and biodiversity loss, food insecurity and violation of human rights provide illustrative examples of wicked problems in agriculture that corporations face.

Consistently with these objectives, empirical results of this study are here synthesized in three points. First, from the standpoint of business managers, the global environmental and social problems at hand have three key dimensions that make them "wicked": (i) *scientific uncertainty*, since there is no scientific agreement of how their causes, symptoms and effects can be framed and disentangled; (ii) *value conflict* among multiple societal groups affecting or affected by them and (iii) *dynamic complexity*, since these problems are continuously evolving with no final solution. Second, business managers in MSIs either "tackle" or "tame" these three dimensions of wicked problems, and they do so either in an inclusive or exclusive way. Third, managers choose their "problem tackling versus taming" and "inclusive versus exclusive" strategies depending on their resources available, their capabilities, and their transaction costs.

These study findings lead to mutual knowledge advancements in the fields of wicked problems and business management. First, introducing an assessment of managers' "perceptions of wicked problems" in three operational dimensions reduces the complexity of previous wicked problems definitions (Rittel and Webber 1973; Conklin 2006, Batie 2008). Second, identifying a set of alternative strategies that business managers undertake to deal with wicked problems in MSIs contributes to explain and predict the organization of institutions dealing with wicked problems (Ney and Verveij 2014), considering that the private sector is often an important player in shaping these institutions. Finally, understanding the reasons *why* business managers adopt different strategies to deal with wicked problems helps assessing what are the relevant outcomes of institutions for the firms, and thus their incentives to participate and invest resources. Understanding firm incentives to deal with wicked problems has important implications also for policy-makers and other societal stakeholders, so that they can encourage companies to invest in institutional reaching sustainable impacts - that is, able to find acceptable compromises in between benefits for people, planet and profit – despite the wicked nature of the problems at hand.

2. Methods

This is a theory-building paper that applies an inductive method of research to understand how corporations recognize and make sense of wicked problems and develop strategies to deal with them through MSIs. Empirical data combine secondary and primary sources. Secondary sources include managers' declarations in MSI websites; 22 research articles included in a recent International Food and Agribusiness Management Review special issue (Dentoni et al. 2012); specialized literature on legitimacy strategies adopted by companies in specific cases of MSIs, which are cited throughout the sections 3 and 4.

Primary sources include interviews to company managers in five different stages between 2009 and 2013. First, in 2009 and early 2010 we joined discussion sessions during five international agribusiness conferences and conducted 34 interviews with business managers, non-governmental organizations (NGOs) and academics who participated in CSPs in the agri-food sector, specifically the Sustainable Agriculture Initiative (SAI) Platform, TransForum, the Roundtable on Responsible Soy, the Carbon Disclosure Project and the Dutch Sustainable Trade Initiative (IDH). Second, between 2010 and early 2011 we undertook a systematic screening of the CSPs created or joined by the 50 largest agri-food multi-national companies (MNCs) (Dentoni and Peterson, 2011). We chose these MNCs because of the large amount of data available through web electronic sources compared to smaller firms, and the rapid proliferation of CSPs in the agri-food sector compared to other sectors. Third, we divided and selected four typologies of MNCs for further study depending whether they were tackling or taming the wicked problem, or if they were recognizing it or not (company names remain anonymous in this paper draft, yet not the names of MSIs). Fourth, from late 2011 to early 2012 we undertook a systematic screening of the sustainability/CSR reports produced by the four typologies of MNCs to triangulate the primary data collected through interviews in the previous research stages.

Consistent with the inductive approach undertaken, in the discussion section we articulated how the empirical results build upon and integrate the existing theory on wicked problems, organizational capabilities and multi-stakeholder institutions. The theoretical perspective is given by a review of Science articles (see section 4.1) as illustration of problems wickedness in the specific case of the agri-food sector; as well as the recent theoretical developments on wicked problems and multi-stakeholder institutions.

3. Theoretical Underpinnings

3.1. Wicked Problems

To discuss the managerial necessity of recognizing and dealing with wicked problems, the concept of wicked problems is revisited as first introduced in political sciences and design. Rittel and Webber (1973) firstly described that a number of public problems were highly intractable, thus "wicked", because multiple societal groups had strongly conflicting views on the desired outcome of certain policies. This class of problems was also difficult, if not impossible, to define and solve. While the literature on policy and public administration has widely adopted the definition introduced by Rittel and Webber (Buchanan, 1992; Conklin, 2006; Lazarus, 2008; Levin et al., 2012), some authors have also tried to reduce the distinguishing features of wicked problems to a smaller set in order to operationalize the concept (Roberts, 2000; Conklin, 2006).

The key policy and managerial implication of wicked problems is that no stakeholder can effectively respond to wicked problems independently from other stakeholders -individual action against wicked problems has limited or no effectiveness if uncoordinated from the action of others (Conklin, 2006). Thus, just like planners and policy-makers, managers facing or even only trying to understand wicked problems need to develop a network and system perspective if they want to deal with them (Weber and Khademian, 2008; Harris et al., 2012). Previous studies have indeed emphasized the relevance of such a network perspective, for instance, when planners are dealing with environmental degradation (Van Bueren et al., 2003), health policy (Westbrook et al., 2007), Asian and then global financial crisis (Sachs et al., 2010), marine and coastal protection (Jentoft and Chuenpagdee, 2009; Gerhardinger et al., 2011), biodiversity conservation (Bal et al., 2011; Schroth and Mcneely, 2011), and food security (Hamann et al., 2011). It is within this perspective that corporations and governments are increasingly encouraged to adopt new approaches to deal with the ambiguities and challenges of wicked problems, for instance by engaging in multi-stakeholder initiatives (MSIs) (Klijn et al., 2007; Sachs et al., 2010). If they do not take appropriate strategies that consider the nature of wicked problems, corporations risk being perceived as part of the problem to be urgently contrasted (Levin et al., 2012).

3.2. Dealing with Wicked Problems through Multi-Stakeholder Initiatives

The concept of MSIs (Utting, 2002) or multi-stakeholder partnerships (Bäckstrand, 2006), defined as “voluntary, self-enforced and non-negotiated agreements between different constellations of governments, international organizations, NGOs and industry partners” (Bäckstrand, 2006, p. 296), was introduced at the World Summit on Sustainable Development in Johannesburg in 2002. At the core of it is the voluntary participation of a wide array of stakeholders, especially non-state actors (mostly businesses and NGOs) that engage in rule-making and standard-setting to guide companies’ environmental and social behaviour (Fuchs et al., 2011). Fransen and Kolk (2007) point out that ‘stakeholder participation’ is so broad that it can capture many different set-ups and practices. Therefore, we explicitly set MSIs apart from looser types of arrangements that are also often mentioned in the literature on CSR, including stakeholder engagement (Payne and Calton, 2002; Greenwood, 2007) and stakeholder dialogue (Kaptein and van Tulder, 2003). As such, MSIs are a type of cross-sector partnerships (Rondinelli and London, 2003; Selsky and Parker, 2005) linked to the implementation of a sustainability goal.

Most contributions from management and business studies have viewed the participation of companies in MSIs as part of an instrumental CSR strategy (Googins and Rochin, 2000; McWilliams and Siegel, 2001; Bryson et al., 2006). In this understanding, CSR constitutes a strategic approach to managing the social role of businesses, and “partnerships represent the alignment of strategic business interests with societal expectations” (Seitanidi and Crane, 2009, p. 414). This attributes CSR the primary function of deflecting public criticism and bestowing competitive advantage on participating corporations (Aguinis and Glavas, 2012). However, this approach has come under growing criticism for providing minimal value to society and little strategic value for corporations (Margolis and Walsh, 2003; Porter and Kramer, 2006). Ruggie therefore urged to expand the debate “beyond establishing individual corporate liability for wrongdoing” (2007, p. 839) towards a model of shared political responsibility as proposed by Young (2006).

Accordingly, company engagement in MSIs and other types of cross-sector partnerships has recently been discussed as ‘political duty’ – or at least political activity – of corporations to provide and protect public goods, such as human rights and food security (Scherer and Palazzo, 2007; Crane et al., 2008; Scherer and Palazzo, 2011; Whelan, 2012). This is particularly the case where public goods are global, i.e. whenever externalities – either positive or negative – cross borders and therefore pose a jurisdictional gap (e.g. Kaul et al., 1999). Young puts forward the argument that “all agents who contribute by their actions to the structural processes that produce injustice have responsibilities to work to remedy these injustices” (2006, pp. 102-103). Quite clearly, such a perspective moves away from the instrumental business case for CSR towards a normative conception of what businesses *should* do. This prescriptive ambition arises from the increasing challenges to legitimacy which multinational companies experience (Porter and Kramer, 2011; Scherer et al., 2013). In other words, businesses are struggling to receive social acceptance if they diverge from what society considers adequate behaviour in the face of various sustainability issues. “Corporations that do not conform to expectations about sustainability will see their legitimacy challenged", argue Scherer et al. (2013). This is especially the case as legitimacy increasingly develops from stakeholders' moral judgments about company actions (moral legitimacy), rather than from taken-for-granted assumptions about companies (cognitive legitimacy) or from tangible results of company behaviour (pragmatic legitimacy) (Scherer and Palazzo, 2011). In this way, political CSR is also guided by corporate self-interest, as it presents a way to (re-)gain corporate legitimacy. However, to ensure that corporate decision-making is accountable to the democratic polity, embeddedness into stakeholder networks is critical. This is where the concept of MSIs gains traction as a potentially democratic way of dealing with social and environmental externalities (Scherer and Palazzo, 2008; Mena and Palazzo, 2012).

3.3. Sensing Wicked Problems and the Structure of Multi-Stakeholder Institutions

The extant literature emphasizes the role of globalization as a key driving force for the increasing complexity of problems and hence, MSIs. Intensified cross-border interactions due to declining costs of connecting distant locations (Scherer and Palazzo, 2011) have led to an expansion of global business activities by MNCs coupled with an increasing fragmentation of authority and ambiguity of borders and jurisdiction (Kobrin, 2009). This makes it difficult to hold MNCs accountable for their negative social and environmental externalities, e.g. for human rights violations (Kobrin, 2009). Processes of globalization also negatively impact the ability of governments and intergovernmental organizations to provide global public goods (Kaul et al., 1999). As a consequence, some MNCs have started engaging in self-regulation and MSIs to provide public goods (Mena and Palazzo, 2012) in areas where governments are not willing or able to exercise their regulatory role (Crane et al., 2008).

However, the inability of governments to provide public goods and the respective new 'political' role of business not only stem from the jurisdictional gap created by globalization, but importantly also from the nature of these public goods. Beyond their attributes as non-excludable and non-rivalrous in use, which make them systematically underprovided by private market forces

(Maskus and Reichmann, 2004), various global public goods, such as biodiversity or climate change mitigation, are in fact part of wicked problems, characterized by causal indeterminacy and the existence of non-immediate effects of their solutions (Lazarus, 2009). Such problems cannot be ‘managed’, but demand a collaborative approach of shared responsibility in line with the political conception of CSR. A closer look at the features of wicked problems may therefore explain the political role of CSR as much as globalization.

Firstly, as mentioned earlier, wicked problems are characterized by scientific uncertainty, including unknown, unclear or hidden cause-effect relationships. The associated complexity of framing and solving wicked problems renders any single actor approaches futile, and underlines the inadequacy of instrumental conceptualizations of CSR based on corporate liability. In the liability model, responsibility is assigned to those actors who have a demonstrated causal connection to a particular problem (Young, 2006). When dealing with wicked problems, such causal connection is often not possible, nor is it possible for any actor to possess the necessary knowledge and resources to address a particular wicked problem. Hence, the growing urgency of wicked problems (Levin et al., 2012) calls for a network logic of collective action and shared political responsibility, based on collaboration among multiple stakeholders (Scherer et al., 2011).

Secondly, wicked problems involve value conflicts, including multiple and possibly opposing frames on the issue at stake (Termeer et al., 2013). Hence, collaboration processes in MSIs are likely to be rife with “struggles over the nature of the problem and its appropriate solutions” (Andonova et al., 2009, p. 64). Different actors will attach different kinds of meanings and values to the same knowledge and information exchanged in MSIs (Weber and Khademian, 2008). At the same time, such processes of interaction between actors involved in MSIs are also one of the major sources of sense making and problem (re-)framing (Rivera-Santos and Rufin, 2011). As wicked problems remain difficult, if not impossible, to solve, collaborative processes rely on moral legitimacy rather than cognitive legitimacy (Scherer and Palazzo, 2011). Therefore, a model of deliberative democracy (Scherer and Palazzo, 2011) seems to be more suitable in a context of wicked problems than in a context of tame problems.

Thirdly, wicked problems mutate over time, as tackling one part of the problem often affects other aspects of the problem, so that a continuous process of knowledge production to adapt to changing problem contexts is necessary (Crona and Parker, 2012). The dynamic nature of wicked problems also entails that static 'by the book' or heavy rule-oriented problem-solving approaches are insufficient (Weber and Khademian, 2008). Soft law based on self-regulation and voluntary action in the context of MSIs is therefore a promising approach where traditional government authority is lacking (Scherer and Palazzo, 2011) and where flexibility in decision-making and action needs to be maintained (Rasche, 2012).

4. Dealing with Wicked Problems through MSIs

4.1. The Nature of Wicked Problems

Deforestation, i.e. the conversion of natural forests, is one of the most severe problems associated with the expansion of agricultural production. Deforestation is particularly acute in Southeast Asia, where the rapidly expanding production of palm oil has been linked to the destruction of tropical forests, loss of biodiversity, and climate change. Studies indicate that more than half of the oil-palm expansion in Indonesia and Malaysia has occurred based on the conversion of rainforest or peat forests (Koh and Wilcover, 2008). The rapid rate of forest conversion turns palm oil production into "the greatest immediate threat to diversity in Southeast Asia" (Wilcove and Koh, 2010) which also contributes to climate change due to the function of rainforests and peat forests as carbon stocks (Bala et al., 2007). However, there are still actors who continue to refute the connection between palm oil production and negative ecological impacts, such as Tan et al. who argue that such claims "are not acceptable" and are based on false statistical information (2009, p. 423). Not only is this a matter of continued *scientific uncertainty* surrounding the complexity of palm oil production and its relationships with a variety of environmental as well as social and economic factors, but also an expression of fundamental *value conflicts* between actors. Whilst proponents refer to the growing market demand for palm oil as a renewable energy source and as a vegetable oil with comparatively much higher production efficiencies that is important for Southeast Asian economies and smallholder farmers (Tan et al., 2009), opponents caution that the expansion of palm oil production may not only have irreversible environmental consequences (Wilcove and Koh, 2010), but is also associated with severe human rights violations (Wakker, 2005) and may lead to the increased marginalisation of smallholder farmers (McCarthy et al., 2012). Meanwhile, deforestation and associated problems have become more acute in Indonesia and Malaysia (Griffiths, 2010; Miettinen et al., 2011), and the market for palm oil continues to expand. China and India have become the biggest markets for palm oil – both of which have significant influence, but have shown little interest in sustainability issues surrounding palm oil (Wilcove and Koh, 2010). This influences the willingness of producers to engage in sustainable production (Schouten and Glasbergen, 2011), thereby impacting on deforestation as a *dynamically evolving*, complex and contested problem in the context of palm oil production.

Food insecurity in the form of hunger and undernourishment remains a pressing problem despite decades of national and international efforts to ensure the right to adequate food as a basic human right. FAO's most recent estimates indicate that about 870 million people were chronically undernourished in 2010-12 (FAO et al., 2012). Moreover, demographic estimates forecast a population growth up to 9 billion world inhabitants by 2050, with Sub-Saharan Africa and Asia – the two most affected regions by food insecurity - being one of the most rapidly growing populations. The *scientific debate* on food insecurity is very divided on its causes and possible solutions. On the one hand, some scientists (mainly life science experts) and corporations (especially fertilizer, chemical and seed companies) argue that food insecurity is mainly a problem of poor and uncertain agricultural productivity in food insecure world regions and advocate a new "green revolution" intended as a coherent effort of funding agencies, research institutions and corporations to advance technology for agricultural efficiency. On the other hand, other scientists (mainly social science experts), international agencies and NGOs argue that food insecurity is mainly an issue of supply chain inefficiency due to poor infrastructures and capabilities across regions affected by food insecurity. This scientific debate has a component of *value conflict* among multiple societal groups which goes beyond different expectations, beliefs and goals on how to address the problem. Many civil society organizations and movements worldwide give highest value to the preservation of local biodiversity and traditions, and strongly oppose change towards new technological and organizational innovations, either at farm or supply chain level. The value conflict related to food insecurity is evident in the exacerbated discussion on the use of genetically modified organisms (GMOs) in food and agriculture, with a marked antagonism between two highly divided camps. International agribusinesses, supported by large foundations, parts of academia and a number of development agencies, advocate the promotion of GMOs to reduce poverty and hunger, while most of local and international NGOs, other parts of academia and the international development community refuse the introduction of biotechnologies as cause of biodiversity loss and increased market power of biotech companies to the detriment of small-scale farmers (Zerbe, 2004). Finally, as updated information on impact assessment of the latest food security programs and on population growth, agricultural productivity and undernourishment estimates become public, the debate focuses on slightly different topics, takes different forms and arenas and involves different societal actors, thus demonstrating *dynamic complexity* (Fish et al., 2013; Hinrichs, 2013; Maye and Kirwan, 2013).

Human rights violations in the agriculture and food sector are mostly noted in the form of labour exploitation and serious abuse, including low wages, unsafe working conditions, harassment, and, most fundamentally, child labour. One of the most affected sectors is the cocoa sector with child labour being deeply rooted in the economic system since colonial times (van Hear, 2008). Child labour is particularly widespread in West Africa, which produces the majority of world's cocoa. Multiple factors have been noted to contribute child labour in agriculture, such as poverty, lack of access to education, lack of law enforcement, HIV/Aids, gender inequality, human trafficking, and the general structure of poor agricultural economies. However, statistical and *scientific uncertainty* remains about the specifics of child labour, including the magnitude of it, the different forms of child labour and the situational complexity of intertwined causes (Andvig, 1998). As cultural factors, such as family structure, birth rates and traditions, also play an important role in affecting the supply of child labour, there are significant *value conflicts* about the nature of child labour – in what situations there is what the ILO considers the worst forms of child labour or acceptable child labour in subsistence households (Andvig, 1998; Matissek et al., 2012). For this reason, there is also no 'magic formula' for effective child protection in poor agricultural areas and simply banning the practice of child labour has had limited effects (Matissek et al., 2012, p. 14). To make matters worse, child labour is a *dynamically complex* problem which continuously changes in the face of demographic, socio-economic, cultural and even environmental developments. The complexity of underlying direct and indirect causes, and the lack of data on the magnitude of these causes makes it "almost impossible at present to make a prediction based on facts concerning whether rural child labour will become a more or less serious problem in the near future" (Andvig, 1998, p. 347) (Table I).

INSERT TABLE I ABOUT HERE

4.2. Tackling vs. Taming Wicked Problems in MSIs

We argue that corporations have four strategies available to deal with wicked problems through MSIs. These four strategies are distinguished according to two dimensions, depending on whether the strategies try to *tackle* or *tame* wicked problems and depending on whether they recognize the wicked nature of the problem at hand, or if they fail to recognize it. In this research draft, we assume that focusing on the *input legitimacy* is a way to recognize the wicked nature of the problem at hand; focusing on the *output legitimacy* of MSIs is a way of failing to recognize the wicked nature of the problems.

The first question of tackling versus taming refers to the *focus on the problem-based strategy* of MSIs. Wicked problems involve complex sets of interrelated subsets of problems whose causes and effects are hard if not impossible to univocally disentangle (Rittel and Webber, 1973; Ritchey, 2005). Thus, through MSIs corporations can decide to take *a broad focus* on the entire wicked problem ("tackling") or *a narrow focus* on a subset of tame issues within the broader problem ("taming"). Moreover, through MSIs corporations can take either a broad or a narrow focus in two subsequent stages, that is, *when making sense of the wicked problem* (understanding) and *when taking action on the wicked problem* (doing). Thus, some MSIs may be chosen by corporations to make sense of the entire wicked problem, but to take action only on a specific subset of tame issues; or to make sense of only a subset of tame issues and to take action of them, while ignoring the rest of the problem.

The second question concerns the *type of legitimization process* of MSIs. Corporations may attempt to legitimize their CSR strategies through *input* and *output legitimization processes* in MSIs (Mena and Palazzo, 2012). Input legitimacy refers to processes of inclusion, procedural fairness, consensual orientation, and transparency in the structures and processes of MSIs, whereas output legitimacy pertains to rule coverage, efficacy and enforcement (Mena and Palazzo, 2012). From the perspective of wicked problems, we argue that corporations in MSIs give priority to either input legitimacy *or* output legitimacy. Corporations that seek inclusion and procedural transparency in the engagement of stakeholders may struggle to move rapidly towards rule-setting, enforcement and wide industry coverage. Vice versa, corporations giving priority to MSIs' output legitimacy may sacrifice inclusiveness as it entails dealing with increased conflict and debate among stakeholders. This results in the following matrix (Table II).

INSERT TABLE II ABOUT HERE

Strategy 1: Corporations sensing and tackling wicked problems in MSIs

The first strategy available to corporations is to tackle a wicked problem through developing input legitimacy in MSIs. This represents the corporate attempt to address a wicked problem in all its multiple dimensions by making sense of the problem through developing an input legitimization process. The three following examples illustrate this strategy. First, the Sustainable Food Lab (SFL) was founded by a coalition of European and US food manufacturing corporations, NGOs and research institutes to shift sustainable development and commodity procurement in food and agriculture from niche to mainstream, especially in marginalized world regions of Latin America, Africa and Asia. Problems are jointly identified by SFL members and external stakeholders through a series of open workshops, learning journeys and online knowledge-sharing evolving around cognitive and experiential learning (Hamilton, 2013). Inclusion into the online and in person knowledge-sharing mechanisms is facilitated by the SFL secretariat which aims to create an atmosphere for the "freedom to explore thinking and acting differently" (Eisenstadt, 2010, p. 35). The idea is to generate innovative pilot projects out of this process, as a form of "conceptual testing" before further developing implementation plans for scaling up (Hamilton, 2013). While focusing on the different problem of food insecurity and its roots, corporations (European food manufacturers and financial institutions; African retailers and agricultural suppliers) in MSIs such as AgriProFocus (APF) and the Southern African Food Lab (SAFL) involve the full range of stakeholders – both MSI members and external stakeholders interested in joining – to collaboratively analyze the problems and experiment, evaluate and replicate solutions (APF, 2013; Waddell et al. 2013). Given their different regional focus and member composition, APF is mainly focused on stimulating farmers' and supply chain actors' entrepreneurship through the creation of national agri-hubs, while the SAFL is mainly focused on improving supply chain efficiency from rural to urban areas through scalable pilot projects (Hamann et al., 2011).

Corporations pursuing a political CSR strategy of tackling wicked problems through MSIs' input legitimacy primarily provide public goods in terms of institutional development. By establishing MSIs that tackle wicked problems through input legitimacy, corporations and their partners create new platforms for representative and transparent participation in the discourse, for interaction and deliberation. This "participation in the discourse" is a public good since it is non-excludable and non-rivalrous, and generates positive externalities to stakeholders (both outside and inside the MSI) in terms of learning and reduction of coordination costs. Hence, the MSIs themselves become a public good. In this way, the role of MSIs lies more in establishing institutions that help tackling wicked problems than in tackling the wicked problems directly (Hamilton, 2013; Waddell et al., 2013). The downside of this strategy is that the scientific uncertainty, value conflict and dynamic complexity in an inclusive setting risks to paralyze decision-making and action after lengthy discussions spent to analyze the problem and experimenting prototypes of solutions at small scale. This the risk of what Conklin (2006) defined as "analysis paralysis", that is, the risk of keeping endlessly studying the problem at hand without moving to implementation while the problem is becoming urgent (Levin et al. 2012).

Strategy 2: Corporations tackling wicked problems in MSIs without sensing them

The second strategy available to corporations is to tackle wicked problems mainly through MSIs' output legitimacy. Differently from the previous one, this strategy involves making sense and taking action on the problem by giving priority to rule setting, coverage and enforcement in MSIs (Mena and Palazzo, 2012). After consultation with non-business stakeholders, the problems at hand are *de facto* analyzed, communicated and tackled by coalitions of business actors only. A first example is the Sustainable Agriculture Initiative (SAI) Platform. SAI was created in 2004 by three European and US companies to accelerate sustainable development by establishing common practices and assessment tools, and training suppliers on economic, social and environmental aspects (what is often referred to as the triple-bottom line). The SAI executive committee is formed only by corporate members, while NGOs, farmers' organizations, research institutes and other stakeholder groups are only admitted to the SAI advisory council, which is elected by business members' invitation every three years (Dentoni and Peterson, 2011). Business members and academics (by invitation) are organized in working teams to deal with the scientific uncertainty of the social or environmental problems at hand, while the advisory board is supposed to maintain the multi-stakeholder nature by representing value conflict among societal groups and assessing how the environmental and social problems change over time (SAI Platform, 2013).

A second example is the Sustainability Consortium (TSC), which was recently established by US business partners (both in food and non-food sectors) in 2010, mainly Wal-Mart's suppliers, and coordinated by two US universities (Hyatt and Spicer, 2012). TSC has recently also expanded to Europe (2011) and China (2013). The explicit goal of TSC is to establish a Sustainability Measurement and Reporting Practices system in an industry pre-competitive setting. TSC membership is assigned to corporations, NGOs and regulating entities through an application process which involves the payment of an annual fee starting from 10,000USD/year (TSC, 2013). In practice, NGOs and universities external to the coordination processes participate through consultation but without a mechanism of joint deliberation or implementation in the sector working groups. A third example is provided by the Global Food Safety Initiative (GFSI) launched by the Consumer Goods Forum with the objective of setting globally accepted baseline requirements for food safety and improving supply chain efficiency (Fuchs et al., 2011).

A fair question is whether corporations undertaking such a CSR strategy through such MSIs aim to provide a public good or not. On the one hand, these MSIs lead to the creation of industry standards, indicators and procedures, thus a soft law regulatory framework that could be adopted by the rest of the industry outside the MSIs and generate positive externalities. On the other hand, exclusion or poor representation of non-business actors in MSIs in a context of value conflict may generate negative externalities for non-business stakeholders and lead to conflict with existing institutions.

Strategy 3: Corporations sensing and taming wicked problems in MSIs

The third strategy available to corporations is to try and tame a particular wicked problem through MSIs' input legitimacy. This indicates that corporations emphasize the element of input legitimacy of MSIs, such as participation and deliberation, to make sense of a wicked problem and then take action by targeting the tame elements of the wicked problem. There are several MSIs that illustrate this strategy, among others, the Roundtable on Sustainable Palm Oil (RSPO). This MSI was officially established in 2004 in the face of severe public pressure on the palm oil sector to address the various wicked problems associated with palm oil production. The idea of the RSPO was to promote sustainable palm oil production based on widespread participation of a vast range of industry stakeholders, producers and NGOs. However, as participating actors had divergent interests and views, collaboration was only possible by leaving out controversial issues and keeping the debate focused on a managerial approach to sustainable development (Schouten et al., 2012). Despite having developed widely accepted rules concerning participation, deliberation and consensus-orientation, the implementation of these rules has proven difficult (Schouten and Glasbergen, 2011). Under the pressure of pragmatism and "the principle of urgency", the RSPO process has been dominated by the search for a "quick and effective solution" (Cheyns, 2011) rather than by developing deliberative capacity (Schouten et al., 2012). Indeed, within a year of its existence, the RSPO had agreed on a set of criteria for sustainable palm oil, to be verified by third party certification. However, several NGOs and activist groups consider the standard to be ill-equipped to deal with the complex wicked problem of deforestation, biodiversity loss and climate change (Laurence et al., 2010; von Geibler, 2012; Schouten and Glasbergen, 2012), rendering the RSPO susceptible to accusations of green-washing.

Similarly, the Roundtable for Responsible Soy (RTRS) and the Common Code for the Coffee Community (4C) have attempted to move from input legitimacy to the quick taming of wicked problems. While the RTRS was designed for broad stakeholder inclusion, already from the beginning a number of discourses had been systematically marginalized or excluded from the debate on sustainable soy (Schouten et al., 2012). This led to the development of a contested standard and aggravated the conflict lines in the soy industry (Hospes et al., 2012). The 4C was launched in 2004 in response to the "coffee crisis" in 2001-2002, which drew attention to the precarious conditions among coffee producers, including concerns about human rights. Whilst the 4C has managed to involve the great majority of large coffee roasters, it has been criticized for not achieving a representative sample of the stakes in sustainable coffee production and for developing a standard which is not stringent enough to address the underlying causes of human rights abuses in coffee production (Bitzer et al., 2008; MSI Integrity, 2013).

Thus, in terms of the provision of public goods, Strategy 3 makes its key contribution in providing access to "participation in the discourse" and institutional development. In this way, the MSIs have a similar public goods character as the ones from Strategy 1. However, this may be threatened due to the focus of such MSIs on the tame elements of wicked problems and to the pressure for quick outputs. While this strategy often results in the development of soft law voluntary standards, contestation among stakeholders may increase rather than decrease, threatening the input legitimacy of the MSI. Individual commitment may decline in the face of continuing contestation, and the MSIs may struggle with wide-spread non-compliance (see, for instance, Laurence et al., 2010).

Strategy 4: Corporations taming wicked problems in MSIs without sensing them

The final strategy is for corporations to 'use' MSIs in order to focus on one tame component of the wicked problem at hand through output legitimacy, without attempting to deal with the most uncertain, complex and controversial aspects of the problem. Differently from the previously described strategies, these MSIs – implicitly or explicitly – avoid making sense and dealing with the entire wicked problem, driven by the need for quick and measurable results. Therefore, they strongly prioritize output legitimacy over input legitimacy.

The example of the International Cocoa Initiative, seeking to address child labor in cocoa production, is a case in point. In the early 2000s, a global campaign by NGOs, US politicians, and the media, revealing the systemic use of child labor on West African cocoa plantations, forced the cocoa industry to abandon their strategy of neglecting the conditions at the production level and shift towards CSR and stakeholder engagement (Bitzer et al., 2012). As part of this shift, the industry established the International Cocoa Initiative (ICI) in 2002 as a multi-stakeholder initiative, together with a number of social NGOs. From the beginning, the work of the ICI was dictated by a six-point problem-solving approach along with a time-bound process for showing results based on an International Protocol, called the Harkin/Engel Protocol, which the industry had signed one year earlier (ICI, 2013a). Activities were thus pre-determined, focusing on field projects for awareness-raising amongst cocoa farmers. At the end of 2011, the ICI had active programs in 290 cocoa communities in Cote d'Ivoire and Ghana, reaching a total of 700,000 individuals (ICI, 2013b). Concurrently, the industry increased its efforts with the launch of several additional MSIs, such as Empowering Cocoa Households with Opportunities and Education Solutions (ECHOES), the Cocoa Livelihoods Program and the African Cocoa Initiative. Individual corporations also established their 'own' MSIs to promote the use of sustainability standards to ensure socially responsible and environmentally friendly production. However, whilst the combination of these MSIs has contributed to spreading such standards (Matissek et al., 2012) and institutionalizing farmer training by private sector actors (Bitzer et al., 2012), the problem of child labor has not been solved. In its final measurement report, the Payson Center of Tulane University concludes that the industry's efforts have fallen short of eradicating child labor and that "activities must drastically expand" (Payson Center, 2011, p.72). These findings are supported by renewed media and NGO reports, fuelling the international debate on child labor in cocoa production once more.

With regard to the provision of public goods, the focus of Strategy 4 lies in addressing a specific sub-set of problems which may result in concrete, measurable outputs, such as the number of beneficiaries having received training. However, in this way the MSIs may show data of their effectiveness whilst there is no scientific or societal agreement on the wider problem at hand. As these MSIs fall short in terms of input legitimacy, which would assist in getting a widely accepted problem definition, the risk of such MSIs is that they provide public goods, such as information, which do not capture critical dimensions of the broader wicked problem.

To conclude, section 3 argued that corporations have two main options of pursuing political CSR strategies to deal with wicked problems: they may either decide to unilaterally deal with wicked problems (individual endeavor) or they may establish or join one or several MSIs (collective endeavor). The latter strategy would appear to have the advantage of offering organizational structures that directly deal with the three main characteristics of wicked problems (scientific uncertainty, value conflict and dynamic complexity). Within the option of joining MSIs, section 4 identified four main strategies of how corporations intend to deal with wicked problems. Together, this can be illustrated in the following figure.

INSERT FIGURE 1 ABOUT HERE

---

5. Discussion

5.1. A three-dimensional conceptualization of wicked problems

In the context of this paper we define wicked problems as societal challenges that are (i) scientifically uncertain, (ii) involve multiple stakeholders with conflicting values and objectives, and (iii) are dynamic in that they have no unique and final solution(s) or outcome(s) (Kreuter, et al. 2004; Batie, 2008). In Table III we present the main characteristics of wicked problems as discussed in the literature (Rittel and Webber, 1973; Ritchey, 2005) and the three dimensions identified in the empirical part of the paper and consistent with the extant literature.

Scientific uncertainty refers to both the formulation of the problem(s) and the potential solutions such that stakeholders have to make decisions in an incomplete information setting. Uncertainty derives from limited availability of information due to gaps in scientific knowledge of the problem(s) and solution(s) and is aggravated by cognitive limits of decision-makers to adequately deal with, process and put into use the information that is available (Dietz et al. 2003; Hajer, 2003; Batie, 2008; Head and Alford, 2013). The presence of *value conflicts* represents another dimension of wicked problems. Multiple stakeholders are affected by wicked problems, each with their own set of values, frames, perceptions, and interests, which may not only diverge but downright oppose and clash with one another. The wickedness of problems is such that there may not even be a general consensus on broad societal goals and much less a consensus on what type of information and knowledge would be relevant to address a particular wicked problem (Batie, 2008). Hence, trade-offs between values are likely to occur (Weber and Khademian, 2008). Finally, as wicked problems involve complex interdependencies, they are volatile and evolve over time, sometimes linearly but frequently unpredictably and unexpectedly (Jentoft and Chuenpagdee, 2009). This *dynamic complexity* implies that there are no 'solutions' in the sense of definite and objective answers to the problem over time (Rittel and Webber, 1973).

INSERT TABLE III ABOUT HERE

5.2. Implications for Managers

The findings of this paper, as synthesized in Figure 1, lead to three key managerial implications. First, the nature of wicked problems poses intricate challenges to corporations, as they require a fundamentally different approach to the way they deal with tame problems. Above all, this entails that managers need to be able to first *recognize* that indeed they are dealing with a wicked problem. Two sources of knowledge to recognize wicked problems are from within or from outside the organization. From within the organization, corporations may activate reflection processes on the issues at hand at all levels within the organization, up to top management (Dutton and Ashford, 1993). Through internal reflection processes, corporations may identify that the cause of corporate struggle to deal with the problem is its uncertain, value-conflict and changing nature itself. From outside the organization, a corporation is more likely to understand the nature of problems at hand if embedded in networks of heterogeneous stakeholders (Wu and Liu 2009; Yang et al., 2011), so that a flow of external information and knowledge about the nature of problems at hand facilitates the recognition processes. For example, corporations may enter into partnerships with stakeholders as part of an isomorphic adaptation strategy to pressures from the external environment (Scherer et al., 2013)and then learn from the established network how to recognize the wicked problem at hand.

Second, to deal with the specific characteristics of wicked problems, corporations have the option of *organizing their political CSR strategy* as a combination of resources *within and outside their boundaries*. From outside their boundaries, the key advantage of engaging in MSIs is to access their working groups, stakeholder forums and permanent observatories as institutional arrangements that facilitate scientific debate, representation of value conflict, and sensing the changing causes, symptoms and effects of the problems at hand. Yet, joining MSIs has trade-offs in terms of organizational costs, benefits and risks that a corporation may face as discussed in section 3.2.We argue that perceived costs, benefits and risks of joining versus not MSIs as part of political CSR strategies vary depending on organizational and strategic factors. Organizational factors which increase the likelihood of developing CSR strategies to deal with wicked problems through MSIs include the size of the firm and its ability to learn from the external environment; for instance, from MSIs (Dentoni et al., 2013). From a strategic standpoint, corporations may decide to joining MSIs to deal with wicked problems depending on their market position, power in the supply chain and on their country of operations. In particular, corporations with a market leader position, with the power of setting standards within their supply chain or industry-wide and operating in countries with less favorable business environments are more likely to receive pressure and higher risks from the external environment on the wicked problems at hand, and therefore to join or establish MSIs.

Third, corporations that decide to deal with wicked problems through multi-stakeholder arrangements outside their boundaries have *four broad CSR strategies that they can adopt through MSIs*, namely I) tackling wicked problems through MSIs' input legitimacy or II) output legitimacy; or III) taming wicked problems through MSIs' input legitimacy or IV) output legitimacy. In contrast with past literature (Kaan and Liese, 2010; Mena and Palazzo, 2012), we argue that the nature of wicked problems makes it unlikey to achieve both input *and* output legitimacy in one MSI. If MSI seeks input legitimacy, the value conflict among a wide representative spectrum of stakeholder included in the discussion does not allow setting and enforcing the agreed rules to the entire industry. Vice versa, a large-scale and rapid setting, implementation and enforcement of agreed rules in the industry does not allow broad MSIs' inclusiveness in a context of scientific uncertainty, value conflict and dynamic complexity. This trade-off seems lie at the bottom of the wide-spread perception that MSIs often fail to complement existing private and public governance institutions in the provision of public goods (Verweij 2006; Fransen and Kolk 2007). This suggests that corporations need to be aware of the legitimacy trade-off in MSIs and seek complementary strategies to achieve a greater balance. Especially corporations participating in a "portfolio of MSIs" (Kolk et al. 2008) within the same wicked problem context should balance and coordinate the four CSR strategies through simultaneous engagement in complementary MSIs.; In turn, coordinating and balancing simultaneous legitimization strategies within MSIs requires that corporations develop structural and contextual solutions (Scherer et al. 2013) which allow reflecting and communicating coherently on the goals and means of the overarching CSR strategy.

