PROCEEDINGS

What is sustainable technology? The role of life cycle-based methods in addressing the challenges of sustainability assessment of technologies

Rome
27 September 2012

edited by Grazia Barberio, Lucia Rigamonti, Alessandra Zamagni

AISME
Accademia Italiana di Scienze Merceologiche

IGWT

Italian National Agency for New Technologies, Energy and Sustainable Economic Develpment

Rete Italiana LCA

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FOREWORD

Technologies are acknowledged to have important implications for sustainability.

Kranzberger[1] stated that “technology is neither good nor bad; nor is it neutral: technology’s interaction with the social world is such that technical developments frequently have environmental, social and human consequences that go far beyond the immediate purposes of the technical devices themselves, and the same technology has quite different results when introduced into different contexts or under different circumstances”. More recently, Mulder et al. stated that technologies have played an important role in creating the problems that we face, but will also play an important role in solving them[2].

These two quotations suggest how complex the concept of technology is due to its consequences and implications on fields not strictly associated with the technology itself. The rapid growth especially in the area of nanotechnology, biotechnology and information and communication technology has important consequences not only on the day-by-day life, but on the whole society. The creation of employment, the improvements of the level of welfare, and the provisions of new functions to satisfy the need of citizens are some examples which highlight how strong and complex is the connection between technology and the social system. Thus, even if the assessment is limited to the environmental dimension, the effects of a technology depend also on the way in which the technology is used and how it interacts with technological systems and physical context, among others[2].

Many approaches to environmental protection continue to be based on end-of-pipe solutions, focused on a single medium (air, water, soil), a single stage in the product’s life cycle (production, use, disposal), or a single issue (e.g., individual chemical limits). These strategies do not always lead to an overall reduction in environmental impacts. Changes may be implemented, which could lead to unexpected impacts elsewhere in the product’s life cycle. Thus, there may be a shift of the burden to other phases of the life cycle; to other regions of the world; and to other impact categories[3]. Clearly, it is not helpful to solve complex problems with a given technology if the same technology increases other problems or creates new ones[2]. Hence the need to use a Life Cycle Thinking (LCT) approach and related life cycle-based methods.

LCA and other life cycle-based methods offer a well-defined basis, which however needs to be coupled and/or integrated with inputs from other domains of knowledge. Such an assessment is in fact quite challenging for three main reasons. Firstly, emergent technologies like nanotechnologies deliver products which often are not end products, but can be applied to a quite broad range of (unforeseen) applications. Secondly, many of these technologies are at laboratory scale and thus data availability and scale up effects are open questions which strongly affect the assessment. Finally, rebound effects may occur, when the increased benefit/efficiency gained by the new technology is partly spoilt or turned into a loss. Overall, technologies in a broad sense behave like complex systems, characterized by non-linear relationships, feedback loops, emergent phenomena, and tangled connections among the parts.

Such a challenging and interesting topic is at the core of the 2nd DIRE Meeting, organised in collaboration with AISME (Accademia Italiana di Scienze Merceologiche) and hosted by the 18th IGWT (International Society of Commodity Science and Technology) Symposium.

DIRE (Development and Improvement of LCA methodology: Research and Exchange of experiences) is a Working Group established in 2010 within the Italian LCA Network. Its main aim is to create a platform for discussing and debating LCA methodology developments in Italy among young researchers, and promoting the exchange of information and knowledge among its participants.

The first DIRE meeting was organised in late 2010 at Ecomondo Fair, Rimini (Italy). The high numbers of attendees and the quality of the research activities presented has impressively demonstrated the need for such an initiative. The DIRE Working Group has now organised a second meeting characterised by an important novelty: its internationalization.

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In line with the theme of the IGWT Symposium, which is about the role of technology and innovation for a sustainable future, the primary scientific aim of the 2nd DIRE meeting is to discuss the role of life cycle-based methods in addressing the challenges of sustainability assessment of technologies.

The meeting will be opened by a speech of Paolo Masoni, from the LCA and Ecodesign Laboratory of ENEA, about the role of networks in facilitating multi-regional collaboration and further applications of life cycle thinking approach. Then, the topic of sustainable technology will be addressed by Stig Olsen, from the Technical University of Denmark, who will give a keynote speech about strengths, weaknesses and opportunities of LCA and other life cycle-based methods for the sustainability assessment of nanotechnologies. Nanotechnologies are indeed of particular interest not only for the application itself but also for the associated methodological issues, both related to the technological system definition and the impact categories (e.g. human toxicity and ecotoxicity).

The keynote speech will address also the needs and opportunities of combining/integrating LCA with other methods. Several approaches in the scientific literature exist, in which LCA is used in combination with linear programming models, benefit analysis and material flow analysis and Risk Assessment, and examples will be provided in the poster spotlight presentations.

In order to cover the comprehensiveness of a life cycle-based sustainability assessment, Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA) have been developed and combined in a Life Cycle Sustainability Assessment (LCSA). Many presentations will show practical applications of these methods and will discuss also methodological proposal, for example for the impact assessment phase in S-LCA, for the integration between LCA, LCC and S-LCA, and for the application of LCC to new technologies.

Moreover, besides the methodological development that is of paramount relevance, given the still immature state of LCSA, it is also important to understand how to use the results of the assessments and how to communicate them, for example by means of a structured Environmental Product Declaration (EPD) system. This will be addressed by several applications in different sectors, such as forestry operations, agricultural practices, energy production from renewable sources, waste management systems and transport, just to mention a few.

All the presentations and the debate that follows will provide food for thoughts for attempting an answer to the main question of the meeting, i.e. *What is sustainable technology*?. Moreover, a plethora of questions can be framed, among which:

- Is LCA suitable for assessing new and emerging technologies, such as nanotechnologies?
- How can LCA be combined with and/or integrated to other methods to overcome its limits? And is there any risk in this integration process to stretch too much methods that have been initially conceived for different applications?
- Are the data and the knowledge necessary to carry out a study of LCSA available? Is there any risk to develop a methodology that is theoretically robust but whose practical feasibility appears to be difficult?
- How can the results of the assessment be used and communicated?

The meeting will provide a first opportunity for discussing such topics, but many other events and appointments will follow, such as ECOMONDO, in Rimini on 7-10 November 2012, during which the meeting of The Italian LCA Network will take place. Another important event is represented by the YES MEETING, organized by the SETAC Europe Student Advisory Council (SAC), which aims to support SETAC Europe's student members in becoming self-confident scientists. To achieve this goal the SAC regularly organizes special student activities. The 3rd Young Environmental Scientists (YES) meeting under the motto "Interdisciplinary Discourse on Current Environmental Challenges" will take place on 11–13 February 2013 in Krakow, Poland (deadline for abstract submission is 30 October 2012) and will address several topics, such as Nanomaterials, Omics and biomarkers, Aquatic ecotoxicology, Terrestrial ecotoxicology, Effects and exposure modeling, Environmental chemistry, Risk assessment and remediation techniques, Life cycle assessment. Because the meeting is organized by students for students it will be tailored to the needs of young scientists, so no conference fees will be charged and all participants will receive a travel grant. More information are available at web site www.sac-online.eu/yes2013.

We would like to take the opportunity to thanks all those who supported us in the organisation of this meeting. First of all, we would like to thank the Italian LCA Network and its President Paolo Masoni (Technical Unit for Models, Methods and Technologies for Environmental Assessments-LCA - ENEA) for always encouraging the activities of the DIRE working group, for the continuous scientific support and advices. A special thank to the Accademia Italiana di Scienze Merceologiche (AISME) and the International Society of Commodity Science and Technology (IGWT) for hosting the meeting and for the organisational support. We are also grateful to Roberto Morabito, head of the technical unit Technical Unit for Environmental Technologies of ENEA, for his support, and to Diana Savelli and her staff of the Relations Central Unit - Communication Service for the publishing of the proceedings. Last but not least, a warm thank to Stig Irvin Olsen for his keynote speech, which will provide many insights among the audience, and to all participants for their contributions, without which this meeting would not have been possible.

We look forward to welcoming all the participants in Rome for starting this challenging discussion!

The organizers: DIRE Working Group, Italian Network on LCA, gruppodire@gmail.com

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POSTER PRESENTATIONS

Life cycle approach and ecoinnovation

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Keywords: Ecoinnovation, enterprises, life cycle approach

Introduction

A review of the LCT approaches within eco-innovation activities is presented in this poster. Increasing public awareness of environmental issues has forced industry and business to develop more ecological products and to acquire new tools to inform on the state of emissions and consume natural resources.

The *enriched LCT approach* [1], including environmental, cost/economic and social analysis, is becoming a significant alternative to the more traditional tools such as Environmental Impact Assessment (EIA), System of Economic and Environmental Accounting (SEEA), Environmental Auditing.

In this poster it will highlight the flexibility of the LCT approaches showing how it is used at firm level not only as an environmental impact assessment tool but also as a strategic support for developing new product. Life Cycle approach, in recent years, has become an embedded element of all company strategies based on innovation within the framework of sustainable development. Table 1 shows time evolution of the definition of ecoinnovation where "life cycle" idea is strongly present since year 2004.

Results and discussion

Life cycle is a central element in defining ecoinnovation both at theoretical level [2] and at policy level (EU, OECD). This cultural shift has been already perceived by leading international companies that are reorganizing their strategy and production towards more sustainable targets.

LCT is no more a mere, but key element, in the environmental assessment performed also at firm level, as showed here below by a recent survey of the Finnish Environmental Institute over 20 multinationals, but is becoming a management tool for strategic and production decision like in Unilever and Ford [3, 4].

In the consumer goods industry Unilever has developed a tool to assess the potential greenhouse gas benefit of an innovative option against the difficulty of its implementation. A simple greenhouse gas benefit assessment method based on streamlined LCA was used to analyze impact reduction potential, and a novel measure of implementation difficulty was developed. The predictions of implementation difficulty were compared against expert opinion, and showed similar results indicating the measure can be used sensibly to predict implementation difficulty

In the automotive sector, Ford of Europe introduced in its evaluating scoreboard a Product Sustainability Index (PSI) as a sustainability management tool directly used by Engineering department. As part of a series of sustainability management tools, a Product Sustainability Index (PSI) is translating the sustainability aspects to the organization of vehicle product development of Ford of Europe, thus allocating ownership and responsibility to that function. The PSI considers environmental, economic and social aspects based on externally reviewed life cycle environmental and cost aspects (Life Cycle Assessment, Cost of ownership / Life Cycle Costing).

Conclusions

This short article shows how LCA has become a central element in the conceptual definition of innovation with a special focus on eco-innovation and also how LCA is gaining consensus also at firm level where its applications are now actual and operative tools in eco-innovative product definition and production.

The analysis is based, as far as the "theoretical" aspects are concerned, on the review of current academic literatures and public institutions documentations regarding innovation policies; while the "marketing and production" issues of LCA are based on business cases from major multinational companies.

1996	1999	2000	2001
"Eco-innovation is the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact" (Fussler and James, 1996).	Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households) which develop new ideas, behaviour, products and processes, apply or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets (Klemmer et al., 1999).	"Eco-innovations are innovation processes toward sustainable development" Environmental innovations are "… measures of relevant actors (firms, …, private households), which: (i) develop new ideas, behaviour, products and processes, apply or introduce them, and (ii) contribute to a reduction of environmental burdens or to ecologically specified sustainability targets" (Rennings, 2000).	Environmental innovation is innovation that serves to prevent or reduce anthropogenic burdens on the environment, clean up damage already caused or diagnose and monitor environmental problems" (VINNOVA, 2001)
2002	**2003**	**2004**	**2005**
"[Eco-innovation is] Innovation which is able to attract green rents on the market" (Andersen, 2002).	Environmental innovations are new and modified processes, equipment, products, techniques and management systems that avoid or reduce harmful environmental impacts ([Kemp and Arundel, 1998] and [Rennings and Zwick, 2003]).	Technological environmental innovations (TEIs) may help to reduce the quantities of resources and sinks used, be they measured as specific environmental intensity per unit of output, or as average consumption per capita, or even in absolute volumes. Overriding priority, however, is given to improving the qualities and to changing the structures of the industrial metabolism. Rather than doing less of something, TEIs are designed to do it cleaner and better by implementing new structures rather than trying to increase eco-productivity of a suboptimal structure which has long been in place. TEIs are about using new and different technologies rather than using old technologies differently. TEIs can be characterised as being upstream rather than downstream, i.e., upstream in the manufacturing chain or product chain respectively, as well as upstream in the **life cycle** of a technology (Huber, 2004).	"Sustainability-driven" innovation is "the creation of new market space, products and services or processes driven by social, environmental or sustainability issues" (Little, 2005).
		Environmental technologies include all those whose use is less environmentally harmful than relevant alternatives (European Commission, 2004).	
2006	**2007**	**2008**	**2009**
"Eco-innovation is the creation of novel and competitively priced goods, processes, systems, services, and procedures designed to satisfy human needs and provide a better quality of life for all, with a **life-cycle** minimal use of natural resources (materials including energy, and surface area) per unit output, and a minimal release of toxic substances" (Europa INNOVA, 2006).	"Eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy" (European Commission, 2007).	"Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout **its life cycle**, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pearson, 2008).	Innovation is "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD, 2005). Eco-innovation is generally the same as other types of innovation but with two important distinctions: 1) Eco-innovation represents innovation that results in a reduction of environmental impact, whether such an effect is intended or not; 2) The scope of eco-innovation may go beyond the conventional organisational boundaries of the innovating organisation and involve broader social arrangements that trigger changes in existing socio-cultural norms and institutional structures; 3) The efforts to improve environmental performance have been shifting from "end-of-pipe" pollution control to a focus on product **life cycles** and integrated environmental strategies and management systems (OECD, 2009).
	"Sustainable innovation as a process where sustainability considerations (environmental, social, financial) are integrated into company systems from idea generation through to research and development (R&D) and commercialisation. This applies to products, services and technologies, as well as new business and organisation models" (Charter and Clark, 2007).	Eco-innovation is "the production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout **its lifecycle**, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)" (European Commission, 2008).	In a broad sense, environmental innovations can be defined as innovations that consist of new or modified processes, practices, systems and products which benefit the environment and so contribute to environmental sustainability (Oltra and Saint Jean, 2009).

Table 1. Time evolution of the definition of ecoinnovation

	Energy consumption	Climate change	Acidification	Europhication	Material depletion	Phochemical ozone formation	Ozone deple-tion	Waste problem	Eco-toxicity	Human toxicity	Water reserve impacts	Land use	Biodiversity
BASF	■	■	■	■	■	■	■	■	■	■	■	■	
Bombadier Transportation	■	■	■	■	■	■	■	■	■				
Continental	■	■	■	■	■								
Daimler	■	■	■	■	■	■							
Electrolux	■	■	■	■	■	■	■	■					
GE	■	■	■	■	■	■	■	■	■	■	■	■	
GlaxoSmithKline	■	■	■	■	■	■					■		
Interface	■	■	■	■	■	■	■	■			■		
KONE	■	■	■	■		■							
Nestle Waters	■	■	■	■	■	■	■	■	■	■	■	■	
Procter & Gamble	■	■	■	■		■	■	■	■	■	■		
Siemens	■	■	■	■	■	■							
Unilever	■	■	■	■	■	■		■	■		■		
Vattenfall	■	■	■	■	■	■	■	■	■		■	■	■
Vestas	■	■	■	■	■		■	■	■	■			
Xerox	■	■						■					

Table 2. Environmental impact categories taken into account by companies surveyed

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Eco-innovation of sand cores in aluminium gravity casting for the automotive supply-chain: an LCA-based analysis

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Keywords: Eco-innovation, Aluminium casting, Sand cores, Life Cycle Assessment

Introduction

This paper presents a preliminary environmental assessment carried out in the framework of a research project named “HI-REACH” [1], whose overall purpose is the eco-(re)design of components (and related processes) of the rear traction module of motorcycles. Specifically, the present analysis concerns solutions aimed at improving technical, economic and environmental performances of sand cores, auxiliary process components in the metal casting industry, used during the melting process to create cavities in the molten metal. Sand cores are usually made of virgin silica sand, bound with organic phenol resins (Fig. 1).

Due to the high complexity of final products, the automotive supply chains feature highly fragmented activities: subcontractors (usually SMEs) are specialised in specific process steps, whilst the end-product manufacturers focuses on the assembly [2]. Therefore, efforts towards eco-innovation are more often found in the technical subcontracting, also considering recent trends in the European legislations [3]. Sand cores may be environmentally critical for the depletion of non-renewable natural resources (sand) and the use of organic binders, which determine the release of noxious airborne emissions [4] during the casting process. Other issues are related to the disposal of spent sands, as well as the flue gas scrubbing.

Methods

The main objective of this analysis is to assess the environmental impacts of production, use and end of life (cradle to grave/cradle approach) of different improvement options concerning sand cores proposed in the HI-REACH project. The functional unit is the creation of a specific cavity in 1 item of aluminium component; the reference flow is 1 unit of sand core, for each option considered. Besides the traditional *solid core* technology (option 0), the improvement options arising from the eco-innovations proposed were: *hollow sand core* (option 1) presenting a cavity inside, resulting in an overall reduction of its mass of 46%; *resin-free sand core* (option 2), a conventional *solid core* where the phenolic resin is replaced by an inorganic binder (a mixture containing boron silicates and other chemicals).

The LCA study is based on ISO14040 series standard procedures and other technical gudelines [5-6]. The LCIA method used was ReCiPe 2008 [8]. Data are referred to the years 2010-2011 and are representative for the sites where the foreground processes takes place. System boundaries start from sand extraction and binder production and go through the final recovery of sand. The only process where allocation was needed is *Flue Gas Scrubbing.* The environmental burdens of the Scrubbing process where allocated among the various components manufactured in the same line, based on the mass of resin contained in the relevant sand cores, following a causality principle. Primary data for the disposal of *Wastewater* deriving from *Flue Gas Scrubbing* (phosphoric acid solution) were not available and suitable secondary data were not found in available databases (Ecoinvent 2009). Environmental credits for the avoided impacts due to the partial recovery of sand at the end-of-life step were considered.

Results and discussion

The two eco-innovations proposed for sand cores in the HI-REACH project have resulted in significant improvements of the environmental performances of the involved components (Fig.1b). In the case of *Option2*, such results become, in general, more evident; improvements mostly derive from: the absence of typical phenolic resin emissions (*Option2*); a significantly reduced time of staying in the heat treatment furnace due to a greater ease in removal of cores after their use (*Option2*); benefits in transportation, due to the significant weight reduction obtained in *Option1*. Another difference in results is related to the recyclability of sand: in the case of *Option1*, a variable percentage of spent sand can be directly recycled for the realization of new cores; at the current state of knowledge, this is not technically feasible for the *Option2*, whose sand can be recycled as filling material for road covering.

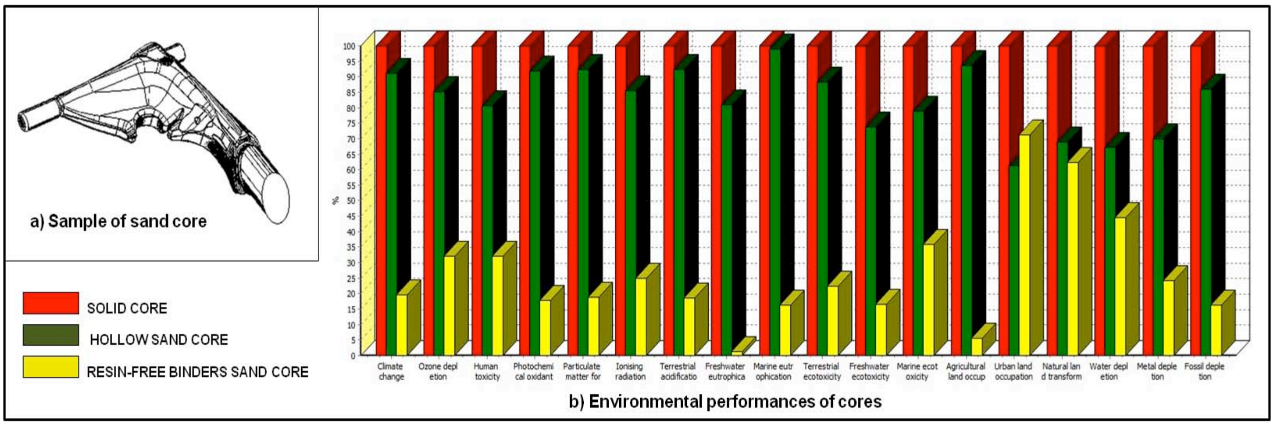

Fig.1. A sample of sand core (a) and the environmental performances of cores (b)

Conclusions

This paper presents a preliminary environmental assessment concerning solutions aimed at improving technical, economic and environmental performances of sand cores. All eco-innovations proposed resulted in improvements of the environmental performances. The innovative solution that entails no-resin binders proved to be the most promising in improving environmental performances of sand cores.

Among the limitations of the study (related to the lack of data) it should be noted that: i) the disposal of waste water resulting from scrubbing was excluded from the system boundaries, because of lack of reliable data; ii) it was assumed that the resin-free cores do not release, any type of airborne pollutant during casting, as the technical literature seems to confirm [9] (the absence of typical emissions of organic (phenol-based) binders was, however, experimentally measured). Further investigations on these issues would be desirable in future studies. Beside the environmental assessment, it should be noted that some of the innovative solutions analysed in this work also present differences in their technical, production and economic aspects, which should be considered with the aim of maximising the quality of final products and the competitiveness of the company

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Life Cycle Analysis of dye sensitized solar cell technology

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Keywords: Dye sensitized solar cell, Life cycle assessment, Photovoltaic, Sustainability

Introduction

Energy lies at the heart of any nation's technological, economic and social development. In recent years, energy demand has grown constantly and is bound to further increase. In this context, the interest of the scientific community is progressively moving towards renewable energy sources, with a particular focus on developing the technologies necessary for their exploitation, and towards sustainable growth. The search for alternative energy sources, able to combine efficiency, ease of use and reduced environmental impact is therefore, together with energy saving, an important challenge for our civilization. Among the various renewable energy sources available on our planet, solar energy is particularly attractive. One of the technologies available to generate electric power from solar energy is photovoltaics. With the aim of achieving a larger distribution, research turned itself to the development of new photovoltaic technologies based on alternative materials, such as organic compounds. To this category belong the solar cells known as dye sensitized solar cells (DSSCs, Figure 1), also known as Grätzel-type cells [1]. Such cells have attracted much interest, especially in the last decade, because of their potentially low cost of production. Thanks to the employment of readily available materials, produced by well-established processes, they actually present drastically lower economic and environmental costs compared with traditional silicon-based cells even though they are not efficient enough yet to be industrially competitive. Compared with the highest efficiencies recorded for thin film cells, which approach 20% on a laboratory scale and 11% on a device scale, DSSC currently give efficiencies of 12% on a laboratory scale and 5-6% on a larger scale. Factors limiting the efficiency of the cells are mostly related to the materials employed but also to the way in which these materials interact within the cell structure. The challenge is to find the right set of materials to obtain dye sensitized solar cells of improved performances. Progress in this field requires major investments in terms of research and development aimed at the optimization of all parameters. The extremely high manufacturing throughput potential of hybrid and organic solar cells could have a positive impact in the markets and therefore is attracting many investors. The European Photovoltaic Technology Platform, supported by the Seventh European Framework Programme for Research and Technological Development, has included the hybrid and organic photovoltaic technologies on its roadmap. This indicates that these PV technologies are on the verge of commercialization and are already producing a rapidly developing global manufacturing base.

