PROCEEDINGS

12th Italian LCA Network Conference

Life Cycle Thinking in decision-making for sustainability: from public policies to private businesses

Messina
11-12th June 2018

**Edited by: Giovanni Mondello, Marina Mistretta, Roberta Salomone
Arianna Dominici Loprieno, Sara Cortesi, Erika Mancuso**

ENEA
Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

Rete Italiana LCA

Life Cycle Thinking in decision-making for sustainability:
from public policies to private businesses

Proceedings of the 12th Italian LCA Network Conference

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Conference program

JUNE 11th, 2018 - Monday

08.30 - 09.00 **Registration to Italian LCA Network Conference**

09.00 - 09.30 **Italian LCA Network Conference - Opening ceremony**

Salvatore Cuzzocrea - *Rector of the University of Messina*
Augusto D'Amico - *Director of the Department of Economics*
Maurizio Cellura - *President of the Italian LCA Network*
Roberta Salomone - *Conference Chair*

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LCA, LOCAL GOVERNMENTS, AND CIRCULAR ECONOMY

Chairs: Maurizio Cellura – University of Palermo
Giuseppe Saija – University of Messina

EU Policies for ENERGY Research: the SET Plan and the new 2018-19 Horizon 2020 Work Program
Riccardo Basosi – *Italian Permanent Representative H2020 Energy EU Programme and MIUR Delegate in the SET Plan Steering Committee*

Life Cycle Assessment of electrochemical storage technologies
Marco Ferraro – *CNR-ITAE*

European Environmental Footprint methods: status update and future outlook
Michele Galatola – *European Commission - DG Environment - Sustainable Production, Products & Consumption*

The Accredia's experience in environmental conformity assessment, supporting LCA-based activities
Filippo Trifiletti – *General Director ACCREDIA*

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Marina Mistretta – Mediterranea University

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Grazia Barberio – *ENEA*

Life Cycle Analysis of an innovative component for the sustainability in the building sector
Maria Laura Parisi – *University of Siena*

Life Cycle Assessment of building end of life
Serena Giorgi – *Politecnico of Milano*

ELISA: A simplified tool for evaluating the Environmental Life-cycle Impacts of Solar Air-conditioning systems
Sonia Longo – *University of Palermo*

A comparative study between a Prefab building and a Standard building for the characterisation of production and construction stages
Mónica Alexandra Muñoz Veloza – *Politecnico of Torino*

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14.00 - 15.00 Poster Session

15.00 - 16.30 **SESSION III**
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Roberta Salomone – University of Messina

Steps towards SDG 4: teaching sustainability through LCA of food
Nicoletta Patrizi – *University of Siena*

The blue water use of milk production in North Italy – a case study
Doriana Tedesco – University of Milan

Practitioner-related effects on LCA results: a case study on Energy and Carbon footprint of wine
Emanuele Bonamente – University of Perugia

Environmental impacts and economic costs of nectarine loss in Emilia-Romagna: a life cycle perspective
Fabio De Menna – University of Bologna

Grana Padano and Parmigiano Reggiano cheeses: preliminar results towards an environmental eco-label with Life DOP project
Daniela Lovarelli – University of Milan

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Anna Mazzi – University of Padova

16.30 - 17.00 Tea break

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Andrea Raggi – University "G. d'Annunzio"

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Luca Ciacci – University of Bologna

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Cristian Chiavetta – ENEA

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Andrea Fedele – University of Padova

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JUNE 12th, 2018 - Tuesday

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Serena Righi – University of Bologna

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11.30 - 13.00

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Marzia Traverso – RWTH Aachen University

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Serena Righi – University of Bologna

Analysis of a recycling process for crystalline silicon photovoltaic waste
Fulvio Ardente – European Commission - Joint Research Centre

Environmental comparison of two organic fraction of municipal solid waste liquid digestate's management modes
Federico Sisani – University of Perugia

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Laura Brenes-Peralta – University of Bologna/Researcher Instituto Tecnológico de Costa Rica

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Andrea Di Maria – KU Leven

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Giuseppe Tassielli – University of Bari "Aldo Moro"

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Paola Masotti – University of Trento

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Rosa Di Capua – University of Bari "Aldo Moro"

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Jonathan Schmidt – RWTH Aachen University

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Michele Del Grosso – APTAR Italia SpA

16.30 - 17.00 Tea break

ROUND TABLE

17.00 - 18.20 **LIFE CYCLE THINKING IN DECISION-MAKING FOR SUSTAINABILITY: FROM PUBLIC POLICIES TO PRIVATE BUSINESSES**

Moderators: Maurizio Cellura – University of Palermo

Bruno Notarnicola – University of Bari "Aldo Moro"

Methodological advancements and remaining challenges after 5 years of Environmental Footprint road field testing
Michele Galatola – European Commission - DG Environment - Sustainable Production, Products & Consumption

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Sangwon Suh – University of California

Life cycle based environmental assessment of EU consumption
Serenella Sala – European Commission - Joint Research Centre - Directorate D – Sustainable Resources, Bio-Economy Unit (D1)

18.30 Bus transfer to Regional Museum

19.00 - 21.30 Guided tour of the regional Museum and Light Dinner

PREFACE

The 12th Italian LCA Network Conference (the 7th Italian LCA Network Association Conference) was held on 11-12 June in Messina (Italy), under the patronage of Ministry for Environment, Land and Sea Protection, SETAC Italian Branch, Municipality of Messina, ARPA Sicilia, AIDIC, AICARR, the Council of Sicily consultant associations of Engineers, the consultant associations of Engineers of Palermo, Agrigento, and Ragusa Provinces, and the consultant association of Architects of Trapani Province.

The conference focused on the role of the "Life Cycle Thinking" (LCT) approach as support to decision-making in the definition of sustainability strategies, thus supporting both public and private businesses in making more informed decisions.

Indeed, life-cycle information is considered crucial to guide policy decisions and business strategies in many contexts.

Policy makers have to promote sustainable consumption and production strategies to respond to national and international environmental challenges, by gathering baseline and future-oriented environmental impact information for market-oriented policies and developing strategies for resource efficiency and eco-design.

Private businesses have to improve efficiency to boost margins and competitiveness, while contributing to sustainability.

Thus, LCT and product sustainability aims to reduce their environmental and socio-economic burdens, while maximizing economic and social value.

The Italian LCA Network conference has become a representative venue for enterprises, public authorities, international academics and researchers in the LCT field in order to discuss, share, and disseminate innovative ideas and advancement on the LCT methodology and case-studies.

The papers published in the volume contribute to new approaches, methods and applications, in order to discuss developments, current policy progress and pathways toward sustainability.

The conference proceedings report 60 papers, which were presented at the conference, both in the oral and poster sessions, after a *double blind peer review* process, managed by the Scientific Committee.

The following topics were covered in the conference:

- Life Cycle Thinking methods and tools in public policies: experiences, limitations and perspectives.
- Life Cycle Thinking methods and tools in private businesses: experiences, limitations and perspectives.
- Life Cycle Thinking and Circular Economy: policies and practices.
- Life Cycle Thinking and the UN Sustainable Development Goals.
- Methodological developments of LCA, LCC, S-LCA and integrated Life Cycle Sustainability Assessment.

The last section includes the three papers awarded the 9th Edition of LCA Young Researcher Award, addressed to promote and disseminate the research activities of young researchers involved in the Life Cycle Assessment research activities.

The President of Italian LCA Network
Maurizio Cellura

ENERGY AND BUILDING

Comparative LCA of renovation of buildings towards the nearly Zero Energy Building

Cutaia L.[1], Barberio G. [1], Elmo G. [1], Longo S. [2], Cellura M.[2], Guarino F.[2], Gulotta T.M.[2]

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Abstract

*The building sector is one of the key sectors to achieve the 20/20/20 targets of the EU as there is the potential to lead to significant energy savings reducing the EU's total energy consumption by 5-6% and lowering CO_2 emissions by 5%. One powerful mechanism to apply principle and criteria of nearly zero-energy buildings **(nZEB)**. This work, done in the framework of the agreement between the Italian Ministry of Economic development and ENEA on the "Research of electric system" (Ricerca di Sistema Elettrico), has the aim to evaluate the environmental impacts of the technological improvements needed for enhancing the performances of an average building to a nZEB (or at least in the direction of a nZEB), performing a comparative Life Cycle Assessment study. Data on building upgrading and energy consumption reduction come from a test case performed by Università degli Studi di Palermo.*

1. Introduction

Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU and almost 75% of building stock is energy inefficient, while only 0.4-1.2% (depending on the country) of building stock is renovated each year. So, the building sector is one of the key sectors to achieve the 20/20/20 targets of the EU and to achieve reductions of greenhouse gas emissions in the residential and service sectors of 88% to 91% compared to 1990 by 2050. In particular, renovation of existing buildings can lead to significant energy savings, which could reduce the EU's total energy consumption by 5-6% and lower CO_2 emissions by about 5% (European Commission). Main directive, laws and strategies, at European and international level, have been promoted to foster the requalification and improve the energy efficiency of building (for instance Energy Performance of Buildings Directive and Energy Efficiency Directive of the EU Parliament). So building renovation and new buildings construction will require low amount of energy and this energy will come mostly from renewable sources, following the principle of nearly zero-energy buildings ***(nZEB)***. Improving the energy efficiency of buildings can also generate other economic, social and environmental benefits.

This work has been done in the framework of the agreement between the Italian Ministry of Economic development and ENEA on the "Research of electric system" (Ricerca di Sistema Elettrico - RdS) that foresee R&D activities for reducing cost of energy for end-users, boosting the quality of service provided, reducing impacts on environment and health of electric system and using energetic resources in a better way. The amount for the contribution for financing the RdS is defined by the Italian Authority for the Electric Energy, Gas and Water Service. Activities are planned every 3 years and subdivided year by year (from October to September). This work has been realised between October 2016 and September 2017, as second year of the three years 2015-

2017 and it is in the specific part of the project addressed to improving and studying energy efficiency and energy use in the building sector.

Aim of the study is evaluating the environmental impacts of the technological improvements needed for enhancing the performances of an average building to a nZEB (or at least in the direction of a nZEB) on their life cycle. Practical application of this kind of assessment is choosing technologies or technical solutions for improving performances of buildings towards a nZEB, with energetic and environmental load that doesn't overcome, over the life cycle, the reduction of consumption during the use phase. This work focus the investigation on environmental performance of a restored office building in two main scenarios: a medium upgrading and a high upgrading towards nZEB conditions, performing a comparative Life Cycle Assessment study on different geographical areas in Italy (North, Centre, South Italy). The focus of this paper is the South Italy (Palermo - Sicilia Region).

1.1. Building certification

Sustainability in building is defined as the control of impacts that the entire building process has on the environment and on the quality of life of users. The following figure shows the articulation of ISO standards on the theme of sustainable construction (Barucco, 2011).

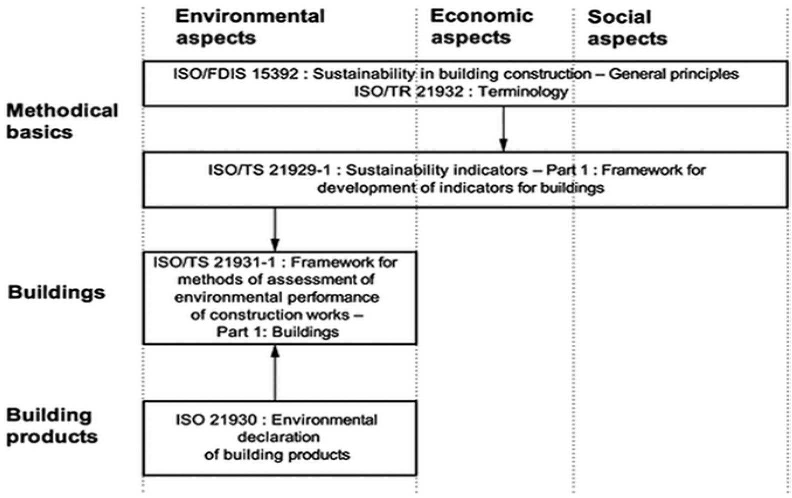

Figure 1: of ISO standards on the theme of sustainable construction

The EU regulation n. 305/2011 establishes conditions for the marketing of construction products, introducing the requirement of sustainable use of natural resources. Buildings shall be designed, built and demolished according to the sustainable use of resources. The reuse or recyclability of construction materials after demolition shall be guaranteed, as well as the use of environmentally compatible raw and secondary materials (Barucco, 2011).

The sustainability criteria of buildings are grouped in six thematic areas: - Efficiency in resource consumption; Limitation of the impact of construction materials, Optimization of the relationship between the building and the surrounding environment, Indoor comfort, Safety, maintenance and building management, and Ethical and social aspects.

Assessments of building sustainability with rating system methods, based on life cycle thinking approach, are used with the purpose give an environmental label to the examined building. Thanks to the certification and the label the overall sustainability performance of a building becomes “visible” to the end-users. The rating system methods work as an “environmental report” of the building, which is then evaluated according to different requirements grouped into classes with a minimum threshold. Final rating goes from a minimum - corresponding to the achievement of threshold values - to a maximum ranking level. The scoring methods depend on the type, size and destination of the building. For example, a requirement on energy performance can not include the same thresholds for both residential and commercial buildings, new buildings or major renovations (Bertagni, 2016).

The most important certification methods or protocols used in Italy are ITACA (Manfron, 2005), LEED (Bertagni, 2016) and BREEAM (Bertagni, 2016).

The **ITACA** Protocol has been adopted by many local administrations to promote sustainable construction through: regional laws, building regulations, calls for tenders, urban plans, etc. The Protocol is derived from the SBTool international evaluation model, adapted to the Italian environmental context. ITACA protocol has different versions, for the evaluation of residential, commercial, school, industrial buildings, etc. both for the new building and for the major renovations. ITACA divides the various requirements into five evaluation areas: Site Quality / Resource Consumption / Environmental Loads / Indoor Environmental Quality / Service Quality (www.proitaca.org).

The **LEED** protocol is managed by United States Green Building Council. There are numerous versions of LEED, valid for different types of buildings. LEED divides the various requirements in the following areas: Site Sustainability / Water Management / Energy and Atmosphere / Materials and Resources / Internal Environmental Quality / Design Innovation / Regional Priority. LEED provides different levels of performance (result of the sum of totalized points), ranging from basic level to Silver, Gold and - the highest level - Platinum.

The **BREEAM** protocol is developed by the British Institute Building Research Establishment. BREEAM also has numerous versions that adapt to different types of applications. BREEAM divides the requirements into classes: Energy / Health and wellbeing / Innovation / Land use / Materials / Management / Pollution / Transport / Waste / Water. Depending on the score obtained with BREEAM the certificates vary in five levels: Exceptional, Excellent, Very Good, Good, Sufficient.

The Directive 2010/31/EU set a limit on December 31st, 2020, when all new buildings are expected to be nZEB. The key points for a design aimed at creating a nZEB building include architectural planning aspects deriving from a detailed knowledge of the geographical context where the building will be located and from design aspects related to technological systems. All these aspects can be well connected in each phase using a certification protocol. In summary the guiding criteria for a nZEB building construction are (Sasso, 2006; Bertagni, 2016):

- The layout must favour the maximum level of sunshine and protection from the prevailing winter winds.
- Compact and lightly dispersed forms shall be preferred.
- The type of building must guarantee the same thermal/energy potential for every accommodation. Terraced and in-line buildings are preferred.
- The internal distribution must favour the positioning of staircases and bathrooms towards the North front and living spaces on the South front.
- Use of passive systems for thermal control and for proper ventilation (thermal mass, greenhouses and solar spaces, solar chimney, green roof, etc.).
- Introduction of shading systems for summer radiation control (vegetation, fixed or adjustable screens).
- Use of active systems for the reduction of residual energy consumption (solar thermal and photovoltaic collectors)
- The openings system must guarantee an excellent level of natural lighting inside each accommodation.
- A careful study of the thermal bridges must be carried out for subsequent elimination or attenuation where not possible.
- Each building must be constructed using eco-compatible materials and with excellent thermal insulation performance of the surface (thermal coat).
- Providing storm-water collection systems reducing water consumption.

2. LCA Study

The comparative LCA study was aimed to evaluate the environmental performance of an average “conventional” building upgrading towards a nZEB by means of new plants and substitution of materials and components. Data on upgrading and energy consumption reduction come from a Test Case analysed by University of Palermo.

2.1. Goal and scope definition

This work has been done in the framework of the RdS activities, financed by part of the fee for the electric energy consumed by Italian end-users, and the whole study will be published on ENEA website and on the CSEA (Cassa per i Servizi Energetici ed Ambientali) website.

Aim of the study is the evaluation of potential advantages coming from building retrofit actions for improving the energy efficiency respect to the potential impacts of upgrading itself in two retrofit scenarios (European Parliament 2010; Presidenza della Repubblica Italiana, 2011, 2015 and 2017): Scenario 1: medium level of retrofitting; Scenario 2: retrofitting to nZEB.

A comparative Life Cycle Assessment study has been carried out on different geographical areas and the focus of this paper is the South Italy (Palermo). The assessment method is Impact 2002+ and the tool used in the study is Simapro 8.5.

Functional unit is the whole retrofitted building, considering 1 year of activity. Concerning system boundaries of the comparative study, the following phases are considered (same phases are deleted in the comparison): new materials production and supply; building maintenance; retrofit actions (new processes and materials replacement, removal and disposal); use phase (energy consumption and production). A general description of retrofit actions and their lifespan is shown in the following table (more details in paragraph 2.2):

Table 1: Retrofit actions and related lifespan

Category	Scenario 1	Scenario 2	Lifespan (y)
Opaque wall	External insulation with EPS	External insulation with EPS	30
Transparent wall	Replacement of the existing fixtures	Replacement of the existing fixtures	30
Power generation	Replacement of the power generation and distribution system.	Replacement of the power generation and distribution system.	15
Lighting system	Replacement of the lighting system with LED	Replacement of the lighting system with LED	8
Renewable sources	NO	Solar thermal system	15
	NO	Photovoltaic system	20

2.2. Life Cycle Inventory

2.2.1 The examined building

The examined building is an office of the 70s located in Palermo (South Italy) with an area of 403.5 m^2, a net height of 3 m and a volume of 1,210.50 m^3. The layout of the building is shown in Figure 2.

The buildings structure is made of reinforced concrete. The external walls (U = 1.183 W/m^2K) include 27 cm of perforated brick blocks, with lime-based external plaster and gypsum internal plaster. The internal walls (U = 3.045 W/m^2K) are 8 cm of perforated bricks covered with gypsum and painting. The floor (U = 1.974 W/m^2K) is 17 cm thick, including bricks and ceramic slabs. The flat roof (U = 1.453 W/m^2K) has a structure made by reinforced concrete and brick blocks, mortar, screed and a clinker external floor.

With regard to the transparent surface, it is about 24 m^2 and represents about 12% of the external vertical surface. In detail, the building is equipped with metal frame and single-glazing windows (U_{frame} = 7.00 W/m^2K; $U_{glazing}$ = 5.75 W/m^2K), with no shielding and blinds.

The building lighting is made by ceiling lights with 34 fluorescent lamps (total power of about 2.3 kW).

Heating and domestic hot water (DHW) are provided by a 36 kW diesel boiler and an 80 l water storage. The heating system is equipped with cast iron radiators and insulated copper pipes for the distribution, except for office 4 that is equipped with a fan-coil system, due to the high heating loads. The heating system uses also further components such as distribution manifolds, electric pumps, valves, etc., while a cooling system is not available.

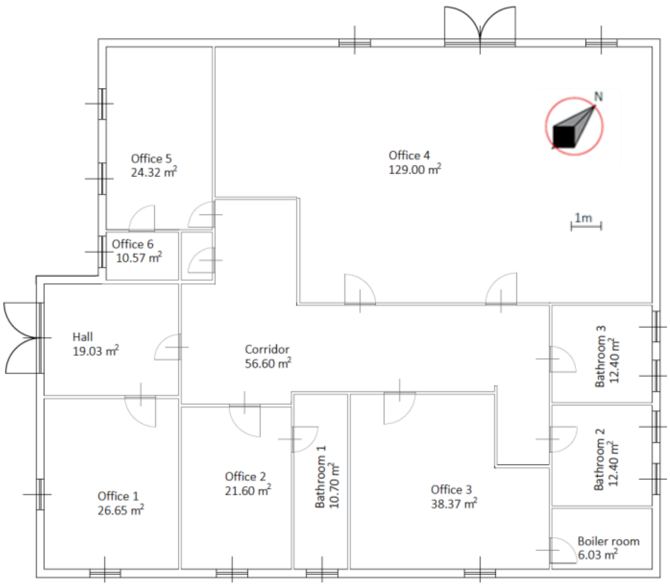

Figure 2: Layout of the building

The energy performance of the building was calculated with a simulation of the thermo-physical characteristics of the building, performed with an energy simulation tool certified by the Comitato Termotecnico Italiano. According to the Italian law, the energy class of the building is E (Presidenza della Repubblica Italiana, 2015).

2.2.2 The retrofitting scenarios

In order to improve the energy performance of the building and to move towards Scenario 1 and 2, some retrofit actions were identified and simulated. In detail, the two scenarios are based on the transmittance limits for both the glazed and opaque surfaces reported in (Presidenza della Repubblica Italiana, 2015) respectively for medium level of retrofitting and nZEB retrofitting.

In order to plan economically, technologically and operationally realistic interventions and to avoid demolition and subsequent replacement in the two scenarios, the retrofit actions of Scenario 1 were selected to be able also to ensure compliance with the nZEB requirements, except for the retrofit of vertical opaque walls. For Scenario 1, the following retrofit actions have been identified:

- External insulation of opaque walls by using EPS (vertical wall) and XPS (floor and roof) insulation panels;
- Replacement of the existing fixtures with PVC frames, with thermal break 12 mm air chamber (air) and 24 mm glass surfaces (U = 2.98 W/m^{2}K);
- Replacement of the power generation/distribution system. In detail, the new air conditioning system is made by a reversible air/water heat pump

equipped with an inverter and a distribution system with fan coils. The DHW is produced by an electric water heater. Other components complete the system (copper pipes, distribution manifolds, electric pumps, etc);

- Replacement of the lighting system composed by 37 LED lamps with a total power of 1 kW.

To achieve the nZEB requirements (Scenario 2), considering the low transmittance of the roof and the floor, only an additional insulation of the vertical opaque walls was hypothesized (1 cm thickness of EPS). In addition, two renewable energy systems were introduced:

- A photovoltaic system of about 1 kW (8 m^2 and 5 PV modules) for electricity production;
- A solar thermal system (2.5 m^2 of flat collectors and a tank with a storage capacity of 180 l) for DHW production.

Table 2 shows the energy consumption during operation for the three scenarios, highlighting the energy savings during the operation due to the implemented scenarios.

For each retrofit action and for each scenario, the main materials and components needed for their implementation were estimated. As an example, Table 3 shows the materials required for retrofit the vertical opaque walls in both scenarios.

Table 2: Energy consumption of the building during operation

	Existing building	Scenario 1	Scenario 2
Electricity consumption (kWh/year)	13,330.38	7,059.22	5,676.83*
Diesel consumption (kg/year)	5,902.95	0	0
*1,327.52 kWh/year self-consumption			

Table 3: Materials required for retrofit the vertical opaque walls (kg)

Material	Scenario 1	Scenario 2
Mesh reinforcement	77.35	77.35
EPS	284.72	35.59
Adhesive	3,321.78	3,321.78
Water	2,524.56	2,524.56
External plaster	6,643.56	6,643.56

2.3. Life Cycle Assessment and conclusion

Main results from Life Cycle Impact Assessment are here presented: comparative results from normalisation and single score assessment and sensitivity analysis on different time horizons. From the single score assessment, that is the most aggregated result, is possible the identification of the worst performance and the scenario 2 seems to have greater environmental impacts respect to scenario 1 (Figure 3a). From the normalisation, most significant impact categories are, for both scenarios, respiratory inorganic, global warming and non-renewable energy (Figure 3b).

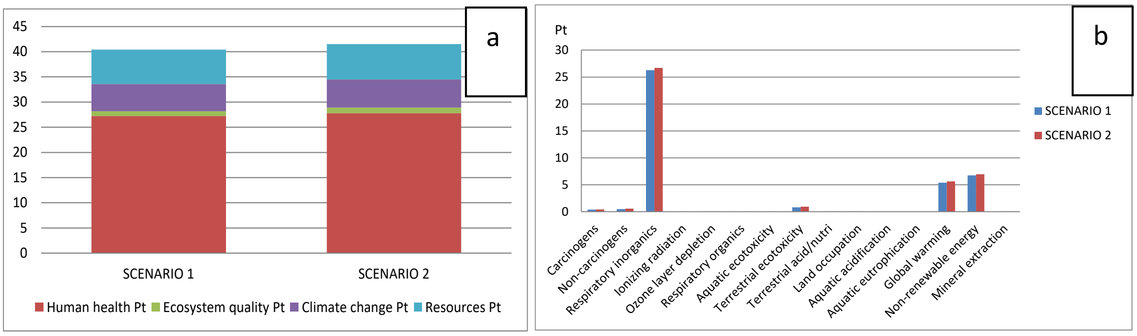

Figure 3: Comparative LCA single score (a) and normalisation (b) results (IMPACT 2002+)

Significant contribute to respiratory inorganic value is due to the opaque wall retrofit action; global warming and non-renewable energy are mainly related to energy consumption and transportation of materials supply, in particular for opaque walls retrofit actions and for new energy systems (photovoltaic and solar thermal systems). A sensitivity analysis has been performed to evaluate a time horizon of 20 years, in order to compare lifespan of the different technologies used as retrofit actions.

As final result it is important to underline that benefits achieved in building upgrading for enhancing energy efficiency not always reflect advantages on other environmental indicators. Further investigations on other R&D actions in technological improvements and further integrated analysis with other payback evaluation are needed in order to have a holist evaluation and to guarantee that energy saving options and policies are coupled to environmental and economic exploitations.

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Life Cycle Analysis of an innovative component for the sustainability in the building sector

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Abstract

The research project SELFIE, funded by MIUR and Tuscany Region in 2016, aimed at the development of innovative building components to increase energy saving of buildings in the Mediterrenean area. Thanks to the combination of several elements, SELFIE modules bear adaptive properties and self-production of renewable energy. The ecoprofile of the innovative component SELFIE2 was evaluated with life cycle analysis and, through a contribution analysis, the most impacting components were identified. In an eco-design approach, improvement actions to reduce the environmental burdens were suggested and validated by applying a sensitivity analysis.

1. Introduction

The building sector contributes significantly to the primary energy consumption and to the associated greenhouse gases emissions. It is estimated to account for about 40% of primary energy consumption in the EU (EPDB, 2010), and the growth of energy consumption in this sector is obviously correlated to the population growth, which, in turn, increases the demand for residential buildings and services. Among the strategies adopted to invert the impacts of the building sector in terms of energy consumption and environmental burdens, the main ones are focused on the use of renewables and on the development of energy efficient buildings, and specifically of new façade systems.

At the policy level, in the EU, the targets set by the Energy Performance of Buildings Directive 2010/31/UE and the Energy Efficiency Directive 2012/27/UE (EE, 2012) concerning the energy performance of buildings, together with the increasing cost of fossil fuels, boost the development of such systems. This framework led the research to aim to what is called 'Near zero energy building' (NZEB), both working on the envelopes and on self-production of renewable energy.

Among the innovative solutions, adaptive envelopes are considered very promising since, thanks to the integration of smart materials and building management systems, they are able to answer in real time to the climatic conditions and to minimize the energy consumption of buildings, providing also occupants' comfort (Baetens, 2010; Kuznik, 2011, Perino, 2007; Saelens, 2003; Favoino, 2014).

Life cycle analysis (LCA) is commonly used to assess the sustainability of buildings. In particular, LCA is a valuable tool to assess the contribution of innovative materials, often used in the new adaptive envelopes, and to compare the global environmental performances of energy-efficient and traditional buildings (Sartori and Hestnes, 2007; Ramesh, 2007; Sierra-Perez, 2016).

In this context, the research project SELFIE (Sistema di Elementi avanzati multi Layer basato su superFici e materiali Innovativi nanostrutturati per una Edilizia sostenibile ed energeticamente efficiente, http://www.progettoselfie.it), funded by the Italian Ministry of University and Research and the regional administration of Tuscany, is aimed to increase the energy saving of buildings in the Med area, by developing and testing innovative envelope solutions.

The SELFIE concept is an adaptive system, combining different innovative technological elements to provide energy and GHGs savings and also adaptation to different construction typologies. Within the SELFIE project, LCA was applied, during the prototypes development, as a tool to support the eco-design of the modules, to highlight the environmental hotspot stages and to suggest for improvement actions.

2. Methodology

LCA was carried out according to ISO 14040-44 standards (ISO, 2006) adopting a cradle to gate approach.

2.1. Goal and scope definition

The objective of this study is the development of a cradle to gate analysis of the innovative modules developed within the SELFIE project and in particular of SELFIE 2 module (Fig. 1). This includes the following elements that contribute to the multifunctionality and to the adaptive properties:

- A Dye Sensitized Solar Cell (DSSC) panel for self energy production. This innovative photovoltaic technology is based on a functioning process that mimics the photosynthesis; moreover, it allows for the use of small quantities of readily-available materials produced by well-established processes and it’s characterized by a high level of versatility, architectural integrability and potentially low cost of fabrication (Parisi et al, 2014). The panel employed in the project is based on the configuration glass-titanium dioxide-ruthenium dye-iodine/triiodide redox couple-platinum-glass, which is one of the most stable and durable configuration developed so far.

- Inorganic support loaded with PCM (phase change material), to enhance the ability to reduce energy consumption for space conditioning and reduce peak loads as well as improving occupant comfort;

- Thermoacustic panel applied on a support frame in aluminum thermal break, with good mechanical properties able to ensure the mechanical safety performance needed for the interior space features.The panel has a sandwich structure: an expanded PET layer (from recycled PET bottles) between two plasterboard layers, a further expanded polystyrene layer and two external aluminium layers to close the component.

- Sensors and actuators, used for an integrated control on humidity and temperature of the building, and thus of its energetic performance.

- Aluminium frame. The frame is taylor-made to assemble the different components and allows easy inspection and maintenance operations, which may be needed during the module lifetime.

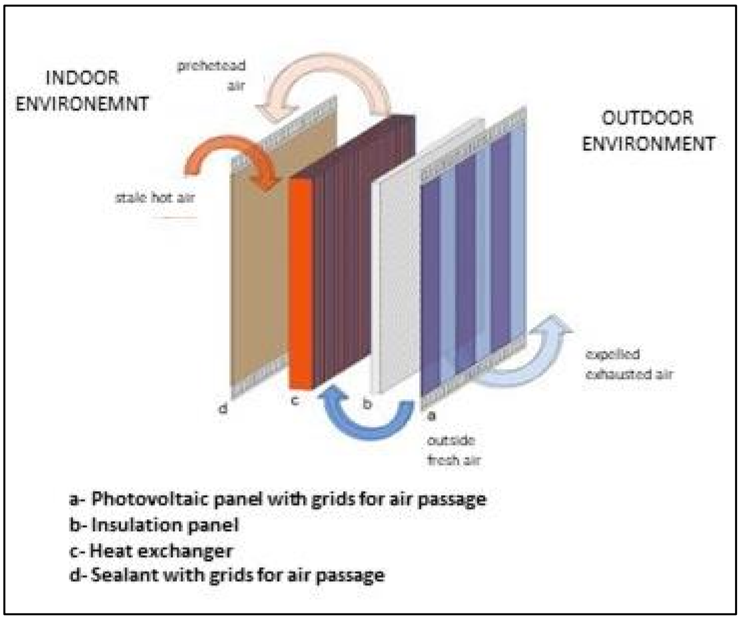

Figure 1: SELFIE 2 module

The system boundaries include the raw materials production and transport; the production of components and finally the assembly of the SELFIE 2 module.

The functional unit applied is '1 SELFIE 2 modular component', with dimensions 90x140 cm. This is the size of the component as elaborated during the project, which is being tested for the operational phase and as it is undergoing the patenting process.

In this study, we have used the LCA software SimaPro 8.02 integrated with the Ecoinvent 3.0 database, and we have applied the ILCD 2011 Midpoint+ method (version 1.0.9, May 2016), developed by the Joint Research Centre of the European Commission, for the impact assessment (EC, JRC, 2012)

2.2. Life cycle inventory analysis

Inventory data were collected during the project (year 2016) through interviews and checklists distributed to the partners involved in the components development and in the assembly of the module. Primary data concern raw materials used for the components production and their provision, production processes of the components (in particular the production of the DSSC photovoltaic panel and of the inorganic support loaded with PCM), the aluminium frame production and, finally, the assembly process of the components into the module. Since some of the components are the outputs of experimental research work developed during the project and still ongoing, data regarding their production have been modeled based on laboratory scale production process. Background data for modelling materials and energy production, transports etc. were taken from the Ecoinvent 3.0 database, eventually customized when necessary. Table 1 lists the main aggregated inventory data for SELFIE 2 module.

Table 1: Aggregated Life cycle inventory data for the production of SELFIE 2 module

Material inputs	**Quantity**	**Units**
Flat glass	40	kg
Solar glass	16,9	kg
Support for PCM	7,68	kg
PCM	16	kg
Insulating material	27,68	kg
Aluminium	33,25	kg
Dye N719	0.001	kg
Electrolyte	0.06	kg
Titanium Dioxide	0.05	kg
Silver	0.020	kg
Platinum	$1{,}68 \cdot 10^{-5}$	kg
Thermoplastic (Polyethylene)	0,3	kg
Transport		
Transport lorry EURO4	34314	kg*km
SELFIE 2 production processes inputs/outputs		
Natural gas	8,41E-03	m^3
Electricity	180.22	kWh
Water	0,12	m^3
Diesel	0,4	l
Solvents	8,28	kg
Waste - non hazardous	23,27	kg

3. Results and discussion

Table 2 lists the impact assessment results of the analysis, referred to the functional unit and Figure 3 shows the contribution of the different components to each impact category.

Table 2: Life cycle impact assessment results for SELFIE 2 module

Impact category	**Unit**	**Total**
Climate change	kg CO2 eq	8,54E+02
Ozone depletion	kg CFC-11 eq	1,64E-04
Human toxicity, non-cancer effects	CTUh	1,98E-04
Human toxicity, cancer effects	CTUh	3,73E-05
Particulate matter	kg PM2.5 eq	1,02E+00
Ionizing radiation HH	kBq U235 eq	3,31E+01
Ionizing radiation E (interim)	CTUe	1,67E-04
Photochemical ozone formation	kg NMVOC eq	2,74E+00
Acidification	molc H+ eq	6,78E+00
Terrestrial eutrophication	molc N eq	1,00E+01
Freshwater eutrophication	kg P eq	1,25E-01
Marine eutrophication	kg N eq	1,15E+00
Freshwater ecotoxicity	CTUe	3,53E+03
Land use	kg C deficit	1,44E+03
Water resource depletion	m^3 water eq	-1,80E+00
Mineral, fossil & ren resource depletion	kg Sb eq	1,18E-01

The contribution analysis shows that the largest impacts on most of the impact categories are provided by the aluminium used in the module frames and by the DSSC module.

For instance, aluminium contributes for about 60% to Climate change, Human toxicity, cancer effects, Particulate matter, Water resource depletion, for about 50% to Photochemical ozone formation, Acidification, Terrestrial eutrophication and for about 40% to Marine eutrophication.

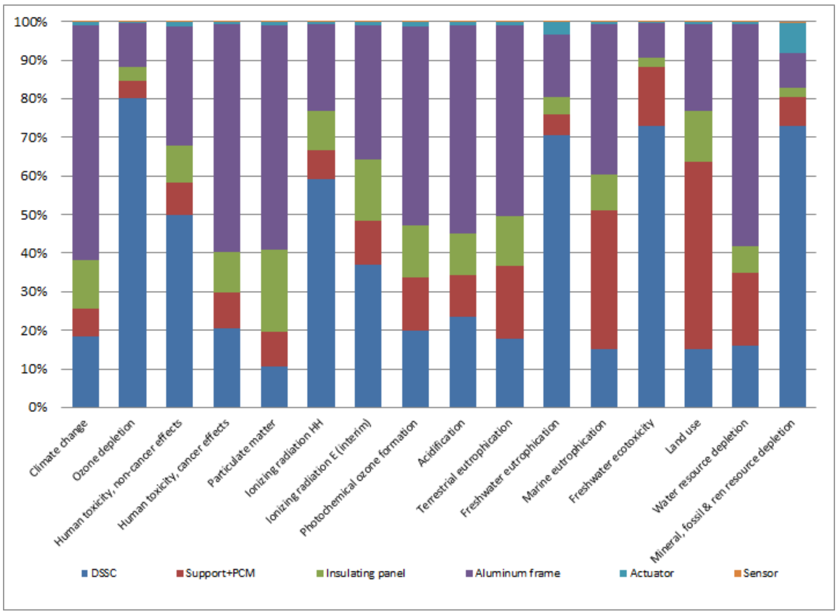

Figure 3: Contributional analysis for SELFIE 2 production

The DSSC photovoltaic panel greatly contributes to Ozone depletion, Human toxicity, non-cancer effects, Ionizing radiation, Freshwater eutrophication, Freshwater ecotoxicity and Mineral, fossil and renewable resource depletion with a percentage contribution ranging from 50% to almost 80%. These impacts are mostly due to the dye molecules and electrolyte solution involved in the photovoltaic modules production process, along with all metals and solvent employed for the syntheses and preparation of the various components of the solar cells.

The PCM-loaded component contributes for about 45% to Land use impact category and for about 35% to Marine eutrophication, due to the production of the PCM material.

Finally, the insulating panel component contribution is between 5 and 10 % to most of the impact categories, achieving 20% only for Particulate matter impact category.

3.1. Sensitivity analysis

In an eco-design approach, to contribute to a reduction of the environmental burdens of the SELFIE 2 module, we tested feasible alternatives on the most contributing components.

In order to reduce the large contribution of the aluminium frame, which is 100% virgin material, we tested with a sensitivity analysis, different contents of recycled aluminium, up to 100%. The aluminium recycled content was modelled applying the CFF (Circular Footprint Formula) formula, recommended for the PEF methodology application (EC, 2017). The parameters used in the 'cradle to gate' CFF module for the recycled aluminium production are : E_v = Aluminium, wrought alloy {GLO}| market for | Alloc Rec, U, $E_{recycled}$ = Aluminium, wrought alloy {RER}| treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter | Alloc Rec, U; A = 0,2; Q_s/Q_p = 1. R1 varies depending on the recycled content percentage (0,5; 0,8; 1).

In general, a reduction of the impacts up to 10-15% is observed on several impact categories such as Climate change, Human toxicity, Particulate matter, Human toxicity, cancer effects. However, this option has only risible effect on other impact categories such as Ozone depletion, Human toxicity, non cancer effects, Resource depletion.

Concerning the other major contributor to the SELFIE 2 eco-profile, namely the DSSC panel, a sensitivity analysis has been performed to assess the potential benefit related with the use of a full organic dye instead of a metallorganic one in the same solar cell configuration. In general, the environmental burden on most of the impact categories of the photovoltaic panel is decreased by 75%. Such trend is much lower (~15%) for the climate change, ozone depletion and water consumption categories due to the use of large quantities of solvents and electricity for the synthesis of the full organic dye. This outcome can be attributed to the fact the organic dye synthesis is not yet optimized compared to that of the ruthenium based dye employed in the solar cell configuration of the SELFIE 2 photovoltaic component.

4. Conclusions

This study reports on the preliminary results of the LCA analysis carried out on the SELFIE 2 component, developed during the SELFIE project. The analysis aimed to support the eco-design of the module, investigating the hot spots of the production stage to provide suitable alternatives for the reduction of the environmental burdens. As emerged, the main contributors have been identified in the aluminium frame and in the DSSC photovoltaic panel. The effect in reducing the impacts of the suggested alternatives, namely the use of recycled aluminium for the frame and the use of a full organic dye for the DSSC, were tested with sensitivity analyses. As much as regards the use of recycled aluminium, this would allow to reduce in general the environmental burdens of up to 15% on most of the impact categories, while the use of a full organic dye would result in an environmental benefit up to 75% for the DSSC photovoltaic panel eco-profile, thus contributing to further lower the environmental footprint of the SELFIE 2 module.