6. Research Implications and Conclusions

Drawing on the existing literatures on wicked problems and multi-stakeholder institutions, we argue that corporations have increasingly engaged in MSIs over the past two decades to face the sustainability problems at hand. These problems are not necessarily global; instead, they are "wicked" (Rittel and Webber 1973). Yet, not all the corporations recognize their wicked nature. This paper first identifies three key dimensions of wicked problems consistent with the established definitions in policy and planning theory (Rittel and Webber 1973; Ritchey 2005): *scientific uncertainty*, *value conflict* and *dynamic complexity*. This implies that managing legitimacy in a context of wicked problems is a more articulated challenge for corporations than in a context of complex environments or in which institutional demands collide (Pache and Santos 2010; Greenwood et al. 2011; Smith and Lewis 2011; Scherer et al. 2013). In such a context, corporations trying to gain or maintain legitimacy need to seek systemic and permanent mechanisms of collaboration and governance with stakeholders to understand and address wicked problems (Rittel and Webber 1973). In MSIs, corporations and their stakeholders can address the scientific uncertainty of problems at hand through *working groups* of experts, manage value conflict through *stakeholder forums* and deal with dynamic complexity through *permanent observatories*. Second, this paper explores CSR strategies available to corporations to deal with wicked problems through MSIs building upon the idea that managers can either tackle or tame their problems at hand (Conklin 2006) and seek democratic legitimacy in MSIs as a combination of input and output legitimacy (Mena and Palazzo 2012). We identify four alternative CSR strategies based on the corporate choice of either *tackling or taming* the wicked problem through an MSI, or in other words, taking a broad focus to address the whole problem or a narrow focus to address only one of its elements; and of either seeking *input or output legitimacy* in a MSI (which we assume to be, respectively, an indicator of having recognized the wicked nature of the problem or not, respectively). This implies that corporations seeking legitimacy through MSIs in the context of wicked problems face intractable trade-offs between being inclusive and representative of stakeholders' beliefs, expectations, goals and values and being able to establish, extend and enforce jointly agreed rules to the entire industry.

The wicked problem perspective taken in this paper to approach political CSR and its organizational forms opens up avenues for future research in at least three domains. The first is the CSR domain, where the broad question of under which conditions companies decide to tackle rather than taming wicked problems is open. Organizational characteristics such as size, position in the supply chain and market leadership is likely to influence the approach taken by companies in managing legitimacy in a context wicked problems. Moreover, pre-existing CSR strategies (Maon et al., 2010) may influence the decision of a corporation of tackling versus taming the wicked problem. Proactive CSR companies may be more inclined to tackle wicked problems than reactive companies, which may instead keeping a narrow focus in dealing with the problem unless receiving pressure to expand their focus (Aragon-Correa and Sharma, 2003; Buysse and Verbeke, 2003). Finally, corporations taking a paradox approach to CSR in uncertain and complex environments (Smith and Lewis, 2011) may be more likely to take a two-way strategy of tackling and taming wicked problems than corporations taking a contingency approach (Scherer et al., 2013).

Second, a wicked problems perspective contributes to the literature on new governance mechanisms for sustainable development (Dietz et al., 2003; Selsky and Parker, 2005; Bäckstrand, 2006; Rasche, 2009; Andonova et al., 2009). Despite the fact that each wicked problems is unique and no one-size-fits-all solution exists (Rittel and Webber 1973), we identified the organizational structures of working groups, stakeholder forums and permanent observatories as key common characteristics of MSIs to deal with wicked problems. The broad question now concerns the effectiveness of these structures to enhance societal learning and reduce coordination costs in the process of dealing with scientific uncertainty, value conflict and dynamic complexity surrounding wicked problems. Looking at the formal and informal rules that govern these structures and how they influence the respective organizational structures may be one promising line of enquiry (Rivera-Santos and Rufin, 2011). At the same time, the effectiveness of the organizational structures of MSIs is not only influenced by general rules and procedures, but importantly also by the participants themselves. This refers to the 'capability of governance' (Argyres et al., 2012) which points to the type of capabilities of companies and other stakeholders needed to make use of MSIs' organizational structures to deal with wicked problems.

As a third avenue for future research, the theory of wicked problems could be advanced as well by analyzing the conditions under which large influential actors in a system, such as a corporation, recognize the problem at hand and take action to deal with it (Ritchey, 2005; Conklin, 2006). It would be useful for policy-makers to analyze the preconditions and forms of corporate participation to wicked problems (Verweij 2006). Due to the trade-offs in the provision of public goods discussed in this paper, we argue that one private (or public-private) institution alone such as one MSI does not achieve democratic legitimacy in a context of wicked problems. The broad question then concerns if corporations can possibly establish a coherent coordination of among multiple institutions to achieve democratic legitimacy in a context of wicked problems. Would corporations coordinating strategies across multiple MSIs be effective in dealing with wicked problems or would they again come up with a "clumsy solution" (Verweij 2006) in the attempt to mediate between input and output legitimacy? A deeper exploration in this direction would clarify whether corporations can at least limit the urgency and intensification of wicked problems or at least moderating the societal perception of being part of the problem (Levin et al. 2012).

References

Aguinis, H. and Glavas, A. (2012). 'What We Know and Don't Know About Corporate Social Responsibility: A Review and Research Agenda'. *Journal of Management*, **38(4)**, 932-968.

Andonova, L.B., Betsill, M.M. and Bulkeley, H. (2009). 'Transnational Climate Governance'. *Global Environmental Politics*, **9(2)**, 52-73.

Andvig, J. C. (1998). 'Child Labour in Sub-Saharan Africa - An Exploration'. *Forum for development studies*, **25(2)**, 327-362.

APF (2013). AgriPro Focus website. Retrieved from: ~~http://www.agri-profocus.nl/~~. Accessed on 31 August 2013.

Aragon-Correa, J. A., & Sharma, S. (2003). 'A contingent resource-based view of proactive corporate environmental strategy'. *Academy of Management Review*, **28(1)**, 71-88.

Bäckstrand, K. (2006). 'Multi-stakeholder partnerships for sustainable development: rethinking legitimacy, accountability and effectiveness'. *European Environment*, **16(5)**, 290-306.

Bal, P., Nath, C. D., Nanaya, K. M., Kushalappa, C. G. and Garcia, C. (2011). 'Elephants also like coffee: Trends and drivers of human-elephant conflicts in coffee agroforestry landscapes of Kodagu, Western Ghats, India'. *Environmental Management*, **47(5)**, 789-801.

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C., and Mirin, A. (2007). 'Combined climate and carbon-cycle effects of large-scale deforestation'. *Proceedings of the National Academy of Sciences*, **104(16)**, 6550-6555.

Barrett, C. B. (2010). 'Measuring food insecurity'. *Science*, **327 (5967)**, 825-828.

Batie, S. S. (2008). 'Wicked problems and applied economics'. *American Journal of Agricultural Economics*, **90(5)**, 1176-1191.

Bitzer, V., Francken, M., and Glasbergen, P. (2008). 'Intersectoral partnerships for a sustainable coffee chain: Really addressing sustainability or just picking (coffee) cherries?'. *Global Environmental Change*, **18(2)**, 271-284.

Bitzer, V., Glasbergen, P. and Leroy, P. (2012). 'Partnerships of a feather flock together? An analysis of the emergence of networks of partnerships in the global cocoa sector'. *Global Networks*, **12(3)**, 335-374.

Bryson, J.M., Crosby, B.C. and Middleton Stone, M. (2006). 'The Design and Implementation of Cross-Sector Collaborations: Propositions from the Literature.' *Public Administration Review* **66(1)**, 44-55.

Buchanan, R. (1992). 'Wicked problems in design thinking'. *Design issues*, **8(2)**, 5-21.

Butchart, S.H., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P., Almond, R. E., Jonathan E. M. Baillie,... and Watson, R. (2010). 'Global biodiversity: indicators of recent declines'. *Science*, **328 (5982)**, 1164-1168.

Buysse, K., & Verbeke, A. (2003). 'Proactive environmental strategies: a stakeholder management perspective'. *Strategic Management Journal*, **24(5)**, 453-470.

Calton, J. M., and Payne, S.L. (2003). 'Coping With Paradox Multistakeholder Learning Dialogue as a Pluralist Sensemaking Process for Addressing Messy Problems'. *Business & Society*, **42(1)**, 7-42.

Camillus, J. C. (2008). 'Strategy as a wicked problem'. *Harvard Business Review*, **86(5)**, 98-101.

CDP - Carbon Disclosure Project (2013). Reducing Risk and Driving Business Value: CDP Supply Chain report 2012-2013. Carbon Disclosure Project: London, UK.

Chazdon, R. L. (2008). 'Beyond deforestation: restoring forests and ecosystem services on degraded lands'. S*cience*, **320** (**5882**), 1458-1460.

Cheyns, E., 2011. Multi-stakeholder Initiatives for Sustainable Agriculture: Limits of the 'Inclusiveness' Paradigm. In: Ponte, S., Vestergaard, J. & Gibbon, P., eds., *Governing through standards: Origins, drivers and limits*, London: Palgrave, 318-354.

Conklin, J. (2006). *Wicked problems and social complexity*. Napa, USA: CogNexus Institute.

Crane, A., Matten, D. and Spence, L.J. (Eds) (2008). *Corporate social responsibility: Readings and cases in a global context*. London: Routledge.

Crona, B. and Parker, J.N. (2012). 'Learning in Support of Governance: Theories, Methods, and a Framework to Assess How Bridging Organizations Contribute to Adaptive Resource Governance'. *Ecology and Society*, **17(1)**, 32.

DeFries, R. S., Rudel, T., Uriarte, M. and Hansen, M. (2010). 'Deforestation driven by urban population growth and agricultural trade in the twenty-first century'. *Nature Geoscience*, **3(3)**, 178-181

Dentoni, D. and Peterson, H.C. (2011). 'Multi-Stakeholder Sustainability Alliances in Agri-Food Chains: A Framework for Multi-Disciplinary Research'. *International Food and Agribusiness Management Review*, **14(5)**, 83-108.

Dentoni, D. and Ross, R. B. (2013). 'Towards a Theory of Managing Wicked Problems through Multi-Stakeholder Engagements: Evidence from the Agribusiness Sector'. *International Food and Agribusiness Management Review*, **16**(A).

Dentoni, D., Bitzer, V. and Pascucci, S. (2013). 'Cross-Sector Partnerships and the Co-Creation of Dynamic Capabilities for Stakeholder Orientation'. *Journal of Business Ethics*, forthcoming.

Dentoni, D., Hospes, O. and Ross, B. (2012). 'Managing Wicked Problems in Agribusiness: The Role of Multi-Stakeholder Engagements in Value Creation'. *International Food and Agribusiness Management Review,* **15 (B)**, 1-12

Dietz, T., Ostrom, E., & Stern, P. C. (2003). 'The struggle to govern the commons'. *Science*, **302(5652)**, 1907-1912.

Dutton, J. E. and Ashford, S. J. (1993). 'Selling issues to top management'. *Academy of management review*, **18(3)**, 397-428.

Eisenstadt, M. (2010). *The Sustainable Food Lab. A Case Study*. Reos Partners, Cambridge, Massachusetts.

Fish, R., Lobley, M. and Winter, M. (2013). '~~A license to produce? Farmer interpretations of the new food security agenda~~'. *Journal of Rural Studies* **29**, 40-49.

Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD) and World Food Programme (WFP) (2012). 'The State of Food Insecurity in the World 2012'. FAO, Rome.

Fransen, L. W., and Kolk, A. (2007). 'Global rule-setting for business: A critical analysis of multi-stakeholder standards'. *Organization*, **14(5)**, 667-684.

Freeman, R. E. (2010). *Stakeholder theory.* Cambridge: Cambridge University Press.

Fuchs, D., Kalfagianni, A. and Havinga, T. (2011). 'Actors in private food governance: the legitimacy of retail standards and multistakeholder initiatives with civil society participation'. *Agriculture and Human Values*, **28**, 353-367.

GAIN Alliance (2013). GAIN Alliance website. Retrieved from: http://www.gainhealth.org/. Accessed on 31 August 2013.

Gerhardinger, L. C., Godoy, E. A., Jones, P. J., Sales, G. and Ferreira, B. P. (2011). 'Marine protected dramas: the flaws of the Brazilian national system of marine protected areas'. *Environmental management*, **47(4)**, 630-643.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C. (2010). 'Food security: the challenge of feeding 9 billion people'. S*cience*, **327(5967)**, 812-818.

Googins, B.K. and Rochlin, S.A. (2000). 'Creating the Partnership Society: Understanding the Rhetoric and Reality of Cross-Sectoral Partnerships'. *Business and Society Review* **105(1)**, 127-144.

Greenwood, M. (2007). 'Stakeholder engagement: Beyond the myth of corporate responsibility'. *Journal of Business Ethics*, **74(4)**, 315-327.

Greenwood et al. 2011;

Griffiths, H. (2010). '"Sustainable" palm oil driving deforestation. Biofuel crops, indirect land use change and emissions. Briefing paper, Friends of the Earth Europe, Brussels.

GRI - Global Reporting Initiative. 2010. GRI Sustainability Reporting Statistics. ~~http://www.globalreporting.org/ReportServices/GRIReportsList/~~ (Accessed on 1 December 2011).

Hajer, M. (2003). 'Policy without polity? Policy analysis and the institutional void'. *Policy sciences*, **36(2)**, 175-195.

Hamann, R., Giamporcaro, S., Johnston, D. and Yachkaschi, S. (2011). 'The role of business and cross-sector collaboration in addressing the 'wicked problem'of food insecurity'. *Development Southern Africa*, **28(4)**, 579-594.

Hamilton, H., 2013. 'Sustainable Food Lab Learning Systems for Inclusive Business Models Worldwide'. *International Food and Agribusiness Management Review,* **16(A)**, 33-38.

Harris, J., Brown, V. A. and Russell, J. (Eds) (2012). *Tackling wicked problems: through the trans-disciplinary imagination*. CRC Press.

Head, B. W. and Alford, J. (2013). 'Wicked Problems: Implications for Public Policy and Management'. *Administration & Society* (on-line first).

Hear, N. (2008). 'Child labour and the development of capitalist agriculture in Ghana'. *Development and Change*, **13(4)**, 499-514.

Hillman, A. J., Keim, G. and Schuler, D. (2004). 'Corporate political activity: a review and research agenda'. *Journal of Management*, **30**, 837–57.

Hinrichs, C.C. (2013). '~~Regionalizing food security? Imperatives, intersections and contestations in a post-9/11 world~~.' *Journal of Rural Studies* **29**, 7-18.

Horn, R. (2001). Knowledge Mapping for Complex Social Messes. ~~http://www.stanford.edu/-rhrn/a/recent/spchKnowldgPACKARD.pdf~~ (Accessed on 10 December 10 2011)

Hospes, O., van der Valk, O. and Mheen-Sluijer, J. (2012). 'Parallel development of five partnerships to promote sustainable soy in Brazil: solution or part of wicked problems'. *International Food and Agribusiness Management Review*, **15**(B), 39-62.

Hyatt, D. G. and Spicer, A. (2012). Walmart's Sustainability Journey: Defining Sustainable Products (A). The University of Arkansas and the University of South Carolina. Retrieved from: ~~http://uarkive.uark.edu/~~. Accessed 31 August 2013.

International Cocoa Initiative (ICI), 2013a. Harkin Engel Protocol. Retrieved from: ~~http://www.cocoainitiative.org/en/reports/harkin-engel-protocol~~. Accessed 27 August 2013.

International Cocoa Initiative (ICI), 2013b. Community-driven action. Retrieved from: ~~http://www.cocoainitiative.org/en/what-we-do/community-driven-action~~. Accessed 27 August 2013.

Jentoft, S. and Chuenpagdee, R. (2009). 'Fisheries and coastal governance as a wicked problem'. *Marine Policy*, **33(4)**, 553-560.

Joseph Wright, S. and Muller-Landau, H. C. (2006). 'The uncertain future of tropical forest species'. *Biotropica*, **38(4)**, 443-445.

Kaan Liese

Kaptein, M. and Van Tulder, R. (2003). 'Toward effective stakeholder dialogue'. *Business and Society Review*, **108(2)**, 203-224.

Kaul, I., Grungberg, I. and Stern, M. A. (1999). 'Global public goods'. *Global public goods*, **450**.

Klijn, E.H., Koppenjan, J. and Termeer, K. (2007). 'Managing networks in the public sector: a theoretical study of management strategies in policy networks'. *Public Administration*, **73(3)**, 437-454.

Kobrin, S.J. (2009). 'Private Political Authority and Public Responsibility: Transnational Politics, Transnational Firms, and Human Rights'. *Business Ethics Quarterly*, **19(3)**, 349-374.

Koh, L.P. and Wilcove, D.S. (2008) 'Is oil palm agriculture really destroying tropical biodiversity?' *Conservation Letters* **1(2)**, 60-64.

Kolk, A., Van Tulder, R. and Kostwinder, E. (2008). 'Business and partnerships for development'. *European Management Journal*, **26(4)**, 262-273.

Kreuter, M. W., De Rosa, C., Howze, E. H. and Baldwin, G. T. (2004). 'Understanding wicked problems: a key to advancing environmental health promotion'. *Health education & behavior*, **31(4)**, 441-454.

Lamb, D., Erskine, P. D. and Parrotta, J. A. (2005). 'Restoration of degraded tropical forest landscapes'. *Science*, **310(5754)**, 1628-1632.

Laurance, W. F. (2007). 'Have we overstated the tropical biodiversity crisis?'. *Trends in Ecology & Evolution*, **22(2)**, 65-70.

Laurance, W.F., Koh, L., Butler, R., Sodhi, N.S., Bradshaw, C.J.A., Neidel, J.D., Consunji, H. and Vega, J.V., 2010. Improving the Performance of the Roundtable on Sustainable Palm Oil for Nature Conservation. *Conservation Biology*, 24(2), 377–381.

Lazarus, R.J. (2009). ‘Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future’. *Cornell Law Review*, **94**, 1153-1234.

Levin, K., Cashore, B., Bernstein, S. and Auld, G. (2012). ‘Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change’. *Policy Sciences*, **45**, 123-152.

Maon et al., 2010

Margolis, J. D. and Walsh, J.P. (2003).‘Misery loves companies: Rethinking social initiatives by business‘. *Administrative Science Quarterly*, **48(2)**, 268-305.

Maskus, K.E. and Reichmann, J.H. (2004).‘The globalization of private knowledge good and the privatization of global public goods’. *Journal of International Economic Law*, **7(2)**, 279-320.

Matissek, R., Reinecke, J., Von Hagen, O.and Manning, S. (2012). ‘Sustainability in the Cocoa Sector-Review, Challenges and Approaches’. *Moderne Ernaehrung Heute, Official Journal of the Food Chemistry Institute of the Association of the German Confectionery Industry*, 1-27.

McCarthy, J.F., Gillespie, P. and Zen, Z. (2012) ‘Swimming Upstream: Local Indonesian Production Networks in “Globalized” Palm Oil Production’. *World Development* **40(3)**, 555-569.

McWilliams, A. and Siegel, D. (2001). ‘Corporate social responsibility: A theory of the firm perspective’. *Academy of management review*, **26(1)**, 117-127.

Mena, S. and Palazzo, G. (2012). ‘Input and output legitimacy of multi-stakeholder initiatives’. *Business Ethics Quarterly*, **22(3)**, 527-556.

Miettinen, J., Shi, C. and Liew, S.C. (2011). ‘Deforestation rates in insular Southeast Asia between 2000 and 2010’. *Global Change Biology* **17(7)**, 2261-2270.

MSI Integrity, 2013. Common Code for the Coffee Community (4C): Evaluation Report. Working Draft. Retrieved from: ~~http://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&ved=0CC4QFjAB&url=http%3A%2F%2Fwww.msi-integrity.org%2Fwp-content%2Fuploads%2F2013%2F04%2F4C-Working-Evaluation-Report.pdf&ei=l3gfUuK_KIbAhAfhgYHACw&usg=AFQjCNFPxAj86S5gUZMagIgS2aEwDPEtmg~~. Accessed 27 August 2013.

Neubauer, P., Jensen, O. P., Hutchings, J. A. and Baum, J. K. (2013). ‘Resilience and Recovery of Overexploited Marine Populations’. *Science*, **340 (6130)**, 347-349.

Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B. and Policansky, D. (1999). ‘Revisiting the commons: local lessons, global challenges’. *Science*, **284 (5412)**, 278-282.

Pache and Santos 2010;

Palazzo, G. and Scherer, A. G. (2006). ‘Corporate legitimacy as deliberation: A communicative framework’. *Journal of Business Ethics*, **66(1)**, 71-88.

Palazzo, G. and Scherer, A. G. (2008). ‘Corporate social responsibility, democracy, and the politicization of the corporation’. Academy of Management Review **33 (3)**, 773–5.

Payne, S.L. and Calton, J.M. (2002). 'Towards a managerial practice of stakeholder engagement'. *Journal of Corporate Citizenship* **6**, 37-52.

Payson Center, 2011. Oversight of Public and Private Initiatives to Eliminate the Worst Forms of Child Labor in the Cocoa Sector in Cote d'Ivoire and Ghana. Final report. Tulane University, USA.

Pikitch, E. K. (2012). 'The risks of overfishing'. *Science*, **338 (6106)**, 474-475.

Porter, M.E. and Kramer, M.R. (2011). 'Creating Shared Value How to reinvent capitalism—and unleash a wave of innovation and growth'. *Harvard Business Review*, **89**, 62-77.

Rangel, T. F. (2012). 'Amazonian Extinction Debts'. *Science*, **337(6091)**, 162-163.

Rasche, A. (2009). 'Toward a model to compare and analyze accountability standards–The case of the UN Global Compact'. *Corporate Social Responsibility and Environmental Management*, **16(4)**, 192-205.

Ritchey, T. (2005). Wicked Problems: Structuring Social Messes with Morphological Analysis. Swedish Morphological Society, www.swemorph.com (Accessed on 20 August 2013).

Rittel, H. W. and Webber, M.M. (1973). 'Dilemmas in a general theory of planning'. *Policy sciences*, **4(2)**, 155-169.

Rivera-Santos, M. and Rufin, C. (2011). 'Odd Couples: Understanding the Governance of Firm-NGO Alliances'. *Journal of Business Ethics*, **94**, 55-70.

Roberts, N. (2000). 'Wicked problems and network approaches to resolution'. *International public management review*, **1(1)**, 1-19.

Rondinelli, D. A. and London, T. (2003). 'How corporations and environmental groups cooperate: Assessing cross-sector alliances and collaborations'. *The Academy of Management Executive*, **17(1)**, 61-76.

Rosegrant, M. W. and Cline, S. A. (2003). 'Global food security: challenges and policies'. *Science*, **302 (5652)**, 1917-1919.

Rudel, T. K., Defries, R., Asner, G. P. and Laurance, W.F. (2009). 'Changing drivers of deforestation and new opportunities for conservation'. *Conservation Biology*, **23(6)**, 1396-1405.)

Ruggie, J.G. (2007). 'Business and Human Rights: The Evolving International Agenda'. *The American Journal of International Law*, **101(4)**, 819-840.

Sachs, S., Rühli, E. and Meier, C. (2010). 'Stakeholder governance as a response to wicked issues'. *Journal of business ethics*, **96(1)**, 57-64.

SAI Platform (2013). SAI Platform website. Retrieved from: www.saiplatform.org. Accessed on 31 August 2013.

Scherer, A.G. and Palazzo, G. (2007). 'Toward a Political Conception of Corporate Responsibility: Business and Society Seen From a Habermasian Perspective.' Academy of Management Review, **32 (4)**, 1096-1120.

Scherer, A. G. and Palazzo, G. (2011). 'The new political role of business in a globalized world: A review of a new perspective on CSR and its implications for the firm, governance, and democracy'. *Journal of Management Studies*, **48(4)**, 899-931.

Scherer, A.G., Palazzo, G. and Seidl, D. (2013). 'Managing Legitimacy in Complex and Heterogeneous Environments: Sustainable Development in a Globalized World'. Journal of Management Studies, **50(2)**, 259-284.

Scherer, A.G. and Palazzo, G. (2008). 'Globalization and Corporate Social Responsibility'. In: *The Oxford Handbook of Corporate Social Responsibility*, A. Crane, A. McWilliams, D. Matten, J. Moon, D. Siegel, eds., 413-431, Oxford University Press.

Schouten, G. and Glasbergen, P. (2011). 'Creating legitimacy in global private governance: The case of the Roundtable on Sustainable Palm Oil'. *Ecological economics*, **70(11)**, 1891-1899.

Schouten, G., Leroy, P. and Glasbergen, P. (2012). 'On the deliberative capacity of private multi-stakeholder governance: the roundtables on responsible soy and sustainable palm oil'. *Ecological Economics,* **83**, 42-50.

Schroth, G. and McNeely, J. A. (2011). 'Biodiversity Conservation, Ecosystem Services and Livelihoods in Tropical Landscapes: Towards a Common Agenda'. *Environmental management*, **48(2)**, 229-236.

Seitanidi, M.M. and Crane, A. (2009). 'Implementing CSR through partnerships: Understanding the selection, design and institutionalisation of nonprofit-business partnerships'. *Journal of Business Ethics,* **85(2)**, 413-429.

Selsky, J. W. and Parker, B. (2005). 'Cross-sector partnerships to address social issues: Challenges to theory and practice'. *Journal of Management*, **31(6)**, 849-873.

Serageldin, I. (1999). 'Biotechnology and food security in the 21st century'. *Science*, **285(5426)**, 387-389.

Smith and Lewis 2011

Tan, K.T., Lee, K.T., Mohamed, A.R. and Bhatia, S. (2009) 'Palm oil: Addressing issues and towards sustainable development'. *Renewable and Sustainable Energy Reviews* **13**, 420-427.Termeer, C., Dewulf, A., Breeman, G. and Stiller, S.J. (2013). 'Governance Capabilities for Dealing Wisely With Wicked Problems'. *Administration and Society*, online first.

TSC (2013). The Sustainability Consortium website. Retrieved from: www.sustainabilityconsortium.org. Accessed on 31 August 2013.

UN Global Compact 2011. *UNGC Annual Review*. New York, NY: United Nations Global Compact Office.

Utting, P. (2002). 'Regulating business via multistakeholder initiatives: a preliminary assessment'. *Voluntary Approaches to Corporate Responsibility: Readings and a Resource Guide*, 61-130.

Van Bueren, E. M., Klijn, E. H. and Koppenjan, J. F. (2003). 'Dealing with wicked problems in networks: Analyzing an environmental debate from a network perspective'. *Journal of Public Administration Research and Theory*, **13(2)**, 193-212.

Verweij, M., Douglas, M., Ellis, R., Engel, C., Hendriks, F., Lohmann, S., and Thompson, M. (2006). 'Clumsy solutions for a complex world: the case of climate change'. *Public Administration*, **84(4)**, 817-843.

von Geibler, J. (2012). 'Market-based governance for sustainability in value chains: Conditions for successful standard setting in the palm oil sector'. Journal of Cleaner Production, 56(1), 39-53.

Waddell, S., McLachlan, M. and Dentoni, D. (2013). 'Learning & Transformative Networks to Address Wicked Problems: A GOLDEN Invitation'. *International Food and Agribusiness Management Review*, **16(A)**, 23-32.

Waddock, S. (2008). 'Building a new institutional infrastructure for corporate responsibility'. *The Academy of Management Perspectives*, **22(3)**, 87-108.

Wakker, E. (2005) 'Greasy palms: the social and ecological impacts of large-scale oil palm plantation development in Southeast Asia.' Friends of the Earth, London, UK.

Wearn, O. R., Reuman, D. C. and Ewers, R.M. (2012). 'Extinction debt and windows of conservation opportunity in the Brazilian Amazon'. *Science*, **337(6091)**, 228-232.

Weber, E. P. and Khademian, A.M. (2008). 'Wicked problems, knowledge challenges, and collaborative capacity builders in network settings'. *Public Administration Review*, **68(2)**, 334-349.

WEF (2011). World Economic Forum Website: Annual Meeting 2011. ~~http://www.weforum.org/events/world-economic-forum-annual-meeting-2011?idsessions=2619~~ (Accessed on 5 March 2013).

Westbrook, J.I., Braithwaite, J., Georgiou, A., Ampt, A., Creswick, N., Coiera, E., and Iedema, R. (2007). 'Multimethod evaluation of information and communication technologies in health in the context of wicked problems and sociotechnical theory'. *Journal of the American Medical Informatics Association*, **14(6)**, 746-755.

Wheeler, T. and von Braum, J. (2013). 'Climate Change Impacts on Global Food Security'. *Science*, **341(508)**, 508-513.

Whelan, G. (2012). 'The Political Perspective of Corporate Social Responsibility: A Critical Research Agenda'. *Business Ethics Quarterly,* **22(4)**, 709-737.

Wilcove, D.S. and Koh, L.P. (2010). 'Addressing the threats to biodiversity from oil-palm agriculture'. *Biodiversity and Conservation*, **19(4)**, 999-1007.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C. and Zeller, D. (2009). 'Rebuilding global fisheries'. *Science*, **325(5940)**, 578-585.

Wu, X., and Liu, X. (2009). 'Absorptive capacity, network embeddedness and local firm's knowledge acquisition in the Global Manufacturing Network'. *International Journal of Technology Management*, **46(3)**, 326-343.

Yang, H., Lin, Z. J., and Peng, M. W. (2011). 'Behind acquisitions of alliance partners: exploratory learning and network embeddedness'. *Academy of Management Journal*, **54(5)**, 1069-1080.

Young, I.M. (2006). 'Responsibility and global justice: a social connection model'. *Social Philosophy and Policy*, **23(1)**, 102-130.

Zarin, D.J. (2012). 'Carbon from Tropical Deforestation', *Science*, **336(6088),** 1518-1519.

Zerbe, N. (2004). 'Feeding the famine? American food aid and the GMO debate in Southern Africa'. *Food Policy*, **29(6)**, 593-608.

Dimension	Characteristic	Explanation
(i) Scientific uncertainty	*There is no definitive formulation of a wicked problem.*	The decision-makers have incomplete information on the problem and its possible causes.
	Every wicked problem is essentially unique.	There is no "solution which fits all", nor the possibility of synthesizing wicked problems into classes to address with similar solutions.
	Every wicked problem can be considered to be a symptom or a consequence of another problem.	Wicked problems are entangled among each other in an ill-defined set of causes and effects.
	Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions.	The decision-makers have incomplete information on the set of possible and desirable solutions.
(ii) Value conflict	*The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.*	Multiple actors influencing or affected by the wicked problems have different assumptions on what causes the problem and should be done about it.
	The decision-makers have "no right to be wrong".	The solutions chosen to deal with a wicked problem have serious repercussions on societal groups, yet, if the solution has not been satisfactory there is no proof that alternative solutions would have been better (or worse).
	Solutions to wicked problems are not true-or-false, but better-or-worse.	Solutions are judged by societal stakeholders based on their personal or group interests, special value-sets, and ideological predilections.
(iii) Dynamic complexity	*Wicked problems have no stopping rule.*	The process of exploring and tackling the problem never ends or, in practice, it ends when actors have exhausted the resources invested into the process but not because the problem has been solved.
	There is no immediate and no ultimate test of a solution to a wicked problem.	Actions taken to tackle the problems have unintended consequences beyond the expected and planned.
	Every solution to a wicked problem is a "one-shot operation".	The decision-makers cannot learn form a trial-and-error approach when tackling the problem because each action changes the decision context substantially.

Table III. Dimensions and characteristics of wicked problems

Source: adapted from (Rittel and Webber 1973; Ritchey 2005)

Table I. Examples of three "wicked" problems in agriculture and food sector

Wicked problem	(i) Scientific uncertainty	(ii) Value conflict	(iii) Dynamic complexity
Deforestation *(and the debate*	• Extent and rate of biodiversity loss due to deforestation in the tropics remains uncertain	• Global and local drivers, urban/rural drivers limit possible solutions to	• Changing drivers and changing solutions (Rudel, et al.,2009).

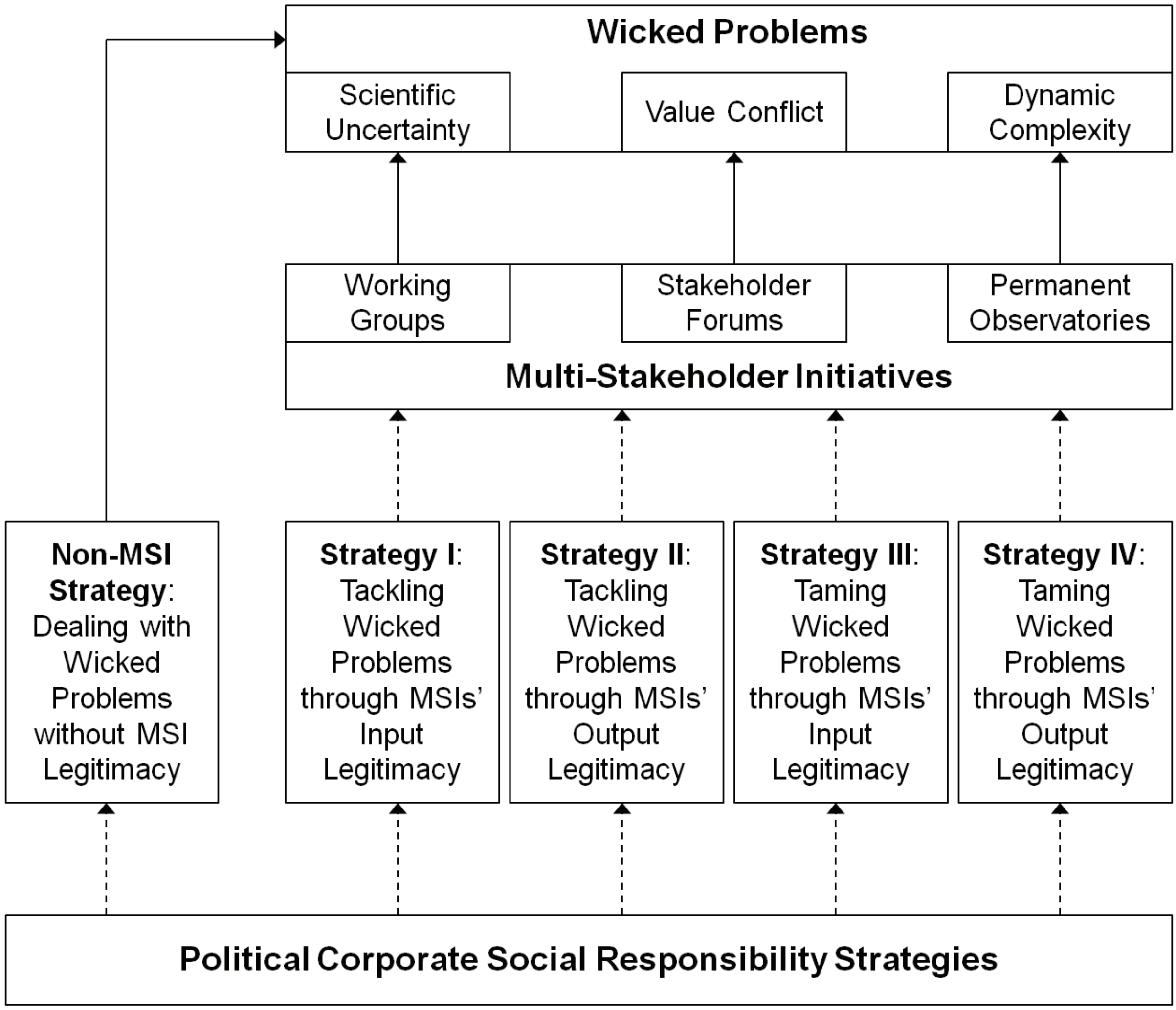
on the destruction of rainforest, biodiversity loss and climate change)	(Joseph Wright, Muller-Landau, 2006; Laurance, 2007). • Amount of carbon sequestration/emission from forestation/ deforestation remains uncertain (Zarin, 2012.) • Relationship between deforestation (habitat loss), climate change and "speed" of species extinction is still unclear (Rangel, 2012) • Data availability and quality is a limiting factor to assess the biodiversity loss at global level (Butchart et al., 2010)	deforestation (DeFries, et al., 2010). • Economic growth leading to further deforestation and impacting biodiversity in Brazil (Rangel, 2012); • Making reforestation attractive to rural communities might be difficult and complex (Lamb et al., 2005)	• Slightly different policy interventions to tackle deforestation and biodiversity loss in Brazil may lead to severely different scenarios (Wearn et al., 2012) • Large-scale forest restoration present complex and poorly understood implications (Chazdon, 2008)
Food insecurity *(and the debate on genetically modified organisms)*	• Hunger has multiple dimensions and causes, with multiple interrelations that are difficult to disentangle (Wheeler and von Braun, 2013) • Measures of food insecurity are fragmented and complex to collect and compare (Barrett, 2010)	• Biotech solutions to address food insecurity stimulate private sector investments but might hamper small-holder farmers' well-being in developing countries (Serageldin, 1999)	• Solutions to tackle food security need simultaneously coordinated actions among and between different actors (Godfray et al., 2010) • Achieving food security needs policy and investment reforms on multiple fronts, including human resources, agricultural research, rural infrastructure, water resources, and farm- and community-based agricultural and natural resources management (Rosegrant and Cline, 2003)
Human rights violations *(and the debate on child labor)*	• Multiple intertwined causes: poverty, lack of access to education (opportunities); lack of law enforcement and monitoring; HIV/Aids; gender inequality; family structure; culture and traditional values (Andvig, 1998)	• Different cultural understandings of what constitutes child labor (Andvig, 1998; Matissek et al., 2012) • Different understandings of how to address child labor	• Child labor as a symptom of a multitude of causes which is continuously influenced by wider demographic, socio-economic and cultural developments

Table II. Four political CSR strategies to deal with wicked problems through MSIs

	Tackling wicked problems	**Taming wicked problems**
Input legitimacy	**STRATEGY I** *Corporations tackling wicked problems through input legitimacy of MSIs* *Examples of MSIs*[1]: Sustainable Food Lab; Southern Africa Food Lab; AgriProFocus	**STRATEGY III** *Corporations taming wicked problems through input legitimacy of MSIs* *Examples of MSIs*: Roundtable on Sustainable Palm Oil (RSPO); Roundtable for Responsible Soy (RTRS); Common Code for the Coffee Community; UN Global Compact for Sustainable Agriculture Business Practices; Global Alliance for Improved Nutrition (GAIN); IDH Sustainable Trade Initiative
Output legitimacy	**STRATEGY II** *Corporations tackling wicked problems through output legitimacy of MSIs* *Examples of MSIs:* The Consumer Goods Forum; Global Food Safety Initiative; Sustainable Agriculture Initiative (SAI) Platform	**STRATEGY IV** *Corporations taming wicked problems through output legitimacy of MSIs* *Examples of MSIs:* International Cocoa Initiative; African Cocoa Initiative; Carbon Disclosure Project; Flour Fortification Initiative; International Council for the Control of Iodine Deficiency Disorders (ICCIDD) Global Network

Note: The examples provided in the table only cover MSIs from the agricultural and food sector addressing one or more of the wicked problems mentioned in section 3.1.