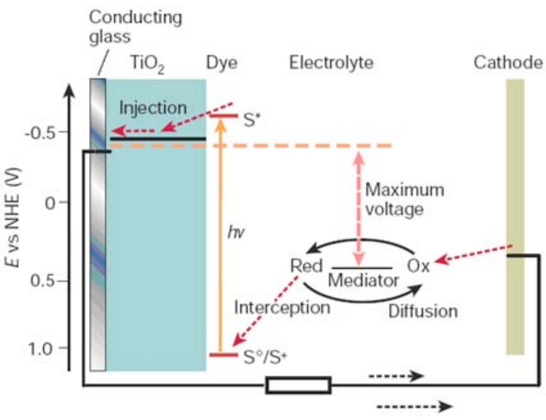

Fig. 1. DSSC functioning (source: http://www.chem.monash.edu.au/staff/bach/research.html)

Results and discussion

The development of new and emerging technologies requires an overall evaluation of the product's environmental impacts and benefits and LCA is one of the most powerful methods for sustainability assessment. In this study we present the results of LCA for DSSC production. This analysis will be pivotal in understanding the environmental dynamics, the benefits and drawbacks associated with DSSC technology that has the potential to become a strong contributor toward the solar energy conversion market with respect to other photovoltaic technologies. In order to carry out the comparative study among various thin film photovoltaic and DSSC technologies, we analyzed the life cycle of a virtual roof-top integrated photovoltaic system. The irradiation level used for the calculation of the total energy produced by the PV system during its operational time was set to 1700 kWh/m^2/year and a 20 years lifetime was taken into account. PV system losses due to the so-called balance of system components and other indirect losses were assumed at 25%. Two impact assessment methods were used to assess the potential impacts of the environmental flows collected in the inventory stage. The GHG emissions were evaluated with the Intergovernmental Panel on Climate Change (IPCC) 2007 data for a timeframe of 100 years, while the Cumulative Energy Demand (CED) was calculated by the method described in Ecoinvent v 2.2 by summing all fossil, nuclear, hydro and renewable energy demand into one single CED value. In order to compare results from this study with those published previously in literature [2-5], we simulated an up-scaling scenario for pre-industrial production of DSSC modules at large scale [6]. The following significant indicators per kWh generated were considered: the net energy ratio (NER) that is the life cycle energy output over its life cycle energy input, which stipulate the renewable energy obtained from each energy input source (most likely to be from fossil fuels); the green house gas (GHG) emissions, that is the calculation of the total emitted GHGs during a system's life cycle divided by the electricity generated over the lifetime; the EPBT, that determines the amount of years needed so that the system compensates for the energy during production.

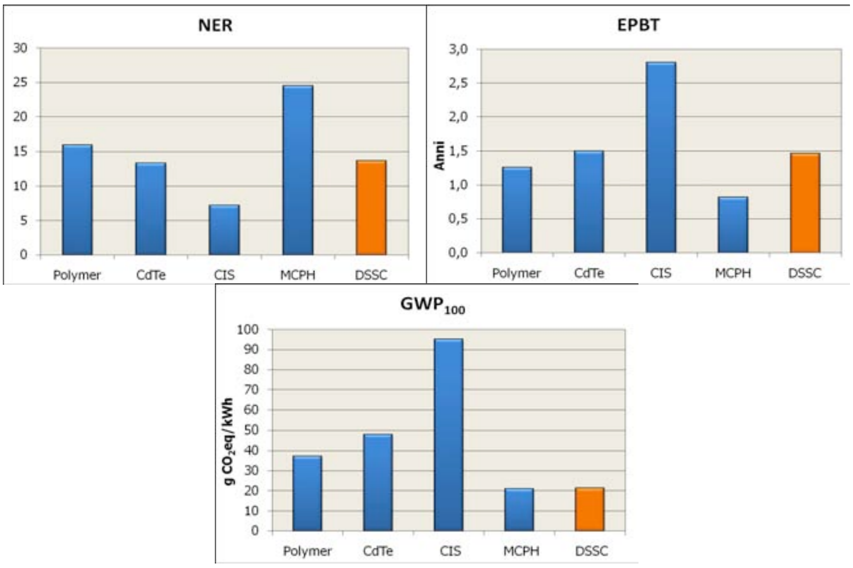

Fig. 2. Comparison among selected indicators for several PV technologies

Results obtained from the analysis show that the DSSC technology performs well compared to other thin film organic and consolidated inorganic PV technologies, even for a far from optimum laboratory fabrication procedure. The energy advantages and environmental benefits of DSSC devices manufacturing (low-temperature fabrication steps, deposition routes compatible with heat-sensitive substrates) are supported and pointed out by the LCA study. Though not as efficient or long-lived as solid-state PV devices, DSSCs can achieve a much better performance in terms of cost per energy produced during their lifetime than any other inorganic technology, provided that the efficiency of these industrial modules is similar to that of actual laboratory cells. In particular, the results showed in this study support the estimation that DSSC technology might be really competitive especially if applications for architectural integration in eco-sustainable buildings and the exploitation of diffuse light for electric power generation are taken into account.

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Efficiency of today's individual passenger transport with respect to its applicability in urban areas. Comparative assessment of the performance of a light weight electric vehicle and conventional vehicle in urban driving

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Introduction

The great importance of the transport sector and its continuously growing environmental implications, such as global warming, local air and noise pollution and fossil fuel depletion requires rethinking of the concept of transport and mobility. In this regard it is crucial to be able to identify paths towards a more sustainable transport system. This includes great changes in the technological area as well as behavioral aspects of the consumer. In order to reduce CO_2 emissions and the dependency on fossil fuels new propulsion and energy storage systems have to be investigated, such as electric drive trains with electrochemical storage units. Along with these changes also the shape and design of the entire vehicle should be reconsidered in order to match the actual mobility needs as it was found that these strongly deviate from the vehicle's properties. Therefore, in this work the performance of different vehicles was compared, addressing problems of urban areas with respect to individual vehicular transport (IVT) as well as actual demands on mobility in terms of vehicle properties.

Methodology of the assessment

Two types of vehicles were compared in the analysis: (1) electric light weight vehicle – SAM EV II (http://friends-of-sam.com) and (2) a conventional most frequently used vehicle – Golf IV. The different vehicle properties can be seen in table 1. The tool chosen for the assessment was a benefit analysis, which may be used for assessments of alternatives that are in fact difficult to compare, due to lack of data, non-measurable parameters and a mixture of quantitative, semi-quantitative and qualitative data [1]. In addition a comparative LCA of both vehicles was conducted, but the results cannot be displayed due to confidentiality issues.

Property	ICEV – VW Golf IV	SAM EV II
Curb Weight	1360 kg	500 kg
Propulsion System	Internal Combustion Engine	Permanent Magnet Motor
Energy Storage	Petrol EU1-4, Diesel EU 1-3	Li-Polymer Battery
Driving Range	660-800 km	80-90 km
Max. Speed	approx. 180 km/h	90 km/h
Space availability - passengers	5	2
Space availability - goods	330 L	-
Outer dimensions	L: 4.2 m - W:1.8 m	L: 3.1 m - W:1.6 m
Noise	63-74 dB(A)	< 45.2dB(A)

Table 1. Properties of the studied vehicles. Data of the ICEV vehicle is partially taken from [2], data for the electric vehicle is mostly based on first hand data of the manufacturer

The analysis was performed following from the main target of applicability of the respective vehicle in the urban area. Based on this two sub-targets were defined, namely the fulfillment of the users mobility needs and minimizing the environmental implications. From these a set of target criteria was defined: for the fulfillment of user mobility needs the following target criteria were defined: space availability for passengers, space availability for goods, driving range and refueling (i.e. abundance of refueling stations and level of difficulty for refueling). For the assessment of the environmental implications noise emission, direct air pollution, size of the vehicle (i.e. outer dimensions) as well as consequences of curb weight (such as increased stress on road or increased fuel consumption) were included.

The degree of importance of the different target criteria varies, as e.g. the direct emissions to air may have a greater impact on the overall performance of the vehicle than space availability inside the vehicle. In order to account for this fact additional weighting factors were introduced ranging from very important to important and less important. For the evaluation a quantitative scale was introduced ranging from very good to very poor with an additional category representing an overachievement of a target criterion. The comparison was done based on statistical data, i.e. average values were taken from statistics and literature with respect to the different target criteria. The scores within each target criterion were then applied according to how well the vehicle fulfills the target value.

Results and discussion

In case of the driving distance it was found that in urban areas the average distance covered per day with a vehicle amounts to 17.4 km. Since the conventional vehicle can drive 660-800 km on a full tank, it is regarded as overachievement. From the purposes of travels one may deduct the needed availability of space in a vehicle. Shopping and commuting each comprise about one third of all destinations [3]. Only 3.5% reported to be commuting as passengers [3]. Unfortunately no similar statistical data can be found for shopping purposes, however in general the load factor a vehicle was found to be 1.2 persons. Therefore, the average space needed for passengers is very low from a statistical perspective, which can be easily managed by the light weight EV and is overachieved by factor of 4 by the midsized car. The same holds true for space availability for goods.

Although specific air emissions of vehicles have been substantially reduced for PM, NO_x, VOC and SO_2 [4], there are counteracting factors such as increased transport services or large scale shifting towards diesel fueled vehicles which e.g. emit much more PM [4]. Therefore, absolute emissions to air are still on a high level particularly in dense urban areas. Based on the emissions expelled by the conventional vehicle as compared to the electric light weight vehicle, the Golf has a bad performance in this target criterion, as opposed to the EV with zero local emissions.

In 1999 roughly 16% of the German population were found to be exposed to levels above 65 dB(A) during day time [5]. Exposure to continuous noise levels above 65 dB(A) may cause health effects. As noise emission from vehicular traffic was found to be increasing, the percentage of affected people may have further increased [6]. Since the electric vehicle emits practically no noise, it is regarded as overachieved because pedestrians have grown accustomed to orienting themselves by hearing, thus no noise emissions may increase the risk of accidents.

Conclusions

Despite the qualitative character of the analysis it was found that the conventional most frequently used midsized vehicle overachieves some of the set target criteria, such as the driving range and the space availability for goods as well as passengers. This means that in order to satisfy the mobility needs with respect to these three target criteria a lower performance would have been enough. However, due to the overachievement, which is for instance in case of space availability directly related to size and mass of the vehicle causing greater consumption and thus environmental burdens during the use phase.

Based on the findings and the evaluation of the benefit analysis it was found that IVT may be more efficient if the vehicles' properties better matched the actual mobility needs along with technical changes of the propulsion system.

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Environmental sustainability assessment of a short wood supply chain

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Introduction

Forest-based products and related industries make up one of the most important sectors in European Union, representing about 10% of the total manufacturing industries. Nowadays, the forest-wood supply chain is a complex system and groups several different areas, such as pulp and paper, paper and board, graphic industry woodworking and furniture [1]. The sector represents an asset for the so-called "Bioeconomy" and requires the development of specific evaluation framework for assuring system's sustainability, from raw material extraction to product's end of life.

Concerning the raw material exploitation, several studies have been carried out highlighting that in most cases the greatest environmental burdens are induced by fuel consumption of machineries in relation to forest operations [2, 3, 4, 5, 6, 7, 8]. In some cases, as in [8], the extraction operations and transports are responsible for 85% of the total environmental impacts of a wood-timber supply chain. Notably, the forest operations are a crucial step in wood-based product life cycle and life cycle-based approach to the sustainability assessment seems appropriate. Nonetheless, Cambria and Pierangeli [9], that examined the production of high quality timber deriving from walnut tree plantation. Werner and Nebel [10] stated that it is hardly possible to depict impacts due to extraction in relation to sustainable forestry in LCA and hitherto it is not possible compare certified sustainable forest management to any other way of forest management.

Accounting for these shortcomings, we carried out a case study in Lombardy region (Italy) for a short wood supply chain in order to highlight potential improvement in the assessment. Lombardy forest area to 31 December 2010 is estimated at 620,122 hectares, with an increase of 1,079 ha compared to the estimate of the previous year. Despite this increase of biomass available, just 234 ha were extracted in 2010 [11] and only one-third of the timber used in Lombardy is produced regionally, while two-thirds mostly come from Eastern Europe, due to its competitive prices and good quality. This leads not only to an underutilization of the wood resource and to a progressive abandon of forestry activities, but also to a considerable amount of wood potentially available. Hence, Lombardy has a great potential that is not properly capitalized.

The present study was developed in the context of an interdisciplinary project called BOMO (*BOsco-MObile*, Forest-Furniture) aimed at studying the economic potential and viability of the use of wood located in the region of Lombardy and to explore the improvements provided by a short-supply chain scheme. The project studied a pilot supply chain using the wood from Intelvi valley forests (Italian Alps). The aims of the study are: i) to evaluate the environmental and energetic burdens associated to wood extraction in Intelvi valley, ii) to compare two different possibilities of extraction (by winch and cable-logging) and iii) to evaluate the environmental impacts induced by the introduction of a new advanced mechanization (with harvester and forwarder), compared to a traditional one, in order to identify the best mechanization method for the site. An additional comparison is about the realization of delimbing phase before or after extraction phase. The evaluation is conducted from an LCA perspective and the study covers the whole life cycle of timber extraction and transport to sawmill.

The objective is to provide decision-makers (producers and policymakers) a system structure to operate in the most favorable way from the environmental point of view, identifying key parameters to help producers within supply chain. Data used in this study were collected with the support of the project partners.

Methods

System boundaries, function and functional unit

The function of the system under study is the extraction of timber and its transport to sawmill. The functional unit is defined as 1 ton of timber and represents the reference point for inputs and outputs [12]. Three different species of trees are extracted in Intelvi valley forest, namely maple, beech and ash. Hence it was necessary to refer all data and calculations to them. All input data about timber referred to the volume (m^3) of wood extracted, therefore, it was necessary transform these data according to our functional unit. The average volumic mass for the three species is 1000 kg/m^3. It was also calculated that it is necessary to cut 1.39 tons of wood to obtain 1 ton of usable timber [13].

The system under study includes forestry activities (cutting, delimbing and extraction) performed with different levels of mechanization. Fig. 1 summarizes the organization of forest sites and the phases analyzed in this study. Traditional mechanization (first option) includes six different phases: (1) felling; (2) extraction (by winch or cable-logging); (3) delimbing; (4) stacking; (5) loading; (6) transport to sawmill. Advanced mechanization (second option) considers the use of heavy vehicles, as harvester and forwarder; this kind of mechanization allows combining multiple operations, reducing the number of processes considered. Therefore, it includes only three phases are identified: (1) felling and delimbing; (2) extraction; (3) transport to sawmill. Fig. 2 focuses on the different options investigated for traditional mechanization, dividing the traditional mechanization option in four different scenarios.

Machines use was taken into account calculating the fossil fuels needed to perform every operation and the emissions produced, while machines production was excluded. The production of capital goods (machineries, buildings and roads) and transport of energy carriers were not included within system boundaries, since their production were found negligible (long life time and high number of operations performed) compared to their operation stage [14, 15].

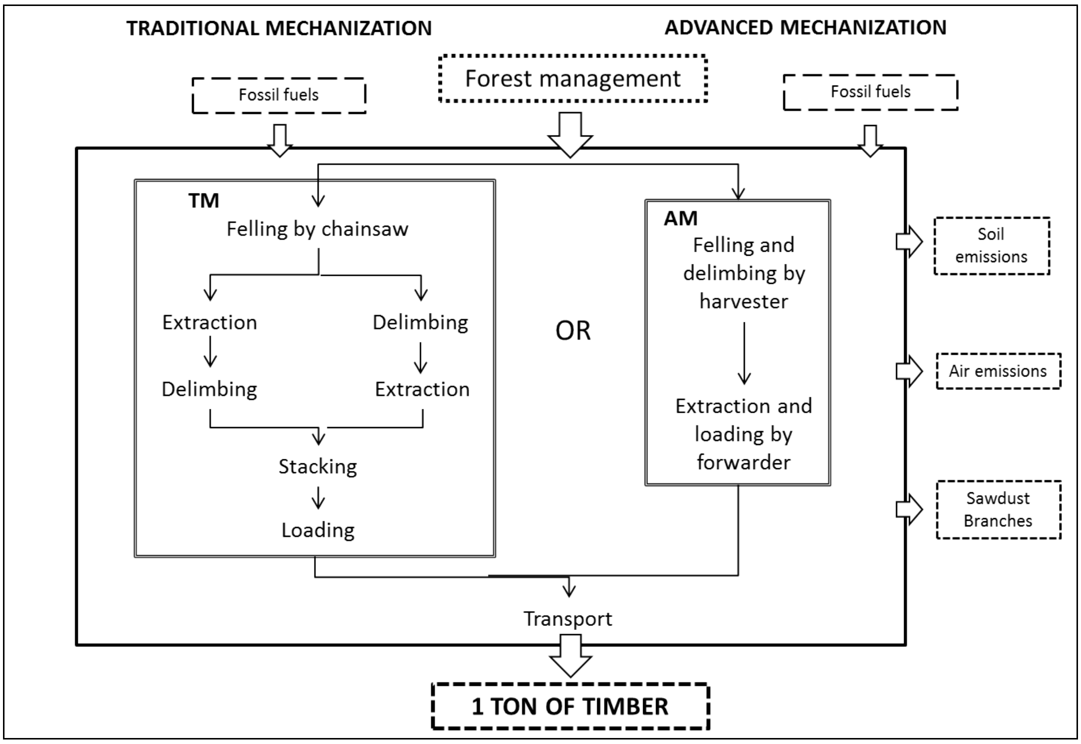

Fig. 1. System boundaries under study for traditional and advanced mechanization.TM stands for traditional mechanization, AM for advanced mechanization

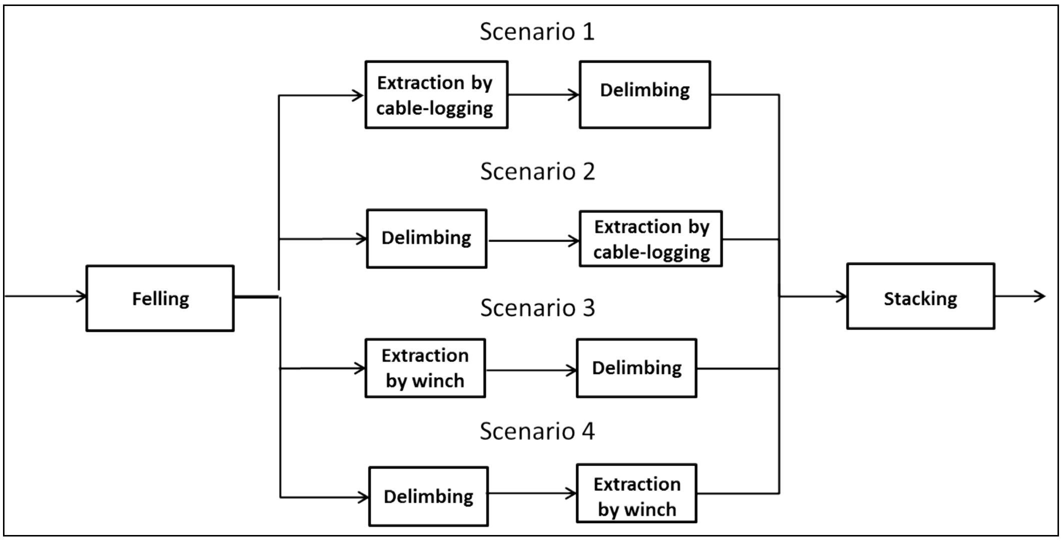

Fig. 2. Focus of 4 different scenarios for extraction and delimbing in traditional mechanization

Inventory data and quality

The different scenarios showed in Fig. 2 are evaluated and compared in order to identify which have the lowest potential environmental impacts and to support the decision making for what concerns traditional mechanization. Data provided for each phase are: (1) machinery used (number and type of equipment); (2) fuels and oil average daily consumption; (3) average daily productivity of timber.

Advanced mechanization scenario implies the use of more modern and technological means, harvester and forwarder. It is important to remark that Intelvi valley morphology did not allow maximizing the productivity of harvester and forwarder that is about 40 m^3/h of timber. This issue and further considerations are tackled in sensitivity analysis. For the two mechanization options, every step was modeled using primary data and information collected from project partners, because forestry operations were not available on Ecoinvent database.

According to the ISO 14040 series [12] the LCI can be compiled from primary, secondary and estimated data. In this study a mix of primary and secondary data were used. Primary data are obtained by on-site measurements and were collected through interviews, informal conversations and visits to local forestry sites. They regard on-site measurements of forestry operations phases in Intelvi valley area. These data refer to the amount of wood extracted, as well as machineries used and their fuel consumption. Other inventory data about operations themselves were obtained from Ecoinvent database, incorporated in SimaPro version 7.2. Inventory data for emissions in the use phase of machineries were drawn from “Non road emission database” by Swiss FOEN [16]. This report quantifies non-road pollutant emissions and fuel consumption in Switzerland. The database provides specific data on hours of operation (hours per machine, according to its year of construction) and the emission factors (kg/hour) of non-road machineries and appliances.

Inventory data regarding the different operational modes and phases are summarized in Table 1 (traditional mechanization) and Table 2 (advanced mechanization), while Table 3 and Table 4 show input inventory data for each operations phase.

Operation	Cable logging, pre-delimbing	Cable logging, post-delimbing	Winch, pre-delimbing	Winch, post-delimbing
Felling	0,107	0,107	0,107	0,107
Extraction	0,035	0,009	0,059	0,0188
Delimbing	0,083	0,083	0,083	0,083
Stacking	0,078	0,078	0,078	0,078
Loading	0,019	0,019	0,019	0,019
Transport	0,098	0,098	0,098	0,098

Table 1. Traditional mechanization inventory data for the four different operational modes. Data expressed as hours for 1 ton of timber extracted

Operation	Amount	Unit
Felling and delimbing	0,072	hr
Extraction and loading	0,071	hr
Transport	0,098	hr

Table 2. Advanced mechanization inventory data, expressed as hours for 1 ton of timber extracted

Operation	Diesel	Oil	Lubricating oil	HC	CO	Nox	CO_2	PM
Felling	-	2.35	1.35	0.911	2.086	0.006	7.126	-
Extraction	4,95[4]	-	-	0.021[1]	0.1217[1]	0.2169[1]	17.351 [1]	0.013 [1]
	5,36[5]	-	-	0.018[2]	0.0922[2]	0.1295[2]	11.171 [2]	0.014[2]
Delimbing	-	2.35	1.35	0.911	2.0864	0.0063	7.1262	-
Stacking	13,2	-	-	0.050	0.2880	0.5185	32.033	0.031
Loading	6,6	-	-	0.028	0.1137	0.1606	12.734	0.017
Transport	6,6	-	-	0.028	0.1137	0.1606	12.734	0.017

Table 3. Traditional mechanization inventory data about fuel consumption and air emissions, expressed as kg per hour of work

Operation	*Diesel*	*HC*	*CO*	*NOx*	*CO_2*	*PM*
Felling and delimbing	10.2	0.0545	0.3157	0.6353	50.7378	0.0346
Extraction and loading	9.35	0.0410	0.2195	0.3950	32.0325	0.0262
Transport	9.35	0.0410	0.2195	0.3950	32.0325	0.0262

Table 4. Advanced mechanization input data of fossil fuel consumption and air emissions, expressed as kg per hour of work

Results and discussion

Considering all steps defined by the impact assessment stage in the LCA methodology [17], classification, characterization and normalization stages were included. Even if normalization is reported as optional, it was decided to include it in this analysis, in order to collect additional useful information. The LCA was carried out according to the Recipe method, hierarchic approach, [18] to quantify the potential environmental impacts. The software SimaPro 7.2 was used for impact assessment. The impact categories considered in this study are: climate change (GW), ozone depletion (OD), human toxicity (HT), photochemical oxidant formation (POF), particulate matter formation (PMF), terrestrial acidification (TA), freshwater eutrophication (FEP), marine eutrophication (MEP), terrestrial ecotoxicity (TE), freshwater ecotoxicity (FE), marine ecotoxicity (ME), fossil depletion (FD). Other categories, namely ionizing radiation (IR), agriculture and urban land occupation (ALO e ULO), natural land transformation (NLT), water and metal depletion (WD and MD).showed output values equal to zero, therefore they were excluded. It is remarkable, that renewable resources are not taken into account by Recipe and further sensitivity analysis with methods accounting for renewable may be beneficial to evaluate potential impact on local carrying capacity.