In a further approach, LCA will be used in parallel to the testing phase, which will provide information regarding the module performance during its use phase.

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Life Cycle Assessment of building end of life

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Abstract

The paper deals with how the buildings' end of life is assessed in LCA, throughout a study based on European Standard and literature review. End-of-life modelling is becoming more important within circular economy policies that improve the extension of buildings' service life (through regeneration and refurbishment processes) and building's components reuse or recycling. The paper highlights different assumptions and different approaches taken in LCA modelling of the building end of life: functional unit, system boundary, allocation method, inventory of quantity and data collection. Moreover the uncertainty and limits of modelling are analysed.

1. Introduction

In the last two decades, many LCA studies of buildings have been conducted, but a lot of them do not include an in-depth analysis of the end-of-life phase (asserted by Paleari et al., 2015). The omission is mainly caused by the lack of information and the difficulty in predicting future scenarios (Oregi et al., 2015). Many studies about building's LCA, in fact, are focused on the product phase (A1-3) and the operational energy use stage (B6); instead the end of life is modelled choosing simplified assumptions, such as an average distance between the building and the place of disposal and landfill for demolition waste of the whole building. In this way, the impact of end-of-life stage, in comparison to the whole life cycle, is less than 1% for the life cycle energy use, so the end-of-life stage loses its relevance (Oregi et al., 2015).

The simplified assumption about landfill for demolition waste of the whole building is no longer possible under the Waste Framework Directive (WFD) 2008/98/EC, which establishes that almost 70% of construction and demolition waste (CDW) have to be reused, recycled or recovered. Hence, the LCA studies from 2008 assume a rate of recovery/reuse/recycle of material over 70%, in order to respect the WFD. Moreover, the circular economy point of view is changing the concept of 'end of life', therefore also the evaluation of it. Circular economy policies aim at efficient use of natural resources and at reduction of waste generation (COM 398, 2014; COM 614, 2015). It is possible to state that, in this context, the promoting routes are:

- remanufacturing / reconditioning of products, which increase the lifetime of products by rebuilding and repairing them;
- a closed-loop system, which transforms products, that have reached the end of their useful life, into something new, by process of reuse and recycling of components.

In the building sector the actions, that respect these two routes of circular economy, are:

- the regeneration of buildings, in order to give back a new function and extend the service life of buildings; in this context the practices of repair, replacement and refurbishment are incentivised;
- the management of construction and demolition waste in order to reuse and recycle waste as secondary materials, avoiding landfill and the extraction of raw materials.

Nevertheless, improper management of refurbishment practices or CDW recycling should result in considerable environmental impacts and recycling processes might cause indirect environmental impacts (JRC, 2011; Mousavi et al., 2016). Within the life cycle thinking approach, it is important to evaluate the impacts of every circular action through scientific methodologies like the internationally standardized procedure of Life Cycle Assessment. In this context, the evaluation of the end of life phase, that has been little treated in the LCA studies, becomes crucial. In fact, with the support of LCA it is possible assess the impact of repair, replacement, refurbishment processes and CDW management: in the EN 15978 (2011) these phases are identified in the Module B3, B4, B5, C1-C4. Moreover EN 15978 sets a module D in order to quantify the environmental benefits or loads resulting from reuse, recycling and energy recovery processes.

The EN 15978 defines the limit between the end-of-life stage and module D. The end-of-life stage starts from the activity that produces waste, and considers the management for waste, as a "multi-output process that provides a source of materials, products and building elements that are to be discarded, recovered, recycled or reused". The impacts assigned to end-of-life stage regard the waste management and disposal until the landfill (considering also the impacts of landfill), if it is the final destination of waste, included the impacts of transports (from building to landfill). But the situation changes when the waste stops being 'waste' to became a second-hand material usable in other processes by recycling or energy recovery. The secondary materials leaves the system, and its burdens are divided between end-of-life stage and module D. The process of collection and transport until the sorting plant of secondary materials are part of the waste processing of the building, so the burdens are assigned to the end-of-life stage; instead the further processes (e.g. recycling process) concern another product system. So the processes' burdens and avoided impacts are assigned to module D (beyond the system boundary), in according to the 'cut-off' approach.

End-of-life modelling needs allocation methods to divide environmental impacts and benefits between the first and second life of products. There are different approaches and different methods of allocation and the debate is open especially in the context of defining the PEF (Giorgi et al., 2016). But, in the case of the building, the EN 15978 sets out a 'cut-off' approach. However in literature there are many building LCA studies that use other types of allocation, because of different goals and scope of the studies. Moreover, many methodological choice still remain without rules, and debates are still ongoing in areas like the definition of (temporal) system boundaries, life cycle inventory generation, selection and use of environmental indicators, and interpretation and communication of the LCA results (Saner at al., 2012). According to Sandin at al. (2014) the four factors that can mainly change the result of LCA are: the type of approach used in modelling between consequential and attributional approach, the end-of-life phases considered, the type of disposal that is chosen among reuse, recycling, incineration or landfill and the impact of technology assumed. This paper shows how some authors have treated LCA in case studies about buildings' end of life, which methods are assumed and which limits have been found.

2. Different goals and scopes in end-of-life modelling

In literature, LCA studies which take into account the end-of-life stage are conducted with different 'goal and scope'. The scientific papers analysed treated the end of life in three different way. Some studies use an approach of whole-LCA modelling in order to assess the entire environmental impact of building considering all stages of life, hence the end-of-life stage, too (e.g. Oregi et al., 2015; Blengini et al., 2010). Other studies regard a LCA which takes into account just few stages of building life. They want to evaluate the impacts of deep refurbishment of a building and assess the treatment of waste produced during the works (e.g. Ghose et al., 2017a). Moreover these studies compare buildings' intervention strategies which minimize the waste to aid decision making (e.g. Ghose at al. 2017b). Other studies consider only the end-of-life stage modelling to assess the impact of management of waste generated from building demolition. The goal of these LCA studies is to evaluate the environmental impacts related to end of life of the different fraction of construction and demolition waste in order to assess the best type of disposal or recovery (e.g. Butera at al., 2015; Sandin at al. 2014, Vitale et al., 2017), considering, also, the quality of recycling of materials. Moreover, studies want to evaluate different alternatives of demolition scenarios and management of waste generated (e.g. Martinez et al., 2013). Different 'goal and scope', brings different approaches and different assumptions in LCA, such as functional unit, system boundaries, data collection, data source and allocation approach.

2.1. Functional unit and system boundary in end of life modelling

According to ISO 14040, the functional unit is a measure of the function of the studied system. The functional unit changes in relation to different studies because it also depends on the reference performance chosen. Whole-LCA studies, focused on whole-life-cycle impact assessment, use a functional unit referred to the entire building and the design requirements, such as thermal comfort. So, results are expressed per unit of useful heated floor area and per year (1 m^2/years) (e.g. Oregi et al., 2015; Blengini et al., 2010; Ghose et al. 2017a; Ghose at al. 2017b). The studies that consider only end-of-life waste management, instead, take into account a functional unit aimed at management of waste generated by demolition activities. The functional unit is expressed in weight (e.g. tonnes) of waste generated, for assessing environmental impacts and benefits of the different scenarios of the management system (e.g. Butera et al., 2015; Vitale at al., 2017).

The Standard EN 15978 states that the system boundary of end of life has to consider the process of selective demolition/deconstruction, collection of waste materials of the building and the processes of on-site sorting, transport to plants for recycling/recovery and/or disposal of waste in landfill. According to the 'polluter pays' principle, loads, (e.g. emissions) from waste disposal are considered part of the building life cycle. However, the benefit of reuse or recycling (for example the energy generated form waste incineration or the benefit of use of secondary materials in the other productions' system) are assigned to module D.

In some studies different scenarios are assessed, hence different system boundaries are analysed in order to choose the most sustainable routes, considering different management processes for the same type of material. Blengini et al. (2010) in whole-LCA modelling consider the phases of: 'pre-use and maintenance', which include structure, finishes and equipment material (quantities estimated from building drawings and field measured data), transportation (average distances estimated from personal communication with designer and contractor), construction stage (estimated from field measured data, personal communication with designer and constructor, literature), maintenance activities (estimated from literature and personal communication with designer and constructor); 'use', which considers energy use for heating, ventilating and DHW, energy use for cooking, washing, lighting and use of appliances (calculated with the software); 'end of life', in particular, which considers three stages (estimated data from literature): selective disassembling of re-usable/recyclable materials and structures (windows, steel, aluminium and roof), controlled demolition of the structure by hydraulic hammers and shears, CDW treatment and recycling, reuse or landfill. In particular, CDW generated from the building process and during maintenance operations was considered: the mineral fraction, such as concrete, mortar, bricks, ceramics, etc., was assumed to undergo a recycling process for the production of secondary aggregates; metal and glass separation and recycling; wood incineration and mixed rubble recycling.

Ghose et al. (2017b), in LCA for different refurbishment assessments, consider three scenarios of different rates of recycling. The first scenario is 'business as usual scenario' which analyses conventional activities from production of refurbished components (without recycling content), transport to construction-site, construction-site activities and transport of waste to treatment site, waste management considering parts of waste to landfill and a little rate of material to recycling (considering, through consequential approach, the avoid loads of production of new materials using the waste as secondary materials and the avoid loads of a avoid landfill). The second scenario regards the 'waste minimization', it considers a rate of materials reused at construction-site and it assumed an higher rate of materials recycling than first scenario. The third scenario regards the ‘reduce demand of primary production’, it consider the use of material with recycled content in the production of refurbishment component phase and it assumed the same rate of materials recycling than first scenario. The fourth scenario regards a waste ‘minimization and reduce demand of primary production’, it consider both the use of material with recycled content in the production of refurbishment component phase and an higher rate of materials recycling than first scenario.

Vitale et al. (2017) analyse with more detail the CDW management, including all activities of selective demolition, collection, sorting, transportation, material and energy recovery, and landfill. It consider, through a system expansion, a system about the building demolition, sorting in situ and transportation, and the recycling chains for metals, plastics and glass, a waste-to-energy chain for combustible materials, and landfill disposal for residual waste.

However the assessment of waste are influenced by the perspective chosen and the assumptions made about material recycling and energy recovery. Therefore, in LCAs of alternative waste treatments, such as studies with ‘gate-to-grave’ system boundaries, the option of waste prevention (such as avoiding demolition) is rarely considered because the functional unit is commonly defined as a certain amount of waste to be treated (Laurence Hamon in Saner at al., 2012).

2.2. Data collection and scenario assumptions

Regarding to quantification of waste in a building refurbishment or demolition, the quantity of waste can be estimated through site measurement and by a model developed with a software, that gives a bill of quantities of material. Ghose et al. (2017a) declare that the estimating of material quantities based on models developed with software (like CAD) is a fairly trustworthy data collection method when bills of quantities of detailed building design are unavailable, and other studies also demonstrate this (Malmqvist et al., 2011).

Otherwise, the quality of secondary materials for recycling is difficult to forecast because it depends on the demolition process (if it is a selective or traditional demolition). Poor quality of recovered material affects its recyclability. In fact, Intini e Kuhtz (2011) explain, through an example of recycling PET, that the mechanical impurities represent the main issue affecting quality in the recycling stream, because manufacturing processes were originally designed for virgin raw materials only. Hence, efficient sorting, separation, and cleaning processes become very important in order to obtain high quality recycled material. Also, Ghose et al. (2017b), referring to a study of Graedel and Reuter (2011), show the importance of material recovery rate and recycling efficiency, which are the two main factors that determine the benefits of recycling. They show, that a low recovery rate (75%) with high recycling efficiency (98%) per kg aluminium scrap results in 0.74 kg of avoided primary aluminium production; instead an high recovery rate (100%) with a low recycling efficiency (70%) per kg aluminium scrap results in 0.70 kg of avoided primary aluminium production.

Moreover the end of life of building does not fall at present but it will occur at a later time. Generally refurbishment assessment studies take a reference life of about 50 years, and new building assessment studies take 100 years as reference life. Consequently, the technologies and processes of recovery should be more efficient than current ones. So, this is another assumption to choose within an end-of-life LCA. In the case study of Sandin at al. (2013), two assumptions of technology are assumed: one assessment takes today's technologies and the other one takes today's low-impact technologies which are representative for the average future technologies (wind power is assumed to replace diesel as energy source in demolition).

Moreover the regulations can modify the recovery rate. For example, the waste management scenarios have changed with WFD, which has changed the landfill scenarios to a rate of 70% recycling of CDW.

In end-of-life modelling, also distances of transport between building and recycling plants are estimated. The distances to recycling and deposit plants are calculated as an average distance of the current plants per region, in the LCA conducts by Martinez et al. (2013). In Butera et al. (2015), the distance from demolition site to landfill is assumed 50 km, while the distance to treatment facility is hypothesized 30 km. Moreover the avoided transport from place of extraction of virgin materials to production place is assumed 50 km. Generally, in every studies, the impacts of transports are a high contribution in a buildings' end-of-life LCA, so the assumption of distance play a crucial role.

2.3. Modelling methods

The great difference in end-of-life LCA studies regards allocation method assumed between attributional and consequential. The first (attributional model) sets the goal towards the analysis and description of the current and real situation. Attrubutional approach "consider the flow in the environment within a chosen temporal window", hence it counts all impacts as a current snapshot of a certain product or service. The second (consequential model) "consider how the flow may change in response to decision", so it hypothesizes the consequences, counting impacts that could be produced or avoided in a future situation (Ekvall, 2016).

It is interesting to note that, generally, the studies which want to predict the environmental impacts in decision-making phase, use a consequential approach with avoided impacts, and all benefits of avoided extraction material and avoided landfill are considered in the counting. Otherwise, other studies choose an attributional approach, calculating the impacts until waste disposal in case of landfill, or until the transport in sorting plant in case of recycling. In case of attributional no avoided impacts or benefit of recycling are considered in LCA results. Blengini et al. (2010), wants to assess the effectiveness of recycling process, so they choose a consequential approach of avoided impacts including the whole recycling chain. All activities and processes from waste collection to substitution of virgin products, are taken into account in order to assess the use of recycled products in comparison to the correspondent virgin products. In the study, the environmental burdens corresponding to manufacturing of new product with second materials are subtracted from the system. So, the environmental balance between impacts and gains can be negative, if the impacts avoided are higher than induced impacts. Attributional approach is adopted by Ghose et al. (2017a), because they want to avoid the risk of double-counting, so no benefits are given for the provision of recyclable materials, analysis the current situation. Instead, Ghose at al. (2017b) in order to assess a situation with future-oriented perspective, adopt a consequential LCA with an approach of avoided burdens. Butera at al. (2015) have the objective of studying the consequences caused by the changes in the modelled system, so they use a consequential LCA. Differently, in the study of Vitale et al. (2017) the allocation problem in the LCA modelling has been avoided by utilizing the system expansion methodology, because the study aim to quantify the contributions of each stage of the end-of-life phase, with a particular attention to the management of the demolition waste, without the problems of allocation.

3. Uncertainty of data

All studies analysed declare that uncertainty of data is the major limit in the assessment of end of life. The limited availability of buildings' end-of-life studies is caused by the lack of data on demolition, recovery and recycling of materials (Blengini et al., 2010). Generally, literature-based data and secondary data (such as international EPD, database) are assumed, but also the database assumption can change the LCA results.

Regarding database, some authors highlight the great lack of flexibility in a life cycle inventory (LCI) before ecoinvent v3. According to Ghose at al. (2017) the earlier versions of the ecoinvent database based on attributional modelling represented a lack of consistency and transparency in the consequential modelling approach. In 2013 the development of consequential datasets in the ecoinvent v3 database has reduced the uncertainty.

4. Conclusions

Recent circular economy policies give a new relevance to buildings end of life decisions so the modelling of this final stage need more careful analysis. The paper take into account different end-of-life LCA studies and the limit of assumptions and the uncertainty of data are stressed. The end-of-life LCA is highly uncertain in building sector, because generally many data are supposed, also because the end of life of building occurs in the future. To calculate benefits and loads there is the need to take into account several assumptions about, for example, types of treatment, distance to plants of treatment, the quantity of materials analysed, the efficiency of material recycling and the efficiency of technology and practices (existing or future). Many discussion are still open, such as about the type of modelling between consequential and attributional, the end-of-life phases to be considered, and the poor of data quality.

Hence, there is the necessity to improve the end-of-life assessment, in order to provide better support in the end-of-life decisions and waste management with LCA. At first, waste prevention, which is the first pillar of waste hierarchy, has to be considered also in end-of-life LCA, then differences among scope definitions, time perspectives and boundaries, and the use of different allocation procedures for waste treatment and recycling have to be minimized, furthermore, data quality must be improved.

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ELISA: A simplified tool for evaluating the Environmental Life-cycle Impacts of Solar Air-conditioning systems

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Abstract

The paper presents ELISA, a simplified tool for estimating the Environmental Life-cycle Impacts of Solar Air-conditioning systems. The tool is designed to support researchers, designers and decision makers in a simplified evaluation of the life cycle energy and environmental potential benefits related to the installation of solar heating and cooling systems in substitution of conventional ones.
The tool was developed within the research activities of Task 53 "New Generation Solar Cooling & Heating Systems (PV or solar thermally driven systems)" of the International Energy Agency.

1. Introduction

The Solar Heating and Cooling (SHC) systems are of great interest in the reduction of the greenhouse gas emissions, particularly in sunny regions, due to the use of renewable energy resources for the buildings air-conditioning (Beccali et al., 2016). Good results in terms of electricity and natural gas savings can be achieved through an accurate design of the SHC systems, which takes into account climate characteristics and building loads during all the year (Beccali et al., 2014a).

Many researchers are contributing in the development of a competitive market for the SHC technologies by focusing on cost-effectiveness and high performance (Chang et al., 2009) in different geographic contexts. However, they often analyze only the SHC systems behavior during the operation stage, neglecting the energy and environmental aspects of the manufacturing and end-of-life of these technologies.

By extending the point of view to the whole life cycle, the benefits of using renewable energy during the operation of the SHC systems could be offset by the impacts of the other stages. For this reason, it is important to introduce the Life Cycle Assessment (LCA) (ISO 14040, 2006; ISO 14044, 2006) for assessing the energy and environmental performances of the systems during their life cycle. However, the development of a complete LCA for a complex system as the SHC can be difficult and time-consuming particularly for no-LCA experts, discouraging them in the inclusion of life-cycle considerations in the assessments.

In order to support the SHC experts in the development of simplified LCAs during the design phase of the SHC systems, the authors developed the tool ELISA. This tool can be used for estimating the environmental life-cycle impacts of solar air-conditioning systems. The tool, although simplified, can be used for understanding the potential energy and environmental benefits/impacts of the solar technologies in different geographic contexts with respect to conventional ones.

2. ELISA tool

ELISA is a tool for developing a simplified life cycle energy and environmental assessment of SHC systems and for comparing them with conventional ones. The tool, developed in Microsoft Excel (Microsoft Excel 2016, 2016), can be used for the comparison of four typologies of heating and cooling systems:

- SHC system;
- SHC system with photovoltaic panels (PVs);
- Conventional system;
- Conventional system with PVs.

The logo of ELISA is shown in Figure 1.

ENVIRONMENTAL LIFE-CYCLE IMPACTS OF
SOLAR AIR-CONDITIONING SYSTEMS

Figure 1: ELISA logo

The tool allows for calculating the following indices:

- Global warming potential (GWP) [kg of CO_{2eq}], calculated using the characterization factors of the "IPCC 2013 GWP 100 year" impact assessment method (IPCC, 2014);
- Global energy requirement (GER) [MJ], calculated using the impact assessment method "Cumulative Energy Demand" (Frischknecht et al., 2010);
- Energy payback time (E-PT) [years], defined as the time during which the SHC system (with or without PV) must work to harvest as much primary energy as it requires for its manufacturing and end-of-life. The harvested energy is considered as net of the energy expenditure for the system use;

- GWP payback time (GWP-PT) [years], defined as the time during which the avoided GWP impact due to the use of the SHC system (with or without PV) is equal to the GWP impact caused during its manufacturing and end-of-life;
- Energy Return Ratio (ERR) that represents how many times the energy saving due to the use of the SHC system (with or without PV) overcomes its primary energy consumption during the life-cycle.

The main page of ELISA is shown in Figure 2.

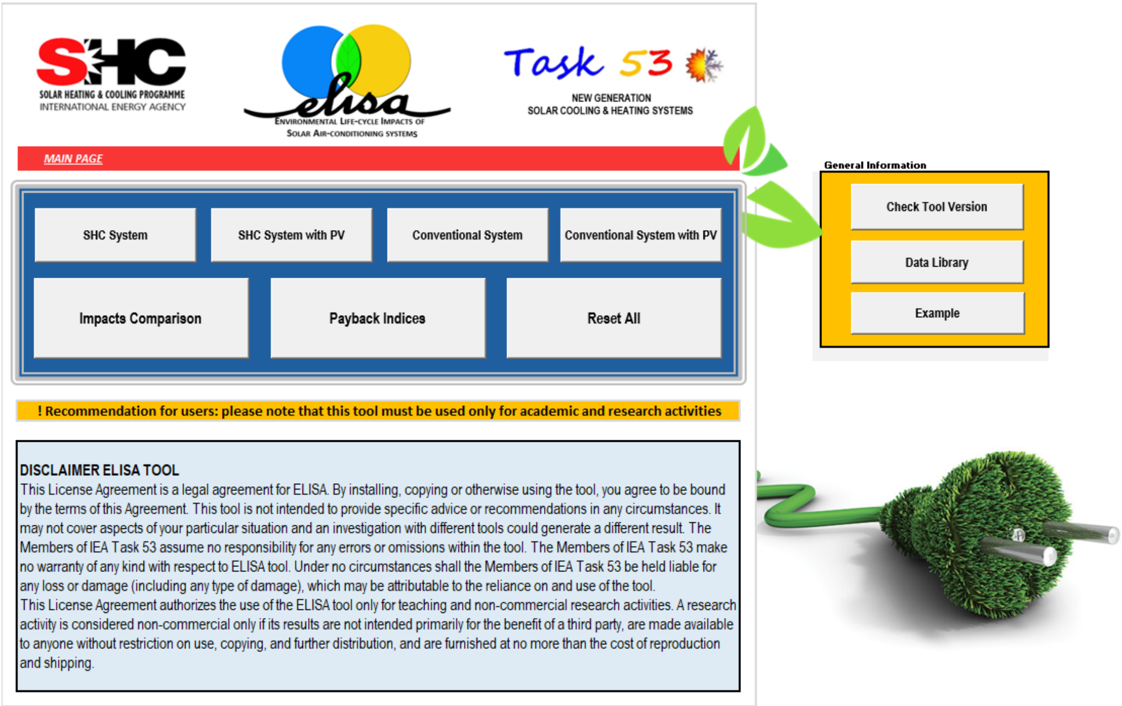

Figure 2: Main page of ELISA

From the main page, the user can access to the data library of the tool (Figure 3) that shows the specific energy and environmental impacts (Beccali et al., 2010 and 2014b; Cellura, 2014; Frischknecht et al., 2007; Longo et al., 2014; Majeau – Bettez et al., 2011; Mc Manus, 2012; Notter et al., 2010), in term of GER and GWP, of the components that are commonly part of a SHC or a conventional system (including the PV system) and of energy sources (electricity and natural gas).

3. Description of the Case study

To illustrate the features of ELISA a simple application is described in the following section, comparing four heating and cooling systems: a SHC system (without and with PV) and a conventional system (without and with PV). The systems are installed in Palermo (Italy) and have a useful life of 25 years.

The SHC system is composed of: an absorption chiller (12 kW); a field of evacuated solar tube collectors (35 m^2); a heat storage (2,000 l); a cooling tower (32 kW); an auxiliary gas boiler (10 kW); an auxiliary conventional chiller (10 kW); pipes (60 m); two pumps (80 W and 250 W); a solution of water and ammonia (15 kg of ammonia and 10 kg of water). The system consumes 1,117 kWh/year of electricity and 414 kWh/year of natural gas. The conventional system is constituted by a chiller of 10 kW and a gas boiler of 10 kW; it requires 1,995 kWh/year of electricity and 2,882 kWh/year of natural gas. In addition, the SHC system and the conventional system coupled with PV include: photovoltaic panels, inverter, electric installation and batteries. The PV system is sized as a stand-alone system with energy storage for supplying the electricity required from the SHC and conventional system during the useful life.

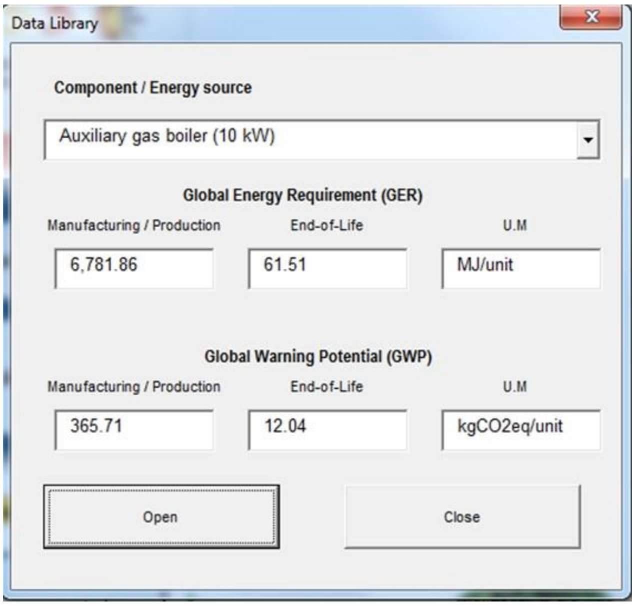

Figure 3: Data Library

3.1.1 Entering data in the input worksheet

ELISA contains four input worksheets, one for each system. Each input worksheet includes a list of the components of the analyzed system, of electricity mixes of 25 localities and of natural gas burned in 10 different systems in the European context. Figure 4 shows, as an example, the structure of the input worksheet for the SHC system.

In addition, ELISA allows for including the number of replacements of each component during the useful life of the system: e.g. the inverter used in the PV system has a useful life of 12.5 years, this means that it will be substituted one time during the 25 years.

3.1.2 Analysis of the results thought the output worksheets

The results are shown in three output worksheets:

The first one presents the GER and GWP results for each system both in table and graphs. In detail, the results in table shows: the total impact for each component/energy source; the impact of the manufacturing and end-of-life steps of each component of the system and the impact of the operation; the total impact of each life-cycle step (manufacturing, operation, end-of-life). The graphs allows for visualizing the contribution of the different life cycle steps to the total impact and the incidence of each component/energy source on the impact of manufacturing, operation and end-of-life. As an example, Figure 5 shows the incidence of each component of the SHC system to the impact on GER during the manufacturing step.

COMPONENTS OF THE SHC SYSTEM

Category	U.M.	Quantity	n° REPLACEMENT
Ammonia	kg	15.00	
Auxiliary conventional chiller (10 kW)	unit	1.00	
Auxiliary gas boiler (10 kW)	unit	1.00	
Absorption chiller (12 kW)	unit	1.00	
Cooling tower (32 kW)	unit	1.00	
<Glycol>	kg		
<Heat rejection system>	unit		
Heat storage (2000 l)	unit	1.00	
<Heat-pump>	unit		
Pipes	m	60.00	
Pump (40 W)	unit	8.25	
Evacuated tube collector	m^2	35.00	
Water	kg	10.00	

ENERGY SOURCES

Category	U.M.	Quantity
Electricity, low voltage, Italy (including import)	kWh/year	1,117.00
Natural gas, burned in boiler atmosferic low-NOx condensing non-modulating, <100 kW, Europe	kWh/year	414.00

Figure 4: Input worksheet of the SHC system

The second worksheet displays the comparison of the results for the different systems (both in table and graphs (Figure 6)).

The third worksheet shows the E-PT, GWP-PT and ERR indices (Figure 7). In detail, each box of Figure 7 indicates the value of the index calculated for the system of the j-th row if compared with the system of the i-th column.

The calculation of the above set of indices is useful to evaluate if the additional impacts usually caused during the production and end-of-life steps of a SHC system if compared with a conventional one are balanced by the energy saving and avoided emissions during its operation.
However, when the conventional system uses energy from renewable sources (e.g. electricity from PV), the impacts of the SHC system during the operation step can be higher than that of the conventional one. In this case, the SHC system has worse energy and environmental performances during the operation step and cannot balance the additional impacts caused during its production

and end-of-life. When this happens, E-PT, GWP-PT and ERR cannot be calculated.

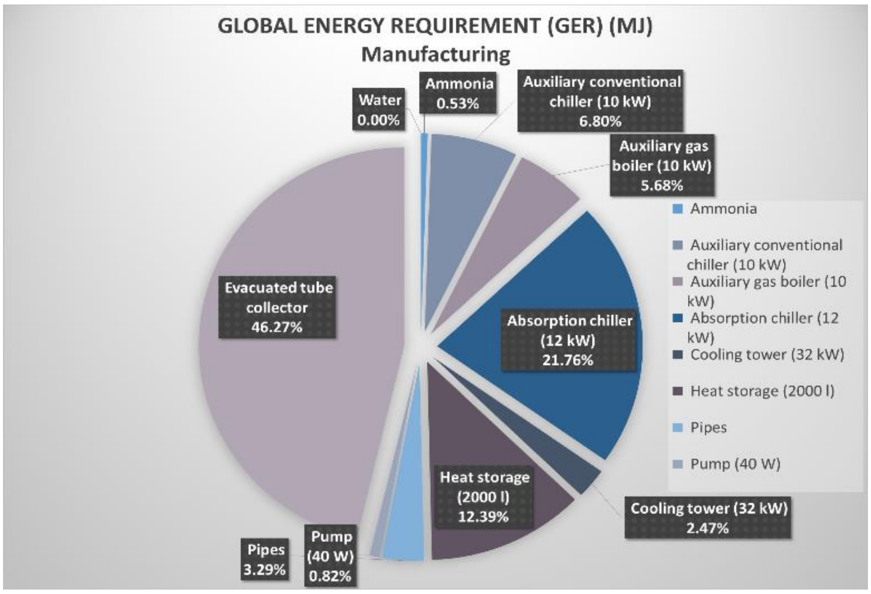

Figure 5: Manufacturing step: GER of the SHC system

SYSTEM	GLOBAL ENERGY REQUIREMENT (GER) (MJ)				GLOBAL WARMING POTENTIAL (GWP) (kg CO_{2eq})			
	Manufacturing	Operation	End-of-Life	Total	Manufacturing	Operation	End-of-Life	Total
SHC System	119,503.54	347,549.01	581.90	467,634.46	7,522.10	20,795.83	210.67	28,528.60
SHC System with PV	176,582.25	47,713.35	3,847.30	228,142.90	10,490.07	2,825.69	558.08	13,873.83
Conventional System	14,912.96	858,476.81	69.34	873,459.11	1,916.17	51,335.67	37.86	53,289.70
Conventional System with PV	112,435.80	322,960.12	5,507.97	440,903.89	7,009.47	19,240.40	582.56	26,832.43

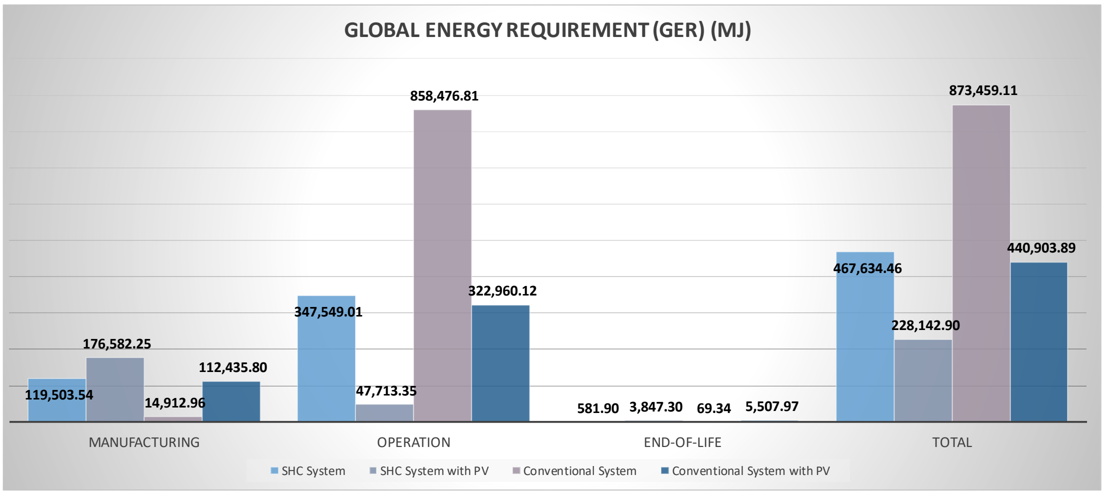

Figure 6: Impacts comparison worksheet

An analysis of the results indicates that the integration of the PV panels in the heating and cooling system can reduce the life-cycle impacts of about 50% for both the SHC and conventional system, although the impacts of the manufacturing and end-of-life steps increase. Comparing the results, it can be observed that, in the selected location, the use of the SHC system with PV allows for the reduction of the impacts of about 74% and 49% if compared with the conventional system without and with PV, respectively.

The analysis of the payback indices highlights that the benefits of using the SHC system with PV if compared with the respective conventional system allows for offsetting the energy and environmental costs due to the life-cycle of the solar system in about 5.5 years. The value of ERR indicates that the energy saved during the useful life of the SHC system with PV overcomes the global energy consumption due to its manufacture and end-of-life of about 4.5 times.

The SHC system has worse energy performances during the operation if compared with a conventional system with PV. In this case, the negative values obtained for the examined indices indicate that E-PT, GWP-PT and ERR cannot be calculated.

	$E\text{-}PT=(GER_{j\text{-}th,SHC\text{-}system} - GER_{i\text{-}th,Conventional\text{-}system})/E_{year}$	
	Conventional System	Conventional System with PV
SHC System	5.14	-2.18
SHC System with PV	5.10	5.68
	$GWP\text{-}PT=(GWP_{j\text{-}th,SHC\text{-}system} - GWP_{i\text{-}th,Conventional\text{-}system})/GWP_{year}$	
	Conventional System	Conventional System with PV
SHC System	4.73	-2.26
SHC System with PV	4.69	5.26
	$ERR=E_{Overall,j\text{-}th,SHC\text{-}system}/GER_{i\text{-}th,SHC\text{-}system}$	
	Conventional System	Conventional System with PV
SHC System	4.25	-0.20
SHC System with PV	4.49	1.53

Figure 7: E-PT, GWP-PT and ERR

4. Conclusions

The paper describes ELISA, a useful tool for the evaluation of the potential benefits due to the installation of the SHC systems if compared with the conventional ones.

ELISA is a simplified tool that cannot be used for complete and accurate LCAs, but it gives a general overview and one order of magnitude of the energy and environmental impacts of the four typologies of systems presented above. In addition, the data library is limited and could be extended in the future with new data. However, ELISA is a user-friendly tool that can simplify the introduction of the life-cycle perspective in the selection of the most sustainable heating and cooling system is a specific geographic contexts.

Researchers, designers, and decision-makers can use ELISA to take environmentally sound considerations in the field of the SHC systems (PV or solar thermally driven systems).

ELISA can be downloaded for free from the website of Task 53 of the International Energy Agency (IEA): http://task53.iea-shc.org/.

6. Acknowledgements

ELISA was developed within the research activities of Task 53 “New Generation Solar Cooling & Heating Systems (PV or solar thermally driven systems)” of the International Energy Agency.

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A comparative study between a Prefab building and a Standard building for the characterisation of production and construction stages

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Abstract

The reduction of heterogeneous systems in a prefabricated house can make improvements both in terms of less environmental impacts and higher efficiency in the construction stage. The aim is to point out the main environmental advantages of a prefabricated building in comparison to a standard building with similar features, in the first two stages of their life cycle: production and construction. The paper also deals with the reuse, recovery and recycling potential of the two buildings in order to determine if the use of only dry construction systems have a positive effect in a future end of life scenario. The results show a better performance of the prefabricated building if compared with the standard building in terms of Global Warming Potential, Embodied Energy and Human Toxicity Potential.

1. Introduction

In the construction sector are now available several studios concerning the impact of manufacturing and use stages of buildings. The construction stage, on the contrary, has not been taken into account consistently among the studies and further researches on the importance of construction processes over the whole life cycle stage of buildings are needed[1,2].

In this work, two buildings with similar geometric features and modelled with comparable criteria but made up with different materials and construction systems were compared. The first one is manly made of wooden-based elements pre-manufactured in the factory and installed as ready-made details using only dry construction systems (Prefab building), while the second one is a traditional construction house fabricated in-situ consisted of clay brick and mortar external walls, clay-tiled roof and plaster finishes (Standard building). The comparison between the two buildings was based on both the inventory analysis and the impact assessment.

The characteristics of the materials, elements and building systems that were part of the study as well as several primary data were collected from datasheets and scientific literature references. The eToolLCD2015[3] database served as secondary and generic source for obtaining the life cycle inventory data and

[1] Vilches et al., 2016.
[2] Achenbach et al., 2017.
[3] Developed by Eng. Alex Bruce and Richard Haynes. eToolLCD2015 software was used to model life cycle impacts of the project. eToolLCD uses third party background processes aggregated as mid-point indicators and stored in a number of libraries within the software which are coupled with algorithms and user inputs to output the environmental impact assessment.

was also the software used to model the project; IREEA[4] (Initial and Recurring Embodied Energy Assessment) worksheet tool was used to implement data concerning some materials that were not present in the eToolLCD2015 database.

Generally, when discussing about environmental impact in the context of construction industry, the emphasis is on pollutant emissions and the use of material and energy (resources)[5]. Considering this information, the following three impact categories were selected for the LCA study:

- Global Warming Potential (GWP) measured in kg CO_2 eq[6]: it refers to the total contribution to global warming resulting from the emission of one unit of a gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1. The normalized value refers to a defined period of time. Generally, 100 years.
- Embodied Energy (EE) quantified in MJ NCV[7]: is the energy sequestered in building materials during all processes of production, on-site construction, and final demolition and disposal[8]. In this study, and due to the aim of the analysis, the EE is given by the sum of the Initial EE (EEi) and the Recurring EE (EEr)[9].
- Human Toxicity Potential (HTP) calculated in uDALY: it takes account of releases of materials toxic to humans in three distinct media: air, water and soil. The toxicological factors are calculated using scientific estimates for the acceptable daily.

2. System description

2.1. System boundary

The system boundary for this study included all the upstream and downstream processes needed to provide the primary functions of the two structures in their first two stages: from raw materials extraction, including the primary energy sources, manufacturing, transportation and finally construction.

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4 Developed by R. Giordano, V. Serra, E. Demaria, A. Duzel. IREEA enables to quantify the EE for any class of building. Particularly it is based on the Swiss SIA 2032 technical specification (Grey Energy of Buildings). IREEA makes possible to evaluate: 1) the initial EE value of each building systems (e.g. floor systems, wall systems, etc), window frames and glazing systems; 2) the simplified initial EE of building services; 3) the recurring EE based on the replacement cycles of material and components; 6) the potential variation of the building's estimated life time; 6) the total EE of a building. IREEA assesses if specific materials and components have a considerable EE impact in the early design stage in order to allow some replacements.

5 Pacheco-Torgal, F, 2014.

6 A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2 eq, is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

7 NCV means Net Calorific Value.

8 Kumar Dixit et al, 2010.

9 Giordano et al., 2016.

The reuse, recovery and recycling potential of both buildings was also included in the study.

2.2. Functional unit

In this study the chosen functional unit was one square meter (m^2) of Gross Floor Area (GFA) normalised over one year (yrs). The estimated life span of the buildings adopted for the LCA study period was 60 years. The total GFA of the two buildings was 163 m^2.

2.3. Characterization of the two buildings

The buildings are located in a residential suburb of Milan. The main building features are displayed in **Table 1**.