Figure 1. Four strategies to deal with wicked problems (thus, practicing "Political" CSR)



Application of the DEMATEL Method to Identify Relations among Barriers between Green Products and Consumers

Jing Shao[a,b,1], Marco Taisch[a], Miguel Ortega Mier[b], Elisa d'Avolio[c]
[a] Dept. of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy
[b] Dept. of Industrial Engineering, Business Administration and Statistics, Universidad Politécnica de Madrid, Madrid, Spain
[c] Dept. of Industrial Engineering, University of Florence, Florence, Italy

Abstract
Sustainable Production and Consumption (SPaC) is an emerging topic since last decades. Changing unsustainable consumption patterns is crucial for achieving the goal of sustainable development. From literature, although consumers begin to have a concern about environmental and social performance of products they are purchasing, these concerns are not necessarily translated to consumer purchase habits. This phenomenon has been noticed in academia and numbers of studies have addressed possible barriers between green products and, but literature in deep investigating and analyzing significance of various barriers are limited. In this study, eight barriers exist between green products and consumers have been specified based on literature. Furthermore, a barriers analysis has been conducted by applying DEMATEL technique, and barrier which has greatest impact has been distinguished. The analysis result showed that "Format of information presentation" has the greatest prominence value and it means this barrier has the greatest impact. And it is found that this barrier is significantly influenced by barrier of "Inadequate information on the product when purchasing". Additionally, barrier of "Acknowledgement on influence of collaborative purchasing behavior" has become one of the most important factors in the whole system. This study brings important insights of analyzing on barriers between green products and consumers through an original way. Based on analyzing results, further research directions are provided at the end.

Highlights:

- The study explores the significance of various barriers and how the barriers relate to each other.
- DEMATEL is applied to model and evaluate the interrelationships among eight barriers.
- The study provides basic understanding for improving SPaC of organizations.
- The result shows that it is important to assure providing adequate quantity of necessary information.
- The study found that education and communication on consumers becomes one of the most important factors in the whole system.

Keywords: Sustainable Production and Consumption, Green Products, Consumers, DEMATEL, barrier analysis

1. Introduction

The definition of Sustainable Production and Consumption (SPaC) is:"the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of

[1] Corresponding author: Jing Shao
Email: jing.shao@polimi.it
Present address: Via R. Lambruschini, 4B, 20156 Milano, Italy, Ph.+39 02 2399 2721

natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not to jeopardize the needs of future generations" (Oslo, 1994). SPaC attracts attention of researchers and practitioners since decades ago. The first time it became a policy concept was in Agenda 21 (UN, 1992). Then it was reaffirmed as the central role in achieving sustainable development in World Summit for Sustainable Development. The revised European Sustainable Development Strategy of 2005 set the goal of more sustainable consumption and production patterns firmly on the political agenda in Europe (EU, 2008). Especially from June 2012, research which focus on SPaC has emerged after the "Global Research Forum on Sustainable Production and Consumption" (Lorek et al., 2013).

Sustainable consumption (SC) is equally important to limit negative environmental and social externalities as well as to provide markets for sustainable products (OECD, 2008). It becomes complementary strategies with sustainable production (SP) for making economics more sustainable (Luskin and Del Matto, 2007). It is because sustainability (or the lack of it) depends on the individual actions of over 6 billion human beings (Dahl, 2012) and consumer buying behavior reflects their consumption patterns and lifestyles. Unsustainable consumption patterns and levels, in particular in industrialized countries, are a major cause if not the major cause of environmental degradation in the world today (UNDP, 1998; Worldwatch, 2004).

However, from literature, it is hard for individuals to appreciate the significance of the cumulative impact of serials small actions that may have a sustainable impact to the world. It is discussed that awareness of influence of collaborative buying behavior is insufficient in consumers' minds (Shao et al., 2014b). But more importantly, because even for green consumers who are much more concerning about sustainability related issues, information transition is lack from sustainable production to sustainable consumption (Lebel and Lorek, 2008).

A number of theoretical and empirical studies have addressed possible barriers between green products and consumers (see section 2.2), but literature in deep investigating and analyzing significance of various barriers are limited. For effective improving SPaC, organizations need to have basic understanding on the relationship among these barriers, and then be able to determine how they should overcome the barriers. These barriers are crucial for developing a holistic policy of organizations.

With this situation, this paper explores the significance of various barriers and how the barriers relate to each other. To model and evaluate the interrelationships among the barriers, this paper applies a grey- based Decision-Making Trial and Evaluation Laboratory (DEMATEL) (Zhu et al., 2011). The overall purpose and contribution of this paper is to gain insights about the barriers between green products and consumers and to provide basic understanding for improving SPaC of organizations. In order to meet this objective, a description regarding sustainability management of fashion industry will be provided first. Secondly, company involved in this case study will be briefly introduced. Then, various potential barriers between green products and their consumers will be specified. After that, the application of DEMATEL methodology will be performed and an exploratory analysis of these barriers will be introduced. The result will be discussed and managerial insights, with possible direction of further research will be provided at the end.

2. Background

2.1 Introduction of fashion industry

Fashion is a complex phenomenon that shows interesting insights from different points of view: psychological, sociological, commercial and engineering. Fashion industry is strongly dependent from the consumers' needs so that effectiveness has always been the main factor that each company has taken into account. Time-to-market (TTM) and quality of products represent the main critical success factors (CSFs). Indeed, fashion industry involve several kinds of environmental impacts in their production process, such as dyeing, drying, finishing (de Brito et al., 2008). Recent studies showed, more and more multinational brands have positioned themselves in the "green" segment of the market with including environmental aspects into a new concept of quality of their green products (Caniato et al., 2012). Meanwhile, some SMEs also have leveraged on environmental sustainability in their business model and supply chain structure, in order to compete in new market niches and establish their brand (Caniato et al., 2012).

The footwear market is one of the biggest markets in fashion industry. EU has the largest market for footwear having about one third of the market value. At the same time, EU has been considered as one of the high quality footwear suppliers in terms of production. Currently, footwear market faces different emerging trends from both consumers and practitioners' perspectives. Consumers are more concerned about the economic value of the products they buy as a result of the recent economic crisis. Meanwhile there are customers, especially in Northern and Western European countries, caring more about eco-design and concerning about materials and circumstance for shoe production (Pourabdollahian, 2013). Environmental concerns have become a major concern for European shoe producers considering the fact that leather production is one of the most polluting industries. In this regard, the manufacturers need to invest in applying green technologies especially for leather tanning. Such a shift can also bring a competitive advantage to them and differentiating them from their Asian competitors by offering not only high quality but also eco-friendly shoes.

This case study conducted in company "X" which was founded in 1996 by shoe designer. Now it becomes a British high fashion house specializing mainly in footwear, but also handbags, accessories and fragrances. It has several shops in UK and two branches in Italy. The headquarter is in London where Design, Product Development and Merchandise Planning processes are coordinated. There, the main stylists take the most part of the decisions about the collections and the catwalk. In Italy the company manages the operative side of the Product Development process and also the Production process is carried out. The brand takes advantage from the exceptional Italian craftsmanship: the center of Italy stands out for the great number and the high handcrafted tradition of small and medium enterprises, where the company can find its best leather suppliers.

2.2 Specify barriers

From literature of consumer studies, although consumers began to have a concern about environmental and social performance of products they are purchasing, these concerns are not necessarily translated to consumer purchase habits. Studies showed that even consumers who are environmentally concerned do not buy green products in overwhelming preference (Tseng and Hung, 2013). The inconsistency between their environmental attitudes and corresponding behavioral intentions has been noticed in academia, as numbers of studies in organic food industry indicated. The potential barrier factors which stand between green products and consumers in general are summarized in this section based on literature and practices.

2.2.1 External barriers

Five external barriers which related to relationships between products and consumers are specified as following. "Green customers" who are sensitive to energy saving and environment protection are ignorant of how to make better purchasing decisions, since lack of energy consumption and environmental impact information of products. It is also discussed in literature that the degree to which consumer use environmental information of a product is disputed (Leire and Thidell, 2005). This problem involves two dimensions as barriers 1 & 2:

Barrier1. Inadequate information about market of green product:
The awareness of existing of green products is lack in current marketing mainly attribute to their tiny shares of market (Bonini and Oppenheim, 2008; Röös and Tjärnemo, 2011). This point of view leads by low availability of green products and they are said to be usually hard to find in normal market.

Barrier2. Inadequate information about the environmental/socially-conscious attributes of product when purchasing:
Green consumers need knowledge, skills and information for making the correct decisions, but information is often confusing. This may either demotivate or serve as an excuse (Moisander, 2007). Some studies showed that consumers are increasingly demanding more information regarding a product's supply chain and production history (Marucheck et al., 2011). But gap between consumer informational needs and current market offerings exist (Shao et al., 2014a; Meise et al., 2014). The obstacle is the lack of adequate information from which allows consumers to obtain reliable information about environmental/socially-conscious attributes of a product, and make informed purchasing decisions (Meise et al., 2014; Caniato et al., 2012).

Barrier3. Consumers are lack of trust
Literature has a wide discussion that consumer trust and motivation are the key determinants for consumers to accept related information of product. However, although Eco labeling has become policy tool in marketing, sustainable consumption patterns is still on a voluntary basis to a large extent. Numerous eco-labels offered extraordinary chances for customers to get the green related information, but it confused consumers mainly because most of them provide polarity, repeat and incomplete information (Lebel and Lorek, 2008; Leire and Thidell, 2005). Furthermore, consumers are distrustful and suspicious of environmental advertising and claims from industry (Rex and Baumann, 2007).

Barrier4. Format of information presentation
Currently, eco-labels are the main approach in marketing to provide sustainable information of products. However, such sustainability labels currently do not play a major role in consumers' food choices (Grunert et al., 2014). Marketing patterns of information which provided to the consumer have become one of the key issues in this subject. From manufacturing studies, numbers of indicators have been provided by international environmental organizations, industries practitioner or researchers, but most of them have long lists of environmental pollutants and abounding with technical terms (Shao et al., 2014b). They are designed only adaptable for

industrial application or academic research, but not for the time limited situations such as purchasing.

Barrier5. Non-competitive price
Studies have shown that perceived high price is the main barrier to purchase and use sustainable products (Röös and Tjärnemo, 2011). And some studies showed the willingness to pay extra for green products was less than anticipated (Rex and Baumann, 2007). It is because green products normally have even higher price that mainly attribute to the cost of production and transportation. It makes consumers harder to make a decision to accept green products many times although they are intent to be green.

2.2.2 Internal barriers

Different from external barriers, internal barriers mainly concerns about the mental and initial factors which influence purchasing behavior of consumers. Three internal barriers are specified from literature as following.

Barrier6. Acknowledgement on influence of collaborative purchasing behavior
In consumer behavior studies, consumers are often assumed to possess a considerable amount of knowledge about complex ecological or ethical issues and their consequences (Grunert et al., 2014; Moisander, 2007), and it might be a reason to explain the inconsistency between consumer attitude and behavior (Rokka and Uusitalo, 2008). From manufacturing perspective, their collaborative purchasing decisions is one of the incentives for manufacturers to adopt clean(er) technologies, However, acknowledgement on this possible consequence is not accessible for consumers. Corresponding education and communications on the awareness of influence from collaborative purchasing behavior are rarely to observe in reality.

Table 1. List of barriers

No.	Barrier	Literature
B1	Inadequate information about market of green product	(Bonini and Oppenheim, 2008; Röös and Tjärnemo, 2011)
B2	Inadequate information on the product when purchasing	(Moisander, 2007; Marucheck et al., 2011; Shao et al., 2014a; Meise et al., 2014; Caniato et al., 2012)
B3	Consumers are lack of trust	(Rex and Baumann, 2007; Lebel and Lorek, 2008; Leire and Thidell, 2005)
B4	Format of information presentation	(Grunert et al., 2014).
B5	Non-competitive price	(Rex and Baumann, 2007; Röös and Tjärnemo, 2011)
B6	Acknowledgement on influence of collaborative purchasing behavior	(Grunert et al., 2014; Moisander, 2007; Rokka and Uusitalo, 2008)
B7	Gaps exist between customers' expectations and their perceptions	(Tseng and Hung 2013)
B8	Consumers are lack of motivation	(Rokka and Uusitalo, 2008; Leire and Thidell 2005; Rex and Baumann 2007; Moisander, 2007)

Barrier7. Gaps exist between customers' expectations and their perceptions
Studies have verified that customers' expectations are higher than their perceptions in 11 items which related to environmental attributes of green information products, by comparing between the mean value of customers' expectations and their perceptions. So to speak, the products in the market do not meet the expectation of customers (Tseng and Hung 2013).

Barrier8. Consumers are lack of motivation

Presently, even green consumers who are much more concerning about sustainability related issues, do not have sufficient motivation to enable them making greener buying decisions (Rokka and Uusitalo, 2008; Leire and Thidell 2005; Rex and Baumann 2007). For green consumers it is often difficult to decide what is the correct thing to do (Moisander, 2007).

The list of the barriers is presented in the Table 1.

2.3 Questionnaire development and data collection

This study focused on identifying and interviewing industrial expert to validate the barriers identified from literature. The respondent we selected is a research fellow at the Industrial Engineering Department in Italy. Now she is a consultant working in High Fashion Industry. Her research interests were related to the fashion supply chain in the Luxury Industry. The expert is able to provide a more complete picture of green product and their consumers, both from academic and industrial perspective.

The questionnaire with three parts has been developed in order to provide complete information to respondent. The first part of questionnaire described the main focus and objective of this study. Then the definitions of barriers have been explained and listed. Lastly, core data is required for further DEMATEL analysis. It was composed of a matrix that required completion by respondent.

3. Methodology

3.1 Evaluating practices adoption

Previous studies have utilized different methods to analyze interrelationships between factors influencing practices. Studies on barriers between green products and their consumers have been conducted by several researchers (Röös and Tjärnemo, 2011; Vermeir and Verbeke, 2006). However, the internal relationships among those barriers are lack.

This study attempts applies Decision-Making Trial and Evaluation Laboratory (DEMATEL) to analyze the barriers between green products and consumers, and their interrelationships to each other. It could be applied to have insights on determinant factors among various barriers. DEMATEL was employed firstly in 1976 and it has managed to solve many global complex problems by considering experts' attitudes, and became a widespread technique in Japan (Falatoonitoosi et al., 2013). Then, this method has been applied in many areas such as knowledge management (Wu and Lee, 2007) and sustainable production (Dou and Sarkis, 2013), green supply chain management (Amiri et al., 2011; Jalalifar et al., 2013). The technique has proven valuable also for managerial decision-making support in environmental and greening issues (Zhu et al., 2008).

3.2 Grey-DEMATEL Method

The analysis was performed based on guidelines presented in (Zhu et al., 2011), where you may also find detailed description of every step. Here, the application of DEMATEL method on company "X" in fashion industry of Italy will be shown as following.

Step1. Define a grey pairwise influence comparison scale for the components. In this study, a 5-level scale was used with the following scale items: 0= no influence, 1= very low influence, 2=

low influence, 3= high influence, 4= very high influence. The grey linguistic scale for the respondents' evaluations is shown in Table 2.

Table 2. The grey linguistic scale for the respondents' evaluations

Linguistic terms	**Grey numbers**	
No influence	[0,0]	0
Very low influence	[0,0.25]	1
Low influence	[0.25,0.5]	2
High influence	[0.5, 0.75]	3
Very high influence	[0.75,1]	4

Step2, Development of the grey pairwise direct- relation matrix X. It is an 8×8 matrix whose assessment number was provided by evaluator. The grey pairwise direct-relation matrix X is shown in Appendix A.

Step3, Transform the grey pairwise direct-relation matrix X into a crisp matrix Z. The overall crisp direct- relationship matrix is shown in Appendix B.

Step4, Obtain the normalized direct-relation matrix N, based on the formula (1) and (2). The normalized direct-relation matrix N is shown in Appendix C.

Step5. Develop the total relation matrix T, based on the formula (3), where "I" represents an n×n identity matrix (Appendix D).

Step6. Calculate the overall importance and net effect, applying formula (4-7), where P_i is prominence and E_i is net effect. The degree of prominence and net effects is shown in Table 3.

Table 3. The degree of prominence and net effects

Barriers	**Prominence (R+D)**	**Net Effect (R-D)**
B1	8.4536	-0.3404
B2	7.6225	0.4111
B3	9.2918	-1.3913
B4	10.0076	0.1089
B5	6.1935	1.3673
B6	8.0208	0.5269
B7	6.8551	-0.5116
B8	9.6687	-0.1708

Step7. Develop DEMATEL prominence-causal graph (Fig.1).

Interrelationships between barriers are indicated with arrows. Only relationships that are over the threshold value θ (0.6589) were in bold in Appendix D and mapped in Fig.1. The threshold equals to the sum of mean (0.5165) and standard deviation (0.1424) of the values from matrix T (Appendix D). All the relationships are represented by solid line in Fig. 1. In this case, only relationship between B4 and B8 has two-way significant relationship. Other significant relationships were: B1-B3, B1-B8, B2-B4, B4-B1, B4-B3, B5-B8, B6-B3 and B8-B3.

4. Results and Discussions

The result of this study shows four barriers that can be identified as net-cause barriers. These four barriers are B4, B8, B3, B1, consequent by their ranking of prominence. Industrial expert views B4 as the most important one with the highest prominence score of 10.0076. Therefore B4 (Format of information presentation) has the greatest impact in the system and it has positive net effect to other barriers. B8 (Consumers are lack of motivation) influences B3, and B8 is influenced by B1, B4 and B5. It indicates that for achieving consumers' trusting, consumers need more motivation which needs to be assured from three perspectives. Besides more competitive price of green product, it is necessary to provide consumers proper format of green information of products and extend their markets. The third prominent barrier B3 (Consumers are lack of trust) is also the one who has greatest negative net-effect scores. It means that other factors may need to be initially addressed in order to remove these barriers. From arrows in Fig. 1, it can be seen that these factors are B1, B4, B6 and B8. Moreover, B4 has the greatest T value on B3. This result means, improving format of information presentation is crucial for increasing consumers' trusting on green products.

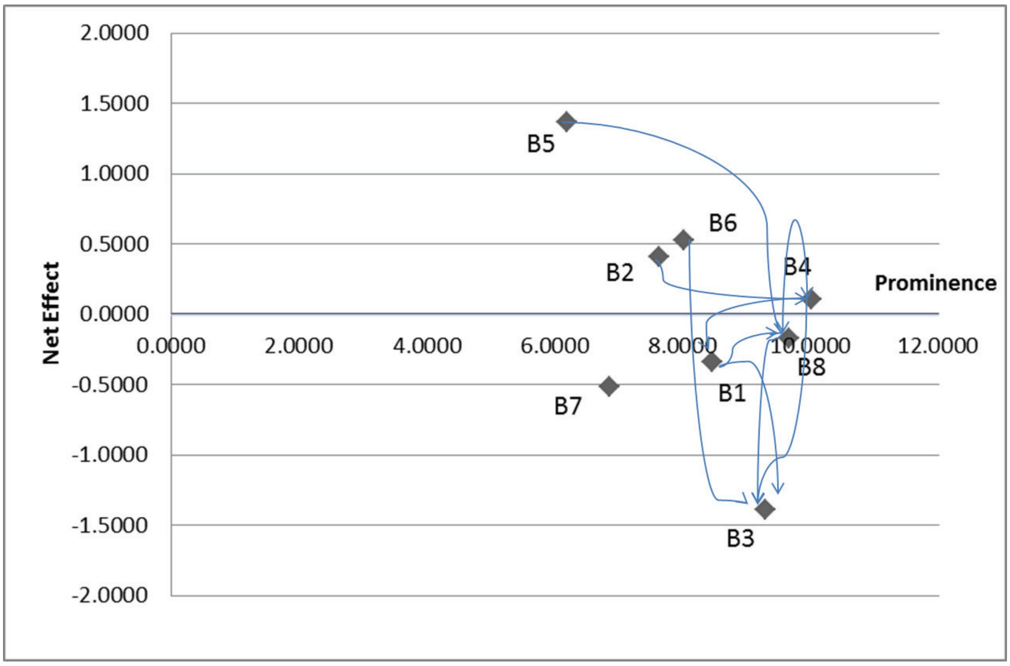


Fig.1. DEMATEL prominence-causal graph

As can be noticed in Table 3, four barriers B5, B6, B2 and B4 with net-effect value over zero become the most influential four barriers from ranking of net effect. Besides B5 which normally has been seemed as the biggest barrier between green product and consumers, it is interesting to see that B6 (Acknowledgement on influence of collaborative purchasing behavior) and B2 (Inadequate information on the product when purchasing) also have very high influence to other barriers. B6 was defined in the group of internal barriers which could be improved by education and advertisement. In this study, it shows that education to consumers on their purchasing behavior is needed. Furthermore, even B4 has the highest prominence value, it is also significantly influenced by B2 (0.6609). This means before choosing proper format of information presentation, it is more important to assure providing adequate quantity of necessary information.

In all, considering results from Table 3 and Fig. 1, it should be noticed that B4 with high prominence have also positive net effect, improving format of information presentation is crucial for increasing consumers' trusting on green products. Furthermore, B2 influences B4 significantly and it indicates that before choosing proper format of information presentation, it is more important to assure providing adequate quantity of necessary information. Therefore, these two factors should be addressed at first, as they have the greatest impact in the system. B6

(Acknowledgement on influence of collaborative purchasing behavior) has become one of the most important factors and play very important role in the whole system.

5. Conclusion

This study showed the interrelationship among barriers which exist between green product and their consumers by applying DEMATEL methodology. The analysis results showed the importance of various barriers, especially, improving format of information presentation is crucial for increasing consumers' trusting on green products. Moreover, it is important to assure providing adequate quantity of necessary information. How to provide adequate and necessary information is still require further investigation. Education and communication on consumers about impact of their collaborative purchasing behavior should be pursued. It has become one of the most important factors and could play very important role in the whole system. This study mainly considers the view from industrial expert, barrier analysis based on multiple stakeholders could provide more complete picture of an industry in the future. On the other hand, the results observed in fashion industry may not be consistent with other industry in Europe.

Acknowledgements

This research is partly conducted within the framework of the European Doctorate in Industrial Management (EDIM) which is funded by The Education, Audiovisual and Culture Executive Agency (EACEA) of European Commission under Erasmus Mundus Action 1 programmes. Furthermore, this research is partly funded by the European Commission through the PREMANUS Project (FoF-ICT-2011.7.3: Virtual Factories and Enterprises, www.premanus.eu).

References

Amiri, M., Salehi, J., Payani, N., Shafieezadeh, M., 2011. Developing a DEMATEL method to prioritize distribution centers in supply chain 1, 279–288. doi:10.5267/j.msl.2011.04.001

Bonini, S.M.J., Oppenheim, J.M., 2008. Helping " green " products grow. The McKinsey Quaterly.

Caniato, F., Caridi, M., Crippa, L., Moretto, A., 2012. Environmental sustainability in fashion supply chains: An exploratory case based research. Int. J. Prod. Econ. 135, 659–670. doi:10.1016/j.ijpe.2011.06.001

Conference on "Visualising and Presenting Indicator Systems" SFSO, Neuchâtel 14 – 16 March 2005, 2005.

Dahl, A.L., 2012. Achievements and gaps in indicators for sustainability. Ecol. Indic. 17, 14–19. doi:10.1016/j.ecolind.2011.04.032

De Brito, M.P., Carbone, V., Blanquart, C.M., 2008. Towards a sustainable fashion retail supply chain in Europe: Organisation and performance. Int. J. Prod. Econ. 114, 534–553. doi:10.1016/j.ijpe.2007.06.012

Dou, Y., Sarkis, J., 2013. A multiple stakeholder perspective on barriers to implementing China RoHS regulations. Resour. Conserv. Recycl. 81, 92–104. doi:10.1016/j.resconrec.2013.10.004

EU, 2008. European Commission communication on the sustainable consumption and production and sustainable industrial policy action plan.

Falatoonitoosi, E., Leman, Z., Sorooshian, S., Salimi, M., 2013. Decision-Making Trial and Evaluation Laboratory. Res. J. Appl. Sci. Eng. Technol. 5, 3476–3480.

Grunert, K.G., Hieke, S., Wills, J., 2014. Sustainability labels on food products: Consumer motivation, understanding and use. Food Policy 44, 177–189. doi:10.1016/j.foodpol.2013.12.001

Jalalifar, S., Hafshejani, K.F., Movahedi, M.M., 2013. Evaluation of the Effective Barriers in GSCM implementation Using DEMATEL Method. Nat. Sci. 11, 95–102.

Khan, F.I., Sadiq, R., Veitch, B., 2004. Life cycle iNdeX (LInX): a new indexing procedure for process and product design and decision-making. J. Clean. Prod. 12, 59–76. doi:10.1016/S0959-6526(02)00194-4

Lebel, L., Lorek, S., 2008. Enabling Sustainable Production-Consumption Systems. Annu. Rev. Environ. Resour. 33, 241–275. doi:10.1146/annurev.environ.33.022007.145734

Leire, C., Thidell, Å., 2005. Product-related environmental information to guide consumer purchases – a review and analysis of research on perceptions, understanding and use among Nordic consumers. J. Clean. Prod. 13, 1061–1070. doi:10.1016/j.jclepro.2004.12.004

Lorek, S., Barber, J., Onthank, K., 2013. Global and Regional Research on Sustainable Consumption and Production Systems: Achievements, Challenges and Dialogues. Workshop Report of the Global Research Forum on Sustainable Production and Consumption. June 13-15, 2012, Rio.

Luskin, J., Del Matto, T., 2007. Introduction to the special issue on, sustainable production and consumption: making the connection. J. Clean. Prod. 15, 489–491. doi:10.1016/j.jclepro.2006.05.009

Marucheck, A., Greis, N., Mena, C., Cai, L., 2011. Product safety and security in the global supply chain: Issues, challenges and research opportunities. J. Oper. Manag. 29, 707–720. doi:10.1016/j.jom.2011.06.007

Meise, J.N., Rudolph, T., Kenning, P., Phillips, D.M., 2014. Feed them facts: Value perceptions and consumer use of sustainability-related product information. J. Retail. Consum. Serv. 21, 510–519. doi:10.1016/j.jretconser.2014.03.013

Moisander, J., 2007. Motivational complexity of green consumerism Johanna Moisander 4, 404–409.

OECD, 2008. Promoting Sustainable Consumption-Good Practices in OECD Countries.

Oslo, 1994. Symposium: Sustainable Consumption: 19-20, January 1994: Oslo, Norway.

Pourabdollahian, G., 2013. Doctor Thesis-Qualitative Modeling of a Dynamic Sustainable Mass Customization Business Model. POLIMI.

Rex, E., Baumann, H., 2007. Beyond ecolabels: what green marketing can learn from conventional marketing. J. Clean. Prod. 15, 567–576. doi:10.1016/j.jclepro.2006.05.013

Rokka, J., Uusitalo, L., 2008. Preference for green packaging in consumer product choices - Do consumers care? Int. J. Consum. Stud. 32, 516–525. doi:10.1111/j.1470-6431.2008.00710.x

Röös, E., Tjärnemo, H., 2011. Challenges of carbon labelling of food products: a consumer research perspective. Br. Food J. 113, 982–996.

Shao, J., Taisch, M., Ortega, M., 2014a. A Systematic Review on Information Transition Approaches of Sustainable Production and Consumption (SPaC). submitted.

Shao, J., Taisch, M., Ortega Mier, M., 2014b. Sustainability Assessment Instruments for Consumers, in: 20th Engineering, Technology and Innovation (ICE 2014). Bergamo, Italy. doi:10.1109/ICE.2014.6871624

Tseng, S.-C., Hung, S.-W., 2013. A framework identifying the gaps between customers' expectations and their perceptions in green products. J. Clean. Prod. 59, 174–184. doi:10.1016/j.jclepro.2013.06.050

UN, 1992. United Nations Conference on Environment & Development Rio de Janerio , Brazil , 3 to 14 June 1992.

UNDP, 1998. HUMAN DEVELOPMENT REPORT 1998. New York.

Vermeir, I., Verbeke, W., 2006. Sustainable Food Consumption: Exploring the Consumer "Attitude – Behavioral Intention" Gap. J. Agric. Environ. Ethics 19, 169–194. doi:10.1007/s10806-005-5485-3

Worldwatch, 2004. THE WORLDWATCH INSTITUTE SPECIAL FOCUS: THE CONSUMER SOCIETY.

Wu, W.-W., Lee, Y.-T., 2007. Developing global managers' competencies using the fuzzy DEMATEL method. Expert Syst. Appl. 32, 499–507. doi:10.1016/j.eswa.2005.12.005

Zhu, Q., Sarkis, J., Debroux, P., 2011. Barriers to environmentally-friendly clothing production among Chinese apparel companies. Asian Bus. Manag. 10, 425–452. doi:10.1057/abm.2011.15

Zhu, Q., Sarkis, J., Lai, K., 2008. Green supply chain management implications for "closing the loop". Transp. Res. Part E Logist. Transp. Rev. 44, 1–18. doi:10.1016/j.tre.2006.06.003

Appendix

Appendix A. The grey pairwise direct-relation matrix X

Barriers	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
B1	x	1	3	2	1	4	2	4
B2	1	x	2	3	1	2	4	4
B3	3	2	x	3	1	3	2	3
B4	4	4	3	x	2	3	2	3
B5	4	2	2	2	x	1	3	3
B6	4	3	3	2	1	x	2	3

B7	1	2	2	2	3	2	x	2
B8	3	3	3	3	2	2	3	x

Appendix B. The overall crisp direct-relationship matrix Z

Barriers	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.0000	0.0500	0.9167	0.5000	0.0833	0.9500	0.3500	0.9500
B2	0.0500	0.0000	0.5000	0.9167	0.0833	0.3500	0.9500	0.9500
B3	0.6500	0.3500	0.0000	0.9167	0.0833	0.6500	0.3500	0.6500
B4	0.9500	0.9500	0.9167	0.0000	0.5000	0.6500	0.3500	0.6500
B5	0.9500	0.3500	0.5000	0.5000	0.0000	0.0500	0.6500	0.6500
B6	0.9500	0.6500	0.9167	0.5000	0.0833	0.0000	0.3500	0.6500
B7	0.0500	0.3500	0.5000	0.5000	0.9167	0.3500	0.0000	0.3500
B8	0.6500	0.6500	0.9167	0.9167	0.5000	0.3500	0.6500	0.0000

Appendix C, The normalized direct-relation matrix N

Barriers	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.0000	0.0101	0.1846	0.1007	0.0168	0.1913	0.0705	0.1913
B2	0.0101	0.0000	0.1007	0.1846	0.0168	0.0705	0.1913	0.1913
B3	0.1309	0.0705	0.0000	0.1846	0.0168	0.1309	0.0705	0.1309
B4	0.1913	0.1913	0.1846	0.0000	0.1007	0.1309	0.0705	0.1309
B5	0.1913	0.0705	0.1007	0.1007	0.0000	0.0101	0.1309	0.1309
B6	0.1913	0.1309	0.1846	0.1007	0.0168	0.0000	0.0705	0.1309
B7	0.0101	0.0705	0.1007	0.1007	0.1846	0.0705	0.0000	0.0705
B8	0.1309	0.1309	0.1846	0.1846	0.1007	0.0705	0.1309	0.0000

Appendix D, The total-relation matrix T

Barriers	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.4578	0.3866	**0.7119**	0.5966	0.2579	0.5567	0.4284	**0.6608**
B2	0.4499	0.3750	0.6264	**0.6609**	0.2796	0.4379	0.5378	0.6493
B3	0.5566	0.4298	0.5371	0.6486	0.2547	0.4977	0.4228	0.6030
B4	**0.7177**	0.6180	**0.8353**	0.6301	0.3837	0.5973	0.5322	**0.7440**
B5	0.5769	0.3990	0.5966	0.5574	0.2325	0.3754	0.4620	**0.5807**
B6	0.6317	0.4984	**0.7353**	0.6257	0.2671	0.4144	0.4550	0.6464
B7	0.3705	0.3535	0.5078	0.4817	0.3595	0.3520	0.2945	0.4523
B8	0.6359	0.5455	**0.7913**	**0.7484**	0.3781	0.5158	0.5507	0.5833

$$\mathrm{N} = \mathrm{sZ} \qquad (1)$$

$$\mathrm{s} = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}} \qquad (2)$$

$$T = N + N^2 + N^3 + \cdots \sum_{i=1}^{\infty} N^i = N(I - N)^{-1} \qquad (3)$$

$$R_i = \sum_{j=1}^{n} t_{ij} \qquad \forall i \qquad (4)$$

$$D_j = \sum_{i=1}^{n} t_{ij} \qquad \forall j \qquad (5)$$

$$P_i = \{R_i + D_j | i = j\} \qquad (6)$$

$$E_i = \{R_i - D_j | i = j\} \qquad (7)$$

Total Site Cleaner Production – Energy Efficiency – Optimisation Approach Based on In-depth Analyses of Versatile Industrial Practices

Janez Petek[1*], Peter Glavič[2], Anja Kostevšek[3]

[1]*STENG-National cleaner production centre Ltd., Pesnica pri Mariboru 20a, SI-2211, Pesnica pri Mariboru, Slovenia*

[2]*Faculty of Chemistry and Chemical Engineering, University of Maribor, Smetanova ulica 17, SI-2000, Maribor, Slovenia*

[3]*Centre for Process Integration and Intensification – CPI[2], Research Institute of Chemical and Process Engineering – MÜKKI, Faculty of Information Technology, University of Pannonia, Egyetem u. 10, HU-8200, Veszprém, Hungary*

Abstract

The Cleaner production (CP) approach is well-known as a tool for waste and emissions' minimisation throughout industry and the service sectors, and has been well established within a variety of industrial processes. This approach allows waste minimisation detection measures inside those processes by performing mass balances. According to our experiences, energy balances calculations, heat and power integration, and optimisation need to be carried out in the cases of energy intensive production processes. On the other hand, energy auditing methodology is a tool for decreasing energy consumption and in many cases for incorporating renewable energy systems such as combined heat and power, heat pumps, solar collectors, and technologies for energy production from biomass.

* Corresponding author. Phone number: +386(0) 41694053; Fax number: +386(0) 59308182

E-mail address: janez.petek@steng-nccp.si (J. Petek)

On-going process optimisation tools such as pinch analysis, TS Methodology, MINLP and others have been introduced for improving process parameters. Collaboration between academia and industry is crucial for presenting relevant novel findings based on real case studies as verifications of theoretical advances and for providing two-way communication. Therefore, various case studies presenting implementations of cleaner production principles, energy audit performance, pinch analysis, various optimisation techniques' calculations are included within this paper.

The company Steng – National Cleaner Production Center Ltd. has carried out several energy audits of industrial processes within dairy, ceramic, metal processing, meat processing industries, services such as laundries, and of public buildings in order to find possibilities for increasing the overall energy efficiency of the industrial processes and energy systems. As Steng – National Cleaner Production Center Ltd. is a spin-off company established by the researchers from the University of Maribor, Faculty of Chemistry and Chemical Engineering, close cooperation with the faculty in the field of cleaner production, waste minimisation and process integration is maintained in order to transfer knowledge and know-how from the university to industry. The Faculty of Chemistry and Chemical Engineering has carried out several cleaner production, resource and energy efficiency, and educational projects such as: Rational use of energy and waste minimisation in a textile dye house, Energy integration opportunities in a formaldehyde plant, Efficient use of energy in a refinery and a petrochemical plant, Resource efficiency optimisation in a methanol plant, Total site optimisation of petrochemical plants, Energy integration a tannin, furfural, and specialty chemicals extraction plants, Heat/energy integration and water usage minimisation in a sugar beet plant, Pilot study on clean products and processes, Sustainable optimisation of integrated bio refineries, Postgraduate School of Industrial Ecology, European Training Partnership on Sustainable Innovation, and Training on Resource Efficiency and Optimisation.

On the basis of the results and knowledge obtained from the projects mentioned above, a Total Site (TS) CP – energy efficiency – optimisation approach is proposed which enables gradual research, development and integration of CP, energy auditing and optimisation combined with the novel optimisation methodologies and approaches.

Key words

Cleaner Production, Energy Audit, Process Integration, Pinch Analysis, MINLP/NLP

1 Introduction

In the 1980's, environmental experts acknowledged that unreasonable consumption of non-renewable sources (e.g. raw materials, energy sources) leads to unsustainable development. Depletion of world resources also causes unreasonable waste and emissions production. The United States Environmental Protection Agency (US EPA) had responded with a new approach towards waste prevention with the broadly accepted waste minimisation methodology (US EPA, 1988). The proposed waste minimisation methodology had been improved by the analysis of steam and condensate systems and thermodynamic analysis, and tested in process industries (Petek and Glavič, 1996). Beside waste minimisation, the United Nations Environment Programme (UNEP) focused on environmental pollution prevention and sustainable development and established a new approach named cleaner production (CP). CP is the continuous application of an integrated preventive strategy to processes and products to reduce risks to humans and the environment. Several institutions have upgraded the CP methodology according to their experiences within industry and services. For example the Centre for Cleaner Production Initiative Barcelona developed the Minimisation Opportunities Environmental Diagnosis (MOED). This tool includes the redesigning of processes and products and involves Life Cycle Analysis (LCA) (Autonomous Government of Catalonia, 2000). The MOED tool, described in this manual, involves a limited economic outlay and an average execution time of 4 weeks in the cases of small business, and 15 weeks in the cases of larger companies. As reported in the manuals the most demanding and very important phase of the CP project is data acquisition and mass and energy balance performing, not only for the processes but also for utility systems. For example, Petek and Glavič (2000) proposed several options for improving the eco-efficiency of steam and condensate systems. It was because process and utility systems are connected, the US EPA issued the Guide to Industrial Assessment for Pollution Prevention and Energy Efficiency (US EPA, 2001) which discussed and proposed possibilities for improving the energy efficiencies of processes, electrical equipment, boilers, heat recovery systems, heating systems, cogeneration, prime movers of energy, thermal applications, and HVAC (heating, ventilation and air conditioning).

Another approach for defining energy savings is **energy audit**. Energy audit can be defined as a methodology for analysing and evaluating energy efficiency during production processes in utility systems and in buildings. From the results obtained during energy auditing, industrial companies, buildings and households can identify opportunities for reducing energy consumption and to implement renewable energy sources. Kumbhar and Joshi (2012) described three types of energy audits depending on the time available and results expected from a walk-through audit, intermediate audit or extended energy audit. Energy audits can be carried out for production processes, buildings or utility systems. Process industries are the more intensive energy consumers and may significantly reduce energy consumption. For example, energy auditing in paper mills showed possibilities for saving substantial quantities of steam by installing flash steam vessels on the high-pressure condensate lines using low-pressure steam in the pre-drying section of the paper machine (Aue and Pierce, 2005). Pinch technology has also been used as a tool for energy audit. Whilst performing energy auditing, the energy consumption target set by the auditor was much higher than what would have been possible by the incorporation of the pinch technique itself (Harikumar, 1996). Such a study was performed in a diary plant in order to reach the minimum heating and cooling demands.

Bhat (2000) discussed a novel energy audit methodology for determining centralised air conditioning systems' efficiencies. The most cost-effective solutions for improving the energy efficiencies of air conditioning systems are effective controls and the insulation of air ducts. There are several case studies regarding energy audits of the utility systems such the lighting systems (Singh at al., 2012), cooling water pumping systems (Jagtap and Pawar, 2013), air compressors, steam and condensate systems (Blatt, 2000), and cooling water systems (Khare at al., 2012). In several cases combined heat and power (CHP) is a valuable option for decreasing energy costs. Investors receive higher price from electricity produced in cogeneration plants (feed-in tariff) whilst using cheaper waste heat. For example, waste energy may be used at two quality levels, firstly for steam generation and secondly for heating lower temperature consumers such as water heating, company heating systems and district heating systems (Kornhonen, 2002).