The comparison of results of the five operation modalities for the characterization step is shown in Fig. 3. The options that show the greater environmental burdens are: i) traditional mechanization by winch extraction before delimbing and ii) advanced mechanization. The option i) presents highest contributions to the following categories: ozone depletion, human toxicity, freshwater eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and fossil depletion. Advanced mechanization, ii), presents major burden for the following categories: climate change, photochemical oxidant formation, particulate matter formation, terrestrial acidification e marine eutrophication.

[4] Cable-logging.

[5] Winch.

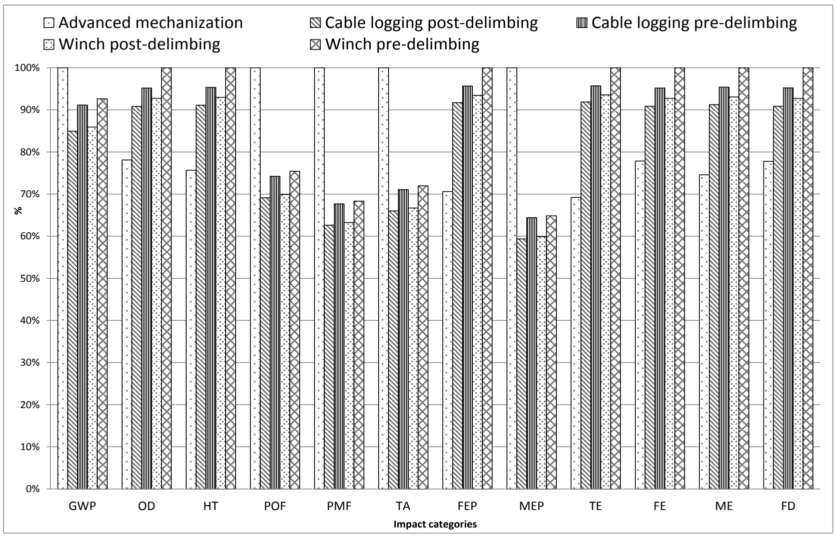

Fig. 3. Results for characterization phase, comparison of the five operation scenarios (in %) (four scenarios related to traditional mechanization and one scenario of advanced mechanization)

At the same time, it is the most favorable choice for the other categories. The activities that mostly affect the overall impacts are: (1) the consumption of fossil fuel for the machinery use [19] confirmed also by previous studies in the same field [4, 8, 20]; (2) use of harvester and related diesel requirement and emissions for advanced mechanization; (3) stacking phase for traditional mechanization and related fuel consumption and emissions.

Due to controversial results found about advanced mechanization, it was decided to perform also the normalization phase, in order to assess which phases have the higher relative contributions to overall impacts. Fig. 4 shows the ReCipe 2008 midpoint category results per functional unit, normalized to the average consumption habits for Europe. Normalized results show that the incidence of advanced mechanization is particularly significant. Therefore the hypothesis of choosing traditional mechanization (cable-logging after delimbing modality) seems the preferable way for Intelvi valley conditions.

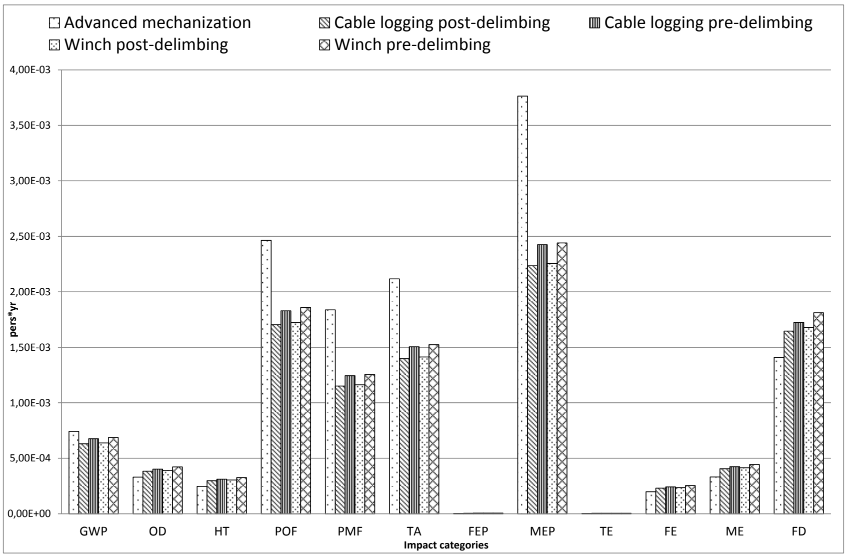

Fig. 4. Results for normalization phase, comparison of the five operation scenarios (in %)

LCA allows to compare different kinds of forestry operations and lets to identify which is the most suitable method to be used for the area investigated. In this case study five different ways were considered and compared, collecting primary data of the area and modeling the operations conditions in detail. The best operation modality is the traditional mechanization with the use of cable-logging before delimbing. In fact, according to Fig. 3 and 4, two processes are significantly critics for the system under study: advanced mechanization and traditional mechanization with extraction operations performed by winch before delimbing.

The results were expected. Indeed, extraction before delimbing does not allow to make full use of potential capacity of the machines (either cable, and winch), since the pulling force is not completely exploited. This extends the time necessary to perform the operations and therefore a major amount of fuel is used.

Furthermore, considering that winch is the slowest machine to be employed, make this option the less favorable to choose. Concerning advanced mechanization, usually the high fuel consumption and related emissions are offset by the high productivity capacity thereof, which makes these operational modes a favorable way to perform forestry operations. However, the morphology of this area does not allow the proper exploitation of the machines and lengthens the time required. The emissions of pollutants are consequently increased and make advanced mechanization unsuitable in these conditions. Finally, traditional mechanization with cable logging before delimbing looks the solution with lower environmental impacts, but with an appropriate control of engine emissions and coming into force of stricter regulations, advanced mechanization could become the preferable way to choose. To test this thesis, a sensitivity analysis was performed taking into account the highest productivity offered by harvesters and forwarder (about 40 m^3/h of timber extracted) and comparing the results obtained with traditional mechanization. The functional unit is always 1 ton of timber. Results (Fig. 5) show that in these conditions, advanced mechanization offer a better choice from the environmental point of view.

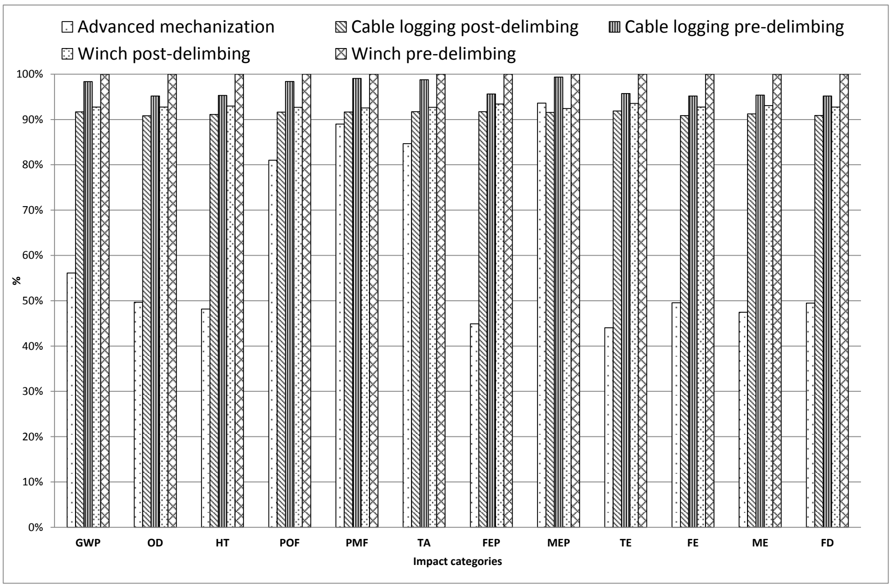

Fig. 5. Results for characterization phase, assuming advanced mechanization at top productivity (in %)

If exploiting the maximum productivity of harvesters and forwarders is not possible (as in Intelvi valley case), the choice of machines equipped with diesel particulate filters (DPF) or selective catalytic reduction (SCR) systems could be a viable option to reduce particulate matter and nitrogen oxides emissions. Hence, a further sensitivity analysis was performed assuming Intelvi valley data and conditions and the use of machines furnished with SCR and DPF technology. Based on European laws [21, 22], a precautionary efficiency removal of 95% for DPF and 90% SCR is assumed.

Comparison results of the three different scenarios involving advanced mechanization (baseline, top productivity and SCR-DPF scenario) are shown in Fig. 6.

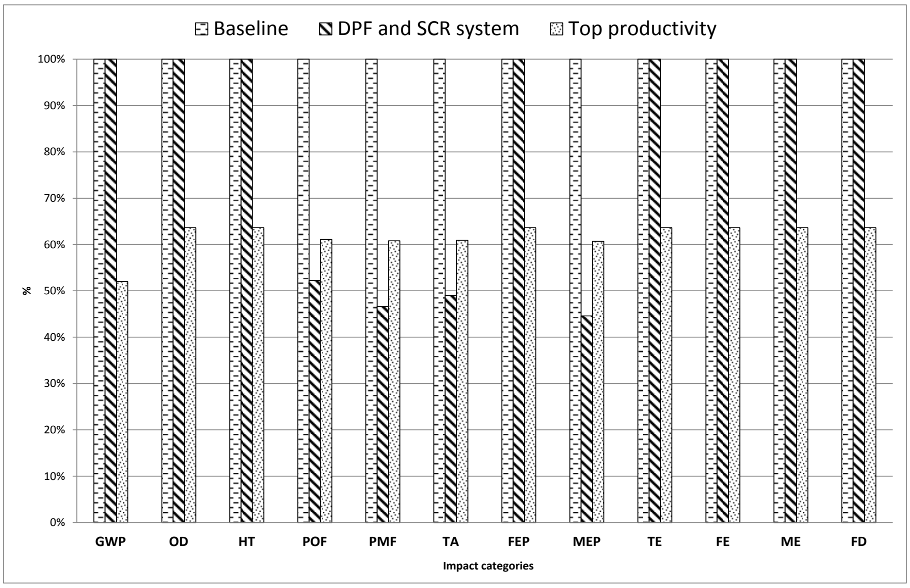

Fig. 6. Comparison of three different advanced mechanization systems: baseline, with DPF and SCR technologies and top productivity

For POF, PMF, TA and MEP reductions for DPF and SCR system compared to baseline range from 48% to 55%, solving criticisms highlighted in previous results. Anyway, the use of forwarders and harvesters at top productivity always looks the preferable way. A third sensitivity analysis was performed to highlight the environmental burdens occurred by long-distance transports in case of foreign timber import. Two different kind of timber were compared: timber from Intelvi valley and standard timber coming from East Europe (ERSAF, 2011), suggested by experts as the major exporter in Europe of timber. Intelvi valley timber gives for every category considered better results, showing that the use of timber coming from local supply chain decreases the environmental burden with respect to the standard timber from foreign regions. There are improvements in each impact category. The lowest reduction occurs in relation to Ozone depletion (55%), while in other categories there is a reduction of environmental impacts ranging from 85% to 99%. The higher impacts for standard timber are caused by transport, as a result of the long distances that have to be covered for its supplying. Comparing only the forestry activities for the two types of timber, transport not included, there is no predominance of one of the two on the other.

Conclusions

This study focused on the evaluation of two different methods to perform forestry operations in Intelvi valley (Lombardy Region, Northern Italy): advanced mechanization and traditional mechanization. For the latter four options and instruments were also taken into account. Aim of the evaluation was to identify the most suitable and sustainable technology for the local context (forest areas in Intelvi valley as a proxy for Lombardy forests).

From the inventory analysis and impact assessment results, hot spots and environmental burdens were identified and assessed. Fuel consumption and related emissions were proved to be main source of impacts, hence, it is very important to privilege the operational mode able to minimize the hours necessary to perform every operation. It was also demonstrated that environmental sustainability assessment may results in different ranking of options, if local condition are taken into account. Thus, every kind of technology should be chosen according to the morphology and peculiarities of the area investigated, and none method is eligible as the best suitable for every conditions. For instance, traditional mechanization with cable-logging after delimbing, seems the best option for Intelvi valley case, whereas it was proved trough sensitivity analyses that advanced mechanization at top productivity or equipped with SCR and DPF could be the best solutions in other cases. The reason stands in its high productivity that let to perform several operations in little time. Finally the comparison between Intelvi valley timber and standard timber coming from East Europe stressed the great influence of transports as responsible of great environmental burdens.

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Development and in-field testing of a sustainability assessment method for durum wheat cultivation

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Keywords: Sustainable agriculture, Durum Wheat, LCA

Introduction

Barilla has promoted specific studies to analyse and compare different cropping systems for the cultivation of durum wheat, since it has been demonstrated that the agricultural phase is the one that most contributes to the environmental impact of the production of pasta. The aim of the project is to create a method to analyse and improve the sustainability of durum wheat production.

Methods

Several typical Italian four-year crop rotations including durum wheat have been investigated as well as agricultural practices, such as tillage and the use of fertilizers, commonly adopted. Agronomic and economic studies were integrated in the calculation with life cycle assessment methodology of carbon, water and ecological footprints. An integrated sustainability indicator was thus created and tested in several farms representing the cultivation of durum wheat in different areas of Italy.

Results and discussion

Text The study demonstrated that in many cases farmers could significantly reduce carbon emissions (up to 320 kg of CO_2-eq per ton of durum wheat) and other environmental impacts related to the cultivation without compromising, often even increasing, net incomes and product quality. To achieve this purpose it's necessary for them to choose crop rotations adequate to the region and to its pedoclimatic characteristics, to consider the possibility of minimum and no-tillage in absence of DON risk, to use fertilizers in relation to the needs of rotation, to be timely in the weeds and pests management.

Conclusions

The conducted analysis led to create a method to compare the sustainability of different crop rotations and agricultural practices. The qualitative results were taken into consideration for the preparation of a Handbook with guidelines for the farmers to improve sustainability of durum wheat production. These indications will be further tested through more extensive in-field experimentations. The project is being extended to other countries and to soft wheat and rye production.

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Is healthy eating healthy for the environment? The BCFN Double Food Pyramid

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Keywords: nutrition, ecological footprint, carbon footprint, water footprint

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Introduction

It is generally known that proper nutrition is an essential condition to health. This is a natural law that; however, has not received due attention in the last few decades. Indeed, the growing impact of disorders related to overeating serves as testimony of this last observation. Common disorders are: obesity, diabetes and cardiovascular pathologies – in people of all ages, including the younger portion of the population.

Aimed at commencing nutritional education, at the start of the 1990s the US Department of Agriculture elaborated and disseminated the first “food pyramid”, based on the scientific studies of Ancel Keys. This structure provided a synthetic and efficient explanation on how to adopt balanced nutrition, serving as a general guideline. Since then, there has been an enormous increase related to confirmation of disease prevention through proper nutrition. Despite this, public awareness seems to lag well behind.

This is the first reason that leads the Barilla Center for Food & Nutrition (BCFN) to the re-proposal of the food pyramid, 20 years after its conception, which has gained ample recognition and foothold in the scientific and nutritional world. This elaboration of the food pyramid put forth by BCFN has been updated to carefully integrate the latest findings by research. The second reason involves global warming and, more in general, the impact of man’s activities on the environment.

Methods

It has been demonstrated that agriculture and animal farming are among the sources that yield the greatest amounts of greenhouse gasses (beating out transportation). Therefore, as is explicitly emphasized and suggested by the paper “Climate Smart Food” – drafted in November 2009 by SIK – the Swedish Institute for Food and Biotechnology as charged by the current mandate of the Presidency of the European Union, held by Sweden – environmental variables must also be taken into account in regards to food and nutritional diet selection. Thereby, analysis of the food pyramid and its categories reveals a wide array of values concerning the environmental impact of each category in terms of Ecological Footprint.

There is a reclassification of food that goes beyond their positive impact on health, encompassing their impact on the environment, as well. These values are overlapped in descending order to obtain an upside-down pyramid that, in good measure, re-proposes the same succession of foods. Such elaboration is called “Double Pyramid”.

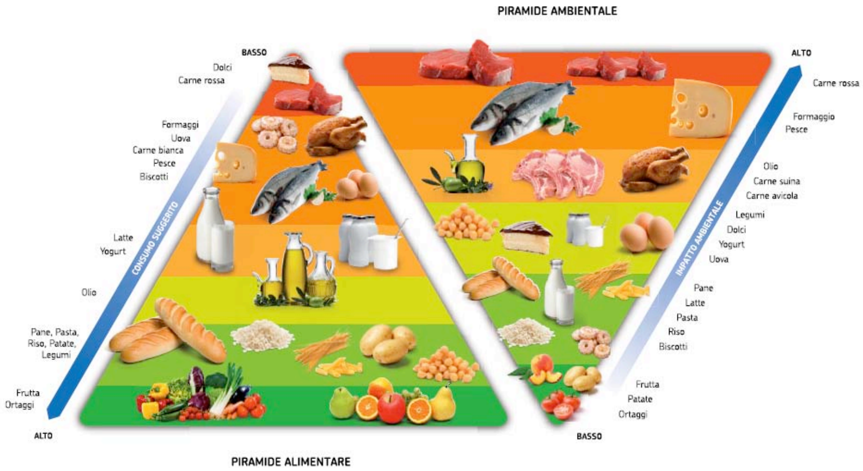

Fig. 1. The Double Nutritional and Environmental Pyramid, (Barilla Center for Food and Nutrition, 2011)

Results and discussion

Use of the Life Cycle Assessment method places all environmental markers on the same level for the duration of the analysis: in this work, carbon, water and ecological footprint have been studied as key performance indicators of food production chains. However, once results have been obtained, a need for both communicational conciseness and clarity imposes a simple method that accounts for all outcomes. This is why the ecological footprint served as base indicator in the construction of the double pyramid. All motivations shall be illustrated in the main paper; but it can be briefly stated that these essentially depend on the ability to easily convey the environmental impacts linked to food chains.

Fig. 2. The LCA analysis is regulated by the international standards ISO 14040

Conclusions

The evidence of true interest that emerges from this new elaboration is the coincidence, in a single food model, of two different objectives that share fundamental importance for man: health and environmental protection. In other words, it has been demonstrated that following a diet put forward by the traditional food-nutrition pyramid not only leads to an improvement in quality of life (longer life-span and enhanced health conditions), but also yields a decisively lower impact, better expressed as Ecological Footprint, on the environment. Indeed, food that should be consumed in greater quantities, for example following the Mediterranean diet, fits into the category that inflicts less environmental impact overall. Vice-versa, foods falling into a recommendation of limited quantity consumption have also the higher impact on the environment.

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The primary importance of more precise and locally available data for the evaluation of net GHG emissions of N_2O by means of LCA applied to agricultural production

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Keywords: LCA, Agriculture, N fertilization, Soil N_2O emission

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Abstract

Global agricultural systems play key roles on the environmental quality since they are fundamental for production of food and raw material for human needs and, moreover, they are a source of different type of pollution at local and global scale.

Nitrogen (N) cycle is dramatically altered in the agro-ecosystems, since N immobilized in plant tissues is removed with harvest, thereby reducing the N availability in soil for the next crop cycle. Loss of N soil fertility is often recovered by means of mineral fertilizers, whose production needs large amount of fossil fuels. Input of reactive N into the biosphere by man now exceeds the rate of biological N_2-fixation in native terrestrial ecosystems [1]. This increased reactive N is due not only by N fertilizer production, but also by the higher use of mechanized agriculture (the fossil fuel combustion used to support different types of management).

One of the main effects of the large use of mineral fertilization is production and emission from soils of N_2O. Soil N_2O emission is directly related to land use and soil management practices, since it is the biogenic product of microbial processes of denitrification and nitrification, as affected by physical–chemical characteristics of soil and crops management, mainly the large application of N fertilizer coupled with low oxygen content in soil [2] [3]. Agricultural soils contribute about 50% of the global anthropogenic N_2O emission [3], this gas has a high global warming potential, 298 times greater than that of CO_2, therefore an emission of 1 kg N_2O-N is equivalent to 0.470 kg CO_2eq.

Life Cycle Assessment (LCA) is one of the best methodologies for the evaluation of the environmental burdens associated with agricultural activities, by identifying energy and materials used as well as waste and emissions released to the environment; moreover it also allows an identification of opportunities for environmental improvement. An important variable in LCA studies is the contribution to net GHG emissions of N_2O. Many LCA studies neglect N_2O emissions otherwise utilize default emission factors published by IPCC [4]. The current IPCC methodology for producing national inventories of N_2O from agricultural land is based on the study of [5] and it assumes a default emission factor (EF) of 1.25% for soil-added mineral nitrogen. This approach does not account for climate, management practices, irrigation, soils and crop types, and other variables. Moreover, the data considered by Bouwman were mainly referred to croplands under temperate climatic conditions. Thus, more data are required to obtain a correct evaluation of N_2O emissions from agricultural lands under different climatic regimes at regional and national scale. Since pedo-climatic conditions are key factors, a monitoring activity at local scale is needed, not only for testing different soil managements but also to obtain data from Mediterranean soil–crop systems. Freibauer [6] has pointed out already that large uncertainties are present in the GHGs inventory for Mediterranean croplands due to lack of extensive monitoring activities. As a matter of fact conflicting conclusions are available. Crutzen and co-authors [7] suggest that the default emission factor may underestimate nitrous oxide emissions three- to five-fold.

On the contrary the few studies conducted in the Italian croplands at Mediterranean climate condition showed EFs under the 1.25% value [8] (Castaldi, personal communication).

The present work intends to underline that a precise evaluation of the contribution to net GHG emissions of N_2O by means of LCA applied to agricultural system, requires locally available data. Considering the high global warming potential of the N_2O, small differences, as percentage value, of this gas may contribute significantly to the warming atmospheric potential of an agricultural product.

The study performed the Life Cycle Assessment by means of the Eco-Indicator 99 method and software SimaPro 7.2. The Eco-Indicator 99 method assumes a default emission factor (EF) of 1.25% for soil-added mineral nitrogen, after IPCC methodology. The study was performed using inventory data from Italian sunflower and maize crops treated with urea and ammonium-nitrate as mineral nitrogen fertilizer. Direct data of soil N_2O emissions from a long term monitoring study on maize crop of Campania Region treated with urea, were used to calculate an EF of 0.8% [8].

The climate change effect due to total N_2O emissions appeared 10% lower in both crops using the EF of 0.8%, regardless of mineral fertilizer.

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Environmental optimization of waste management systems by integrating LCA and linear programming: a simulation

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Keywords: Life Cycle Assessment, Integrated Waste Management, Linear Programming Models

Introduction

LCA can be used to assess the environmental performance of an integrated waste management system or to identify the most environmentally-sound waste management scenario through a comparative analysis of different scenarios [1]. In the planning phase, we can define scenarios assuming the rate of each waste fraction that will be conveyed to each of the various treatment/disposal options available. In order to avoid making such assumptions, linear programming (LP) models integrated to LCA may allow us to identify an optimum scenario of integrated waste management, from the environmental point of view, among all those theoretically available. We developed an LP model and a multi-objective LP (MLP) model that aim to identify the optimal allocation of waste to minimize environmental impacts [2]. In this study the developed models were tested through a simulation based on realistic data to verify its validity.