Table 1: Building features

	Prefab building	Standard building
Building type	Residential building	Residential building
Stories	2	2
Bedrooms	3	3
Average floor-to-floor height	3,5 m	3,5 m
Usable Floor Area	144 m^2	144 m^2
Fully Enclosed Covered Area	135 m^2	135 m^2
Unenclosed Covered Area	28 m^2	28 m^2
Gross Floor Area	163 m^2	163 m^2

The main materials used in each building system are summarised in **Table 2**. For the Prefab building, the only element build in-situ is the foundation system. On the contrary, for the Standard building most of the materials are made and applied on site.

Table 2: Building systems and main materials used in the two building solutions (Prefab building and Standard building)

Building system	Prefab building	Standard building
Substructure	Reinforced concrete	Reinforced concrete
Structure	Composite wood	Masonry
Wall system and partitioning	Composite wood	Masonry
Floor system	Composite wood and particleboard	Reinforced concrete, floor tiles, wood and PU Coating
Insulation	Polystyrene panels	Glass fiber
Internal finishes	Particleboard	Cement plaster, plasterboard, paint and wall tiles
Roof system	Composite wood and metal roofing	Timber and clay tiles
Ceiling system	Particleboard	Plasterboard
Wall cladding	Metal and timber cladding system	Cement plaster
Windows and doors	Timber and corkboard	Aluminum, PVC and timber

2.4. Cut off Criteria

According to EN 15978:2011 standard, cut off criteria were used to ensure that all relevant potential environmental impacts were appropriately represented.
In order to do that, it was important to determine the flows for each of the building systems compared. The criteria can be summarised as follow:

- Transportation from production site to construction site data: an average value of 100 Km was assumed.
- Operators and equipment: flows related to human activities such as employee and equipment transport were included.
- Foundation system: this building system was left out of the study since it was the same in both case studies.
- Material disposal: no type of disposal process was assumed.

3. Life Cycle Inventory Analysis (LCI)

Both buildings were modelled consistently with the following flows:

- Raw materials extraction.
- Primary and secondary energy sources.
- Manufacturing of goods: materials and components.
- Transportation.
- Construction: including each process/step, the time used (man-hours and equipment) to make up every building system and the materials used in each one.

The methodological approach for the inventory analysis of the two building solutions is summarised in **Table 3**.

Table 3: An extract of the Life cycle inventory analysis per functional unit for the two building solutions (Prefab building and Standard building)

Inputs and Outputs per m² GFA/year for the two building solutions			
		Prefab building	**Standard building**
Inputs	Materials	Raw materials	Raw materials
	Energy flows	Manufacturing flows	Manufacturing flows
		Transport flows	Transport flows
Outputs	Materials and components	Particleboard	Floor tiles
		Polystyrene panels	Glass fiber
		…	…
	Waste for treatment	Hazardous waste	Hazardous waste
		Non-hazardous waste	Non-hazardous waste
	Emissions to air	CO_2	CO_2
		Methane	Methane
		…	…
	Emissions to water	Suspended solids	Suspended solids
		Nitrogenous matter (as N)	Nitrogenous matter (as N)
		…	…

4. Life Cycle Impact Assessment (LCIA)

The life cycle impacts of the two buildings for the same functional unit are provided and summarised in **Table 4** consistently to EN 15978:2011 standard.

Table 4: Life cycle impacts per functional unit for the two building solutions (Prefab building and Standard building)

ENVIRONMENTAL IMPACTS - Characterised Impacts per m² GFA/year						
Impact categories and their category indicators		Product stage	Construction Stage			
		Raw material extraction and manufacturing processes	Transport	Construction-installation	Reuse, recovery and recycling potential	Total
GWP-kgCO_2 eq	Prefab	1,4e-1	0,09	1,17e-1	-4,81e-1	-1,38e-1
	Standard	2,44	1,06	2,45e-1	-1,19e-1	3,63
EE - MJ NCV	Prefab	137,02	1,35	1,68	-5,36	134,69
	Standard	70,80	15,84	2,07	-2,85	85,86
HTP - uDALY	Prefab	4,43e-1	3,14e-4	1,80e-3	-1,80e-2	4,27e-1
	Standard	8,93e-1	8,08e-3	2,97e-3	-6,46e-3	8,98e-1

The total contribution from the two building solutions according to the system boundary for the three environmental indicators chosen is illustrated in **Figure 1**.

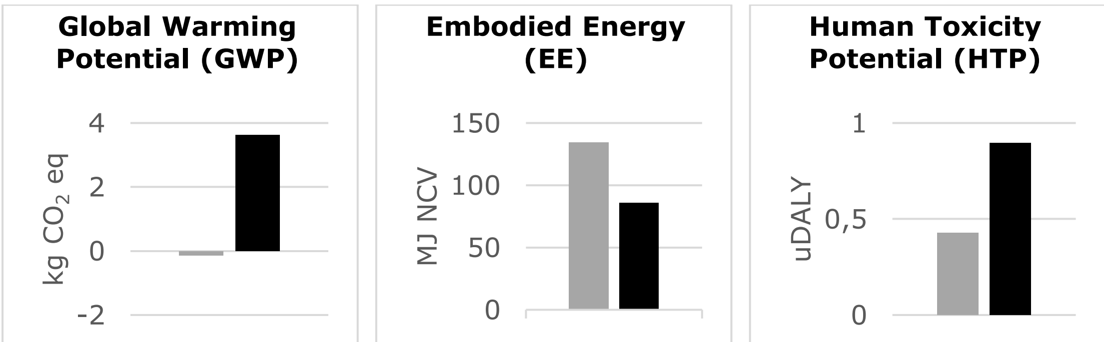
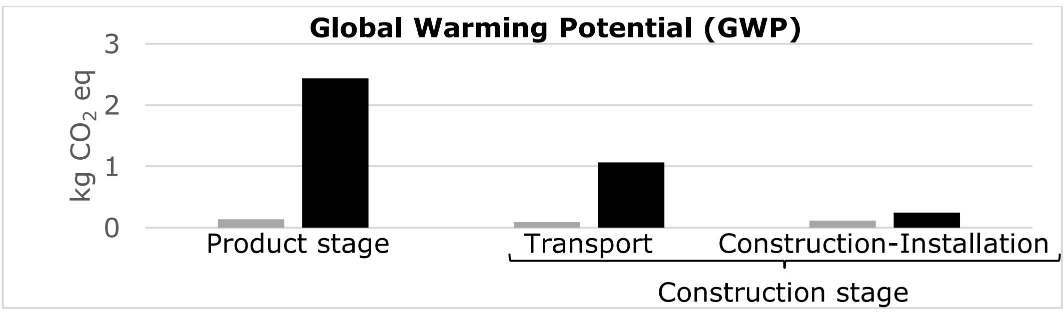


Figure 1: Comparison between the system boundary's total value of the Prefab building (grey bars) and the Standard building (black bars) according to three environmental impact categories

The contribution to the three environmental indicators of the two buildings for the stages analysed: product and construction (this last one divided into two modules: transportation and construction-installation), is shown in **Figure 2**.



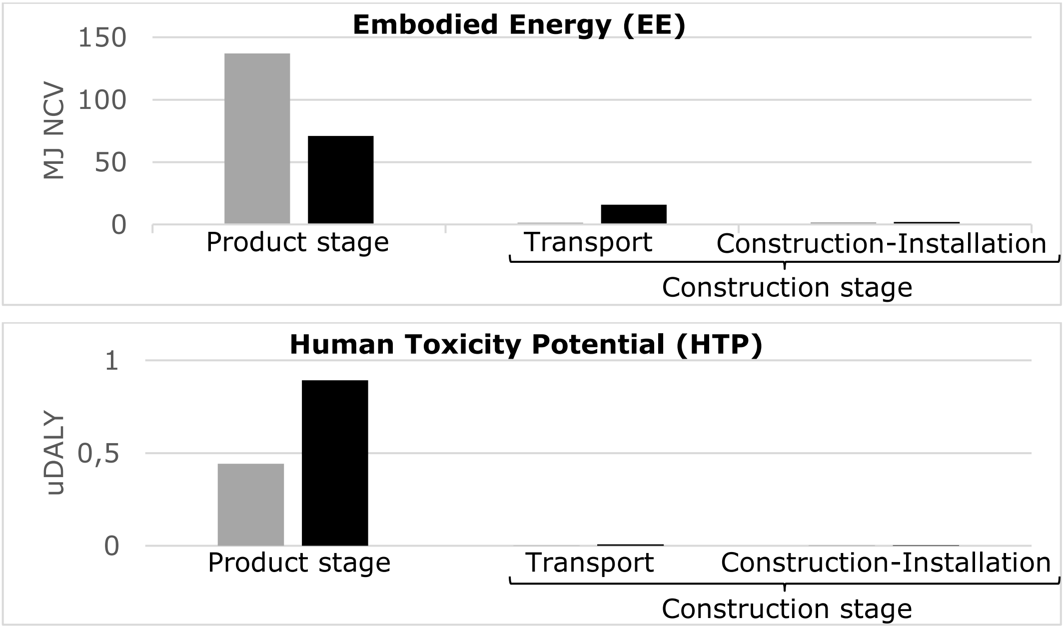


Figure 2: Comparison between the Prefab building (grey bars) and the Standard building (black bars) for each of the stages assessed according to three environmental impact categories chosen

5. Life Cycle Results Interpretation

As mentioned before, the life cycle results interpretation refers only to the two stages considered for the study and the reuse, recovery and recycling potential of the materials used in both case scenarios (Prefab building and Standard building).

5.1. Global Warming Potential

According to the information described above, for GWP, the majority of the contribution in both case scenarios came from production stage (1,4e-1 kgCO_2 eq for the Prefab building and 2,44 kgCO_2 eq for the Standard building), where CO_2 is mainly generated from the production of electricity. As for the construction-installation module, the Standard building value was more than twice as big as the Prefab building's result (2,45e-1 kgCO_2 eq against 1,17e-1 kgCO_2 eq respectively). When the Prefab building's GWP total result was compared with that of the Standard building, the environmental advantage of the first one was evident (Prefab building's total was -1,38e-1 kgCO_2 eq while Standard building's total value was 3,63 kgCO_2 eq). This is mainly due to the great quantity of wood used in the Prefab building that absorbs CO_2 during the growth of plants. The remarkable GWP result for the Prefab building is also attributable to the reuse, recovery and recycling potential of the materials used where the Prefab building had a lower GWP (-4,81e-1 kgCO_2 eq) than the Standard building (-1,19e-1 kgCO_2 eq). Therefore, the Prefab building gets an environmental positive credit for the stages included in the study ad it is near to a zero CO_2 emission building.

5.2. Embodied Energy

In regard to the EE of the Prefab building, the highest value was present in the production stage (137,02 MJ NCV) and it was even higher than the Standard building's value (70,80 MJ NCV). The construction stage instead, had a much lower value in the Prefab building (3,03 MJ NCV transportation and construction-installation included) and in the construction-installation module alone the value was definitely higher for the Standard building (2,07 MJ NCV while 1,68 MJ NCV for the Prefab building). It is necessary to take into account that the indicator is given by the sum of the EE from renewable sources (such as biomass) and the EE from non-renewable sources (such as aluminium, oil and carbon). According to IREEA database, wood-based materials' EE from renewable sources account for the 60% of the total. Considering that the Prefab building was mainly built with wooden-based materials (78%), its high EE in the product stage depended mostly on the renewable sources embedded in the materials. This characteristic not only impacted the EE result, but also the GWP low value was certainly influenced by this. As for the reuse, recovery and recycling potential, it can clearly be seen that the Prefab building had a lower impact in comparison to the Standard building (-5,36 MJ NCV against -2,85 MJ NCV).

5.3. Human Toxicity Potential

Regarding the HTP category, the highest value in both case scenarios was found in the product stage (4,43e-1 uDALY for the Prefab building against 8,93e-1 uDALY for the Standard building) while it was definitely lower in the construction stage (transport and construction-installation modules together: 0,0021 uDALY for the first one and 0,011 uDALY for the second one). This shows that the results of the Prefab building in the two stages analysed were much lower than those of the Standard building. The same occurred when the HTP's total values of the Prefab building and the Standard building were compared (4,27e-1 uDALY for first one while the Standard building had a HTP of 8,98e-1 uDALY). Concerning the reuse, recovery and recycling potential, the results show that the Prefab building had also a lower impact for this indicator in comparison to the Standard building: -1,80e-2 uDALY against -6,46e-3 uDALY respectively.

6. Conclusions

To sum up, the results of the study proved that for the product and construction stages, the Prefab building had a lower environmental footprint than the Standard building and that the construction-installation module has a low impact in the three impact categories chosen. The reduction of heterogeneous systems in the Prefab building made an improvement both in terms of less environmental impact (lower GWP value, higher use of renewable source EE[10], lesser HTP value) and a higher efficiency in the construction stage, since fewer people and

[10] Bearing in mind that a higher EE isn't an undesirable outcome and does not mean a significant burden on the environment.

equipment need to be used. As for the reuse, recovery and recycling potential, the Prefab building exceeded the Standard building thanks to the dry construction system used in the first one that makes it easier to disassembly for future closed loop end-of-life scenarios.

Despite this comparison requires a broader analysis and further improvements (e.g. transportation requires more detailed data), it provides a framework of the ecological properties of the Prefab building if compared with a Standard building in the production and construction stages.

Finally, regarding the possible outlooks of the study, a further analysis might be considered for the stages not yet taken into account, aimed at modelling the environmental impacts of the entire Prefab building's life cycle. It would be even more interesting to split the analysis for every single stage assessing all the modules. Thus, it would be possible to point out the strengthens or, eventually, the weakness stage by stage. In the interest of highlight the environmental performance of the Prefab building, a more in-depth comparison can be made with other building solutions already on the market.

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Energy saving in LT/MT transformers

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Abstract

In Europe, the energy losses related to the transformation of energy from medium to low voltage represents approx. 2.5% of total EU energy consumption. In this paper, an innovative production process and product is studied by a comparative Life Cycle Assessment, between a innovative transformer and a conventional one. The LCA analysis highlights the high impact of the raw materials consumption during the manufacturing phase. Concerning the use phase, assuming a life time (in terms of time and loading condition) of 25 years for both the transformers, the difference in electricity losses is remarkable: the energy loss is 94.17 kWh for the conventional transformer and 17.52 kWh for the innovative one. Therefore, the advantage deriving from the greater efficiency of electrical transformation and lower loss of electricity is essential for the development of the future TANC transformer and for the development of future energy strategies of EU market.

1. Introduction

In Europe, the number of Medium Voltage/Low Voltage (MV/LV) transformers in 2005 amounted to over 4.5 million. Over 430000 units (for a total output of 79 GVA) are installed on the distribution network in Italy. Market estimates foresee up to 2020, an annual growth rate of around 2% and a replacement rate that will reach 4%. The MV/LV transformer is then, given the annual sales volumes, subject to Directive 2009/125/EC (Eco-design): in May 2014 the implementing regulation (European Commission, 2014) entered into force, which defines the minimum efficiency requirements that, starting from 2015, the MV/LV transformers placed on the market should have. This allows to estimate a saving of 16.2 TWh per year by 2020.

Eco-design regulation imposes in EU the maximum level of losses for transformers “Placed On The Market” or “Put Into Service”. After 1 July 2015 it will not be possible to place on the market transformers not fulfilling the minimum requirements. Energy savings become important particularly for the reduction of the environmental burdens of grid and buildings (Psomopoulos et al, 2010). Power Transformer losses represent approx. 2.5% of total EU energy consumption. By 2020, savings of approximately 16 TWh/year would be achievable with the new regulation.

The conventional production process has a lower degree of automation and consists in the cutting of the sheets of ferromagnetic material and the subsequent assembly of the columns and the “yokes” of the magnetic structure. At the same time, we proceed to manufacture the coils that make up the primary and secondary windings, with a rolling process. Once the windings have been inserted into the columns of magnetic material, the magnetic circuit is closed by connecting the columns by means of the “yokes”. The contact surfaces between the latter and the columns constitute the magnetic joints which, inevitably, introduce surfaces of discontinuity of the magnetic circuit. This, increases the losses in the iron and the sites of localized heating which, during the operation of the machines, could jeopardize the integrity of electrical insulation.

The innovation in the TANC project consists in realizing the continuous magnetic core (without joints) by wrapping a strip of amorphous magnetic material directly around the primary and secondary windings, creating a process similar to matassing in the textile sector.

In this work, these innovative production process and product are analyzed by a comparative LCA (Life Cycle Assessment) assuming the conventional oil immersed transformer as a reference.

2. Goal and scope definition

The main goal of this work is the evaluation of the environmental performances of two MV/LV transformers: i) a conventional transformer used as a reference and ii) a innovative TANC (Continuous Nucleus Amorphous Transformer) transformer. The study is focused on the comparison between the two life cycles. The raw materials extraction and processing, the industrial production process and the use phase are included in the system boundaries of the two systems (see Fig. 1). Since the TANC electrical transformer is in an early stage of development, the use phase of this device is assessed by a preliminary analysis with hypothetical operation conditions.

The end-of-life phase is so far not taken into account: in fact, the transformer components will dispose to feedstock recycling (oil, aluminum) or to local landfill (iron based materials). Since the amount of materials are the same for both transformers, the analysis of the end-use phase is negligible for comparison purposes. Moreover, the unknown final destination would lead to a high level of uncertainty, due to lack of data and information.

Therefore, the LCA analysis is performed by a cradle-to-gate approach.

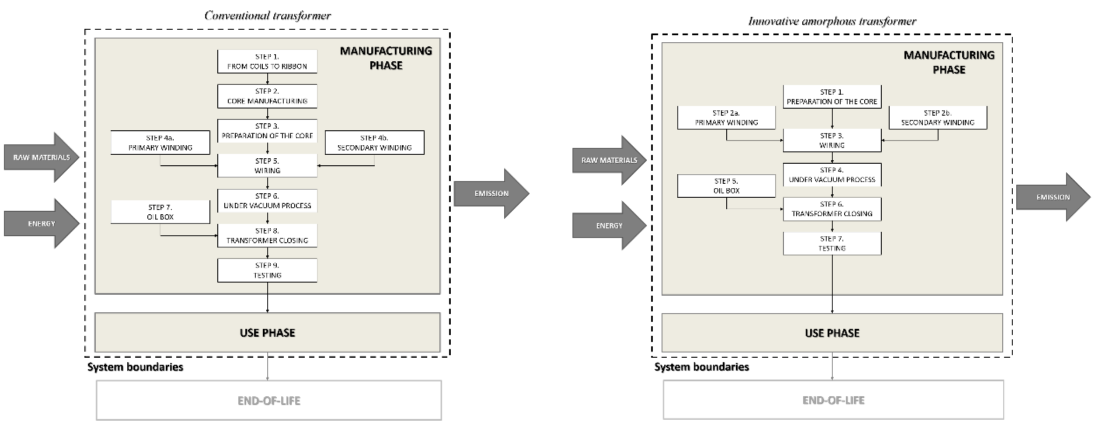

Figure 1: Flow chart representing the system boundaries of conventional and innovative electrical transformers

Some of the early phases of the conventional transformer production process are carried out by various companies. Since some of the main differences between the two systems are related to these phases, it is essential to include them in the analysis: data and information were obtained from the manufacturer of the two transformers.

The chosen functional unit is the amount of electricity transformed in a certain amount of time. In this way, it is possible to quantify the efficiency of the transformer, enhancing the service (transformation of electricity) for which the final product (transformer) is manufactured. The system boundaries and the LCI (Life Cycle Inventory) of conventional and TANC transformer have been outlined with primary data and information provided by Newton industry.

Since the production processes for both transformers are located in Italy, the Italian electricity mix of EcoInvent 3 was used. However, considering 25 years of life-time, structural transformation in the system will probably change the composition of energy sources. For this reason, further improvements of this study will involve future electricity mix scenarios in the analysis.

2.1. Description of the systems

The main differences between the two production processes are related to the first three steps of the manufacturing phase and to the nature of the primary raw materials, i.e. steel. In the TANC amorphous transformer, the steel that is employed in the core fabrication is an "amorphous steel". Whereas, in the traditional electrical transformer the core is manufactured with an "oriented grain steel" (Hegedic et al., 2016). The differences between the two production processes are negligible.

Concerning the first three steps of manufacturing phase of conventional transformer, the steel comes from Germany and undergoes two production processes that take place in two external companies, one located in Milan and the other located in Naples. In order to evaluate the environmental impacts of these production phases, primary data were collected also for these processes. All the inputs and output flows related to manufacturing, transport and lamination processes, have been accounted for.

The innovative TANC transformer is characterized by the use of amorphous steel and it does not require these process steps (see Fig. 1). Therefore, the energy and raw materials consumption during the fabrication of the core is considerably lower, the wastes produced during the process are eliminated and the transport is made by freight.

Furthermore, for TANC transformer, it is assumed that a complete automation of the production process could be implemented. This could lead to a significant increase the number of transformers built per day, going from the current 18 pieces/day (for the traditional transformer) to 50 pieces/day.

The use phase is the same for both systems and the main difference between them is only the electricity transformation yield. In order to model the use phase, it is necessary to consider some hypothetical data and information for the TANC transformer, since it is not yet possible to evaluate the performance of this system. Some scenarios that allow us to model the use phase are performed, considering the information and data concerning a traditional transformer and adapting them to the innovative TANC system.

As reported in literature (Debusschere et al., 2007; Hegedic et al., 2016; Karlson, 2004), the use phase and the energy losses of the transformer during its life time are the principal environmental and economic issues that must be taken into account for a comprehensive LCA analysis.

Generally, these losses are of two types: i) losses in the loading phase and ii) no-load losses, with the latter clearly higher than the first ones (Hegedic et al., 2016). Therefore, the transformer efficiency can be calculated as follows:

$$\eta = (P \times \cos\varphi \times \xi) / (P \times \cos\varphi \times \xi + P_o + P_c \times \xi^2)$$

where η as efficiency

P as ransformer power in kVA,

ξ as applied load percentage

P_o as “no load” losses in kW

P_c as load losses in kW

Energy saving of a TANC transformer respect to a conventional one comes from its higher efficiency, with regard to no-load losses, which can be estimated as 0.6 kWh. Assuming 25 years as the transformer life-time, the estimated energy saving is relevant:

0.6 kWh x 24 hours/day x 365 days/year x 25 years = 131400 kWh

2.2. Method applied

The calculations were performed with the SimaPro software version 8.4.0 and the main database used for this study is Ecoinvent version 3.3. The Life Cycle Impact Assessment (LCIA) method that were employed for the environmental characterization of the two systems is ReCiPe v1.12 (Geodkoop et al., 2009).

3. Results and discussion

3.1. Transformers production process

In Figure 2 the environmental profile of the traditional and TANC transformer production process is reported, calculated using the ReCiPe Endpoint method on the two pieces. Results show that the steps contributing most to the environmental impact are Step 1 and winding steps. The inputs that contribute most to the environmental profile of each step and of the whole production process are the consumption of raw materials, such as aluminum and steel. Furthermore, mineral oil shows a remarkable load on the whole environmental impacts.

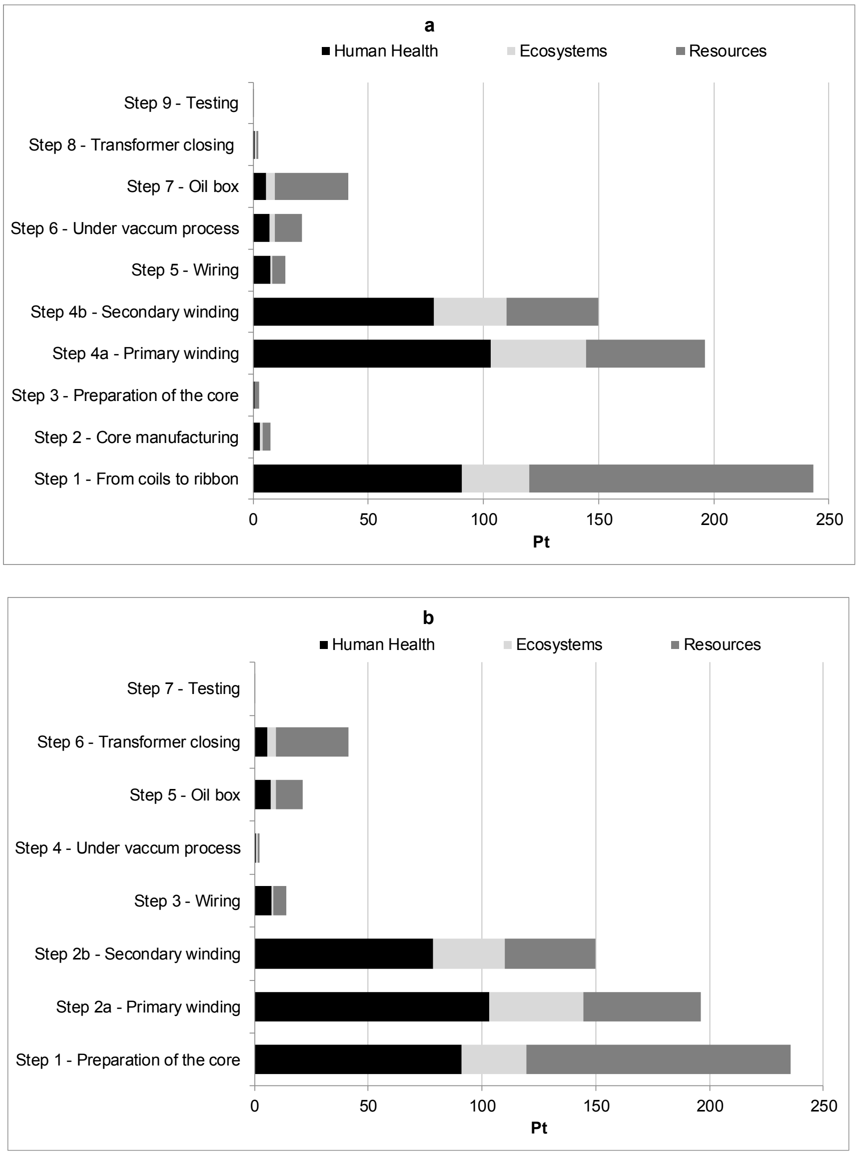

Figure 2: Environmental profile of the production process of conventional transformer (a) and of TANC innovative transformer (b), calculated by the ReCiPe Endpoint method (calculated for 1 trasformer)

Since raw materials (same amounts of steel, aluminum, mineral oil, etc.) data were taken from EcoInvent, differences between the conventional and TANC production processes arise essentially from transportation, waste and human labor.

The differences between the environmental impacts related to the production phase of the electrical transformer are minimal (less than 1% for all the LCIA methods). The innovative TANC transformer does not show appreciable advantages in the production phase, despite the absence of waste during processing (steps 1 and 2) and the different kind of transportation. The hypothetical environmental advantages due to these changes is totally overwhelmed by the high impact of raw materials and their production and manufacturing processes. These inputs are the same for both systems and contribute similarly to the environmental burdens of the systems.

As reported in Section 2.2, the main difference between the two analyzed manufacturing processes is the number of transformer produced during time. This parameter, as well as the different efficiency of the electricity transformation, are taken into account in the use phase evaluation.

3.2. Use phase

Considering the efficiency data reported in Section 2.2 and assuming a life time of 25 years for both transformers, the difference in electricity losses during the use phase is remarkable (see section 2.1).

The parameters concerning productivity, efficiency and life time have strong influence on the environmental profile of the transformer. The results and the comparison between the two whole life cycles (see Fig. 1) are shown in Figure 3.

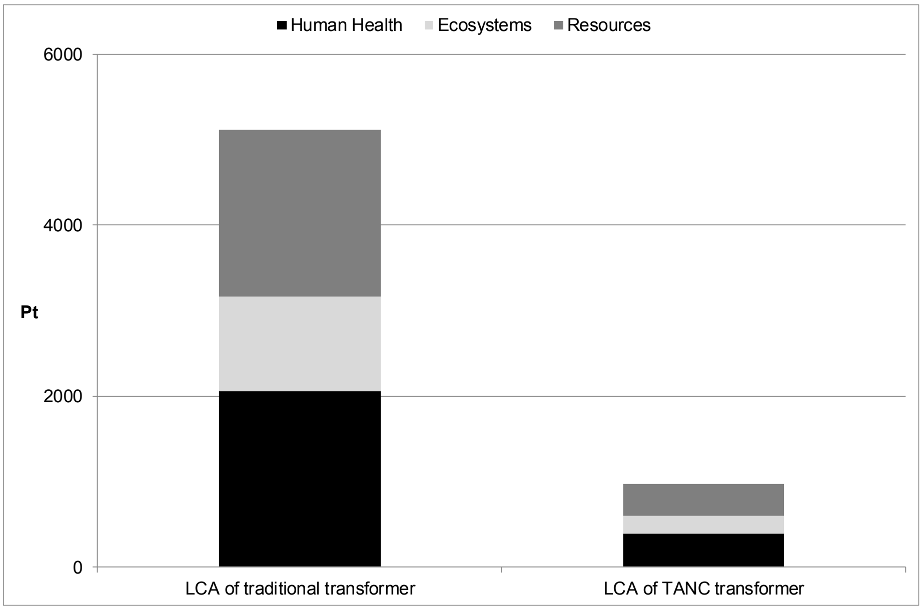

Figure 3: Comparison between the environmental profile of the two life cycles, calculated with ReCiPe Endpoint method

The environmental advantages due to the greater efficiency and lower losses in the non-load phase of the innovative TANC transformer is remarkable. The impact of the manufacturing phase is practically negligible considering the whole life cycles of the systems.

4. Conclusion

The LCA analysis highlighted the high impact of the raw materials consumption (mainly steel) during the manufacturing phase. The environmental profile of production process could be improved by reducing the transport and improving the energy efficiency. However, the best results would be obtained by decreasing the raw materials consumption or by replacing some of them with others with higher environmental performances.

Concerning the use phase, the advantage deriving from the greater efficiency of electrical transformation and lower losses of electricity is essential for the future development of the TANC transformer. The environmental benefit achievable due to the very good performances of the innovative TANC transformer could be the key issue for the improvement of future Italian and European electricity network and can contribute to the achievement of the energy efficiency goals in EU.

5. Aknowledgments

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AGRI-FOOD APPLICATIONS

Steps towards SDG 4: teaching sustainability through LCA of food

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Abstract

This paper presents the results of an experiment of teaching sustainability trough Life Cycle Assessment of food, carried out at the University of Siena. Students involved were High School Students during apprenticeships schemes and undergraduate students. Students have been firstly introduced to Life Cycle Thinking (LCT) rationale and then asked to evaluate the Carbon Footprint (CF) of their daily food choices. Meat consumption is the main factor for High School Students' CF, while dairy products are the one for undergraduate students. Discussions with students highlighted that food choices are driven by parents' for High School Students and economic possibilities for undergraduate students. Therefore, the LCT may add new information for taking decision in this field. The experiment confirms the fundamental role of University on delivering Sustainable Development concepts to pave the way for SDGs implementation.

1. Introduction

During the 70th General Assembly of the United Nations, held in New York on 25th September 2015, all the 193 countries participating adopted the Sustainable Development Goals (SDGs). The goals belong to the so-called "2030 Agenda for Sustainable Development" (UN, 2015a), and set universal objectives for countries to move towards sustainable development in all its three dimension (i.e. social, economic and environmental). The goals are coupled with 169 targets to be achieved by 2030. 241 indicators have been chosen to monitor achievements obtained. The SDGs cover the world's most impending challenges, starting from ending poverty and hunger; to safeguarding the planet from degradation and tackling climate change; considering the need to ensure to all people prosperous, healthy and fulfilling lives; and booster peaceful, just and inclusive societies free from fear and violence (SDSN Australia/Pacific, 2017).

The SDGs recall to three pillar concepts: *universality*, *integration* and *transformation*. In fact, these apply to every nation, cities, businesses, schools, organizations that are called to act; moreover, SDGs are all interconnected in a system and considering one goal in isolation from each other is not appropriate; finally, it is widely recognised that to achieve these goals a change in how humans live on the Earth is needed (UN, 2015b).

Goal number 4, fully dedicated to education, recognizes that obtaining quality education is the ground for the achievement of many SDGs. Vladimirova and Le Blanc (2016), also, demonstrated that SDG 4 can be linked with 16 of the 17 SDGs. In particular, sustainable, equitable education and sustainable lifestyles have been made a core objective of Target 4.7 (UN, 2015a; UNESCO, 2017).

Education for Sustainable Development (ESD) concept emerged in late ‘90 to expand the rationale of environmental education in connection with social and economic aspects (Vladimirova, 2015). Major outcome of ESD results in promoting sustainable behaviours through transferring enabling knowledge (Stought et al., 2017). Sidiropoulus (2014) acknowledges that sustainability is a learning journey and each educational intervention contributes towards building greater understanding and orientation towards sustainability”.

In this light the use of sustainability indicators can support both teacher and those being taught in connecting their daily activities with the sustainability challenge (Kapitulčinová et al., 2018). Numerous indicators and tools have been introduced in the international scientific community to help society recognize the environmental consequences of their activities (Moreno Pires, 2014). Among these tools Life Cycle Assessment (LCA) has been widely used since its introduction in early 1990’s to evaluate product chains, including food. Food in fact has high relevance both in terms of impacts generated along its production chain and in everyday life of consumers (Notarnicola et al., 2015). Moreover, during the opening key note speech of the Stockholm EAT Food Forum (2016), Johan Rockström and Pavan Sukhdev demonstrated how food connects all the SDGs. By using a “wedding cake” representation it has been demonstrated how society and economy are embedded in the biosphere.

Alongside its wide application to every type of production chains, LCA can be used as tool to inform young students about environmental consequences of their food choices. In a recent paper Collins and co-authors (2018) highlighted that the major driving consumption category of the Ecological Footprint of a sample of students at the Universities of Cardiff (UK) and Siena (Italy) was food. Building on results obtained in this preview study, this paper focuses on Carbon Footprint (hereafter CF) assessment of dietary habits of Italian high school and University students’ attending apprenticeship schemes or *curricular* courses.

2. Material and Methods

2.1. Students

This paper focuses on two groups of students (High School and Bachelor) that have been engaged in the evaluation of their dietary habits through the LCA at the University of Siena. High School students involved in this study belong to different backgrounds and attended University apprenticeships schemes. During apprenticeships, students are informed on the academic educational offer and, at the same time, are involved in seminars on the environmental consequences of their consumption behaviour. High school students have the same age (16-17 y.o.) and come from Technical High School (TCHS), Agronomic Technical High School (ATHS), Biotechnology Technical High School (BTHS) and Scientific High School (SCHS). Technical High Schools are designed to integrate theoretical sciences with laboratorial teaching and to foster students towards scientific university degrees. Scientific High School provides a high-level education based on the balance between the linguistic, literary and philosophical culture, and the acquisition of scientific knowledge (maths, physics, chemistry, natural sciences) and methodologies.

Bachelor students attend the Environment and Workplace Prevention Techniques (TPAL) programme. The TPAL programme focuses on the promotion and protection of public and professional health. All activities required for the prevention, control and control related to hygiene and environmental safety in places of life and work, food hygiene and veterinary, hygiene and environmental protection are faced during the three years of the bachelor course.

2.2. Measuring students' CF of food habits by using LCA

Before calculating their CF, students received teaching that included an introduction to the sustainability concept and a special focus on LCA: its rationale, rules and examples of application. Particular attention has been paid to the environmental impacts due to the consumption of food and dietary choices. The Double Pyramid, developed by Barilla Center for Food and Nutrition (BCFN, 2016), has been presented as an example of product ranking based on environmental impact/pressure.

The introductory seminar for High School students lasts around 1.5 hours; the Bachelor students attended a two-hours lesson including more details.

After the seminar/lesson, students calculated the CF of their dietary habits as an interactive teaching session by using desktop pc and a pre-structured excel sheet in which the quantity of CO_2eq per gram of different food items - derived from their respective Environmental Product Declarations (EPD) – are indicated. For each food item the file also indicates its energetic value in kilo calories per gram as well as some notes useful for calculations (e.g. the weight of a single cookie or of an egg). Students were asked to evaluate an average school day considering food eaten at breakfast, mid-morning break, lunch, mid-afternoon break and dinner.

Each student filled its own sheet reporting the amount of food type eaten obtaining the equivalent CF and energy requirements. All the single results have been collected, elaborated and displayed to the whole class in order to stimulate the debate around results obtained.

Though the database is not complete, by virtue of freely available EPDs used as data sources, all LCAs are consistent and have been carried out mostly for Italian food. Table 1 reports a summary of food items presented (15 types) the number of EPDs available (89) and the average CF.

This experiment represents a good basis for introducing concepts and knowledge especially in the field of environmental sciences in an interactive teaching way. As acknowledged by Dieleman and Huisingh (2006), the use of game is essential in Education for Sustainability as it can foster understanding in concrete organizational setting.

Table 1: Summary of food type, number of EPDs considered and average CF per gram of food item

Food types	number of EPD considered	g CO_2eq/g
WATER	10	0.16
COOKIES	11	1.50
MEAT	6	19.58
SWEET SNACK	14	2.08
SALTY SNACK	3	1.06
LEGUMES	1	0.001
RUSKS	4	1.60
BREAD	10	0.99
FRUITS	3	0.51
DAIRY PRODUCTS	10	3.16
CONDIMENTS	6	2.19
PASTA	7	1.74
VEGETABLES	2	0.65
EGG	1	2.70
SUGAR	1	3.80

3. Results and discussions

Carbon Footprint of daily food consumption has been estimated by 63 students: 57 High School students (90%) and 6 undergraduates (10%). High School student from all the different curricula were: 42 from technical curriculum of which 52% female and 48% male, and 15 from scientific curriculum of which 53% female and 37% male. The sample of undergraduate students was composed by 83% of female and 17% of male. Table 2 provides a summary of the average, minimum and maximum CF and calories per student across all programmes. Results of students' dietary habits show that the average per capita CF ranged from 2.46 to 9.13 kg CO_2eq with an average of 5.73 kg CO_2eq per capita.

Table 2: Average, minimum and maximum Carbon Footprint and energy requirements values, by student programme

	Sample size students (#students)	Av. CF (kg CO_2eq/cap)	Min. CF (kg CO_2eq/cap)	Max. CF (kg CO_2eq/cap)	Av. energy (kcal /cap)	Min. energy (kcal /cap)	Max. energy (kcal /cap)
TCHS	3	9.13	8.83	9.30	2,032.74	1,519.25	2,404.06
SCHS	15	4.97	1.68	9.70	2,196.50	1,125.44	4,232.79
TAHS	32	7.30	1.90	13.32	2,722.91	917.03	7,733.91
BTHS	7	4.80	3.06	8.86	1,412.51	814.77	2,029.31
TPAL	6	2.46	0.65	4.95	1,769.17	1,013. 11	2,401.84
average	-	5.73	3.22	9.22	2,026.76	1,077.92	3,760.38
Legend: TCHS= Technical High School; TACHS= Agronomic Technical High School; BTHS = Biotechnology High School; SCHS= Scientific High School; TPAL= Environment and Workplace Prevention Techniques							

Values obtained from students are in line with data obtained by Tagliabue and co-authors in 2015 for the average Italian diet (7.6 kg CO_2eq per day per capita including the wasted food). It should be noted that Tagliabue et al. (2015) used the FAO's Italian food balance sheet as proxy for the Italian per capita food supply that represents the total per capita available food, including wasted food, exported food, livestock food.

As shown in Table 2, the per capita CF of post graduate students is lower than that for High School Students. Moreover, students attending the Technical High School (TCHS) resulted those with a dietary habits more carbon intensive. Surprisingly scholars attending the Agronomic Technical High School were found the second highest group. This result is in contrast with that showed in Collins et al. (2018) in which authors demonstrated that students attending programs focussed in environmental knowledge and food showed the lower food-footprint component. It should be noted that students represented in this paper are younger than those reported in the paper from Collins and co-authors (2018). Figure 1 summarizes the general result of the experiment with the various groups of students and the details for each group.