As a response to the first energy crisis in the 1970s, process industries developed a design/retrofit method for **heat exchanger networks** (HEN) called Pinch Analysis (Linnfoff and Flower, 1978). Cold process streams were composed within a cold composite curve; and hot streams were then added to form hot composite curves (CC). The composite curves were superimposed within a temperature / enthalpy flow-rate diagramme (*T/I*) to be separated by the minimum temperature interval $\Delta_{\min}T$ at the closest approach of the composite curves (pinch). During the design process the minimum utility requirements, and minimum number and surface areas of the heat exchangers were targeted subject to minimum cost at optimal temperature difference, $\Delta_{\mathrm{opt}}T$ (energy-capital trade off or Super Targeting). Heat had not be transferred across the pinch; there should have been no cooling above the pinch, and no heating below it. This concept was reported to save on average 30 % of the energy cost, coupled with capital savings in new plant designs.

A few years later the pinch concept in heat recovery network design developed into powerful techniques integrating not only heat exchangers but also **separators**. In ICI it achieved energy cost savings of 50 % in new designs and 6 months payback times in retrofits (Linnhoff and Vredeveld, 1984). The Grand Composite Curve (GCC) was invented in order to place the distillation columns against the CCs and select the best utility or utility mix (Linnhoff and Polley, 1988). GCC presents the profile of the horizontal (enthalpy flow-rate) separation between the CCs with a built-in allowance for $\Delta_{\min}T$. Appropriate placement of evaporators, condensers, heat pumps and heat engines against the GCC was enabled (Hindmarsh et al, 1985).

Thermodynamic analysis of **chemical reactors** and their energy integration with HEN was developed by superimposing the reactor profile (chemical utility) on the GCC (Glavič et al., 1988); the reactor profile can be matched with the process profile by changing the process structure (number and volume of reactors, HEN, and boilers). Utility composite curves, energy donors and energy acceptors were defined (Kravanja and Glavič, 1989).

Pinch analysis was later extended to low temperature process design, integration between the process and the **refrigeration system**. The work led to shaft work targets for overall low temperature systems (Linnhoff and Dhole, 1992). The Carnot Factor substituted the temperature on the vertical axis of the GCC. Process changes, HEN design and refrigeration system design were managed in one coherent approach.

Batch processes are frequent in the food and drink, and in the manufacture of pharmaceuticals and other low volume specialist products. Batch processes are controlled by: material-flow, heat-flow, equipment capacity, and/or labour (Linnhoff, 1993). Careful energy management usually results in cost savings for capacity (debottlenecking), yield and product quality, and energy (in that order). Cycle time can be reduced and capacity increased simultaneously.

Pinch principles have been applied to **water** and waste water **minimisation**, too. Instead of using fresh water, the spent water can be reused. Another method used is regeneration, re-use with partial treatment prior to re-use. In both cases a reduction in overall water flow-rate results. Energy costs (pumping), capital costs (piping) and environmental load all usually improve. Concentration is used instead of temperature in the CCs giving the so-called 'water pinch' (Wang and Smith, 1993). There must be no concentration mixing across the Pinch. Minimum overall water flow-rate (water target) can be estimated. The concept can be used for multi-component impurity systems.

Total Site Integration uses traditional Pinch Analysis when optimising several processes at the same site. Usually, the central combustion of fuel and cogeneration of power and steam levels exist on site. The sink profile and the source profile (Total Site Profiles) are made up from the GCC. The vertical axis is the Carnot Factor, again. Energy costs and capital investment can be reduced at the same time.

Emissions reduction and targeting can be applied on a process or a total site dimension. Better separation involves additional energy. Therefore, the reduction in process emissions needs to be assessed relative to the increase in fuel- related emissions. Using a fuel emissions / temperature diagramme, Pinch Analysis enables designers, planners, and legislators to arrive at a rational assessment of trade-offs between process-related and fuel-related emissions and to agree on achievable targets (Smith et al, 1990). Total Site Pinch Analysis brings together central site combustion, total electric power (import or export), decentralised combustion on site and global CO_2 emissions (Linnhoff and Dhole, 1993).

Mathematical methods have been introduced in order to optimise the structure and parameters of a process design or retrofit. One of the more advanced is the Mixed Integer NonLinear Programming (MINLP) one. The advantages and disadvantages of MINLP/NLP and thermodynamic Pinch Analysis are shown in Fig. 1. Pinch Analysis and heuristics (Douglas, 1988) enable the designer to invent several possible and promising structures for a process and thus reduce the search space of infinite solutions. The MINLP allows him/her to determine the best structure forecast and its parameters by the thermodynamic method. Physical insights based on thermodynamics are the ‘eye’ of the engineer; numerical methods are his ‘muscle’ (Linnhoff, 1993).

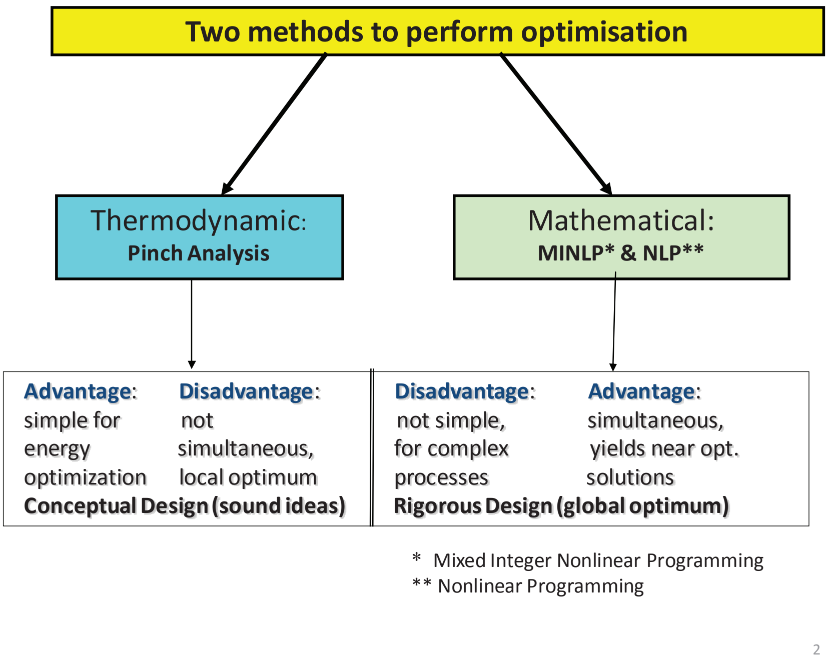


Fig. 1: Two methods for process optimization: their advantages and disadvantages.

Mathematical analysis starts with mass and energy balances, and needs an objective function which can be the maximum profit or the minimum costs. A superstructure is determined first, and then an MI tool enables the designer to find the best structure, whilst NLP is used to find the best parameters (Fig. 2).

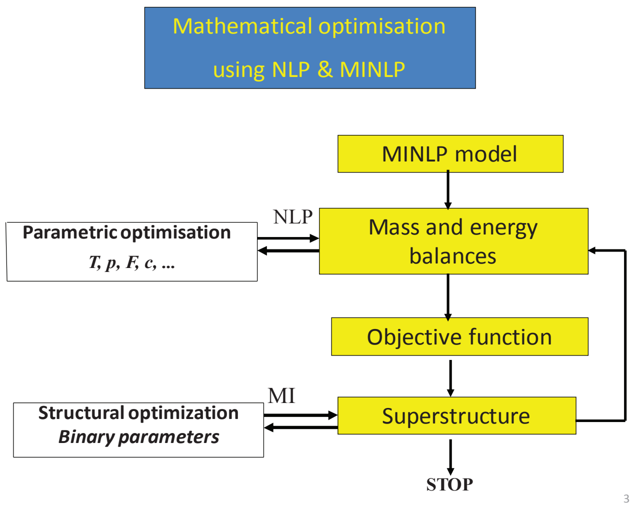


Fig. 2: Structural and parametric optimisation model using MINLP/NLP tools

This methodology has been tested using an ammonia plant as a case study (Novak Pintarič and Glavič, 2002). After elaborating the amount and enthalpy balances, energy targets were estimated using CCs. Utilities were selected using the GCC, followed by applying an extended GCC for the analysis of energy intensive unit operations. After studying those possibilities, a superstructure was generated and a modified HEN synthesized using MINLP optimisation and total costs as the objective function. Using the pinch approach only, the total costs could be reduced from 3.85M€ to 2.20M€; by applying the additional MINLP optimisation yields total costs of 2.03M€, a 47 % reduction of the base case.

2 Industrial practices

2.1 Industrial practices by performing energy audits within a variety of process industries

Energy audit in industries shows those possibilities for significant decreases of energy consumption and reduction of environmental impacts, and for integration of renewable energy technologies, too. In the following, the results are presented of energy audits during sugar production, in a dairy, in an industrial laundry, and in bakery.

2.1.1 Case study – Energy audit within a sugar production facility

This Sugar facility had ordered an energy audit of the company and utility systems. The main focus was detailed mass and energy balances of the all processes within the company: sugar beet slicing, diffusion of the cossettes, drying and pelletisation of the cossettes, carbonatation of the raw juice, evaporation, crystallisation and sugar drying. On the basis of the results, additional mass and energy balances were carried out in: the CHP plant with the steam-condensate system, the milk of lime production, and the compressed air system. Several organisational measures were proposed such as use of surplus condensate water for diffusion, preventing leaks from the cossette dryer, reuse of the air compressors cooling water. The investment measures proposed were: controlled blow down of the steam boilers, additional installation of a warm water boiler and installations of stirrers in the evaporators. The overall investment costs of 380k€ would contribute to savings of electrical energy by 0.7 % and fuel of 6.4 %. The mass and energy balances were used for further study of process optimisation and waste water minimisation (Žbontar Zver and Glavič, 2005, Krajnc at al., 2007).

2.1.2 Case study – Energy audit within a dairy

A Dairy produces several products: skimmed milk, yogurts, milk powder, concentrated whey and curd. Within the framework of the energy audit a process flow-sheet was drawn up regarding mass and energy balances of the process units, of processes, of the steam and condensate system, of the air pressure system, of the water cooling system, of the heating and of air conditioning system, as performed. With the mass and energy balance, significant losses could be identified: 33% of steam, 65 % of condensate and 40% of compressed air. Several options for energy savings were proposed and evaluated:

a) Electricity system:

- Power factor correlation (savings of 840€/a).

- Controller of the peak power demand would decrease the electricity costs by 20% from an investment of 8,000 EUR (savings of 6,400€/a).
- Implementation of an energy-efficient lighting system would demand 16,000€ of investment but save 13,000€/a.

b) Steam and condensate system:

- Controlled blow-down of the boilers would save on water and natural gas (9,500 euros/a).
- Waste heat recovery (flash steam of the boiler water and energy recovery from flue gas), investment: 92,900 €, savings: 23,200 €/a.
- Replacement of the feed boiler water pumps: investment 30,000 €, savings 7,200 €/a.
- Implementation of new steam and condensate pipes would decrease the steam, condensate losses and heat losses through poor thermally insulated pipes. The total savings would be 92, 000€/a (1,300t/a steam and 8,500t/a of condensate), an investment of 366,000€.

c) Compressed air system:

- Decreasing compressed air leaks.
- Joining the several air compressors within a new room using a new controlling system would decrease energy costs by 6%, and maintenance costs (5,800 €/a) at an investment of 42,000 €.
- Waste heat recovery from air compressors to product 9,000 m^3/a of hot water at 70°C requiring an investment of 26,000€.

d) Heating system:

- Energy renovation of the management buildings (facade, energy efficient windows, thermal insulation of the ceiling, installation of the thermostatic radiators' valves, heating using the waste heat). Investment costs: 62,500€, savings of 65.2MWh/a or 4,000 €/a.

e) Water and wastewater minimisation:

- Minimisation of sealing water would decrease wastewater by 16,000 m^3/a or 37,000€/a, investment 73,000€.
- Renovation of the washing equipment in production (improved temperature control of the washing water heating, installing valves on the hoses) would decrease steam consumption by

30 t/a, and water by 680 m^3/a (total savings of 3,000€/a). Investment for new steam water wash-down units and valves with nozzles on hoses would be 68,000€.

- Optimisation of the cleaning (CIP) plants using hot water instead of cold would remove the need for heating the wash water with steam and would reduce steam consumption by 2,010t/a and water by 3,070m^3/a (total savings of 63,000€/a).
- Decreasing the cooling water by 2,600m^3/a from the sample coolers in the boiler house and an additional decrease of natural gas by 25,000 m^3/a (13,000 €/a) – investment of 10,500€.
- Waste heat recovery from the NH_3 refrigeration system by a high temperature heat pump. Using the waste heat there it would be possible to heat 38,000m^3/a of water thus causing decreasing steam consumption by 4, 500 t/a (135, 000 €/a) and all hot water produced would be used as washing water. The investment in heat pump and a new hot water distributing system would be 150,000 €. The difference between savings and operating costs of the operating system would be 95,000 EUR/a. The payback period of the waste heat recovery system would be 2 years and the internal rate of return 49 %.

2.1.3 Case study – Energy audit within an industrial laundry

This Industrial laundry washes and irons the clothing of miners from a nearby coalmine and linen from hotels, hospitals and restaurants. Laundry processes include washing with water containing detergents and chemicals, agitation, rinsing, drying, and ironing. The laundry is equipped with 6 washing machines, 7 drying machines and 6 irons of various types and capacities. The nearby thermal power plant supplies hot and cold water, heat is produced by their own steam boiler with power of 655 kW. During the assessment phase two flowsheets were carried out (the process flowsheet and the steam-condensate system flowsheet), mass and energy balance of the process, steam-condensate and water systems. The following process parameters were calculated as a result of mass and energy balances:

- Steam production: 37.87kg/m^3 of LPG, 32 % returned condensate into the boiler, average efficiency of the system is 73.8 %, costs of the steam: 74.4 EUR/t.

- Operating costs of the laundry are 1.68 EUR/kg, possibly decreasing to 0.69 EUR/kg with the full capacities of the laundry processes.

Several organisational options for resource minimisation and energy efficiency were proposed:

- Nominating an energy manager of the laundry and implementation of the energy bookkeeping.
- Planning the laundry processes to avoid half-empty washing and drying machines.
- Optimisation of the washing processes to avoid a third washing operation saves 24 % of water and 34 % of steam.
- Consider installing the newest controllers into the washing machines to optimise the washing operation (measuring water and electricity consumption, weighing the laundry for optimal dosing of the water and chemicals).
- Regular cleaning of the filters and heat exchangers in drying machines would decrease steam consumption by 10% (13,000 €/a).

The following investments into energy efficiency and cleaner production options were proposed:

- Recycling of the rinsing water would be an efficient way of decreasing wastewater production.
- Neutralisation of the wastewater with CO_2 would save 6t/a of citric acid, total saving of the citric acid would be 5,300 €/a.
- Reuse of the waste heat. Heat of the waste air flow from the dryers and ironers could be used during the winter for producing hot water and preheating the fresh drying air. During the summer, the waste heat s could be used for cooling the production building. The possible saving could be 12,000€/a (28% steam used for drying) at an investment of 63,000€.
- Improving the eco-efficiency of the steam-condensate system: correct installation of the steam traps, optimisation of the boiler blowdown (the existing blowdown rate of 36% could be decreased to 9.2%), waste heat recovery from the flue gas and water boiler blow-down would decrease steam production by 100 t/a, water consumption by 515 m^3/a and LPG consumption by 20, 100 L/a (14, 800 €/a) at an investment of 23, 300 €. The payback on the investment would be 1.9 years and an internal rate of return of 53%.

2.1.4 Case study – Energy audit within small bakery

This small **bakery** employs 3 workers, only. The oven for baking bread is more than 100 years old (52 kW) and has been renovated to be heated by heating oil instead of coal. Maximum production is 500 kg/d of bread. An additional boiler (30 kW) has been installed for heating the building. The main option for waste emissions reduction as proposed would be replacement of the existing heating oil burner with a burner using wood pellets (replacement of heating oil by wood pellets). The saving on heating oil would be 8,500L/a (3,300 €/a) and a decrease of CO_2 of 23t/a. The investment would be 4,800 EUR, the payback period 1.5a.

Additional energy efficiency options as proposed: thermal insulation of the ceiling (investment would be 2,800€ and savings of 500€/a, payback period 6 years), waste heat recovery from flue gas (investment would be 4,800 € and savings of 100 €/a, negative net present vaslue) and installation of the new heating boiler on wood pellets (savings of 2,200 €/a and 13 t/a of CO_2 at investment costs of 10,000€, payback period 5 years).

2.2 Industrial practices by performing optimisations of industrial processes

Pinch Analysis found practical applications early in its history. The first publicly reported ones from ICI (UK) producing averaged energy savings approaching 30 % in processes previously thought to be optimised (Linnhoff and Turner, 1980). Applications reported by Union Carbide (USA) a few years later showed even better results. After completing 150 projects, BASF (Germany) reported about achieving site-wide energy savings of over 25% in retrofits within their main site in Ludwigshafen; they also reported about significant environmental improvements (Korner, 1988). By 1993, projects had been reported in over 30 countries. Commercial software was made available from Aspen (ADVENT), Linnhoff March (SUPERTARGET), N.E.L. (HEATNET), Simulation Sciences (HEXTRAN) and others.

2.2.1 Case study – Energy integration within of a Sulphuric acid plant

Our (Laboratory for Process Systems Engineering, University of Maribor) first practical results came from the energy integration of a **sulphuric acid plant** in Slovenia. Burning of sulphur, oxidation of SO_2 to SO_3, its absorption in water, and H_2SO_4 dilution are all exothermic chemical reactions. Therefore, modelling of the reactors had to be carried out first (Glavič et al, 1987). Thermodynamic analysis of the reactors and their integration into the overall process followed, and the exothermal reactor profile was placed above the pinch by changing the process structure and reactor parameters (Kravanja and Glavič, 1989). The effectivenes of the modelling and energy integration was proved: additional investment of 4.55 M€ yieled additional sales of 2.59 M€/a and an additional profit of 0.96 M€/a.

2.2.2 Case study – Total site integration within of a Methanol production plant

The existing **methanol process** had been modelled and optimised using a 4-step approach (expected additional profit in million euros per year is presented in parantheses):

1. Generation of a simplified superstructure by pinch analysis (0.23M€/a)
2. Formulation of a MINLP model, integrated within an NLP one (0.60M€/a)
3. Simultaneous optimisation using a process simulator and NLP (1.09M€/a)
4. Total site integration (1.50M€/a).

The results showed that additional production of: methanol (10.5kt/a), high pressure steam (1.4 MW/a) and low pressure steam (1 MW/a) could be expected. Simultaneous energy integration between several processes at a petrochemical site oil refinery, solvent, methanol, and formalin production) using the pinch and MINLP approaches yielded 0.4M€/a of additional profit (Kovač Kralj et al, 2002). Simultaneous external heat integration between the better internally-integrated processes using MINLP gave additional profit of 1.46 M€/a (Kovač Kralj et al, 2005). In another study a simultaneous mathematical optimisation technique using NLP included combined heat and power as well as increased ethanol production. The reactor's high recycle ratio and operating pressure were exploited to produce electricity by the open circuit gas turbine. Conversion of methanol could be increased by 0.54

% (690 t/a), whilst simultaneous heat and power optimisation could promise an additional profit of 1.7 M€/a (Kovač Kralj and Glavič, 2007). Finally, simultaneous NLP optimisation for electricity cogeneration using a gas turbine could be supplemented by increased production when changing the amounts of flow rates regarding the raw materials (hydrogen and steam). Additional flow-rate of H_2, and the reduced flow-rate of steam as reactants could be optimised: reactor conversion rate, temperature efficiency of flash separation, flow-rate fraction of flash separation regarding the exhaust (purge) stream, and energy integration would increase the conversion of methanol by 2.5% (3.2kt/a). Simultaeous heat, power and reaction optimisation would yield an additional profit of 2.5M€/a.

2.2.3 Case study – Energy integration within a specialty chemicals plant

Specialty chemical plants' energy and water usages are rarely taken as a serious problem. Small plants are usually easier to handle and monitor, energy and water are rather unimportant resources. Therefore, we investigated such a site consisting of two plants producing tanin and furfural by steam extraction from oak wood, and a cogeneration (heat and power) plant burning the rest of the wood. Total site analysis using a modified Site Sink Source Profiles (SSSP) found the existing design to be good. With only a few modifications, 9% of the hot utilities and 5% of the cold utilities could be saved with a payback time of 0.45 a (Goršek et al, 2006). The existing cogeneration system could be replaced by a new one with 2.4 times increased eletricity production having a payback time of 2.3 a.

2.2.4 Case study – Water minimisation within a sugar beet plant

Water minimisation was carried out within an existing sugar beet plant by an extended and combined systematic approach (Žbontar Zver and Glavič, 2005):

- Good housekeeping and regular maintenance.
- Division of wastewater streams into different qualities for water reuse, regeneration reuse, or recycling reuse (e.g. in cooling systems, pumps packing, equipment cleaning, floor washing).
- Mixing of wastewater with fresh to adjust contaminant concentration and temperature
- Reuse of steam condensate in the boiler house and other process operations.
- Wastewater regeneration with less complicated procedures (desinfection, neutralisation).

Fresh water consumption could be reduced by 54 m^3/h (69 %) by investing 1.9 k€ (thousand euros) only, and saving 120 k€/a with only 5d (days) payback time.

3 Results and discussion

This paper has presented and discussed several CP, energy audits, optimisation methods and methodologies including good practices and case studies. All approaches found real possibilities for decreasing waste, emissions production, energy consumption and production costs. First and the most important step is analysing the existing situation of the plant: data collection, flow sheets' preparation and mass-energy calculation. Many processes may be modelled by process simulators, for others such as milk production, laundries etc. the Excel and Open Office spread sheets are two of the more appropriate tools for data processing, mass and energy balances calculations. Real values from mass and energy balances have strong impacts on the savings calculations and on the implementation decisions. Fig. 3 shows that mass and energy balance is the common step amongst all the approaches: in CP, in energy auditing, in Pinch analysis, in waste/water minimisation, and in MINLP/NLP optimisation.

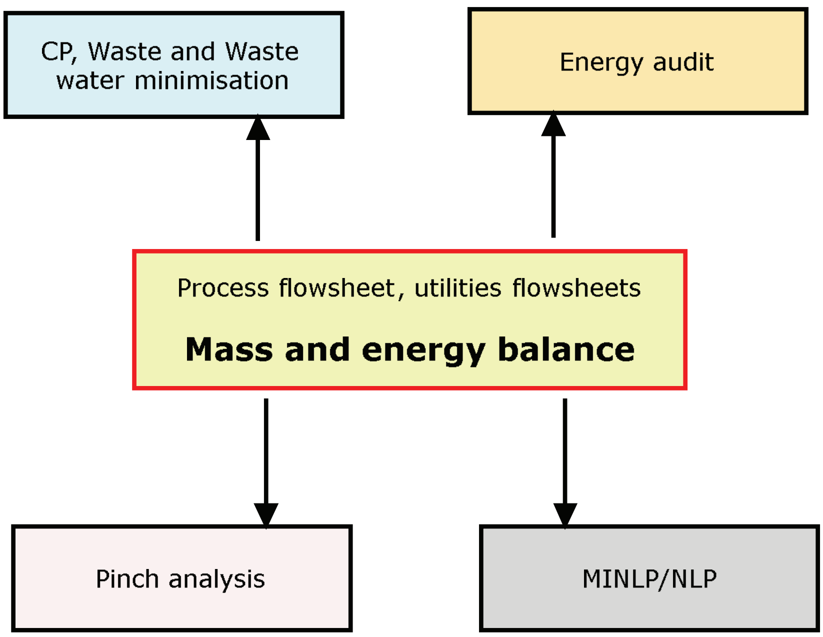


Fig. 3: Connections between mass – energy balances and other resources efficiency and optimisation tools

Production plant (and/or service facility) basically consists of one or more production processes, utility systems (hot water, steam, hot oil system with boiler house, compressed air system, cooling system), electrical system, and buildings (production areas, management building, maintenance, laboratories, warehouses etc.). Total site optimisation of the entire facility is complex and demands a gradual approach, as presented in Fig. 4. Firstly CP and energy audits should be carried out in order to enable in-depth presentations of the processes, utility systems and buildings. The proposed CP and energy efficiency measures should be implemented before further optimisation activities in order to:

- generate savings from good housekeeping and maintenance activities (low hanging fruits);
- improve process control and utility system management;
- prevent and avoid leaks and heat losses;
- improve product quality;
- reuse waste, heat and water;
- improve environmental and energy efficiencies.

After the implementation phase, new flowsheets, mass and energy balances should be carried out. The decisions regarding further steps should be performed: whether to proceed with Pinch analysis or with MINLP/NLP optimisation. This decision depends on various factors such as the type of process, complexity of the site, numbers and structures of the heat exchangers, size of the plant etc. In both cases, new flow-sheets and process simulation have to be carried out in order to perform mass and energy balances for both process and utility systems. Several possibilities may appear, for example integration of a steam boiler house and a process by reusing waste heat from the boiler house for process heating and the opposite, reuse of process condensate as feed water for steam boilers, design of a CHP plant, reuse of low temperature heat for refrigeration, integration of the heat pump into the refrigeration plant etc. Regardless of the approach selected, the new mass and energy balance should be carried out in options proposed and implemented prior to further research (such as Pinch analysis and/or MINLP/NLP optimisation). The final results are optimal process structures, efficiently integrated utility systems, reused mass and energy flows and improved eco and energy efficiency with reasonable costs, and finally global optimum according the goals and objective functions.

Fig 4 Triple- Phase approach to Total Site CP – energy efficiency – optimisation approach of the plant

This Total Site CP – energy efficiency – optimisation approach demands a highly skilled project team consisting of CP and energy efficiency experts (team 1), process engineers (team 2) and MINLP/NLP experts (team 3). CP and energy efficiency team is responsible for carrying out CP and energy audits including implementations of the proposed options. The novel – improved mass and energy balance is the input to the Pinch Analysis. Optimisation of HEN and options considered for implementation should be coordinated and checked by the team 1 in order to regularly check if the proposed integration options are technically feasible. After the final results obtained by team 2, team 1 produces final detailed drawings for implementation. Similarly, team 1 and team 2 produce new mass and energy balance (by process simulation and/or process modelling) which is the basis for setting the superstructure and objective function. After the MINLP/NLP optimisation phase is finished, teams 3 and 1 transfer the data obtained by optimisation (MINLP/NLP) into technically clear newly – optimised flow-sheets, and final drawings for implementation.

4 Conclusion

Various environmental and energy issues were successfully addressed within the industrial processes using a variety of existing methodologies. However, the industrial practices had shown the need for establishing novel approaches combining CP, energy auditing and optimisation techniques. This approach was named as the Total Site CP – energy efficiency – optimisation approach. The novelty is attained from the specially ordered structures of the already known methodologies. The novel structure consists of various steps. The initial step in CP, energy auditing, waste/water minimisation and optimisation techniques are the mass and energy balances' calculations and also recognised as the first activity within the Total Site CP – energy efficiency – optimisation approach. Afterwards, CP and energy audits should be carried out in order to enable in-depth presentations of the processes, utility systems and buildings. The implementation of the CP and energy efficiency measures should be followed by new calculations of the mass and energy balances. The decisions regarding further steps should be based on the process features, complexity of the process and optimisation requirements. One possibility is to perform the pinch analysis for the simple energy optimisation but not simultaneously. Another one is to conduct the MINLP/NLP optimisation for the complex processes and simultaneous optimisation. As the final step the optimal mass and energy balances are performed and the possibility for the real implementation is accomplished.

The scientific added-value of this paper is the proved applicability of this newly presented approach within the industrial processes, whilst its development results from identified requirements from the industrial practices themselves. This paper exposes the importance of establishing novel methodologies and approaches as responses to the requirements of industrial practices. This approach should be recognised as a dynamic one as it enables upgrading using novel techniques.

5. Nomenclature

CC	Composite Curve
CHP	Combined Heat and Power
CP	Cleaner Production
GCC	Grand Composite Curve
HEN	Heat Exchangers Network
HVAC	Heating, ventilation and air conditioning
LCA	Life-Cycle Assessment
MINLP	Mixed Integer NonLinear Programming
MOED	Minimisation Opportunities Environmental Diagnosis
NLP	NonLinear Programming
TS	Total Site Methodology
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency

References

Aue L.J., Pierce S.P., 2005. Energy Audit Uncovers Major Energy Savings for Paper Mill. ACCEEE Summer Study on Energy Efficiency in Industry. Reference documents <https://www.aceee.org/files/proceedings/2005/data/papers/SS05_Panel01_Paper01.pdf> Last accessed: 26 August 2014.

Autonomous Government of Catalonia, Ministry of the Environment, Centre for Cleaner Production Initiatives, 2000. MOED: Minimisation Opportunities Environmental Diagnosis.

Bhat S. M., 2000. Energy Audit case studies I – steam systems. Appl. Thermal Eng. 20, 285 – 296.

Bhat s.M., 2000. Energy audit case studies II – air conditioning (cooling) systems. Appl. Thermal Eng. 20, 297 – 307.

Douglas, J., 1988. Conceptual Design of chemical processes. McGraw-Hill, New York.

Glavič, P., Kravanja, Z., Homšak, M., 1987. Modeling of reactors for process heat integration. Comput. Chem. Eng. 12/2–3, 189 – 194.

Glavič, P., Kravanja, Z., Homšak, M., 1988. Heat integration of reactors I. Chem. Eng. Science 43/3, 593 – 608.

Goršek, A., Glavič, P., Bogataj, M., 2006. Design of optimal total site heat recovery system using SSSP approach. Chem. Eng. And Process. 45, 372 – 382.

Hindmarsh, E., Boland, D., Townsend, W., 1985. Maximizing energy savings for heat engines in process plants. Chem. Eng. February, 38 – 47.

Harikumar R., 1996. An Approach to Energy Audit Using Pinch Analysis. Chem. ENG. World 31/4, 73 – 74.

Jagtap S.P., Pawar A.N., 2013. Cooling Water Pumping Systems-Energy Analysis. Int. J. of Researchers, scientics and Developers 1/1, 1 – 6.

Khare S. at al., 2012. Energy Conservation through Energy Audit. Int. j. of Current Research 4/09, 144 – 148.

Krajnc D. et al., 2007. Improving the economic and environmental performance of beet sugar industry in Slovenia: increasing fuel efficiency and using by-products for ethanol. Journal of Cleaner Production 15, 1240 – 1252.

Korner, H., 1988. Optimal use of energy in the chemical industry, Chem. Ing. Tech. 60/7, 511–518.

Kornhoner J., 2002. A material and energy flow model for co-production of heat and power. Journal of Cleaner Production 10/6, 537 – 544.

Kovač Kralj, A., Glavič, P., Krajnc, M., 2002. Waste heat integration between processes. Appl. Thermal Eng. 22, 1259 – 1269.

Kovač Kralj, A., Glavič, P., Kravanja, Z., 2005. Heat integration between processes: Integrated structure and MINLP model. Comp. Chem. Eng. 29, 1699 – 1711.

Kovač Kralj, A., Glavič, P., 2007. Optimization of a gas turbine in the methanol process, using the NLP model. Appl. Thermal Eng. 27, 1799 – 1805.

Kovač Kralj, A., Glavič, P., 2009. Multi-criteria optimization in a methanol proces. Appl. Thermal Eng. 29, 1043 – 1049.

Kravanja, Z., Glavič, P., 1989. Heat integration of reactors II. Chem. Eng. Science 44/11, 2667 – 2682.

Kumbhar N., Joshi R.R., 2012. An Industrial Energy Auditing: Basic Approach. Int. J. Modern Eng. Research 2/1, 313 – 315.

Linnhoff, B., 1989. Supertargeting: Optimum Synthesis of energy management systems. J. Energy Resources Technology 11, 137 – 147.

Linnhoff, B., 1993. Pinch Analysis – a state-of-the-art overview. Trans IchemE 71/A, 503 – 522.

Linnhoff, B., Dhole, V. R., 1992. Shaftwork targets for low temperature process design. Chem. Eng. Sci. 47/8, 2081 – 2091.

Linnhoff, B., Dhole, V. R., 1993. Targeting for CO_2 emissions for total sites. Chem. Eng. Technol. 16, 252 – 259.

Linnhoff, B. Flower, J. R., 1978. Synthesis of heat exchanger networks. AIChE J 24, 633 – 654.

Linnhoff, B., Poley G. T., 1988. General Process Improvements Through Pinch Technology. Chem. Eng. Progress June, 51 – 58.

Linnhoff, B., Turner, J. A., 1990. Heat recovery networks: new insights yield big savings. Chem. Eng. Nov. 2, 56 – 70.

Linnhoff, B., Vredeveld, D. R., 1984. Pinch technology has come of age. Chem. Eng. Progress 80/7, 33 – 40.

Novak Pintarič, Z., Glavič, P., Integration of flue gas into the process flowsheet by combined pinch–MINLP aaproach, 2002. TransIChemE 80/A, 606 – 613.

Siddharta B. M., 2000. Energy audit case studies II – air conditioning (cooling) systems. Appl. Thermal Eng. 20/2000, 297 – 307.

Smith, R., Petela, E. A., Spriggs, H. D., 1990. Minimization of environmental emissions through improved process integration. Heat Recovery Systems & CHP 10/4, 329 – 339.

Petek J., Glavič P. 2000. Improving eco-efficiency by auditing steam and condensate systems. Hungarian journal of industrial chemistry 2, 30 – 35.

Singh M., Singh G., Singh H., 2012. Energy Audit: A Case Study to Reduce Lighting Costs. Asian J. Comp. Sci. and Inf. Techn. 2/5, 119 – 122.

US EPA, 2001. Guide to Industrial Assessment for Pollution Prevention and Energy Efficiency, Hazardous Waste Engineering Research Laboratory, Office of Research Laboratory, Cincinnati.

US EPA, 1988. Waste minimization Opportunity Assessment Manual. Hazardous Waste Engineering Research Laboratory, Office of Research Laboratory, Cincinnati.

Wang, Y. P., Smith, R., 1993. Wastewater minimization. Chem. Eng. Sci. 49, 981 – 1006.

Žbontar Zvez, L., Glavič, P., 2005. Water minimization in process industries: case study in beet sugar plant. Resour. Conserv. Recycl. 43, 133 – 145.

Mercury Chemistry in Wet Flue Gas Desulfurization Process

Miloš Bogataj[a], Peter Glavič[a]*, Andrej Stergaršek[b], Milena Horvat[b]

[a]*Faculty of Chemistry and Chemical Engineering, University of Maribor, Smetanova 17, SI-2000, Maribor*

[b]*"Jožef Stefan"Institute, Jamova 39, SI-1000 Ljubljana, Slovenia*

Abstract

This work is aimed at a simulation of mercury speciation in FGD process. The chemical reaction model is being developed to describe the aqueous mercury-sulfite/sulfate-chloride-carbonate system. The model takes into account the simultaneous occurrence of a number of reaction steps and coexistence of three-phases (gaseous, aqueous and solid). It is to be used to correlate pilot-scale experimental results as well as to predict kinetics at critical experimental conditions, such as low pH regions and the SO_2 gas-aqueous interface, which are difficult to investigate experimentally. The currently obtained results indicate some agreement between the simulation and the experimental solution.

Keywords: mercury, wet flue gas desulfurization, modelling, reactions

1. Introduction

Mercury emissions from coal-fired generators are a major environmental concern due to the toxicity and persistence of mercury that accumulates in our waterways (UNEP, 2013a; Pacyna et al., 2010). New regulations to limit mercury emissions from coal-fired generators are being enacted in countries around the globe (EU: COM 2005/0020, COM/2010/0723; EPA; MATS; UNEP, 2013b).

During combustion, the mercury (Hg) in coal is volatilized and converted to elemental mercury (Hg^0) vapour in the high temperature regions of coal-fired boilers. As the flue gas is cooled, a series of complex reactions begin to convert Hg^0 to ionic mercury (Hg^{2+}) compounds and/or Hg compounds that are in a solid-phase or Hg that is adsorbed onto the surface of other particles. This relative distribution has great influence on the behaviour of Hg in the atmosphere and its deposition in the reactive environment (EPA, 2006). The understanding is reached of the possibilities to achieve effective and stable removal of Hg^0 in wet FGD with the use of air (added into absorbing slurry for the oxidation of SO_2 in first place) (Stergaršek et al, 2010),

*corresponding author (e-mail: peter.glavic@um.si)

however the mechanisms and the kinetics is not developed to the extent needed, yet. Beside the oxidation of Hg^0 to Hg^{2+}, which is perfectly soluble in the solutions, the fate of Hg^{2+} in the suspension of solids (gypsum, calcium sulphite, insoluble residues of calcite, chemical precipitates in trace level) has also not been determined to the extent needed to predict final equilibrium or steady state in continuous operation. It is agreed that to fully address and solve the mercury emission threat, an understanding of flue gas desulfurization process (FGD) chemistry is crucial; unfortunately, this is not a straight forward task. Nevertheless, a development of efficient and reliable computer simulation models as tools for speciation of mercury might fill in the missing gaps in the knowledge.

2. PHREEQC software

The simulation of mercury speciation in a FGD process was performed in PHREEQC. PHREEQC is a computer program for simulating chemical reactions and transport processes in natural or polluted water, in laboratory experiments, or in industrial processes. The program is based on equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers, and sorption surfaces, which accounts for the original acronym – pH-REdox-EQuilibrium, but the program has evolved to include the capability to model kinetic reactions and 1D (one-dimensional) transport. Rate equations are completely user-specifiable in the form of Basic statements. Kinetic and equilibrium reactants can be interconnected, for example, by linking the number of surface sites to the amount of a kinetic reactant that is consumed (or produced) in a model period (Parkhurst, Appelo, 2013).

3. Model

The reaction model used in this study comprises a set of chemical elements (Br, C, Ca, Cl, Fe, H, Hg, Na, Mg, N, O, S) in their relevant oxidation states and a set of over 100 equilibrium equations (Stergaršek et al., 2013; Brandon et al, 2001; Clever et al., 1985,). In Table 1 we present those relevant to mercury species. Table 2 comprises the reactions involving sulphite, sulphate, thiosulphate, dithionate, trithionate, tetrathionate and pentathionate species. Alongside the reactions, corresponding equilibrium constants (K_{eq}) used in this work are presented.

Table 1: Equilibrium reactions involving mercury species.