Methods

The LP model and the MLP model developed solve the following problems, respectively, which can be formulated in terms of linear programming:

- Problem P: determine an allocation/distribution of the total amount of each waste fraction to the destinations, in order to minimize a single environmental impact. That can be formulated as follows:

  $$\min \sum_{i=1}^{n} \sum_{j=1}^{m} (\gamma d_j + b_{ij}) x_{ij} \ .$$

  subject to constraints on the amount of the waste fractions and on the capacity of the destinations. In particular: variable x_{ij} denotes the units of waste fraction i to destination j; b_{ij} denotes the environmental impact for assigning 1 unit of waste fraction i to destination j; d_j denotes the distance to reach destination j; γ denotes the environmental impact for transporting 1 unit of waste over 1 unit of distance.

- Problem $P_{general}$: determine an allocation/distribution of the total amount of each waste fraction to the destinations, in order to “minimize a set of environmental impacts all at once”, subject to constraints on the amount of the waste fractions and on the capacity of the destinations. Actually, in general, the existence of a solution which really minimizes all the environmental impacts all at once is not guaranteed, as in general a solution which minimizes a given environmental impact does not minimize all the remaining environmental impacts.

Then solving this kind of problem means to determine a solution which is efficient, i.e., a solution x is *efficient* if there exists no solution y such that y does not worsen x with respect to every environmental impact and strictly improves x with respect to at least one environmental impact. In particular, that requires an active role of the decision maker, so to focus on the efficient solutions he prefers. Different methods to determine an *efficient* solution are known in the literature (see e.g. [3], [4]).
Methods that are closer to our goals are: methods without preferences, a priori methods (method of weights, the lexicographic and ε-constraints method), a posteriori methods, interactive methods. In the simulation we considered 5 waste fractions (organic, mixed paper, mixed glass, mixed plastics and mixed municipal solid waste) and 6 destinations (landfill, incinerator with energy recovery, composting plant and 3 recycling plants for paper, glass and plastics). Since all waste must be allocated, a residual destination identified in a landfill outside the region, at a distance of 600 km, was provided.

This destination collects the waste that the previously described destinations cannot receive for capacity reason. The amount of waste assumed to be generated was estimated based on an average regional production and the capacities of plants were assumed according to the relevant national average capacities. In order to assess the impact of transport, average distances between the collection centre and the plants were assumed (the transports from urban collection to collection centre were excluded).

Unit impact factors for the various waste fractions and disposal/treatment options were assessed by using the CML 2001 method with SimaPro 7.2 and Ecoinvent Database. For the sake of this simulation, only 3 impact categories were chosen, notably: Global Warming Potential (GWP), Acidification Potential (AP) and Eutrophication Potential (EP). Environmental impact indicators were normalized using the default settings.

Linear programming problems were solved by standard Excel 2010. Three solution methods were chosen to solve the MLP model: method without preferences, weights method and lexicographic method.

Results and discussion

Solving an LP model by considering an impact category at a time gave the following results. To minimize GWP it is suggested that recycling and composting plant capacities are fully exploited, except as regards the paper fraction, which was assigned to incineration. The surplus of recyclable fraction was allocated to landfill. Instead, to minimize AP the total capacity of recycling plants should be used, whereas the organic fraction was assigned to landfill. The surplus of paper and plastics fractions was allocated to incineration, and the glass fraction to landfill. Note that the organic waste burned in the incinerator generates lower impacts than the other alternatives, but since the plant is more distant this is not the preferred one. In order to minimize EP, capacity of recycling plants and composting plant should be fully exploited. The surplus of organic and glass should be sent to the local landfill, whereas the other fractions to the residual destination. In all three cases the mixed municipal solid waste fraction was allocated to cover the remaining capacity of the incinerator and the landfill. But we can highlight that in the case of EP, mixed municipal solid waste was assigned to fully exploit the capacity of incinerator although the paper fraction sent to incinerator is less impacting. This is because the benefit of avoiding landfilling mixed waste offsets the benefit of incinerating paper rather than mixed waste.

Solving the problem with the MLP method without preferences, that minimizes the sum of the impacts, resulted in exploiting the recycling and composting facilities at their full capacity. The remaining part that cannot be recycled should be sent to landfill, with the exception of the plastics fraction that was assigned to the residual destination. The mixed municipal solid waste fraction was allocated to fully exploit the capacity of the incinerator. The weights method (assuming the following weights: 0.5 for the GWP, 0.3 for the AP and 0.2 for EP) resulted in recycling facilities being allocated their maximum capacity. The remainder of the recyclable and compostable fractions were allocated to landfill (organic, glass), incineration (paper) and the residual destination (plastics). The mixed municipal solid waste fraction was assigned to fully exploit the capacity of the incinerator and landfill. In the lexicographic method we set as a constraint the minimum on the AP and we calculated the function for the EP first and GWP later. Also in this case the recycling plants were allocated their maximum capacities. The non-allocated rate of recyclables fraction were assigned to incineration (paper, plastic) and landfill (glass), whereas the organic fraction to the residual destination. When the minimum for the EP was set as a constraint, the allocation of waste did not change.

In general, the simulation resulted in most cases in recycling being the preferred solution. Furthermore, transport and distances of plants affected the solutions.

Conclusions

The LP and MLP model developed aims to identify an environmentally optimal scenario of integrated waste management system with reference to one or more impact categories simultaneously. This model integrates linear programming and the data about impacts of waste management from LCA. A simulation was carried out which showed, as expected, that transport distances affect the results of the study. The location of a plant at some distance from the collection centre can influence the choice of the scenario. Moreover, the choice of method for solving the multi-objective model affects the results and the allocation of waste fractions. The simulation, carried out by assuming a realistic context, highlighted some aspects that will be further explored with the application to a real case-study.

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Social LCA: a methodology for the application to the tourism sector

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Keywords: Business Assessment, LCA, Social Impacts, Social Responsibility

Introduction

The attention towards social, economic and environmental issues for the creation of sustainable development patterns increases the value of a company in terms of image and credibility with customers and business partners. Sustainability is therefore an important factor of competitiveness and integration with the local community and all the stakeholders.

Social impacts' evaluation is one of the cornerstones of products and services sustainability. About that, Social Life Cycle Assessment focuses on studying the social impacts of life cycles but, as this is a relatively new analytical approach, no globally shared application tools have been developed yet. Because of their specific service features, touristic activities are well suited for the elaboration of data related to social sustainability.

The Social Life Cycle Assessment (SLCA hereafter) methodology can be described as a tool that allows a strategic vision and management of the social sustainability of the product and takes the form of an analysis that lets the company observe the social impact of the product through its sustainability evaluation throughout the life cycle (Benoit C. et al., 2010).

Objective of the study

The aim of this study has been the analysis of the social impact of an accommodation facility, through the association of existing Social Life Cycle Assessment tools with data resulting from social accounting and business management tools, in order to point out the criticalities of the organization. Defining the methodology, we elaborate and evaluate a questionnaire to collect the data on which the analysis will be conducted and finally show the application to a specific accommodation facility as a case study. A touristic facility which applies a structured model for detect and monitoring its social sustainability, based on the life cycle, as it highlights its level of sustainability (as already verified for environmental sustainability) is able to offer higher quality service to its customers and remains most impressed in the experiences of guests, contributing to the retention and thus placing the foundation for a long-term economic sustainability (Arcese et al., 2011; De Camillis et al., 2010). The ultimate objective for conducting a Social LCA is to promote the improvement of social conditions and of the overall socio-economic performance of a product throughout its life cycle for all its stakeholders.

Theoretical review: Life Cycle Assessment and social aspects

The Life Cycle Assessment (LCA) as regards the recognition of environmental aspects appears to be a consolidated tool on the international scenario, but its use still presents some critical points and the opportunity for further developments. Totally new or evolving approaches are frequently applied, instead of the life cycle and its applications to the recognition of the social aspects of survival (Kloepffer W., 2008).

Discussions on how to deal with social and socio-economic criteria of products throughout a product life cycle started in the 1980 (UNEP, 2011).

At that time in Germany was started a specific project Group on Ecological Economics within ÖkoInstitut and in the SETAC Workshop reports a conceptual framework for the impacts classification already include social aspects for the holistic assessment (Fava et al.,1993).

In recent years, thanks to the thrust of various international organizations the SLCA, at first less considered through the historical development of Life Cycle Thinking theories, took a growing importance, highlighting some improvement and completion needs for a methodology that is still in a preliminary stage of processing (Petti L., Capannella P., 2010).

SLCA is defined as the methodology for the assessment of positive and negative social impacts that are generated by a product / service in its life cycle and in relation to different groups of stakeholders involved, with the aim of promoting the improvement of a product socio-economic performance throughout its life cycle (Weidema BP, 2005).

The SLCA has not yet been formalized in an international standard. For this reason, the methodology refers to the steps proposed by the ISO 14040 standard on Environmental Life Cycle Assessment and its application, according to guidelines drawn up by SETAC (Society of Environmental Toxicology and Chemistry) in collaboration with UNEP (United Nations Environment Programme), (Traverso M., M. Finkbeiner, 2009; UNEP, 2011; Reitinger C. at al, 2011). Although the method is in an early stage of development, examples of application of the methodology to specific products can already be found in literature, and well-known research centers have proposed various developments of qualitative and semi-quantitative analysis (Hauschild M.Z, 2008). On the other hand, it is important to point out the existence of other analytical models that use different approaches and indicators, in connection with the three different ways in which SLCA can have an improvement effect as outlined: consequential SLCA, educative SLCA and management SLCA. Many empirical and theoretical studies in relevant fields of research have been conducted in order to evaluate the claimed improvement effect of the three SLCA models, and some critical aspects were put in evidence for all the three methods. (Waidema B.P., 2006; Jørgensen A., 2008; Jørgensen A., 2011).

Focusing on tourism and accommodation facilities sustainability

Tourism has been defined as "… the sum of the phenomena and relationships resulting from travel and stay of non residents…" (Burkart and Medlik, 1972). Mass consumption is endangering the future of our world, and tourism has significantly contributed to this situation. However, tourism can also bring extensive benefits to society. In an attempt to promote sustainable practices, different kinds of eco-labelling in this sector have been developed (Font, 2001).

Moreover, tourism is a complex sector, characterized by the combination of activities encompassing areas as diverse as energy, agriculture, transport, etc. For this reason, the sector's relationship with sustainability has gradually consolidated, given the increasing importance of consumption and its environmental impacts (Harris 2007). Sustainability appears to be a key business variable for tourism. As evidence of this, data on the European Ecolabel granting for accommodation facilities show a significant development in Italy: 157 licenses in October 2011, with a trend of strong growth in the 2004-2009 period and a decrease between 2009 and 2011, probably depending on the entry into force of the new EU Ecolabel criteria, specific to this sector, that required a new effort of alignment for many facilities, in addition to being the category with the highest number of total license (Arcese and Martucci, 2010; Arcese, et al., 2011; Bartolomeo et al., 1995; Vinci et al., 2010).

Despite the European Ecolabel diffusion, the real commitment of this sector in the direction of social sustainability, and also of the achievement of a strong sustainability, intended as the right conjugation of environmental, economic and social aspects, still remains generally inadequate (Parent et al., 2010). A sustainable accommodation consists of personal and professional sensitive to a proper social and environmental management, in response to business needs and customer satisfaction (Alyfanti et al., 2004). Small firms often show relevant skills in managing these relationships, since they are themselves an integral and visible part of the community in which they operate (D. Hunkeler, 2006).

The theoretical model: the importance of stakeholders

Stakeholders need to be central in this kind of analysis, and consequently are considered from the first stage, which includes the impact analysis. They can be grouped into five main categories (UNEP, 2009), and then macro classes can be adapted to the specific case of accommodation; specifically they can be grouped like shown in the Stakeholders' classification of UNEP-SETAC Guideline (2009).

Each class of stakeholders has been associated with its objectives and impacts, which identify, shape and modify the boundaries of the system, contributing to its definition.

In this specific analysis, the stakeholders' involvement quantification is heavily influenced by the various sub-categories of impact (Parent J. et al., 2010).

The choice of indicators, as often happens, led to identify a set of mixed indicators (quantitative, semi-quantitative and qualitative) with a strong characterization given in relation to the geographical area.

The second phase, related with the preparation of the inventory data, defines the most appropriate indicators. The international scientific community has defined different criteria with the aim to get a complete set in order to meet all the testing requirements.

In this particular case, indicators established by Jørgensen were taken into account; they are expressed in a matrix structure for the various impact categories, divided into subcategories as defined by international guidelines, with the necessary adaptations and changes for the contextualization of the case and properly integrated with the indicators provided by the Guidelines (Jørgensen A. et al., 2009).

The hypothesized model for the case study

With the aim to analyze the accommodation facility sustainability, the key variables to be studied are related to the sector criteria, namely:

• tourists accommodation capacity planning in the geographic area;

• rational use of natural resources (energy, water, soil);

• natural Landscape preservation;

• controlled management and eco-friendly urban waste;

• controlled management and eco-friendly waste water treatment;

• protection of natural habitats;

• respect and sensitivity to local cultures;

• construction and operation of tourism infrastructure in compliance with the environmental characteristics of the area;

• management of eco-friendly roads and local traffic;

• use of products and consumer goods produced by the local community;

• training of tour operators on the cultural and environmental conditions.

In the analysis we have conducted, the main source of data have been direct interviews and monitoring of the structure in a given time slot (3 months for the interviews and 6 months for the monitoring of activities).

The requested information have been classified according to the categories of stakeholders and monitored data were calibrated according to the specific sustainability criteria for the sector mentioned above, with specific reference to sector analysis of the category Bed & Breakfast (B & B) at which the considered structure belongs.

Afterwards, the system of accommodation was taken into account to detect hotspots and make suggestions for an improvement strategy, enabling management structure to focus on potential causes of un-sustainability, in order to reduce or eliminate them.

In this phase the special features connected with the facilities classified as B & B category have been particularly outlined. A sectorial analysis carried out by several groups at the national level, has shown a fragmented reality; however, the sector is still in a development phase, with a wide community of stakeholders that often move in a fragmented way.

Different research projects conducted by the Specific Observatory of the Italian Touring Club, founded in 2002, showed that the phenomenon is rapidly growing, and put in evidence two main categories of stakeholders among those with the highest expectations: customers who benefit from the service and people of the local community.

The examined tourist structure is located in the Lazio region. In this area there is the highest concentration of B&B structures in Italy, with a share of over 10% on a national scale.

The area currently presents 37 accommodations listed as B&B. For these structures potential customers can be collected into four distinct categories:

1. tourists looking for a familiar treatment, interested to know the area and aspects of life of residents, feeling more similar to them;

2. tourists watching for the most inexpensive solution;

3. tourists travelling for business reasons and visitors who are involved in work activities in the area: this category is extremely variable in number, with relation to the activity in the area at different periods. Sales representatives and consultants are the main categories of customers in this class;

4. passing tourists not willing to spend several days and only interested in an overnight stay.

In this accommodation facility, the data collected for the preparation of the inventory shows that the categories of customers that are associated with higher frequencies belong to the first and third categories. The category with higher incidence is the one composed of people travelling for business (more than 50%).

The category of workers has been recognized but not analyzed because the facility is completely family owned.

Therefore, resting upon the customers' analysis it can be concluded that the most affected category of stakeholders is the Local Community, which receives the main impacts of the activity of the facility.

The choice of a Functional unit is an important point of the SLCA; in this case we have considered the service provided for a stay of two days, which corresponds to the average time spent at the facility by customers.

Examining the data of customers' attendance, in fact, almost the entirety of business tourists has a stay longer than two consecutive days; moreover, once they have been customers of the structure, business tourists tend to be loyal and return several times. The 2-days stay can therefore be considered as the functional unit of the analysis system.

For the definition of system, boundaries have been outlined, taking into account the length of staying in the structure (arrival in the structure, permanence, the end of the stay and departure of the visitor).

The 'inventory results in the processing of different sources:

• primary data coming directly from water, electricity and gas invoices;

• interviews, realized through the distribution of a questionnaire for customers, and directly conducted with the staff ;

• Secondary data analysis from the tourism sector, databases and external documents.

By reason of the peculiarity of the examined case, it was necessary to adapt the existing methodologies to assess the specific aspects of the functional unit considered.

The methodology: the questionnaire

Qualitative and quantitative surveys were conducted. With respect to the quantitative survey, a set of items was adopted as specific questions in the descriptive phase. Considering the exploratory nature of the research, the proposed structure was derived from the authors' original investigation. In this way a questionnaire was designed and administered. The questionnaire was composed of 28 questions (multiple-choice and open-ended), and tested through a pilot survey on a small sample (n=10) of respondents, after which the formulation of some questions was adapted to guarantee clearness and consistency.

It was organized on three sections: Profiling, General Section and Specific Section.

The first part (profiling) gathers information on name, geographical location and in particular on respondent's role within the company. The second part (General Section) contains information about the labelling, the management system, the description of the structure and additional services. The specific part is divided into sub-categories that reflect the categories of stakeholders of the guideline:

- *Workers*

1. How many people are engaged in work on the farm?

2. Typically, how many hours per day are used for activities related to the company?

3. What type of contract or agreement of collaboration they have with the company?

4. What is the average hourly salary of workers in the different company's activities?

5. What are the personal characteristics of the team (Mean age, number of women, nationality, etc.)?

- Local Community and Society

1. How the resources and raw materials needed for the activity are purchased?

2. What is the relation with local community initiatives?

3. Are you informed about the socio-cultural initiatives in the area and if so, you have ad-hoc company policies?

4. In which ways does your activity contributes to the development of the local economy?

5. As you stand in relation to technological development? Do you think that applying new technologies it's helpful?

- Customer

1. Who are your customers? (Gender, age, characteristics, etc.)

2. Why they benefit of your services?

3. How many are regulars? If yes, how often they return?

4. What is the average stay?

5. The loyal customer enjoys discounts or other benefits?

Moreover, some questions were modified or moved to amend some logical gaps. The questionnaire was administered on-site directly in the B&B structure.

Social Inventory analysis

Sub-categories related to stakeholder identified as "most impact categories" has been considered in the Inventory analysis like specified in Grießhammer R. (2006).

When studying the sub-categories of impact on the Local Community, the categories "Safe and Healthy Living Conditions", "Respect of Indigenous Rights" and "Secure Living Conditions" defined by the UNEP-SETAC Guidelines were excluded, as they were considered not appropriate in relation to the characteristics of the environment and the territory in which the activity is managed.

Local Comunity sub-category	Indicators	Impacts	Incidence on value
Access to material resources	Partially considered	Positive	Loyal suppliers
Access to immaterial resources	Partially considered	Positive	Loyal suppliers
Migration and delocalization	Partially considered	Negative	High rate of migration in the geographical area and production outsourcing
Cultural Heritage	Yes	Negative	High concentration of cultural and artistic heritage, not always appreciated in the geographical area of reference
Safe and Healthy living Conditions	No	-	-
Respect of Indigenous rights	No	-	-
Community Involvement	Yes	Negative	Low commitment to local initiatives, government initiatives for the enhancement of the B & B
Local Employment	Yes	Positive	High rate of unemployment
Secure Living Conditions	No	-	-

Table 1. Identification of the parameters of evaluation of the category Local Community

Even evaluating the secondary data from the general environment, gathered by the main public databases, the three variables do not appear to be relevant to the analysis.

The impact categories related with the procurement of resources (tangible and intangible) and with "migration and relocation" have been taken into account only partially, because, as the B & B structures are relatively small, they are not able to separately influence the surrounding system.

On the contrary, different considerations can be made if B&B structures are evaluated as a set of structures of the same class of service. In this case the variables with the higher impacts are "Cultural heritage", "Community involvement" and "Local Employment", and they can be directly influenced by the individual accommodation.

Results

Examining the indications emerging from the interviews on the supply side, the demographic composition of the structure coincides with the national average data in the field. Ownership and management are composed in the majority by women with a high average level of education (tertiary level) and low knowledge of foreign languages.

An important factor for the evaluation of the impact on the local community is that the structure that previously worked entirely personal to the management of the structure resulted in the absence of stable employment. The economic rationale is, therefore, the main thrust to undertake this type of activity.

The building in which the activity is located is an independent residence, and that circumstance allows the management to easily monitor the impacts and take initiatives in the direction of an increasing sustainability, like a rationalization of the use of water resources, a differentiation of energy sources (for example, the introduction of photovoltaic panels that cover about 40% of the overall energy needs, in particular for outdoor lighting) and finally the installation of an automated heating system which permits a significant energy saving, in winter, being active only in the rooms with customers.

Regarding promotion and communication, a remarkable lack in participating in networking initiatives or being present on different channels of intermediation was pointed out. The only effective means of promotion and communication is, in fact, word-of-mouth advertising, partly because of the particular type of customer hosted.

Room rates in the region are generally placed in a range between 13 and 100 €, with an average price of 35 € per night. In the detailed analysis of the considered variables (see Table 2) an overall negative result has been found for two of the impact categories considered.

The negative impact on 'Cultural Heritage' mostly depends on the lack of participation in tourism network and the lack of collaboration with cultural and artistic organizations, impeding the promotion and development of the area. This assessment is confirmed by the second category considered, also with a negative evaluation as evidence of lack of commitment to the territorial initiatives.

In conclusion, the two underlined variable seemed to be the only ones with a critical situation and negative impacts.

Conclusions

The assessment of the social impacts of a product/service through the assessment of its life cycle, which is still at an early stage of diffusion, presents a lack of proper quantitative indicators.

The main problem is related with the difficulty in linking social indicators with the functional unit of the system/product to make them manageable and significant indicators. Precisely for this reason, the actual qualitative and semi-quantitative approaches suffer from a lack of quantitative and well defined indicators.

This does not mean that the model is not operative. The effectiveness of the model structure has been widely demonstrated in literature and through the empirical analysis carried out on specific products.

In particular, the SLCA application presented in this paper has stressed the importance of the relations which should exist between the tourist accommodation services and the local community taken as a whole, with particular reference to local administrative structures and companies networks. Finally, the importance of this type of relationship is reinforced by the increasing demand from customers, looking for a different kind of tourism experience, presenting a familiar atmosphere and directed to the local characteristics.

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PLATFORM PRESENTATIONS

Modelling biogenic and fossil carbon among domestic wastes with a material flow analysis model

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Abstract

The scope of the paper is to start from the results of C14 monitoring campaign for better assessing the amount of biogenic and fossil carbon associates to the domestic waste and for better modelling the carbon flow analysis in the Northern Vicenza district. The study was performed according to Alto Vicentino Ambiente (AVA), an Organization operating in all the wastes management activities, collecting separate wastes and burning the remaining domestic waste in a thermal treatment plant.

Further study would be necessary for a complete understanding of the global carbon flow analysis considering the Urban Metabolism.

Wastes analysis and limits

Up to now the standard method for determining the waste energy content of a mixed waste is to sample the waste for composition and assess carbon content and/or calorific analysis. For heterogeneous wastes, like is the case of municipal solid wastes, the sampling method could be extremely difficult, costly and inaccurate due to the great difficulty of obtaining representatives samples [Ferrari et others, 2009]. The sampling procedure means separate physically the waste according to the waste size in many physical groups (paper, plastic, inert, called merceological classes) and from each group take sample to be analysed in analytical laboratory for assessing chemical composition, focusing on Carbon Content.

Such method is not able to separate biogenic and fossil carbon, the separation of carbon is then based on the merceological classes repartition, grouping together organic wastes, inorganic wastes and inert wastes.

As it is evident from the analysis waste results (Table 1) there is a great variability among the waste components, this variability is find whether it be summer or winter, and either for any collecting areas. The variability is so wide that for some waste fraction the standard deviation, not reported, is as great as the mean value.