To understand the factors that may drive the scale of students' CF, a breakdown of their CF by food types was necessary. As shown in Figure 1, the consumption of meat was found to account for the largest proportion of students' CF (ranging from 66% to 85% of the total). Conversely, the undergraduate students' results showed that the largest proportion of their CF were due to the consumption of dairy products. These results are in line with that found for food consumption in Europe (Notarnicola et al., 2017) where meat and dairy have been found the food categories with the greatest environmental burdens. During the discussion on results obtained, it emerged that high school students' food choices were mainly related to choices of their parents. Majority reported that, according to their mother thoughts, meat dishes resulted faster to be cooked than vegetables ones therefore their meat consumption resulted high because the low amount of time of their parents for coking. Conversely, undergraduate students, living outside family houses and buying by themselves food, reported that their food choices fall in dairy products and pasta mainly because these are cheaper than meat. Pasta, the most typical Italian food, was found to account for a very low share of the total CF per capita, ranging from 2% (students from BTHS) to 8% (TPAL undergraduate students). Fruits and vegetables items were found to give negligible contribution to the students' CF, this result being also affected by the low number of items students found in the provided database. Bottled water consumption accounts for the 6% of the TPAL students' CF, whereas the opposite was found for High School students'. During the discussion of results, students justified that value because of time spent at the University Campus where bottled water is sold in half litre plastic bottles. All other available food items were found negligible to the total students' food daily CF.

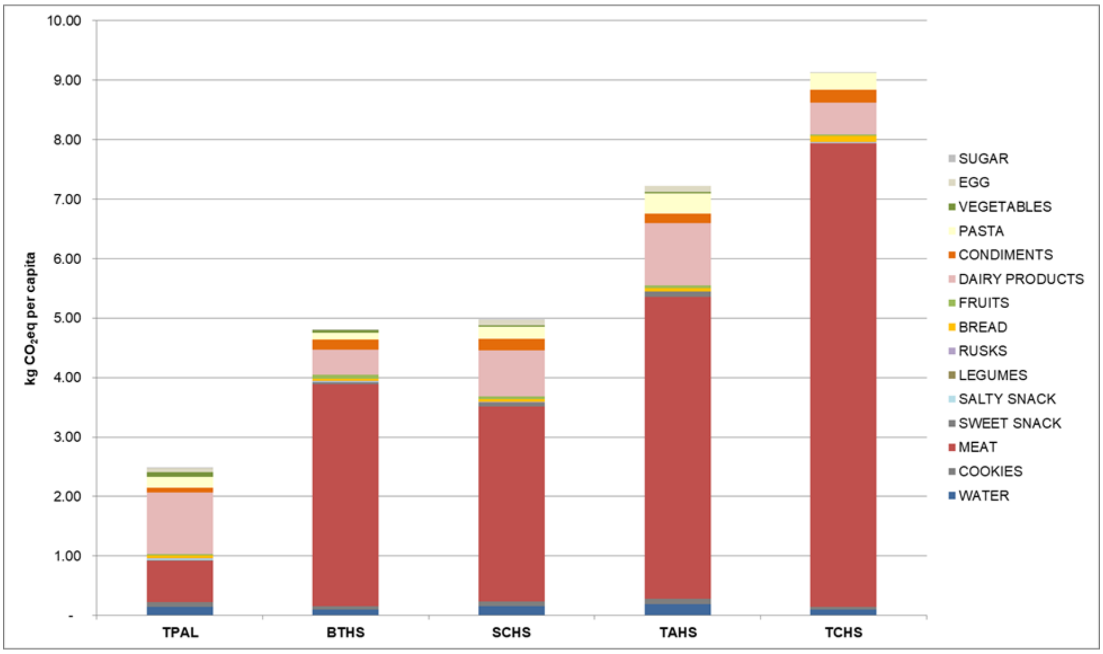

Figure 1: Carbon Footprint of students by food types

After the discussion carried out on CF results, teacher showed results in terms of kcal. Results of students' dietary habits show that the average per capita energy intake ranged from 1,412.51 to 2,722.91 kcal with an average of 2,026.76 kcal per capita per day (Table 2).

To understand the differences between per capita CF and daily energy intake, a graph showing the breakdown of both indicators is presented in Figure 2.

Teacher highlighted the difference between the "weight" of each item and the total per capita CF and daily energy intake using the example of meat. While eating high quantity of meat results in high values of per capita CF, the opposite occurs from the energy intake viewpoint. This consideration is also true for all other food types. In this ranking, pasta acquires a different value, contributing to daily energy intake from 17% to 26%.

Students have learnt the definition of sustainable diets and how they can contribute to make small changes in their food habits towards a more sustainable food consumption. High School students still live with their parents and do not perceive the responsibility of their choices yet. The experiment also invited students to transfer the new acquired knowledge on food impacts and energetic values to their parents, in order to change daily food choices at the family level. In fact, High School students recognised that small changes in food habits can result in decreasing their daily CF. Undergraduate students, conversely, were directly challenged to make changes in their food choices starting from using public tap water available within University Campus instead of using plastic bottled water. Another proposed change was towards eating more fruit and vegetables instead of dairy and meat foods.

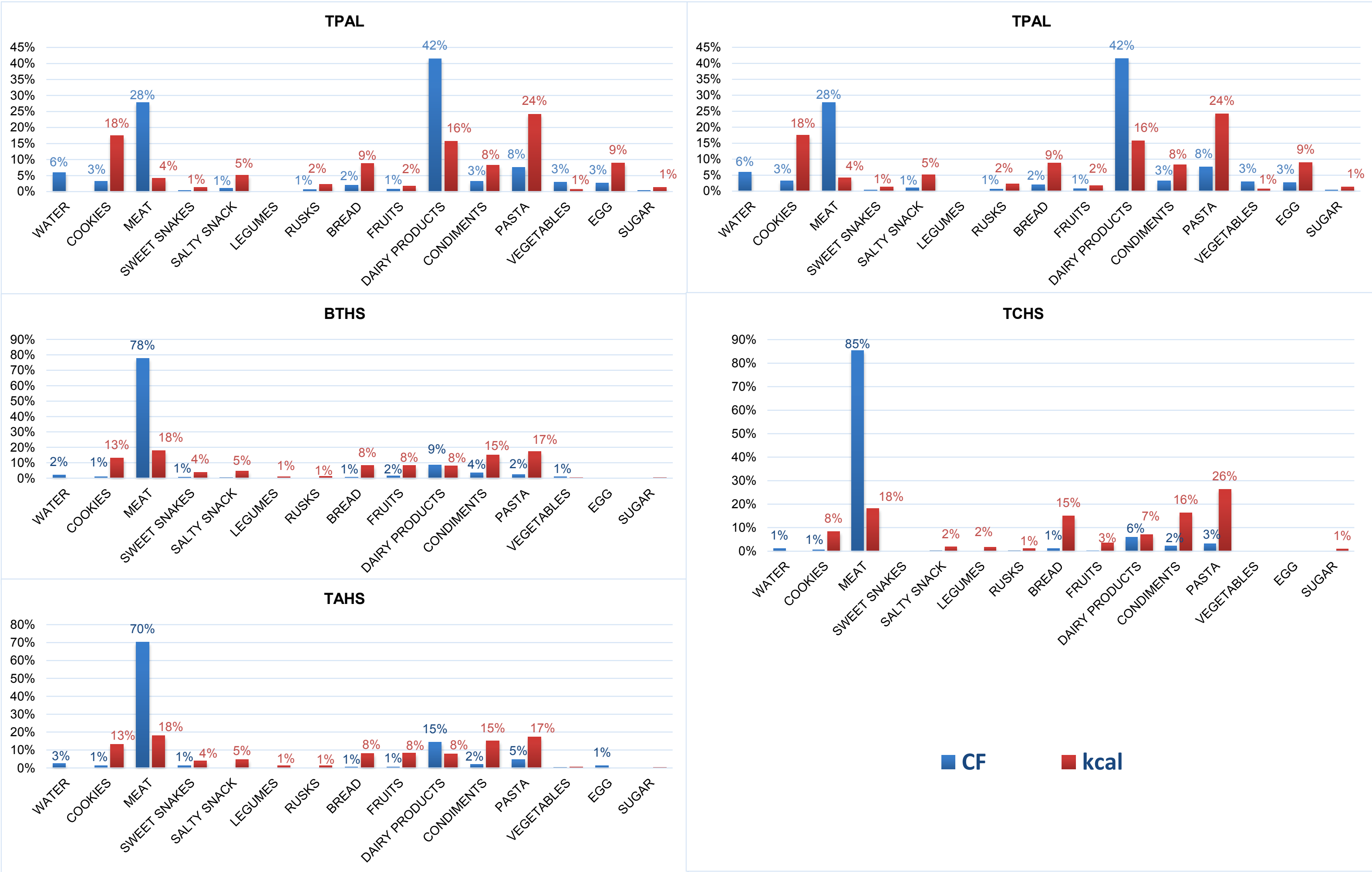

Figure 2: Contribution of different food groups to the total carbon footprint and dietary energy intake in students' diets

Even if limited in terms of statistical validity, this experiment is an effective way to stimulate participative discussions on environmental sustainability and consequences of resource use. This study gave students the opportunity to reflect on their everyday life choices. This is the core principle behind the concept of Higher Education for Sustainable Development: educate students to foster innovative and sustainable ideas within the society (Lozano et al., 2013). In turn, High Education for Sustainable Development is the cornerstone of SDGs, in particular of Goal number 4 (SDSN, 2017). The case of food is also important as a link with a wide series of other Goals in the field of poverty (#1), hunger (#2), ecosystem integrity (#14, #15), sustainable production and consumption (#12), inequalities (#10), water use (#6) and energy (#7).

4. Conclusions

Self-calculating CF of daily diets has directly and indirectly enhanced students' knowledge and understanding of environmental sustainability and the consequences of unsustainable resource use. The approach used is in line with what Lozano et al. (2013) claimed regarding the necessity of transdisciplinarity and holistic perspective and represented a participatory approach to transfer sustainability concepts to students, in line with what has been claimed by UNESCO (2017). It can be also considered as an operationalization of the "learning by doing" paradigm, implementing the theory of "experimental learning" by applying the game as tool for education for Sustainable Development (Dielman and Huising, 2006). Moreover, the experiment of teaching food sustainability through LCA at the University of Siena can be considered as first step for implementing SDGs. This is in line with what SDSN (2017) and UNESCO (2017) recognized: education is one of the bedrocks of the SDGs and Universities play a crucial role in SDG implementation, through their learning and teaching activities.

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The blue water use of milk production in North Italy – a case study

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Abstract

Water use in livestock sector is a source of concern for the high water requirements needed to produce milk and dairy products. In this context, water footprint has become an important tool of water use in milk production life cycle. The present study focuses on the assessment of environmental impact associated with the freshwater use (blue water use) of milk production in a dairy farm of North Italy. The blue water use was 52.5 L per kg FPCM^{-1}. The results show two main impacting sources on water use: the production of on-farm crops (44.5%) and purchased feed (39%). The findings of the current evaluation are relevant to identify improvement options, such as water use effectiveness in on-farm crops irrigation, sourcing off-farm feed with only rainwater requirements or purchasing feed from countries where water scarcity is lower.

1. Introduction

Currently water use in dairy farms is a source of concern for the high water requirements for the production of one kilogram of milk. High-input, resource-intensive farming systems, which have caused massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions, need innovative systems that protect natural resources (FAO, 2017). According to Mekonnen and Hoekstra (2012), 29% of the total water footprint (WF) of the agricultural sector in the world is related to the production of food products, where irrigation accounts for the largest water withdrawals (WWAP, 2014). By far, the largest water demand in animal production is the water needed to produce animal feed (Mekonnen and Hoekstra, 2010a). The need for mitigation solutions will be more and more strategic. For example, the implementation of efficient irrigation schemes can greatly reduce the water demand for the production of animal feed. Moreover, the assessment of the WF of a product contributes to identify other points of improvement. The WF of a product is the volume of freshwater used to produce the product over its life cycle. The WF consists of three main components: blue, green and grey water. The blue water refers to the consumption of blue water resources (surface and groundwater); the green to the consumption of green water resources (rainwater); the grey to the volume of freshwater that is required to assimilate the load of pollutants (Hoekstra et al., 2011). The present paper evaluates the environmental impact associated with freshwater use (blue water use) (BWU) of milk production in a dairy farm located in Northern Italy. Life Cycle Assessment (LCA) methodology was followed to identify the farming activities that mainly contribute to the freshwater use up to the farm gate. The choice to take into account the BWU is related to its scarcity in comparison with the green one (Hoekstra et al., 2011).

2. Materials and methods

2.1. Farm description

For the present study, data and characteristics of an intensive dairy farm were taken into account. The case farm was a conventional dairy herd of Italian Frisian cows (1368 animals) located in the province of Bergamo (Italy) (45°29’1”N and 9°48’33”E). The farm also bred, to a lesser extent, male calves for meat production. The herd composition is shown in Table 1.

Table 1: Dairy herd composition

Category	Number
Lactating cows	460
Dry cows	78
Heifers 2-15 months	292
Heifers 15 months-partum	100
Fattening calves	187

2.2. Goal and scope definition

The objective of the present study was to measure the environmental impact associated with freshwater use (BWU) of milk production. According to Hoekstra et al. (2011), the blue WF is an indicator of consumptive use of fresh surface and groundwater. Therefore, the scope of this study was to estimate the effective direct use of freshwater through a cradle-to-farm-gate approach to detect the major contributors to the water consumption of the dairy farm under investigation.

2.3. Life cycle assesment methodology

The WF analysis was carried out following the LCA approach. LCA is a structured, comprehensive and internationally method standardized by ISO 14040 and ISO 14044 standards (ISO 2006a; ISO, 2006b). According to ISO standards (ISO, 2006a; ISO 2006b), the LCA methodology consists of four phases: goal and scope definition, life cycle inventory, impact assessment and interpretation of results.

2.4. Functional unit, system boundary and allocation

The functional unit (FU) chosen for the study was one kilogram of fat-and-protein-corrected milk (FPCM) as recommended by the International Dairy Federation (IDF) guidelines for dairy farming systems (IDF, 2010).

The system boundary was cradle-to-farm gate, considering the water required for: 1) the cultivation of on-farm maize and alfalfa crops, 2) the production of purchased feed, 3) the animal husbandry and farm manteinance, 3) the milk pre-cooling system and, 4) the farm manufacturing inputs (Figure 1).

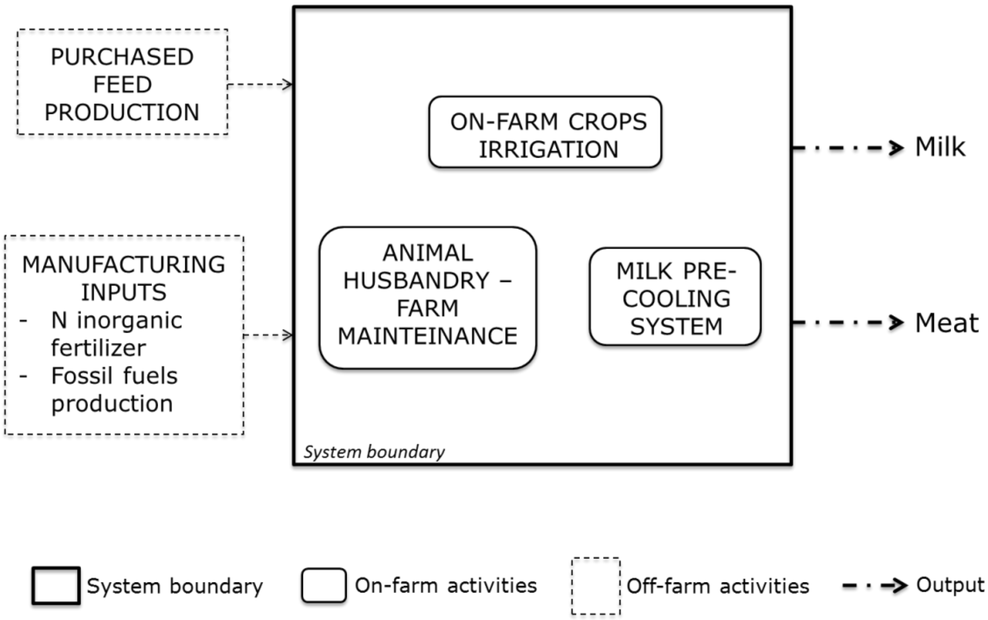

Figure 1: System boundary of the processes considered in the freshwater use assessment

The choice of the allocation procedure may be difficult when dealing with multifunctional production systems. The multifunctionality problem can be solved by splitting up the amounts of individual inputs and outputs between the co-functions according to allocation criterion, since it is a property of the co-functions (e.g. element content, energy content, mass, market price etc.) (ISO, 14044). In the present case farm, milk was the main product of the animal husbandry and meat the co-product generated from the fattening male calves and culled dairy cows. Thus, the physical allocation factors proposed by the IDF (2015) were applied to share the BWU between the two products (milk, meat).

2.5. Life cycle inventory (LCI)

The inventory data relate to 2016, including primary data, collected by means of interviews with farmer and purchase invoices, and secondary data from databases and literature when specific data lacked. The main primary data of the dairy farm analysed are described in Table 2.

Table 2: Main primary inventory data

Item	Amount	Unit
Milk	5,943.159	t
Meat	120	t liveweight^{-1}
Maize silage	80	ha
Alfalfa silage	20	ha
Moisture corn silage	50	ha
Sorghum silage	40	ha
Ryegrass hay	20	ha
Wheat	13	ha
Purchased feed	4160.18	t
Nitrogen inorganic fertilizer	1.2	t
Diesel use	75,000	L
Electricity	431	MWh
On-farm crops irrigation	146,000,000	L
Animal husbandry and farm mainteinance	43,800,000	L
Milk pre-cooling system	9,720,000	L

2.5.1. Blue water use for on-farm crops irrigation

The amount of water needed to irrigate crops cultivated on the dairy farm was estimated for maize and alfalfa because their growth exceeds the availability of rainwater (de Boer et al., 2013). The coefficients of water consumption for the irrigation of maize and alfalfa crops were taken, respectively, from Bacenetti et al. (2016) and Bacenetti et al. (2018).

2.5.2. Blue water use for purchased feed production

The BWU necessary to the production of purchased feed was estimated using the region-specific water use coefficients of feed-crops as reported by Mekonnen and Hoekstra (2010a,b,c,d).

2.5.3. Blue water use for the animal husbandry and farm mainteinance

The water use necessary for animal husbandry and farm maintainance included the freshwater for the dairy herd drinking requirements, cooling cows and for the farm cleaning activites day-by-day. Informations of the water consumptions were collected from the dairy farm.

2.5.4. Blue water use for the milk pre-cooling system

Water use during milk pre-cooling was calculated making an average evaluation of the water consumed per minute (L/min) by the pumping systems.

2.5.5. Blue water use for manufacturing inputs

The manufacturing inputs included nitrogen (N) inorganic fertilisers and fossil fuels (diesel and electricity). The freshwater use requirements for the manufacturing of N inorganic fertilisers and fossil fuels were taken from the assumptions of de Boer et al. (2013).

2.6. *Life cycle impact assessment (LCIA)*

The environmental impact associated with freshwater use of milk production was estimated for the categories reported in section 2.5: 1) on-farm crops irrigation, 2) purchased feed production, 3) animal husbandry and farm mainteinance, 4) milk pre-cooling system and, 5) manufacturing inputs. Primary data of water consumptions were used to measure the BWU for the third and fourth categories. Secondary data were used for estimating the BWU of the on-farm crop irrigation (Bacenetti et al., 2016; Bacenetti et al., 2018) and of the purchased feed production and manufacturing inputs (de Boer et al., 2013; Mekonnen and Hoekstra 2010a,b,c,d).

3. Results and discussion

The BWU of the dairy farm evaluated was 52.5 L per kg $FPCM^{-1}$. Figure 2 shows that the BWU for the dairy farming activities was: 44.5% for on-farm crops irrigation, 39% for purchased feed production, 0.5% for manufacturing inputs, 13% for animal husbandry and farm mainteinance and 3% for milk pre-cooling system.

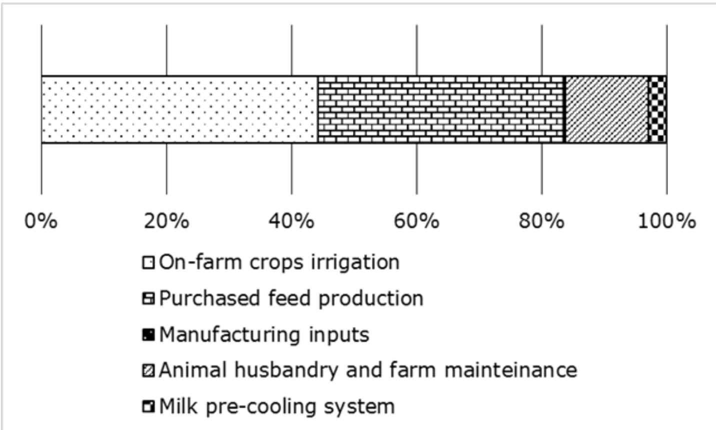

Figure 2: Results of the BWU for dairy farming activities

Results showed that on-farm crops irrigation, followed by purchased feed production, were the main factors of BWU for milk production. The highest share of impact is related to the use of water for high-energy feed. Nevertheless, high-quality feed given to dairy cows is necessary to obtain high milk yields.

The BWU reported in other studies is in the range of 42-66 L per kg $FPCM^{-1}$ (de Boer et al., 2013; Mekonnen and Hoekstra, 2010a; Sultana et al., 2014). The common outcome is the high BWU for on-farm and off-farm feed production.

Although in these studies milk production yields were comparable, the differences can be also due to the irrigation intensity for on-farm crops production. In the present evaluation on-farm crops irrigation was 44.5%, whereas in the study of de Boer et al. (2013) it was higher (74%). The water requirements for on-farm crops growth highlight the increased water need. As reported by de Boer et al. (2013), the BWU for farm situated on a soil less sensitive to drought, was estimated to be 16 L per kg FPCM.

Adopting smart irrigation technologies can be a valid strategy to reduce the BWU per kilogram of FPCM enhancing the effectiveness of irrigation practice and avoiding deep seepage or runoff. Smart irrigation is based on irrigation scheduling methods and software that manage weather data and determine irrigation timing (Gu et al., 2017). No-tillage in maize continuous cropping systems and the use of maize hybrids with low water requirements are another strategies of mitigation (Nagore et al., 2017; Sun et al., 2018).

Sourcing off-farm feed ingredients from non-water stressed areas or with only green water requirements, further reduce the burden on freshwater resources and ameliorate the sustainability of WF in high-yield milk production (Murphy et al. 2017).

Within dairy farm activities, implementing wastewater-recycling systems can reduce the BWU. The wastewater-recycling systems allow the re-use of the final effluent with a minor content of suspended solids (pollutants) for on-farm crops irrigation (Ruane et al., 2011). In the present study, sensitivity analysis was performed in order to evaluate how the implementation of a wastewater-recycling system would affect the BWU reduction. The hypothesys was a variation of - 20% of water input for on-farm crops irrigation due to the water supply by the recycling system. The BWU per kg FPCM^{-1} decreased from 52.5 L to 47.8 L.

The results were relevant to identify improvement options for a more sustainable milk production.

4. Conclusions

The aim of the present study was to evaluate the environmental impact associated with BWU of milk production. The freshwater use assessment was carried out following the cradle-to-farm gate approach to detect the main hotspots of water consumption in the dairy farm. The result obtained in this study was 52.5 L per kg FPCM^{-1}. On-farm crops cultivation was the most demanding in term of water use, followed by purchased feed.

Our results showed that feed crop irrigation and purchased feed production are the most impacting sources of BWU of milk production. The implementation of mitigation strategies is a priority key driver to reduce the pressure on freshwater availability.

The sustainability of the dairy farm need to be improved by irrigation water use effectiveness for on farm feed production implementing wastewater recycling. Purchasing feed from countries where water scarcity is lower or purchasing feed with only rainwater requirements could reduce the contribution of water use from off farm feed. These options are valuable strategies on WF mitigation of milk production in the studied intensive dairy farm.

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Practitioner-related effects on LCA results: a case study on Energy and Carbon footprint of wine

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Abstract

LCA is widely acknowledged as a valid tool to assess the potential energy and environmental impacts of a product along its lifecycle. As for any experimental result, LCA outcomes are affected by uncertainties that, when not properly taken into account, may give rise to incorrect conclusions. However, uncertainties are generally not discussed at all or they are accounted for incompletely. The focus of the present paper is the evaluation of practitioner-related effects on LCA results, i.e. the estimate of the results variability range linked to the methodological/arbitrary choices performed during the LCA study implementation. The study is carried out considering a red wine produced by a medium-size Umbrian winery and it is focused on the evaluation of two environmental indicators: Energy and Carbon footprint. Results show that practitioner choices can have a role far from negligible on LCA outcomes producing a reproducibility variation of approximately 50% at the 95% confidence level for both indicators.

1. Introduction

LCA represents a methodology widely acknowledged as valid to assess the potential energy and environmental impacts related to the lifecycle of a product, from raw material acquisition, via production and use phases, to end-of-life management. It is also widely recognized that LCA results are affected by uncertainty, and that if the uncertainty is not accounted for, LCA studies may give rise to incorrect conclusions. However, not all LCA practitioners treat uncertainties properly and, even when they are considered, they are usually accounted for incompletely. LCA studies, in fact, usually report the evaluation of the effect on the results due to the uncertainty affecting the inventory data, neglecting all the effects related to other sources of uncertainty (such as, for instance, inaccurate parameters measurement, lack of data, methodological choices regarding system boundaries, functional unit, allocation procedures, etc.). A proper sensitivity analysis can help estimating such effects on the results variability, yet it is often limited to most impacting processes and rarely applied to methodological choices.

The present paper is focused on the evaluation of the effects on LCA results due to the LCA practitioner, i.e. the estimation of the results variability range related to the methodological/arbitrary choices performed during the LCA study implementation. The product under study is a red wine produced in the Umbria region, Italy, by a medium-size winery, and the indicators considered are the

Energy Footprint (EF) and the Carbon Footprint (CF). The quantification of the variation of LCA results as a function of subjective choices (i.e. analyst interpretation), when evaluating simple end-point indicators for the same product starting from the same dataset, is presented. Even under the guidance of the same *standardized* methodological procedure (ISO, 2017), a large degree of freedom is left to the analyst. The quantification of the level of variation on the outcome is expected to produce valuable information for the interpretation and communication of a typical LCA result.

2. Types of uncertainties in LCA studies

When computing and communicating the result of an experimental activity, including modelling and simulations, it is utterly important to provide a properly-computed uncertainty, in order to be able to perform comparisons with other results and discuss the consistency of different outcomes. Uncertainty differs from variability – that is due to the natural heterogeneity of values – and can be intended as the statistical “difference between a measured or calculated quantity and the true value of that quantity” (Finnveden et al., 2008). LCA results with a high degree of variability demonstrate true differences among equivalent products (different lifecycles, different production processes, supply chains, etc.). On the other hand, LCA results dominated by uncertainty can not be reliably used to state whether a product has an environmental impact significantly different from another one. In this case, additional work/research (more reliable data acquisition, selection of more precise emission factors, etc.) may help reducing the uncertainty and, consequently, change the overall environmental outcomes (Steinmann et al., 2014). The main typologies appearing in LCAs can be divided in the following categories:

- **Parameter uncertainty**. Parameter uncertainty reflects the partial knowledge about the true value of a parameter and, therefore, concerns the empirical accuracy of measurements, as well as their eventual unrepresentativeness (incomplete or outdated measurements) and estimations used to obtain the numerical parameter values (Huijbregts, 1998). Different methods have been proposed to face this kind of uncertainty, and stochastic modelling performed by Montecarlo simulation is the one considered most suitable and the one most used in LCAs.
- **Model uncertainty**. Model uncertainty is due to those aspects associated with the product system under study that cannot be modelled within LCA structure, i.e. the assumptions and simplifications. Significant sources of model uncertainty are, for instance, the non-consideration – or the loss by aggregation – of spatial and temporal variability regarding locations/ processes/factors in the receiving environment, the consideration of linear instead of non-linear models and the computation of characterization factors with simplified environmental models (Huijbregts, 1998; Huijbregts et al., 2003);
- **Scenario uncertainty**. Scenario uncertainty encompasses all the uncertainties related to unavoidable choices that occur in all the phases of LCA studies. Significant sources of scenario uncertainty are, for instance,

the choice of functional unit and system boundaries in the goal and scope definition phase, the choice of the allocation procedures in the inventory phase, the choice for a particular time horizon in the impact assessment phase (Huijbregts et al., 2003).

It is evident, even from such a brief introduction to the possible sources of uncertainty, that an LCA analysis is exposed to a variety of factors potentially limiting the reliability of results. Such limitations are often addressed only in part, for example performing standard Montecarlo analyses focusing on input parameter uncertainty (Golsteijn, 2015) and/or dedicated sensitivity studies on most impacting processes (Bonamente et al., 2015). Those approaches, however, do not take into account another major source of variability in LCA studies: the analyst choices in building the life-cycle model. It is, somehow, a common experience among LCA practitioners that apparently minimal changes in the model setup can produce a large variation of the final result. In general, a through check of the entire project can help identifying errors and converging on a stable solution, but some other times this process does not improve the results sensibly. Additionally, it can be not easy to distinguish between real errors (i.e. mistakes) and variability due to subjective (and acceptable) choices when the discussion is focused on the selection of a particular process from a database, the allocation procedure, the system boundaries, etc.

3. Methodology

CF and EF are used as indicators for assessing the potential environmental impacts of a product in terms of global warming potential and primary energy demand. The CF evaluates the overall greenhouse gas (GHG) emissions released into the atmosphere (Ertug et al., 2007). CF is usually measured in terms of kilograms of carbon dioxide equivalents ($kgCO_2eq$) and its calculation is standardized by the international standards ISO TS 14067 (ISO, 2013) and ISO 14064 (ISO, 2012). In this study, the emission factors of the IPCC 2013 GWP 100a method are used (Myhre et al., 2013). The EF evaluates the total energy supply in terms of primary energy demand, including all the direct uses and the indirect (e.g. due to the use of raw materials, construction materials, …) consumption of energy. It is usually expressed in terms of mega joules (MJ). The characterization factors used in this study were obtained by the Cumulative Energy Demand (CED) method (Althaus et al., 2010). Both methods can be used within an LCA framework (ISO, 2006a,b).

In this work, CF and EF were calculated for a red wine bottle, the LCA study was independently conducted by six LCA practitioners (P1 to P6).
Each analyst modelled the life cycle according to the *Product Category Rules* (PCR) of wine of fresh grapes, as defined in ISO 14025 (Environdec, 2015).
The life cycle inventory analysis was performed starting from the same data set. The chosen functional unit is a 0.75-litres (l) red-wine bottle, corresponding to a unit of sold product. All the stages from grapes production to bottling and distribution were performed by the same winery. Collected data refers to vintage year 2012. Primary data are shown in Table 1 and Table 2.

Processes were modelled using the Ecoinvent database (Ecoinvent, 2013).
The total amount of produced grapes was 239,760 kg, cultivation was referred to a total surface equal to 24.1 ha. The total yearly production of the winery was 1,874.60 hl of wine. The yearly production of the examined product was 40.20 hl (2.1% of the total). The cropped surface used for the examined product is 0.67 ha.
As already mentioned, even if all pratitioners performed the required allocations according to (ISO, 2006b), analysts adopted different allocation procedures to disaggregate the inventory flows, and consequently the environmental impacts, based on physical quantities (area, mass, and volume) and economic value. The different allocation approaches adopted by each analyst are reported in Table 3. Regarding the reuse or recycling of packaging materials, some practitioners allocated end-of-life processes according to the "Polluter-Pays (PP) allocation method" (Environdec, 2017).
The environmental impacts were calculated using the SimaPro software version 8.4 (Prè Consultants, 2017). The results variability was computed in terms of Standard Deviation of the Cell Averages and Reproducibility (R), as defined in the ASTM E691-05 standard (ASTM, 1999). R identifies the value below which the absolute difference between two test results (obtained under reproducibility conditions) may be expected to occur with a probability of approximately 95%.

Table 1: Primary data related to total winery production

Material and energy inputs	***Unit***	***Total amount***	***Fertilizers (active ingredients)***	***Unit***	***Total amount***
Diesel	l	5,800	Nitrogen	kg	540
Electricity	kWh	44,561	Phosphorus	kg	225
Glycol	kg	0.75	Potassium	kg	675
Acetic acid	kg	3.33	Organic	kg	450
Soap	kg	385	Packaging plastic	kg	18
Potassium metabisulfite	kg	50	Transportation	tkm	45,18
Enzyme	kg	0.4	***Pesticides and treatments (active ingredients)***	***Unit***	***Total amount***
Yeast	kg	10	Sulphur	kg	992.5
Diammonium phosphate	kg	100	Acetamide	kg	4.711
Plastic packaging	kg	20.42	Triazine	kg	4.725
Paper packaging	kg	0.4	Mancozeb	kg	27.4
Refrigerant load	kg	0.21	Fosetyl-Al	kg	120.9
Carbon dioxide	kg	840	Copper	kg	77.4
Transportation			Other pesticides	kg	48.48
Delivery van 3.5 t for 470 km	tkm	465.3	Packaging plastic	kg	371
Delivery van 3.5 t for 45 km	tkm	166.42	Packaging paper	kg	1449
Lorry 3.5-7.5 t	tkm	94.08	Transportation (Delivery van < 3.5 t)	tkm	32.76

Table 2: Primary data for the bottle

Material and energy inputs	***Unit***	***Total amount***	***Material and energy inputs***	***Unit***	***Total amount***
Glass	kg	0.45	Packaging film	kg	0.000558
Cork	kg	0.004	Packaging plastic	kg	0.008606
Capsule	kg	0.001	Transportation for 1039 km	tkm	0.0034
Label	kg	0.001	Transportation (Lorry 3.5-7.5 t)	tkm	0.022
Cardboard box	kg	0.048	Transportation (car)	km	0.0374

Table 3: Allocation procedures

Analyst	**Type of allocation used**					
	Grapes production	Co- and by-products	Vinification	Bottling	Distribution	End-of-Life
P1	A, M	V2	V5	V6	V6	R1
P2	A, V3	E	V5	V6	V6	R2
P3	A, M	M	V4	V6	V6	R2
P4	A, V2	V2	V4	V6	V6	R1
P5	A, V3	V3	V3	V6	V6	R2
P6	A, V1	V1	V1	V6	V6	R1
A (allocation on area basis) product/total cropped surface		**E (economic allocation)** all grapes for product		**M (allocation on mass basis)** all grapes for product		
V (allocation on volume basis) V1 = total wine; V2 = all grapes for product; V3 = product/ total production; V4 = product/ total wine; V5 = bottled product/total wine; V6 = bottled product				**R (recycling allocation)** R1 = substitution approach; R2 = polluter-pays approach.		

4. Results

The results of the carbon footprint assessment computed by the six practitioners are shown in Figure 1 (*left*). P1, P3, and P6 show a lower value than the average (11.20%, 20.41%, and 16.49%, respectively), while P2, P4, and P5 are above the average (13.36%, 21.67%, and 13.07%, respectively). The same trend can be observed for the energy footprint indicator in Figure 1 (*right*). The maximum deviation (27.20% for P3) from the mean value was higher than those registered for the carbon footprint indicator.

Results show that the average EF value is equal to 21.12 MJ with a standard deviation of 4.05 MJ, while, regarding CF, the average value and the standard deviation are, respectively, equal to 1.22 kgCO_2eq and 0.22 kgCO_2eq.

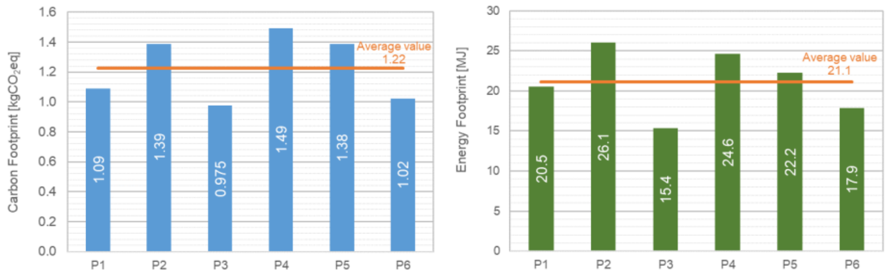

Figure 1 : Carbon footprint (left) and Energy footprint (right) results for the six analysts

Table 4 and Table 5 show the most impacting processes in terms of GHG emissions and primary energy consumption. In both cases, the most relevant processes for each practitioner are: the production of glass, the distribution of wine bottle to the consumer, the production and use of diesel in agricultural equipment, and the electricity consumption in the winery. In particular, different choices were made among the operators for the glass production: P1 used the process *Packaging glass, brown {RER w/o CH+DE}| production brown* from the Ecoinvent Database, P2 used *Packaging glass, green {RER w/o CH+DE}| production,* P3 and P6 used *Packaging glass, green {GLO}| market for*, and P4 and P5 used *Packaging glass, white {GLO}| market for*. The distribution phase of the product was mostly influenced for both indicators by the choice of the vehicle for distribution of wine bottles in Europe. All practitioners selected a freight lorry of 3.5-7.5 metric tons but characterized by different emission classes from EURO 3 to EURO 6.

Table 4: Most relevant processes contributing to the Carbon footprint

	P1	P2	P3	P4	P5	P6
Glass production	0.438	0.400	0.466	0.478	0.476	0.466
Distribution	0.555	0.435	0.472	0.465	0.393	0.436
Diesel, production and use	0.177	0.250	0.216	0.230	0.263	0.215
Electricity	0.0946	0.0943	0.0932	0.0932	0.094	0.0926
Recycling of glass	-0.415	-	-0.415	-	-	-0.417
Other processes	0.238	0.209	0.143	0.224	0.186	0.230
Total	**1.09**	**1.39**	**0.975**	**1.49**	**1.38**	**1.02**

Table 5: Most relevant processes contributing to the Energy footprint

	P1	P2	P3	P4	P5	P6
Glass production	7.550	7.330	7.560	7.640	7.270	7.560
Distribution	8.860	6.960	7.540	7.430	6.100	6.960
Diesel, production and use	2.495	3.530	4.340	3.250	3.720	4.180
Electricity	1.900	1.720	1.770	1.770	1.740	1.760
Recycling of glass	-5.950	-	-5.950	-	-	-5.970
Other processes	5.662	6.523	0.116	4.546	3.414	3.396
Total	**20.52**	**26.06**	**15.38**	**24.64**	**22.24**	**17.89**

With respect to the production and use of diesel, the choice of different allocations by the practitioners (see Table 3) generated a unitary flow associated to the functional unit sensibly different (from a minimum of 0.025 kg for P1 to a maximum of 0.029 kg for P5) and therefore produced dissimilar results. P1, P3, and P6 considered the environmental and energy credit related to the recycling of the end-of-life materials (e.g. glass, plastic, paper, board) adopting the substitution approach (SA). P2, P4, and P5 assumed the Polluter-Pay (PP) allocation method, in which the waste producer carries the total environmental impact until the point at which the waste is transported to a waste processing plant or collection site. The benefit deriving from the recycling process of glass, plastics, paper, and board is considered out of the system boundary.

Incineration was the considered process for the disposal of pesticides and fertilizers packaging. P2 and P4 assumed that only 50% of the impacts was attributed to the studied product, according to Environdec (2017).
Other differences among the operators arise from the “Other processes” category. The co-products of the winemaking process (lees and marc) were allocated applying the economical approach only by P2. The allocation factor was equal to 99.83% for the studied product. Other practitioners considered the impact related to the transport of co-products to the treatment plants. P1, P3, P4, and P5 assumed that wood pallet is reused for an average of more than 1,000 cycles and its environmental impact was considered negligible. P2 and P6 took into account the impact related to the production of wood pallet assuming that it was reused but outside the system boundaries. In terms of GHG emissions, this impact was negligible while the primary energy consumption amounted to about 0.9 MJ.
The reproducibility variation of the results due to the practitioner choices at the 95% confidence level was estimated using the ASTM E691-05 standard. R is found to be 11.331 MJ for EF and 0.620 $kgCO_2eq$ for CF. According to the standard, the true value of the two indicators fall in the range EF = (21±11) MJ, CF = (1.2±0.6) $kgCO_2eq$.