Reaction	log(K_{eq})
$Hg^{2+} + H_2O \leftrightarrow Hg(OH)^+ + H^+$	–3,6
$Hg^{2+} + 2H_2O \leftrightarrow Hg(OH)_2 + 2H^+$	–6,2
$Hg^{2+} + Cl^- \leftrightarrow HgCl^+$	6,7
$HgCl^+ + Cl^- \leftrightarrow HgCl_2$	6,4
$HgCl_2 + Cl^- \leftrightarrow HgCl_3^-$	0,9
$HgCl_3^- + Cl^- \leftrightarrow HgCl_4^{2-}$	1,2
$Hg^{2+} + SO_3^{2-} \leftrightarrow HgSO_3$	12,7
$HgSO_3 + SO_3^{2-} \leftrightarrow Hg(SO_3)_2^{2-}$	11,4
$Hg^{2+} + HSO_4^- \leftrightarrow HgSO4 + H^+$	–0,6
$Hg^{2+} + CO_3^{2-} \leftrightarrow HgCO_3$	11,1
$Hg^{2+} + 2CO_3^{2-} \leftrightarrow Hg(CO3)_2^{2-}$	14,5
$Hg_2^{2+} \leftrightarrow Hg + Hg^{2+}$	1,94
$HgCl_2 + SO_3^{2-} \leftrightarrow ClHgSO_3^- + Cl^-$	15,0
$ClHgSO_3^- + H_2O \leftrightarrow Hg + HSO_4^- + Cl^- + H^+$	-0,1
$Hg_2^{2+} + S_2O_3^{2-} \leftrightarrow HgS_2O_3$	7,3
$2Hg^{2+} + H_2O \leftrightarrow Hg_2^{2+} + 2H^+ + 0,5O_2$	–12,2
$Hg_2Cl_2 \leftrightarrow Hg_2^{2+} + 2Cl^-$	–17,8
$Hg_2SO_4 \leftrightarrow Hg_2^{2+} + SO_4^{2-}$	–6,11
$HgO + 2H^+ \leftrightarrow H_2O + Hg^{2+}$	2,4
$Hg + 2H^+ + 0,5O_2 \leftrightarrow H_2O + Hg^{2+}$	14,2

Table 2: Equilibrium reactions for sulphite, sulphate, thiosulphate, dithionate, trithionate, tetrathionate and pentathionate species.

Reaction	log(K_{eq})
$SO_4^{2-} \leftrightarrow SO_3^{2-} + 0,5\ O_2$	–46,6
$2H^+ + SO_3^{2-} \leftrightarrow SO_2 + H_2O$	9,1
$2H^+ + SO3^{2-} \leftrightarrow H_2SO_3$	9,2
$SO_3^{2-} + H^+ \leftrightarrow HSO_3^-$	7,2
$2H^+ + 2SO_3^{2-} \leftrightarrow S_2O_3^{2-} + O_2 + H_2O$	–40,3
$2H^+ + 2SO_3^{2-} \leftrightarrow S_2O_4^{2-} + 0,5O_2 + H_2O$	–25,2
$2SO_3^{2-} + 0,5O_2 + 2H^+ \leftrightarrow S_2O_6^{2-} + H_2O$	41,8
$2SO_3^{2-} + 1,5O_2 + 2H^+ \leftrightarrow S_2O_8^{2-} + H_2O$	70,7
$3SO_3^{2-} + 6\ H^+ + 2e^- \leftrightarrow S_3O_6^{2-} + 3H_2O$	–6.2
$4SO_3^{2-} + 12H^+ + 6e^- \leftrightarrow S_4O_6^{2-} + 6H_2O$	–38,4
$5SO_3^{2-} + 18H^+ + 10e^- \leftrightarrow S_5O_6^{2-} + 9H_2O$	–99,4

In addition to the above reactions, a kinetic reaction (1–2) governing the dissolution/precipitation of calcite (Plummer et al., 1978) was used. The rate of dissolution is given by:

$$R_d = k_1\gamma\left(\mathrm{H}^+\right) + k_2\gamma\left(\mathrm{CO_2}^{\mathrm{aq}}\right) + k_3\gamma\left(\mathrm{H_2O}\right) \qquad (1)$$

where γ is the ionic activity of species and $k_1 = 10^{\left(0{,}98\,-\,\frac{444{,}0}{T}\right)}$, $k_2 = 10^{\left(2{,}84\,-\,\frac{2177{,}0}{T}\right)}$, and $k_3 = 10^{\left(-1{,}1\,-\,\frac{1737{,}0}{T}\right)}$ are the rate constants.

The overall rate (forward rate minus backward rate) for calcite is given by (2):

$$R_{\mathrm{calcite}} = R_d\left(1 - 10^{\left(\frac{P_{\mathrm{IA}}}{K_{\mathrm{calcite}}}\right)^{\frac{2}{3}}}\right) \qquad (2)$$

where P_{IA} is the ion activity product and K is the equilibrium constant.

4. Simulation and results

The simulation setup is given as follows. Flue gas composed of carbon dioxide, sulphur dioxide, oxygen, nitrogen, water vapour, and mercury in traces (its detailed composition is given in Table 3) is in contact with water, which is saturated with calcite. The initial mass concentration of mercury was set to 5 µg/L and concentrations of sodium and chlorine ions to 0,14 mol/L . The initial pH was set to 2,4, pE to 15 and temperature of the aqueous solution to 50 °C. The goal was to inspect the distribution of mercury species once the equilibrium was reached.

Table 3: Flue gas composition.

Component	x (%)
CO_2	16,5
SO_2	0,125
O_2	7
N_2	63,875
H_2O	12,5

Several different simulation runs were performed. During these, some of the parameters (equilibrium constants and reaction rate constants) were varied to achieve maximal agreement among the results of the simulation and experimental results. The results obtained after 800 iterations indicate that the pH of the solution is 4,6. The change in pH as a function of time is depicted in Figure 1. The increase in pH is a consequence of calcite dissolution and formation of gypsum. Despite many changes in the parameters, a considerable discrepancy between the pH of the experimental solution (pH = 5,6) and the simulated one is noticeable. On the other hand, the changes in molalities of various species in the solution exhibit minute dynamic behaviour as their values remain practically constant during the simulation. An example for $HgCl_2$ and $HgCl^+$ is shown in Figure 2.

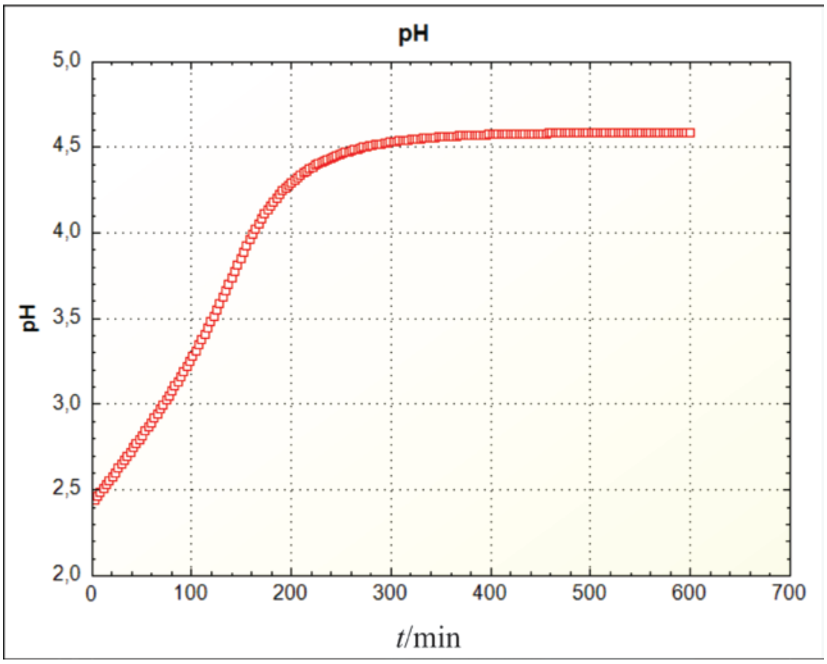


Figure 1: Change in pH as a function of time.

The simulation results regarding molalities of various species are given in Table 4. Note that only the species with molalities greater than 10^{-6} mol/kg are presented. The results indicate that mercury is predominantly present in the form of $HgCl_2$ and $HgCl^+$. Their existence in the experimental solution is for now a matter of speculation as they should be confirmed by analytical procedures. Additionally, the simulation predicts a complete absence of sulphite species (SO_3^{2-}), although the species should be present in the range of $1 \cdot 10^{-3}$ mol/kg.

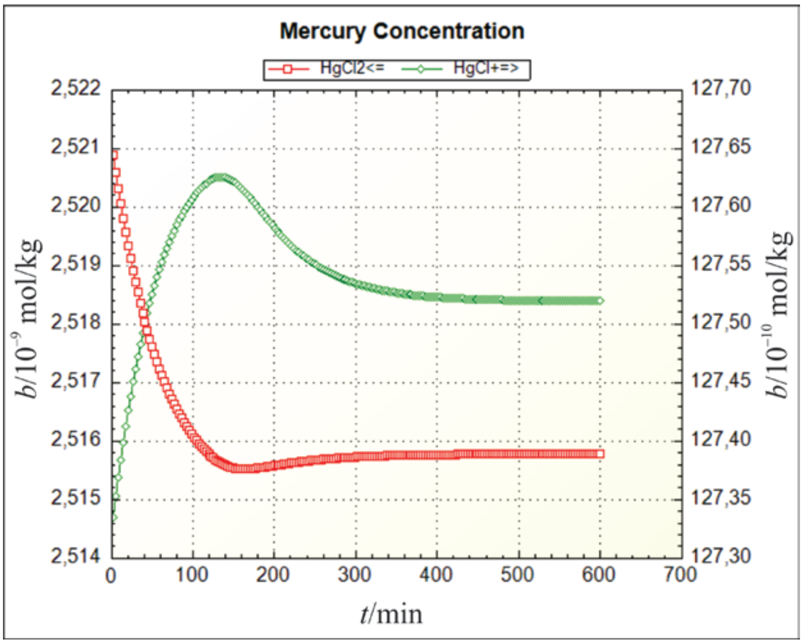


Figure 2: Change in molalities of $HgCl_2$ and $HgCl^+$ species as a function of time.

Table 4: Distribution of species.

Species	*b*(mol/kg)	Species	*b*(mol/kg)
H^+	$2{,}20 \cdot 10^{-02}$	$CaCl^+$	$6{,}77 \cdot 10^{-01}$
OH^-	$2{,}08 \cdot 10^{-06}$	$CaCl_2$	$4{,}44 \cdot 10^{-02}$
H_2O	$5{,}55 \cdot 10^{+04}$	Cl^-	$1{,}11 \cdot 10^{+02}$
CO_2	$5{,}62 \cdot 10^{+01}$	NaCl	$9{,}05 \cdot 10^{-0}1$
$CaHCO_3^+$	$1{,}20 \cdot 10^{+01}$	HCl	$4{,}64 \cdot 10^{-04}$
HCO_3^-	$2{,}99 \cdot 10^{+00}$	$HgCl_2$	$2{,}52 \cdot 10^{-06}$
$NaHCO_3$	$1{,}24 \cdot 10^{-01}$	$HgCl_3^-$	$1{,}66 \cdot 10^{-06}$
$CaCO_3$	$7{,}50 \cdot 10^{-03}$	Na+	$6{,}31 \cdot 10^{+01}$
CO_3^{-2}	$4{,}80 \cdot 10^{-05}$	$NaSO_4^-$	$5{,}54 \cdot 10^{+01}$
$CaSO_4$	$7{,}13 \cdot 10^{+01}$	O_2	$4{,}55 \cdot 10^{-04}$
Ca^{+2}	$1{,}33 \cdot 10^{+01}$	SO_4^{-2}	$1{,}29 \cdot 10^{+03}$
$CaNO_3^+$	$6{,}82 \cdot 10^{-01}$	HSO_4^-	$8{,}53 \cdot 10^{-01}$

5. Conclusions

In this work a simulation of mercury speciation in FGD process was performed. The reaction system is highly complex involving many species. The results show some agreement between the experimental solution and the simulation results, however, the model still does not represent the actual reaction system well enough. Knowledge and experiences obtained clearly point to expanding the model by thiosulphate radical reaction mechanism, which is believed to play a crucial role in the given system.

Acknowledgment

The work was supported by the Slovenian Research Agency, Project J1-4288.

Symbols and abbreviations

b	molality
k	rate constant
K	equilibrium constant
pE	redox potential
P_{IA}	ion activity product
R	reaction rate
x	molar fraction
γ	ion activity

References

1) UNEP, (2013a), Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport. UNEP Chemicals Branch, Geneva, Switzerland, available at: http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf.
2) Pacyna E.G., Pacyna J.M., Sundseth K., Munthe J., Kindbom K., Wilson S, Steenhuisene F., Maxsonf P. (2010), Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. Atmos. Environ. 2010 ; 44(20):2487–99.
3) Community Strategy Concerning Mercury (COM 2005/0020), (2005), available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0020:FIN:EN:PDF.
4) On the review of the Community Strategy Concerning Mercury (COM/2010/0723), (2010),available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0020:FIN:EN:PDF.
5) MATS – Mercury and Air Toxics Standards, US Environmental Protection Agency, available at: http://www.epa.gov/airquality/powerplanttoxics/.
6) UNEP (2013b), Minamata Convention on Mercury – Text and Anexes, available at: http://www.mercuryconvention.org/Portals/11/documents/Booklets/Minamata%20Convention%20on%20Mercury_booklet_English.pdf.
7) EPA (2006), Control of mercury emissions from coal-fired electric utility boilers, available at: http://www.epa.gov/ttnatw01/utility/hgwhitepaperfinal.pdf.
8) Stergaršek A., Horvat M., Frkal P., Stergaršek J., (2010), Removal of Hg0 from flue gases in wet FGD by catalytic oxidation with air – An experimental study, Fuel, (89), p. 3167–3177.
9) Parkhurst, D.L, and Appelo, C.A.J, (2013), Description of input and examples for PHREEQC version 3 – A computer program for speciation, batch-reaction, one-dimensional transport, and inverse

geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 pp., available only at http://pubs.usgs.gov/tm/06/a43.

10) Stergaršek A., Horvat M., Frkal P., Ribeiro Guevara S., Kocjančič R., (2013), Removal of Hg0 in wet FGD by catalytic oxidation with air – A contribution to the development of a process chemical model, Fuel, (107), p. 183–191.

11) Brandon N.P., Francis P.A., Jeffrey J., Kelsall G.H., Yin Q., (2001), Thermodynamics and electrochemical behaviour of Hg-S-Cl-H_2O systems, Journal of Electroanalytical Chemistry (497) p. 18–32.

12) Clever H. L., Johnson S.A., Derrick M.A, (1985), The solubility and some sparingly soluble mercury salts in water and aqueous electrolyte solutions, Journal of Physical and Chemical Reference Data, (13)3, p. 632–675.

13) Plummer, L.N., Wigley, T.M.L., and Parkhurst, D.L. (1978), The kinetics of calcite dissolution in CO2-water systems at 5 to 60 C and 0.0 to 1.0 atm CO_2, American Journal of Science, (278), p. 179–216.

Efficient use of energy in small size brewery

Anna Beloborodko, Liga Zogla, Marika Rosa
Institute of energy systems and environment, Riga Technical University, Azenes Str.12-1, Riga, Latvia, LV-1048
Anna.Beloborodko@rtu.lv, Liga.Ozolina@rtu.lv, Marika.Rosa@rtu.lv
Corresponding author: Anna Beloborodko, Riga Technical University, Azenes Str.12-1, Riga, Latvia, LV-1048, Tel: +371 26357568, Anna.Beloborodko@rtu.lv

Abstract

Industrial production is a significant consumer of materials and energy, therefore efficient use of energy in industrial processes is important to reach the global sustainability targets. This study examines a small-size brewery in Latvia. As most of Latvian breweries are of small size and generally produce for local market, they are not affected by the EU or national legislation on energy efficiency; therefore the global trends to increase energy efficiency have weak effect on them. Increased resource and energy efficiency could help these breweries reduce production costs and environmental impact from beer brewing. The aim of this study is: (1) to analyze the historical resource and energy consumption in case study brewery and compare it to available benchmarks and (2) to determine the potential resource and energy efficiency improvements for the case study brewery. To evaluate the efficiency of resource and energy consumption in the brewery, two year (2011-2012) historical energy and resource consumption data is analyzed and compared to the recommendations of the Reference Document on Best Available Techniques in the Food, Drink and Milk Industries (BREF)[1], and other studies on energy and resource performance of medium-sized breweries. The determined specific water consumption corresponds to the typical benchmarks given in BREF. Specific thermal and electricity consumption exceeds the reference values. To investigate energy consumption patterns in brew house process, the heat losses are calculated. The results suggest significant potential for energy savings by implementing heat recovery after wort boiling. To determine the specific electricity consumption, a monitoring system was set up for three different types of bottling (glass packaging, plastic packaging and barrels). Results show that specific electricity consumption (kWh/hl) for different types of packaging varies up to 7.6 times. Also, results of the implemented monitoring system provide valuable data for determining the correction factors for different bottling possibilities for the brewery.

Highlights

Analysis of small size brewery provides energy consumption data lacking in literature
Monitoring of electricity use shows the differences between three types of bottling
Measured data can be used for correction factors for different bottling possibilities

Keywords

Energy intensity, Resource intensity, Small size brewery, Heat loss, Electricity monitoring

1. Introduction

Industrial production is related to large consumption of energy and materials; therefore energy efficiency in industry is pursued through various global and European Union (EU) initiatives (e.g. EU 20-20-20 targets). To implement energy efficiency measures, current energy consumption of companies must be analyzed and compared to benchmarks for potential improvements.

---

1 European Commission, 2006. Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 682 pp.

Industrial companies can be divided into two parts according to their energy consumption – energy intensive (e.g. pulp and paper, steel, chemical production) and non-energy intensive (e.g. manufacturing and food industries) (Sandberg and Söderström, 2003). Due to higher energy consumption and, therefore, larger potential for improvements, energy intensive industries have been in the scope of numerous researches. The potential energy efficiency improvements for these industries have been identified through the analysis of the best practice and by setting benchmarks for potential energy savings (e.g. benchmarks for energy intensive industries have been identified within the project ODYSEE (ODYSEE, 2014)).
Presently increasing attention is devoted to energy savings in small and medium enterprises (SME). The EU Energy efficiency Directive encourages energy auditing and implementation of energy efficiency measures in SME (European Parliament, 2012). But as the majority of SME are energy non-intensive industries, and energy costs typically constitute 1-3% of their total production costs (Sandberg and Söderström, 2003; Muller et al., 2007), they are less interested in implementing energy efficiency. There are also few studies on energy efficiency in non-energy intensive industries and SME in the Baltic States; and the lack of available data limits the estimation of potential improvements and establishment of relevant energy improvement benchmarks. Therefore, general benchmarks for large size industries are typically applied for SME analysis. To improve the knowledge on potential energy efficiency improvements, the analysis of the actual data for non-energy intensive industries and SME is necessary.
Food and beverage production is one of the most important local industries in Latvia (Rosa and Beloborodko, in press). Beer brewing has long traditions in Latvia; many breweries are famous for their specific taste and the non-filtered („live") beer. There are more than 20 breweries in Latvia, most of which are small and medium size breweries. As these breweries generally produce for local market, they are not affected by the EU or national legislation on energy efficiency; therefore the global trends to increase energy efficiency have weak effect on them. To identify the potential energy efficiency improvements and gather data for future benchmarking, a small size Latvian brewery is chosen as a case study. The aim of this study is: (1) to analyze the historical resource and energy consumption in case study brewery and compare it to available benchmarks and (2) to determine the potential resource and energy efficiency improvements for the case study brewery.
The article is organized as follows: chapter 2 summarizes the applied methodology, chapter 3 presents the case study brewery, chapter 4 provides the results and discussion, and finally conclusions are presented.

2. Material and methods

2.1. Analysis of the historical resource and energy consumption

Company's production performance can be described by specific resource or energy consumption indicators (European Commission, 2006). The performance of case study brewery is determined by analysis of production data for a two year period (2011 and 2012). The specific consumption of thermal and electrical energy, water, malt and hops is calculated from monthly or annually consumption data and normalized by the amount of produced beer. The thermal energy consumption is calculated based on natural gas consumption records. Because of on-site heat production and distribution through a single system, company's records declare only the total gas consumption, without distinction for process heat and space heating. The data for total electricity and water consumption is gathered from on-site meters. Malt and hops are delivered in batches and there is no daily accounting for their use. The specific malt and hop consumption is analyzed for annual data.
To analyze the current resource and energy consumption and identify potential improvements, the identified specific consumption indicators must be compared with benchmarks. Due to the absence of a reporting system for companies to declare their production performance results, there is an absence of statistical data for comparison of case study brewery with other breweries in the region; the literature regarding specific energy consumption in small-size breweries is scarce as well. Therefore case study results for a small scale brewery are compared with the benchmarks for

medium size brewery in the United Kingdom (UK) (Sturm et al. 2013) and BAT recommendations based on data about modern large scale breweries in Germany (European Commission, 2006).

2.2. Analysis of brew house heat losses and monitored electricity consumption in the bottling department

As historical consumption of thermal and electrical energy was identified to be significantly higher than given by relevant benchmarks, the potential sources of inefficiency were investigated through determination of heat losses at the brew house and monitoring and analysis of electricity consumption in the bottling department.
The heat losses at the brew house are calculated to determine the energy efficiency of the brewing process. Transmission heat losses are calculated for each considered process stage, while evaporation losses are evaluated only for wort boiling, as in this stage steam is emitted into atmosphere. Brew house heat losses are determined according to the method presented by Sturm et al. (2013) for a case study of process-wise similar medium size brewery in the UK.
Three different types of packaging are used in the analyzed brewery - bottling in plastic (PET) bottles, glass bottles and metal barrels. To determine the electricity consumption for each bottling station, monitoring was performed from October to December 2013. Measuring points were set up at five power inputs (2 at a glass bottling station, 2 at a PET bottling station, 1 at a metal barrel filling station). Split core AC current sensors (CTV-A, CTV-B, CTV-C, CTV-D) and four-channel data loggers (U12 U12-006) were installed. The sample recording time for all loggers was set to 5 minutes. The amount of bottled beer was recorded simultaneously with electricity consumption. Eq. 1. was applied to convert from measured data to electricity consumption.

(A)

where:
P - power, W,
I_{vid} - average-current, A,
U_{vid} - average voltage at input, V,
$\cos\varphi$-power factor.

3. Description of the case study beer brewery

The case study is a small size brewery producing 5 types of beer with annual production amounts approximately 15 000 hl. The technological process of beer production includes milling of malt, mashing, preparing and boiling of wort, beer fermentation, conditioning, filtration and pasteurization and bottling. Beer production requires materials (malt, hops and water) and energy (electricity and thermal). Electricity is provided from power grid, but process heat is generated in on-site natural gas boiler house. During the beer brewing process a solid fraction – brewers spent grain - is separated from mash. In the case study brewery, the brewers spent grain, which is high in protein, is collected and supplied to farmers to be used as animal feed.
Due to the small size of the brewery, raw resource costs constitute the largest share of total production costs, which is the most important concern, and constitute more than 50% of production costs annually (Lursoft, 2013). Breweries representatives do not consider the costs of energy to be of high concern. Electricity costs constitute only 3% of total production costs, but the combined share of heat and electricity costs in 2012 was 9% of total production costs (Lursoft, 2013). Due to an increasing energy price trend, brewery is interested to determine and identify potential efficiency improvements.

4. Results and discussion

4.1. Analysis of historical data for energy consumption

The specific consumption of thermal and electrical energy is calculated from monthly data provided by brewery. Average annual specific thermal energy consumption in 2011 was 245 MJ/hl and in

2012 – 231 MJ/hl. Average annual specific electricity consumption was 92 MJ/hl in 2011 and 82 MJ/hl in 2012. The relation between monthly beer production and specific thermal energy and electricity consumption is depicted in Fig.3.

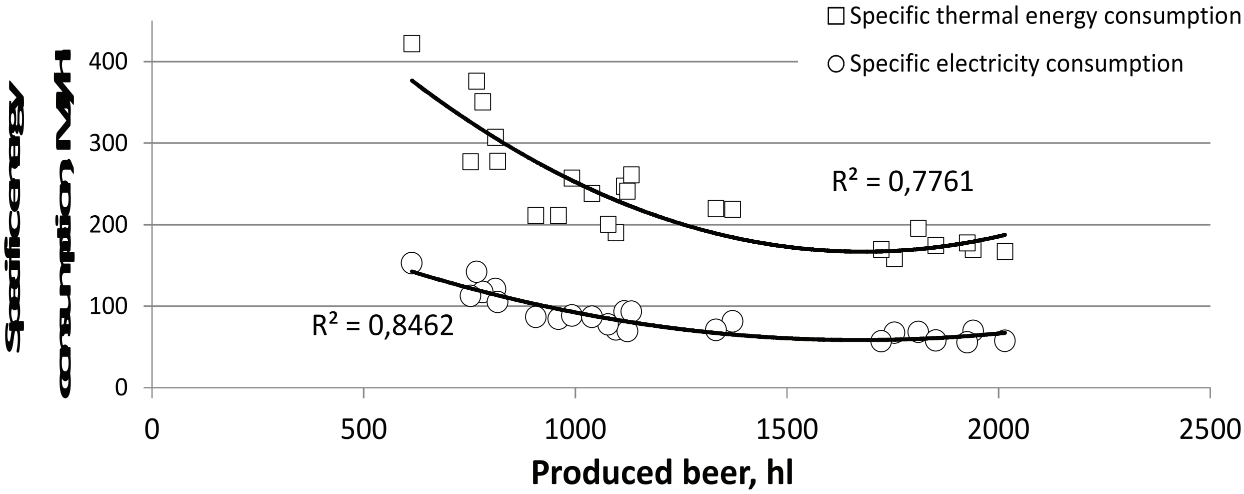


Fig.1. Specific energy consumption according to amount of produced beer

To evaluate potential energy savings, the specific energy consumption indicators for case study brewery were compared with the recommendations of BREF (providing benchmarks for breweries with capacity over 1 million hl of beer per year) (European Commission, 2006) and specific energy consumption in medium size brewery in UK (Sturm et al., 2013) (see Table 1).

Table 1
Comparison of specific energy consumption

	Specific thermal consumption, MJ/hl	Specific electrical consumption, MJ/hl
BREF recommendations (large size)	85 - 120	37.8 – 43.2
UK case study (medium size)	160 – 180	45–60
Case study (small size)	231 – 245	82 – 92

The specific energy and electricity consumption exceeds the best practice reference values in large and medium size breweries. This could be due to better technologies, larger amounts of beer produced and continuity of processes, as well as production of other alcoholic and non-alcoholic products. Respectively, the cause of higher specific energy consumption should be investigated and potential improvements should be suggested for small size breweries.

4.2. Analysis of historical data for resource consumption

The specific consumption for malt and hops is calculated from annual data and for water from monthly data provided by brewery representatives. Both high and low specific water consumption is seen per unit of beer produced. This is due to at least two week time shift between the consumption of water and other resources (malt and hops) and the delivery of the beer. Therefore the annual specific water consumption is compared to BREF and UK case study (see Table 2). In Latvian case study specific water consumption is from 0.78m^3/hl (2012) to 1.0m^3/hl (2011), suggesting that water consumption in this brewery correspond to recommendations for modern breweries.
Specific consumption of malt was 28.0 kg/hl in 2011 and 31.6kg/hl in 2012. Specific consumption of hops was 0.073 kg/hl in 2011 and 0.074kg/hl in 2012. Annual differences of raw material consumption can related to changing proportions of light and dark beer. The reported malt consumption for large breweries is 1.4 times lower than for case study brewery, but for a small size

brewery the current consumption is relevant, taking into account large proportion of dark beer being produced.

Table 2
Comparison of specific water consumption

	Specific water consumption, m^3/hl	Specific malt consumption, kg/hl	Specific malt consumption, MJ/hl
BREF recommendations (large size)	0.4 - 1.0	20	–
UK case study (medium size)	0.64 – 0.72	–	–
Case study (small size)	0.78 – 1.0	28.0 – 31.6	0.073 – 0.074

4.3. Investigation of energy losses in brew house

Though the case study brewery is quite new (it is in operation only since 2002) the performance analysis identifies that the specific thermal energy consumption exceeds the recommendations. This could be because the installed equipment is not new but has been bought from older breweries and its thermal efficiency may not the same as for new equipment. To determine heat loss in the brew house, data was collected and calculations were made for a single brew batch of case study brewery's most popular beer – light lager. To identify the cause of the large energy consumption, energy losses for each stage of brewing were calculated according to the method presented by Sturm et al. (2013). To calculate heat losses all vessel dimensions are measured (vessels are approximated to be cylindrically shaped), fluid filling height is calculated according to the amount of ingredients filled in tanks, temperature regimes for each process are provided by brewery representative. There is a shortage of information on heat loss for small size breweries in literature. To analyze the obtained results a process-wise similar but higher capacity (250 000 hl beer per year) brewery in UK was used as reference (Sturm et al., 2013) (see Table 3).

Table 3
Comparison of heat losses in cases study and reference brewery

Heat loss, MJ/hl		Mashing tank	Mash filtration	Wort boiling	Whirlpool
Transmission heat loss	Case study	0.047	0.59	0.12	0.12
	Reference	0.06		0.17	0.04
Evaporation heat loss	Case study			20.54	
	Reference			6.67	
Heat lost due to spent grains discharging	Case study	0,80			
	Reference	1.68			
Overall heat loss during process	Case study	0.85	0.59	20.66	0.12
	Reference	1.74		6.84	0.04

The total heat loss in brew house is 22.22MJ/hl of witch 93% is heat loss due to evaporation of water during wort boiling. In the reference case study total heat loss (taking into account losses at fermentation department) is half lower - 9.68MJ/hl, mostly due to difference in evaporation heat loss. Transmission heat losses are similar in both cases studies. Though Latvian brewery is smaller and has higher specific thermal energy consumption, the specific brew house energy loses are similar in both cases, which is a good indicator for a small brewery. As shown by Sturm et al. (2013) the reduction of evaporation heat loss could noticeably contribute to reducing overall energy consumption in the brewery. The recovered energy could be used to heat the water in the accumulation tank. The evaporation heat recovery would reduce overall thermal energy consumption, costs and fuel demand.

4.4. Monitoring of electricity consumption in the bottling department

The specific electricity consumption of different bottling stations can be determined by attributing the electricity consumption to the volume of bottled beer. When the specific electricity consumption for all three different bottling stations is normalized by production units, it can be compared.
The equipment for filling of 30 l metal barrels (KEG) has one power input for all its sections - barrel rinsing, disinfecting and filling. Monitoring data for barrel filling station is available for a period from 10.03.2013. to 10.28.2013. taking into account 9 days of barrel filling. The statistical analysis shows weak correlation between the amount of filled beer and specific electricity consumption (see Fig. 2). This means that KEG filling line power consumption significantly influenced by factors other than beer filling KEG barrels, that should be investigated in-depth to provide specific improvements.
At the glass bottle filling station beer is bottled in 0.33l, 0.5l glass packaging. The bottling station consists of a bottle washing and rinsing, bottle filling, corking, and labeling conveyors. There are two power inputs for glass bottling line - one for the labeling equipment and a lighting appliance (hereinafter - *glass bottle labeling equipment*), and second for other sections (*glass bottling equipment*). Monitoring data for glass bottling equipment is available for the period from 10.03.2013. till 12.17.2013. (7 days of bottling). Due to monitoring equipment misstep, measurements for glass bottle labeling equipment are available only for four bottling days. The trend lines (see Fig. 2) indicate that the specific electricity consumption of the glass bottle labelling and bottling equipment decreases with increasing amounts of daily bottled beer, which demonstrates higher efficiency at larger capacity.
The beer is filled 1l and 2l plastic (polyethylene terephthalate, PET) bottles. Only clean and pre-inflated bottles are used, so there is no need for bottle rinsing. The bottling line consists of filling, corking, labelling and multi-pack packing equipment. Monitoring equipment was installed separately at two power inputs - one for multi-pack packaging equipment (*PET packaging equipment*), and another for other sections (*PET bottling equipment*). The monitoring data for both inputs are available for the period from 10.03.2013. to 12.17.2013 (6 days of bottling). The specific electricity consumption for PET packaging equipment and PET bottling equipment varies greatly, former being even 20 times larger than the latter (see Fig. 2). The trend lines for specific electricity consumption for packaging and bottling of PET bottles show a statistically significant relationship (R^2=0.9587 and R^2=0.912 accordingly).

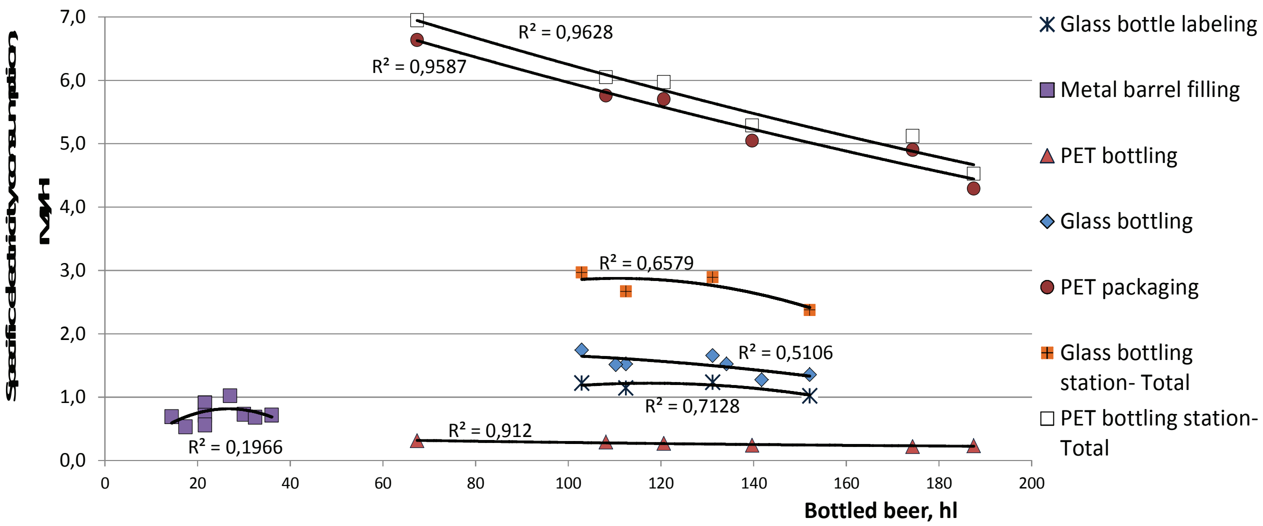


Fig.2. Specific electricity consumption at different power inputs

Fig. 2.also presents the summary of the specific electricity consumption for the entire bottling stations in case study brewery. PET bottling station has the highest specific electricity consumption in the analyzed brewery, glass bottling station – the second largest, metal barrel bottling station - the lowest. The average specific electricity consumption of PET bottling station is 7.6 times higher than that of metal barrel filling station. Even though in summary the PET bottling station has the highest

total specific electricity consumption, the PET bottling equipment has the lowest specific electricity consumption of all equipment in brewery's bottling department. Analysis of consumption patterns for each power input shows that the most crucial sections for implementation of energy efficiency measures in case study brewery are PET packaging and KEG filling equipment.

A significant energy consumption was also identified during production off-time was determined in bottling department, potential savings could be provided by improved equipment management and production planning. These indicative monitoring results different bottling stations in case study brewery can be used to determine correction factors for benchmarking and for further analysis.

5. Conclusions

Though beer brewing is not considered as an energy intensive industry, significant differences of the specific energy consumption are observed for small, medium and large size breweries. The identification of potential energy efficiency improvements and benchmarks relies on availability of precise data. Currently such analysis for energy efficiency in non-energy intensive industries and SME in Latvia is restricted due to small number of detailed studies. To overcome the existing lack of data, within this research the specific energy and material consumption in small size Latvian brewery is analyzed. In addition, this is one of few researches within Baltic States providing results of electricity monitoring in industry.

The results of historical data analysis show that specific water and material consumption in case study brewery corresponds to results reported in other studies, but the specific energy consumption is significantly higher. To identify the cause of high specific energy consumption, the brew house heat losses and electricity consumption for bottling was analyzed. The results suggest that the highest heat losses in brew house result from water evaporation during wort boiling and energy efficiency could be improved by recovering energy from steam. The electricity monitoring results show that specific electricity consumption (kWh/hl) for different types of packaging varies up to 7.6 times. As well significant energy consumption during off-time is determined and important savings could be provided by improved equipment management.

As determined, the specific electricity consumption for different equipment even in the same bottling station can vary importantly. This also impacts the electricity savings potential for beer in different packaging. One of possibilities to consider such differences is the use of correction factors. The specific electricity consumption for different bottling station, which was determined in this study, can be used for application of correction factors for particular brewery. Furthermore, the benchmarks for identification of energy efficiency improvements in industry should be advanced so that they could account for varying processes and potential improvements due to varying design of each production.

Acknowledgments

Support for this work was provided by the Riga Technical University through the Scientific Research Project Competition for Young Researchers No.ZP-2013/14.

References

European Commission, 2006. Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Food, Drink and Milk Industries, 682 pp.

European Parliament, 2012.Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0027 (accessed 30.09.14.).

Lursoft, 2013. Lursoft data bases of enterprises.

Muller D.C.A., Marechal F.M.A., Wolewinski T., Roux P. J., 2007. An energy management method for the food industry. Applied Thermal Engineering 27(16), 2677-2686.

ODYSSEE 2014. Online: http://www.indicators.odyssee-mure.eu/online-indicators.html (accessed: 30.09.14)

Rosa M., Beloborodko A. In press A decision support method for development of industrial synergies: case studies of Latvian brewery and wood-processing industries. Journal of Cleaner Production, Available online 28 September 2014

Sandberg P., Söderström M., 2003. Industrial energy efficiency: the need for investment decision support from a manager perspective. Energy Policy 31(15), 1623-1634.

Sturm B., Hugenschmidt S., Joyce S., Hofacker W., Roskilly A.P., 2013. Opportunities and barriers for efficient energy use in a medium-sized brewery. Applied Thermal Engineering, 53(2), 397-404.

University Educators for Sustainable Development

Peter Glavič, University of Maribor, Slovenia

Abstract

A new education initiative is planning to shake up the way teaching and learning occurs at the university level to equip students with the skills needed to counter increasing social, economic and environmental inequalities.

University Educators for Sustainable Development (UE4SD, http://www.ue4sd.eu) is a project that brings together 55 partners (mainly universities) from 33 countries across Europe and beyond to rethink the higher education curriculum to address sustainable development. The 3 year-project, funded by the European Commission under the Lifelong Learning Programme - Erasmus Academic Networks, will focus on linking Education for Sustainable Development and the drive to improve quality in higher education generally. UE4SD will seek to innovate academic practice and curriculum by creating opportunities for university educators to develop professional competences and the academic leadership capabilities linked to Education for Sustainable Development. In other words, it will support teaching colleagues, to enable them to prepare students, regardless of their courses or specialisation, to understand and apply their professional and global responsibilities in sustainability. Ultimately, it seeks to contribute to the reorientation of higher education so that it is more future facing and able to support the construction of a better world.