Parameter		m.u.					
			A1	A2	B1	B2	Average (A and B)
Organics	Organic waste from food	%	16.92	19.36	2.81	10.04	12.28
	Gardening organic waste	%	10.65	2.46	0.67	1.64	3.85
	Leather	%	2.31	0.00	0.20	0.76	0.77
Cellulosics	Paper and paperboard	%	9.35	23.97	23.83	24.77	20.48
	Wood	%	0.31	0.37	2.22	0.38	0.82
	Textil	%	1.60	2.70	8.78	6.49	4.89
Plastics	Plastics and rubber	%	9.46	16.79	25.05	26.57	19.47
	Baby napkins	%	36.42	24.89	30.05	17.37	27.18
Metals	Metals	%	1.02	2.21	2.81	1.90	1.98
	Batteries	%	0.29	0.05	0.22	0.00	0.14
Inerts	Glass	%	0.83	2.70	0.18	0.81	1.13
	Inerts	%	0.08	0.51	2.46	0.34	0.85
	Other grouped materials	%	10.77	3.99	0.71	8.93	6.1

Table 1. "Domestic wastes composition analysis"

Grouping all the waste components containing biogenic carbon, (summing Organics + cellulosics and napkins) we find about 70% and excluding glass, metals and inert, the other waste components containing fossil carbon are about 28%.

The data are in line with other similar analysis [Ferrari, 2009] [Rigamonti, 2010].

Using the literature data for the Heating Calorific Value and the wastes composition it is possible to obtain the heating value of the waste that, generally speaking, is around 13-15 MJ/kg of waste.

This assumption is based on research results that the Gross Calorific Value for unit mass of carbon is consistently constant either for

a) biogenic carbon biomass or

b) fossil carbon components,

c) and is considered zero for Inert wastes.

Background of radiocarbon analysis of combustion gases

Carbon 14 (^{14}C) is a radioactive isotopes of carbon ^{12}C, it is produced by a nuclear reaction with Nitrogen in the upper part of atmosphere at a constant atmospheric concentration of 1 part of ^{14}C each trillion of ^{12}C. In the same ratio it is regularly intaken by leaving organisms, as well as trees, so at the end of life starts a natural exponential decay according to the half-life time of 5730 years, reducing the ^{14}C content [Weart, 2004].

When we consider biogenic carbon among waste the amount of ^{14}C could be considered at the rate of 1 part per trillion of ^{12}C as the vegetables and foods are consumed in a short time compared to the half live of radiocarbon; similar consideration are applicable when we deal with paper, paperboard and wood.

On the other side all the plastic materials contain fossil carbon, created million of years ago, so it is reasonable that it will not contain ^{14}C, according to the decay law.

The radiocarbon monitoring method was tested using a number of sample mixing known amount of paper (Biogenic) and polyethylene (non-biogenic) [Themelis, 2007], for each sample burned, the combustion gases were analyzed for measuring C14 and so correlate the measured C14 to the biogenic fraction of carbon in the waste.

The condition under which the results could be applied to generic domestic wastes is that it is known the average chemical composition.

Despite the variability of wastes composition, measuring the CO_2 and the carbon fractions, biogenic and fossil, the results could be affected by an overall uncertainty of about +/- 5%, to compare with the uncertainty of assessing the GHG that, for [Marland, 2008] is around at 5% for Nation with well developed energy data systems and rise to 10% for the other Countries with less developed energy data systems.

AVA Analysis with radiocarbon

Alto Vicentino Ambiente (AVA) waste incinerator contracted an accredited laboratory for analysing the flue gases of the wastes combustion using the radiocarbon method: the analysis was made in December 2011 measuring [CEN/TS 15747, 2008 method] the combustion gases for a significant time interval, the test run was repeated 3 times taking 3 samples; all the test were performed on line 3 incinerator having a reference wastes combustion capacity of 4 t/h (Table 2).

The measured data [Indam 2011] could be commented as follows

1) the total CO_2 has very little variation during the combustion test time,

2) the biogenic CO_2 tends to decrease after the initial combustion and this explain also the reduction of steam formation,

3) the fossil CO_2 tends to grow as it requires a longer burning time,

Total amount of CO_2 for the first test run was 5485 kg, corresponding to 1496 kg/h of total carbon content in the waste of which 54% of biogenic carbon and 46% of fossil carbon, the total carbon content represents 37.4% of the total waste weight.

Test run	Total CO_2	Biogenic CO_2		Fossil CO_2	
	% dry volume	% of total CO_2	CO_2 mass flow (kg/h)	% of total CO_2	CO_2 mass flow (kg/h)
1	6.4	53	2907	47	2578
2	6.1	54	2738	46	2333
3	6.0	51	2363	49	2271

Table 2. "Biogenic and fossil carbon analysis"

The carbon content measured is consistent with the literature data [Gambarelli, Froldi, 2005] of the carbon content among Municipal Solid Wastes (MSW).

Carbon flow analysis method

The data available at the AVA facilities were used according to the material flow analysis for better understanding how to implement a carbon indicator of sustainability associated to human consumption of goods and foods. Even if many material and carbon study are available they describe part of the consumption or carbon footprint. In this study the existing data at AVA site and other data were put together for assessing the global carbon footprint associated to human food and goods consumption. The model was applied at the district served by AVA for collecting separate wastes and burning the remaining urban waste.

So starting from the carbon (biogenic and fossil) emitted from the incineration was create a mass balance adding all the other streams like paperboard and plastic separation, the big wastes collection and treatment even the human metabolism emission of carbon.

Biogenic and fossil carbon flows analysis

During the late decades there has been a significant use of Material Flow Analysis in addition and integration of LCA studies or for modelling raw material flows, waste flows management [D'Incognito, 1991] [D'Incognito, 1997] or urban metabolism.

Dealing with MFA applied to real situation, and not laboratory scale, links, strictly, with mass balance difference and the same occur for waste management [Brauner, Weng Ma, 2009].

SFA will be used for assessing the carbon flow analysis using a reverse logistic approach [P.T. Jones 2009].

For the data of goods consumption the statistical data from Italian Statistical Bureau had been used as first approximation [ISTAT, 2009].

The data let to understand that the average family is composed by 2.4 person and with the average annual income of 19,040 € is able to satisfy the primary and part of voluptuary needs, considering the local habits of self production of fruits and vegetables.

Following the MFA methodology a model was created for separating the flows according to human and/or urban metabolism:

The overall streams of consumption could be separated in:

- a) food consumption, digestion by mean of the human metabolism and dejections (short metabolism),

- b) domestic wastes (food and packaging) produced in a very short period (urban short metabolism),

- c) goods (wears, household, furniture) accumulated and used according with the respective life cycle span (middle urban metabolism).

Human metabolism

Food consumption weight pro capita, depending from the diet habits, could range around 2.5 kg per capita and per day, such amount of solid (about 1 kg) and liquid (1.5 kg) are ingested daily.

Using the extremely interesting research of Munoz, Milà i Canals and Clift on the direct human impact [I. Munoz, L. Milà i Canals and R. Clift, 2009] we can assume that about 1.8 kg per day per capita is the excreta (1.6 litres of urine and 0.2 kg of feces); the little difference with the data are due the difference diet more reach in Italy of bread and pasta and of drinkable water.

Again looking at the same research, we could assume an average CO_2 emission for human respiration of about 0.2 kg for kg of food ingested and, hopefully, all the carbon must be considered biogenic carbon even if traces of fossil carbon contamination could be present in food chain.

Urban short metabolism

Domestic waste are produced unavoidably for the fraction of food not eatable, for the food scraps and for the direct (primary) food packaging (ex. yogurt cup) and secondary food packaging (ex. paperboard grouping 2 or more yogurt cups).

Such domestic waste according to Municipality indications are separated for collecting wet food fraction for composting and paper, plastic, glass and cans that are sent to the recycling chains.

After the waste separation the remaining fraction of wastes is send to incineration, normally, the waste production occurs in a very short period of time that does not have any influence on carbon 14 transformation and of course biogenic carbon is again associated to food fraction and paper products and the fossil carbon is more linked to plastic packaging and other plastic products.

Considering the official data the global packaging is about 0.8 kg per day and per capita of which about 0.58 kg are fully recycled and about 0.45 kg per day per capita, containing remaining fraction of organic wastes, packaging and other wastes, is send to incineration.

Urban medium metabolism

The goods like household appliances, clothes, furniture are part of the carbon flow analysis, those categories of products are purchased according to products availability, personnel and family needs and income, such products will be used many times considering that the life extension could range from some to many years, depending from the product functions (clothes to furniture).

For such products we could consider a function of accumulation that in subsequent years will contribute to waste productions.

Of course it is of great interest the understanding of such wastes for the planning of future waste management, but for the scope of the research the urban medium metabolism is not considered, specially for the carbon flow analysis.

The late assumption is supported from the fact that the wastes collection among the 3 collecting basins includes a very limited amount of old furniture not affecting the statistical data.

Results and discussion

The actual data of wastes production, collection and combustion were used creating a model of mass balance per day and per capita, the resulting model is adequate for understanding the waste flow material that will be regularly received and burned at AVA incineration. Looking only at the food consumption and associated packaging the mass balance is self-standing and globally the total weight is 3.5 kg of which 2.5 kg are ingested (1.5 liquids and 1 kg of solid food) and about 1.1 kg is the waste fraction of which 0.68 kg are recycling material and the remaining 0.45 kg is the burned fraction.

Associated to the waste mass balance a carbon flow analysis and carbon mass balance was tempted using the same per day and per capita, considering separately the biogenic carbon and fossil carbon.

The incoming biogenic carbon average is 450 g (per day, per capita) and is metabolised by the human body and transformed and emitted as feces (20 g) as urines (12 g) as respiration (200 g) as wet food waste (45 g) as waste contributing with combustion gas (108 g).

Part of the data had been measured and part are referred to [Munoz et al., 2008].

The biogenic carbon mass balance give a 65 g of difference that should be attributed to the human metabolic energy balance, this is a reasonable data as such amount of carbon contribute for about 3000 MJ or 550 kcal of energetic contents in the diary diet.

The fossil carbon mass balance, mainly due to packaging plastics, contains about 340 g of carbon of which 240 g are collected for the recycling chain and about 97 g are emitted with the flue gas as carbon dioxide.

The combination of existing “man spherical model” and the reliable data on carbon emission from waste combustion is a significant base for modelling carbon mass balance associate to wastes mass balance.

Using the model data it is possible to calculate the year 2008 emission of 23834 tons of CO_2 of which something less of ½ is of fossil origin and the remaining part is of biogenic origin, now the question is how such (and all the other emissions) influences the surrounding territory. For example using the emission fallout modelling at local scale could be necessary for assessing the alteration of soil composition and measuring the carbon contents and the carbon content modification.

For understanding the global Carbon Cycle among the goods consumption we need to proceed in research applying Input-Output analysis and specially dynamic model of Material/Substance accumulation inside the technosphere, as it is confirmed by [Nakamura et others 2009]. New line of research are necessary for modelling the accumulation of material and the delayed disposal at the end of life of medium life cycle products and, once more, the reverse logistic approach could be useful for designing the centres for handling and disassembling such products, as is the case of WEEE in the late years.

We need to expand our systems and from the waste and/or substance material analysis we move to Industrial Ecology concept applied to carbon dynamic flow at same real scale and as it is evident data on material, substance and waste flow analysis are more and more necessary for addressing debate and the decision for decision making concerning the sustainable development. The dynamic carbon flow index per capita could become a new sustainability indicator.

Conclusion and next

The target of the research was to use the carbon flow analysis for assessing the dynamic carbon among the full human consumption in a district of Vicenza, Italy.

According to the target the method used is very useful and was based on the availability of good quality data of biogenic and fossil carbon emission based on the new usage of radiocarbon methodology. Combining the direct data of emission from the incineration and all the other contribute from the separate waste collection a global carbon index was create reaching the important result of a dynamic carbon flow index per capita knowing the contribute of fossil and biogenic percentage of carbon.

The first important limitation is that the model is applicable to human and urban short metabolism as the urban metabolism of goods has a different behavior and time of replacement.

New steps

To include and complete the dynamic carbon flow index per capita the knowledge of economic incoming per capita of the territory under investigation is necessary as such information could be used from the chamber of commerce of the Vicenza district to fully understand which kind of goods were bayed.

An additional survey is necessary for understanding the time of replacement of goods and household appliances; a dynamic analysis is necessary for understanding the dynamic balance between the goods bayed today and the goods bayed some years ago and disposed nowadays.

Such information will be searched using the existing information of WEEE collection and similar data in other industries.

The potentiality of such information is to complete the dynamic carbon flow index per capita and the capacity to plan the waste management at the local area. As soon as new results will be available they will be communicated and applied at a bigger scale.

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A methodological approach to Life Cycle Costing of an innovative technology: from pilot plant to industrial scale

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Introduction

Innovative technologies are increasingly required in order to face sustainability goals, which have configured new frameworks for market competition. Indeed, international legislators are currently asking for raising R&D expenses towards sustainable productions. However, developing new technologies poses many issues with regards to the large amount of both the long-run investments required and the subsequent operating costs. In particular, the former will be the most affected, if the innovative technology brings about radical changes in the life cycle of traditional processes. Therefore, it could be useful applying Life Cycle Costing (LCC) analysis before implementing the new technology. This method allows providing an estimate of the economic sustainability of a planned item, such as a technology in its phase of development through a pilot plant.

Currently, innovative technologies are required to be more environmentally sustainable too. In this regards, conventional analysis based on LCC is a purely economic evaluation, considering various stages in the life cycle. It is usually presented with the perspective of a producer or a consumer, and environmental costs that are expected to be internalized in the near future are neglected. These externalities are included in the so-called Environmental LCC (eLCC). The latter goes one step further than conventional LCC by including environmental issues that will be internalized in the decision-relevant-future and that can be expressed in monetary terms. A number of conventional LCC case studies have been done on durable and non-durable goods and on services but few examples of eLCC exist. Moreover, no examples on innovative technologies still to be implemented at industrial level could be found.

The aim of this work is providing a methodological pathway to be used when assessing innovative technologies that are implemented just at pilot plant scale. Environmental LCC from the producer perspective is the first result of the method proposed, while a brief introduction to and some preliminary suggestions about externalities accounting and societal LCC from the public body perspective are discussed in the conclusions.

The pathway has been modelled for the TyGRe technology, a new system for the production of silicon carbide (SiC) using the energy produced from gasification of waste tyres. The paper shows the main assumptions and stages designed in order to scale-up to industrial level the costs derived from the pilot plant. The total cost and revenue for the industrial producer applying TyGRe have been estimated starting from the cost structure and EBITDA margin of a possible competitor, Kollo BV. This company employs the conventional technology used for the SiC production, represented by Acheson process. The latter is the reference scenario with which the innovative one, namely TyGRe, has been compared in order to evaluate the latter's economic sustainability.

Partial results have been discussed, although the analysis is still in progress. In particular, additional assumptions are needed to perform a better analysis of environmental externalities for the industrial application of TyGRe technology, as well as the complete eLCC for the conventional scenario. The main findings presented in this paper refer to a more conventional analysis of life cycle costs, and a first estimation of environmental externalities in the decision-relevant-future have been assessed only for the pilot plant of TyGRe.

Because of the originality of the process and the involvement of industrial and research partners on it, detailed information about the technologies used and the relative costs will not be provided for confidentiality reasons.

Methods

Review of the concept of Life Cycle Costing

Innovative technologies and processes usually require a large amount of investments because they need many research activities and their implementation could require a high quantity of resources as well. Planned results can be hard to obtain, increasing operational costs and investments, and delaying the production time, and, as a result, economic returns. Therefore, cost uncertainties should be adequately evaluated before planning and developing a new system of production in order to avoid losing profitability and competitiveness. To this purpose, cost accounting scholars and practitioners have developed many instruments and methodologies. Among the latter, Life Cycle Costing (LCC) is very popular[1]. The life cycle cost of an item has been defined as 'the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life ' [2]. Many scholars have argued that large part of the total costs of a product life – or a service or a technology – are defined during planning and designing [3,4,5].

In particular, life cycle costs include expenses related to research and development, installation, operation and support, maintenance and disposal [6,7,8]. Analysis of life cycle costs was originally implemented for procurement purposes by the U.S. Department of Defence in 1970s [2] and its application is currently very common in the military sector and in the construction industry [9]. Although Life Cycle Costing is little adopted by other industries [5], the literature reveals that this method is of increasing importance for firms because it properly supports decision making. Indeed, Life Cycle Costing allows to evaluate 'the effectiveness of planning by comparing actual with budgeted life cycle costs as well as the distribution of those costs, […], to enhance their capacity to make better pricing decisions, […], to improve the assessment of product profitability' [10]. However, a methodological framework or model has never been developed, even though there have been efforts in this direction [11]. In fact, Durairaj et al. have identified and compared eight different methods [12] whereas Korpi et al. have considered relevant only three of them in describing a better LCC model and they have added a fourth study in order to build a methodological framework [5]. These three methods principally differ in the estimation of future costs, which mostly depend on the availability of data and the stage of the analysis, as well as on the time-value of money [13]. With regards to cost estimation, possible alternatives are based on engineering procedures, analogy, and parametric methods, respectively. The second one is the cheapest because it needs fewer data than the other methods, but it requires many subjective judgements in drawing analogies between different items [5]. Lastly, Emblemsvåg has proposed using Activity-Based Costing (ABC) in order to evaluate future costs, a well-known method of cost accounting that entails a comprehensive activity-cost database [14]. The above mentioned scholars have not elaborated a standard commonly accepted method aimed at calculating and comparing future costs, and they have rather highlighted the sense of life cycle thinking and importance of the systems view [15]. Therefore, LCC has been usually applied with procedures specifically configured on the basis of corporate or industry features because it is effectively set up to support management decisions about production in strategic planning. A generalization of the method would need a translation from business-specific cost configurations to more general ones with loss of efficacy.

A particular characteristic of LCC is to grasp costs coming from the demand that have not yet a price [16]. This may result useful in designing more environmental friendly products or technologies [17,18], by considering possible impacts along the life cycle [19,20,21]. Demands for the reduction of environmental impacts, or more ethical behaviours, are examples of expenses not economically appraised by the market. However, these demand costs without a price have not been included in the first wave of LCC-based studies. In fact, demands for more, environmentally and socially, sustainable products are more recent than the first applications of LCC for procurement purposes. Secondly, including these costs into the life cycle cost analysis requires a more structured approach and a well-defined methodology in order to enable consumers – in addition to producers – making comparisons among products, services, and technologies. In this way, LCC may also support responsible consumption choices. Environmental LCC has been actually aimed at taking into consideration costs concerning environmental impacts that do not depend on internal decisions, but expressing external demands coming from consumers, institutions and civil society in general. Environmental LCC was conceptually born between the end of the last century and the first years of 2000s [22, 23, 24] but its conceptualisation occurred in 2008 and is due to Hunkeler et al. [25].

These scholars have also made an additional step by proposing a clear structure for the LCC, in its original, or conventional, version. Indeed, a three-stage model of life cycle costing is presented: conventional, environmental, and societal. Conventional LCC is exclusively devoted to the assessment of real, internal costs, sometimes even without end of life (EoL) or use costs if these are borne by other actors. Indeed, this instrument usually applies the perspective of a single market actor (manufacturer, user or consumer) [26]. The Conventional LCC configured by Hunkeler et al. and, more recently, by Swarr et al. has been also defined as a quasi-dynamic method. Generally speaking, the static model is the simplest one as it would exclude any time evaluation, assuming that all technologies remain constant over the period under review. On the contrary, a dynamic model reveals the dependence on time of the variables evaluated for the purpose of analysis. The quasi-dynamic model represents a compromise between the static and the dynamic model: most of the parameters taken into consideration are assumed to be constant over time, while only a few of them are considered as variable [25,26]. Environmental LCC (eLCC) has been configured to be suitable for assessing the economic implications of a product throughout its life cycle within the framework of sustainability. Therefore, eLCC is not envisioned as a stand-alone technique, but rather as a complementary analysis to LCA. To this purpose, the methodology should reach the needed standardization of the calculation procedure that is still missing. This could be done in analogy to ISO 14040/44:2006 that represent the general framework for LCA. In addition to internal costs, eLCC includes externalities, namely environmental costs expressed in monetary units that are not directly borne by an actor of the product chain. Noteworthy, these costs are already priced due to their feature of being relevant for future decision-making processes. There is no conversion from environmental measures into monetary ones, or vice versa, avoiding the problem of double counting of externalities if eLCC is applied in combination with LCA. Carbon taxes or other forms of taxes on pollutants are the typical examples of external costs accounted in eLCC. Regarding the dynamic dimension of the analysis, eLCC uses the discount cash flow in order to calculate money flows occurring at different times of the life cycle of a product. Lastly, eLCC could provide results from different perspectives (product manufacturer, supplier, user, end-of-life actor) and this responds to a need leaved unsatisfied by conventional LCC.

Hunkeler et al. have also defined a third level of LCC, the Societal LCC. Societal LCC is an assessment of all costs associated with the product life cycle covered by anyone in the society both at the present time and in the future. Societal LCC includes real money flows – as Conventional LCC –, the monetization of externalities in the decision-relevant-future – as Environmental LCC –, and any other externality that could be monetized or even those that are difficult to monetize and may therefore only be considered qualitatively. The damage costs of emissions are possible external costs belonging to the first group, while public health and social well-being could represent externalities to be qualitatively measured. By quantifying environmental effects on society in money terms, this tool could link environmental life cycle approaches to Corporate Social Responsibility, and effectively support institutional and political decision-making.

Modelling Life Cycle Costing for an innovative technology

LCC has been developed in order to evaluate the sustainability of an innovative technology. In particular, the research was aimed at applying a methodology complementary to LCA, so that results could be integrated within the logic of Life Cycle Sustainability Assessment (LCSA). Therefore, the approach used has led to apply the structure of LCA in order to define the Environmental LCC phases, as many previous studies have done to maintain consistency and comparability of results [26]. In particular, the Goal and Scope of this study is the assessment of the economic sustainability of an innovative technology for SiC production called TyGRe (High added value materials from waste tyre gasification residues), which employs the energy produced by treating waste tyres through a gasification reactor and a plasma torch reactor. Another product of this innovative technology is electricity. When assessing innovative technologies or innovative processes, the starting point is represented by the information about the pilot plant used to develop and test them. The Environmental LCC has been firstly developed for the pilot plant, and then, just for conventional costs, a methodological approach for the scale up to the industrial level has been proposed. To this purpose, two different scenarios have been considered: the reference scenario, and the innovative one.

As said above, the TyGRe technology is a multi-output system whose major outputs are SiC and the electricity produced by gasification of waste tyres. Following the principle that systems can be compared only if functions are the same, the two scenarios have been designed taking into consideration the multiplicity of outputs. Indeed, the reference scenario has included the production of energy by waste tyres currently used in cement kilns, the production of SiC by conventional technologies, starting from silica sand and coke, and, lastly, the production of electric energy in order to balance the part produced from gasification of tyres in TyGRe.

On the other hand, the innovative scenario has covered the generation of thermal energy from coke for the cement production, in addition to the functions of TyGRe delivering energy, electricity and, obviously, SiC.

It has to be noted that the costs to be considered in the two scenarios are not borne by a unique actor. Hence, it is complicated making the costs evaluation of the two scenarios by considering the perspective of all the subjects that bear costs. The purpose of this study is to assess the economic sustainability of TyGRe with respect to the reference scenario, namely to the conventional production system of SiC. The assessment of the economic convenience of cement factories in the alternative scenarios is not required. Therefore, the perspective chosen for this environmental LCC study is only the one of the SiC producer. The latter is represented by a producer using the TyGRe technology in the innovative scenario, and by the producer applying the conventional system, in the reference one. In particular, LCA data used for the reference scenario are related to the Acheson technology. Therefore, the latter is also the conventional process for the reference scenario of the eLCC. In Europe, this conventional technology is mainly implemented by Kollo Silicon carbide BV, which has been chosen as the reference producer company. Since, the SiC producer is the chosen perspective, the Functional unit has been defined as the production of 1 kg of SiC. Moreover, the conventional production system of SiC has represented the starting point for calculating life cycle costs, mostly in analogy with the structure and proportion of costs and assets of Kollo BV. In spite of that, relevant data needed to calculate eLCC were not easily available in both scenarios and their replacement has required making a number of assumptions.