5. Conclusions

A novel approach is proposed for the evaluation of the uncertainties related to practitioner choices in LCA analysis. The same dataset was used by six analysts who independently computed carbon and energy footprint of a red wine bottle produced by an Italian winery using a cradle to grave approach. It is found that the standard deviation for the two indicators is 18% (CF) and 19% (EF). However, the 95% confidence level reproducibility is 53.6% and 50.8%, respectively. According to the ASTM E691-05 standard, the carbon footprint is (1.2±0.6) $kgCO_2eq$ and the energy footprint is (21±11) MJ.
Such a result needs to be carefully interpreted in order to come to correct conclusions. On the one hand, it needs to be stressed that those numbers are obtained for a specific product and any attempt to come to a general rule out of them would be, at least, premature. On the other hand, the reproducibility variability is large enough to deserve a deeper investigation, especially considering that it was obtained starting from exactly the same dataset, using the same LCA database and methods, and after a through revision to avoid accidental errors. Under these considerations, there is a strong evidence that uncertainties, and among them the variability generated by the analyst’s subjective choices, need to be considered seriously, especially when comparing the outcome of different studies. A preliminary interpretation of these results would be that of suggesting particular caution when comparing the nominal value of impact indicators of two products, since differences up to 50% might not be strictly significative but depending on the analyst choices rather than a real difference in the environmental performance. However, in the case of a comparative analysis of two products, or a performance tracking study, made by the same operator and/or using the same model, such variability is expected to drastically decrease, allowing for an easier and more direct comparison.

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Environmental impacts and economic costs of nectarine loss in Emilia-Romagna: a life cycle perspective

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Abstract

Fruit has a lower environmental impact than other food products. However, its production can be quite resource, labour, and capital intensive, as well as characterized by relevant losses. This study carried out a combined life cycle assessment (LCA) and costing (LCC) of nectarine production in Emilia-Romagna, with a focus on losses. System boundaries were cradle-to-farm gate and all impacts were referred to 1 kg of sold fruit. Primary data on environmental and cost aspects (land, labour, materials, fuels, chemicals, machineries, etc.) were collected through interviews in farms from different production areas. Climate change, terrestrial acidification, freshwater acidification and water depletion were assessed together with costs and profits. Results show that diesel consumption, fertilization, pesticides, and irrigation are the main environmental hotspots, while labour and chemicals are relevant for costs. Reducing losses could help reduce these impacts.

1. Introduction

Fruit is often attributed a lower environmental impact than several other food products largely consumed in western diets, such as meat or milk. Nevertheless, fruit farming systems can be quite intensive both in terms of production inputs and natural resource use (Cerutti et al., 2014). Fruit production can be also characterized by high economic costs, not only for the initial investment (orchard planting), but also and foremost for harvest costs, which are usually associated to energy and labour prices (De Luca et al., 2014; Pergola et al., 2013; Tamburini et al., 2015). Considering fruit producer price variability, these costs may play a crucial role in farmers' decision to harvest fruit or leave it on trees or fields.

Fruit, as vegetables, are characterized by several losses and waste along the supply chain. Basing on ISTAT (2016), on average each year about 250,000 t of fruit (around 2% of whole Italian production) are not harvested. This figure is estimated from farm data surveys and it does not include what is defined by Gustavsson et al. (2011) as "losses due to mechanical damage and/or spillage during harvest operation (e.g. threshing or fruit picking), crops sorted out post-harvest, or left in fields due to sharp drops in prices". Thus, real fruit production losses at farm are probably underestimated. Considering the environmental and costing impacts of fruit, wasting this potentially edible food represents a double wastage of the resources and energy used in its production (Vittuari et al., 2016).

While several studies analysed the environmental impact of fruit production and orchards (Cerutti et al., 2014; Milài Canals and Polo, 2003) and/or their cost (De

Luca et al., 2014; Pergola et al., 2013; Tamburini et al., 2015), few studies focused on the influence of losses, their impact, and potential reduction strategies.

Thus, this paper analysed these aspects, through a combined LCA and LCC, using nectarine farming in Emilia-Romagna as a case study. Italy, together with Spain, is leader in Europe in the production of peaches and nectarines. In 2015, 1.42 Mt were produced from about 72,000 ha (ISTAT, 2018). The most important regions for peach and nectarine production are Campania, Emilia-Romagna, Veneto and Piemonte. Despite of a significant reduction of peach production and cultivated surface in Emilia-Romagna in the last years, the region is still relevant for both quantity and quality of production. Several studies have been already carried out on the environmental impacts of peach and nectarines in various areas and using various methods (Cerutti et al., 2010; Fiore et al., 2017; Ingrao et al., 2015; Scherhaufer et al., 2015; Vinyes et al., 2015). However, only few (De Menna et al., 2015; Vinyes et al., 2015) specifically addressed losses, using secondary data, and none of them included the assessment of costs.

2. Materials and methods

2.1. Goal and scope

The aim of this study was to assess the environmental and economic impacts of nectarines in Emilia-Romagna and to evaluate the extent and role of farm losses. The system studied is the production of nectarines and the chosen functional unit was 1 kg of nectarines sold. Therefore, the system boundaries were cradle to farm gate and included all processes from raw materials extraction and inputs processing, to orchard establishment and management, to production of fruit and disposal of waste and by-products.

2.2. Life cycle inventory

In order to collect primary data on nectarine farming, large producers' organisations were contacted to select a regional sample of farms from main production areas, namely Ravenna, Bologna, and Forlì-Cesena provinces.

Table 1: Sampled farms (IF: integrated farm)

	IF1	**IF2**	**IF3**	**IF4**
Nectarine area (in ha)	7	14	2	3.2
Sold nectarines (in kg/ha*y	37,500	32,500	30,000	30,000
Average price (in €/kg)	0.38	0.27	0.36	0.3

A total of 4 farms were provided (table 1). All of them were managed according to the regional disciplinary for peach and nectarines integrated production.

On-farm visits and interviews were conducted in the period May-October 2017 to collect primary data on:

- Production and losses: species and varieties cultivated and related area; yearly sold production; losses, related causes, and disposal;
- Orchard: age, previous land use, planting density, type of soil, type of irrigation and other installations;
- Cultivation: number and duration of farm operations, machine power, type and amount of fertilizers, pesticide applied;
- Costs: general costs (services, insurances, and certifications), fixed costs (planting, irrigation system, machineries, land), variable costs of inputs (energy, fuels, fertilizers, pesticides, etc.) and workforce (family, seasonal, etc.)
- Revenues: selling price and subsidies.

All variable data were collected as average of three consecutive farm years (2014-2016) to account for seasonal differences and climate variability. Farmers reported most of data during interviews, providing the farmbook, and the income statement.

Secondary data from Ecoinvent v.3 were used for some cost items and background processes, such as raw material extraction, input production and transport. Field emission were modelled following the methodological guidelines by the World Food LCA Database (Nemecek et al., 2015).

2.3. Impact assessment

The LCA followed the requirements set by ISO in the 14040-44 standards (International Organization for Standardization, 2006a, 2006b), while an environmental LCC was carried out according to the code of practice proposed by the SETAC (Hunkeler et al., 2008; Swarr et al., 2011).

Environmental impact categories were calculated according to the Recipe v1.13 (Midpoint Hierarchist). Considering the relevance for fruit production, the following environmental impact indicators were selected:

- Climate Change (CC) in kg $CO_{2\ eq}$;
- Terrestrial Acidification (TAC) in kg $SO_{2\ eq}$;
- Freshwater Eutrophication (FEU) in kg P_{eq};
- Water depletion (WDP) in m^3.

As far as LCC is regarded, the following cost categories and indicators were taken into account:

- fixed and variable costs;
- life cycle costs;
- life cycle profits.

Environmental and cost impacts were assessed separately (i.e. no scoring or weighting). All impacts were calculated through Simapro 8.3.

3. Results and discussion

Table 2 shows the results per each farm for the selected environmental indicators. The average CC impact per kg of sold nectarines is around 0,132 kg $CO_{2\ eq}$. In all farms, most of the impact derives from direct emissions of CO_2 from diesel consumption in farm operations and of N_2O from fertilization. There is however a certain variability among the sample, due to the diverse amount of fuel consumption, which is quite higher in IF3 (about 40l/ha more than the average). These results on average in line or lower than previous comparable studies (De Menna et al., 2015; Ingrao et al., 2015; Vinyes et al., 2015)

Table 2: LCA results per kg of sold nectarines

Impact	Unit	IF1	IF2	IF3	IF4
CC	kg $CO_{2\ eq}$	1.12E-01	9.04E-02	2.26E-01	9.96E-02
TAC	kg $SO_{2\ eq}$	1.06E-03	7.00E-04	1.97E-03	7.90E-04
FEU	kg P_{eq}	5.00E-05	3.00E-05	7.00E-05	4.00E-05
WDP	m^3	3.53E-02	2.29E-02	2.00E-02	4.29E-02

Impact on TAC amounts at around 1.13E-03 kg $SO_{2\ eq}$, and depends mostly on 3 emission flows: NO_X, NH_3, and SO_2. Nitrogen oxides derives mostly from diesel consumption, while ammonia is emitted via fertilization and sulphuric dioxides are indirect emissions related to pesticides production (e.g. dithiocarbamate-compounds). Variability in the use of fertilizers, diesel, and pesticides influence the total result. For example, IF2 and 4 are consuming less pesticides than other farms.

Freshwater eutrophication is caused by PO_3^- (phosphate) and P (phosphorus) leaching in water. However, while the latter is directly related to fertilization, the former is more dependent on the production of copper sulphate, which is largely used in IF1 and 3. WDP is obviously linked with irrigation. On average, about 0.03 m^3 of water are depleted per kg of sold nectarines, with an average consumption of 990 m^3 per ha.

Also FEU and TAC results are in line with previous literature, and in particular with the study from Vinyes et al. (Vinyes et al., 2015), while WDP value is quite lower, probably due to the different year and climate.

Table 3 shows the results per each farm for the selected cost indicators. On average, farming 1 kg of nectarines costs about 0.49 €, if retribution of family work is included. Variable costs are obviously more relevant. Labour is the most impacting cost item (between 80 and 90% of the variable costs) but there is a large difference between farms in the amount of seasonal and family workers.

Other relevant variable costs are plant protection products and fertilizers. Among fixed costs, plants (including royalties) and structures (irrigation and hail protection systems) are the most important items, while insurances are only relevant for IF1 and 3.

Table 3: LCC results per kg of sold nectarines

Impact	**IF1**	**IF2**	**IF3**	**IF4**
Fixed costs	0.10 €	0.08 €	0.13 €	0.06 €
Variable costs	0.35 €	0.47 €	0.38 €	0.38 €
LCC	0.45 €	0.55 €	0.51 €	0.44 €

When revenues are considered it is possible to evaluate the profitability of farms (Figure 1). Depending on the selling price and the amount of subsidies received, integrated farms are earning between 0.28 and 0.40 €/kg. When subtracting life cycle cost with the exclusion of family salaries, profits are positive for most of farms except IF2. This is due to the low selling price and the high share of seasonal workers. However, when family salaries are included, profits are negative for all sampled farms.

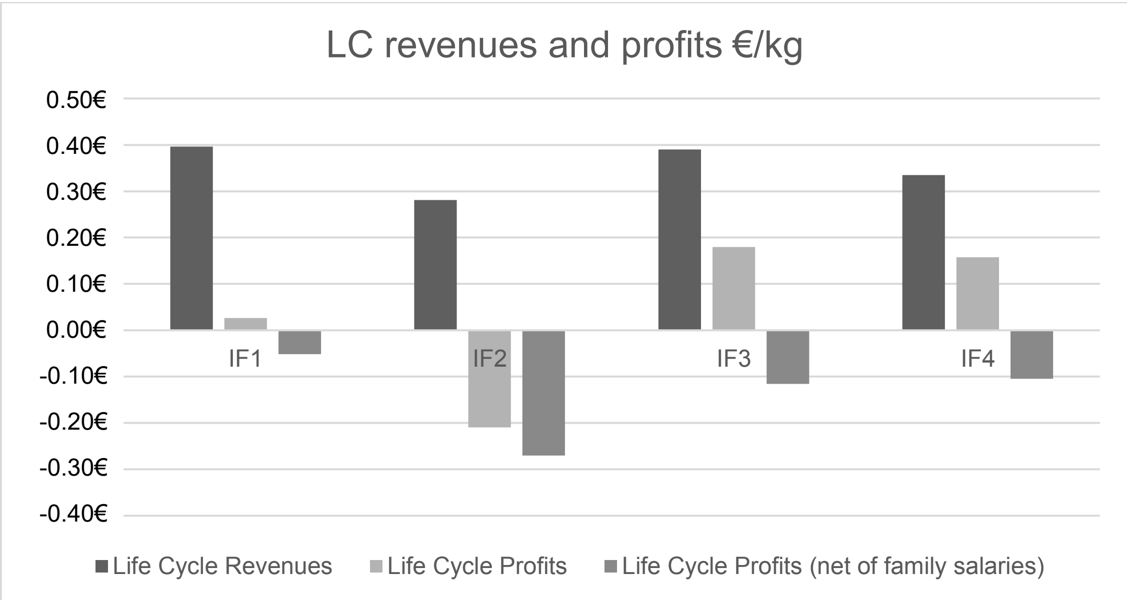

Figure 1: Life cycle revenues and profits per kg of sold nectarines

No previous literature focused on peach or nectarine production from a LCC perspective. However, it is possible to argue that these results are in line with the general findings from studies on different crops. In fact, as mentioned, such studies highlighted how harvest costs play a major role in the total figure mainly due to labour, energy, and other variable cost inputs (De Luca et al., 2014; Pergola et al., 2013; Tamburini et al., 2015).

Farm losses due to different drivers are reported in Table 4. Figures about not harvested products are consistent with national estimates. The total however is significantly higher since other drivers are taken into account. In the specific, for most farms, mold and fungi are the largest cause of losses, followed by losses due to damage during harvest. Only in one case market standards play a large role (IF3), since most producers’ association are collecting also defected product to be sent to processing.

Table 4: Loss mass in kg per kg of FU

	IF1	IF2	IF3	IF4
Pre-harvest losses due to molds and fungi	0.05	0.15	0.04	0.10
Losses and damages during harvest	0.05	0.01	0.01	0.03
Not harvested due to price	0.01	0.01	0.02	
Not harvested/sold due to market standards			0.05	
Total	**0.12**	**0.17**	**0.12**	**0.13**

Considering that losses due to molds and fungi might be difficult to prevent, it is possible to note how reducing fruit losses could result in environmental impacts and cost savings.

4. Conclusions

This paper presented preliminary results from a research on the environmental and cost impacts of fruit losses. The study focused on nectarine farming in Emilia Romagna as case study. By collecting primary data from different representative farms, it was possible to carry out a combined LCA and LCC assessing the impacts related to 1 kg of nectarine and the related losses.

Results show that nectarine production can be quite intensive as far as farm operations, fertilization, and plant protection are regarded. Integrated farming could potentially benefit from further input efficiency and reduction. Results are in line with previous comparable studies, also considering the different agronomical practices and climate conditions. From a costing perspective, integrated nectarine production is highly influenced by labour cost and only marginally by fixed costs. When analysing profits it is also possible to note how several farms are yielding negative profits, especially when retribution of family workers is included. Finally, significant losses are related to molds and fungi and damage at harvest, while further losses might occur due to price dynamics.

However, there are some limitations deriving from the size and representativeness of the sample, as well as from the quality of some data (e.g. self-reported). Furthermore, some impacts were not assessed despite their potential relevance, such as the toxicity impact of pesticides

Therefore, further research might include the comparative assessment with organic production systems in order to capture differences in market dynamics and losses, as well as the inclusion of downward supply chain segments in the system boundaries to identify losses hotspots and burden shifting.

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Grana Padano and Parmigiano Reggiano cheeses: preliminar results towards an environmental eco-label with Life DOP project

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Abstract

Grana Padano and Parmigiano Reggiano are two of the most important Italian PDO cheeses. To improve the environmental impact performances of their production, the Life Cycle Assessment (LCA) method has been used. In the Life DOP Project, LCA of milk production at farm will be completed on about 120 dairy farms of the province of Mantova (Northern Italy). Mitigation strategies to improve both environmental and economic production sides will be suggested, focusing on forage crop production (yield increase), milk production (dairy efficiency increase), herd management (animals' health and welfare) and off-farm purchased feed. From the preliminary results, shown on 4 farms, there is evidence that improvements are needed. In particular, the most efficient farm (farm C) has the best environmental sustainability, while the others have worse outcomes, mainly due to poor dairy efficiency and related issues.

1. Introduction

Grana Padano and Parmigiano Reggiano cheeses are two of the most important dairy products of Protected Designation of Origin (PDO) in the Italian agri-food context. Their production has a huge market impact because they are among the most exported Italian agri-food products worldwide (Bava et al., 2018). The production chains of Grana Padano (GP) and Parmigiano Reggiano (PR) are quite complex, thus involving several stakeholders and producers that contribute to the environmental sustainability of these cheeses. More in detail, to produce GP and PR, the environmental impacts related to the cheese factory phase as well as to the milk production phase, including production of animals' feed and slurry management must be taken into account. In addition, the dairy farming context is quite complex and several farms must be investigated to get statistically relevant information about the local milk production system. This complexity supports the need of detailed primary data for agricultural production systems when reliable environmental analyses are searched (Lovarelli and Bacenetti, 2017).

In order to promote, among others, (i) mitigation strategies for milk production and for manure/slurry management and the related emissions to the environment and (ii) a manure-slurry exchange system among farmers, the project Life DOP (LIFE15 ENV/IT/000585) has started since 2016 (www.lifedop.eu/en/). In particular, in order to make available to farmers an organic fertiliser characterised by an adequate nitrogen content and a higher solid matter respect to slurry, an exchange system for manure and slurry has been promoted. It permits to farmers to sell slurry and manure that are mixed in a dedicated implement and digested in two anaerobic digestion plants. After, the digestate fraction is returned to farmers according to the exchange system, and is spread on fields. This allows introducing the concept of circular economy on livestock farms, exploiting the capabilities of slurry and manure and bringing environmental benefits. Since policy makers must promote strategies for a sustainable consumption and production, this project is in line with the European goals and challenges for low environmental impact productions.

In this context, efficiency improvements for dairy farms, animal management and animal feeding are key aspects. Thus, about 120 dairy farms in the province of Mantova in Northern Italy were investigated to carry out a Life Cycle Assessment (LCA) analysis of each farm and promote mitigation strategies for a sustainable milk production pathway. On about 10% of the farms investigated, the suggested improvements will be re-analysed by means of LCA and the reduction in environmental impact due to the efficiency increase will be quantified and suggested for future mitigation strategies. Moreover, an environmental sustainability label will be developed to certify the commitment of GP and PR producers towards sustainable productions and resource use efficiency. In particular, improvements in resource use efficiency and animal care, balanced feed intake and feed self-sufficiency allow a better use of resources and an increase in milk productivity. As a result, this will provide both environmental and economic benefits.

The aim of this study, being part of the project, is firstly to improve the dairy efficiency of cows, their productivity and the on-farm feed production in qualitative and quantitative terms to reduce the environmental impact of off-farm feed and, especially, of its transport from other countries. Secondly, to get information and the best mitigation strategies for cheese production. The development of an environmental label will allow policy makers to understand:

- the importance of circular economy and of the value of environmental assessment studies to make valid decisions,
- how environmental assessments can support business strategies,
- the environmental consequences of mitigation strategies by evaluating their effective applicability on farms.

2. Materials and methods

2.1. Goal and scope

In this study, LCA (ISO 14040 series, 2006) is applied to quantify the environmental impact of milk production on the analysed farms and to investigate the possible improvements for producing milk more efficiently.

2.2. Functional unit and system boundary

The selected Functional Unit (FU) for the analysed farms is 1 kg of Fat and Protein Corrected Milk (FPCM) produced by milking cows. This decision is made according to several studies about milk production (Bacenetti et al., 2016; Bava et al., 2018; Zucali et al., 2017) and to the recommendation by IDF (2015).

This assessment has a cradle-to-farm gate approach. In the system boundary are included all inputs (e.g., machinery, fuel, lubricant, organic and mineral fertilisers, pesticides, water, off farm feed) and outputs (emissions to air, soil and water) as reported in Figure 1.

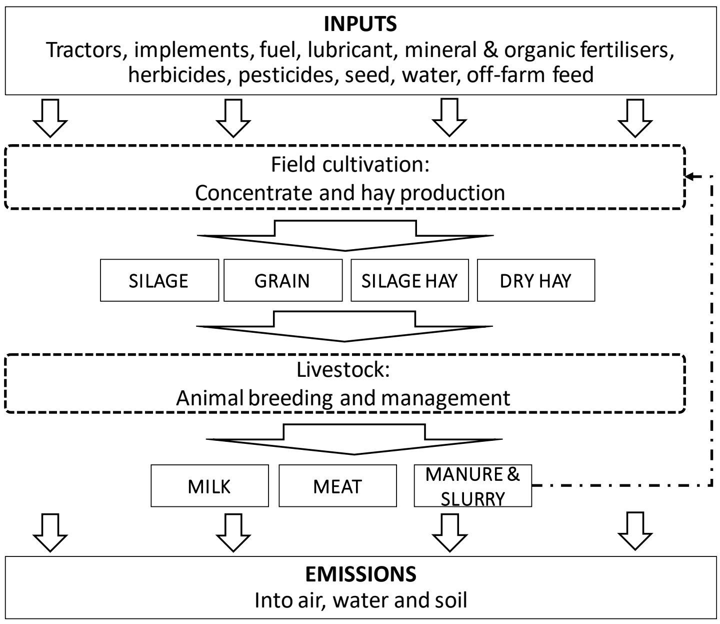


Figure 1: System boundary

2.3. Description of the system and data collection

During the project, about 120 dairy cattle farms have been analysed. They sell milk to 9 dairies, of which 4 produce Grana Padano cheese (GP) and 5 produce Parmigiano Reggiano cheese (PR). The project Life DOP foresees the completion of LCA of the milk production at the farm gate and a second LCA of the cheese production at the dairy factory gate.

In this paper, the attention will be focused on the milk production phase and, in particular, results of 4 dairy farms are reported. In more details, the environmental results related to the first of the three years of analysis will be shown for 2 farms (Farm A and B) selling milk to a dairy for PR production and 2 farms (Farm C and D) selling milk to a dairy for GP production. A

ll data were collected during surveys on farm carried out by experts by asking for information about:

- Field production (e.g., cultivated crops, cultivation practices, inputs such as fertilisers, water, machinery, etc.),

- Herd management (e.g., number and type of animals, purchasing/selling of animals, etc.),
- Milk production (e.g., milk yield and quality, protein and fat content, etc.),
- Feeding (e.g., type and quality of feed, on farm cultivated feed, off farm purchased feed, etc.),
- Manure and slurry management (e.g., availability of manure/slurry, storing system, time and spreading technology adopted, etc.),
- Infrastructure of the dairy farm (e.g., cattle housing, milking parlour, slurry and manure storage, etc.).

Table 1 and Table 2 report the main inventory data about the cultivated crops, herd composition and milk production. Table 3 shows the allocation values adopted for milk (physical allocation between milk and meat considering feed energy by dairy cows and feed requirements for producing milk and meat) calculated in accordance with IDF (2015).

Table 1: Main inventory data about the on-farm field cultivation. (*) with average self-sufficiency is meant the ratio between the on-farm produced feed and the total feed for cows

Variable	Unit	Farm A	Farm B	Farm C	Farm D
Total agricultural area	ha	21.3	60.2	92.5	64.9
Alfalfa, area	ha	10.0	50.3	28.2	27.9
Ryegrass, area	ha	8.0	-	4.7	6.9
Winter cereals, area	ha	-	3.3	-	-
Maize for silage, area	ha	3.3	-	59.6	13.2
Maize grain, area	ha	-	-	-	10.0
Soybean, area	ha	-	-	-	6.9
Minor cereals, area	ha	-	3.3	-	-
Mixed cereals, area	ha	-	3.3	-	-
Average self-sufficiency (*)	%	71%	63%	55%	81%

Table 2: Main inventory data about herds and milk production

Variable	Unit	Farm A	Farm B	Farm C	Farm D
Total number of cows	no.	177	188	285	112
Lactating cows	no.	85	85	52	56
Dry cows	no.	15	15	629	10
Delivered milk	t FPCM/yr	726.0	813.6	3729.9	578.1
Milk per cow	kg FPCM/d	23.3	29.2	35.7	28.1
Dairy Efficiency	kg FPCM/kg feed	1.16	1.19	1.57	1.27
Dry Matter Intake	kg/d	21.2	22.8	23.2	22.6

Table 3: Allocation values for milk (IDF, 2015)

Variable	Unit	Farm A	Farm B	Farm C	Farm D
Mass allocation	%	84%	82%	84%	88%

2.4. Impact assessment

The following environmental impacts were considered by using the ILCD characterisation method (Wolf et al., 2013):

- Climate Change (CC, kg CO_2 eq),
- Particulate Matter (PM, kg $PM_{2.5}$ eq·10^{-4}),
- Acidification (TA, molc H^+ eq·10^{-1}),
- Freshwater eutrophication (FE, kg P eq·10^{-4}),
- Marine eutrophication (ME, kg N eq·10^{-2}),
- Land Use (LU, kg Carbon deficit·10^{1}),
- Mineral, fossil and renewable resources depletion (MFRD, kg Sbeq·10^{-5}).

3. Results

Table 4 shows the environmental impacts of milk production in the 4 dairy farms analysed. The two farms producing milk for PR cheese have an environmental impact quite close to each other, except for CC (1.58 and 1.17 kg CO_2 eq/kg FPCM, respectively for A and B) that is mostly affected by animal emissions. PM and TA result higher in respect to C and D, mostly because of field emissions in the cultivation practice. In particular, farm A has the lowest milk production, field area and dairy efficiency, which deeply affects the environmental outcomes.

On the contrary, the two farms producing milk for GP cheese (farms C and D) have a different production disciplinary, which allows them introducing energetic animal feeding such as cereal silages characterised by annual cropping cycles. Accordingly, their environmental impact shows bigger variability due to the better and more variable dairy efficiency (1.57 and 1.27, respectively).

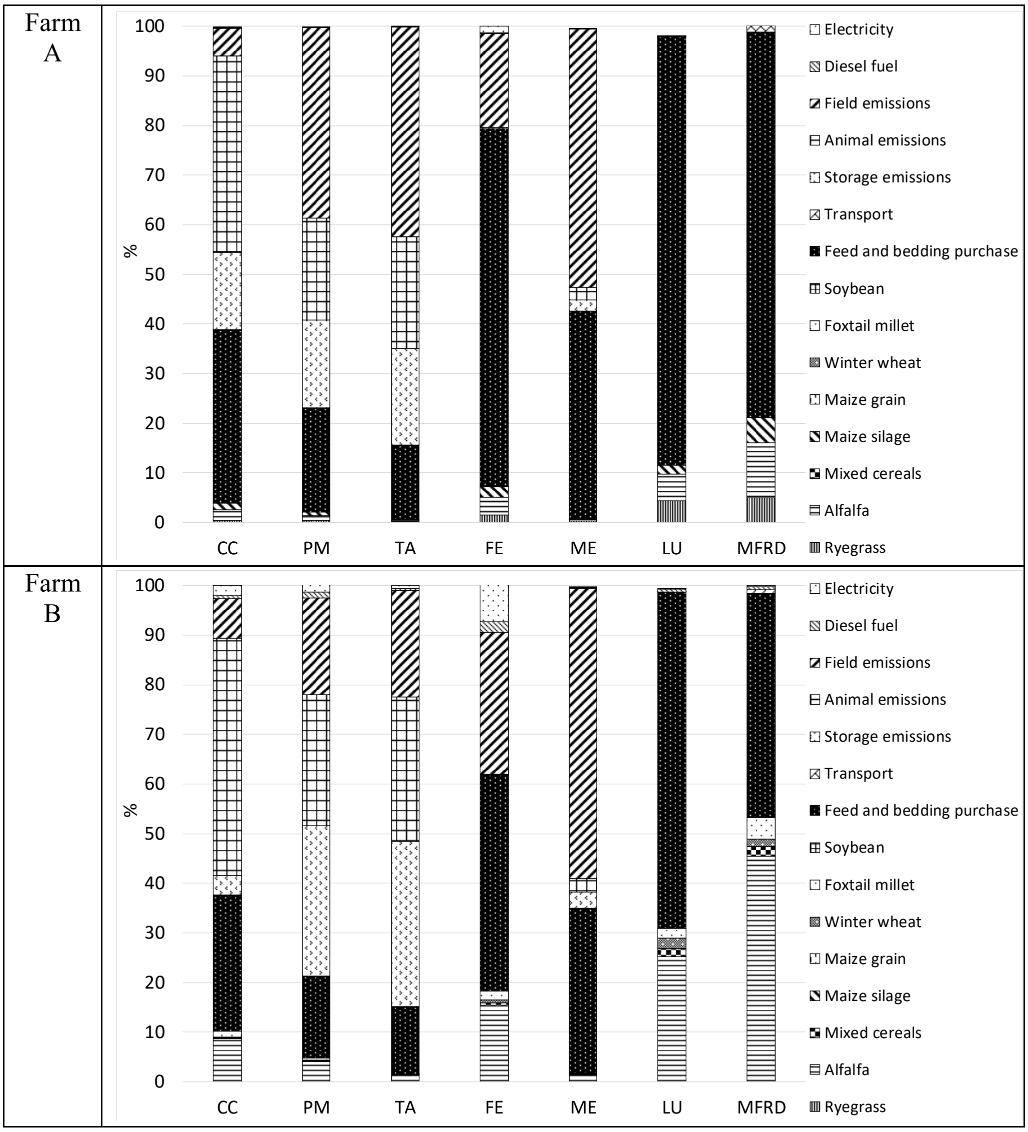
Table 4: Environmental impact of milk production per kg FPCM in the studied farms: A, B (milk for Parmigiano Reggiano cheese) and C, D (milk for Grana Padano cheese)

Impact category	Unit	Farm A (PR)	Farm B (PR)	Farm C (GP)	Farm D (GP)
CC	kg CO_2 eq	1.586	1.173	0.999	1.643
PM	kg $PM_{2.5}$ eq·10^{-3}	0.798	0.579	0.463	0.618
TA	molc H^+ eq·10^{-1}	0.329	0.238	0.185	0.225
FE	kg P eq·10^{-4}	0.835	0.625	0.471	1.127
ME	kg N eq·10^{-2}	0.874	0.763	0.533	0.887
LU	kg carbon deficit·10^{1}	2.651	2.349	1.328	2.785
MFRD	kg Sb eq·10^{-5}	0.550	0.452	0.365	0.990

In particular, for farm C (highest milk production per cow: 35.7 kg FPCM/d) and D (lowest milk production per cow: 28.1 kg FPCM/d), CC is 0.99 and 1.64 kg CO_2 eq/kg FPCM, respectively. Farm D shows the worst performance not only for CC (mainly caused by high methane enteric production) but also for FE and

ME (due to field emissions during cultivation) and for LU and MFRD (due to feed and bedding purchase and the adopted field cultivation practice). Thus, farm D represents the worst performing farm among the four studied ones.

Figure 2 reports the hotspot processes of the four farms.



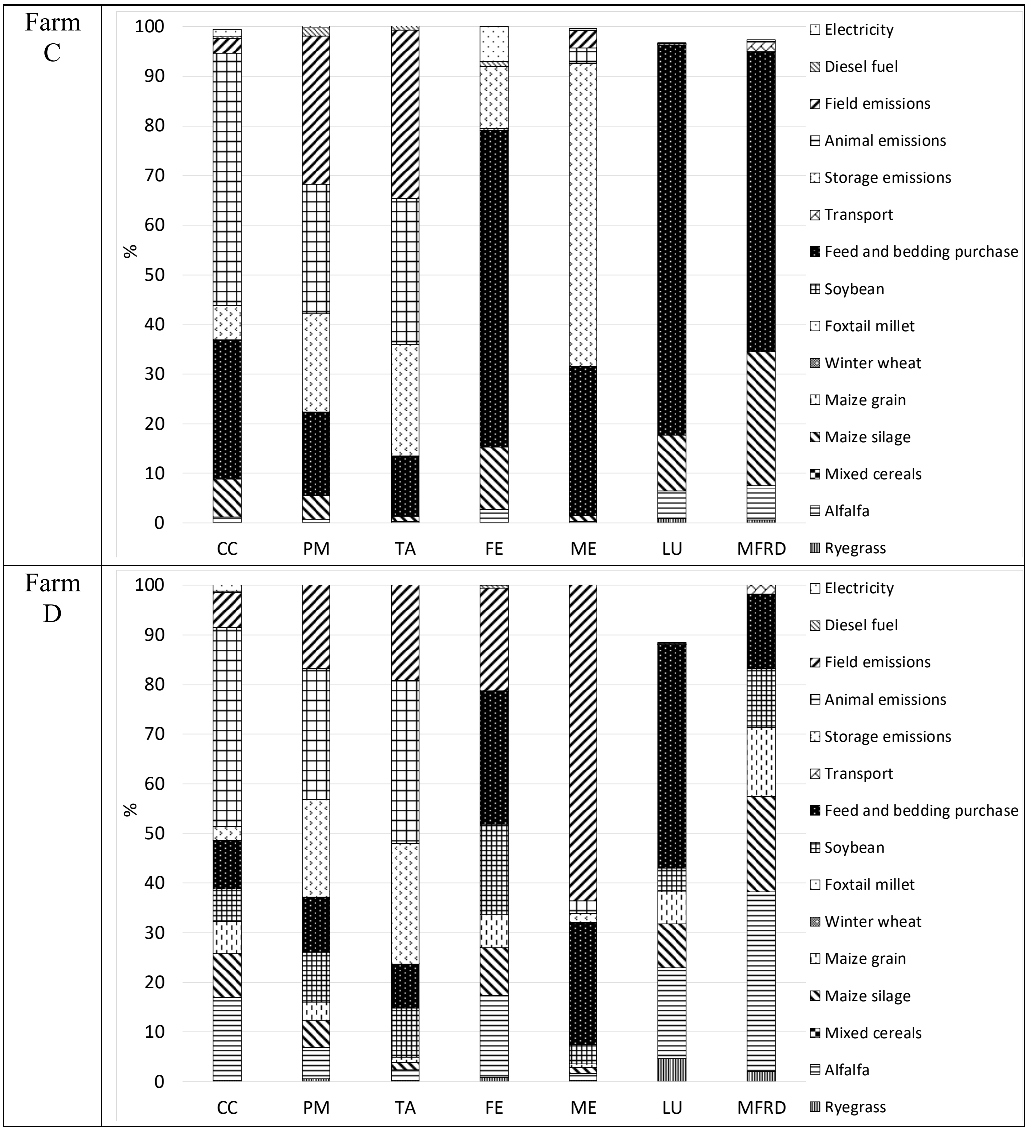


Figure 2: Process hotspots of milk production in the studied farms

4. Conclusions

The outcomes of the present study are referred to just four of all dairy farms taking part in the Life DOP project. Moreover, these results are preliminary ones, and further analyses will be performed along the years. In particular, the improvements suggested to each farm will be studied (e.g., crop yield increase, milk production and dairy efficiency increase, slurry and manure management, animal health and welfare) as well as those at the cheese factories.

From the results, it emerges that the most efficient farm shows also the lowest environmental impact per kg FPCM, pointing out that farms with an efficient farming system have also the best environmental performances. Consequently, it is essential to go towards this direction. An efficient milk production system brings benefits also on the related systems of manure/slurry and cheese transformation, thus it represents an essential step for the circular economy life cycle thinking and for lasting sustainability goals of the agricultural sector. In this context, the introduction of an eco-label for GP and PR will represent a certificate for stakeholders for their commitment, for consumers to understand the role of environmental sustainability and its significance on the production point of view and for other producers to be driven to the same direction.

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Life Cycle studies in agrifood sector: focus on geographical location

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Abstract

Coherently with the attention of international policies on environmental impacts related the agrifood chain, in the last decade the adoption of a life cycle approach in this sector increases. Through the review of scientific papers recently published in international indexed journals, the study investigates the adoption of some life cycle tools such as Life Cycle Assessment, Product Carbon Footprint and Water Footprint in 412 life cycle studies of agrifood products. Aim of the study is to understand the lifecycle stages more frequently analyzed, as cultivation/raising/finishing, processing/operatios and retail/consumption. Moreover, the review identifies the top five countries where these studies took place in the agrifood chain.

1. Introduction

Life Cycle tools (LC tools), such as Life Cycle Assessment (LCA), Product Carbon Footprint (PCF) and Water Footprint (WF), aim at evaluating the environmental impacts of a product considering the flows of matter and energy of which this product is responsible throughout its life, from cradle to grave (Borsato et al, 2018; Rothwell et al, 2018). In the agrifood sector these LC tools are frequently adopted, with the aim of identifying the more impactful phases of the production/transformation process of a food product from an environmental point of view. The environmental consciousness deriving from life cycle studies of agrifood products becomes the starting point to recognize the best scenarios of production and logistic solutions related the entire supply chain (Nemecek et al, 2016; Sala et al, 2017; Tilmann et al, 2011).

Although observing the entire chain is essential to know the environmental hotspot of a food product, often the studies are limited to analyzing only some phases of the life cycle, preferring, for example, a cradle to gate approach. This limitation could be justified by the fact that the manufacturing companies have limited contractual power in distribution choices and cannot intervene in the consumption behavior of their products (Notarnicola et al, 2017/a; 2017/b).

Our research deepens the diffusion of life cycle studies in the agrifood sector, with the main objective of understanding if the attention towards the various phases of the life cycle of a food product is growing over the years and if it is possible to identify the “top five” countries most involved in these studies for each lifecycle stage. Through a systematic analysis of scientific papers published in recent years, the research observes the distribution of life cycle studies in terms of LC tools adopted, lifecycle stages included in the study and country and mainland related each agrifood stage.

The statistical analysis of data collected must lead to understanding the lifecycle stages of agrifood products more frequently included in the life cycle studies, and those less frequently studied.

2. Methodology

To investigate the research topic, we conducted a research based on a systematic literature review, exploring the life cycle studies in agrifood sector in scientific papers published during the period 2012 – 2017. To verify which papers concern life cycle studies in the agrifood sector, a bibliographical survey was conducted consulting international databases (ISI Web of Knowledge and the main editors' libraries[11]) using the following research keywords: "life cycle", "life cycle assessment", "carbon footprint", "water footprint", "agrifood", "food", "food and beverage". In order to include all the relevant papers in the literature analysis, we selected them on the basis of the following criteria (coherently with Luederitz et al, 2016 and Mazzi et al, 2016):

- Data Screening, which concerns the search in the established databases through the established keywords;
- Data Cleaning, which concerns the evaluation of each papers selected in the previous step (Data Screening), in order to decide their inclusion in the research sample, based on the coherency of the title, abstract and full text with the research topic.

Each paper has been categorized through the following variables, explained in Table 1: year of publication, LC tool used, LC stage investigated, Country of each LC stage. Then, a descriptive analysis of the selected papers was conducted in order to know the statistical distribution of LC tools adopted, LC stage investigated, country and mainland of each LC stage in the recent scientific papers.

Table 1: Variables considered in order to categorize selected papers

Variables considered	**Possible values for each variable**
Year of pubblication	2012, 2013, 2014, 2015, 2016, 2017
LC tools	Life Cycle Assessment (LCA), Product Carbon Footprint (PCF), Water Footprint (WF), Others
LC stage investigated	Cultivation/raising/fishing, Processing/operation, Retail/consumption
Country	Country when took place the life cycle of Cultivation/raising/fishing, Processing/operation, Retail/consumption
Mainland	Mainland when took place the life cycle of Cultivation/raising/fishing, Processing/operation, Retail/consumption

[11] Editors' libraries consulted: https://www.sciencedirect.com; https://link.springer.com; https://www.emeraldlink.com.au; https://onlinelibrary.wiley.com.

3. Results

The selected papers from literature analysis are 299, published in several scientific journals from 2012 to 2017. Moreover, we must consider that several of the selected papers concerned of more than one life cycle study. Then, these papers were divided into singular observations, correspondent to 412 studies.