The project focus is innovative as not much is known about how the Education for Sustainable Development competences of university educators are supported and developed. To overcome this barrier, project partners will conduct a grounded study to map and analyse existing professional development opportunities in Education for Sustainable development at a country and regional level. A systemic collection of information will result into four European sub-regional mapping reports and one state of the art report across all 33 partner countries. Leading practice will be identified and will form the basis of a publication and online platform of resources. These project resources will support and Academy of Education for Sustainable Development in Higher Education which seeks to support higher education institutions to implement change programmes in the area of Education for Sustainable Development and professional development.

UE4SD activities are closely associated with COPERNICUS Alliance, the European Network of Higher Education for Sustainable Development, and the "Rio+20 Treaty on Higher Education" which was launched at the UN United Nations Conference on Sustainable Development in Rio de Janeiro in June 2012. The project is led by the University of Gloucestershire (UK) who works very closely with three core partners: Autonomous University of Madrid (Spain), Charles University (Czech Republic) and Leuphana University of Lunenburg (Germany). [Partner name] is a UE4SD partner and will be sharing and comparing professional experiences with other partner institutions, seeking to drive curriculum change for sustainability through a focus on Education for Sustainable development capabilities.

Keywords:

university educators, sustainable development, competences, professional development

Introduction

Higher education institutions have a prominent role within the United Nations Decade of Education for Sustainable Development (DESD, 2005–14) as they prepare the future generation of professionals, challenge dominant paradigms and produce ground-breaking research. There is evidence that universities and colleges have engaged and influenced policy and practice in the area of sustainability, but progress in reorienting the curriculum in relation to sustainable development has been slow.

About the Project

UE4SD is a partnership of higher education institutions (HEI), organisations, agencies and associations across Europe and beyond seeking pathways for progressing sustainability innovation in higher education. This is important as the higher education sector is well positioned to bring about change for sustainability as it prepares the future generation of leaders and professionals, challenges dominant paradigms, produces ground-breaking research and plays an important role in facilitating social change.

The quality of academic provision in higher education requires institutional structures which support sustainability values and practice, but also university educators who are able to embed Education for Sustainable Development (ESD) principles into their teaching and research. However, little is known of the ESD competences of university educators and how these are supported and developed. This is because research, and practice, in higher education has focused on student rather than staff learning in the area of sustainability.

UE4SD aims to close this knowledge gap and work in partnership to map opportunities for university educators to develop ESD competences [1] through professional development and identify how competences can be best developed to enhance quality academic practice in the area of sustainability. It will identify leading practice in this area in Europe and develop an online database of resources to support changes to curriculum development and academic provision in universities. The Network will also frame and trial a Sustainability in Higher Education Professional Development and Networking Platform (Sustainability in Higher Education Academic).

UE4SD has its roots on the work of COPERNICUS Alliance[2] and the *People's Sustainability Treaty on Higher Education*[3] which support change for sustainability in higher education.

The Network

UE4SD is a consortium of higher education institutions (HEI), organisations, agencies and associations gathered around four regions across Europe (Eastern, Northern, Southern and Western Europe).

The consortium has been created taking into account geographical balance, including 54 partners from 33 EU countries, and key international networks and associations. Partners have been selected because of their commitment towards sustainability and ESD in higher education as shown from their COPERNICUS Alliance membership and/or endorsement of the *People's Sustainability Treaty on Higher Education*. The partnership includes all the skills and recognised expertise in the areas of sustainability and ESD in higher education. Tasks have been distributed across the partners taking into account their specific expertise and nature of the activities planned.

Focus of the Network

In recent years we have seen a rise of initiatives which have created momentum to address ESD in higher education and which have pointed to the urgency of advancing issues regarding teaching and learning quality and professional development through ESD competences. Perhaps the most important ones are the United Nations Decade of Education for Sustainable Development (UN DESD, 2005-2014), the *UNECE ESD Competence Framework for Educators* (2011) and the *People's Sustainability Treaty on Higher Education* (2012).

There is a global agreement that future quality academic practice in higher education requires institutional structures which support sustainability principles and practice, but also university educators who are motivated and capable of embedding sustainability in their teaching and research. However, little is known to date on what ESD means in relation to the quality of teaching and learning; how universities can respond to this; what strategic concerns have university educators in relation to ESD; and, how educators develop ESD competences through training and professional development in universities. UE4SD seeks to close these knowledge gaps through:

- Mapping opportunities for university educators to develop ESD competences through professional development.
- Identifying quality issues associated with the development of ESD competences of educators in universities.
- Identifying and capturing leading practice in the area of ESD competences and professional development in universities as well as develop an online database of resources.
- Framing and trialling a Sustainability in Higher Education Professional Development and Networking Platform in Europe (Sustainability in Higher Education Academy).
- Providing strategic advice on how to develop the ESD competences of educators.

Through European and international co-operation, SPHEre will undertake grounded studies to further understand the links amongst teaching and learning quality, professional development and ESD competences. It will provide guidance to universities to enhance the quality of teaching of learning in the area of sustainability.

Relevance

The European Council[1] has confirmed that sustainable development is one of the main challenges in Europe and remains a fundamental objective of the European Union under the Lisbon Treaty.

- Key documentation[2] from the EU acknowledges that education and learning play an important role to achieve sustainable development goals. They equip citizens with the knowledge, skills and attitudes needed to understand and deal with the challenges and complexities of sustainable development.
- The potential of higher education in addressing sustainable development has been widely acknowledged internationally. This recognition is founded on the notion that universities improve the life chances of graduates and the communities they belong. They are recognised for their influence on policy directly, as well as indirectly, through the education of policy makers. They are influential in the development of leaders and future professionals.
- A recent review of articles and experiences carried out by the Network suggests that universities are responding to the sustainability mandate and engaging in sustainability activities. There is evidence which demonstrates that universities have influenced campus management towards sustainability and reduced their carbon footprint. However, progress on the curriculum in relation to sustainability has been slow.

- Re-orienting the curriculum towards sustainable development requires not just the inclusion of relevant subject matters and the pursuit of inter- and trans-disciplinary approaches, but also a pedagogy which engages the learner in challenging unsustainable development practices and models, understanding their professional responsibilities and creating alternative pathways for the future. This requires university educators who are motivated and capable of integrating sustainability in their teaching practice.
- Research and practice in higher education has primarily focused on student rather than staff learning in the area of sustainability. A deeper understanding on how university educators develop ESD competences through professional development is required. The *UNECE Competence Framework for Educators* is a useful tool to understand which competences are needed to effectively embed sustainability in teaching and learning in higher education.
- There is need to identify quality issues associated with ESD competences of educators in universities and provide guidance to enhance the university academic provision in the area of sustainable development.

Ambitions of the Network: Outputs and outcomes

Outputs:

- A document which maps opportunities for university educators to develop ESD competences through professional development in Europe.
- A publication which will showcase 8 case studies from the leading practice identified.
- An online database of resources to assist universities interested in supporting the development of ESD competences of educators.
- A document which will outline a framework of a Sustainability in Higher Education Professional Development and Networking Platform in Europe (Sustainability in Higher Education Academy).
- A conference organised by UE4SD open to the general public.
- A website to support information and knowledge exchange as well as dissemination of Network activities and materials.

Outcomes:

- A review of the state of the art in the areas of ESD competences, professional development and teaching and learning quality.
- A deeper understanding of the connections between ESD and teaching and learning quality.
- A platform for supporting university educators in developing their own competences in ESD.
- An increased level of awareness on the importance of addressing ESD competences in professional development and training in universities.

References

[1] United Nations Decade of Education for Sustainable Development (UN DESD, 2005–2014).
[2] *UNECE ESD Competence Framework for Educators* (2011).
[3] *People's Sustainability Treaty on Higher Education* (2012).

"Experiences with the use of renewable energy in industry, especially in the food processing sector"

Prof. Hans Schnitzer, Graz University of Technology

Introductory presentation to: Innovative Approaches to Energy Efficiency and Application of Renewable Energy in Industry

Acknowledgement:

This paper has been produces on the basis of several projects in cooperation with a number of people and institutions:

- GREENFOODS (IEE-Project)
- UNIDO: Regional LOW CARBON Project: Participants on Balkan; National Cleaner Production Centers (NCPC) of
    - Macedonia: www.ncpc.com.mk
    - Serbia: www.cpc-serbia.org
    - Albania: www.ecat-tirana.org
    - Croatia: www.cro-cpc.hr
    - Montenegro
    - Moldova: www.ncpp.md
- AEE Intec, Gleisdorf Austria
- IEA-SHC Task 33 and Task 49
- Cooperation with Ho Chi Minh University in Vietnam

And others, …

1. European goals regarding energy and GHG-emissions from industry A critical challenge[1]:

One of the EU's key ambitions must be to develop a low-carbon economy. The EU has put in place a comprehensive policy framework, including among others: the climate and energy targets for 2020 and a carbon price through the Emissions Trading System. Now, we have to deliver, both in terms of the 2020 targets and, in the longer term, aiming for an 80% cut in greenhouse gas emissions by 2050 compared to 1990 levels. Reinventing our energy system on a low carbon model is one of the critical challenges of the 21st Century. Today, in the EU, our primary energy supply is 80% dependent on fossil fuels.

> Networks and supply chains have been optimized over decades to deliver energy from these sources to our society. Economic growth and prosperity has been built on oil, coal and gas. But, they have also made us vulnerable to energy supply disruptions from outside the EU, to volatility in energy prices and to climate change.
>
> There are different possible pathways to a low carbon economy. Clearly, no single measure or technology will suffice, and the precise mix in each country will depend on the particular combination of political choices, market forces, resource availability and public acceptance.

[1] Source: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Investing in the Development of Low Carbon Technologies (SET-Plan)

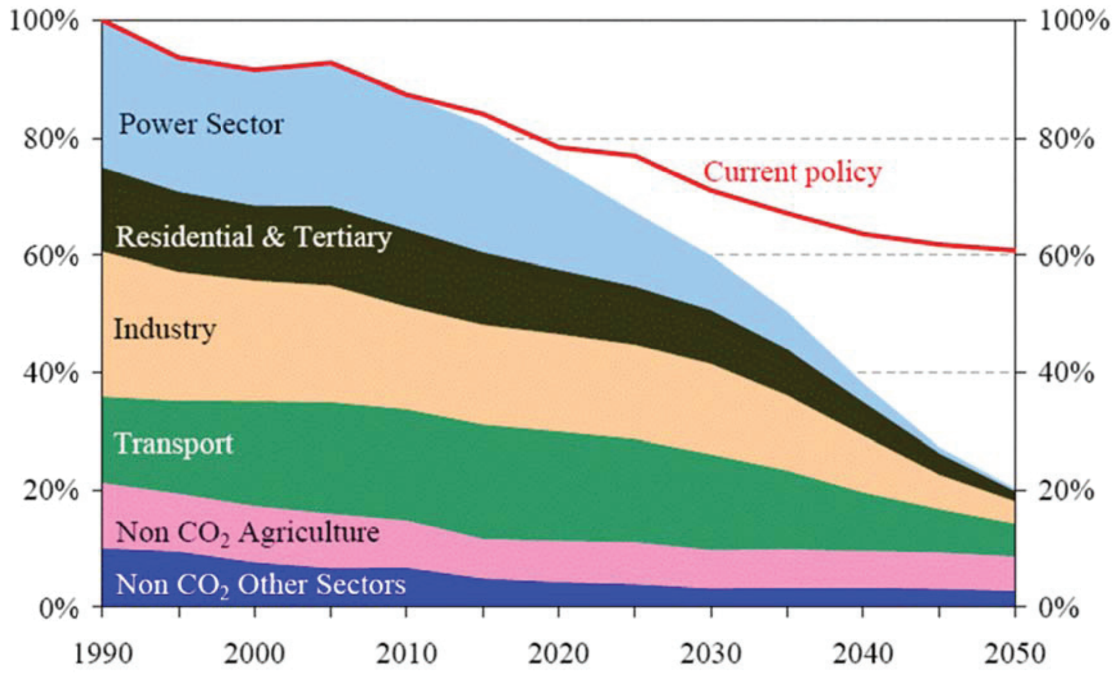


Figure 1-1: EU GHG emissions towards an 80% domestic reduction (100% = 1990); Source: EUROPEAN COMMISSION (2011): A Roadmap for moving to a competitive low carbon economy in 2050.

A need for a transition:

Out of several circumstances, there is a need for a transition of the whole energy system. Squandering resources, climate change and critical political dependencies from a small number of states with non-democratic regimes should be argument enough to work on a new energy system with high power.
The European Union as well as other bodies asks for a reduction of Green House Gases (GHG) of at least 80% till 2050. Figure 1-1 shows the European goals for different sectors. While the power sector has to reduce GHG totally, industry has to aim for a reduction of around 80%.
The reduction of the energy consumption can be seen separated from the fuel shift from fossil fuels to renewables (comp. Figure 1-2). It is important to consider the improvement of the energy intensity before the improvement of the carbon intensity.
Up to now, the main goals of projects regarding cleaner production and energy efficiency concentrated on the improvement of the existing system. If one is aiming at an improvement of 80% (factor 4), improvements will not be enough: we need radical innovations.
So the question arises, how radical innovations can be reached. Innovation is always more risky than improvement.

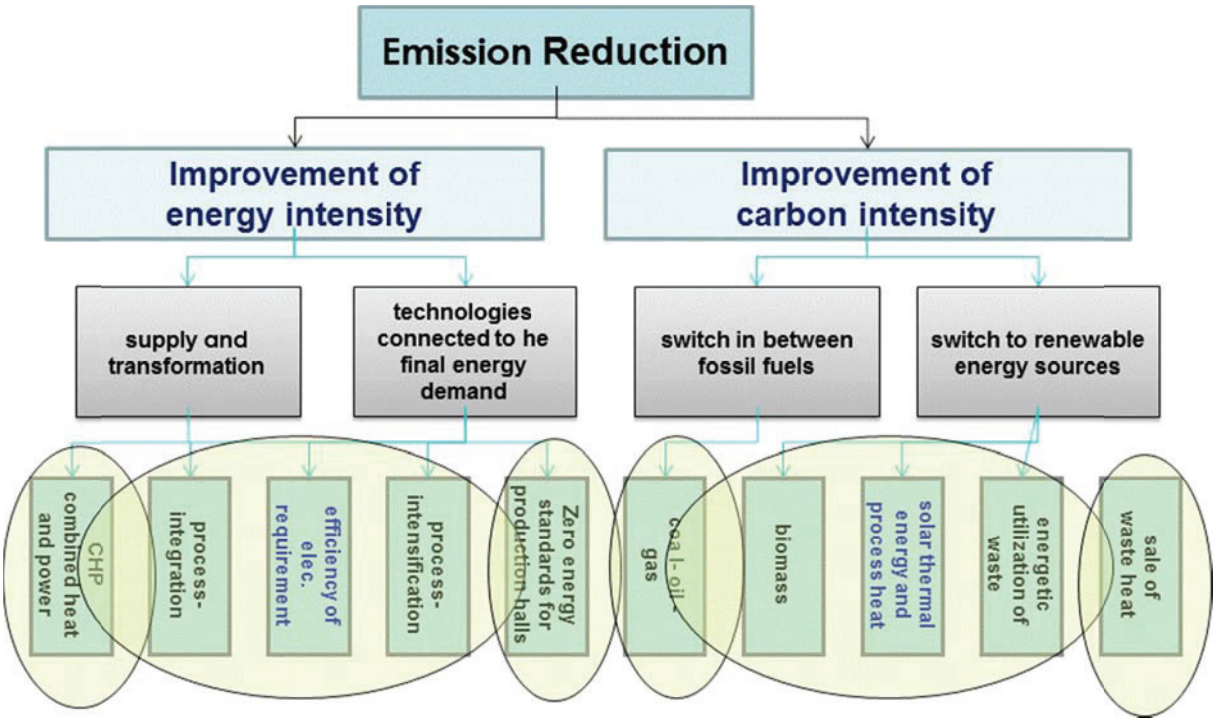


Figure 1-2: Ways to reduce energy consumption and GHG-emissions in production

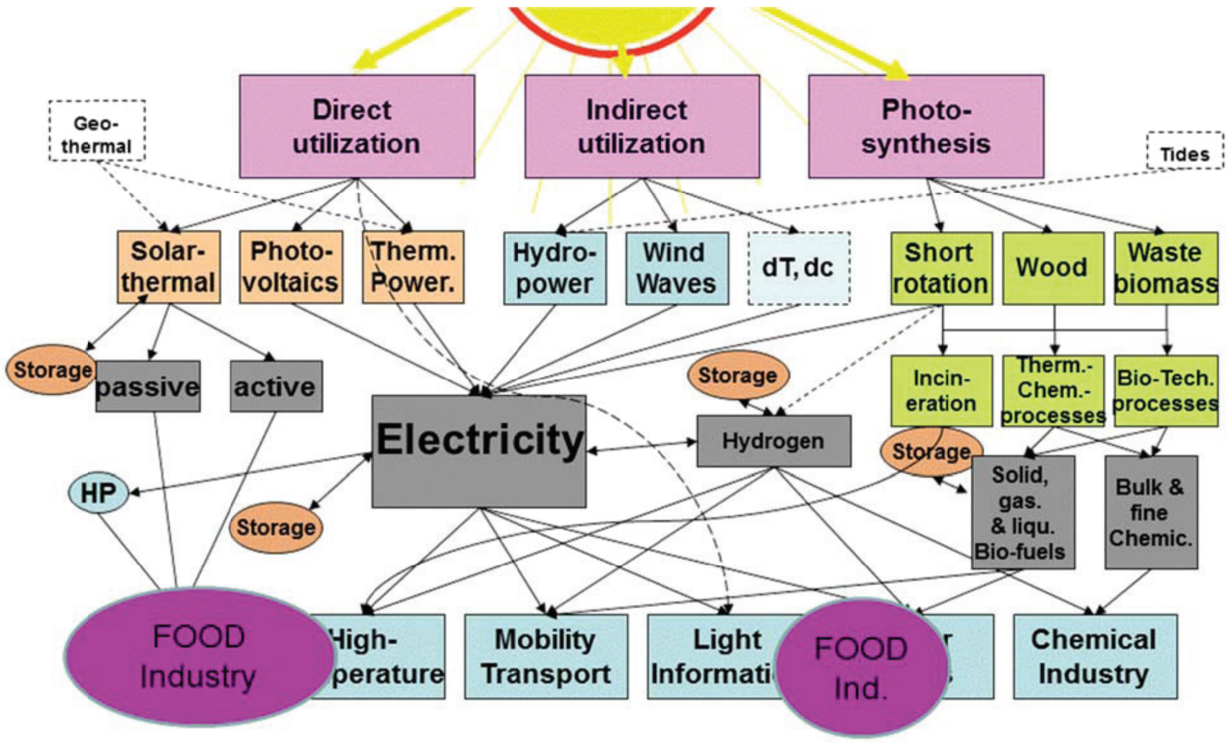


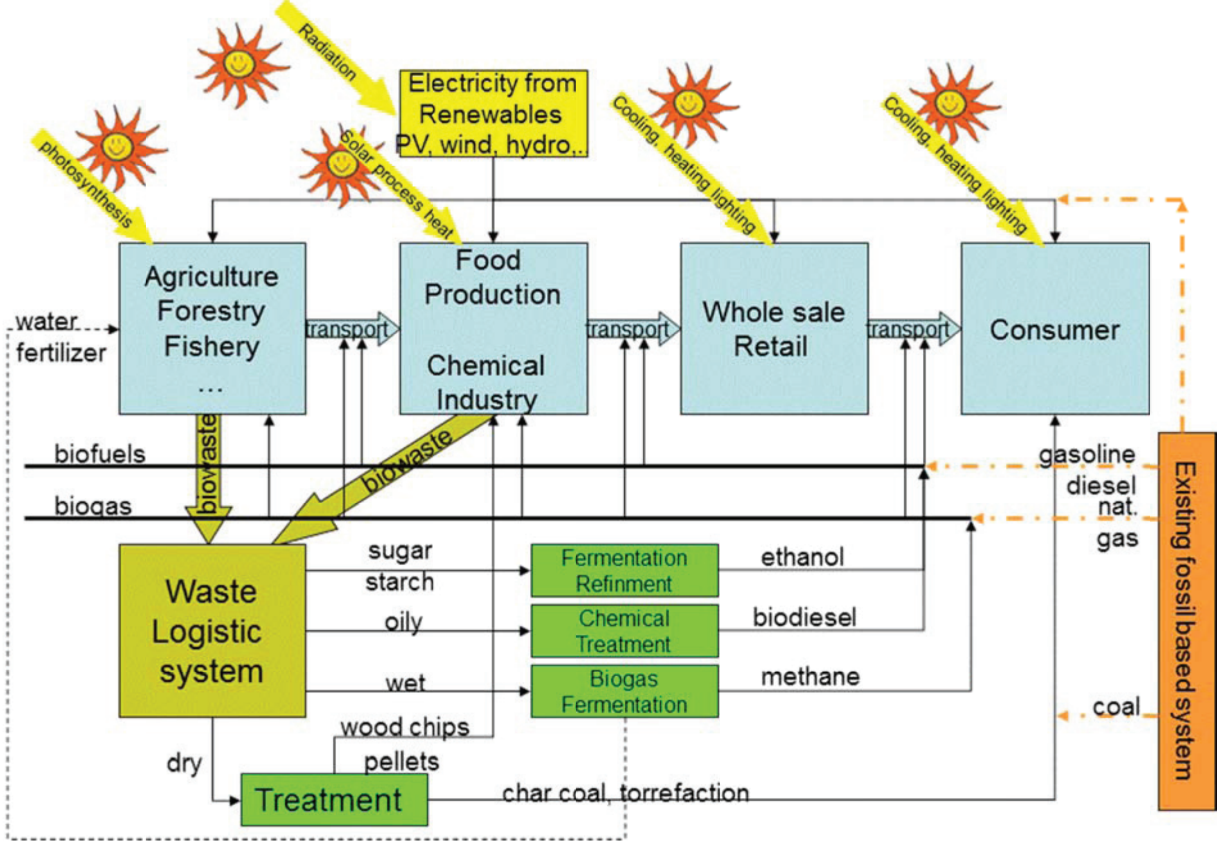
Figure 1-3: Technological pathways from solar radiation to energy services

2. Typical processes and temperature levels in food processing

Why did we select the agro-food sector?

- The raw materials for the food sector are renewable. The food sector is based on plants, produced out of CO_2 and water with the help of sunlight – a process called photosynthesis.

- Only a small fraction of the plant material harvested ends finally up at the consumer's table. The majority of the mass (including carbon) is "lost" or "wasted" along the production chain and can be used for valuable by-products and useful energy.
- At the same time, this sector uses great amounts of fossil energy for processing, storage and transport.
- The agro-food sector offers possibilities for the recovery of organic and organic components for recycling to and reuse in the agriculture.



- Waste water from the food processing can be recycled to the agriculture as well.
- New business opportunities in this sector are in the production of fine chemicals and energy (gaseous, liquid and solid biofuels).

Typical processes in the food sector

- pasteurization, sterilization
- bio-chemical reactions, fermentation
- drying
- evaporation, distillation
- washing, rinsing (bottles, kegs, boxes, cars, tanks,...)
- CIP
- …

3. Approaches to reduce energy consumption and GHG emissions in food processing

Process intensification addresses the need for energy savings, CO_2 emission reduction and enhanced cost competitiveness throughout the process industry.

The potential benefits of PI that have been identified are significant:

- Petro and bulk chemicals (PETCHEM): Higher overall energy efficiency – 5% (10-20 years), 20% (30-40 years)
- Specialty chemicals, pharmaceuticals (FINEPHARM): Overall cost reduction (and related energy savings due to higher raw material yield) – 20% (5-10 years), 50% (10-15 years)
- Food ingredients (INFOOD):
  - Higher energy efficiency in water removal – 25% (5-10 years), 75% (10-15 years)
  - Lower costs through intensified processes throughout the value chain – 30% (10 years), 60% (30-40 years)
- Consumer foods (CONFOOD):
  - Higher energy efficiency in preservation process – 10-15% (10 years), 30-40% (40 years),
  - Through capacity increase – 60% (40 years)
  - Through move from batch to continuous processes – 30% (40 years)

Integration of operations: Several processes occur in a sequence, like milling and mixing (e.g. cacao beans, sugar and milk powder). The integration of these process steps would not only reduce the operation time and energy consumption but also the need for cleaning the equipment.

Shift from batch processes to continuous operation: Most processes in the agro-food sector are operated in batch mode. We hardly found any continuous processes for the treatment of raw materials or the production of the final products. Drying, roasting, milling, mixing and sieving are used in most companies, but the opportunity of a continuous process is practically not used. The batch processes are hardly equipped with control devices and the operation instructions are poor. Many apparatuses (e.g. mixers, smelters, roasters) are just filled and switched on, there are no or at least few instructions about when and why to stop the process; operators just have a look and decide if they stop the operation or not. A continuous process with a suitable process control could not only utilize the equipment better and offer the possibility for heat integration, but also would guarantee a better quality

Heat integration and energy recovery,

- process intensification: Heat recovery from hot streams within the production process
- Heat exchange with another process in the company, but in another production line
- Heat pumps (compression and absorption)
- Waste heat driven ORCs
- Heat delivery to customers outside company (other company, fish farm, district heating, …)

Aims of Pinch Analysis:

- Visualization of the total cold- and heat demand of a system in one diagram – energy demand of single processes and which temperature level the energy has to be supplied
- Maximum of heat recovery
- Heat exchanger network – combination of the process streams
- Be aware of existing piping systems and heat exchangers and the location of the buildings and processes

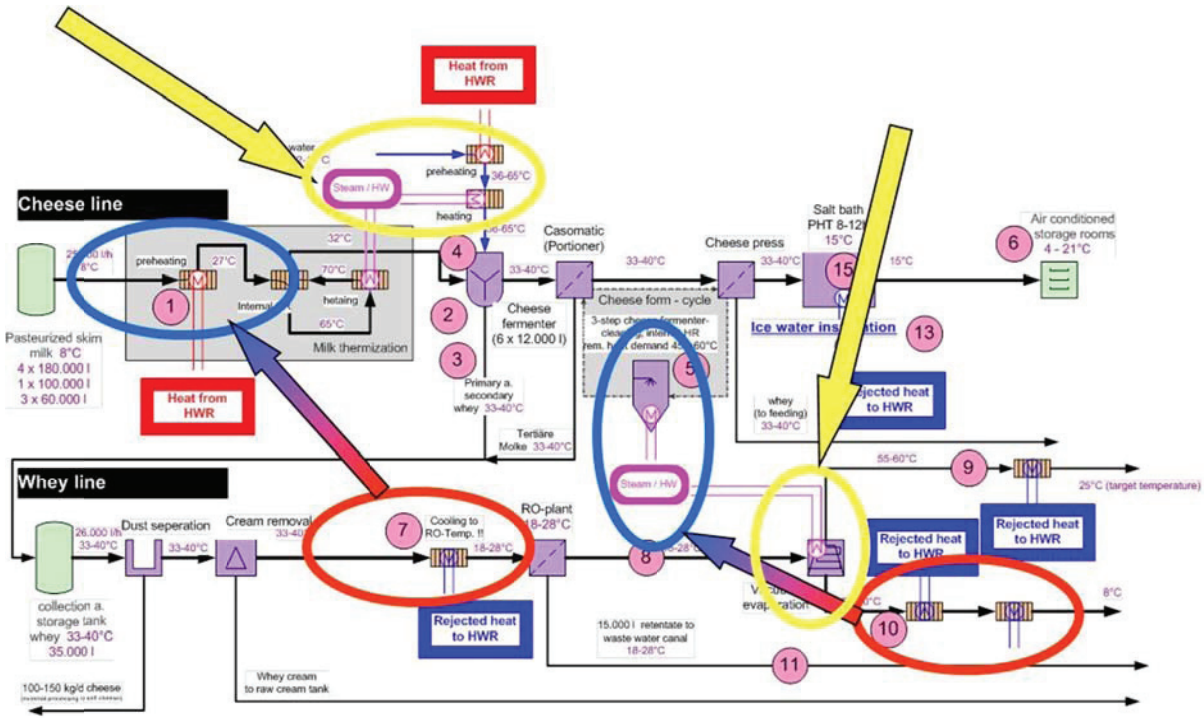


Figure 3-1: Possibilities for the integration of heat recovery and solar thermal heat for a cheese production plant

Cogeneration of power, heat and cold

In practically every company there is a need for electricity, heat and cold. Most thermal processes run at rather low temperatures, so that their heating by fuels offers a very low 2nd law efficiency. "Thermodynamic heating" – taking the energy from the environment and only the exergy from the fuel – will become more and more important in future. In some cases this could conflict with the promising technologies of volumetric heating, but high exergetic sources of energy should not be used at low temperature applications if possible. So could "in plant" cogeneration of heat and power be done in spray drying plants

Heat recovery from effluents.

Based on the fact that most operations are in batch mode, but also due to missing equipment and awareness, heat recovery or heat integration are hardly applied. In food processing we have on the one side large amounts of waste heat from cooling and freezing devices and on the other hand a large demand for warm water for cleaning purposes. We hardly found any installation for that. Many materials have to be heated and cooled in sequence (e.g. for pasteurisation, melting, roasting, …), where heat integration could take place.

Integration of solar thermal energy

The food sector is especially well suited for the integration of solar thermal heat, since most of the process that require heat operated at rather low temperature levels.

Figure 3-2: Solar thermal energy can be integrated into energy supply, processes and cooling systems

It is more efficient, but at the same time more difficult, to integrate solar thermal energy in the processes direcly than to integrate it to the energy supply system. The reason is that the temperature levels are always much higher in the hot water or steam net than at the final user`s place.

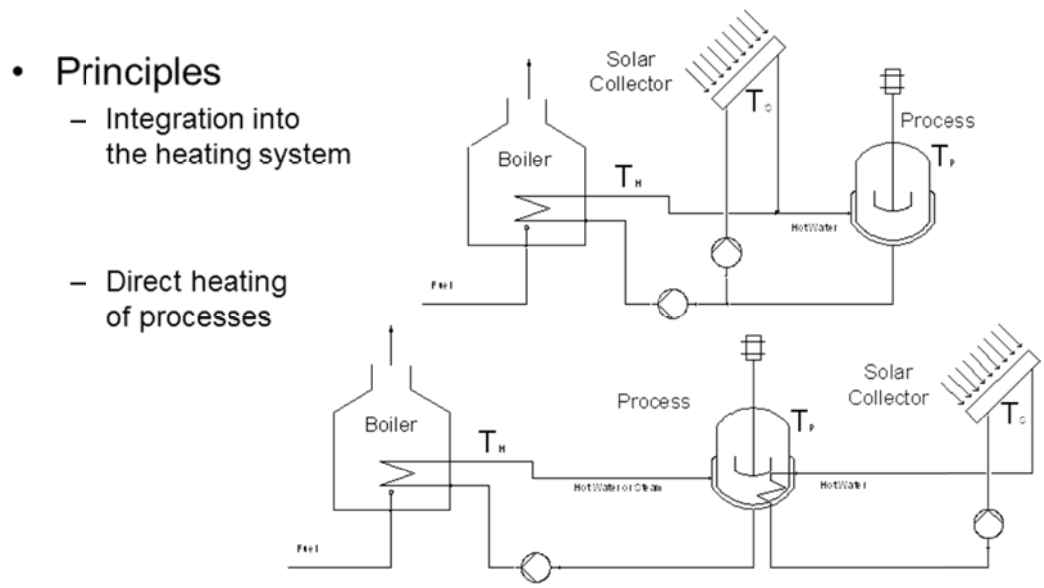


Figure 3-3: The difference between process integration and energy systems integration

4. GREENFOODS and IEAtask 49

In the project GREENFOODS, funded by the European Union, the expertise of 14 Partners from 6 countries in the area of greening the food industry is summarised. GREENFOODS (www.green-foods.eu) mainly targets the sectors meat industry, drink industry (breweries and fruit juice), bakery, baby food, cereal producer, animal food and the fish industry.

Through the implication of eco-efficient production patterns, the position of the European food and beverage industries should be strengthened. By increasing energy efficiency and the reduction of fossil based emissions the path towards a sustainable processing of food and beverages in Europe will be trodden. To realize this vision this project takes several actions. 200 companies in the 6 countries are analysed by a basic audit, in which the current energy situation and the main processes are surveyed. The results show on the one hand optimization proposals and on the other hand the status quo of the energy supply and demand patterns. From these 200 audits 20 are chosen for a detailed audit. Concurrently a core part, the GREENFOODS branch concepts for the sectors, will be developed and evaluated.

A branch concept in this project is defined as the combination of calculation tools and guidelines. After the energy balance calculation of the current system, step by step - heat integration, process optimization, efficient heat and cold supply and the integration of renewable energy (solar process heat, CHPs, biomass and biogas boilers, industrial heat pumps and absorption chillers) will be analysed by considering economic and environmental aspects as well as country-specific funding and restrictions. In order to enhance the realisation potential new country and sector specific funding schemes will be developed.

The International Energy Agency has launched a Task to state the latest state of research and application in solar thermal heat in industries. The main goals of the IEA_SHC Task 49activity will are (http://task49.iea-shc.org/objectives):

- Further develop and improve solar process heat collectors and components
- analyze and provide new knowledge on high temperature behavior of process heat collectors and solar loops
- develop a testing procedure and to provide a basis for the comparison of collectors under certain conditions
- provide engineering tools for optimized heat integration and optimized planning of solar thermal integration by advanced pinch analysis and storage management
- identify new applications for solar thermal energy in several production processes through the combination of process intensification technologies
- develop planning tools, calculation tools for solar yields in large scale plants
- gain proven solutions for stagnations behavior
- install and monitor large-scale demonstration systems
- develop guidelines for solar process heat
- to lower the barriers for market deployment

5. Case studies

Currently, 120 operating solar thermal systems for process heat are reported worldwide, with a total capacity of about 88 MWth (125,000 m^2). The first applications have been of an experimental nature with relatively small scale. In recent years, significantly bigger solar thermal fields have been applied and are currently in the project pipeline.

The Solar Heat for Industrial Processes – SHIP database has been created in the framework of the IEA Task 49/IV. This online database contains a worldwide overview on existing solar thermal plants which provide thermal energy for production processes for different industry sectors. Each plant description contains a number of informations about e.g. the size of the collector field, collector technology or integration point in the production process.

An initial survey has been developed and sent out to different solar companies by AEE INTEC. The returned data has been collected, structured and integrated into the database by them. All the programming work for the database's structure and design has been done by the PSE AG.

The user of the database has now the possibility to extract detail information from all identified solar thermal plants and create statistics like the share of collector technologies, size of the collector field per country or industry sector and cost per square meter. The SHIP database is a living platform and will grow continuously.

6. Conclusions

Industry has to contribute to slowing down climate change. This mainly will be done by increasing the energy efficiency and the switch to renewable energies.

On the other hand, industry has also a great responsibility regarding the products manufactured. The energy efficiency of the products might be more important than the energy spend at the production process.

Knowledge based energy management system in a wire producing company

Christina Krenn [a], Thomas Weichbold [b], Gunter Korp [b], Erich Meixner [b], Heinz Stockner [b], Dominik Berger [c], Johannes Bernreiter[c], Friedrich Bleicher [c], Georg Geiger [c], Johannes Fresner [a]

[a] *STENUM GmbH Geidorfgürtel 21, 8010 Graz*

[b] *voestalpine Austria Draht GmbH, Bahnhofstraße 2, 8600 Bruck a. d. Mur*

[c] *TU Wien, Institut für Fertigungstechnik Labor für Produktionstechnik, Landstraßer Hauptstraße 152, 1030 Wien*

Abstract

Energy management systems are considered as appropriate instrument to identify and realize energy efficiency potentials in industrial plants. Studies point out a largely untapped potential for energy efficiency in industry through the adoption of systematic energy management. This paper describes the case of voestalpine Austria Draht GmbH, an Austrian wire rolling mill. voestalpine Austria Draht GmbH at present is implementing a knowledge based energy management system. An important basis for further energy optimization is the analysis of energy performance indicators calculated from continuously recorded energy consumption data of the production units and the infrastructure equipment and model based interpretation of the data.

Specific selection, prioritization and combination of data provide the basis for monitoring and controlling. Consequently, these data in a condensed form provide the relevant basis to develop strategies to optimize the operation of the plants and to identify optimization potential

Within the work described in this paper, a plant model was developed consisting of a qualitative systems model and the combination of physical input-output models for several energy intensive units. These models are used to identify the parameters which have a strong impact on the energy efficiency of the plants as well as a basis for prediction of the heat and power consumption depending on the production program. This study revealed a significant potential to save electricity by optimizing the control of cooling water pumps along the milling train and to recover heat from the final products.

The biggest single energy loss in the mill is the heat from air cooling the products on hook conveyors. These heat flows contain about 30 – 50 % of the energy input for heating up the billets. Pilot tests were run to characterize the realistic potential of heat recovery on the hook conveyor. Based on the test results, feasibility studies for large scale plants were carried out. As a result, 2 GWh of electricity can be saved and 0.8 GWh of heat can be recovered.

Key words

Energy management, energy efficiency, process optimization, knowledge based energy management, recovery of radiative heat

Introduction

Potential for energy saving in the rolling mills

Over 1.3 billion tons of steel are manufactured and used every year globally (World Steel Association, 2014). In hot rolling the size, shape and metallurgical properties of steel are changed by repeatedly compressing the hot metal with temperatures ranging from 1,050 to 1,300 C between electrically powered rollers. Total EU production in 1996 of hot rolled products was 127.8 million tons. Surveys have shown that steel processing companies still have potential to reduce their CO_2 emissions. Johansson and Söderström (2012) describe options for steel mills and for hot rolling. According to the authors, for hot rolling the use of biomass as fuel in heating furnaces, heat radiation converted to electricity by thermo photovoltaic technology and the use of Organic Rankine Cycles or Kalina cycles, the generation of hot water from cooling beds, the use of hot water from cooling for district heating are important options to reduce energy intensity. (Hammer, 1990; Held, 1985; Krimmling, 1997; Nolzen, 1984)

Krenn et al. (2009) did a study in Austria on the technical and economic feasibility of the application of Organic Rankine Cycles to use the energy content of exhaust gases of walking beam furnaces to generate electricity in hot rolling mills. The payback time of the ORC modules was between 5 and 6 years, neglecting the cost of integration to the exhaust gas system and the cooling system.

Johansson and Söderström quote a Swedish paper (Nilson, 2003) describing tests in two Swedish hot rolling mills, in which solar collectors from copper were used to recover heat from cooling beds of long products successfully. They concluded, that by a broad application of radiative heat recovery on cooling beds, 20 to 50 % of the heat contained in the products could be recovered, e. g. for district heating at temperatures of 60 to 90 °C.