The *Inventory analysis* has accounted costs at the unit process level. Since the objective of this case study refers to the technology, overheads have not been allocated to different products, but directly assigned to the technology itself. Inventory analysis starts from the study of all sub-processes and the definition of their requirements – inputs – and their outputs. The starting point is the table used for LCA inventory that provides a catalogue and quantification of the energy and materials used, as well as the environmental releases associated with all the processes included in the system boundaries.

Aggregating costs by cost categories is useful to structure the whole costs in various cost elements, in analogy to what happens in the systems of cost accounting business. The costs collected or estimated during the inventory are assigned to a given category of cost as a function of one or more criteria. Huppes et al. have identified four main categories to be used in sequence when making an environmental LCC: economic cost categories, life cycle stages, activity types, and other categories [27]. Since the available data mostly refers to market cost and overheads are all related to the TyGRe activity, only costs related to life cycle stages have been assumed to be relevant for this study. In particular, the Life cycle costs taken into account were those related to the stages of R&D, implementation, and operation because these phases have been assumed to be the most relevant in order to compare the innovative technology with the conventional one. Maintenance and EoL costs are important as well, but available data did not allow drawing valid hypothesis about their quantification. Moreover, since TyGRe has been designed to be innovative and, ideally, more sustainable, it seems reasonable to assume that TyGRe will require less maintenance and perform better in EoL than Kollo does.

The costs related to the above-mentioned stages of the life cycle are mainly those accounted within the balance sheet and the income statement of a company. The R&D phase includes costs of speculative research and investments in development. In this regard, it has been assumed that R&D activities for TyGRe mostly concern the development of the technology, then the related expenditure has been capitalised as intangible and analysed pro rata as annual depreciation, in accordance with the IAS 38. During the implementation, costs for plant and equipment and their installation are covered by capital mostly provided by lenders. In that phase, costs are represented by investments in tangible assets and long-term loans, which are annually accounted in the income statement as depreciation and financial charges, respectively. The production phase considers all operational costs, namely expenditures for production inputs, such as labour and raw materials, and services, such as utilities, transportation, administrative and commercialisation expenses. The expenditure for thermal energy has been accounted in order to balance costs among scenarios. Lastly, CO_2 emission costs have been integrated within the analysis as environmental externalities to be internalized by the producer at the current prevailing price of CO_2 in the European Union market.

In analogy with the LCA model, the last phase of eLCC structure is devoted to *Results interpretatio*n. Anyway, the analysis applied to the pilot plant has revealed that only a few costs may be accounted for the innovative scenario, and their entity is much lower than the costs included within the reference scenario. Therefore, the scale up to industrial level of values calculated for TyGRe pilot plant is needed in order to make a more concrete comparison between the two scenarios in terms of the economic sustainability of TyGRe.

Lack of information and data about all hardware components used to develop TyGRe, and about the proportional relationship that links their size and their price, has led the authors to scale up costs derived from the pilot plant in analogy to the costs resulting from the financial statement of Kollo BV. Another reason of this choice was that a lot of cost elements are hidden at a pilot plant size. For instance, administrative and commercial costs are not present in the small pilot plant, but must be included at an industrial level. Furthermore, personnel costs cannot be scaled up starting from those of the pilot plant because the latter generally involves only researchers.

The application of the analogy to estimate potential industrial costs of TyGRe has required some assumptions and several stages that have formed the scale-up. First of all, it has been assumed that the unitary cost for material remains constant when passing from a pilot plant to an industrial scale since the quantity of input required to produce the functional unit (1 kg of SiC) does not change. Secondly, it has been assumed that the industrial producer applying TyGRe will have a structure of production costs similar to that of Kollo BV because they procure some resources on the same market of production inputs, and they will employ personnel with similar characteristics. In addition, TyGRe will probably have to compete on the same market of Kollo BV. Therefore, TyGRe should have a total cost similar to the one related the Acheson technology (at least in percentage terms) in order to be competitive (i.e., economically sustainable) with the latter.

Supposing that the producer applying TyGRe for SiC production and Kollo BV will compete on the same market implies that they will also have the same operating marginality, usually expressed by the EBITDA (Earnings Before Interest Taxes Depreciation and Amortisation), which explicates the firm ability to generate profit in the future. This margin substantially consists in the revenue that remains after all operating costs have been covered, namely subtracted. The revenue is affected by plant capacity of production and the SiC price.

The price of SiC mostly depends on its quality or grade that defines its subsequent application. The main uses of SiC are the metallurgical industry, the production of several ceramic components and the abrasive sector, as well as some electronic applications. The grade of SiC largely varies among these sectors, as well as its price. In particular, SiC for metallurgical application, the grade with the lowest value, are quoted few euros per kg, while nanometric powder for electronic industry, the most expensive quality, has a price higher than € 100 for an equal quantity – and sometimes it can reach up to € 1.000. Sintering grade of SiC has an intermediate price, but closer to the one of abrasive applications. Kollo BV mostly produces SiC for metallurgical and abrasive applications. Engineers and technical researchers working at TyGRe hypothesise that this technology will produce a valuable grade of SiC regime. They have also set a capacity plant regime, and the time needed to reach this quantity. The latter also represents the volume of production used in order to calculate the ideal price of SiC starting from the revenue, which in turn has been estimated maintaining the operating marginality of Kollo BV.

After drawing assumptions and hypotheses, the first phase of the analysis has required the recognition of production costs by the income statement (profit & loss account) of Kollo BV. Data from statement refers to the 2007 fiscal year, but the volume of production of Kollo BV has been found for the year 2008. The costs taken into account are the same previously described concerning the life cycle stages considered for TyGRe, namely material costs, administrative and commercial costs, which also include utilities and transportation, costs of employees and depreciations. In particular, the percentage of these costs on their total amount has been calculated in order to define the cost structure to be used for the scale up. Once defined this structure, it has been possible to estimate the costs that were negligible for the pilot plant by applying the weight of each cost of Kollo to the costs of materials of TyGRE. The latter have been calculated dividing the unitary cost derived from the pilot plant of TyGRe for the related weight shown in cost structure of Kollo BV.

From the income statement of Kollo BV, it has also been possible to extract the EBITDA, and then, to calculate the percentage on revenue in order to estimate the turnover of the SiC producer applying TyGRe.

Results and discussion

Table 1 shows the cost structure of Kollo BV that has been calculated and used in order to scale-up to industrial scale the costs related to the pilot plant of TyGRe. The last column on the right shows the same structure of the pilot plant of TyGRe, for which administration and commercialisation costs have been considered as negligible.

	Kollo BV	Pilot Plant of TyGRe
Material costs	59.90%	21.83%
Adm&comm costs	18.14%	Not presented
Costs of employees	15.46%	30.57%
Depreciations	6.49%	47.60%
Interests paid	0.25% *	6.49% *

* The weight of the interests paid has been calculated but it has not been included in the summation to get the total production costs.

Table 1. Cost structure of production costs, comparison between Kollo BV and pilot plant of TyGRe

Applying the cost structure of Kollo BV to the total costs of materials for TyGRe has led to the conclusion that the industrial producer using TyGRe will have to bear a total cost about 16 times higher than that of Kollo BV. In spite of that, a major proportion has been revealed for revenue (about 19 times). Moreover, the analysis of revenue has shown that the value of each functional unit sold, which can be considered as a proxy of the SiC price, is twice that of the cheapest application, but it is lower than that of sintering grade. Therefore, these findings show that TyGRe technology is not economically sustainable if it is applied by companies operating on the market of the abrasive grade of SiC. However, each little improvement that TyGRe will be able to obtain with respect to the cheapest quality of SiC, it will be largely financially rewarded. If the application of TyGRe at industrial level could produce the sintering grade of SiC, TyGRe will likely be more economically sustainable than Kollo BV currently is on the market of abrasive SiC.

This study has calculated costs of CO_2 emissions in order to include environmental externalities in the decision-relevant-future as requested by the eLCC analysis. However, in the current phase of the study, eLCC has been calculated only for the innovative scenario, by including data from the pilot plant of Tygre. Table 2 presents the weight of different cost types on the total eLCC value, by including costs about balancing and environmental externalities.

Cost type	**Origin**	**Cost item**	**%**
Operational cost	Internal	Labour	28.7%
	External	Raw materials	3.2%
		Transportation	0.3%
		Utilities	17.0%
		Administrative	0.0%
		Commercialisation	0.0%
Depreciation		Intangibile	24,3%
		Tangible	20,4%
Financial charges			6,1%
CO_2 emissions	Direct	SiC Emissions	0.1%
eLCC			**100%**

Table 2. Weights of costs on the total eLCC of the pilot plant of TyGRe

As we can see from Table 2, CO_2 emissions costs have a low weight on the total eLCC costs. However, this result is of limited interest because it refers to the pilot plant of TyGRe and for this reason it is not comparable with the industrial scale of the reference scenario. Among the next steps, it will be necessary to make assumptions in order to properly scale up to the industrial scale the costs of CO_2 emissions of the TyGRe pilot plant, as well as to compute the amount of these costs for Kollo BV.

Conclusions

Environmental Life Cycle Costing is an effective method to assess the economic sustainability of products and it allows also including environmental externalities in the decision-relevant-future within the total cost. The objective of the study presented in this paper is to apply the eLCC method to an innovative technology which is currently in its research and development phase. As the technology is not implemented yet, there is no information at the industrial scale, but only data concerning the pilot plant could be found. At this size, some cost categories could be missing or negligible with respect to the industrial level (e.g. land rent) and others (e.g. labour cost) are much more relevant in the total cost due to lack of economies of scale and of experience. Therefore, some assumptions have been required in order to define a proper model for scaling-up this innovative technology to the industrial level. Because of that, the final result will suffer from the uncertainties related to the assumptions made and the approximations they required. Better accuracy of the data coming from pilot plant is necessary. At present, several data are secondary, i.e. coming from technical papers and not process-related. Optimization of the process or little changing in it could sensibly modify the data. Moreover, life cycle costs have not been entirely detected and estimated. For instance, EoL and disposal costs have not been calculated because this task can result very difficult in case of durable technologies or complex systems. Little attention has also been paid to possible economies of scale linked to the experience and the non-linear price of some equipment. Lastly, the impossibility to study the real system has led to overemphasize some cost items in addition to the many that have been neglected.

Despite such limitations, the analysis of LCC only in terms of internal costs has been effectively useful in order to understand possible strengths and weaknesses of TyGRe technology from the economic point of view. Indeed, it has emerged that the innovative technology could be more profitable than the conventional technology, if the TyGRe technology at the industrial level is devoted to producing a SiC grade with a better quality (hence, with a higher price). Indeed, TyGRe seems to economically perform better than Acheson in market where at least a sintering grade is requested. In this sense, taking into account a conventional producer of the sintering grade will allow making a more precise evaluation of the economic sustainability of the industrial level of TyGRe than the one emerged from this part of the study.

With regards to environmental externalities, the current findings are of limited usefulness because they refer only to the pilot plant of TyGRe and both the scale-up and the estimation of externalities for Kollo BV have not been developed yet.

Lastly, future research could integrate the analysis of all the costs associated with the life cycle of the innovative technology and that are borne by anyone in the society by applying the Societal LCC. The government perspective is useful and relevant when assessing systems that have direct and important impacts on population's health (public transport, waste disposal, etc.). However, very few societal LCC case studies have been proposed so far in the literature (see, e.g. [27]) because of, among others, the newness of this instrument, its undefined borders, and the possible overlapping with LCA and social LCA. In spite of that, starting from the environmental impacts calculated in the LCA study, it is already possible to give a preliminary assessment of the environmental externalities associated to TyGRe technology. Database such as the ones resulting from the EU projects ExternE and Exiopol, for instance, provide a monetary evaluation based on willingness-to-pay methods or market values. In particular, these projects estimate the impacts on human health of emission values of different sources by using the dose-response function. Similarly, accidents costs, energy security costs and other social costs or benefits could be estimated.

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Subcategory Assessment Method (SAM) for S-LCA: stakeholder “worker” and “consumer”

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Introduction

Social Life Cycle Assessment (S-LCA) is a technique to evaluate potential positive and negative social impacts along the life cycle of a product [1]. Similarly to an (environmental) LCA, S-LCA follows four phases: goal and scope definition, inventory analysis, impact assessment and interpretation; nevertheless it demands adaptations [2].

Going from data to impact assessment in S-LCA is still a challenge. UNEP and SETAC [1] have presented a contribution by providing a list of 31 subcategories related to 5 stakeholders (workers, consumers, local community, society and value chain actors). Not taking into account one of these subcategories needs to be justified, but new subcategories can be included. As for workers, 8 subcategories were listed: freedom of association and collective bargaining, child labour, forced labour, fair wages, working hours, equal opportunities and discrimination, health and safety, social benefits and social security.

Later on, methodological sheets for each of the subcategories were elaborated, including definition, contribution for the sustainable development, unit and even possible data sources [3]. Assessing these subcategories requires the use of performance reference points [1]. The use of the reference points is useful to understand the magnitude and the significance of the data collected in the inventory phase. One example is the use of the “occurrence of consumer complaints regarding the lack of feedback mechanism” as reference based on Global reporting definition [4]. Then these subcategories can be either be related to impact categories or stakeholder [1].

Over the years, two methods have been presented in the literature, which can be used for the stakeholder categories. The first is a framework for Social Life Cycle Impact Assessment defined and proposed by Dreyer, Hauschild and Schierbeck [5]. Years later, a characterization model based on multi-criteria indicators for the four subcategories of the stakeholder worker was defined by the same authors [6] (forced labour, discrimination, restrictions of freedom of association and collective bargaining and child labour). By that time, the authors named these subcategories as impact categories, but in this paper it has been chosen to use the definitions according to [1], which is stakeholder subcategory. Although the method is clear for the worker stakeholder, it is limited to this stakeholder.

The second method was proposed 2009 by Ciroth and Franze [7] including an assessment method to evaluate social impact based on UNEP and SETAC [1] which was further improved in 2011 [8]. It is a simple assessment method which evaluates either qualitative or quantitative data and transforms them into a quantitative evaluation for each subcategory through a rating scale (1 to 6), the former attributed to the best and the latter to the worst. Thereafter, these points are aggregated into impact categories, obtaining a single score [8]. This method was applied for a laptop which was one of the first applications involving almost all the subcategories in [1], except for the stakeholder consumer. On the other hand, how to go from data to the subcategory and how to aggregate subcategories into impact categories, is not clear.

Due to the limits of the method of [6] and [8], the objective of the current study is the proposition of a Subcategory Assessment Method (SAM) to reduce the variability of the evaluation of subcategories in the S-LCA studies. In this work, a proposal for the stakeholder worker and consumer is presented.

SAM

The Subcategory Assessment Method (SAM) for Social Life Cycle Assessment follows the subcategories presented by UNEP and SETAC [1] and the definitions and possible data source suggested in the methodological sheets [3]. SAM assesses the company perspective as suggested by Dreyer, Hauschild and Schierbeck [5], who affirm that companies have a responsibility for the people affected by their business activities, but are also able to compete and make a profit in order to survive in the marketplace. To provide a more objective assessment of the inventory indicators, SAM is based on a Likert scale, which is a measurement scale with a write verbal statement that express a range of positive and negative expressions to obtain the reliability required to use, analyze and interpret the data collected [9]. Generally, this scale varies from 4 to 11 levels and the most common are the 4 and 5 levels. SAM has four levels for each subcategory which enables analyzing the organization along the life cycle in four classes (A, B, C and D) according to its behaviour. The basic requirement (BR) is defined for each subcategory, based on International Agreements as suggested in the methodological sheets [3]. In this method the basic requirement plays the role of reference point. Class B is when the organization applies the BR, for instance, complying with the law. Fulfilling Class A means that the organization shows a proactive behaviour compared to the BR, which may be: the organization promotes that it suppliers have the same actions related to BR. Classes C and D identifies the organization that does not meet the BR and are differentiated due to the context, as generic data of the sector or region; which provides background information concerning the possibility of the environment to have a positive outlook on social issues and where generic data is not available, it is defined on the basis of organization information. An example, if there are two organizations, but one of them is in a region (country) where there is no incentive to attend the BR, this organization is classified in C.

SAM for stakeholder worker

For workers, the BR was defined according to Conventions of the International Labour Organization [10] (Table 1).

For example, when analyzing the subcategory "Freedom of association and collective bargaining", the BR is to find evidence that employees of the organization are associated with a union (at least one), as the ILO Convention n.87 [10]. Therefore, during the evaluation process, if this requirement is fulfilled, the organization is classified as B. Furthermore, if the organization presents a proactive behaviour, for example, influencing their suppliers to adopt the same action described by the BR, it will be classified as A. For this subcategory, the difference between C or D classification depends on the Worker Rights Score (Worker Rights Score - WRS) in the country where the organization is located.

The WRS is an indicator used by CIRI Human Rights dataset [11] and refers to the right of collective bargaining, the right to minimum working conditions, freedom of assembly and association, including the rights of citizens to assemble freely and associate with other people in political parties, trade unions, cultural organizations, or other groups. This index ranges from 0-4, with the lowest score considered worst conditions, and the highest score, the best ones. In the present method, the countries were split in two levels: those that are scored from 0 to 2 (bad WRS) and those scored from 3 to 4 (good WRS). Therefore, an organization that does not fulfil the BR in a country with good WRS is classified as D. Otherwise, in C.

For the subcategory child labour, the BR is when the organization has no child labour. Child labour is defined by ILO Convention n.138, as being for developed countries age for admission to employment under 15 years; and for developing and least developed countries age for admission to employment under 14. To be classified as A, the organization promotes fulfilling the BR throughout the suppliers. Class C identifies the organization which presents child labour, which is not defined as worst child labour by ILO Convention 182 [10], and the child who works attends school. On the other hand, in D.

The BR, for the subcategory fair salary, is when the organization pays a worker`s wage equal to the minimum wage based on the country/sector where the organization is located, according to the ILO Convention n. 131 [10]. Class A identifies the organization which promotes fulfilling the BR throughout the suppliers. For the differentiation between C and D, it was decide to use two indicators: “GDP on a purchasing power parity basis divided by population” (I) and “living wage x purchasing power parity conversion factor”(II).I is defined by the World Bank [13] and observe the per-capita welfare and compare living conditions or use of resources across countries. II was created in order to compare the GDP on a purchasing power parity basis divided by population with the living wage. This indicator was created with base in the concept of living wage from Citizansuk [14], considering: hourly rate = 7.85 GBP, average weekly hour worked equal to 39.4 (average weekly hours worked in United Kingdom [12]), per month of 4 weeks, 12 months as well as 13th moth bonus and holiday pay.

This value was translated into the country currency through average currency exchange for the year 2010. Moreover, this value was multiplied by the Purchasing power parity conversion factor (PPP conversion factor) of the corresponding country. The difference between I and II tries to characterize the country context. A positive context is defined when the country has I higher than II, in this case the organization classification is D. Otherwise, it is classified as C.

For the subcategory working hours, the BR is when the organization workers have an average weekly hours equal to 48 and 8 hours per day, according to ILO Convention n. 1 and 30 [10], or respect the national law for the work type. To be classified as A, the organization promotes fulfilling the BR throughout the suppliers. If the organization does not meet the BR, it can be classified as C or D. It is classified as C if the organization has an average weekly hour worked lower than the average weekly hours worked for the sector/country. If it is higher, in D.

The BR, for the subcategory forced labour, is when the organization has no evidence of forced labour, in compliance to ILO Convention n.29 and n.105. Class A identifies the organization which promotes fulfilling the BR throughout the suppliers. If the organization does not meet the BR, it can be classified as C or D. Class C identifies the organization which is located has forced labour presence. Otherwise, in D.

For the subcategory equal opportunities/discrimination, the BR is when the organization has a management system, policy or actions to prevent discrimination and promotes equal opportunities for workers, according to the ILO Convention n.100, 111 and 169 [10]. Furthermore, if the organization presents a proactive behaviour, for example, influencing their suppliers to adopt the same action described by the BR, it will be classified as A. For this subcategory, the difference between C or D classification depends on the gender equity index (GEI) in the country where the organization is located. GEI is an indicator from the United Nations Development Programme [15], which measures gaps in women`s participation in the labour market and salaries earned by them as compared to men. This index ranges from 0- 100, with the highest score considered worst conditions, and the highest score, the best ones. In the present method, the countries were split in two levels: those that are scored from 0 to 49 (worst conditions) and those scored equal or higher to 50 (good conditions). Therefore, an organization that does not fulfil the BR in a country with good conditions is classified as D. Otherwise, in C.

The BR, for the subcategory health and safety, is when the organization meets the national law related to health and safety, in compliance to ILO Convention n.115, 161 [10]. Moreover, if the organization presents a proactive behaviour, for example, influencing their suppliers to adopt the same action described by the BR, it will be classified as A. For this subcategory, the difference between C or D classification depends on the rates of fatal injuries and occupational fatal injuries, according to ILO Convention 115, 161 [10], The organization is classified as C if the occupational accidents of the organization (fatal and no fatal) is lower than occupational accidents (fatal and no fatal) of the country/sector where the organization is located. If it is higher, in D.

For the subcategory social benefits/social security, the BR is when the organization provides to its workers more than 2 social benefits suggested by the ILO Convention n.130, 134, 128, 121, 168, 118, 157 and 183 [10] listed in Table 1. Class A identifies the organization which promotes fulfilling the BR throughout the suppliers. If the organization does not meet the BR, it can be classified as C or D. Class C identifies the organization which provides to its workers at least 2 social benefits listed in Table 1. Class D identifies the organization which provides any social benefits to its workers or it has presence of worker without an employment contract.

Subcategory	Basic requirement	Class C	Class D	Additional Information
Freedom of association and collective bargaining	In the organization there is evidence of workers being associated in the workers' union.	Worker rights score of the country where the organization is located is between [0; 2.9].	Worker rights score of the country where the organization is located is between [3; 4].	"Freedom of association and collective bargaining basic requirement" is based on the ILO Convention 87. Worker rights score is an indicator used by CIRI Human Rights [11], which assesses the workers' rights, The raw data range from 0 to 4, with a low score being the worst situation [12].