Figure 1 represents the distribution of selected studies in terms of adopted LC tools. The main findings are:

- From 2012 to 2017 the number of life cycle studies is strongly increasing (more than doubled).
- The LC tool more frequently used is LCA, followed by PCF; PCF is the LC tool with the greatest increase in papers in the last years (more than tripled).
- Instead, WF remains the less frequently used tool, despite in this economic sector the water availability represents a felt problem.
- In the group "Others" there is a consistent number of studies that have adopted other LC tools as partial LCAs, Ecological Footprint, Life Cycle Costing, Social LCA.

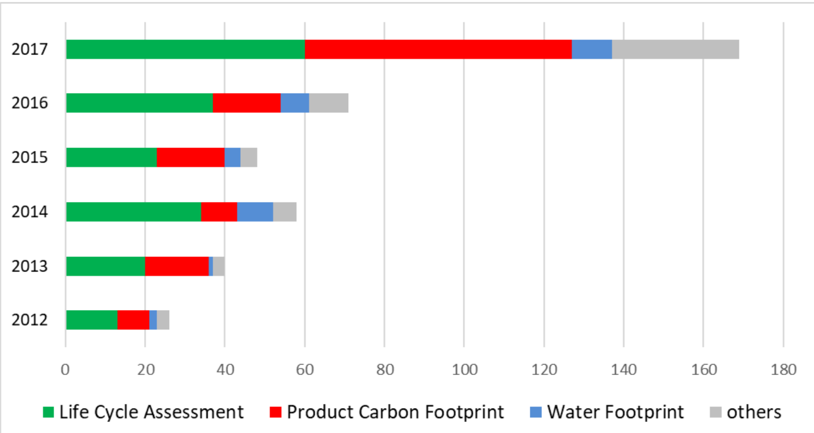

Figure 1: Distribution of life cycle studies based on LC tool adopted

Figure 2 reprents the frequency of life cycle studies published from 2012 to 2017 that included each life cycle stage in their system boundaries. We can underline following remarks:

- More than 90% of these studies considers the LC stage of cultivation/raising/fishing and about 85% investigates the LC stage of processing/operation.
- On the other hand, about 40% of the studies do not investigate the LC stage related retail and consumption.

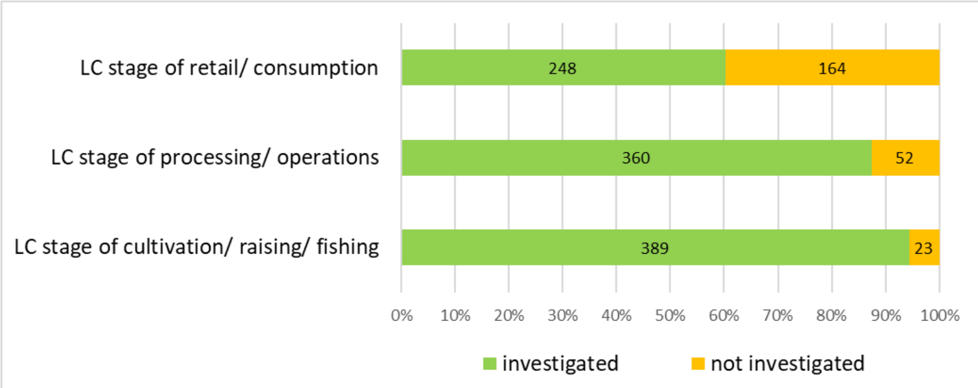

Figure 2: Frequency of life cycle studies based on the lifecycle stages investigated

Figures 3, 4 and 5 represent the frequency of countries where the LC stages of cultivation/raising/fishing, processing/operation and retail/consumption took place. This distribution allows us to state that the countries more frequently involved in LC studies related to agrifood products are the following:

- with reference to cultivation/raising/fishing stage: Italy, China, Spain, United States, and Australia;
- with reference to processing/operations stage: Italy, China, United States, Spain, and Australia;
- with reference to retail/consumption stage: Italy, China, Sweden, United Kingdom, and Spain.

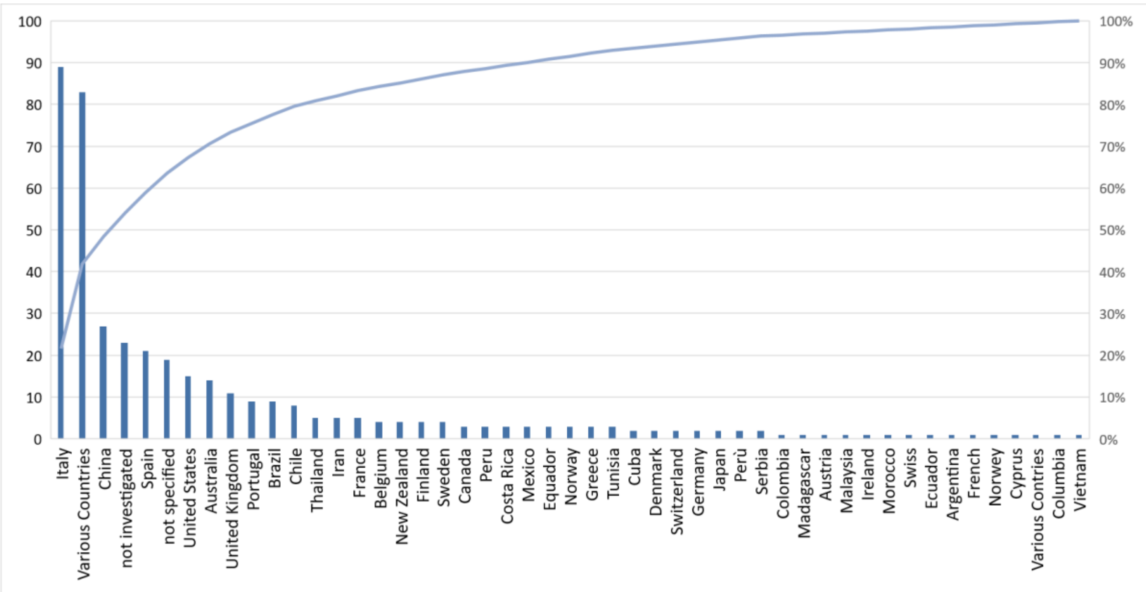

Figure 3: Frequency of life cycle studies based on countries of cultivation/raising/fishing

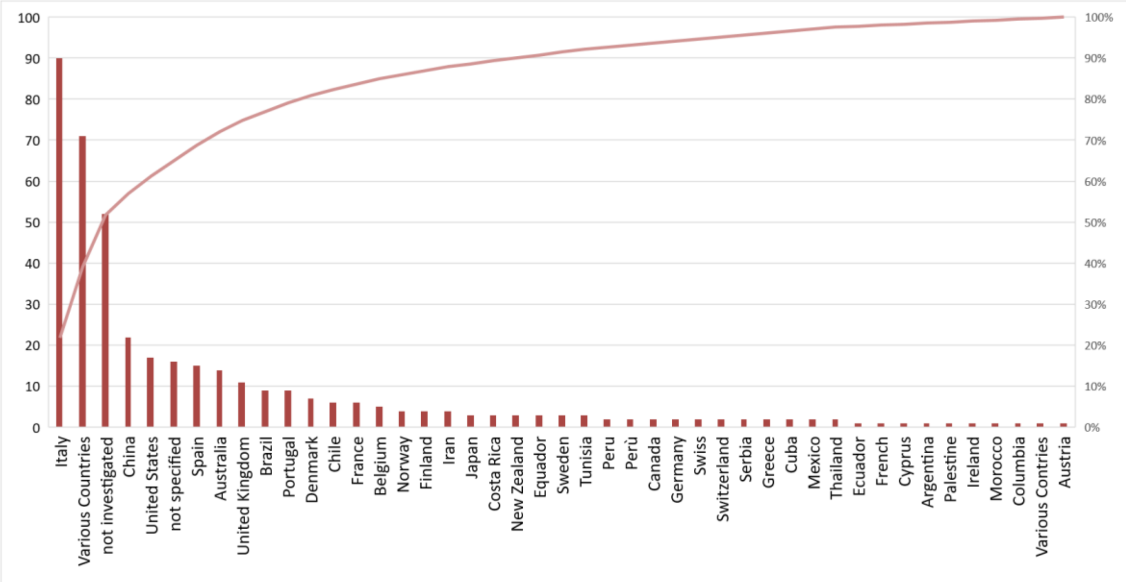

Figure 4: Frequency of life cycle studies based on countries of processing/operations stage

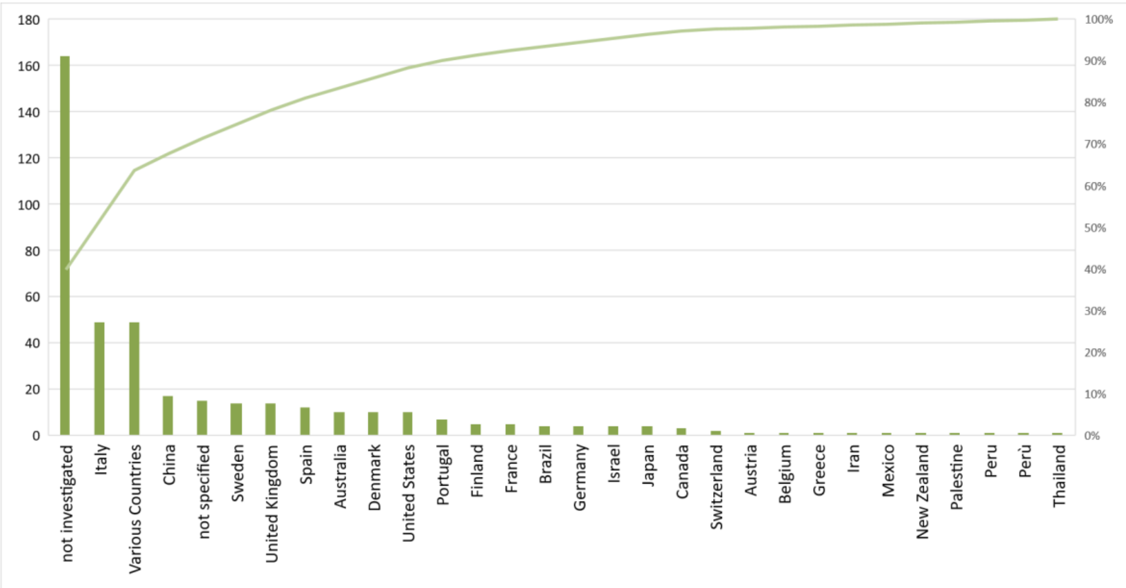

Figure 5: Frequency of life cycle studies based on countries of retail/consumption stage

Figures 6, 7 and 8 represent the frequency of mainlands where the LC stages took place: cultivation/raising/fishing (figure 6), processing/operations (figure 7) and retail/consumption (figure 8).

The mainland more frequently involved in LC studies related agrifood products is Europe, for all the lifecycle stages considered.

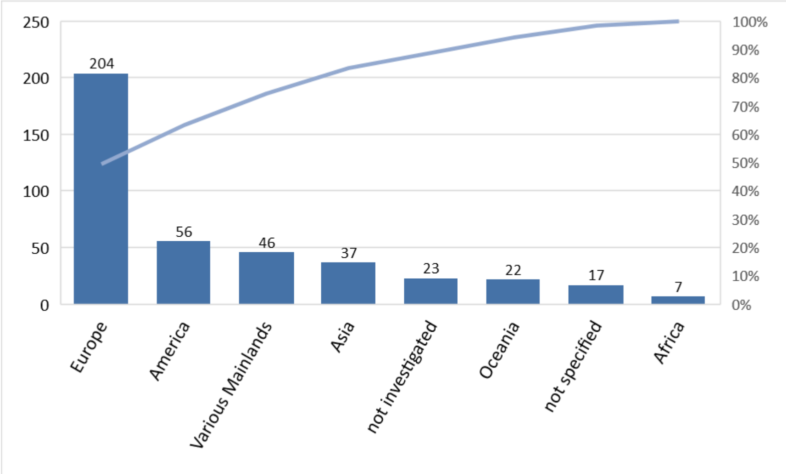

Figure 6: Frequency of life cycle studies based on mainlands of cultivation/raising/fishing stage

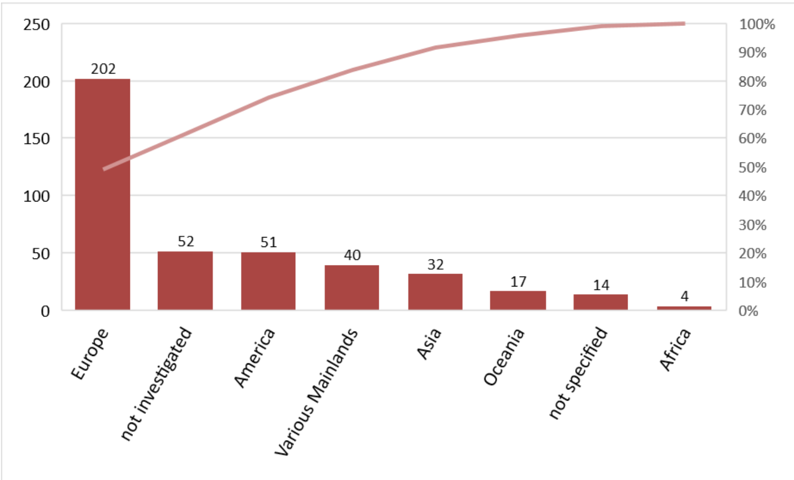

Figure 7: Frequency of life cycle studies based on mainlands of processing/operation stage

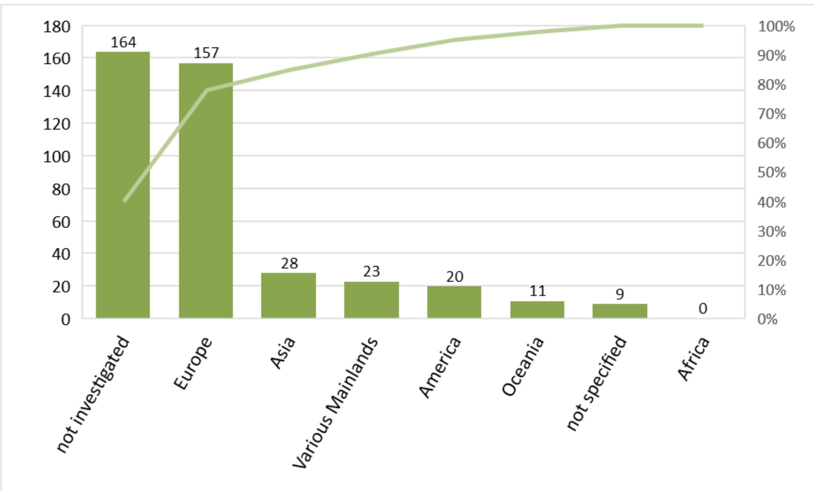

Figure 8: Frequency of life cycle studies based on mainlands of retail/consumption stage

4. Conclusions

In order to conduct a literature review of a systematic review of scientific papers related to the adoption of LC tools in agrifood sector, 299 papers, concerning 412 life cycle studies, have been analyzed in terms of LC tools adopted, LC stage investigated, country and mainland where each LC stage took place. On the basis of the review results, it is possible to reach the following conclusions.

In recent years, the adoption of LC tools in the agrifood sector is constantly growing. The LCA is the preferred tool, following by the PCF; the Water Footprint, instead, is still rarely adopted. The LC tool with a more significant increase in the last few years is PCF.

Lifecycle stages more frequently considered in life cycle studies related agrifood products are cultivation/raising/fishing and processing/operations. Instead, almost half of life cycle studies did not include the lifecycle stage related retail/consumption. However, the number of life cycle studies including the distribution and consumption phases is recently increasing.

The countries where more frequently life cycle studies related to agrifood sector took place are Italy, China, Spain, United States and Australia. For all the lifecycle stages considered, the mainland more frequently involved is Europe. Besides, almost all the studies that include the lifecycle stage of retail/consumption took place in Europe.

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LIFE CYCLE THINKING METHODS AND TOOLS

A case study of green design in electrical engineering: an integrated LCA/LCC analysis of an Italian manufactured HV/MV power transformer

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Abstract

The aim of this study is to present an experience of the application of the Sustainability Assessment Methodology to a traditional private business. It deals about a significant case study in which CESI S.p.A. applied an integrated LCA/LCC analysis to a 250 MVA HV/MV power transformer produced from the Italian Tamini Trasformatori S.r.l. and remanufactured from the traditional design- according to an innovative environmentally sustainable vision – changing the insulation material from mineral to ester oil. The study was the starting point to realize an Environmental Product Declaration and the preceding Product Category Rules, currently underway. Such an innovative and green product development tries to anticipate market demands, to improve the environmental performance and benefits of the energy transformation process, to increase the migration to bio and renewable sources solutions.

1. Introduction

Electric power has nowadays undertaken a critical role in modern society and in its functioning, and energy transmission is the fundamental connection between users and electricity producers. Power transformation acts an essential part in enabling the transmission and - at the same time – granting the highest efficiency and reducing the losses during the whole process. Power transformers functioning and manufacture is as well the ring of the chain to refer to, in order to try to further enhance efficiency and sustainability. It deals, however, of a mature product, which embodies a great potential thanks to its fundamental role, its relevant size and its worldwide spread.

In recent years eco-design principles have started to be applied also in the electrical engineering field, as attested by some works appeared in the literature (Debusschere et al., 2007; Berti et al., 2009; Tran et al., 2009; Lindner et al., 2010; Wei-Han et al., 2012; Spinosa et al., 2013), which is, nonetheless, still very scarce. However, only few of them are reporting dedicated LCA studies of power transformers (Berti et al., 2009; Jorge et al., 2012; Wang & Bessède, 2014), although some works are including transformers in their system boundaries (Jorge & Hertwich, 2013; Turconi et al., 2013).

This study relates of an exceptional case study of an Italian company that started applying *Ecodesign* concept to its activity, i.e. power transformers manufacturing. Tamini remanufactured a traditional 250 MVA HV/MV (high voltage/medium voltage) power transformer substituting - as insulation fluid - ester oil for mineral oil. Consequently, other changes had to be studied and applied to the transformer structure, in order to maintain the performances and to obey to the international standards in force. CESI was designated of the impacts analysis of the new product according to the Life Cycle Thinking methods, namely an integrated LCA/LCCA (Life Cycle Assessment and Life Cycle Costing Assessment) analysis.

Beside the assessment analysis, for this product it has been drawn up an environmental product declaration (EPD, ISO 14025:2010), now published as pre-registered EPD from Environdec, and drafted in compliance with the International EPD® System General Programme Instruction of the International EPD® System. The EPD will be officially registered after the publication of the document containing the Product Category Rules for that product class (the product is an oil-immersed transformer and as such is part of a subgroup of category *UN CPC 46121 Electrical transformers).* The previous PCRs were as a matter of fact expired as they had been registered in 2000 and de-registered since 2013 (www.environdec.com).

The importance of this experience of green design applied to private business lies in many factors, as already showed:

- the product studied is one of the first high power HV/MV transformer with vegetal oil on the market;
- the study of the sustainability assessment of such a product (and its publication through the EPD) is a pioneering one;
- it represents a green design example in a traditional sector and applied to a traditional and mature product, but which contains a great "improvement" potential affecting global market, due to its relevant dimensions and its essential function.

2. The "green" transformer

Figure 1: Tamini "green" transformer (ATR 15T037)

The product - the "green" 250 MVA autotransformer (Figure 1) - is an innovative environmentally sustainable and eco-efficient product, insulated with ester oil, and which commits to preserve environment and health, providing:

- an increase in the transformer life due to a longer life of the inside cellulose based insulation;

- a limited pollution risk (in case of spillage or loss, or during operation, installation and end-of-life phases) because ester oil is biodegradable and less toxic;
- a greater safety (toxicity and anti-fire), because ester oil has a higher flash point (more than double than the mineral oil one). This practically reduces to zero the fire ignition possibility due to a fault;
- a potential strong reduction of the site construction related impact (smaller distances between transformers and no longer indispensable collection tank, even if still required by legislation);
- an improvement of the efficiency and of the environmental performance, the power being equal.

3. Material and methodology

The LCA study presented in this document is a complete and detailed product LCA, as defined in the ISO standards. It is important to notice that input data and results exposed in this paper do not coincide exactly to those shown in the EPD, as the functional units and the system boundaries considered are different.

3.1. Goal and scope definition

The aim of the study was to evaluate the environmental impacts of an HV/MV transformer insulated with an innovative bio-material. The assessment was essentially conducted for external purposes, with green marketing goals. Accordingly, this policy led to the development of the EPD.

The study was performed in accordance with the methodology defined by the ISO standards (ISO 14040:2006, ISO 14044:2006) and adopted the “from cradle to grave” perspective. Accordingly, the analysis includes raw materials and components production, their transports and assembly, the use phase for an average lifetime at a certain load and at a certain efficiency, with the necessary ordinary and extra-ordinary maintenance, ending with the transformer dismantling and disposal.

3.1.1. Functional unit

The function of the system is the HV/MV transformation of a 250 MVA power at operating voltages of 400/135 kV. The functional unit adopted is therefore the life of a 250 MVA power transformer insulated with vegetable oil for 35 years of useful life (average life) at an average load of 70%.

3.1.2. System boundaries

The study uses the “from cradle to grave” perspective; therefore, it considers upstream, core and downstream phases (Figure 2).

The upstream phase includes components supply, namely their production, manufacturing and treatments. The core phase includes the following processes: components transport to the assembly site, transformer assembly at the factory, assembly factory consumptions and wastes; tests during the assembly and partial disassembly processes (the latter, in order to be sent to the operation site). The downstream phase includes the distribution, the use phase and the end-of- life. Distribution process considers the transformer transport - with its packaging - to the use site, and its installation. Use phase consists of losses related to the operation and functioning during the product average life, the ordinary maintenance and extraordinary maintenance. The end of life includes transformer dismantling and its subsequent disposal.

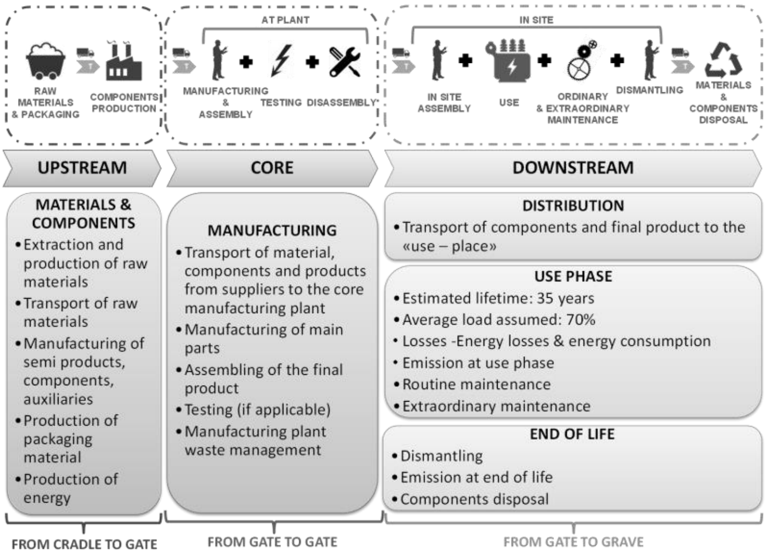

Figure 2: System boundaries

Other relevant boundaries are linked to time and place. The reference year for primary data is 2016. The geographical boundaries considered are different for phases: global for the upstream, Italian for the core, Italian for the downstream. The national one is just a possible downstream scenario - related to a real case study - but the company is selling worldwide; other geographical scenarios, although feasible, were not presented for brevity reasons.

3.1.3. Data quality

According to their quality level and to the source, the primary (and site specific) data used to perform this LCA study are those referred to: inputs and outputs of the assembly site (water, gas, electricity, waste, work force); timing and absorptions of the assembly activities; tests features; year detailed production; components detail, masses, materials and origins; production and treatments processes; packaging quantity and type; transformer destination; ordinary and extraordinary maintenance activities; disposal at end of life.

3.1.4. Study assumptions

The end-of-life scenarios of the materials to be disposed have been defined according to the national statistics (ISPRA, 2017).

The phase of raw materials transport from the place of extraction to the components production sites has been accounted for by using secondary data including general transport scenarios; for some minor flows these data were unavailable, then were excluded from the system boundaries.

3.1.5. Allocation rules

The allocation was necessary because in the reference period other transformers were produced in the plant. The applied allocations are based on physical quantities. The variable used to allocate total consumptions, wastes and packaging is the percentage corresponding to the green transformer power (250 MVA) compared to the total power produced in the reference year. The allocation used for energy absorption of manufacturing phase refers to the production worked hours with respect to the total working hours of the plant in the reference year.

A system expansion was considered to account for avoided products due to end of life recycling.

4. Life Cycle Inventory Analysis

The inventory analysis consists in the identification and quantification of data related to energy, water, flows and emissions into the environment for every phase of the life cycle of the system. The total weight of the "green" transformer (upstream phase) is around 220t, distributed among the components and materials listed in Table 1.

Table 1: Inventory analysis for components (left) an for materials (right)

Component	Weight	
	kg	%
Core	71610	32,09%
Oil filling	60700	27,20%
Tank assembly (Tank, Cover, Conservator,..)	40800	18,28%
Windings	24600	11,02%
Frame	7040	3,15%
Winding insulation	5400	2,42%
Fans	5292	2,37%
Magnetic shields	2170	0,97%
RIP Bushings HV	2100	0,94%
Connections supports	660	0,30%
Insulation frame/core	633	0,28%
Connections braidings	570	0,26%
Tap changer	555	0,25%
Handrail & gratings	500	0,22%
RIP Bushings MV	420	0,19%
RIP Bushings neutral	65	0,03%
Gaskets	50	0,02%

Materials	Weight	
	kg	%
Ferrosilicon	73672	33,01%
Soybean oil	60700	27,20%
Steel	51691	23,16%
Copper	24785	11,11%
Cellulose	3743	1,68%
Wood	2052	0,92%
Alluminium	1814	0,81%
Paper	1052	0,47%
Epoxy resin	837	0,38%
Fiberglass	738	0,33%
Polyester resin	480	0,21%
Plastic	372	0,17%
Iron alloy	342	0,15%
Glue	291	0,13%
Cast iron	176	0,08%
Insulating foam	171	0,08%
Silicone	129	0,06%
Electric camponents	71	0,03%
Rubber	50	0,02%

As it deals of an LCA of an high energy consuming product, energy plays a relevant role in the impact assessment; for every energy absorption of this life cycle, the reference was the Ecoinvent profile related to the Italian energy mix ("Electricity, high voltage {IT}| market for | Alloc Rec, U"). A relevant part of the impacts, as shown later, is due to energy losses during the transformer life-time, as assessed according to legislation limits and carried out taking into account impacts generated by the production of the electricity required to offset them.

5. Impact Assessment

This LCA study was performed using the SimaPro 8.0.5 Software. The source of eco-profiles of the materials is the Ecoinvent database (also available in the SW itself).

The environmental impacts were assessed using the multi-category method "Recipe Midpoint Hierarchist / Europe (v1.12). This method links the inventory analysis results to 18 impact categories, so it covers a broad category range. In addition, the energy assessment ("Cumulative Energy Demand" method, v.1.09, CED) and the system CO_2 content ("Greenhouse Gas Protocol" method, GGP) are presented.

The results of the environmental analysis are integrated with a simplified economic assessment. The Environmental LCC is based on the same model, system boundaries, functional unit, on the product whole life cycle as the LCA. Both the assessments are performed through the SimaPro SW; a specific method ("LCC, v.1") and database was built on puropose. To evaluate a product life cycle costing (Hunkeler et al., 2008) some costs (maintenance) needed to be updated to their net present value ("values discount").

6. Results

6.1.1. LCA Output

Almost all the categories, as shown in Table 2, are dominated by downstream phase, except "marine eutrophication" and "metal depletion", in which the upstream phase prevails, due to the production of the components, for the significant amount of metals involved). The use phase is far and wide dominant in the other considered categories, because of the impacts generated by the production of the electricity - necessary to compensate the losses - through the considered mix.

The core phase is almost always negligible, with the exception of the two categories linked to aquatic ecotoxicity, "freshwater ecotoxicity" and "marine ecotoxicity", due to the waste disposal processes impacts of some waste generated in the assembly plant.

Lastly, the end-of-life phase gives a negative contribution in all impact categories except those connected to aquatic toxicity. The "positive" effects of this phase are attributable mainly to the processes of recycling and reuse of materials.

According to the CED method assessment (Table 3), in each considered phase the non-renewable energy content prevails; however, the use of a biological fluid instead of one from fossil source causes enhances the renewable energy content.

Analogously, the content of CO_2 stored in the "green" system increases (Table 4) moving from the traditional transformer to the "green" one. Therefore the green transformer has a good CO_2 storage capacity (the amount of carbon dioxide stored in the system for its useful life represents an equivalent amount of CO_2eq seized from the environment for a significant number of years, 35). In addition, there is an increase in the ratio "stored CO_2eq" on "emitted CO_2eq".

Table 2: Detailed contributions of the "green" transformer life phases to ReciPe impact categories

Impact Category	M.U.	Total	*Upstream*		*Core*		*Downstream*	
Climate change	kg CO2 eq	6,4E+07	9,3E+05	*1,5%*	1,1E+05	*0,2%*	6,3E+07	*98,4%*
Ozone depletion	kg CFC-11 eq	8,4E+00	5,4E-02	*0,6%*	1,5E-02	*0,2%*	8,4E+00	*99,2%*
Terrestrial acidification	kg SO2 eq	2,4E+05	5,1E+03	*2,1%*	4,5E+02	*0,2%*	2,3E+05	*97,7%*
Freshwater eutrophication	kg P eq	1,0E+04	1,0E+03	*10,1%*	1,2E+01	*0,1%*	9,2E+03	*89,8%*
Marine eutrophication	kg N eq	8,4E+03	7,6E+03	*91,2%*	1,5E+01	*0,2%*	7,2E+02	*8,6%*
Human toxicity	kg 1,4-DB eq	9,4E+06	1,6E+06	*17,1%*	1,4E+04	*0,1%*	7,8E+06	*82,7%*
Photochemical oxidant formation	kg NMVOC	1,4E+05	3,8E+03	*2,7%*	3,5E+02	*0,2%*	1,4E+05	*97,1%*
Particulate matter formation	kg PM10 eq	7,4E+04	3,2E+03	*4,3%*	1,5E+02	*0,2%*	7,1E+04	*95,5%*
Terrestrial ecotoxicity	kg 1,4-DB eq	2,3E+03	6,7E+02	*29,6%*	7,9E+00	*0,4%*	1,6E+03	*70,0%*
Freshwater ecotoxicity	kg 1,4-DB eq	3,4E+05	4,2E+04	*12,5%*	1,7E+04	*4,9%*	2,8E+05	*82,6%*
Marine ecotoxicity	kg 1,4-DB eq	3,0E+05	4,1E+04	*13,7%*	1,4E+04	*4,7%*	2,5E+05	*81,6%*
Ionising radiation	kBq U235 eq	1,1E+07	9,1E+04	*0,8%*	1,3E+04	*0,1%*	1,1E+07	*99,0%*
Agricultural land occupation	m2a	1,5E+06	5,8E+05	*38,5%*	1,7E+03	*0,1%*	9,3E+05	*61,4%*
Urban land occupation	m2a	2,1E+05	1,4E+04	*6,7%*	1,1E+03	*0,5%*	1,9E+05	*92,8%*
Natural land transformation	m2	9,7E+03	9,3E+02	*9,6%*	2,2E+01	*0,2%*	8,8E+03	*90,2%*
Water depletion	m3	4,3E+05	1,7E+04	*4,0%*	6,9E+02	*0,2%*	4,1E+05	*95,8%*
Metal depletion	kg Fe eq	1,7E+06	1,4E+06	*84,6%*	1,5E+03	*0,1%*	2,6E+05	*15,4%*
Fossil depletion	kg oil eq	1,9E+07	1,9E+05	*1,0%*	3,4E+04	*0,2%*	1,9E+07	*98,8%*

Table 3: Contributions of the CED method

	Upstream		**Core**		**Downstream**		**Total**	
	MJ	*%*	MJ	*%*	MJ	*%*	MJ	*%*
Primary energy non renewable **PE-Nre**	9,89E+06	*68%*	1,68E+06	*92%*	9,80E+08	*87%*	9,92E+08	*87%*
Primary energy renewable **PE-Re**	4,57E+06	*32%*	1,48E+05	*8%*	1,43E+08	*13%*	1,47E+08	*13%*
Total	1,45E+07	1%	1,83E+06	0%	1,12E+09	99%	1,14E+09	

Table 4: Contributions of the GGP method

Impact category	**M.U.**	**Total**	**Upstream**	**Core**	**Downstream**
Total	kton CO_2	63817,2	703,6	117,5	62996,1
Fossil CO2 eq	kton CO_2	63502,9	749,9	109,7	62643,3
Biogenic CO2 eq	kton CO_2	1324,8	56,1	8,9	1259,8
CO2 eq from land transformation	kton CO_2	6,7	169,0	0,0	-162,2
CO2 uptake	kton CO_2	-1017,1	-271,3	-1,1	-744,7
% (uptake/emissions)	%	*1,6%*	*27,8%*	*0,9%*	*1,2%*

6.1.1. LCC Output

According to the LCC method, the predominant economic impact is due to electricity costs (67,8%), whose main contribution comes from the energy consumption necessary to compensate the losses in the use phase, in line with the LCIA results. Other quantitatively major contributions are components (22,1%) and personnel (9,7%) costs.

7. Conclusions

The study presented the results of an integrated environmental and economic analysis on a high energy consuming traditional object, remanufactured in an "eco-friendly" way. The results locate the main impacts – both economic and environmental – on the use phase, due to the energy consumptions necessary to compensate the transformation losses. In conclusion, the work demonstrates that there is room also for green design on market-mature and traditional products with positive consequences on their environmental performances.

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Eco-design of wooden furniture based on LCA. An armchair case study

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Abstract

The European wooden furniture industry is currently more and more involved in enhancing the sustainability of its products. In this context, this paper analyses the case study of a wooden armchair currently on the market, with the aim of defining some eco-design solutions able to improve its environmental profile. The Life Cycle Assessment (LCA) method is employed to identify processes and materials majorly responsible of the armchair impacts. Three integrated solutions are here proposed: the use of local wood, the substitution of urea-formaldehyde resin with soya-based adhesive and the substitution of foam cushion filler with poplar cotton. Through a second LCA it emerges that these solutions can significantly enhance the armchair sustainability. Beyond the specific armchair case study, the eco-design solutions here proposed can be applied to other wooden furniture with similar supply chains.

1. Introduction

The furniture industry is an important sector in Europe, employing around 1 million workers and being the world leader for high-end segment (EU Commission, 2013). The European furniture sector is nevertheless currently facing a strong and increasing competition from overseas competitors, having low production costs. In response to the high competition, but also to the recent European Environmental policies and to the increase of consumers awareness toward environmental issues, the EU furniture industry is currently focusing the attention to the reduction of potential impacts caused by its products.

In order to assess the sustainability of furniture, a high number of ecolabels have been developed. Among the most recognised ecolabels that certify the environmental excellence of products, there is the European Ecolabel, whose logo is the well-known flower. As far the furniture product category is concerned, the ecological criteria for the award of the EU Ecolabel have been reviewed by the European Commission in 2016 (EU Commission, 2016). Specific criteria have been published for wood, cork, bamboo, rattan, plastics, metals, textiles, leather, coated fabrics, polyurethane foams, latex foams and glass. Moreover, restrictions have been introduced for limiting the presence or the emission of hazardous substances, such as formaldehyde and VOCs. Formaldehyde can therefore cause respiratory problems and irritation to eyes, nose and throat (McGwin et al., 2010) and it has been classified as a human carcinogen by the International Agency for Reaserach on Cancer (IARC) in 2004. Formaldehyde is often present in composite wooden products that are made with urea-formaldehyde resin. Moreover, varnishes, paints, primers, wood stains, biocidal products (such as wood preservatives), flame retardants, fillers, dyestuff are potential sources of VOCs and toxic gas release. Finally, beyond the human toxicity, the different materials employed in wooden furniture industries (necessary, for example, to produce upholstery, wheels, hinges, etc.) could have more or less significant potential environmental impacts depending on their specific supply chain.

Therefore, furniture industries interested in minimising environmental impacts of wooden furniture should start from the design conception and study the product with a Life Cycle approach. Different research groups have focused on wooden furniture ecodesign: Lähtinen et al. (2014) identified ecological criteria to be applied to Scandinavian wooden furniture industries; Gonzales-Garcia et al. (2012) proposed strategies to mitigate the main environmental impacts detected in the material stage, production and use of wooden furniture; Mestre and Vogtlander (2013) describe how sustainable furniture can be produced with cork, which is a natural, recyclable, renewable and non-toxic material.

In this context, the aim of this paper is to contribute to define eco-design solutions for the wooden furniture industry. To this purpose, a wooden armchair currently on the market has been taken as case study and it has been analysed through a Life Cycle Assessment (LCA) to identify the main environmental impacts and the related sources. Alternative more sustainable materials are then proposed in substitution to the elements causing the major impacts, without modifying the esthetical and geometrical characteristics of the armchair.

2. Methodology

A Life Cycle approach has been applied to identify eco-design solutions able to enhance the environmental profile of the armchair chosen as case study.

The wooden armchair has been assessed with a Life Cycle Assessment (LCA) developed according to the indications given in the ISO 14040-44 standards and in the ILCD (International Reference Life Cycle Data System) Handbook (EU Commission, 2010).

The Functional Unit is 1 armchair and the system boundaries include materials, energy and emissions involved in the production of the armchair components, the related transportation and the final assembly till the factory gate (from-cradle-to-gate analysis). The producer provided primary data on the origin of the armchair components and on their physical and geometrical characteristics. Secondary data from Ecoinvent v2.2 database and from scientific literature were employed for background data of components production.

The Life Cycle Impact Assessment (LCIA) has been carried out with ReCiPe Midpoint (H) method, focusing in particular on the impact categories of climate change, fossil depletion, human toxicity and ozone depletion. Climate change category has been chosen because it is the most worldwide recognised impact category connected to the international low-decarbonization strategies. Moreover, together with ozone depletion, the robustness of the related impact methods is confirmed by the extensive scientific consensus on the respective characterisation factors. Human toxicity has been chosen in reason of the considerations made in the Introduction paragraph, while fossil depletion was analysed because of the presence of some petroleum-based armchair components.

From the interpretation of the LCIA results, the materials and processes majorly responsible of the impacts were identified. With the aim of enhancing the environmental performances of the armchair, possible alternative solutions were studied. The eco-design phase took into account materials and products already available in the market, as well as processes investigated by the scientific literature. The solution proposals have been checked with a further LCA and impact results of the enhanced armchair were compared with the standard one.