General measures to reduce energy consumption regarding furnace design or operation and maintenance of the furnaces include to avoid excess air and heat loss during charging by operational measures, the implementation of automatic furnace control to optimize the firing conditions, the recovery of heat in the waste gas by feedstock pre-heating, the recovery of heat in the waste gas by regenerative or recuperative burner systems, the recovery of heat in the waste gas by waste heat boiler or evaporative skid cooling (where there is a need for steam), the reduction of heat loss in intermediate products; the change of logistic and intermediate storage to allow for a maximum rate of hot charging, direct charging or direct rolling (the maximum rate depends on production schemes and product quality) and for new plants, near-net-shape casting and thin slab casting, as far as the product to be rolled can be produced by this technique. (Johannsson, 2011; Rentz, 1999)

Morrow et al (2014) did a study of the effect of the following energy efficient technologies applied to hot rolling in India:

- Recuperative or regenerative burner
- Process control
- Waste heat recovery from cooling water
- Heat recovery on the annealing line

- Automated monitoring and targeting systems
- Variable speed drives for flue gas control, pumps, fans

They conclude, that in India´s iron and steel industry cumulative cost-effective electricity savings between 2010 and 2030 could be 66 TWhs or 65Mt of CO_2, and cumulative cost-effective fuel syvings are 768 PJ, with an associated CO_2reduction potential of 67 Mt CO_2. Assuming similar use of electric arc furnaces, energy intensity would be comparable. Moya and Pardo (2013) extrapolated the application of best available technology in energy efficiency and CO2 emissions in the EU27 iron and steel industry. Additionally to the measures suggested by Morrow they highlight the potential of insulation of furnaces and hot charging. The paper suggests that if all measures with a payback time of two years or less are implemented, carbon emissions until 2020 can be reduced by about 5 % using 2010 as base line, without technologies based on direct reduced iron. Until 2030, these measures have the potential to reduce specific carbon emissions by about 20%. On the longer term (until 2030) and allowing payback times around 10 years, carbon emissions can be reduced by 60%.

The authors learned from discussing with management in several mills in Austria that for a retrofitting project a payback time of 1 to 3 years is requested to qualify for implementation. Significant reductions for the steel production as a whole therefore may be possible only long-term, if new processes can be developed and successfully introduced. This would require large investments.

Interestingly, Thollander found (2010), that even in energy intensive industries, energy management does not seem to be fully a priority, not even in energy intensive pulp and paper mills and foundries which were included in his research. The wide range application of energy management seems to be a large untapped potential with regard to achieving cleaner and more environmentally sound production in different industrial sectors.

Bunse et al. (2011) conclude from their research, that the needs of industry in the area of energy management in production are different from approaches to energy management described in literature. Industry needs energy efficiency metrics at process and plant level, benchmarks for individual process units, knowledge-based systems on the basis of real-time data, a conceptual framework for the evaluation and assessment of data, and tools for simulation and visualization of energy efficiency.

The hot rolling mill of voestalpine Austria Draht GmbH

In the mill, annually about 500,000 tons of rolled wire with a diameter of 5.0 to 32.0 mm are produced. After water cooling the wire is laid onto the loop cooling conveyor by the loop laying head and formed to coils in the coil forming chamber. By controlling the cooling speed the properties of the material can be influenced.

At the moment, about 4,000 points of measurements are installed. Their location was selected to facilitate operational control, not to provide data for energy management. The data are recorded in the data acquisition system. Some data are visualized as trends in the control room. During the history of the plant a complex structure of the energy distribution system has evolved.

voestalpine Austria Draht GmbH has worked for many years systematically to optimize energy consumption. Potentials for improvement were identified in the following areas: heat recovery from a dryer to preheat wire coils before pickling, minimization of heat losses of steam pipes by better insulation, efficient lighting, optimization of the hydraulic system of cooling water supply. Step by step, a number of options were implemented.

Now it is important to design a systematic approach to disentangle and assess energy flows using the automatic mill monitoring system. In the mill of voestalpine Austria Draht GmbH the relevant impacts on energy consumption are:

- Production of a variety of products in different steps in rolling, heat treatment and surface treatment in changing quantities, temperatures and mechanical strength
- Mode of operation (load, set up, maintenance)
- Waste heat from product cooling (hot air at the hook conveyor, cooling water from cooling rolling stands and exhaust gas from furnaces)
- Optimization of process organization, maintenance, change overs

Automation technology has a key role in improving energy efficiency. Automatic computer based energy management systems available in the market however mostly aim at the reduction of peak loads and optimization of purchasing. The key to effective energy management is to have all available information about the process transparent and in real time.

Several projects therefore were set up to systematically reduce energy consumption as much as possible. This paper describes the approach and the result of the projects:

- INEMO - Integrated and optimized energy management system and
- RADREC - Recovery of radiative heat from product cooling

Energy management and heat recovery from products as key potential areas

INEMO - Research project do develop an integrated and optimized energy management system

Method and approach of INEMO

In INEMO a combination of two steps was taken to combine the readily available data from the data acquisition system with a knowledge base which facilitates the interpretation of the raw data:

Step 1: Systems analysis according to Frederic Vester (2001)

The dependencies of the demand for process media (natural gas, electricity, compressed air, process gases, cooling water, hot water) on process conditions were studied by a systems analysis and weighing of variables to identify the important ones which have the biggest impact on the overall performance of the system

At this stage, all the production processes were analyzed systematically. The most important variables on process energy consumption were identified in a ranking.

Step 2: Gap analysis

The observed situation and the desired, ideal situation were compared regarding availability of measured data characterizing energy consumption and energy demand, availability of process data for process models to calculate consumption depending on production load, data acquisition and processing, reporting system, model based identification of operational and strategic optimization potential. The goals are to reduce the consumption of electricity and heat and to forecast energy consumption depending on production program and energy cost.

A systems analysis is the systematic study of "elements" which are related. Network analysis according to Frederic Vester was selected as methodological approach.

As initial step the elements which make up a system were entered in a matrix as lines and columns. Then the interactions are analyzed. The strength of the impact of one element on the others is evaluated and a corresponding value entered into the cells of the matrix. The defined grades are: 0 - no impact, 1 - Impact exists but is weak, 2 - Explicit impact and 3 - Strong impact

The use of the matrix guarantees that all potential interactions are considered.

After the evaluation the total of the lines is calculated. These totals are the "active sums". The totals of the columns result in the "passive sums".

Consequently a diagram was drawn, in which the active sums are entered over the passive sums. The diagram is divided into four equally large segments. These represent the following segments:

- Active: have an active impact on the system
- Passive: are controlled by other elements
- Critical: have both a strong active and passive effect
- Reactive: have a puffer effect in the system

For more detailed analysis, the elements, which are located in the active and critical segments, were considered. The passive and reactive elements were not studied further.

Theory and calculations

Using this method, various processes in the hot rolling mill were analyzed. This included the walking beam furnace, the rolling mill train, the cooling water system and the annealing furnaces. As an example, the analysis of the cooling water system is described here:

The total process water is treated in a central water treatment station. Here the used cooling water is passed through three sedimentation tanks and 18 gravel filters. Pumps with a combined power of 1.8 MW transport the water to the consumers. From the consumers the water returns in open channel into the water treatment station.

The main cooling positions are located at the 20 rolling stands in the rolling train. At these stands, there are no temperature probes in the cooling water.

Figure 1 shows the result of the system analysis for process water.

Figure 1: Evaluation matrix for process water

In Table 1 the gaps between actual situation and desired situation are summarized.

Table 1: Summary of gap analysis for the cooling water system

Actual situation	Gap
Data acquisition Data acquisition is done with WinCC (from Siemens). Data are collected electronically or read manually	– Additional measuring points needed along the mill train at the individual rolling stands – Fully automatic control on the basis of these numbers – Automatic calculation of indicators and reports – Visualization of data depending on plant status
Data flow and data processing Energy controlling is done on a monthly basis. Consumption data are collected in an MS Excel worksheet. From this, production specific indicators are calculated.	– Automatized real time data processing and visualization – Automatic calculation of indicators and automatic report generation – Definition of an appropriate visualization method
Potential for optimisation of the media system is elaborated in designated projects	– Definition of process models and data models – Continuous calculation of indicators and automatic comparison with benchmarks or predefined values – Definition of models for analysis – Detailed analyses of process sections to understand the potential for heat recovery better
Forecast of energy consumption and energy cost A forecast is done by the plant manager on the basis of data from reference periods and the expected production	– Definition of a model for forecasting – Automatic and real time forecasting on the basis of production planning and predefined specific consumption values for different products to account for the production mix

The temperature increase in the cooling water was modeled doing material and energy balances for the main units (Pumping station, rolling train, sedimentation tank) and the mixing and splitting points (addition of freshwater, overflow of sedimentation tank). Heat input was calculated from production data, electricity input from measured data. Water flows were taken from measurements.

Figure 2 shows the results for one exemplary day. The calculated temperature increase correlates very closely with the measured data.

Figure 2: Temperature increase on 3.3.2014 from 14:00 to 22:00 hours

Results of INEMO

In the process water system, the cooling water flow rate, the pump capacity, control of the pumps and pressure loss are the critical parameters. The total installed capacity of pump drives is 1.7 MW Control of pumps determines the flow. Temperature dependent control for the different sections of the rolling train using frequency controlled drives has a significant potential for electricity savings.

Based on these findings, parameter studies were done for the cooling water system, to understand the temperature dependency on production volume, initial temperature of the material, the final diameter of the product and the cooling water conditions (temperature of fresh water, evaporation) to calculate the minimum requirement of cooling water. Extrapolating these parameter studies, it was found, that compared to constant flows of cooling water, about 2 GWhs of electricity could be saved annually. The fresh water addition could be reduced by almost 80% for all the analyzed production shifts.

RADREC - Recovery of radiative heat from product cooling

Method and approach of RADREC

From the initial system analyses it became clear, that there was a major source of waste heat along the hook conveyor, where the wire coils are cooled from the process temperature to ambient air temperature. A project to study options to recover this potential was designed, as until to this analysis, no study had been done regarding the feasibility to use this significant source of waste heat. At the end of the production process the milling products contain about 31 % of the primary energy used in the walking-beam furnace. The rolled wire coils leave the forming chamber on hooks at a temperature of between 600 °C and 700 °C. A literature review surfaced several designs which were developed in Germany and Japan in the 1970s and 1980s.(Krimmling et al, 1997)Basic ideas from these publications were used in the design of two pilot plants for heat recovery from wire coils and tubes.

Theory and calculations

The designed pilot plant consists of two separate elements. The pilot plant enclosed the coil as completely as possible to maximize heat recovery and minimize heat loss. The two parts of the pilot plant were mounted on racks with rollers to enable easier transportation to different positions along the overhead conveyor with hooks.

The active part of the pilot plant was a conventional flat radiator which was located close to the coils for radiative heat recovery. Furthermore, an additional rib radiator was installed at an angle of 30° above the coil for convective heat recovery.

Results of RADREC

The following tests were carried out:

In a first step several coils were singled out from the main hook conveyor, moved to a side rail and the radiative and convective heat flow were measured for thirty minutes.

In a second step the pilot plant was integrated into the continuous production process in a fixed position in the main hook conveyor.

Data for the first test step are included in Table 2.

Table 2: Characteristics of the first test step with the pilot plant at voestalpine Austria Draht GmbH

Position	Coils singled out on the side rail, with reflective screen
Heat transfer	Radiation and convection
Heat transfer surface to collect radiative heat	1.98 m²
Distance between heat exchanger and coil	0.3 m
Heat transfer surface to collect convective heat	1.44 m² , fan activated
Water flow	0.22 l/s to both heat exchangers

Table 3: Characteristics of the wire used in the test

Diameter	19.0 mm
Weight on one coil	1,437 kg
Steel grade	Fine grain steel, high carbon
Temperature before forming chamber	924 °C

Figure 3 shows the recovered radiative and convective heat flow per m^2 during the measurement period of 30 minutes for the singled out coil.

Figure 3: Radiative and convective heat collected in the two heat exchangers during the test with the singled out coil

Figure 4 shows an infrared photo of a wire coil in the position during measurements. For the selected dimension, the maximum surface temperatures range between 600 and 550 °C.

Figure 4: Surface temperatures of the wire coil in front of the pilot plant

In the second step of the tests, the test plant was installed in line at the hook conveyor. Figure 5 shows the radiative heat flow and the heat flow from convection during an actual production week and the product mix (wire dimension).

Figure 5: Results of the test phase from 26.-30.04.2010

The heat flow is calculated from the measured water flows and the measured temperatures. Negative heat flow is observed at times when there are for no coils moving on the hook conveyer because of changes in dimension or production stops. Regarding the grain distribution and other quality parameters of the wire, no impact by the installation could be detected.

With these data, a full scale installation was designed. Figure 6 shows the heat recovery potential for the proposed installation of 112 m² heat exchangers along the hook conveyor. The wire dimensions and the respective heat recovery during the tests are shown.

For the calculation of the heat recovery potential only radiative heat was considered. The extrapolation is based on the test result (heat output related to the heat transfer area of the heat exchanger [kW/m²]).

Figure 6 shows the resulting heat recovery potential based on these assumptions and the actual production program.

Figure 6: Heat recovery potential, 122 m² heat exchangers installed, calculated for the period from 26.-30.04.2010

With these data, a full scale installation was designed. An automatic monitoring system for temperature in all modules and a control system to control water flows was planned to minimize the risk for leakage of water. Water is critical because of the potential rapid steam formation on the hot surfaces of the coils. The payback time for this plant was calculated as 8 years (without subsidies) to 6 years (with subsidies), which is considered too long for actual implementation.

Figure 7 shows the theoretical radiative heat transfer potential depending on the temperature of the wire.

Figure 7: Calculated radiative heat transfer

The recovered heat from the singled out coil is higher than from the moving conveyor in the production process. Comparing the result of the theoretical calculation of the radiative heat capacity with the results of the test phase for a wire temperature of 400 °C the results show a considerable variation, because of the impact of wire diameter, initial temperature before the cooling section, and non-uniform temperature distribution in the coil and material (see Table 4).

Table 4: Comparison of calculated and measured radiative heat transfer

Average surface temperature of wire in the pilot plant	550 °C
Calculated radiative heat transfer potential	16 kW
Measured at static coil	6.52 to 13.13 kW/m²
Measured at moving coils	4.40 kW/m² to 7.17 kW/m²

As a result of the comparison, about 25 to 50 % of the heat available for radiative heat transfer could actually be recovered by the pilot installation.

The calculation considering the calculated investment cost, estimated costs of operation, costs of maintenance and the actual value of the supplied heat neglecting increase in energy prices by inflation, carbon taxes and subsidies gives a static payback time of 8 years. A calculation assuming an increase in energy prices by 3% per year results in a static payback time of 6.5 years. If no energy price increase is considered, but emission trading at 2012 carbon prices, and a subsidy of 35% the resulting payback time is 6 years.

Discussion and conclusions

In steel mills energy cost is a relevant cost factor. Systematic optimization can be done on the basis of knowledge based energy management, including real time data collection, qualitative systems analysis using Vesters approach and gap analysis, and modeling of energy intensive units The combination of these approaches was used at the hot rolling mill of voestalpine Austria Draht GmbH. The analysis showed that there is significant potential for energy savings:

Potential for electricity savings exists by optimizing the control of the big pumps for the cooling water of the mill. At present a concept is being developed how to measure temperatures in the rolling train section wise and use the temperatures for controlling the cooling water flows. This measure suggests a potential reduction of 30% of pumping electricity, or 2 GWh annually.

Heat can be recovered from the hook conveyors, where about one third of the total energy used in the walking beam furnaces is released to the environment. About 0.8 GWh can be recovered practically in the plant which was analysed.

This potential can be tapped by simple, solar collector like heat exchangers. At 2 kW per m² the yield at 6,000 hours of operation can be up to 16,000 kWh/m² and year[1]. As the heat is collected at a rather low temperature level of about 60 to 90 °C heat can be supplied to consumers like pickling tanks, degreasing, space heating, or district heating.

The results of the theoretical calculations showed that the heat recovery potential that could be realized during the test phase is much lower than the theoretical one. On the hook conveyor, on average 35 % of the theoretical potential could be realized in the pilot plant.

Possible wider target groups for radiative heat recovery are companies from the steel, glass and cement industry.

Acknowledgements

We gratefully acknowledge the support of all employees of voestalpine Austria Draht GmbH who were involved in the projects.

The Project „INEMO-Integrated and optimized energy management system“ was funded by the Austrian Climate and Energy Fund and conducted under the "e!MISSION.at" program. The Project “RADREC - Improvement of the energy efficiency in steel industry by recovery of radiative heat

1 For comparison: one m² solar collector in Austria can generate about 400 kWh/m²a warm water, one m² of photovoltaic modules can generate about 1,000 kWh/m²a electricity

from cooling beds and hook conveyors" was commissioned under the program "Neue Energien 2020".

References

Bunse, K., Vodicka, M., Schönsleben, P., Brülhart, M., Ernst, F. O., Integrating energy efficiency performance in production management - gap analysis between industrial needs and scientific literature, Journal of Cleaner Production 19 (2011) 667 - 679

European Commission, Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry, December 2001

European parliament, Commission Implementing Decision of 28 February 2012 establishing the best available techniques (BAT) conclusions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions for iron and steel production (notified under document C(2012) 903) , Official Journal of the European Union, L 70, 8 March 2012 , http://eur-lex.europa.eu/JOHtml.do?uri=OJ:L:2012:070:SOM:EN:HTML, acessed July 2014

Hammer E. E.: Heat recovery and energy efficiency through high temperature cooling in kiln of the iron and steel industry (Wärmerückgewinnung und Energieeinsparung durch Heißkühlung an Öfen- der Eisen- und Stahlindustrie), Neue Hütte - 35.Jahrgang - Heft 11 - November 1990 (in German)

Held B., Nyland H., Reinitzhuber F.,: Practical experience with the recovery of exhaust gas heat from steel mills for district heating (Betriebliche Erfahrungen in Abgaswärmenutzung in Eisenhüttenwerken für Fernheizzwecke), Stahl und Eisen 105 (1985) Nr. 22 (in German)

Johannsson M., Söderström M.: Options für the Swedish steel industry, 2011, Energy, (36), 1, 191 – 198

Krenn, C., Fresner, J., Bürki, Th., Wastl, H., Eco-Efficiency by head recovery in the steel industry (Ökoeffizienz durch Abwärmenutzung in der stahlverarbeitenden Industrie), in Ökoeffizienz, Konzepte, Anwendungen und Best Practises, Rainer Hampp Verlag, Baumgartner, Biedermann, Zwainz (Hrsg.), München und Mering 2009, ISBN 978-3-86618-329-2 (in German)

Krimmling J., Nitz K.-H., Preuß A.: Heat recovery in a steel mill (Abwärmenutzung in einem Stahlwerk), TAB 11/1997, Seiten 49-52, 1997 (in German)

Morrow, W., Hasanbeigi, A., Sathaye, J., Xu, T., Assessment of energy efficiency improvement and CO2 emission reduction potentials in India´s cement and iron & steel industries, Journal of Cleaner Production 65 (2014) 131 - 141

Moya, J. A., Pardo, N., The potential for improvements in energy efficiency and CO2 emissions on the EU27 iron and steel industry under different payback periods, Journal of Cleaner Production 52 (2013) 71 - 83

Nilsson J. Heat recovery from cooling beds in the iron and steel industry: Heat from the cooling beds - 100 times better than solar (Värmeåtervinning från svalbäddar inom järn- och stålindustrin: Värme från svalbäddar – 100 gånger bättre än solvärme). Jernkontorets forskning, Slutrapport TO 51-43, Report no 809; 2003. (in Swedish)

Nolzen H.-M.: Options for energy recovery in the steel industry, especially in the production of wire (Möglichkeiten der Energie-Rückgewinnung in der Hüttenindustrie, insbesondere bei der Walzstahlerzeugung), Stahl und Eisen 104/ 1984), Nr. 14, Seite 671 ff (in German)

Rentz O., Jochum R., Schultmann F.: Report on Best Available Techniques (BAT) in the German Ferrous Metals Processing Industry, DFIU Karlsruhe, March 1999

Thollander, P., Ottosson, M., Energy management practises in Swedish energy-intensive industries, Journal of Clenaer Production, 18 (2010) 1125 - 1133

VDI-Wärmeatlas, Heat transfer calculations (Berechnungsblätter für den Wärmeübergang), VDI Gesellschaft, 10. Auflage 2006, Strahlung technischer Oberflächen, ISBN 978-3540412007 (in German)

Vester, F., The art of networked thinking, Report to the Club of Rome (Die Kunst vernetzt zu denken, Ein Bericht an den Club of Rome), ISBN 978-3421053084, Deutsche Verlags-Anstalt DVA; Auflage: 7., Aufl. (2001), (in German)

World steel association, Steels contribution to a low carbon future, position paper, http://www.worldsteel.org/publications/position-papers/Steel-s-contribution-to-a-low-carbon-future.html, accessed July 2014

Resource efficient and cleaner production in Moldava - lessons learnt

Lucia Sop, Moldavan Resource efficient and cleaner production program[1]
Johannes Fresner, STENUM GmbH[2]

Abstract
This paper describes the setup of the Resource efficient and cleaner production program in Moldawa. The program actually was started already in 2008. It had to be adapted to the national situation several times until a setup was defined which allows an effective operation of the program. In the last year there was remarkable progress. All in all, about 40 companies are involved in inplant assessments, regional programs are under way. A high reputation has been build in industries and with regional governments. This paper quantifies results and impacts and elaborates lessons learned for the future design of centers working in comparable environments by tackling the problems of working with a limited legal background, companies in difficult economic situation and with limited resources for the program.

Key words
Resource efficient and Cleaner Production, UNEP, UNIDO, program design, progress

Cleaner production in Moldava

The National Cleaner Production Programme (NCPP) is aimed at contributing to improved resource productivity and environmental performance of enterprises and other organizations in the Republic of Moldova , through the uptake of Resource Efficient and Cleaner Production (RECP). The NCPP targets in particular the agro-food processing, and construction materials sectors, chemical producers, as well as municipal services. The program formally started in September 2011. Programs focussing on environmental management, cleaner production and energy efficiency had been carried out since 2001 within a Norwegian Program and later on an UNIDO program.[3]

The NCPP is implemented by the United Nations Industrial Development Organization (UNIDO) in the framework of its global cooperative RECP Programme with the United

1 Enter address

2 Geidorfgürtel 21, A-8010 Graz, Austria, fresner@stenum.at

3 http://cea.eurocontrol.biz/projects2.php?id=3&idn=16&L=en, accessed February 2014

Nations Environment Programme (UNEP). It is funded by the Government of Austria, and implemented in partnership with Government of Republic of Moldova (in particular the Ministries of Economy and Environment).

The National Cleaner Production Programme(NCPP) is being implemented along three workstreams, respectively:

1. RECP Capacity-institutional and human capacity building;
2. RECP Implementation - RECP methods in enterprises/organizations;
3. RECP Policy and Strategy - policy support

The main activities implemented in the last years include:

A series of trainings, attended by over 50 participants under the guidance of international RECP expert built the basis for a strong capacity of national experts, who are familiar with the principles of preventive environmental protection, accounting of material and energy consumption, cost and use, process analysis and idenfication of options. In these trainings, also practical implications, like data collection, analyis of quality of data, benchmarking, modelling of consumption, measurements, information sources, contacts with potential suppliers were considered.

Tools, in particular the UNIDO Cleaner Production Toolkit, PRE SME, Responsible ProductionToolkits, complemented by the Tool for Enterprises on Resource Efficiency and Pollution Intensity Indicators[4] are used as the basis for the trainings. These tools are available to support the experts in their practical work and are applied readily. The training in RECP was followed up with coaching on walk through assessments. Consequently, the experts worked together with more than 20 companies.

For that preparations have been done in advance, and announcementsfor expressions of interest from suitably qualified specialists[5], as well as enterprises[6] in the food-processing, construction materials/chemicals and municipal services' sectors were displayed on the webpage of UN representative in Moldova.

4*UNIDO Cleaner Production Toolkit (UNIDO, 2008), (http://www.unido.org/index.php?id=o86205) complemented by Promotion of Resource Efficiency in Small and Medium Enterprises (UNEP and UNIDO, 2010) and Responsible Production Handbook (UNEP, 2010).*

Enterprise Level Indicators for Resource Productivity and Pollution Intensity: a primer for small and medium enterprises, UNIDO and UNEP, 2010, (http://www.unido.org/index.php?id=1001348)

5*http://www.un.md/tenders/2013/027_UNIDO/index.shtml*

6*http://www.un.md/tenders/2013/021_UNIDO/index.shtml*

Rounds of consultations have been held in different regions of the country with the mayors offices that showed interest to participate in RECP replication and demonstration programmes in their regions, also being committed to enable the framework for rolling the implementation of regional RECP Clubs.

Currently, RECP Clubs are organised in three regions: Causeni, Ungheni, and Chisinev. The events attracted the participation of mayors and vice-mayors, and other local governmental officials. This is a group based approach, in which company representatives come together to regular workshops, learn about RECP and implement applicable measures in their enterprises.

A final report on Policy Measures to Promote Resource Efficient and Cleaner Production in the Republic of Moldova wassubmitted to the Governmental decision makers(Ministry of Environment, Ministry of Economy, Ministry of Agriculture and Food Industry), Austrian Development Agency(ADA), UN Representative in Moldova, and to the related stakeholders.

It bolstered already discussions. Generally the report strives to provide a set of measures that are feasible given the realities connected with institutional and economic constraints facing the Republic of Moldova currently. The conclusion is that main measures to promote Resource Efficient and Cleaner Production (RECP) in Moldova today have less to do with the wording in laws and policy documents, and instead it is the implementation of policies and related measures that should be in focus. The key recommendations given in the report are the following[7]:

- The fiscal and environmental policy measures need to be predictable and transparent for Moldovan businesses.
- Price structures and control of payments need to reflect the use of various key resources and materials, including water and energy.
- Environmental charges and taxes are most efficient when focussing a limited number of key polluting substances and a limited number of polluters in order to also enable efficient and transparent enforcement.
- In the short term there is a need for continued education and training for professionals in businesses and government, combined with an improved access to information on technologies and methods for pollution prevention and minimisation, resource efficiency and pollution control.
- For long-term results the education on all levels should be reformed to include elements of environmental awareness and, more importantly, knowledge of how RECP actions can be taken in various organisations and by various employees.

7 Lundquist Th., Policy Measures to support RECP in Moldava, UNIDO, 2014

A gradual implementation of a permit system built on the principles of the Integrated Pollution Prevention and Control approach in line with the EU IPPC Directive is important for the long-term development of environmental initiatives in the companies.

Results of the first three years of the RECP program in Moldova

Review of the 19 RECP demonstration projects completed in 2012 in the participating enterprises from food processing, construction materials, and municipal services sectors was done to see the implementation status of RECP options recommended. The review aimed also to compile post-implementation stories based on the common set of RECP indicators.

Collectively, the enterprises achieved annual savings worth USD 217 500. In so doing, they collectively avoided 720,000kWh annual energy use, some 5800 m^3 annual water use, and more than 7491 tons of materials/chemicals used every year.

Case study: Orhei Vid (fruit and vegetable processor)

"Orhei-VIT" is the leading producer of canned fruit and vegetables and different types of juices. The company exports its products to several countries in the region: Russia, Belarus, Kazakhstan, Germany, Poland, and the Baltic States etc.

The Căuşeni branch of the company covers approximately 20 ha and it used to be one of the two largest fruit and vegetables factories in the Soviet Union with established production capacity of 1 mln conventional jars per day. At present the factory is specialized in the production of: canned peas, pickles, tomato paste, plum paste, tomato juice and concentrated apple juice. RECP options have been recommended for implementation:

- Reduction of energy and water losses in the pea sterilization process at the autoclaves;
- Reduction of water and energy losses of the cucumber pasteurizer;
- Installation of water guns on open hoses;
- Condensate return in the apple juice production process;
- Insulation of steam transportation and condensate pipes, of condensate and brining tanks;
- Replacement of old gas meter with high displaying threshold.

In the first year, since starting Resource Efficient and Cleaner Production, the company already implemented return of condensate, separation of waste, and replaced an inadequate gas meter. By this, they achieved annual savings exceeding USD 17,000. Further savings are expected following implementation of additional options that have already been identified, yet require preparation time and greater investments, which have recently been approved.

Case study: Stauceni vineyard

"Stăuceni" wine factory pertains to the National College of Viticulture and Vinification – an educational institution with its peculiar historic record in Chişinau municipality. It was founded back in 1842 by the order of Tsar Alexander II to open a School of Viticulture, Gardening and Viniculture of Bessarabia located in suburban area of Chişinau.

the following options have been recommended for implementation:
- Installation of water and electricity meters at significant consumers for a better monitoring and control in the future;
Optimization of heating expenses during winter time;
- Use process pigging for cleaning glass tubes for transportation of crushed grapes and juice to recover raw material, reduce water consumption and minimize quantity and BOD of waste waters;
- Use CIP plant for tank cleaning to reduce detergent and water use;
- Optimization of grapes pressing to increase yield;
- Change some equipment to increase yield, quality of wine and minimize waste.

As a result of implemented low investment Resource Efficient and Cleaner Production options, the company achieved annual savings of USD 4,700 in the first year already. Further savings are subject to implementation of new set of RECP options which require investments and change of equipment.

Case study: Doina Vin

"Doina Vin" winery produces quality and ordinary wines from selected European Grape Varieties. The history of Doina Vin dates back to 1875, when a Polish landlord established a cellar in the neighborhood of Chisinau, where he was both producing and selling wine.

As a result of a thorough analysis and process mapping, the NCPP experts team lead by UNIDO International expert have identified the following areas of improvement:
- Installation of water and electricity meters at significant consumers for a better monitoring and control in the future;
- Insulation of pipes and heating jackets, return of condensate, better combustion control to reduce energy and water consumption;
- Changing incandescent light bulbs with fluorescent to reduce electricity consumption;
- Use process pigging for cleaning glass tubes for transportation of crushed grapes to recover raw material, reduce water consumption and reduce volume and BOD of waste-water;
- Use CIP plant for tank cleaning to reduce detergent and water use.

Upon implementation of the first Resource Efficient and Cleaner Production options, the company achieved, in the first year already, annual savings of USD 11,000. Further savings potential is possible with other options still being evaluated and considered for implementation. Being a consumer oriented winery "Doina Vin" worked with 3 oenologists and sommeliers from Italy and France to evaluate the product and adjust winemaking techniques to modern consumer demands. They were present at the factory facilities when wine was manufactured and prepared for deposit, to monitor the entire process in order to evaluate the quality of produced wine and share information and know-how that helped the company target specific markets based on consumer preferences in these countries. To preserve the genuine taste of its wine, "Doina Vin" is currently restructuring its wine plantations, continuously trains staff for better performance, and adopts an annual investment budget for renovating its facility.

As a follow up a booklet in both Romanian and English languages regarding track record of RECP assessed enterprises and organizations in 2012, and their benefits after RECP options implementation was prepare. Full-fledged format stories are disseminated also by means of publication on the NCPP webpage.[8]

The participating companies mentioned that their motivation for participation and implementation mostly resulted from the simple approaches used to show the potential for improvement, the rules of thumb applied during the initial assessments which served as eye openers and the simple measurements (e. G. Using a bucket and a wrist watch to measure water flows) and the calculations to extrapolate losses from actual observation.

They appreciated the community of people struggling with the same issues, the involvement of the regional governments, which came not to punish but to assist in problem solving. There is a strong committment by the leaders not to pollute, to want transparency regarding the environmental impact of their businesses (and the neighbours contribution).

Analysing for existing technology gaps, the following problems were observed:

On a community base, collection and recycling systems should be set up. This starts at the company level (as with Orhid Vid) and reaches out to the community level. The companies want to separate and recycle their waste, however the infrastructure is not in place. A system, fitting the needs of enterprises should be established.

Common issues were the need for measuring equipment, the interest in energy reduction and the interest in waste water.

In the past, measurement equipment was not accessible. The equipment which the programm brought (flue gas analyser, power clamps, waste water quality, air flow measurements, temperature, humidity) was readily used to collect data on the performance of equipment.

8 http://www.ncpp.md/en/index.html, accessed February 2014

Energy is a burning issue: cost is significant and transparency is lacking. So measurements, energy flow mapping and benchmarking of efficiency proved very well accepted tools. Correspondingly, measures to reduce energy consumption, like insulation of pipes, return of condensate, adjustments of boiler control were readily implemented.

In the existing plants, typically infrastructure is oversized. Buildings, roads, boilers, water pumps, pipe diameters, transformers, compressors, controls all are designed for much bigger capacities than they are used for at present. So controlled downsizing and adapting the existing infrastructure to the present needs of the processed helps a lot to increase efficiency. This means focussing activities in sections of the original plants, shutting down reduntant boilers, combining plants to more effective ones to increase their occupancy, install smaller, more efficient pumps, smaller motors etc. can help to increase the overall efficiency of plants greatly.

The use of indicators for monitoring, controlling and targetting proved a very effective, low cost measure to understand the impacts on consumption and to suggest solutions. The corresponding data collection, normalisation to production, reporting and discussion was perceived as a very valuable tool. The tools provided by UNIDO and UNEP to assess and monitor resource efficiency support the implementation very well.

Other gaps include

- lack of technical training provided to the staff
- missing command of English as a basic requirement to collect and analyse information from suppliers, and the internet in general
- lack in access to financing and very high interest rates
- little or no cooperation with national and international universities for a variety of reasons

In the following areas technological gaps, comparing to best available technologies were identified:

- regarding cleaning, the use of cleaning in place plants apparently is in its infancy, modern, foam based cleaning and desinfection chemicals are not used
- regarding waste collection and treatment, there is no infrastructure for separated collection and recycling
- regarding the use of waste to generate energy, biomass, e. G. In the form of apple pommace is not used as a fuel
- regarding waste water treatment, no use is made of anaerobic decomposition of BOD to generate biogas as a fuel
- In boilers, the use of sensors and appropriate control, e. G. With frequency controlled drives on blowers, is not used
- Instruments for control (sensors, data acquisition, data visualisation, monitoring and controlling) are usually very weak in relation to best practises

The way forward

The next steps involve continuation in training to build and expand national capacity, to strengthen the institutional setup by transforming the RECP program to a permanent center, to involve communities even stronger.

It is planned to keep the approach simple, convincing, and transparent. At the same time it is important to advance it to be able to provide up to date, technically impeccable suggestions for the respective sectors. This requires contacts with potential suppliers abroad, detailed knowledge on practises and technologies, and the ability to analyse and model existing equipment. Also the ability to do proper financial analysis of proposals and the correct presentation of bankable projects will become more and more important, as the program advances. The installation of a permanent center at a faculty of the National University will facilitate to stand these challenges.

The communities have proven to be the most convincing instrument of multiplication of the approach to the enterprises working in their area. By leading by example involving community owned enterprises like schools and waterworks the communities show in an authentic way that they apply the concept themselves and thus promote its application. In four regions RECP clubs have been established and are running, in more regions similar programs are planned. In these clubs also the veteran experts from the pioneer companies are active as national consultants. This boosts the credibility of the program in the eyes of the novices. These regional clubs also provide an effective platform for companies to present themselves seriously as good citizens, who work actively for a better environment for all fellow citizens.

Conclusions

The lessons learned from Moldava are:

RECP assessments, as well as energy audits with a more limited scope, need to be of a good standard in order to allow for investment decisions to be based upon them. This demands a credible and accountable group of experts. To facilitate the development of such a group within the country there is a need for a high-class system of training and accreditation of these auditors.

Convincing steps are transparent measurements, preferably with simple means, understandable and clear in extrapolation of results, as well as the on the spot application of rules of the thumb to analyse existing equipment, evaluating the results and deducting recommendations. The so defined baselines should be the starting point for the application of indicators in monitoring and controlling to guarantee the application of best organisational practises. Standardized approaches to technology transfer hardly work: the local conditions have to be considered to identify appropriate, workable solutions.

In this process, it is good to start small, to implement simple good housekeeping solutions to demonstrate the benefits and to get used to the logic of locating improvement potential in processes.

Upon harvesting the low hanging fruits, the logical next steps is to renovate equipment and infrastructure. Here it is important to optimise equipment according to the process tasks and to size and control utilities in an optimised way.

There is already a long list of case studies showing that the RECP concept has been applied successfully to companies in Moldava. These good examples should be promoted and recognised. This requires a well maintained, apealing webpage, the documentation of authentic case studies and their publication. A national RECP award could help to promote successful application of the RECP practises among companies in Moldova.

The involvement of regional communities is an important success factor. The direct involvement of regional authorities excludes bureaucracy and intransparent procedures. If community representatives focus on problem solving together with companies who are motivated to be transparent and clean instead of punishing them, they are very welcome and meet open doors.

The project management needs to fill the gap between academia, companies, and regional governments. This role depends on personal skills and must not be mixed with political interest to be perceived as authentical and supportive. Ideally, the fiscal and environmental policy measures initiated by governments to support the uptake of RECP need to be predictable and transparent for the businesses to adopt.

Acknowledgments

The Resource efficient and cleaner production program in Moldaw is supported by UNEP (United Nations Environmental Program), UNIDO (United Nations Industrial Development Organisation), and ADA (Austrian Development Agency)

THE THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ) AS OPTION GENERATION TOOL WITHIN CLEANER PRODUCTION PROJECTS

Dr. Johannes Fresner[1]

STENUM GmbH, Geidorfgürtel 21, 8010 Graz, Austria

j.fresner@stenum.at

DI Jürgen Jantschgi, Mag. Stefan Birkel, DI Josef Bärnthaler, DI (FH) Christina Krenn

Abstract

Cleaner Production is an organized approach to minimize industrial waste and emissions by increasing the efficiency of the use of materials and energy. It is propagated especially by UNIDO and UNEP as an approach to identify preventive measures to cut on waste and emissions from industrial activities. Case studies conducted by the authors in the last 10 years demonstrate, that in a number of cases water consumption per production unit of industries from the surface treatment sector, from food processing and from the textile industry could be reduced by 30 to 90%, auxiliary materials consumption could be reduced by 30 to 50%, and energy consumption of processes could be reduced by 15 to 25%. All these measures were actually economically beneficial for the companies, most of these measures paid back in less than one year [1].

The standard approach to apply Cleaner Production originates from chemical engineering. It follows the steps of: Drawing a process flowsheet – collecting input/outputdata – doing mass and energy balances – identify sources for waste and emissions – set priorities - identify options. In the process of option generation one generally relies on expert

[1] Author to whom correspondence should be addressed, j.fresner@stenum.at, STENUM GmbH, Geidorfgürtel 21, 8010 Graz, www.stenum.at

knowledge or on checklists which are available in different manuals or in the Best available technology referenence (BREF) notes[2]. This approach is strong with teams with a (chemical) engineering background.

The authors wanted to develop a generic approach for option identification especially for teams with little formal engineering background or teams which have to go beyond their professional experience by using elements of the socalled TRIZ method (Theory of inventive problem solving, or originally Russian: "теория решения изобретательских задач" (Teoria reschenija isobretatjelskich sadatsch)). TRIZ offers very strong tools for developing process improvement options on a generic level without specific technological knowledge about the process which shall be improved. The authors have found from their research, that especially the concept of the Ideal Final Result, and the Laws of Evolution form a conceptual framework which can aid effectively in the identification of improvement options in a systematic way.