Table 1. Method classification to the stakeholder worker (to be continued)

Subcategory	Basic requirement	Class C	Class D	Additional Information
Child Labour	For developed countries Minimum Age for Admission to Employment is 15. For Developing and least developed countries, the Minimum Age for Admission to Employment is 14.	There is evidence of child labour in the organization, but it is not defined as the "worst forms of child labour"; and the child attends school.	There is evidence of child labour defined in the "worst forms of child labour" or the child does not attend school.	"Child labour basic requirement" is based on the ILO Convention 138. The worst forms of Child Labour are based on the ILO Convention 182 and Recommendation 190 [10]. Any type of work which can be identifying on the ILO Convention 182 is defined as the "worst forms of child labour".
Working hours	Average weekly hours equal to 48 and 8 hours per day or limitations according to the national law.	The Average weekly hours worked is higher than 48 and lower than the average weekly hours worked for the sector/country	The Average weekly hours worked is higher than 48 and higher than the average weekly hours worked for the sector/country	"Working hours basic requirement" is based on the ILO Convention n.1, n.30 and Recommendation n.116 [10]. Average weekly hours worked for the sector/country [12].
Fair Salary	The worker's wage is equal to the minimum wage based on the country/sector where the organization is located.	The country has "GDP on a purchasing power parity basis, divided by population" smaller than the "living wage x purchasing power parity conversion factor"	The country has "GDP on a purchasing power parity basis, divided by population" higher than the "living wage x purchasing power parity conversion factor".	GDP on a purchasing power parity basis divided by population [13]. "living wage"- An hourly rate, set independently, every year [14] for 2010 equal to 7.85 GBP, "Purchasing power parity conversion factor"[13]. "living wage x purchasing power parity conversion factor": is based on living wage considering: average weekly hour worked equal to 39.4 (average weekly hours worked in United Kingdom, per month of 4 weeks, 12 months (average for one year of work), as well as 13^{th} month bonus and holiday pay. This value was translated into the country currency through the average currency exchange for the year 2010. Moreover, this value was multiplied by the Purchasing Power Parity conversion factor (PPP conversion factor) of the corresponding country.
Forced labour	The organization has no evidence of forced labour.	The organization has evidence of forced labour as well as the country where the organization is located.	The organization has evidence of forced labour and the country where the organization is located has no presence of forced labour.	"Forced labour basic requirement": based on ILO Convention n.29 and n.105 [10]. Presence of forced labour in the country [12].
Equal opportunities/ discrimination	The organization has a management system, policy or actions to prevent discrimination and promotes equal opportunities for workers.	The organization has evidence of discrimination and the country where the organization is located has a GEI score lower than 50.	The organization has evidence of discrimination and the country where the organization is located has a GEI score equal to or higher than 50.	"Equal opportunities/Discrimination basic requirement" is based on ILO Convention n.100, n.111 and n.169 [10]. The economic dimension of the gender equity index (GEI) measures gaps in women's participation in the labour market and in salaries earned by them as compared to men [15].
Health and Safety	The organization meets the national law related to health and safety.	Occupational accidents of the organization (rates of injuries and occupational injuries) are smaller than the Occupational accidents of the country/sector (rates of injuries and occupational fatal injuries) where the organization is located.	Occupational accidents of the organization (rates of injuries and occupational fatal injuries) are equal or higher than the Occupational accidents of the country/sector (rates of injuries and occupational fatal injuries) where the organization is located.	Basic requirement based on ILO Convention n. 115, n. 161, Recommendation n.164 [10]. Occupational accidents of the country/sector (rates of injuries and occupational fatal injuries) definition ILO Convention 115, 161, R164 [10] – data available [12].

Table 1. Method classification to the stakeholder worker (to be continued)

Subcategory	Basic requirement	Class C	Class D	Additional Information
Social benefits/ social security	i. Countries having a healthcare public system (Social benefits/social security Basic Requirement Social Security benefits (more than 2): Retirement, Disability, Dependents, Survivors benefits, Paid maternity and paternity leave (parental leave), Paid sick leave, Education and training.) ii. Countries which have a healthcare public-private system or private system (Social benefits/social security Basic Requirement Social Security benefits (more than 2): Retirement, Disability, Dependents, Survivors benefits, Medical insurance, Dental insurance, Paramedical insurance including preventive medicine, Medicine insurance, Wage insurance, Paid maternity and paternity leave (parental leave), Paid sick leave, Education and training.)	The organization fulfils at least 2 items of the Social benefits/social security basic requirement.	The organization does not fulfil any item of the Social benefits/social security basic requirement or the organization has workers without an employment contract.	Social benefits/social security basic requirement is defined based on the ILO Conventions n.130, n.134, n.128, n.121, n.168, n.118, n.157, and 183 [10].

Table 1. Method classification to the stakeholder worker

SAM for stakeholder consumer

SAM includes the 5 subcategories (health and safety, feedback mechanism, consumer privacy, transparency, end of life responsibility) from the stakeholder consumer presented in UNEP and SETAC [1]. Only consumers of the final product are taking into account.

For this stakeholder, the BR is based on International Agreements, such as ISO 26000 [16], GRI [4] and Consumer Protection Act [17] (Table 2).

For instance, the BR of the consumer privacy subcategory is evidence of protection of the consumer's right to privacy in the organization policy, according to the Universal Declaration of Human Rights, Article 12 [18], Consumer Protection Act [17]. As for example provided to the stakeholder worker, to be classified as A, the organization promotes fulfilling the BR throughout the suppliers. The differentiation between C and D was established considering the score of the country where the organization is located according to the Privacy International Ranking Score (from 1.1 to 5) [19]. In SAM, the countries were split into two levels: those that are scored from 1.1 to 3 (I) and those that are scored from 3.1 to 5 (II). Countries classified as I are those with the worst conditions regarding the national privacy ranking. Those organizations located in countries in I are classified as C because it is in accordance to the country context. Otherwise, the organization which is in a country where the context is adequate is classified as D.

The BR, for the health and safety subcategory, is when the organization is in compliance with the national law regarding consumer product health and safety standards. The situation proves to be better if the organization fulfils the BR and promotes the same actions involving the suppliers (Class A). If the organization does not meet the BR, it can be classified as C or D. It is classified as C if the organization does not have proven cases that violate consumer health and safety. If the organization has proven cases it is then classified as D.

For the subcategory feedback mechanism, the BR is when the organization has customer feedback mechanism and practices related to customer satisfaction. It includes all the following practices: suggestion box on the help desk, conducting customer satisfaction surveys, providing a complaint service or a section on the website. The situation improves if the organization fulfils the BR and promotes the same actions involving the suppliers/value chain. If the organization does not meet the BR, it can be classified as C or D. If there is no record of consumer complaints regarding the lack of Feedback mechanism, it is classified as C. If on the contrary, there is a record of consumer complaints regarding the lack of Feedback mechanism, it is classified as D.

The BR, for the transparency subcategory, is when the organization has a report that communicates the social responsibility. For example: Corporate Social Responsibility (CSR), Social Balance Report, Global Reporting Initiative (GRI), Accountability 1000,Social Accountability 8000, ISO 26000. If the organization meets the BR and promotes the same actions involving the suppliers, the organization presents a proactive behaviour (Class A). If the organization does not meet the basic requirement, it can be classified as C or D. If the organization has no formal report that communicates the social responsibility, but can show its technologies, good practices and management conduct to its consumers, it is classified as C. For example: through events or web site information. If the organization has neither a formal report to communicate its social responsibility nor ways to show its technologies, good practices and management conduct to its consumers, it is then classified as D.

The BR regarding the End of Life Responsibility subcategory is the presence, within the organization, of management systems which provide clear information on end-of-life options to consumers. For example: Product Responsibility Performance Indicators, PR4 (GRI 2006) or recall policy for its product on end-of-life phase (for example battery cases, glass bottle). If the organization promotes fulfilling the BR throughout the suppliers, the organization is classified as A. If the organization does not meet the BR, it can be classified as C or D. If there are no internal management systems which provide clear information on end-of-life options to consumers, but the product at its end of life may be recycled by the municipal waste collection, it is classified as C. If there are no formal management systems on end-of-life options and the municipal waste collection system does not provide for recycling product at end of life, for example batteries, the organization is classified as D.

Subcategory	Basic requirement	Class C	Class D	Additional Informational
Consumer privacy	The organization protects the consumer's right to privacy through a privacy policy.	The organization does not meet the basic requirement; and the country where the organization is located has Privacy International Ranking score [1.1; 3].	The organization does not meet the basic requirement; and the country where the organization is located has Privacy International Ranking score [3.1; 5].	Basic requirement was based on Universal Declaration of Human Rights [18], Consumer Protection Act. Privacy [17], International Ranking Score [19].
Health and safety	The organization is in compliance with national law regarding consumer product health and safety standards.	The organization does not meet the basic requirement, but has no proven cases that violate the consumer health and safety.	The organization does not meet the basic requirement; and has presence of proven cases that violate the consumer health and safety.	Basic requirement was based on the definition of the methodological sheets [3], which states that each country has its own consumer product safety standards and other safety requirements for consumer's products.
Feedback mechanism	The organization has customer feedback mechanism and practices related to customer satisfaction. It provides all the following practices: suggestion box on help desk, customer satisfaction surveys, complaint service and/or section on the website.	The organization does not meet the basic requirement and there is no record of consumers complaints regarding the lack of Feedback mechanism.	The organization does not meet the basic requirement and there is record of consumers complaints regarding the lack of Feedback mechanism.	Basic requirement was based on the global reporting initiative definition [4].
Transparency	The organization has a report that communicates the social responsibility. For example: Corporate Social Responsibility (CSR), Social Balance Report, Global Reporting Initiative (GRI), Accountability 1000,Social Accountability 8000, ISO 2600.	The organization does not meet the basic requirement, but it has ways of showing their consumer technologies, good practices and management conduct. For example: through events or web site information.	The organization does not have a report that communicates the social responsibility nor ways of showing their consumers technologies, good practices and management conduction.	Basic requirement was based on the definition of the methodological sheets [3], which states that: "It is essential that consumers are informed about the impacts of a product/organization/site in order to assume responsibility for their consumption".
End of life responsibility	There are internal management systems that provided clear information to consumers on end-of-life options. For example: Product Responsibility Performance Indicators, PR4 or recall policy for its product on end-of-life phase (for example: battery cases, glass bottles).	The organization does not meet the basic requirement; but the end of life product can be considered recycled by the municipal selective collection.	The organization does not meet the basic requirement; and the end of life product is not recycled by the municipal selective collection. For example: batteries.	Basic requirement was based on the definition of the methodological sheets [3] and ISO 2600 [16].

Table 2. Method classification to the stakeholder consumer

Final remarks

Nowadays, there is no clear method to go from social inventory indicators to subcategories in an S-LCA. In this study, a method is proposed based on the book from UNEP and SETAC and methodological sheets for consumers and workers. SAM establishes a basic requirement for each subcategory, which is constructed with indicators suggested by the methodological sheets. Those requirements define the four assessment classes (A, B, C and D). The classes C and D consider the country context to differ behaviour organizations which cannot reach the basic requirement. Therefore, the method shows to be objective in analyzing the organization behaviour over the life cycle of products.

Future development of SAM will include the remaining subcategories, adapting the basic requirement for each of them.

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Life-cycle methods as design tools for sustainability assessment of technologies

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Keywords: Life Cycle Assessment, costs, building technology, energy performance

Introduction

In the building sector, technology is essential for establishing an integrated design approach and to achieve an overall sustainable performance (environmental, social and economic).

However contractors, owners and designers are often at issue over the cost of sustainable projects. Moreover, in the last two decades, a variety studies arose to include the social and environmental effects into economic evaluations.

The aim of the research is to compare building components and select the more environmentally sound solution for the best price. In addition, the results of a research for €CO Tool, an assessment model based on the integration of LCA and LCC [1] are applied to a case study.

Materials and methods

The case study is represented by TEA spa Headquarters. A complex of three buildings for a public company supplying water, power and environmental service for the city of Mantua, Italy (Fig. 1). The green roof is the defining element of the design developed by the project team BV Srl and PAT. associates [2, 3].

Fig. 1. Case study. Building complex of TEA (water, power and environmental service company)

In order to evaluate the best solution for the building envelope, the study has included all the key elements of the project, such as: natural ventilation, green roof, low environmental impact on the existing context, low budget. Methods of impact assessments and functional unit take into account:

- LCA impacts linked on GWP and CED
- Costs in the service life of the building
- Periodical Transmittance (Y_{IA}) and Thermal Resistance (R-Value)

Results and discussions

€CO tool is applied for the assessment (Fig. 2 on the right). The model is based on a economic-environmental efficiency factor combining the effects of environmental impact of the building components with its overall costs through the entire live cycle.

Afterwards, different methods, coming from published international researches, have been applied and implemented to evaluate potential options for the TEA building roof's envelope in order to validate and verify the outcome of €CO model. Three alternative approaches are built.

A. Monetisation

Methods based on the monetization of externalities, as the European ExternE Project [4] and the Swedish EPS method [5] were taken into consideration. The EPS 2000 was used to make an economical assessment of the damage.

B. Integration of LCA and LCC

Originated from an intersection of scientific studies that take into account environmental and health impacts without weighting them, such as *SETAC Environmental LCC* [6] and *CES Selector* (the methodology developed by Mike Ashby of Cambridge University) [7].

In the bubble diagram (Fig. 2 on the left) the GWP is on the x axis, CED is on the y axis, while the costs are represented by the bubble size. The functional unit is the same for both LCA and LCC.

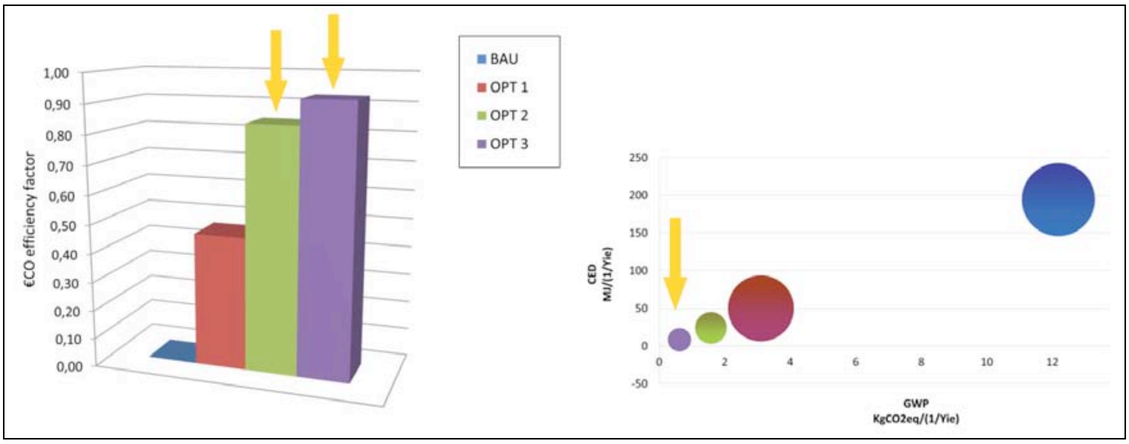

Fig. 2. €CO diagram compared with bubble diagram for the evaluation of costs, Carbon dioxin emissions and energy required(CED). The functional unit includes energy performance of each building technology options

C. Marginal Abatement Cost Curve

Based on the application of the Emission Trading [8], market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. The research tries to shift this approach to the construction market applying the Marginal Abatement Cost Curve (MAC), which is the cost of eliminating an additional unit of pollution.

Conclusions

Comparing the results obtained through €CO model with the methods described, it is possible to affirm that the scale of values is substantially unaltered. Main research findings can be summarised below:

- Providing an innovative contribution in sustainable architecture, through the development of new synthetic indicator €CO
- Implementing the integration of LCA and LCC for the development of environmentally friendly design practices.
- Ensuring that stakeholders involved in the design process (owners, suppliers, designers, etc.) can make decisions on the base of price/quality ratio, including environmental aspects into the "quality" concept.

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An Improved Grey Relation Analysis for Technologies Selection based on Life Cycle Sustainability

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Keywords: Grey Relational Analysis, Grey Number, Technology Selection, Life Cycle Sustainability

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Introduction

In the highly competitive global scenarios, technology selection and justification involve decisions and choices that are critical to the profitability and growth of a company [1].

With depletion of resource, the shortage of energy and the pollution to the environment, the technology which has the best performance on sustainability attracts more and more useful concept to measure the sustainability of such technologies. LCSA is an LCA, a life cycle costing (LCC) and a social life cycle analysis (SLCA), done in a consecutive way: LCSA=LCA+LCC+SLCA [2].

LCA, LCC and SLCA can be used to measure the performances of the technology in environmental, economic and social aspects respectively. However, owing to the availability and uncertainty, it is difficult to obtain the exact assessment data such investment cost which has been usually in LCC [1]. Furthermore, LCA will involve significant uncertainties concerning data, models and practitioner's choice [3]. And SLCA which concerns social aspect is the most difficult to present quantified results. Consequently, it is difficult to provide exact and quantified results when LCSA has been selected to measure the sustainability of the technologies. But it is possible for the decision-makers to evaluate the technologies using linguistic terms such as "very good", "bad", "very bad" ,et al. The importance of the LCA, LCC and SLCA in the judgment of sustainability of technology can also be evaluated by linguistic terms.

Grey analysis has been widely used to evaluate and analyze the performance of the complex systems with various correlated indicators [4]. Many researchers had used grey analysis as a tool for sustainability assessment, for instance Baskaran et al. had used grey approach to evaluate the Indian textile suppliers' sustainability [5].

In this paper an improved grey relation analysis has been developed to select the best technology based on life cycle sustainability assessment and to avoid the problems relevant to uncertainty of data used for evaluation It allows decision-makers to give linguistic assessment on the technologies, after the linguistic assessment have been transformed into grey numbers, then the improved grey relation analysis can be used to rank the priorities of the alternatives.

Method

The grey relation analysis can easily reflect the preferential order of different investigated objects according to a certain performance [4]. The traditional Grey Relation Analysis has been shown as follows (from step 1 to step 6) [6].

Traditional Grey Relation Analysis

Step 1: Establish the decision making matrix (X), assuming that there are m alternative characterized by n criteria.

$$X = \begin{vmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & & x_{mn} \end{vmatrix} \tag{1}$$

Where x_{ij} represents the value of the (j)th criterion of the (i)th alternative

Step 2: Normalize the data in the decision making matrix, the methods for data processing should be chosen according to the types of the criteria: benefit criteria are the ones with positive impacts (the larger the better type), cost criteria are the ones with negative impacts (the smaller the better).

Benefit criteria can be processed as follows:

$$y_{ij} = \frac{x_{ij} - \min_{i=}^{m}\left\{x_{ij}\right\}}{\max_{i=}^{m}\left\{x_{ij}\right\} - \min_{i=}^{m}\left\{x_{ij}\right\}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{2}$$

Cost criteria can be processed as follows:

$$y_{ij} = \frac{\max_{i=}^{m}\left\{x_{ij}\right\} - x_{ij}}{\max_{i=}^{m}\left\{x_{ij}\right\} - \min_{i=}^{m}\left\{x_{ij}\right\}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{3}$$

Step 3: Generate the reference alternative. The reference alternative in this method is referred as the best alternative.

First of all, to generate the reference alternative, the normalized matrix is to be determined using Eq.2 and Eq.3. The result is shown in Eq.4.

$$Y = \begin{vmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & & y_{mn} \end{vmatrix} \tag{4}$$

Then the reference alternative can be determined by using Eq.5 and Eq.6

$$y^0 = \left\{y_1^0, y_2^0, \cdots, y_n^0\right\} \tag{5}$$

$$y_j^0 = \max_{i=1}^{m} y_{ij}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{6}$$

Where y_j^0 is the reference value in relation to the (j)th criterion and determined by the largest normalized value of each criterion.

Step 4: Calculate the difference between the alternatives and the reference alternative, and construct the difference matrix.

The difference matrix has been shown in Eq.7, and the elements in the difference matrix can be calculated by Eq.8.

$$\Delta = \begin{vmatrix} \Delta_{11} & \Delta_{12} & \cdots & \Delta_{1n} \\ \Delta_{21} & \Delta_{22} & \cdots & \Delta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \Delta_{m1} & \Delta_{m2} & & \Delta_{mn} \end{vmatrix} \tag{7}$$

$$\Delta_{ij} = \left| y_j^0 - y_{ij} \right|, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{8}$$

Step 5: Calculate the grey relational coefficient for each alternative. The formulation for the calculation of grey relational coefficient has been shown in Eq.9.

$$\varepsilon_{ij} = \frac{\min_{i=1}^{m} \min_{j=1}^{n} \Delta_{ij} + \rho \times \max_{i=1}^{m} \max_{j=1}^{n} \Delta_{ij}}{\Delta_{ij} + \rho \times \max_{i=1}^{m} \max_{j=1}^{n} \Delta_{ij}} \tag{9}$$

Where ρ represents the distinguishing coefficient. In most situations, ρ takes he value of 0.5 because of the moderate distinguishing effects and good stability. [4]

Step 6: Calculate the grey relational degree. A grey relational degree is a weighted sum of the grey relational coefficients.

$$\gamma_i = \sum_{j=1}^{n} \varepsilon_{ij} \times \omega_j \tag{10}$$

Where ω_j represents the weight of the (j)th criterion.

When the grey relational degrees of the alternatives have been calculated, the sequence of the alternatives can be obtained according to the rule that the bigger the grey relational degree, the better is the corresponding alternative.

The traditional grey relation analysis which can only deal with the problems with crisp values does not have the ability to analyze the problems with interval grey number. The improved grey relation analysis has been developed to address the problems concerns interval numbers.

Improved Grey Relation Analysis

In this paper, an improved grey relational analysis has been presented, the proposed methodology can be used to address the uncertainty problems and evaluate the performance on LCA, LCC, SLCA without data. The experts and decision-makers can give qualitative evaluation on LCA, LCC, and SLCA of the technologies once the boundaries have been determined according to their experience, and if the data about LCA, LCC, and SLCA can be obtained, it can also be referenced by the decision-makers.

Grey number is not sufficient to represents complete information, as it is represented by a range instead of crisp value [7]. A grey number x denotes by $\otimes x$

$$\otimes x = \left[x^{-}, x^{+}\right] \tag{11}$$

Where x^-, x^+ represent the lower and upper bound of the interval.

Grey number arithmetic operations

Let $\otimes x_1$ and $\otimes x_2$ be two grey numbers, a be a crisp number

$$\otimes x_1 = \left[x_1^{-}, x_1^{+}\right] \tag{12}$$

$$\otimes x_2 = \left[x_2^{-}, x_2^{+}\right] \tag{13}$$

Grey number addition

$$\otimes x_1 + \otimes x_2 = \left[x_1^{-}, x_1^{+}\right] \bar{+} \left[x_2, x_2^{+}\right] = \left[x_1^{-} + x_2^{-}, x_1^{+} + x_2^{+}\right] \tag{14}$$

Grey number subtraction

$$\otimes x_1 - \otimes x_2 = \left[x_1^{-}, x_1^{+}\right] \bar{-} \left[x_2, x_2^{+}\right] = \left[x_1^{-} - x_2^{+}, x_1^{+} - \bar{x}_2\right] \tag{15}$$

Grey number multiplication

$$\otimes x_1 \otimes x_2 = \left[\min\left\{x_1^{-}x_2^{-}, x_1^{-}x_2^{+}, x_1^{+}x_2^{-}, x_1^{+}x_2^{+}\right\}, \max\left\{x_1^{-}x_2^{-}, x_1^{-}x_2^{+}, x_1^{+}x_2^{-}, x_1^{+}x_2^{+}\right\}\right] \tag{16}$$

Grey number division

$$\frac{\otimes x_1}{a} = \left[\frac{x_1^{-}}{a}, \frac{x_1^{+}}{a}\right] \tag{17}$$

$$\frac{a}{\otimes x_1} = \left[\frac{a}{x_1^{+}}, \frac{a}{x_1^{-}}\right] \tag{18}$$

Where $x_1^{-} > 0, x_2^{-} > 0, x_1^{+} > 0, x_2^{+} > 0, a > 0$

The improved grey relation analysis with grey numbers has been developed, as shown from step 1 to step 7. The traditional grey analysis has been popularized to address interval problems; it is a method combining both qualitative and quantitative evaluations to rank the alternatives.