3. Case study: the armchair

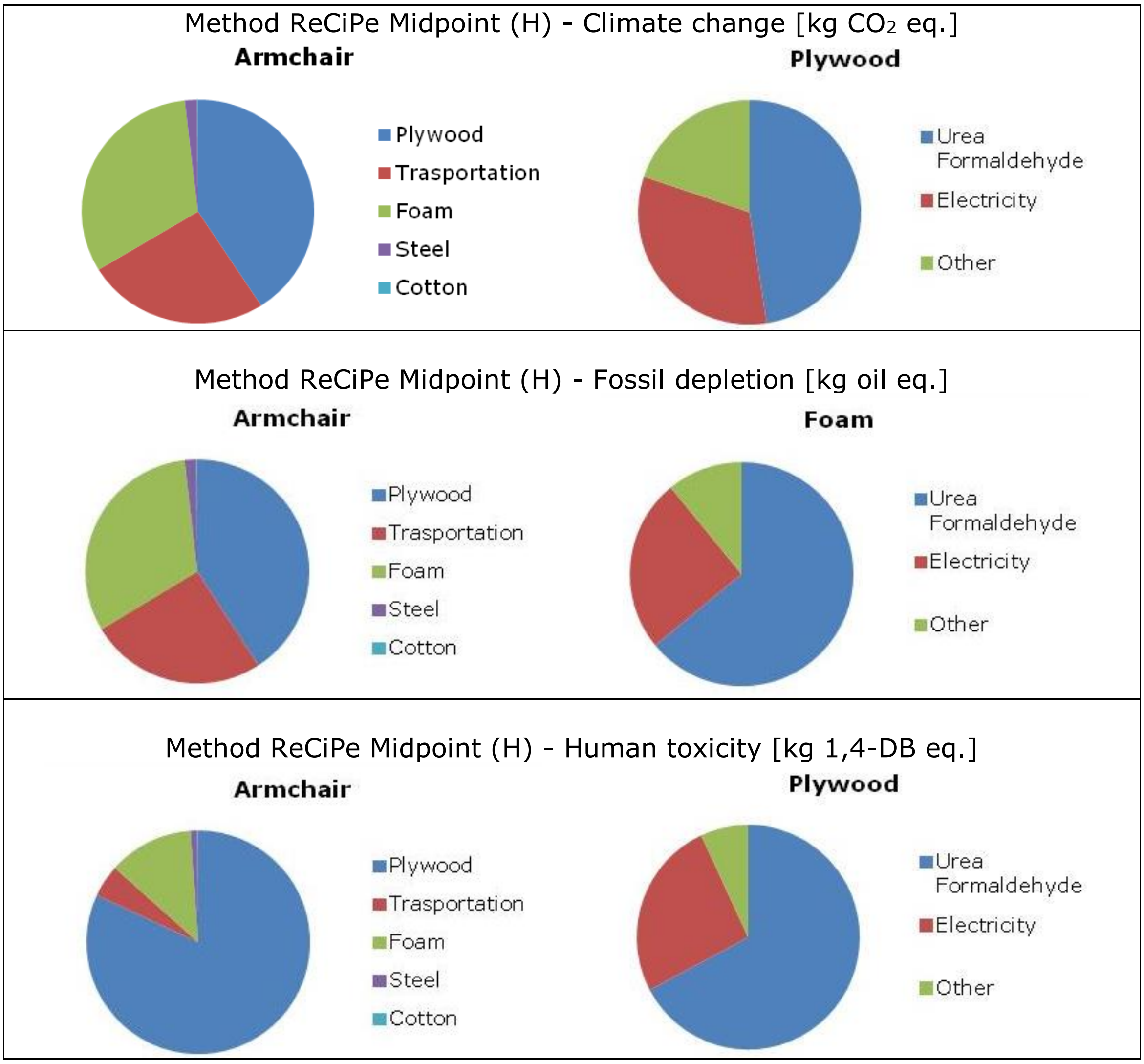
The case study is a wooden armchair (Figure 1) produced by an architectural and design studio located in Turin (northern Italy). The armchair is obtained from a sheet of birch plywood having dimensions of 1525x1525x15 mm^3. The plywood contains formaldehyde resin and it is produced in St. Petersburg (Russia) and transported to Italy with a lorry. The armchair cushion is made with foam rubber filler and cotton upholstery. Finally, a steel bar supports the backrest.

Figure 1: Case study armchair

The inventory is showed in Table 1: input/output quantities are primary data provided by the design studio, while datasets from Ecoinvent v2.2 database were employed for the processes of transportation and for the production of plywood, foam and steel. As it can be noticed from the graphs showed in Figure 2, for all the analysed impact categories, the higher impacts are related to the formaldehyde contained in the plywood, to the foam production and to the transportation of plywood from Russia to Italy. These results are in line with similar studies in the wooden furniture field.

Table 1: Input/output table related to the production of 1 armchair

Input	Quantity	Unit of measure	Reference process
Plywood	0.02590	m^3	ecoinvent2.2/wooden materials/extraction/plywood indoor use at plant - RER
Transport with Lorry	47219	kg*km	ecoinvent2.2/transport system/road/lorry 16-32t EURO 3 - RER
Foam	2	kg	ecoinvent2.2/plastics/polymers/polyurethane flexible foam at plant -RER
Steel	0.401	kg	ecoinvent2.2/metals/general manufacturing/average metal working - RER
Cotton	0.002	kg	ecoinvent2.2/textiles/production/woven cotton at plant - GLO
Output	Quantity	Unit of measure	
Armchair	18.973	kg	-



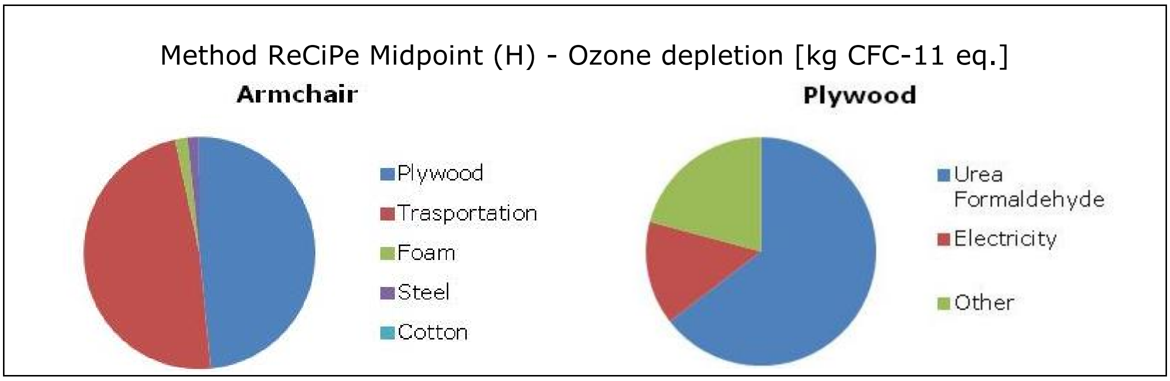


Figure 2: Impact contribution of materials and processes related to the standard armchair supply chain

4. Eco-design solutions

From the LCIA results, it comes to light that to enhance the armchair sustainability it is necessary to identify design solutions able to avoid the use of formaldehyde in the plywood production, minimise the transportation and provide alternative materials for the cushion filler. For each of these three goals this paper proposes a possible solution, hereafter described.

4.1 Local wood

Since the armchair final assembly takes place in Turin (Piedmont, northern Italy), the impacts due to plywood transportation could be highly minimised employing a local plywood. The wood industry in Piedmont has a long tradition and it still represents an important production activity; according to the last statistics of Regione Piemonte (2006), the total wood production is of 215000 m^3 and about 50% comes from poplar plantations. Poplar wood has a lower density than birch wood and it has good mechanical properties to bending and tensile strength, which allow this wood to be used for many different purposes, included furniture production.

Beyond the significant environmental benefit due to the avoidance of long-distance transport, a short supply chain would also enhance the local economy and resources.

4.2 Soya-based adhesive

Urea-formaldehyde (UF) resins employed for the plywood production could be replaced by an alternative, formaldehyde-free adhesive. Soy protein-based adhesives were used from the 1930s (Liu, 1997), but since the World War II period they have been replaced by petroleum-based adhesives, that provided higher water resistance. Currently, restrictions on formaldehyde emissions bring back the soy adhesives, which have been object of research and industrial developments to provide a product that performs as well as UF resins.

Huang and Li (2008) and Zhu and Damodaran (2014) studied chemical processes able to provide soy flour (SF)-based adhesives that improve strength and water-resistance of plywood panels. The process for producing this adhesive takes place with chemical phosphorylation of SF (PSF), using $POCl_3$ as the phosphorylating agent. Therefore, since this method replace petroleum-derived elements with abundant, renewable and inexpensive soy flour, it could represent a valiant solution to increase the sustainability of plywood.

4.3 Poplar cotton

The armchair cushion, currently produced with foam rubber, should be replaced with a renewable, non petroleum-based material. Since as described in paragraph 4.1, poplar is a diffused resource in the Piedmont area, it is here proposed the use of poplar cotton. This latter is obtained from poplar seed hair fibres, which are harvested from the poplar seed pods and then ginned. Poplar cotton is used since XIX century as filler for cushions and despite nowadays it has not a wide market, it is still employed, especially in North America, for the production of cushions, mattresses and as insulating material. Therefore, according to Chen and Cluver (2010), poplar seed hairs have a higher fill power (defined as fibre volume per unit of mass) than both down and wool.

5. LCA comparison between standard and enhanced armchair designs

A LCA has been developed considering the production of the same armchair with local plywood produced with soy-based adhesive and with a cushion made of poplar cotton. The steel bar and the cotton upholstery of the cushion remained unchanged; since poplar plantations are located in Piedmont, a transportation of 50 km with lorry has been estimated. Process data were found in literature, while for background processes the Ecoinvent v2.2 database was used. ReCiPe Midpoint (H) method has been employed to calculate the impact of the armchair produced with the proposed eco-design solutions.

A comparison between the standard and the proposed designs of the armchair has been carried out. Table 2 shows the absolute values obtained for the four analysed impact categories. Since the lifetime of the armchair is estimated to be shorter than 100 years (that is the time horizon of the chosen method for the climate change impact category), the biogenic carbon stocked by wood plantations is not calculated. Therefore, the treatment that the armchair will undergo at its end-of-life will presumably cause the release of the CO_2 stocked during the plant growing to the environment.

Graph in Figure 3 shows the role of each choice in the reduction of impacts for the four analysed impact categories; it is therefore compared the contribution of the two types of plywood (respectively with formaldehyde and soya-based adhesive), of wood transportation (respectively from Russia and within the

Italian region of Piedmont) and of the cushion filler (respectively made of foam and poplar cotton).

From Table 2 and Figure 3 it clearly emerges that the new design solutions generate significant environmental benefits.

Table 2: LCIA results related to the armchair with standard and new proposed design

Impact category	Standard armchair	Proposed armchair
Climate Change [kg CO_2 eq.]	32,06	4,81
Fossil depletion [kg oil eq.]	11,87	1,38
Human toxicity [kg 1,4-DB eq.]	2,96	1,85
Ozone depletion [kg CFC-11 eq.]	2,84E-06	4,26E-07

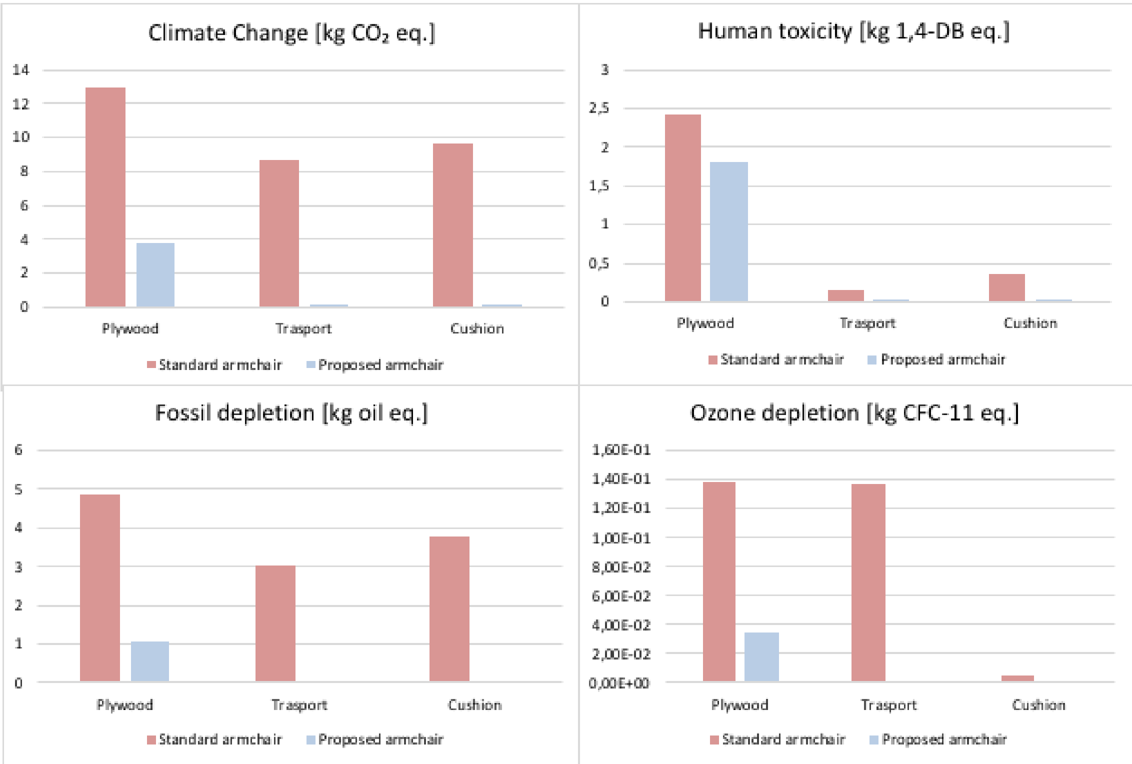


Figure 3: Comparison of environmental impacts for each of the three variants analysed for the new armchair design

6. Conclusions

The study presented in this paper aims to identify possible eco-design solutions to increase the environmental profile of a wooden armchair currently on the market. LCA has been employed to identify materials and processes causing the major environmental impacts (with reference, in particular, to climate change, fossil depletion, human toxicity and ozone depletion impact categories). From this analysis it emerged that the highest impacts contribution comes from the use of urea-formaldehyde resins in the plywood production, from the long-distance transport of wood and from the use of foam rubber as cushion filler. Subsequently, solutions able to avoid or reduce the impacts have been studied and proposed. The actual benefit has been checked through a comparative LCA between the standard and the enhanced armchair designs. This evaluation confirmed that the use of local wood, together with the substitution of urea-formaldehyde resins with soy-based adhesive and of foam rubber with poplar cotton, lead to a significant enhancement of the armchair sustainability. The developed LCA presents some limits, mainly due to the unavailability of primary data for the armchair components production. Nevertheless, the main focus of this study was not the quantification of the specific impacts values of the armchair, but rather the identification of solutions able to improve the global environmental performance. Moreover, beyond the specific case study, this paper aims to contribute to the identification of eco-design solutions to be applied also to analogous supply chains of wooden furniture.

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Life Cycle Thinking in online accommodation booking platforms: making a more sustainable choice

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Abstract

The rise in tourism arrivals and the need for the achievement of sustainability goals have also caused an ever-growing attention towards sustainable tourism. Recently, online platforms and tour operators have become one of the most common means of booking in tourism and they can play an important role for the promotion of sustainable tourism. The objective of this paper is to identify to what extent and how the concept of sustainability can be integrated within these websites and whether this has already been done. Additionally, a set of life-cycled-based indicators is aimed to be identified or proposed for the selection of sustainable accommodation within these websites. Tourists would therefore be assisted when it comes to choosing the most sustainable option of accommodation, in the same way as they can already do today when selecting the most convenient fare or the most suitable location and features.

1. Introduction

Recently, tourism arrivals reached a total of 1,322 million worldwide in 2017 (UNWTO, 2018) and they are expected to increase by 3.3% a year between 2010 and 2030 to reach 1.8 billion by 2030 (UNWTO, 2017a). Furthermore, the need for achieving the sustainability goals has also caused an ever-growing attention towards sustainable tourism. Recently, online platforms and tour operators have become one of the most common means of booking in tourism (Dutta and Manaktola, 2009). Although most of sustainability challenges depend on human behaviour (Baddeley and Font, 2011), it is this behaviour that can be aided and guided when it comes to making the right choices -a "nudge" as described by the Nobel laureate Thaler (Thaler et al., 2014)-, e.g., selecting an environmentally friendly or so-called "green" hotel through the interface of an online booking platform.

Most of the sustainability-related impacts in tourism take place throughout the supply chain of a tour operator (Schwartz et al., 2008). Life Cycle Assessment (LCA) is a robust and standardised methodology that follows the concept of Life Cycle Thinking and helps evaluate the environmental impact of goods and services throughout their supply chain. This can also be of help to select the most environmentally sound choice between two or more options (ISO, 2006). Tourism is one of the sectors where LCA has been increasingly studied by the scientific community (De Camillis, 2010). This is also because tourist activities can be considered as a global power towards a local economic development, particularly for some regions of the world (Hsieh and Kung 2012; Rizzi and Graziano, 2017). Finally, there is a great number of eco-labels in tourism (De Camillis, 2010), which can be somehow confusing for the final users.

This paper builds on previous research (Raggi et al., 2018) and has a twofold objective. One aim is to identify to what extent and how the concept of sustainability can be (or has already been) integrated within accommodation booking websites. Additionally, even though the identification or proposal of sustainability indicators for the tourism sector is quite common (see, for example, Agyeiwaah et al., 2017), an attempt will be made here to identify a set of life-cycle-based indicators for the selection of environmentally-sound accommodation within these websites.

This paper is structured as follows: in Section 2 the methods and strategies for the analysis of this study are described in detail. In Section 3 the results obtained are presented and discussed. Finally, some conclusions are drawn in Section 4.

2. Materials and Methods

The first objective required the identification of the extent and the way the concept of sustainability can be integrated within online booking websites and whether this process has already started. This was addressed by means of a literature review and via the analysis of the websites, as it will be described hereafter.

A literature review was performed in order to identify whether the concept of sustainability has been tackled so far by online booking platforms and tour operators. This was carried by searching the Scopus and WebOfScience databases. The keyword combinations used for the literature search included: ("online booking" OR "online platform") AND ("hotel*" AND "accommodation" AND hospitality") AND ("sustainab*" OR "environmen*"); and ("online platform" OR "tour operator*") AND "sustainab*", in the fields of article title and abstract. The results were then evaluated with regard to their relevance to the topic. The screening resulted in 8 scientific contributions. The results of the literature review are presented in Section 3.1.

The second part of the analysis concerned the online booking platforms. The aim here was to explore whether the existing platforms have somehow incorporated the concept of sustainability. Initially, a set of platforms had to be identified from the vast number of existing ones. This was performed through a selection procedure. The hypothesis made was that in order to depart for an overnight trip one needs to book for an accommodation; thus, the number of visits to online booking platforms is assumed to be related to the number of trips. Based on the available statistics, the number of trips for each country of the world was calculated as the sum of the domestic trips of overnight visitors (UNWTO, 2017b) and the departures from the country of usual residence to any other country (World Bank, 2017), for 2015. The results showed the countries with the most trips[12], which included (in order of magnitude): India, Japan, Germany, France, United Kingdom, Spain, Canada, South Korea, Australia, Poland, Turkey, Italy, Saudi Arabia, Netherlands, Finland, Argentina, Hungary,

[12] The databases do not always provide data for all countries of the world. In this study, the analysis was performed for the countries for which there was available data.

Czechia, Romania, Chile, Austria, Switzerland, Belgium, Ireland, Venezuela, Ecuador, Greece, Georgia, Uruguay, Bulgaria, Croatia, Latvia, Lithuania, Slovenia, Estonia, Cyprus, Armenia, Swaziland, Luxembourg, Zimbabwe, Belarus, Malta, Moldova, Tajikistan (Raggi et al., 2018). The ones that cumulatively made up a percentage of more than 80% of the total trips were considered (India, Japan, Germany, France, United Kingdom, Spain, Canada, Australia, Poland and Turkey)[13].

Then the most visited websites for online accommodation booking for the previously identified countries were identified. This was accomplished using a research service for online marketing (Semrush, 2018), through the search option for competitors for one of the platforms[14]. This provided detailed results for the traffic (number of visits) of online booking websites performed through the Google research engine for all the selected countries. Once the various traffic-related visits were summed up, the 10 most visited websites were identified (Booking, 2018; Cleartrip, 2018; Etstur, 2018; Expedia, 2018; Holidaycheck, 2018; Hotels, 2018; Kayak, 2018; Makemytrip, 2018; Tripadvisor, 2018; Trivago, 2018).

In the third step, the selected websites were analysed in order to identify whether they had included the concept of sustainability. This was performed by (a) visiting the websites and trying to perform a test search for accommodation; and (b) searching in the web (by using the Google search engine) for sustainability-related issues regarding those websites. As far as (a) is concerned, the procedure included a search for the keywords “sustainable”, “sustainability”, “environment” or “green” in three different phases of a normal booking process, that is: i) the home page of the website; ii) the page with the resulting list of accommodation proposals[15]; iii) the page of selected accommodation. Regarding (b), the search was conducted to understand whether the specific platforms were somehow involved in schemes, promotions or awards concerning sustainability issues. The results of this analysis are presented in Section 3.2.

The second objective of this study was to identify whether any life cycle-related indicators could be identified for the sector. This was performed via another review of the scientific literature. As with the first review, this was carried out searching the Scopus and WebOfScience databases. The used keyword combination included: “indicator*” AND “life cycle” AND “environment*” in the field of article title; and “indicator*” AND (“LCA” OR “Life Cycle Assessment”)

[13] The initial list included South Korea instead of Poland and Turkey. However, no data were found regarding the Korean internet traffic towards the various online booking platforms. For this reason, this country was substituted by the next ones in the classification, until the 80%-trip minimum threshold was reached.

[14] The cited service compares different competitor websites in terms of their common keywords. This was done in order to include all possible online booking platforms for each country (both local and international) and not to be limited to a list of platforms that would have been set *a priori*.

[15] During the test search performed, the same destination city (Rome) and days of overnight stay (November 11th to November 12th, 2017) were selected for all websites.

AND ("touris*" OR "accommodation") in the fields of article title and abstract. The results were then evaluated with regard to their relevance to the topic. The screening[16] resulted in 6 papers, which are presented in Section 3.3.

3. Results and Discussion

3.1. Literature review on sustainability and online booking platforms and tour operators

The review on whether sustainability has been tackled so far by online booking platforms and tour operators (see Section 2) resulted in 8 scientific contributions: seven journal articles (Schwartz et al., 2008; Sigala, 2008; Dutta and Manaktola, 2009; Baddeley and Font, 2011; Nicoli and Papadopoulou, 2017; Ponnapureddy et al., 2017; Tasci, 2017) and one book chapter (Hamid and Isa, 2017).

A general result to be highlighted is the scarcity of the findings. Indeed, none of the reviewed papers reports any case of online booking platform having actually implemented sustainability issues. Nevertheless, some of the identified articles try to define what sustainable tourism actually is, as well as the importance of the online tour operators and booking platforms and in promoting it. Furthermore, the choice of a sustainable accommodation was found to be dependent on socio-demographic factors or be somehow unintentional/incidental (Ponnapureddy et al., 2017; Tasci, 2017). The practices towards a sustainable tourism development may require several approaches, such as Supply Chain Management (Schwartz, 2008; Sigala, 2008; Hamid and Isa, 2017) and Corporate Social Responsibility (Dutta and Manaktola, 2009; Hamid and Isa, 2017). Furthermore, the importance of the companies' awareness of their potential to promote (or not) sustainability issues is highlighted (Schwartz, 2008; Dutta and Manaktola, 2009). The issue of a sustainable Supply Chain Management (SCM) in tourism is stressed also from the difficulty a company may face when trying to persuade its external contractors or suppliers to gather and report all the necessary information (Sigala, 2008). Nonetheless, a successful sustainable SCM may be hindered by cultural and/or political issues affecting a country (ibid.). Moreover, the need for use of SCM sustainability indicators in the sector is underlined (Schwartz, 2008; Baddeley and Font, 2011; Hamid and Isa, 2017). Finally, since the customers' review schemes used by some online booking platforms were found to be able to determine the reputation of a hotel (Nicoli and Papadopoulou, 2017), they can be used ideally for the promotion of sustainable tourism.

3.2. Analysis of the identified booking platforms

The analysis of the identified online booking platforms (Section 2) was twofold. Firstly, the interface of the various websites was taken into account. A careful examination showed that in 8 cases out of 10, the platforms did not provide any information regarding the environmental-friendliness or sustainability) of the

[16] The screening process for the general review on life cycle indicators for the environment was performed for articles tackling this issue not limited to only one economic sector.

hotels, etc. This was identified both regarding the research filtres and within the selected accommodation solution as well as their home page. Only one of the websites provided the option to search for “green” accommodation. Nevertheless, this was not a direct option from the home page, rather a filtre that could be selected once the list of available hotels, hostels etc., had been obtained. Furthermore, once a “green” hotel had been selected, more information could be found on its platform-related webpage under a green leaf logo. This information was related to a hotel award scheme of the specific website, which will be described below. Finally, two of the platforms were found to be only available in languages other than English. The first one was in German and was evaluated; the second one was in Turkish and it was excluded from this analysis due to lack in understanding it. For a schematic representation of the results, please refer to Fig. 1.

The second part of the analysis included the search of sustainability-related issues for the identified websites. For four platforms no results emerged; two of them included dedicated pages on “green” accommodation, one specifically on “green” hotels and its own award scheme and the other on how to reduce one’s carbon footprint by donating money to an environmental promoter in India.

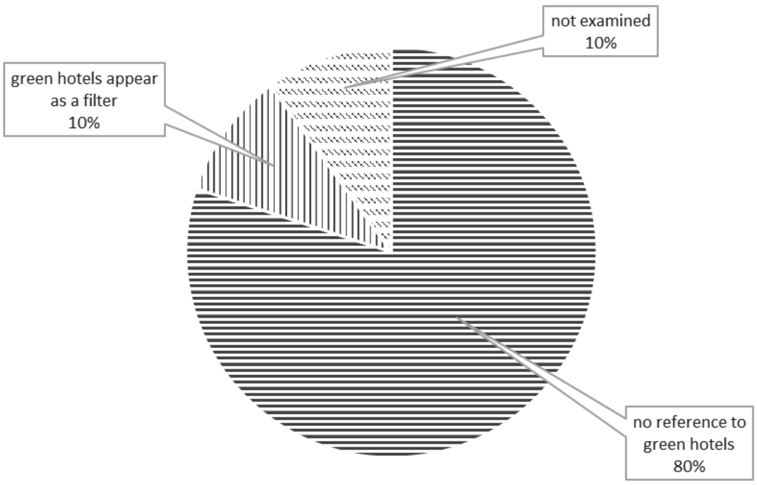

Figure 1: Green accommodation within online platforms

The award scheme of the first one consists of four badge levels: bronze to platinum. These are appointed in terms of a property’s level of participation in environmentally-friendly activities. The indicators used for these awards comprise energy efficiency, waste management, water use, purchasing, education of the public on these issues, innovation. A third site also had an environment-dedicated website, which did not appear to be working during this analysis. Finally, two websites had separate domains (e.g., blogs) related to sustainability issues and their promotion. One of them specifically promotes an accelerator programme for new start-ups to stimulate sustainable tourism. The other one specifically stresses the importance of some hotels’ sustainability initiatives.

However, once on the webpage of the hotel, no relevant information could be found whatsoever. For a schematic representation of the results[17], please refer to Fig. 2.

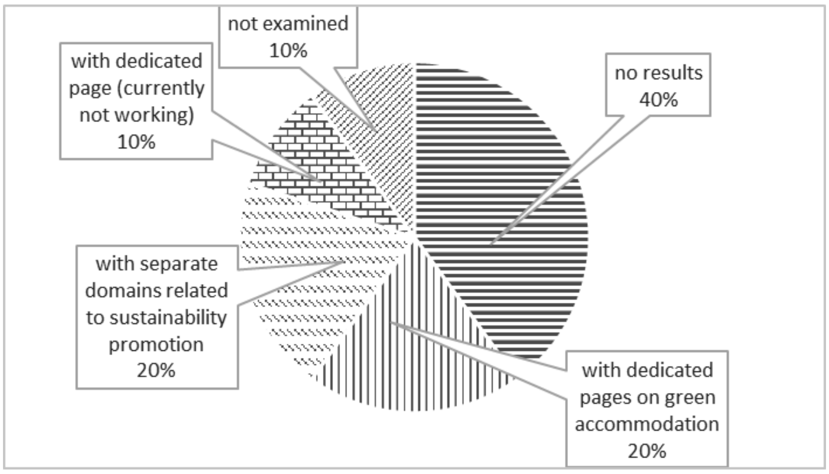

Figure 2: Sustainability-related issues of online platforms, e.g., awards, blogs etc.

3.3. Review on life-cycle indicators for tourism

The review on whether there were life cycle-related indicators that could be proposed for the tourism sector (Section 2) resulted in 6 scientific contributions, five journal articles and one PhD thesis.

It can be noted that this issue has been tackled with poorly so far. The screening procedure for this review provided a few articles, which however tackled the issue only marginally. Indeed, two articles (Kulkajonplun et al., 2016; Puig et al., 2017) actually propose sustainability-related indicators, e.g., loss of biodiversity, land management, atmospheric carbon emissions, energy use, and climate change. Kalbar et al. (2017) propose using a sum of indicators, e.g., accommodation, thermal energy, electricity, road transport, air travel, and food, or alternatively the use of a single indicator, i.e., carbon footprint (CF) for the residences (possible application to the tourism sector). The use of a single indicator (CF) is also proposed by Filimonau (2011). In this case, the proposed indicator is, indeed, life cycle-based. Finally, Michailidou et al. (2017) proposed the use of LCA along with Tourism Environmental Composite Indicator for a Defined Area of Concentrated Tourism, including energy-, water-, waste- and carbon footprint-related indices.

A general look at the use of environmental life-cycle indicators was made by Steinmann et al. (2016), who propose using a minimum number of indicators in a “one-size-fit-all” solution of 6 indicators: climate change, ozone depletion,

[17] During this search, another website came out that declared to promote “green” accommodation. Since it was not amongst the websites resulting from the selection procedure, it was not considered in Fig. 2, although it was still analysed. This website proposed a series of “green” solutions in the globe. On the hotel page, however, no additional information was provided regarding why a hotel was considered to be “green”.

acidification and eutrophication, terrestrial ecotoxicity, marine ecotoxicity and land use, accounting for 92% of the variance of the analysed product rankings. A restriction to 84% of the variance provides a set of 4 indicators (energy, water, land, materials). However, tourism was not explicitly cited.

4. Conclusions

This paper aimed at examining whether the concept of sustainability can be integrated within online accommodation booking websites and whether this process has already started. The literature review that was carried out showed that this issue has not been tackled with so far. An analysis of selected platforms confirmed this statement, with few exceptions where “green” accommodation was either proposed, via special webpages, filtres within the incorporated search engines or affiliated blogs, or awarded for the hotels that promoted it. Another objective was to try to identify life cycle-based indicators that could be suitable for the selection of environmentally-sound accommodation within these websites. This also resulted to be a poorly tackled issue. The promotion of a life-cycle indicator emerged only via the proposal of a single indicator or a set of indicators (for general use). Future developments would thus include the identification or the proposal of a set of indicators that would be suitable for the sector and helpful for users when booking online for accommodation to make more sustainable choices. Even though the concept of sustainability has been inadequately introduced in online booking platforms so far, there is still plenty of room for both its integration and dissemination. This article can be a basis for future tourists to help them select a more sustainable accommodation via online booking platforms, and thus reduce the overall environmental impact of the sector.

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Matching Life Cycle Thinking and design process in a BIM-oriented working environment

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Abstract

In the construction sector, the integration of life cycle approach and the implementation of the related methodologies are even more considered as a turning point to promote sustainability. To support Architectural, Engineering and Construction firms in life cycle design, a framework is proposed to implement Life Cycle Thinking in design process, according to different process' phases and empowering different actors. The framework is presented from the conceptual to the technical perspective, selecting Building Information Modeling as the most suitable tool currently spread in practice and able to handle the wide range of information required and the plurality of interactions between the actors involved. The outcome is a well-framed and organized set of life cycle data to orient decision-making process and enforce life cycle design for environmental but also wider (e.g. economic) purpose.

1. Introduction

Worldwide, the growing awareness of sustainability and environmental goals boosts the ongoing process of transformation and increasingly complexity of building sector, bringing out new pressure and more radical changing (Deamer and Bernstein, 2010; BCG, 2016). Indeed, while until a short time ago environmental targets were seen as constraints, today they are even more considered as a way to improve performance and increase competitiveness. For that reason, Architectural, Engineering and Construction (AEC) firms – as key actors jointly responsible for the built environment – are changing step by step the current practice (Dalla Valle et al., 2016). The transformation process involves all the firms' assets: tangible resources, such as materials, buildings, plant, equipment, tools, money; and intangible resources, such as knowledge, organization and intelligence of people (Sinopoli, 1997).

In this context, the integration of Life Cycle Thinking (LCT) represents a turning point to support sustainable practice, promoting environmentally-friendly strategies and business models. In fact, understood as a learning process, LCT helps to identify hotspots where actions are most effective and thus to improve resource efficiency with environmental, social and economic benefits (UN environment, 2017).

1.1. Life Cycle Thinking in design process

Actually, LCT is not so far established and embedded in design and construction practice. It represents a challenging task, due to the complexities of buildings, the wide range of requirements to be achieved and the plurality of practitioners and disciplines involved. Furthermore, it demands within the practice a shift both in thinking (first step) and in process (second step).

Indeed, during the design process, buildings should be considered not as objects, but rather as unique systems where each individual part affects and is in relationships with the others. Moreover, each part and in turn the building as a whole should be envisioned and designed keeping in mind their entire life cycle and not involving only the construction or use phase. In this way, products are evaluated in relation to the proprieties and performance provided as well as, for instance, in relation to the following hotspots: amount of material demanded, distance between factory and site, energy and water used for the installation, maintenance required, waste derived, reuse and recycle possibilities.

In addition, to face the complexities of buildings as systems and the amount of information and choices required during the decision-making, a shift in process is needed to change management in the way of participating. In our age of specialization, one person cannot address all buildings data and aspects: different competences must be involved, bringing their specific knowledge and interacting to look at the whole considering the entire life cycle. This requires not only an understanding that every building system is in relation with other systems and the surrounding environment, but it also demands a holistic process where everybody integrates their work rather than design their systems in isolation. For this reason, the challenge is twofold. Not only buildings need to be designed as systems, the design team itself need to function as a system (Boecker et al., 2009). In this way, all design members have to understand how the decisions undertaken by each affect the decision made by all other, with the aim to jointly design and achieve sustainable and high-performance buildings.

1.2. Life Cycle Thinking in design process within a BIM environment

As results, building sector demands a new process that encourages design teams and construction professionals to strengthen the two main tendencies in action. On one hand, the understanding of the building in a systematic way. On the other, the interaction with a much higher level of communication, collaboration and communication for reducing environmental impacts and costs. The advancement of technology certainly supports the transition of building sector in that direction, providing a wide range of tools to help practitioners in the enlightenment of buildings as systems and as parts of a larger system of its context (Boddy et al., 2007; Rezgui et al., 2011; Riese, 2012; Ortiz et al., 2009).

Moreover, Building Information Modeling (BIM) is even more adopted in AEC practice to face the hard tasks distinctive for the construction sector, as stated by its denomination. The term “Building” concerns the physical characteristics of the model and stresses its capability to virtually recreate the facility considering the project-based tangible features. The term “Information” concerns the intangible characteristics of the model and stresses its capability to organize the set of facility’s data in a meaningful and actionable manner. Lastly, the term “Modelling” concerns the act of shaping, forming, presenting and scoping the facility and stresses its capability to enable multiple stakeholders to collaboratively design, construct and operate (Succar and Kassem, 2015). BIM is therefore conceived as a database that embedded, display and calculates graphical/tangible and non-graphical/intangible information, linking each part and data of the systems and forming a reliable basis for decisions in the whole project life cycle. For this purpose, it was conceived and tailored to fit all the multitude of practice and projects, providing the maximum flexibility but requiring a lot of effort to arrange all data in an efficient and effective way.

In this context, to support AEC firm in life cycle design, the paper presents a framework able to orient and streamline the design process in line with LCT. The framework is envisioned within a BIM-oriented working environment to be spread and as much as possible well-integrated in AEC practice, providing a worthy support in the shifting both in thinking and in process.

2. Framework proposal

For a long time, the construction sector was material oriented in the approach to design, since it was focused on the palette of products necessary to produce sustainable buildings. However, "products are of limited value if viewed only as things that are added to building to make it green" (Boecker et al., 2009). Nowadays, sustainable goals call even more for a different mind-set, asking practitioners to change their mental model and way of practice, from stuff (i.e. products and technologies) to purposeful systems- and life cycle-thinking.

To this end, a framework was developed with the aim to integrate LCT in design and construction practice. To facilitate its implementation and to truly orient decision-making starting from the early stage of the project, the framework was tailored to fit the peculiarities of design process' phases.

2.1. Basic matrix of the framework

The framework results from a matrix that combines life cycle perspective with AEC firms design process. In particular, to put into effect LCT, that represents a general mind-set, Life Cycle Assessment (LCA) was taken as reference frame, providing an added value since depicts an international standardized methodology. The framework spring thus from environmental issues but with wider purpose, representing for instance the elementary frame for economic issues. In this way, the underlying basic matrix of the framework is established, in the horizontal axis, by the different stages of life cycle from cradle to grave and, in the vertical axis, by the different phases of design process.

LCT is thus depicted by LCA methodology with the connected stages and set of data. It was analyzed according to European Standard (EN 15978:2011) and EPD Product Category Rules of building, the only available at building level (EPD PCR 531:2014). Therefore, the identification of life cycle stages follows the typically classification prescribed by the standards: product stage, construction stage, use stage, end of life stage, benefits and loads beyond the system boundary. Instead, design process phases were pointed out referring to the supporting materials developed by international and national institutions (UNEP, 2014; AIA, 2014; RIBA, 2013). In this case, due to the different partitioning, the terminology was harmonized splitting the design process in five main phases: concept phase, design phase, construction phase, in use phase and end of life phase. Note that despite the similarity of the terms, life cycle stages do not correspond to those of design process. In fact, for example, the design phase should take into consideration all life cycle stages, while the process in use phase should consider the life cycle use stage but also the product stage with regards to the maintenance and operational activities. In the following paragraphs, to avoid the ambiguity of terminology, the word “stage” refers to life cycle approach, while the word “phase” refers to design process.

Starting from the basic matrix, the framework interrelates design process with life cycle approach setting out the following assets: i) the life cycle information required; ii) the actors engaged to gather that type of data; and iii) the related tools and sources used to provide that data.

2.2. Framework explanation from life cycle perspective

To face the complexity of the systems and to handle the large amount of data, the framework was developed taking as a starting point life cycle standards and extracting from them the complete list of life cycle information. In this way, the framework helps in the data collection required to perform the inventory phase of an LCA study, identifying the actors in charge and the tools and sources suggested in relation to each process phase, as depicted for example for the production phase in Fig.1.

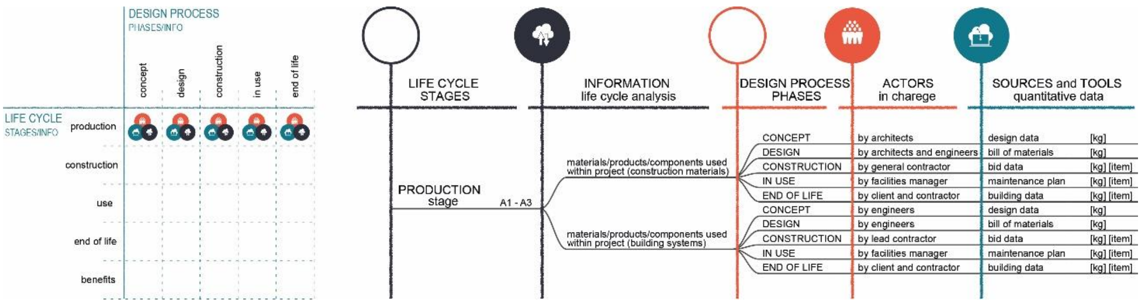

Figure 1: Framework explanation from life cycle perspective – production stage

However, it is important to underline that the framework focus only on life cycle quantitative data, since they represent the type of information directly demanded by AEC firms and therefore to bear in mind during the design process. As a consequence, environmental and economic data, conventionally required for the inventory phase respectively of an LCA and an LCC, are not reported since not tied to design practice, but rather attributed to literature, database or primary data, according to the phase of process and the type of information.

2.3. Framework explanation from design process perspective

Despite set up starting from life cycle stages, the framework can be reversed by explicating it in relation to the design process phases. In this way, it supports the implementation of life cycle practice, encouraging designers and practitioners in life cycle design and operations and orienting the decision-making with the aim to reduce the impacts and streamline the process. Indeed, for each phase of the process are pointed out the life cycle information to be considered, the actors who can collect that data and the source and tools where information can be taken. In the following paragraphs a synopsis is provided to briefly explain the framework according to the design process phases. Nevertheless, it is worth mentioning that the framework recommends the most virtuous life cycle-oriented practice and so its application depends case by case on how deeply life cycle perspective is integrated in design process and on how it is required by the project at issue.