Keywords:

*C*leaner production, material efficiency, waste minimisation, zero emission, TRIZ, energy efficiency, ideal final result, laws of evolution

1. Cleaner Production in a nutshell

Production-integrated - or preventive - environmental protection aims at reducing the amount and danger of waste and emissions and - as a consequence - also the costs for raw materials, water, and energy. Compared to the disposal of waste and to end-of-pipe technologies preventive environmental action offers several advantages:

- Reducing waste and emission generally means using smaller quantities of materials and energy, which has the potential for economic savings

[2] The BREF-notes are documents developed by the European Comission to support companies and the relevant authorities in the process of upgrading their technology to best practice standards, as required by the IPPC directive (Integrated Pollution Prevention and Control; Directive 2008/1/EC). The state best practise regarding pollution prevention for most industrial sectors.

- Reduction of waste and emissions usually triggers an innovative process in the company because of the intensive focus on the analysis production processes
- Risks regarding environmental liability and disposal are reduced to a minimum
- Reduction of waste and emissions means moving towards sustainable economic development

In traditional waste management the question is:

- What is to be done with the waste and emissions generated?

Preventive, integrated environmental protection on the other hand asks:

- Where do waste and emissions in my company come from?
- Why have they become waste and what can we do to minimize their generation?

Main tools of cleaner production are flow sheeting, and material and energy balances [1, 2]. Flowsheeting uses black box modelling of process steps as a tool. This provides for a quick overview, especially of complex manufacturing processes. However, it does not necessarily analyse the activities within these black boxes in detail. It therefore depends also on the skills and experience of the expert building the black box model to do it detailed enough to account for process steps relevant in identification of sources of waste and emissions but keep it simple enough to keep the model managable. Data for material and energy balances often can be taken from accounts (for a year), but have to be weighed and measured for more detailed balances. This makes this step time consuming and sometimes difficult in practise, if process documentation is not in place and has to be developed for the CP project.

Out of experience, a systematic representation of cleaner production strategies has been developed.

Generally, cleaner production strategies aim at the optimisation of material and energy flows by process modification (change of raw materials, changes in operational practice, technological changes), internal and external recycling. The following table gives an overview of interpretations of these strategies (Table 1, table 2).

Table 1: Cleaner Production Strategies

CP Strategy	Description
Changes in operational practises	Standardization of processes (training) Control (improve accounting, create responsibilities, Improvement of process utilisation Improvement of dosage (see standardisation) Longer intervals for changes of auxiliary materials Improvement of procurement (see raw materials)
Change of raw materials	Use of less toxic materials (organic solvents, hogenated solvents, petrochemical products, cleaner raw materials, less asbestos, less heavy metals) Use of waste materials Use of less different materials
Technological change	Use mechanical processes instead of physical or chemical ones Use of counter flow processes Separation of waste Improvement of process conditions Improvement of energy efficiency of processes (by insulation, heat recovery) Reduction of drag in of impurities
Internal recycling	Re-use of material Re-use of structure Re-use of energy
External recycling	Re-use of material Re-use of structure Re-use of energy e. g. for district heating

Table 2: Specific examples for Cleaner Production strategies for metal manufacturing and the textile industries

CP Strategy	Example
Changes in operational practises	- documentation of key process data (consumption of water, energy, chemicals) - use of indicators for process analysis and control - switching off equipment which is not used - planning production so that it is as continuous as possible (to minimize start up, shut down, idle phases)
Change of raw materials	- use of water based paints instead of solvent based paints - use of water based degreaser instead of solvents - replacement of asbestos fibre insulation materials by mineral wool - replacement of cyanides in galvanizing - use of heavy metal free dyes in the dyeing of textiles
Change of technology	- installing a humidity sensor and automatic control of air flow in a stenter - installing a three stage counterflow rinsing cascade in a galvanising plant - improvement of process conditions by automatic dosing pumps for the process chemicals - removal of water by pressing and by vacuum from fabrics before thermal drying
Internal recycling	- shreddering gate system in injection moulding and mixing the granulate to the raw material - reusing heated cooling water in cleaning the plant
External recycling	- use of returnable packing system - use of process waste heat to heat office buildings - recycling of polyethylene film through re-granulation

These strategies act as general principles. In a cleaner production project, firstly waste and emissions will be identified, quantified, prioritized according to the monetary value of waste materials calculated from the price of raw materials, energy, and processing, and energy and because of hazards involved in manipulating materials. Consequently in a team session involving plant personnel and external consultants during a brainstorming these principles are used to generate ideas which then can be used to minimise waste and emissions. This works nicely, if at least somebody in the team knows from experience or training about options which can be applied to the case.

Most of the environmental managers working on Cleaner Production projects, however, seem to have little formal higher technical education. A recent survey of 45 companies currently participating in the Ecoprofit Club in the City of Graz done by the authors shows, that 24 % are skilled workers, 22 % have a highschool degree, 22 % a technical highschool degree, 10 % an University degree in natural science (master), 9 % a business degree, 6 % a law degree, and 7 % an engineering degree. None had a chemical engineering degree.

Therefore the authors were looking for an approach

- which is applicable without chemical engineering training
- which includes tools which use a modelling language as close to natural language as possible
- which is helping groups to go beyond the knowledge they have from their own training and experience in the identification of options for improvement

2. Cleaner Production and TRIZ – a comparision

TRIZ was defined by Russian researchers from the 1940s on as the "Theory of inventive problem solving". These researchers, pioneered by Genrich Altshuller looked for fundamental principles of inventive problem solving. Altshuller analysed a big number of Russian patents for generic principles how the patented solutions were arrived at. He identified the following laws of evolution of technical systems:

1. Stepwise evolution of systems: Systems evolve in discrete steps

2. Increasing ideality[3]: Systems evolve towards ideality, characterized by supplying the technical function without causing any harmful effects (in terms of effort, resource consumption, etc.)
3. Different evolution of system elements: System elements evolve on different levels
4. Increase in dynamics and control: systems are dynamized, control increases over evolution
5. Increase in complexity and decrease again: the complexity of a system increases and decreases again after reaching a certain level of complexity
6. Increase of coordination: the rhythm of the different elements of a technical system becomes more and more coordinated
7. Miniaturisation: the system and its elements tend to become miniaturized
8. Decrease in human interaction: Human interaction with the system decreases with evolution

The authors found during their analysis, that the eight TRIZ principles show similarities and some correspondance to the strategies of Cleaner Production. Table 3: Comparison of the strategies of Cleaner Production and the Laws of Evolution

CP strategy → Line of evolution ↓	**New raw materials**	**Changes in operational practises**	**Internal recycling**	**External recycling**	**Technology change**	**Product redesign**
Stepwise evolution of systems	Acquiring Material safety data sheets, evaluating them, using them in supply chain management	Improved organisation of processes, continuous control, full implementation of management system	Separate useful fractions, reuse them, install continuous process	Separate useful fractions, find application, install continuous process	Mechanical instead of physical or chemical (decrease number of transformations)	New materials, new technologies, new manufacturing processes
Increasing	Purer raw	Narrow	Close cycles	Industrial	Reduce drag in,	Avoid

3 "Ideality" in TRIZ is defined as: total of useful functions over total of harmful functions (harmful functions include waste and cost), functions are defined strictly from a client´s perspective

ideality	materials, with less toxic substances	process conditions to optimum conditions	internally (e. g. cooling water, vapor recompression)	Ecology	improve process conditions, improve mixing, avoid dead zones	harmful materials, longer life
Different evolution of system elements	New materials with special properties to replace standard ones	Less developed components are typically control of utilities and auxiliary materials	Technology used in sensors, controls, drives	Quality control of waste	Heaters, drives, controls	New materials, new manufacturing processes
Increase in dynamics and control	Automatic control of dosage	Organisation, control, standardisation	Conditional internal recycling (e. g. by conductivity control)	Considering feedback from external companies regarding specifications	Countercurrent flow, cascaded use, Energy efficient systems	Use of recycled materials
Increase in complexity and decrease again	Automatic dye preparation system, finally based on three elementary colours only	Integrated management systems	Process integrated internal recycling (runners in injection moulding), reactants in chemical processes	waste separation, replaced by application for mixed waste (yarns for carpets, plastic for fuel)	Separate waste	Integration of additional functions
Increase in Coordination	Electronic purchasing, automatic stock control	Improving utilisation of plants, synchronise processes, preparatory action	Reuse waste in same process immediately	Customer specifications for accepting by products	Size/speed of equipment, preliminary action	Design for recycling
Miniaturisation	High tensile steel, thinner film	5S: minimize stock	Minimize holdup, high pressure cleaning instead of flushing	Continuous supply	Micro reactors, use of staged systems	Integration of electronic elements, sensors
Decrease in human interaction	Preformulation of tailored formulations	Automatic process control	Automatic recycling (coolant, water)	Automatic sorting (e. g. glass, paper)	Automatic control	Automatic functions (calibration)

compares the strategies of Cleaner Production to the Laws of Evolution as defined by Genrich Altshuller [3].

Genrich Altshuller also found, that the process of inventing actually means to locate “contradictions” in a system, which keep it from performing according to the ideal solution, and to solve them. Contradictions can be either technical, or physical. Technical contradictions appear, when there are conflicting requirements regarding two different paramenters of a technical system (e. g. the display of a laptop should be bright, and the life of the battery should be long, at the same time). Physical contradictions appear, when the same parameter should show different properties at the same time (e. g. a coffee mug should be hot (to keep the coffee hot) and cold at the same time (to allow to touch it). If the underlying physical contradiction can be identified, it usually can be solved by

- separating the system in time (change properties, so that they can vary in time and thus comply: store the coffee first in an insulated mug and transfer it to a cup just before serving it)
- separating the system in space (change properties, so that they can vary locally and thus comply: e. g. adding a handle to the coffee mug)
- separating the boundary conditions (e. g. change the process of coffee making to instant coffee which can be prepared at a lower temperature)

A full explanation of these separation principles can be found in [4]. The process of problem analysis, identification of technical contradictions, transferring them to physical ones and solving them later on was codified and called ARIZ [5].

Scholars of Althshuller later on worked on rephrasing these prinicple to facilitate their appliction. An easy to apply version are the socalled “Lines of evolution” [4].

TRIZ was applied in a number of companies in the last 20 years to solve different problems (among them Procter & Gamble, Ford Motor Company, Boeing, Philips Semiconductors, Samsung, LG Electronics). TRIZ applications to the design of products incooperating sustainability and ecoefficiency related problems are documented in the literature, however rare ([6], [7], [8], [9], [10]). Explicite use of TRIZ within CP is not documented until today, according to the knowledge of the authors. TRIZ, however, has been used within six sigma projects effectively [11].

Table 3: Comparison of the strategies of Cleaner Production and the Laws of Evolution

CP strategy → Line of evolution ↓	**New raw materials**	**Changes in operational practises**	**Internal recycling**	**External recycling**	**Technology change**	**Product redesign**
Stepwise evolution of systems	Acquiring Material safety data sheets, evaluating them, using them in supply chain management	Improved organisation of processes, continuous control, full implementation of management system	Separate useful fractions, reuse them, install continuous process	Separate useful fractions, find application, install continuous process	Mechanical instead of physical or chemical (decrease number of transformations)	New materials, new technologies, new manufacturing processes
Increasing ideality	Purer raw materials, with less toxic substances	Narrow process conditions to optimum conditions	Close cycles internally (e. g. cooling water, vapor recompression)	Industrial Ecology	Reduce drag in, improve process conditions, improve mixing, avoid dead zones	Avoid harmful materials, longer life
Different evolution of system elements	New materials with special properties to replace standard ones	Less developed components are typically control of utilities and auxiliary materials	Technology used in sensors, controls, drives	Quality control of waste	Heaters, drives, controls	New materials, new manufacturing processes
Increase in dynamics and control	Automatic control of dosage	Organisation, control, standardisation	Conditional internal recycling (e. g. by conductivity control)	Considering feedback from external companies regarding specifications	Countercurrent flow, cascaded use, Energy efficient systems	Use of recycled materials
Increase in complexity and decrease again	Automatic dye preparation system, finally based on three elementary colours only	Integrated management systems	Process integrated internal recycling (runners in injection moulding), reactants in chemical processes	waste separation, replaced by application for mixed waste (yarns for carpets, plastic for fuel)	Separate waste	Integration of additional functions
Increase in Coordination	Electronic purchasing, automatic	Improving utilisation of plants,	Reuse waste in same process	Customer specifications for accepting	Size/speed of equipment, preliminary	Design for recycling

	stock control	synchronise processes, preparatory action	immediately	by products	action	
Miniaturisation	High tensile steel, thinner film	5S: minimize stock	Minimize holdup, high pressure cleaning instead of flushing	Continuous supply	Micro reactors, use of staged systems	Integration of electronic elements, sensors
Decrease in human interaction	Preformulation of tailored formulations	Automatic process control	Automatic recycling (coolant, water)	Automatic sorting (e. g. glass, paper)	Automatic control	Automatic functions (calibration)

This comparision of CP and TRIZ indicates, that – using the language of TRIZ - CP actually focuses on understanding optimum process conditions, optimising control and reducing human interaction to develop the process towards the ideal result and the ideal process. The ideal result in CP is defined by reaching the main useful function of the process in the absence of waste and emissions, minimum generation of by products, and minimum consumption of water and energy and thus minimum unnecessary cost. This formulation of Cleaner Production using the definitions of TRIZ can lead to a more generic definition of the concept of Cleaner Production as compared to the strategies of Cleaner Production.

The appropriate optimisation strategy can be derived from the concept of the ideal final result (

Figure 1: Solving optimisation problems using the Ideal Final Result ([13]) and backcasting

). The TRIZ algorithm requires that at the beginning of the problem solving process a model of the current situation should be developed, picturing it accurately, showing the elements of the problem and their interactions, together with the resources available for problem solving. This is called function analysis. A function analysis models a technical system as a system of components and functions. A function is an activity, by which one component of a system changes a property of another component (Subject changes a property of an object). The definition of functions is similar to describing activities in natural language, and therefore easy to comprehend and apply also for non-technical members of the team. The function model literally opens up the blackbox models of process steps normally used in CP. It very quickly guides to the elements of a problem that require change and very often also helps to trigger suggestions how to change.

On the basis of the function model, the ideal final result is developed. The ideal final result is defined as the delivery of the main useful function of the system without any harmful functions. This analogy then is taken as a starting point for the identification of a practical realization.

If the model of the ideal final result cannot be translated into a practical solution, a backcasting procedure is recommended. Starting with the question: what keeps us from realizing the ideal solution, intermediate stages for problem solving are identified and again corresponding potential solutions. When again no corresponding practical solution can be identified, this step is repeated, until solutions have been found [12].

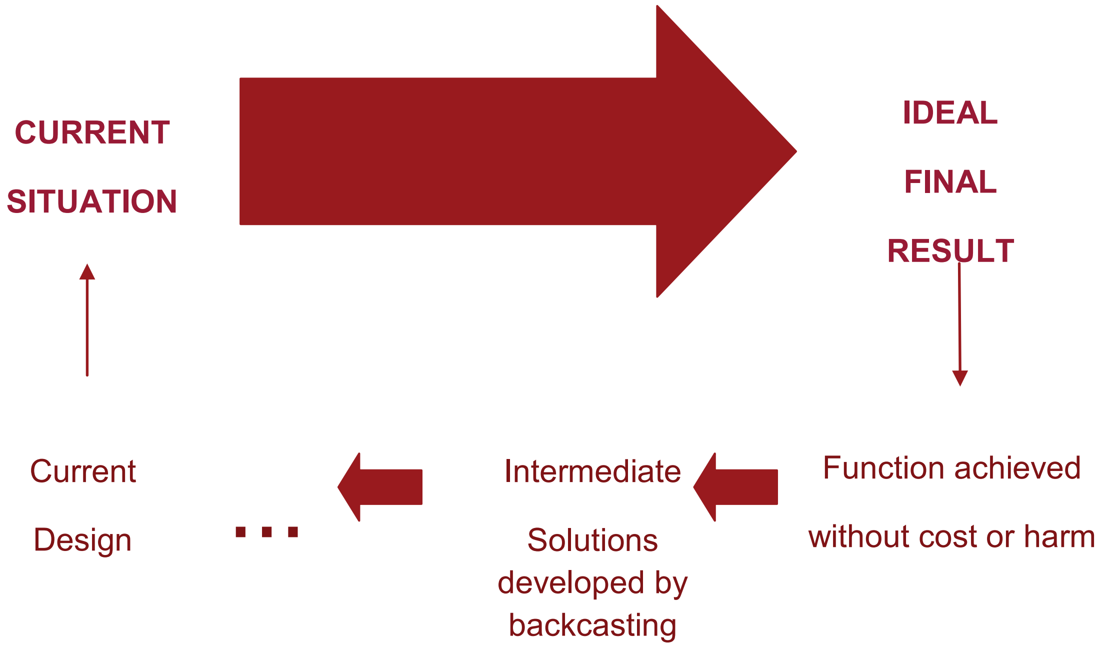


Figure 1: Solving optimisation problems using the Ideal Final Result ([13]) and backcasting

Grawatsch uses the following questions in the optimisation procedure after defining the ideal final result (as defined by achieving the desired function of the process without cost or harm) [13]. Grawatsch calls this process “trimming”:

- Can components or (ancillary) functions be gotten rid of?
- Can the need for a function be eliminated?

- Can functions of other components or the components themselves be taken over?
- Can unwanted functions be eliminated by other functions?
- Can operating components be replaced by other components?
- Can operating components be replaced by existing resources?
- Can the system take over functions itself?
- Can freely available resources be used?

These questions are derived from the Laws of Evolution and can be correlated to these (Table 4). These questions can be considered a very basic representation of TRIZ problem solving knowledge.

Table 4: Comparing the questions of the trimming procedure to the Laws of Evolution

Laws of Evolution	Corresponding optimisation questions
Stepwise evolution of systems	Can the need for a function be eliminated?
Increasing ideality	Can operating components be replaced by existing resources (free, perfect, now)?
Different evolution of system elements	Can operating components be replaced by other ones (more advanced ones)?
Increase in dynamics and control	Can the system take over functions itself?
Increase in complexity and decrease again	Can components or functions be gotten rid of?
Increase of coordination	Can unwanted functions be eliminated by other functions?
Miniaturisation	Can operating components be replaced by other ones (smaller ones)?
Decrease in human interaction	Can unwanted functions be eliminated by other functions (automatic control)?

For example, the application of the trimming procedure to rinsing in galvanizing would produce the following reasoning:

The problem is the consumption of rinsing water used to dilute the film of dragged out chemicals on the surface of the parts.

A brief excursion: During the analysis the question could be risen, whether the parts require galvanic surface treatment or whether the process could be avoided at all by applying alternatives, like powder coating. This is a justified question, which needs to be analysed. To ask this question in many applications will be out of the scope for small and medium sized enterprises which use processes specified by their suppliers. In some cases truly new process alternatives can be initiated by asking this fundamental question.

Assuming we need galvanic treatment, the ideal final result for rinsing in galvanising would be a surface free from contaminants ready for the next process step, without any harmful functions (wastewater, waste, energy consumption). In process optimisation we can get closer to this goal by the elimination of the adhering film on the workpiece from the very beginning, as this is causing the need for rinsing and the need for rinsing defines the use of water, the rinsing technology, etc.

In order to identify the useful function and the harmful functions of a process, a function analysis of the relevant process steps generating waste and emissions is performed. A plant consisting of a pickling tank and a rinsing water tank has the following elements:

- parts
- oxide
- racks
- acid solution
- acid tank
- rinsing water tank
- rinsing water
- valve
- operator
- crane
- etc.

The plant is modelled in a function analysis in the following way (Figure 2):

- Acid bath dissolves oxide (main useful function)
- Acid bath adheres to surface (of part)

- Parts hold an acid bath film
- Rinsing water dilutes acid film
- Valve controls water (flow)
- Operator opens valve
- Racks hold parts
- Crane holds racks
- Operator measures concentration (of acid in tanks)
- Operator adds acid
- Water generates waste water
- Oxide reduces activity of bath
- Acid bath generates spent bath
- Etc.

Except from the one useful function, all other functions are actually harmful: They do not contribute to the goal of the process, and cause cost or waste or emissions.

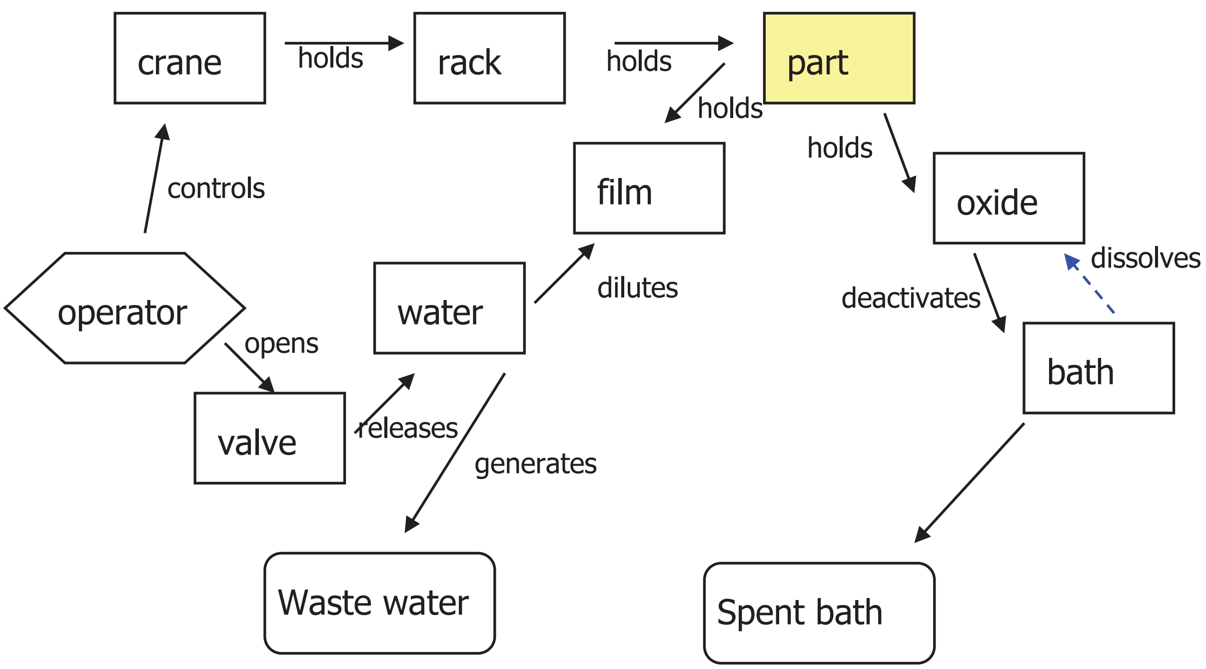


Figure 2: Function analysis of the pickling process (dotted line: useful function, full lines: harmful functions, boxes: elements of the system, rounded boxes waste, hexagon: supersystem)

Applying the questions from above after a function analysis and the definition of the ideal final result gives the following results (table 5):

Table 5: Backcasting as problem solving approach in optimising a galvanising plant (ideal final result: minimum adhering film of active bath, minimum necessary dilution of this film)

Question for backcasting from ideal final result	Questions risen during function modelling	Examples
Can the need for a function be eliminated?	How can the need for rinsing with water be eliminated?	Reducing drag out by longer dripping times, mounting parts at angles, avoid scooping, defining proper rinsing criteria,
Can components be gotten rid of?	Which components of the galvanising system (surface of parts, racks, drag out) can be gotten rid of?	Reduce drag in of impurities (grease, oil), Reduce surface area of parts, but also of racks Reduce components which increase viscosity of solutions (by reducing the contents of metals)
Can functions be taken over by other components?	Can components be introduced which can perform the functions of diluting the adhering film?	cascade, spray rinses
Can unwanted functions be taken over by other functions?	Can dilution of adhering film be achieved in a different way?	Blowing, use of recycled water, reduce viscosity of films by increasing temperature
Can the system take over functions itself?	Which functions of the galvanizing system can be assigned to the system itself?	conductivity control of rinsing water, automatic control of the crane to guarantee dipping and draining times
Can operating components be replaced by existing resources?	Which components could be replaced by plant resources (heat, pressurized air)?	Air blowing to blow of drag out
Can free resources be used (time, air, space …)?	Can resources like air, time, space help to improve the system?	improve dripping time, overflow in rinsing cascades by gravity

Possible solutions according to the definition of the Ideal final result asking Grawatsch´s questions would be:

- no adhering film to workpiece (e. g. by using surfactants which facilitate perfect draining because of low surface tension)
- maximum reduction of dragout (e. g. by longer dripping times to allow perfect draining)

If these solutions cannot be realised, the solution finding process would propagate back from the ideal final result asking the question: What is the next best solution?

In the case of the rinsing problem this solution could be

- most effective dilution of adhering film to the concentration tolerable in the next process step
- optimum reuse of rinsing water if we cannot avoid rinsing (e. g. by cascading rinsing water)
- optimum use of water (e. g. by defining a rinsing criterion and measuring the conductivity of the effluent water)

Starting from 2008 on, the authors applied the TRIZ based Cleaner Production procedure to several textile mills in Austria (Fussenegger, Leichtfried, Baumann) Initially, a flowchart was drawn for the processes in each of these mills. These flowcharts were used to identify sources of waste water and energy emissions. Then together with the project teams in the companies, priorities were assigned. Consequently, detailed analyses were conducted for priority areas.

The case of a stender is described in the following paragraphs. A stender is a unit commonly used in textile plants to dry fabrics while preserving the desired shape of the fabric after washing and also for wet finishing (the application of aqueous solutions of resins and chemicals to the fabric which are fixated by drying afterwards).

A stender consists out of two parallel chains with needles, which hold the fabric. These chains guide the fabric to a dryer, up to 50 meters long, which is heated to the process temperatures (80 to 150 °C) directly by gas, or by thermooil or steam. Air is extracted from the stender to remove humidity (and chemicals, which evaporate from the fabric).

Figure 3 shows the function analysis for a stender.

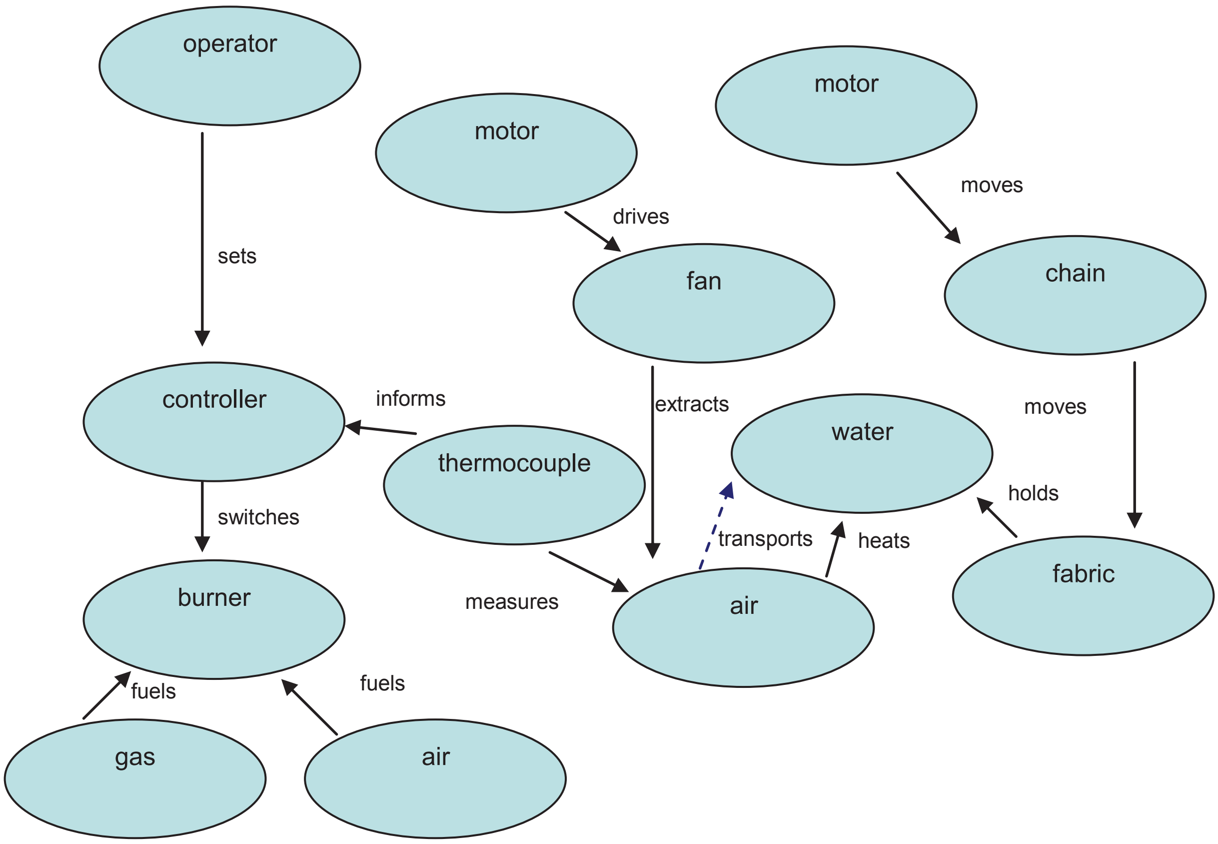


Figure 3: Function analysis of the drying process in a stenter (dotted line: useful function, full lines: harmful functions, no waste or elements of the supersystem included)

Looking at this analysis in two plants the following optimisation routes were identified:

The function analysis showed, that in the stender air is heated to transfer heat to the water which is contained in the fabric. At the same time some of this air is used to transport the humidity, therefore a continuous stream of air is extracted via a fan.

The ideal solution would be dry fabric without any harmful functions (costly use of energy, generation of waste heat in the exhaust air). Replacing the wet process at all was out of scope because of the specific requirements of the client.

The closest approach to the ideal final result could be realized by eliminating the water first mechanically by squeezing the fabric (not feasible because of the nature of the fibres). What is the next best solution?

Changing the drying mechanism to high frequency microwave drying, would eliminate the need for air for heat transfer and reducing its function to the transport of humidity. This approach was already applied in drying specific fibres in one of the mills. For the other applications, this idea was abandoned because of the high investment. What is the next best solution?

In the case of two companies, the motor was driving the fan at a constant speed, regardless whether they were drying heavy fabrics holding 200 g/m² of water or light ones with less than 70 g/m². This was pointed out during the discussion in the team while developing the function model. Measuring the humidity in the exhaust and controlling the volume of airflow accordingly was the approach that led to a 30% reduction in gas consumption.

Figure 4 shows the function analysis for a washing process. Before weaving, size is applied to the yarn to strengthen it and to reduce friction. After weaving it has to be washed out of the fabric, because it would interfer with the consecutive wet finishing process. In the washing process, water and detergent is applied to solve the size. Rinsing water is used to rinse the dissolved size until the concentration of size in the fabric is below the maximum permissable concentration. The operator manually controls the water flow. During the discussion it was found that the water flow had been set for a worst case scenario of very heavy fabrics with a high concentration of sizes. Most of the fabrics actually contained a lot less size.

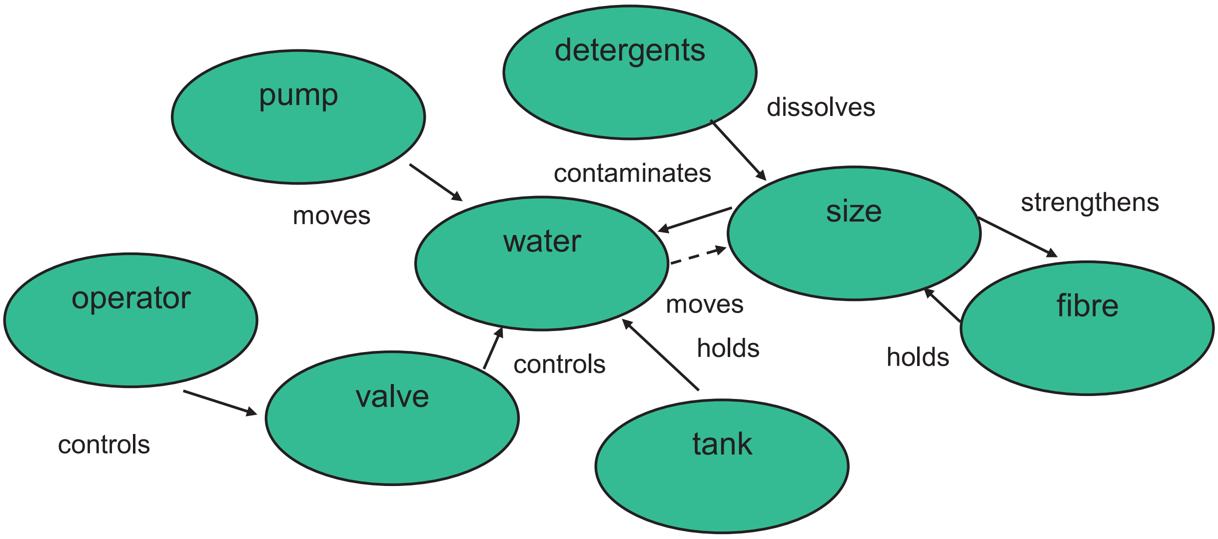


Figure 4: Function analysis of the drying process in a stenter (dotted line: useful function, full lines: harmful functions, no waste or elements of the supersystem included)

Figure 5: Function analysis of the drying process in a stenter (dotted line: useful function, full lines: harmful functions, no waste or elements of the supersystem included)

In this system, the use of size could not be changed. The company also did not want to change the chemicals used. The starting point for improvement was control of water: During the process of performing the function analysis it was discovered, that in the plant originally a conductivity control of the water flow had been installed. Because of technical problems it had been decomissioned years ago. The feasibilty analysis showed that repairing it would save 35% of water consumption at a payback of three months.

3. Conclusions

Analysing the strategies of cleaner production and comparing them to the Laws of Evolution from TRIZ has yielded a useful new interpretation of the strategies of Cleaner Production. The result is also a new convenient interpretation for explaining them in teaching. An effective approach to the minimisation of waste and emissions from industrial production processes is to conduct the following steps:

1. drawing of a flowsheet of material streams, auxiliary materials, water and energy, highlighting waste streams, waste water generation, energy consumption and emissions, including auxiliary processes (like steam generation, air compression, water treatment)
2. performing a function analysis in the process steps where waste and emissions are generated
3. definition of ideality in these steps, applying trimming and backcasting intermediate solutions
   - select ideal raw materials (air, water, biogenic materials)
   - improve control of the process (documentation of key indicators, maintain optimum process conditions)
   - reduce human interaction by identifying possibilities for automatic control
   - improve the coordination of the production process with external requirements (also including recycling and passing function to the supersystem)
   - look for alternative technologies (following the principles of reduction of number of transformations, use countercurrent flows, use staged processes)
4. collect data on flows and monetary value of raw materials, energy and waste and evaluate the feasibility of the options.

This approach takes the Ideal final result as a starting point for optimisation. This vision can serve as a long-term objective to focus the decisions about possible options for change towards the most useful ones, given the greater picture of the ideal feasible result. Because it is more qualitative and relies on less data it is apparently easier to apply, less time consuming than the usually applied mass and energy balance based approaches to implement Cleaner Production and it requires less detailed expert knowledge for the identification of options. The TRIZ based approach is a valuable tool to moderate group work on developing CP options, also with team members with little engineering background. It does not require encyclopaedic knowledge of sector specific technologies. It is a systematic semantic approach to create powerful, though simple models for project steps, allowing to identify the origin of process inefficiencies. The approach also allows to expand the problem solving space beyond the original disciplines of the team members.

This approach is easy to explain to project groups in companies, because it starts analysis at a concrete function, which is not performed in the best possible way using simple, familiar language. This again leads to the search for physical and chemical effects which improve the situation supporting or even replacing encyclopaedic expert knowledge which otherwise would have been necessary to interpret the CP principles.

4. Acknowledgements

The authors are grateful to the Austrian research programme Fabrik der Zukunft for funding ZERMET, especially to Michael Paula, Hannes Bauer and Hans Günther Schwarz. The authors also appreciate the support of Andreas Tschulik.

5. References

[1] Yaacoub, A., Fresner, J., Half is enough, ISBN 3-9501636-2-X, Beirut, Graz, 2006

[2] Fresner, J., Setting up effective environmental management systems based on the concept of cleaner production: Cases from small and medium sized enterprises, in R. Hillary: „ISO 14001 Case Studies and Practical Experiences“, October 2000, ISBN 1 874719276

[3] Altschuller, Genrich Saulowitsch, Erfinden – Wege zur Lösung technischer Probleme, PI Verlag, 1998

[4] Mann, D., Hands-On Systematic Innovation. CREAX Press, Ieper 2002, 462, ISBN 90-77071-02-4

[5] http://www.ideationtriz.com/TRIZ_tutorial_2.htm, last accessed July 2009

[6] Hockerts, K. (1999), 'Eco-efficient service innovation: increasing business - ecological efficiency of products and services', in Charter, M., Greener Marketing: a global perspective on greener marketing practice, Greenleaf Publishing: Sheffield, UK, pp. 95-108

[7] Jones, E., Mann, D., An Eco-innovation Case Study of Domestic Dishwashing through the Application of TRIZ Tools, Creativity and Innovation Management, Volume 10, Number 1, March 2001 , pp. 3-14(12)

[8] Chen, J. L., Liu, C., An eco-innovative design approach incorporating the TRIZ method without contradiction analysis, The Journal of Sustainable Product Design, 1367-6679, Springer

[9] Kobayashi, H., A systematic approach to eco-innovative product design based on life cycle planning, Advanced Engineering Informatics , Volume 20, Issue 2, April 2006, Pages 113-125

[10] http://www.sixsigmatriz.com/

[11] Ericson, A., Bertoni, M., Larsson, T., Needs and requirements – How TRIZ may be applied in product-service development, 2nd Nordic Conference on Product Lifecycle Management – NordPLM’09, Göteborg, January 28-29 2009

[12] Jantschgi, J., J. Fresner, Linking TRIZ & Sustainability (Training and Consulting Models), 4th European TRIZ Symposium, Frankfurt/Main, June 30th – July 1st, 2005

[13] Grawatsch, M., Module 3 of the Support Training course, Montanuniversität Leoben, 2005

[14] www.fabrikderzukunft.at, last accessed March 2009

[15] Fresner, J., Galvanik ohne Abfall – ein unerreichbarer Wunschtraum?, Österreichische Chemiezeitschrift, 106. Jahrgang, 5/2005, p 6-8

[16] Nagy, R. A., The analysis and design of rinsing installations, http://www.pfonline.com/articles/web070001.html, last accessed July 2009

[17] Kimmerl, P., Ausschleppverluste in der Galvanotechnik, Galvanische Berichte, VEB Galvanotechnik Leipzig, Jg. 5, Heft 1, pp 15, 1968

[18] Fresner, J., J. Sage, P. Wolf, A benchmarking of 50 Austrian companies from the galvanizing and painting sector: current implementation of cleaner production options and active environmental management, Proceedings of the 8th European Roundtable on Cleaner Production, Cork, October 2002

Organizers

Supporters