Step 1: Establish the grey decision making matrix (X), assuming that there are m alternative characterized by n criteria.

$$\otimes X = \begin{vmatrix} \otimes x_{11} & \otimes x_{12} & \cdots & \otimes x_{1n} \\ \otimes x_{21} & \otimes x_{22} & \cdots & \otimes x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes x_{m1} & \otimes x_{m2} & & \otimes x_{mn} \end{vmatrix} \tag{19}$$

$$\otimes x_{ij} = \left[x_{ij}^{-}, x_{ij}^{+} \right], i = 1, 2, \cdots, m; j = 1, 2, \cdots, n \tag{20}$$

Where $\otimes x_{ij}$ represents the value of the (j)th criterion of the (i)th alternative

Step 2: Normalize the data in the decision making matrix, the methods for data processing should be chosen according to the types of the criteria. Benefit criteria and cost criteria can be processed by Eq.21 and Eq.22, respectively.

$$\otimes y_{ij} = \frac{\otimes x_{ij}}{\max_{i=1}^{m} \left\{ x_{ij}^{+} \right\}}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n \tag{21}$$

$$\otimes y_{ij} = \frac{\min_{i=1}^{m} \left\{ x_{ij}^{-} \right\}}{\otimes x_{ij}}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n \tag{22}$$

Step 3: Generate the reference alternative, the normalized matrix has been shown in Eq.23, and the reference alternative can be determined by Eq.24 and Eq.25.

$$\otimes Y = \begin{vmatrix} \otimes y_{11} & \otimes y_{12} & \cdots & \otimes y_{1n} \\ \otimes y_{21} & \otimes y_{22} & \cdots & \otimes y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes y_{m1} & \otimes y_{m2} & \cdots & \otimes y_{mn} \end{vmatrix} \tag{23}$$

$$y^{0} = \left\{ y_{1}^{0}, y_{2}^{0}, \cdots, y_{n}^{0} \right\} \tag{24}$$

$$\otimes y_{j}^{0} = \max_{i=1}^{m} y_{ij}^{+}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n \tag{25}$$

Where y_{j}^{0} is the reference value in relation to the (j)th criterion

Step 4: Calculate the difference between the alternatives and the reference alternative, and construct the difference matrix by Eq.26 and Eq.27.

$$\otimes\Delta = \begin{vmatrix} \otimes\Delta_{11} & \otimes\Delta_{12} & \cdots & \otimes\Delta_{1n} \\ \otimes\Delta_{21} & \otimes\Delta_{22} & \cdots & \otimes\Delta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes\Delta_{m1} & \otimes\Delta_{m2} & & \otimes\Delta_{mn} \end{vmatrix} \tag{26}$$

$$\otimes\Delta_{ij} = \left[y_j^0 - y_{ij}^+, y_j^0 - y_{ij}^- \right], i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{27}$$

Step 5: Calculate the grey relational coefficient for each alternative by Eq. 28, Eq.29 and Eq.30.

$$\otimes\varepsilon_{ij} = \left[\varepsilon_{ij}^-, \varepsilon_{ij}^+ \right] \tag{28}$$

$$\varepsilon_{ij}^- = \frac{\min_{i=1}^m \min_{j=1}^n \Delta_{ij}^- + \rho \times \max_{i=1}^m \max_{j=1}^n \Delta_{ij}^+}{\Delta_{ij}^+ + \rho \times \max_{i=1}^m \max_{j=1}^n \Delta_{ij}^+} \tag{29}$$

$$\varepsilon_{ij}^+ = \frac{\min_{i=1}^m \min_{j=1}^n \Delta_{ij}^- + \rho \times \max_{i=1}^m \max_{j=1}^n \Delta_{ij}^+}{\Delta_{ij}^- + \rho \times \max_{i=1}^m \max_{j=1}^n \Delta_{ij}^+} \tag{30}$$

Where ρ represents the distinguishing coefficient, it takes the value of 0.5 in this paper.

Step 6: Calculate the grey relational degree. A grey relational degree is a weighted sum of the grey relational coefficients, as shown in Eq.31.

$$\otimes\gamma_i = \sum_{j=1}^n \otimes\varepsilon_{ij} \times \otimes\omega_j \tag{31}$$

Where $\otimes\omega_j$ represents the grey weights of the (j)th criterion

Step 7: Whiten the grey relational coefficients and rank the alternatives. The final relational coefficients can be calculated by Eq.32 and Eq.33, and the bigger the final relational coefficient, the better the corresponding alternative

$$\otimes\gamma_i = [\gamma_i^-, \gamma_i^+] \tag{32}$$

$$\gamma_i = \frac{\gamma_i^- + \gamma_i^+}{2} \tag{33}$$

Where $\otimes\gamma_i$ and γ_i represent the grey relational coefficient and final relational coefficient of the i(th) alternative respectively.

Framework of technology selection by improved grey relation analysis

The framework of technology selection by improved grey relation analysis has been shown in Figure 1. When the alternative technologies have been determined, then LCC, LCA and SLCA have been used to analyze the alternatives, with the results, the decision-makers can give linguistic assessments on each alternative according to the scale of grey number for the assessment of the alternative in LCC, LCA and SLCA aspects as shown in Table 1. If the exact data about LCC, LCA, and SLCA can not be obtained or can not be obtained completely due to uncertainty problems, decision-makers can evaluate according to their experience.

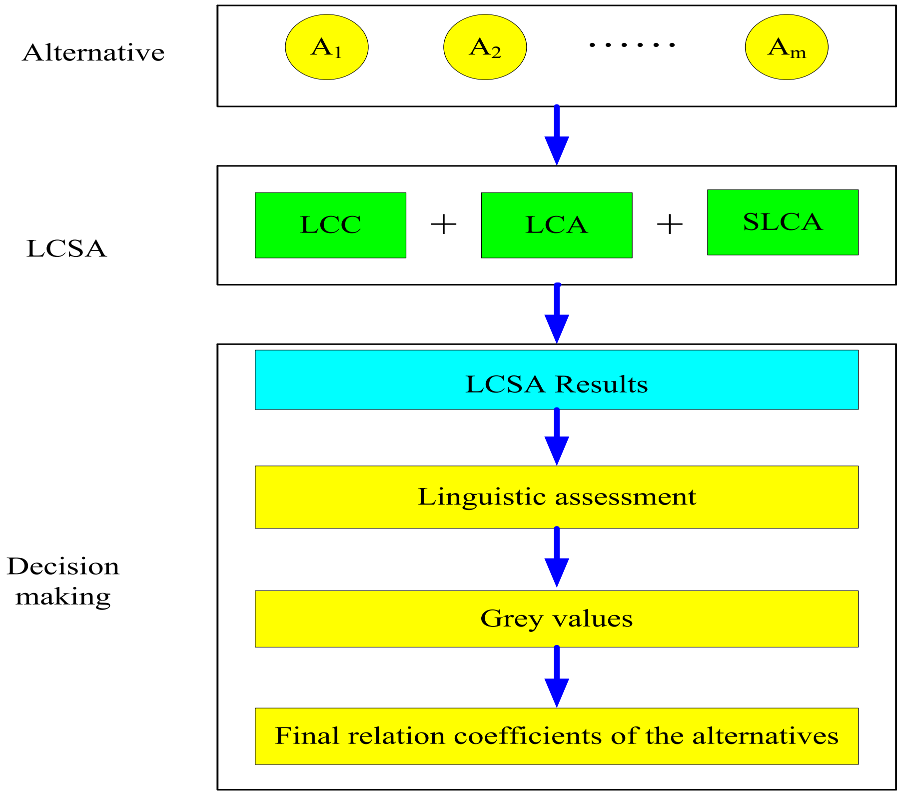

Fig. 1. Framework of technology selection by improved grey relation analysis

The importance of LCC, LCA and SLCA is different for the sustainability assessment in the views of different decision-makers', the decision-makers can determine the importance of them with the scale of grey number for the weighting coefficients of the criteria, as shown in Table 2.

Performance	Abbreviation	Scale of grey number
Very Poor	VP	(1.5,3.0)
Poor	P	(3.0,4.5)
Medium	M	(4.5,6.0)
Good	G	(6.0,7.5)
Very Good	*VG*	*(7.5,9.0)*

Table 1. The scale of grey number for the assessment of the alternative

Importance	Abbreviation	Scale of grey number
Very Low	VL	(0.0,0.2)
Low	L	(0.2,0.4)
Medium	M	(0.4,0.6)
High	H	(0.6,0.8)
Very High	VH	(0.8,1.0)

Table 2. The scale of grey number for the weighting coefficients of the criteria

Results and discussion

Limited by the space, the detailed procedure of LCC, LCA and SLCA have been omitted. An example has been constructed to illustrate the procedure of improved grey relation analysis for technology selection. The decision-makers can give linguistic assessment according to the results of LCC, LCA and SLCA and their past experience, assuming that four types of technologies A_1, A_2, A_3, A_4 have been evaluated by the decision-makers, as shown in Table 3. Then the linguistic assessment can be transformed into grey number, as shown in Table 4.

Aspect	Importance	Linguistic assessment			
		A_1	A_2	A_3	A_4
LCC	H	M	G	VG	G
LCA	VH	P	M	G	M
SLCA	L	G	M	VP	P

Table 3. The linguistic assessment of the four technologies

Aspect	Weight	Grey Value			
		A1	A2	A3	A4
LCC	(0.6,0.8)	(4.5,6.0)	(6.0,7.5)	(7.5,9.0)	(6.0,7.5)
LCA	(0.8,1.0)	(3.0,4.5)	(4.5,6.0)	(6.0,7.5)	(4.5,6.0)
SLCA	(0.2,0.4)	(6.0,7.5)	(4.5,6.0)	(1.5,3.0)	(3.0,4.5)

Table 4. Grey values for assessment of the four technologies

Then the improved relation analysis has been used to analyze the four technologies, the results have been show in Table 5, with the rule of “the bigger the final relational coefficient, the better the technology”, the associated sequence is $A_3 > A_2 > A_4 > A_1$. A_3 has been ranked at the first place and recognized as the best and most sustainable technology, and A_2 has been ranked at the second place, follows by A_4 and A_1.

Technology	A_1	A_2	A_3	A_4
Grey relational coefficient	(0.72,1.34)	(0.83,1.50)	(1.02,1.96)	(0.81,1.43)
Final relational coefficient	1.03	1.16	1.49	1.12
Ranks	4	2	1	3

Table 5. The grey relational coefficient, the final relational coefficient and ranks

Conclusions

Selection of the most sustainable technology is meaningful for the development of sustainability. A novel methodology for selecting the most sustainable technology has been presented in this paper. The methodology is an improvement of traditional grey relation analysis.

Life cycle sustainability assessment including life cycle costing, life cycle assessment and social life cycle assessment have been used to analyze the alternative technologies firstly, with the results, the decision-makers can give linguistic assessments and judgments on the technologies, the linguistic variables can be transformed into grey values. The developed grey relation analysis that has the ability to deal with grey values can be used to rank the technology and indentify the most sustainable technology.

Limits are missing, I would remark here the subjectivity that involves qualitative evaluations, moreover I would say that this methodology aims at evaluating and selecting the alternative technologies once the boundary has been determined no matter the data about LCA, LCC, SLCA have been obtained or not. Our objective was to provide a methodology that can help the decision-making select the technology among alternatives. The future work is about how to design the suitable and specific criteria concern LCA, LCA, SLCA for technology selection.

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Barilla EPD Process System to increase reliability, comparability and communicability of LCA studies

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Keywords: PCR, EPD, EPD Process System, LCA for food

Introduction

Barilla, one of the top Italian food groups, produces more than 100 products in about 50 plants around the world. The company has been using the LCA for more than a decade. Since 2008, life cycle thinking made its way into company strategy, as an instrument to thoroughly study the production chain and localise the most substantial environmental impacts.

Barilla decides to join the International EPD System for several reasons: the System acts following the International Standards (ISO 14025); the reliability of the LCA is assured by the Product Category Rules (PCR); the System allows the comparability among the same product group, each document with a public interest (such as Product Category Rules (PCR) and General Program Instruction (GPI)) is published; public register on PCR and EPD is regularly updated; EPDs and LCAs must cover all the environmental issues not merely focusing on greenhouse gases emissions; the System gives the possibility to develop an EPD Process Certification.

Barilla's aim is to develop the EPDs for the major part of its product and the only way to make it in an easy, simple and reliable manner is to use an EPD Process System; for this reason, during 2010, it was developed and in certified by Bureau Veritas in 2011.

The scope of the Process System is to prepare, verify and publish EPDs for Barilla's products related to the following Product Category Rules:

- Product Category Rules 2010:01 (CPC 2371): Uncooked pasta, not stuffed or otherwise prepared
- Product Category Rules 2012:06 (CPC 234): Bakery Products
- Product Category Rules 2010:09 (CPC 23995): sauces; mixed condiments; mustard flour and meal; prepared mustard

General Structure of the Barilla EPD Process

All EPDs coming from the Barilla's EPD Process System are based on the Life Cycle Assessment methodology; using the following three main elements:

1. The Product Specific data
2. The LCA dBase
3. The Product System

The system works like a "funnel process", as showed in figure 1: product specific information are collected and elaborated by the product system using the LCA dBase, then results are collected in a specific LCA data sheet, that is then used for the preparation of the EPD.

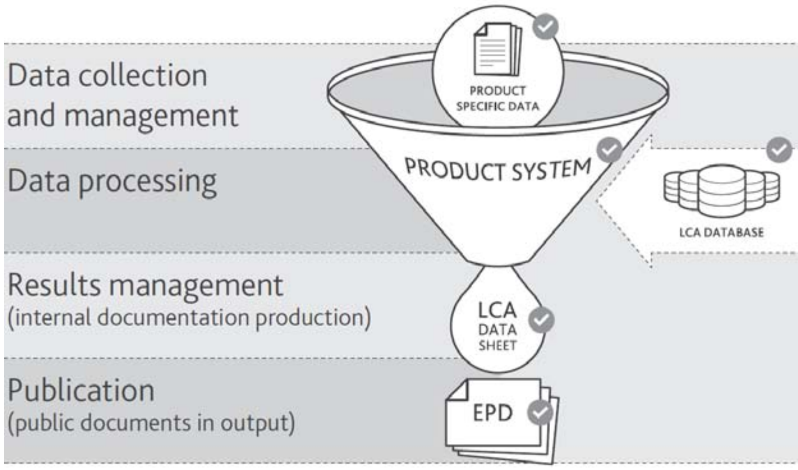

Fig. 1. The "funnel process"

Product Specific Data

Product specific data represent all the specific information related to the product that has to be analysed:

- Product recipe (food raw materials)
- Bill of materials packaging list
- Production plants where the product is manufacturing
- Production volume
- Finished product logistic distribution data (kilometers covered and transport means)

Other relevant environmental aspects, such as liquid nitrogen and carbon dioxide consumption used for product cooling.

LCA dBase

The database is organized among different data modules groups:

- Raw materials: includes information about materials used for food product recipe (e.g. durum wheat cultivation for semolina production)
- Packaging raw materials (e.g. cardboard manufacturing for American box production);
- Energy: includes data about the energy mixes used in the countries in which the Barilla's plants are located. The database is updated every time new information is available;
- Plants: contains information about the processes that take place in the Barilla's plants. These data are based on the data collection and they are updated every year.
- Transports: data on the main means of transport used for the Barilla's purposes

Each data module contains all the environmental aspects related to material or process, main hypothesis applied, as requested by the ISO 14040 series (functional unit, system boundaries, data quality, data collection and treatment, allocation and cut-off rules).

All data modules are internally verified and are ready to be used for EPD purposes, they are inserted in software SimaPro®, that was selected as the modeling and calculation tool for the Barilla EPD system process.

The Product System

The Product System represents the product group model calculation tool. It is developed for each product group in a specific fashion following the Product Category Rule (PCR) and is internally vetted.

Barilla's EPD Process System includes Product Systems for pasta, bakery and sauces products. An example of product system for bakery product is reported in figure 2.

	Product specific data		LCA database		Total
Product Recipe	Grams of ingredients per kg of product	X	Impacts per kg of ingredients	=	Impacts per kg of products due to the ingredients
					+
Bill of materials packaging list	Grams of materials per kg of product	X	Impacts per kg of packaging materials	=	Impacts per kg of products due to the packaging
					+
Plants	Plants in which the product is made and quantities	X	Impacts per kg of products made by the specific plants	=	Impacts per kg of products due to the production
					+
Logistic distribution	Km covered by train, truck and ship	X	Impacts per km by train, truck and ship	=	Impacts per kg of products due to the transportation
					+
Other aspects	Natural gas for bakery	X	Impacts per Nm^3 of burned NG	=	Impacts per kg of products due to the bakery
					=
				LCA Data sheet	Impacts per kg of product

Fig. 2. Example of product system for bakery products

Verification levels

The reliability of the EPDs is ensured by several verification levels done by Data Assessor, Process Assessor and Verification Body:

1. Product System and LCA Database verification is performed by the Data Assessor;
2. Product specific data, LCA data sheet and EPD Document verification is performed by the Data Assessor per each EPD realized
3. EPD Process verification by means of:
    - internal audit, performed by the Process Assessor
    - external audit, performed by a Verification Body (accredited body certified for audit of management systems)

Process operations

Barilla EPD Process System is organised in three main processes, under the control of the management activities: EPD project, database update and product system update.

The management activities take into consideration all the actions that are necessary for activities coordination and organization, such as EPDs planning, competences evaluations, process assessment planning, non conformity management and system documentation updating.

An overview of the processes is given in figure 3.

The first activity of the system is the EPD planning, it is performed each year to organize all the works related to the EPD Process System.

In order to do a reliable planning of the EPD projects, the collection of the entire product recipe is necessary to identify raw material still not covered by an update data module.

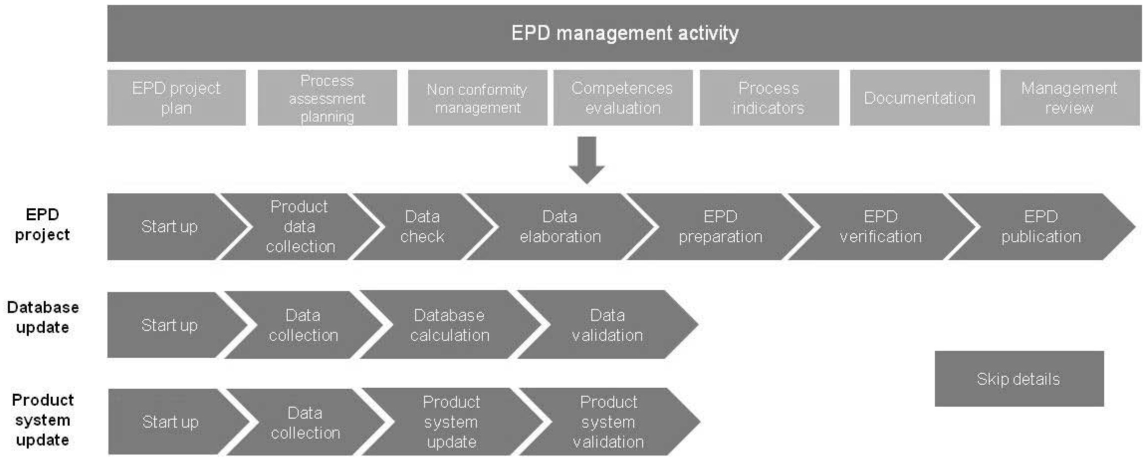

Fig. 3. Overview of the process operations

The main process of the system is the EPD Project, which leads to the verification and publication of the EPD document, starting from the Product data collection and passing through data check and elaboration and EPD verification.

Database update is performed each time data must be updated (e.g. for energy mix) and at least once a year. In addition, data is updated during the data check of the EPD Project when data is unavailable for the model. This puts the EPD project process in standby and the database update process starts. The EPD Project process resumes only when all data necessary for the EPD preparation is available and validated.

The product system update process updates the product system model when there is a change to its product category rules and compiles a new product system when a new product must be analysed and inserted into the system.

4. Process Indicators

The Barilla EPD process performances are evaluated by mean of specific indicators, reported in table 1.

Indicators	Unit	Description
Product volume covered by EPDs	%	Percentage of product volume covered by EPDs
Planned projects	n°	Number of the EPD projects planned each year (one EPD project may have one or more products)
Open Projects	n°	Number of the EPD projects that are still open in a specific moment
Frozen Projects	n°	Number of the EPD projects that are stopped because a database/data system update is running
Validated EPD	n°	Number of validated EPD (not all of them are published)
Published EPD	n°	Number of published EPDs available
Product System	n°	Number of product system available for all the Barilla products
Product System validated	%	Percentage of total product system validated and available for EPD realization
Product Volume covered by Product System	%	Percentage of product volume covered by Product System
Total module	n°	Total amount of the data modules that are needed for completing the EPD activities included in the running project.
Available data module	%	Percentage of the total data module available for EPD realization. It represents how much the data collection performance is completed.
Validated data module	%	Percentage of the total data module that is validated and ready for the EPD calculation. It represents the measure on how much the database is completed with validated information.

Table 1. Overview of the indicators used for measuring the EPD Process performances

Actors and roles

EPD Process management is guaranteed by the mutual works of different actors: EPD process owner, LCA developer, data owners, data expert. All roles are described below:

- EPD Process owner: is the EPD system process responsible who has decision-making power and represents Top management for the EPD purposes; defines the policy and approves all documents and decisions related to EPD issues, avails himself of an EPD Process Manager;
- LCA developer: is supported by an LCA team, that manages all the activities necessary for the EPD document preparation, data modules and product system development and update;
- Data owners are in charge of providing data and information needed for LCA calculations. They usually have precise functions and are responsible for specific areas (e.g. packaging production, production process, product transport, etc). They are identified and involved in data collection according to the annual EPD work plan and they have to know the procedure for the data collection;
- Data expert represents personnel that could assist both specific data verification (peer review) during LCA calculation and EPD preparation. A data expert may be identified during the management review to support data collection and verification during LCA calculation. A data expert may be sought for strategic and relevant information such as wheat cultivation, palm oil production, etc. This figure can either be an internal or external resource;

The system reliability is guaranteed by several verifiers (data assessor, process assessor and verification body), their roles are described below:

- Data assessor: is personnel responsible for the verification of the LCA calculation and of the EPD document. The data assessor conducts internal assessments at planned intervals to determine the reliability, relevance and independence of the EPD;
- Process assessor: is an internal verifier that regularly assesses the conformity of the EPD process. The process assessor is the internal verifier that has the responsibility to perform periodic audits on system application;
- Verification Body: represents an accredited body certified for audit of management systems that verifies the entire EPD process system.

Each actor in the process has qualified and formalized competences.

Results and conclusions

Barilla is the first private company that has developed an EPD Process System.

About the 46% of the products put on the market by Barilla during year 2011 are covered by an Environmental Product Declaration (EPD). At 30th April 2012, fifteen EPDs were published on the website and about six hundreds data modules were realized; the available data modules are over the 90% and validated data modules among the available ones are over the 75%.

The use of the Barilla EPD Process System has shorten EPD publication timing, that now lasts about 6 - 10 weeks.

Indicators	Unit	Data
Product volume covered by EPDs (year 2011)	%	46%
Planned projects (year 2012)	n°	39
Open Projects (point at 30/04/2012)	n°	13
Frozen Projects (point at 30/04/2012)	n°	0
Validated EPD (point at 30/04/2012)	n°	18
Published EPD (point at 30/04/2012)	n°	15
Product System (point at 30/04/2012)	n°	6
Product System validated (point at 30/04/2012)	%	67%
Product Volume covered by Product System (year 2011)	%	99,7%
Total module (point at 30/04/2012)	n°	610
Available data module (point at 30/04/2012)	%	97
Validated data module (point at 30/04/2012)	%	79

Table 2. Performance of the EPD Process System

Table 2 shows the Barilla EPD Process System performances through the system indicators, from 2010 to April 2012. Looking at the table, it's important to point out that:

- There are 39 EPD projects planned for 2012; 13 of these contain more than one product to be analysed because there are several recipe variants for some products;
- There are no frozen projects because there were no problems with data availability;
- There is a higher number of validated EPDs respect to published EPD because it was decided to not publish three of the validated EPDs;

From year 2010 to April 2012 forty verifications were performed: four external verifications made by Bureau Veritas, and the others made by data and process assessors for internal verifications.

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