The first phase of the design process is the concept phase. This phase does not assume a key role in finding information but rather in setting targets to be achieved in the subsequent stages. For that reason, providing the whole list of life cycle information, the framework supports practitioners in selecting and fixing life cycle-oriented targets for the project, such as the reduction of energy consumption, the use of recycled materials and the limitation of emissions. In addition, the framework affects the preliminary strategical design decisions, encouraging practitioners to evaluate with a life cycle perspective the different design concept, such as the choice to reuse existing structures or to opt for alternative solutions like expansions, renovations or new construction. Moreover, it orients the decision-making about the structure and the building envelope, stressing design team in esteem materials altenatives in a life cycle way. All these decisions are crucial from a life cycle perspective and must be defined and shared with the design team as well as the clients from the inception of the project to have an effect on the whole decision making process.

Shifting the design from a traditional to a life cycle perspective, the design phase should embrace all life cycle stages, with the exception of repair and refurbishment, since they refer to activities that cannot be predicted in advance. In this way, the design team is encouraged by the framework to deal as soon as possible with all the different stages, using LCT as a decision-making aid and checking the compliance with the settled targets. For the product stage, as a common practice, they should choose the building components and systems, considering the relative amount of materials. For the construction stage, they should select the manufacturers not only in relation to the products and performance provided but also considering, for instance, the distance from the factory to the site. For the use stage, they should esteem the energy and water demand as well as the maintenance and replacement process of both materials and systems and the emission of finishes. Finally, for the end of life stage, they should account the materials diverted to landfill and the potential materials to be reused or recycled. Starting from the early phases of the process, designers and engineers are responsible for the collection of the above-mentioned information, collaborating in some case with manufacturers and empowering therefore the respective fields of expertise. Concerning source and tools, in this phase a key role is played, on one hand, by the bill of quantities and, on the other, by software simulations, even if some information could refer to products or also literature data.

As the previous one, the construction phase, involving both the preparation of bid documents and the execution of works, must take into account all life cycle stages, considering the information embedded in the design phase as thresholds for the decision-making process. In this way, this is a progressive definition of the set of information, with deepened data especially regarding the construction process and the specific life cycle information of the materials selected for the building. Here quantitative data turn out to be more accurate and reliable: the amount of materials and related data refers not to metric estimate but to tender documents and the information about construction and installation process refers not to literature data but, possibly, to real data measured on site. Instead, concerning the additional information, such as materials, transport, energy and water used on site during the construction process, they are included by means of tender specifications or local measurements. In this phase, the actors involved are mainly general contractor and sub-contractors, for the most specific and demanding aspects.

The use phase of the design process must monitor the current state of buildings, taking into account all the life cycle stages with the exception of the construction stage. Certainly, the use stage assumes a key role, on one hand, for maintenance and facility process and, on the other, for energy and water consumption. Indeed, during the operational phase, it is possible to compare, confirm or adjust the value derived from software simulations with the real consumption. Moreover, it is possible to check if the maintenance and replacement activities were confirmed as predicted in the previous phase, recording at the same time the information about repair and refurbishment operations. Here, the selection of the new building materials must be done with the same life cycle parameters adopted during the design phase and thus embracing from the production to the end of life stage of the products to be added. The actors in charge for gathering that type of data are facility managers and, if expected, the commissioning authority.

Finally, the end of life phase should consider the end of life stage with the addition of the related possible benefits beyond the system boundary. Here, like happens in the previous phase, the life cycle information embedded in the framework are taken as thresholds and are deepened, confirmed or adjusted in relation to real data. As in the construction phase, the actors engaged are the general contractors responsible for deconstruction, demolition, transportation, waste treatment and disposal or reuse, recycling and recovery process.

2.4. Framework within a BIM-oriented working environment

To face the hard tasks and consistently with the trends currently underway in AEC practice, BIM is identified as the most suitable tool to embed the suggested framework and thus to shift it from the theorethical to the practical level. Indeed, it allows to create over time a project-based and well-framed set of data of the facility along the whole life cycle. Since BIM provides the maximum flexibility to tailor different practice and to fit the data needed, the implementation of the framework lets to arrange all data in an efficient and effective way and to progressively develop the life cycle database during the design process by means of the following steps. The first step is the insertion of life cycle information within BIM, enriching the set of information just embedded in the model and connecting when possible the data with the relative parametric objects. The second step is the grouping of information according to the phase of the design process, including a wider range of data with the advancement of the process. The third step is the insertion for each life cycle information of the additional linked data, such as the actors involved and source used. In this way, the responsible parties are able to input individually the life cycle quantitative data and build up the shared model database in the course of the process.

3. Discussion

The proposed framework supports the implementation of life cycle practice within building sectors, by matching the large amount of life cycle information with the different phases of design process and setting out the related actors involved and tools used. The application of the framework in practice reveals several potentialities. The first key factor is that all life cycle quantitative data are collected progressively in one-record, according to the different phases of the design process. The second key factor is that life cycle information are gradually defined, specified and detailed in conjunction with the process phases, becoming even more accurate, reliable and corresponding to reality. The third key factor is that life cycle data are gathered in every phase process by different actors, empowering the responsible parties for the choices and activities taken in their expertise area.

Moreover, by joining the framework within a BIM-oriented environment, the same understanding of BIM turns out to be enhanced. The traditional vision of BIM as a shared platform of exchange among different practitioners and stakeholders and as a life cycle information database of the facility, will be definitely proved and disclosed. Matching life cycle perspective and design process, BIM becomes a feasible supporting tool and process to reduce impacts and optimize building process. In the evaluation of a project, in fact, if the life cycle quantitative information are lowered in value with the progressive advancement of the process, necessarily at the end they will cause low impacts. However, this statement is effective only when the same items and materials are considered during the design process (e.g. specific type of concrete), changing progressively the related quantities. By contrast, the reasoning lapses when items and materials are replaced during the process (e.g. switching EPS with mineral wool). Here, the arrangement with environmental and/or economic data is demanded to make comparable the different materials in question.

The establishment in one-record of the life cycle information of the building in question, from inception onward, represents an added value for all the actors involved in the process. In fact, from early design to even the decommissioning phase, all the stakeholders in charge and/or allowed contribute information to and extract information from the building virtual model, providing a lifelong view of the facility. In this way life cycle BIM allows a continuous built-up of know-how, meeting and reinforcing two shared goals. On one hand, it enables a seamless flow of information across the process phases and stakeholders. On the other, it provides a life cycle database strategical for clients to have full control of the facility and thus a more efficient asset management and crucial for practitioners to compare their input data with the others and thus broaden their know-how for the following projects.

Nevertheless, in this perspective, it is important to not underestimate the following AEC main barriers. First of all, the fact that construction sector is considered resistant to change, whereas the suggested framework demands a radical shifting both in thinking and process. In addition, the framework implementation presumes the BIM equipment of all the AEC firms involved. Nowadays the uptake and maturity of BIM vary considerably from country to country and from company to company, according to their size and position. Another barrier is the need of a "wide and open" BIM, with the aim to integrate the entire value chain and to provide full interoperability of software and open access to it. While the technical challenges are likely to be overcome in the next future, it might be more difficult to change the existing processes and to enhance collaboration and data sharing. Lastly, the fact that digital technologies will realize their full potential only if they are widely adopted and regulated by norms and standards. This task is crucial to create a fertile environment for the digitalization of the construction sector and it is demanded to the government, as regulator and incubator as well as often a key project owner.

To conclude, it is worth mentioning that the proposed framework was developed on the basis of LCA methodology (environmental impacts) but can easily represents the input data frame also of Life Cycle Costing – LCC methodology (economic impacts) and with greater effort of Social Life Cycle Assessment – S-LCA methodology (social impacts).

4. Conclusion

Due to the high impacts of buildings at a global scale, the implementation of the aforesaid methodologies into the design process represents the forthcoming challenge of the construction sector. To this end, the integration of the suggested framework into a BIM-oriented working environment turn out to be crucial for two main reasons. Firstly, since BIM is nowadays widespread, to support, foster and put into action LCT in practice. Secondly, to orient the decision-making of all the actors involved starting from the early phases of the process and to streamline the building process.

Whereas BIM and life cycle methodologies are both available and the construction sector is just involved in the process of transformation and change management, the need is to seize the opportunity, orient the process development in the right direction and figure out how to exploit the most of it.

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Lithium-ion batteries for electric vehicles: combining Environmental and Social Life Cycle Assessments

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Abstract

Electric vehicles (xEV) are a key low carbon technology for mobility. Although xEV have no tailpipe emissions, the production of traction batteries leads to environmental and social burdens. In this context, authors assess the environmental and social impacts of a cell of Lithium ion traction battery in order to identify the most relevant aspects and the potential added value of performing both the assessments. Results show the relevance of the resources in terms of both environmental and social impacts. Moreover, the social assessment results pointed out the relevance of the geographical boundaries, often overlooked for in the environmental analysis. The combination of both the assessment represents an added value to assess the sustainability of products; however, data collection (e.g. sources, quantities, quality) still represents a major bottleneck in this type of assessements.

1. Introduction

Hindering global warming and achieving a more sustainable economy are some of the most relevant goals of the European Union (EU). According to various authors, electromobility is a key technology for the decarbonization of European transport sector (Thiel et al., 2016). The transition towards a low-emission mobility entails a fast increase of the electric vehicles (xEVs) (UNFCCC, 2015), and consequently an increasing demand of high performant traction batteries. In this context, the most promising battery technology is Li-ion (Blagoeva, Aves Dias, Marmier, & Pavel, 2016). Although the traction batteries have no tilepipe emissions, high environmental impacts are related to their production (Ellingsen et al., 2014). Moreover, according to the battery chemistry, Li-ion batteries contain different quantities of Critical Raw Materials (CRM) (e.g. cobalt) or raw materials (e.g. lithium) that, although are not perceived as a CRMs, call for new assessment due their increased demand in traction batteries (Bohnes et al., 2017; Blagoeva et al., 2016; Lebedeva et al., 2016). In addition, issues related to human rights risk can affect the supply of raw materials employed in Li-ion batteries (Blengini, Blagoeva, Dewulf, & Others, 2017).

Life Cycle Thinking (LCT), officially introduced in the framework of the Sustainable Consumption and Production and Sustainable Industrial Policy of the EU (COM(2008) 0397), contributes to identify potential improvements along the whole life-cycle of products (and services) in order to decrease the environmental impacts and reducing the adoption of resources increasing their circularity[18]. This approach should be enlarged allowing to cover the three pillars of the Sustainable Development (economic, environmental and social)[19].

In this context, authors assess the environmental and social aspects of a Li-ion battery cell in a life-cycle perspective. In the followings, the results of the environmental and social assessments are illustrated. Then, results are discussed and links between the two assessments are highlighted.

2. Methodology

2.1. Goal and scope definition

The goal of this analysis is to assess the environmental and social impacts related to the manufacturing process of a Li-ion cell of a traction battery in a life-cycle perspective and to highlight the potential links between the two analyses. The case study is represented by a cell of a Li-ion battery[20] used in the Mitsubishi Outlander Plug-In Hybrid Electric Vehicle, characterized by a composite cathode active material made of lithium-manganese-oxide and lithium-nickel-manganese-cobalt-oxide (LMO/NMC).

The environmental impacts of the battery cell were assessed through a Life Cycle Assessment (LCA) according to the international standards (ISO, 2006a) (ISO, 2006b). The eco-profiles of materials and energy sources used to produce the cell components are based on Ecoinvent 3 database (Wernet et al., 2016) (all material components are modelled as 100% of primary production).

With reference to the social impacts, a Social Life Cycle Assessment (S-LCA) was performed according to the "Guidelines for social life cycle assessment of products" produced by the UNEP/SETAC Life Cycle Initiative (UNEP Setac Life Cycle Initiative, 2009). The analysis especially focuses on social impacts related to the supply chain of 4 materials embedded in the cathode of the LMO/NMC cell: Cobalt (as CRM and recognized as a risky process for exploiting forced labour and children, mostly in artisanal and small-scale mines (Thorsen, 2012)); Lithium (due to its increasing demand); Manganese (previously a CRM and now still on the border); Nickel (as intensively used in the EU market). The social data are inferred from the Product Social Impact Life Cycle Assessment (PSILCA) database (Ciroth & Eisfeld, 2016). Missing information derived from literature (e.g. percentage of children in employment in China (Tang, Zhao, & Zhao, 2016)).

The recommended ILCD/PEF impact categories are used for the LCA analysis (EC - JRC, 2012). Consistent with Bobba et al. (2018) and the goal of the analysis, three impact categories are reported: 1) Global Warming Potential (GWP) because of its high societal and policy relevance, 2) Abiotic Depletion Potential - mineral resources (ADP-res) because of the relevance of the availability of natural resources for economic development and the increase of the political interest in resources consumption, 3) Water Depletion (WD) since

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[18] http://www.europarl.europa.eu/atyourservice/en/displayFtu.html?ftuId=FTU_2.5.7.html
[19] https://ec.europa.eu/environment/efe/content/long-term-vision-sustainable-future_en
[20] The battery pack consists of 10 modules, each made up of eight battery cells and it has a nominal capacity equal to 11.4 kWh, and weighs 175 kg.

water has relevant consequences both in terms of environmental and social aspects and then could be useful in order to identify potential links between LCA and S-LCA assessments.

The S-LCA is performed according to the categories selected by (Mancini et al., 2018): child labour (CL), contribution of the sector to the economic development (CE) and industrial water depletion (WU). These impact categories refer to different stakeholder groups we selected: 'Workers', 'Society' and 'Local community'. In detail, within the stakeholder 'Workers', CL is one of the most recognized category by the general public due to the widely spread information related to the manufacturing of Li-ion batteries from organizations like Amnesty Inter-national, United Nations International Children's Emergency Fund (UNICEF). CE, subcategory of stakeholder 'Society', is the first indicator provided by PSILCA with a positive evaluation (opportunity) in the social life cycle impact assessment (Ciroth & Eisfeld, 2016). It assesses organizations' and industries' contribution for the economic development. WU was selected for the 'Local community' stakeholder category. This impact category highlights the importance of industrial water compared to other water uses and provides a different kind of information if compared with WD assessed in the LCA. In fact, while WD provides an indication about the pressure on the water resource, high levels of industrial water can be associated with high levels of water pollution and then with different risks for local communities, e.g. health risks, destruction of local economic structures, and an overall deterioration of quality of life (Ciroth & Eisfeldt, 2016). Moreover, this indicator is linked to the water use indicator also considered by the environmental assessment.

The functional unit of the study is one LMO/NMC cell. The cell is the electrochemical unit of the batteries; it contains the raw materials (e.g. Cobalt) expected to account for the highest contribution to environmental and social impacts. According to the goal of the study, a cradle–to-gate analysis was performed for both assessments including all the input and output flows of the system from the extraction of materials up to the assembly of the cell.

2.2. Life Cycle Inventory

The Life Cycle Inventory (LCI) of the cell is compiled by combining primary data obtained by the dismantling of the LMO/NMC cells (Pfrang et al., 2018) with secondary data from the available literature (Ellingsen et al., 2014; Majeau-Bettez, Hawkins, & StrØmman, 2011). The detailed inventory of the battery cell is illustrated in (Cusenza, Di Persio, Bobba, Ardente, & Cellura, 2018). The battery cells are characterized by a composite cathode active material: $0.52\ LiMn_2O_4 + 0.48\ LiNi_{0.4}Mn_{0.4}Co_{0.2}O_2$ with a graphite-based anode.

While LCA inventories consist of physical quantities related to the product system, S-LCA inventories requires quantitative and qualitative information on organization-related aspects (Mancini & Sala, 2018). In detail, to build the model, social information (e.g. share of children in employment) and prices of specific materials (e.g. Co price) are necessary. For investigated materials contained in the cathode (Co, Li, Mn and Ni), the mining processes were assumed to take place in the major world producer countries[21]. Manufacturing of cell components and assembly processes take place in China (Brunot, Charreyron, Chung, Mitrofan, & Rietveld, 2013). Inventory data (e.g. prices) are based on the available raw material profiles provided by the Raw Materials Information System developed by European Commission[22]. It is underlined that, due to the lack of primary social data, industry sectors do not refer to the specific production phase (e.g. Cobalt mining corresponds to "Mining and Quarrying" in DR Congo). In this case the social assessment is carried out without primary data; therefore, results highlight a social risk assessment rather than a social impact.

The working time needed for producing a monetary unit (1US$) of output for each production process (measured in worker hours[23] [h]) were derived from similar processes in PSILCA (e.g. Mining and Quarrying in DR Congo referring to Co mining). Table 1 shows social LCI data used to create the model for the extraction phase of Co, Li, Mn and Ni.

Table 1: social LCI information for analysed materials in the cathode

Material	**Major world producer**	**PSILCA sector**	**Amount [kg/cell]**	**Worker hours [h]**	**Price [US$/kg]**
Co	DR Congo	Mining and Quarrying	2.3	0.08	25.7
Li	Chile	Other minerals	2.7	0.02	7.1
Mn	China	Non-ferrous ore mining	25.0	0.13	2.0
Ni	China	Non-ferrous ore mining	6.5	0.13	16.8

3. Results

3.1. Environmental LCA (LCA)

Results illustrated in Figure 1 point out that the energy used for the cell assembly is quite relevant for the GWP category, which is dominated by energy consumption. On the contrary, the ADP-res is dominated by the resources consumption; in this case, the most relevant contribution is related to the copper in the anode and the cell case (more than 75% of the ADP-res impact). Concerning WD, both the solvent and the process water for the production of the cell have relevant contributions for both anode and cathode of the cell. In addition, the process water for the cell assembly contributes for more than 30% to the overall impact.

Especially for the ADP-res impact category, the relevance of resources emerged from Life Cycle Impact Assessment (LCIA). However, not specific data and the need to resort to secondary of aggregated of average data to model the impact of specific materials is source of uncertainty for the LCA. In particular, geographical boundaries are not always taken into account in creating LCA models and often aggregated data are adopted, as in case of "Cobalt {GLO}".

[21] Data for production from BGS World Mineral Statistics database
[22] http://rmis.jrc.ec.europa.eu/
[23] The activity variable 'worker hour' is a common unit giving relative indication of the importance of different unit processes in a product's life cycle.

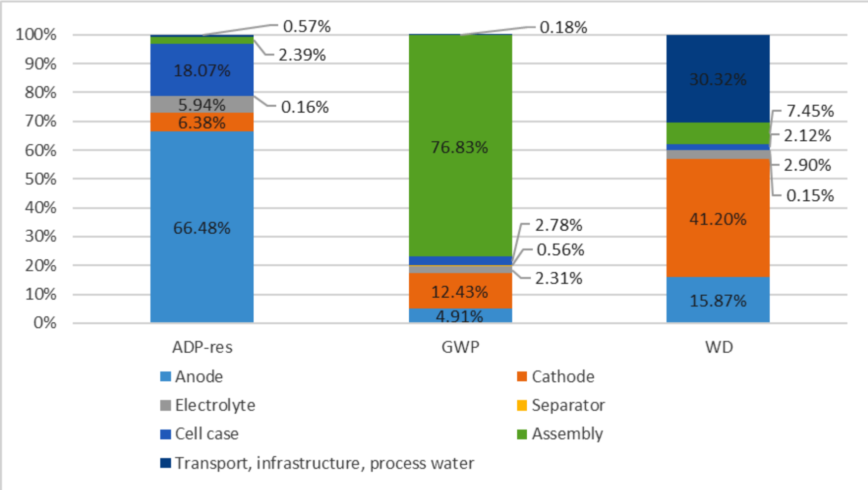

Figure 1: Environmental LCA results

Moreover, despite the relevance of some materials embedded in Li-ion cells (Mathieux et al., 2017), this relevance is not kept by the analysis. Looking for Co used in the battery, it is indeed possible to identify the absolute quantity used in the manufacturing process but also quantities indirectly used in the life-cycle.

Due to the relevance of resources for two out of three categories, material recovery in the end-of-life (EOL) could be potentially relevant to decrease the environmental impact of cells, and consequently Li-ion batteries. Recycling processes already allow to recover some materials from cells (e.g. Al, Ni, Co); new processes are under development aiming at improving the recycling efficiency of already recovered materials but also to recover new materials like graphite and Li (e.g. through hydrometallurgical processes (Mathieux et al., 2017; Swain, 2017)).

3.2. Social LCA (S-LCA)

Processes considered in the analysis refer to production phases and to the Country in which the production occurs. Figure 2 shows the S-LCIA of 1 cell manufacturing. Figure 3 llustrates the contribution of processes involved in the active material production. The main contributing sectors are: "Other manufacturing products" and "Cathode" in China (Figure 3). Note that "Other manufacturing products" is a general sector in PSILCA referring, in this analysis, to the manufacturing sector of components such as anode and separator. Moreover, the anode component has a higher economic value, which results in a significant contribution in all the examined impact categories. As shown in Figure 3, impacts are not equally distributed; for instance, in case of Co, labour conditions are very critical and therefore the risk of occurrence of children in employment results quite high; whereas in case of Ni, relevant impacts in all the categories are linked to the high amount of material used in the cathode. Concerning Mn, despite the same industry sector was used for mining Ni (i.e. "Non-ferrous ore mining, China"), its risk is lower than Ni due to the very low price of Mn (2 USD/kg compared 16.8 USD/kg for Ni) (Table 1).

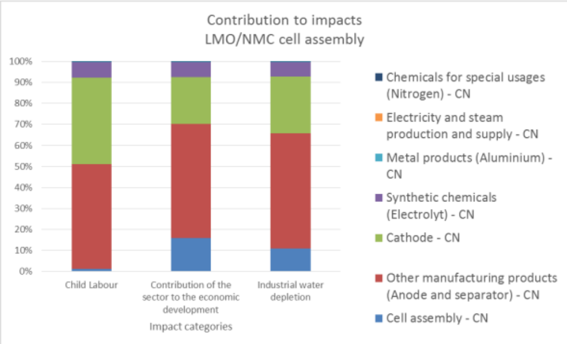

Figure 2: Contribution to impacts for the cell assembly process

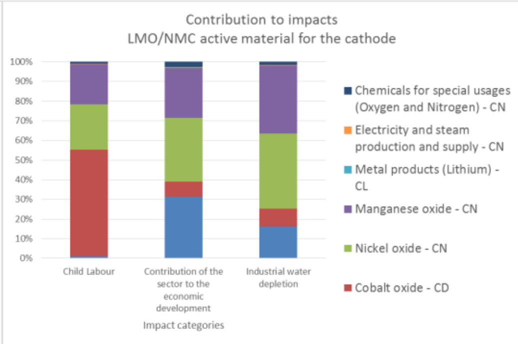

Figure 3: Contribution to impacts for the active material production process

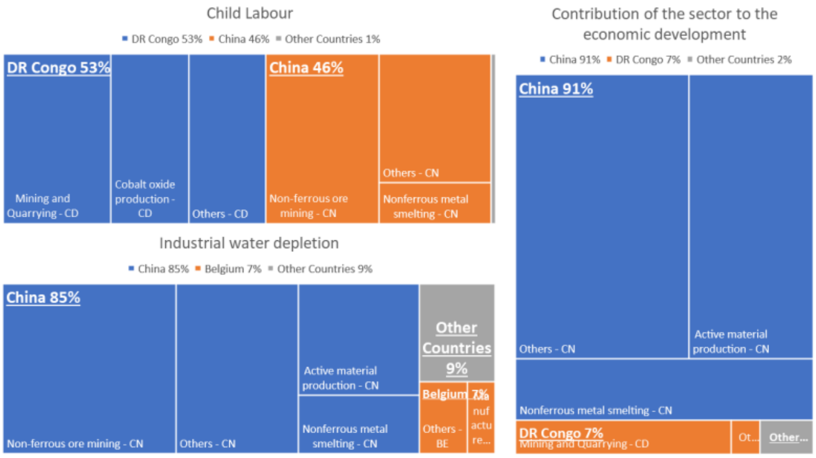

Figure 4: Treemaps: contribution by location for active material production

Concerning the CE impact category, results reflect to what extend the sectors contribute to the economic development of the Country, which is a positive impact for the society. The WU category shows a very low impact for Li extraction, even if it is extracted from brines containing lithium carbonate (Buratovic & Danestig, 2017). This is mainly due to the absence of specific mining sector in PSILCA.

In addition, results can be analysed taking into account geographical locations where impacts occur along the supply chain. Figure 4 combines results by location showing the sector contribution within each Country. For the impact category CL, the main contributing Countries are Congo DR and China, as expected. Mining and refining sectors have the highest contribution in Congo DR and in China as well, meaning that impacts are directly related to the processes analysed. Other sectors contribute to the overall impact, but for less than 10% of the total (grey area of the chart). In case of WU, the main contributing Country is China with mining, smelting of non-ferrous metals sectors and with the production of the active material. Even though not straight implicated in the inventory phase, the contribution of Belgium is not negligible, mainly due to “Manufacture of furniture”.

This result depends on the Eora Multi-regional Input/Output database, backbone of PSILCA, which worldwide connect economic activities among Countries. This result occurs because relevant economic activities in Belgium are linked with the “Mining and Quarrying” sector in Congo DR. Moreover, PSILCA provides a high risk level for Belgium because industries account for a large share of water withdrawal. Concerning CE (Figure 4, right), it is observed that the most relevant positive contribution is located in China, where many manufacturing processes occurr. Note that this is a relevant positive social impact (more than 90% of the total impact). An interesting contribution is related to Congo DR where the sector “Mining and Quarrying” reveals a positive opportunity for the country’s Gross Domestic Product (GDP).

4. Discussion and conclusion

In this paper, some preliminary results of both an LCA and a S-LCA of a LMO/NMC battery cell are provided. Results are analysed in order to identify the most relevant aspects of both assessments and the potential links between the LCA and the S-LCA of a specific product. Due to a lack of primary data, a different level of assessment was carried out for the potential environmental and social impacts. In detail, an impact assessment was performed for the environmental aspect and a risk assessment for the social aspects.

In the performed analysis, the common starting point is represented by the LCI of materials needed in the battery cell manufacturing. However, the Bill of Materials of the product is not sufficient for modelling both the environmental and social LCAs. At the same time, stakeholders should be involved to gather different type of information useful both for LCA and S-LCA. Compared to the LCA, the inventory of the S-LCA requires a broader overview of the involved processes and materials along the life-cycle and different stakeholders should be involved for the data collection, e.g. manufacturers, workers, local community.

Results also highlighted that the geographical boundary, often not considered as a crucial aspect for LCA, is relevant in identifying social aspects in specific Countries involved in the supply chain. Therefore, it is possible to identify the most critical sites along the supply chain in which both environmental and social impacts occur. For that, site-specific data collected from the supply chain are needed in order to minimize the uncertainty related to the generic data provided by databases. This analysis shows that more efforts in terms of data quality and representativeness could lead to a better understanding of the results (e.g. the contribution of Belgium in WU results).

Considering an emerging technology such as Li-ion batteries, the combination of both environmental and social LCIA could offer a wider overview of impacts of products for which strategic materials for Europe are used (e.g. CRMs). Recycling processes for some relevant materials for the market (e.g. aluminium, nickel, cobalt) can mitigate the environmental burdens related to these materials but also cause positive/negative social impacts in specific areas (e.g. job creation, illegal shipment to third Countries from Europe). Then, a further development of the study should include the EOL of cells.

In conclusion, within the context of LCT, links and complementarity between LCA and S-LCA emerged as an added value for a more complete sustainability assessment of products. Results of both assessments underlined that, although limitations due to the lack of data and the novelty of the topic, the combination of different assessments is recommended to identify the most relevant hotspots along the value chain of products and to improve their sustainability.

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State of art of S-LCA: case studies and applications

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Abstract

The realization of global sustainability takes place through the development of the triple bottom line (environmental, economic and social dimension.) The S-LCA methodology, used to evaluate the social aspects according to the life cycle approach, still remains a weak instrument as it needs a greater number of applications. This work aimed at reviewing the literature, proposing a case study analysis focused on the products and methods of application of the S-LCA, highlighting the categories of stakeholders and the sub-categories investigated. as in the last period the case studies have significantly increased.

1. Introduction

Although nowadays there are only the guidelines (UNEP/SETAC 2009) to evaluate some social aspects of products, the S-LCA methodology follows ISO 14040-44 (2006a, 2006b) standards, which are available for the ELCA analysis.

The general principles of guidelines (UNEP/SETAC 2009), define the S-LCA as "a valuation technique of social impacts (or potential impacts) in order to evaluate socio-economic aspects of products and their potential impacts, which could be positive and negative, during their life cycle, including the extraction and the working of raw materials, the production, the distribution, the use, the re-use, the maintenance, the recycling and the ultimate disposal". Social impacts are classified according to five protection areas, matching five categories of stakeholder, namely, workers, consumers, local community, society and actors of value chain. Social impacts categories of S-LCA are: human rights, health and security, worker's conditions, cultural heritage, socio-economic administrations and repercussions.

In order to provide elements for the identification of inventory indicators, related to each categories of stakeholder and then to methodological schedules of reference, it is introduced the concept of impacts subcategory as indicated in the schedule drawn up by UNEP/SETAC. (UNEP/SETAC, 2013). This paper shows the results of a case studies review, based on the literature.

2. Materials and Methods

The following analysis was carried out through a study of literature (from 2013 to 2017), using Scopus database and initially taking into account all available documents (235 articles). The review of the literature was carried out with a qualitative approach through automated analysis of the texts (ATA) which, together the analysis of lexicon to identify the keywords, has allowed to draw a map of the current methodology application. Thanks to this procedure, it was possible to create a representative sample of 48 documents, containing study cases and applications of S-LCA.

3. Results and Discussion

Starting from the review of literature about S-LCA it appears that the number of the study cases during the last years (from 2013 to 2017) has increased, proving that this tool has elicited steady interest from the scientist research, as shown in Table 1 below this one some cases examined will be outlined briefly.

In the Weldgiorgis and Franks (2013), the study concerns the steel sector and for the energy supply in Australia 3 different alternatives are examined, (charcoal produced by the revegetation of eucalyptus, charcoal produced by the forestry and metallurgical coal). The indicators used are: the impact on soil, the employment, the health and the safety in the workplace. The results of this work have shown as the alternatives of biomass create direct employment at regional level, they record lower work accidents and represent a significant change in the land use. Smith and Barling (2014) propose a methodology which focuses on the working conditions along the supply chain for food and drink products of small and medium-sized enterprises (SME). The classification of the key stakeholders is limited to workers/employees and to local communities affected by the production process. After a review of literature about the life cycle assessment (LCA) and its relation with S-LCA and SME, it was administered to SME of food and European beverage sector and trade associations a questionnaire about their knowledge, experiences and dedication to social impacts. The study case of Dong and Ng (2015) relates to the evaluation of social impacts of a construction project of buildings in Hong Kong. The category of stakeholder, which was selected, concerns workers, local community and society. For the local experts the most important social aspect concerns the health and the safety of workers. The results of this work, which represents the first attempt of a S-LCA analysis in Hong Kong, have highlighted how the adoption of prefabricated components in concrete could generate negative impacts on the fair wage and the local employment, because this type of material generally was produced outside of Hong Kong. Usually the study case presents positive social impacts, its best performances are recognized during the building phase. Wang et all. (2016) have evaluated the social impacts in the electronics industry and those of operations at work in three factories (A, B and C) of a packaging company. Once the subcategories of impact are selected (Freedom of association and collective bargaining; Child labor; Forced labor; Fair salary; Working hours; Equal opportunities; Health and safety), between that three packaging factories integrated circuit (IC), the C factory was classified as the lowest social impact on work with the higher performances, followed by B and A factories.

Table 1: Study cases and applications (Elaborations of the authors)

Year	Author	Article	Sector/product
2013	Musaazi et al.	Quantification of social equity in life cycle assessment for increased sustainable production of sanitary products in Uganda	Sanitary pads
2013	Hosseinijou et al.	Social life cycle assessment for material selection: a case study of building materials	Building materials
2013	Fitsum et al.	Social dimensions of energy supply alternatives in steelmaking: comparison of biomass and coal production scenarios in Australia	Biomass and coal production
2014	Umaira et al.	Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines	Electronic waste
2014	Martínez-Blanco et al.	Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment	Mineral fertilizers and industrial compost
2014	Ekener-Petersen	Screening potential social impacts of fossil fuels and biofuels for vehicles	Fossil fuels and biofuels
2014	De Luca et al.	Social Life Cycle Assessment and Participatory Approaches: A Methodological Proposal Applied to Citrus Farming in Southern Italy	Citrus farming
2014	Smith et al.	Social impacts and life cycle assessment: proposals for methodological development for SMEs in the European food and drink sector	Food and drink sector
2015	Dong et al.	A social life cycle assessment model for building construction in Hong Kong	Building sector
2015	Papong et al.	Development of the Social Inventory Database in Thailand Using Input–Output Analysis	Thailand economy
2015	Sanchez Ramirez et al.	Subcategory assessment method for social life cycle assessment. Part 2: application in Natura's cocoa soap	Cocoa soap/ cosmetic sector
2015	Ren et al.	Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multicriteria decision-making	Bioethanol production
2016	Souza et al.	Social life cycle assessment of first and second-generation ethanol production technologies in Brazil	Ethanol production technologies (sugarcane for bioethanol)
2016	Fan	Evaluation for social and humanity demand on green residential districts in China based on SLCA	Building sector (green residential)
2016	Siebert et al.	Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany	Wood-based production system
2016	Petti et al.	An Italian tomato "Cuore di Bue" case study: challenges and benefits using subcategory assessment method for social life cycle assessment	Tomatoes

Year	Author	Article	Sector/product
2016	Zamani et al.	Hotspot identification in the clothing industry using social life cycle assessment—opportunities and challenges of input-output modelling	Clothing industry
2016	Touceda et al.	Modeling socioeconomic pathways to assess sustainability: a tailored development for housing retrofit	Retrofitting of a house
2016	Chen et al.	Social life cycle assessment of average Irish dairy farm	Dairy farm
2016	Wang et al.	An analytical framework for social life cycle impact assessment—part 2: case study of labor impacts in an IC packaging company	Integrated circuit packaging
2016	van Haaster et al.	Development of a methodological framework for social life-cycle assessment of novel technologies	Novel technologies
2016	Agyekum et al.	Environmental and social life cycle assessment of bamboo bicycle frames made in Ghana	Bamboo bicycle frames
2016	Tecco et al.	Innovation strategies in a fruit growers association impacts assessment by using combined LCA and s-LCA methodologies	Agro-food sector
2016	Reuter	Assessment of sustainability issues for the selection of materials and technologies during product design: a case study of lithium-ion batteries for electric vehicles	Lithium-ion batteries
2017	Valente et al.	Testing environmental and social indicators for biorefineries: bioethanol and biochemical production	Chemical sector
2017	Kolotzek et al.	A company-oriented model for the assessment of raw material supply risks, environmental impact and social implications	Raw material supply chain/ capacitor
2017	Prasara-A et al.	Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field	Sugar industry sector
2017	Siebert et al.	Social life cycle assessment indices and indicators to monitor the social implications of wood-based products	Wood-based product
2017	Zimdars et al.	Enhancing comprehensive measurement of social impacts in S-LCA by including environmental and economic aspects	T-shirts and residential housing heating systems
2017	Hannouf et al.	Subcategory assessment method for social life cycle assessment: a case study of high-density polyethylene production in Alberta, Canada	Chemical sector (high-density polyethylene production)
2017	Cardoso et al.	Economic, environmental, and social impacts of different sugarcane production systems	Sugarcane production system
2017	Singh et al.	Social life cycle assessment in Indian steel sector: a case study	Steel sector
2017	Corona et al.	Social Life Cycle Assessment of a Concentrated Solar Power Plant in Spain. A Methodological Proposal	Solar power plant
2017	Lenzo et al.	Social Life Cycle Assessment in the Textile Sector: An Italian Case Study	Textile sector products (soft blend of

Year	Author	Article	Sector/product
			wool and cashmere)
2017	Aleisa et al.	A triple bottom line evaluation of solid waste management strategies: a case study for an arid Gulf State, Kuwait	Waste management system
2017	Lu et al.	Inventory Analysis and Social Life Cycle Assessment of Greenhouse Gas Emissions from Waste-to-Energy Incineration in Taiwan	GHG management of waste to energy inciniration plants
2017	Tsalis et al.	A social LCA framework to assess the corporate social profile of companies: Insights from a case study	Energy sector
2017	Santos et al.	Assessment of health and comfort criteria in a life cycle social context: Application to buildings for higher education	School building for higher education
2017	Peruzzini et al.	A social life cycle assessment methodology for smart manufacturing: The case of study of a kitchen sink	Kitchen sinks
2017	Hossain et al.	Development of social sustainability assessment method and a comparative case study on assessing recycled construction materials	Recycled construction materials
2017	Opher et al.	A comparative social life cycle assessment of urban domestic water reuse alternatives	Urban domestic water reuse
2017	M. Pastor et al.	Social aspects of water consumption: risk of access to unimproved drinking water and to unimproved sanitation facilities—an example from the automobile industry	Water consumption in automobile industry
2017	Yi Teah et al.	Support Phosphorus Recycling Policy with Social Life Cycle Assessment: A Case of Japan	Phosphorus mining
2017	van der Velden et al.	Monetisation of external socio-economic costs of industrial production: A social-LCA-based case of clothing production	Supply chain of clothing T-shirt and a pair of jeans
2017	Subramanian et al.	Assessing the social impacts of nano-enabled products through the life cycle: the case of nano-enabled biocidal paint	Nano- enabled product/oxidebased paint
2017	Holgera et al.	The social footprint of hydrogen production - A Social Life Cycle Assessment (S-LCA) of alkaline water electrolysis	Hydrogen production
2017	Hake et al.	Towards a Life Cycle Sustainability Assessment of Alkaline Water Electrolysis	Alkaline water electrolysis system
2017	Yıldız-Geyhan et al.	Social life cycle assessment of different packaging waste collection system	Packaging waste collection

Moreover, the results show that for four indicators there are social impacts on work during the IC packing production. The study case led by Kolotzek et al. (2017) considers the selection process of three different capacitor technologies (aluminum-based, niobium and tantalum based). The small and medium-sized enterprises (SME) of this study case assemble small electronic components, like capacitors or resistors, for printed circuits manufactured individually and ordered by different customers. The study case focuses on how the SME can handle the tantalum capacitor, having regard to the risk of supply based on raw materials, environmental impacts and social implications. The niobium turned out to be the less critical material except for “health” and “safety”. By comparing the aluminum and the tantalum, both of them show very similar results. The tantalum is the most critical material as regards the indicators “cultural heritage” and “child labor”, whereas the aluminum is considered the most critical material in these cases “forced labor” and “working hours”.

4. Conclusions

The analysis points out that, especially in the last two years, the number of study cases about S-LCA has been significantly risen for the increased adoption of guidelines. Moreover, it was observed that there is a growing combination between S-LCA and E-LCA. The numerous efforts made by scientific research on the S-LCA have led to a wide diffusion of the works and the case studies, mainly due to the extent of the results that can be obtained through its application. However, the absence of a reference standard, as in the case of the E-LCA, leaves considerable discretion in carrying out the analysis, preventing the definition of a univocal and consolidated analysis process. The Guidelines and the Methodological Sheets of the UNEP are fundamental as starting point for any type of study that intends to evaluate the social aspects of any type of product or service, but it is necessary that the research undertakes to pursue a shared direction of the modalities on which to carry out the assessment of social impacts. The main critical issues that emerged from the carrying out of this work of review of the case studies concern the difficulty, on the part of the authors, of finding sufficient data to conduct the analysis work, and in some cases, the lack of participation of some categories of stakeholders .The consolidation of this analysis methodology is in fact threatened by the absence of an agreement on key aspects such as functional units, system limits, bottom-up and top-down approach, etc.. Analyzing case studies, it emerges the need to create and develop techniques and indicators for each sub-category applicable to the various economic sectors and for small and medium-sized enterprises (SMEs).Analyzing case studies, it emerges the need to create and develop techniques and indicators for each sub-category applicable to the various economic sectors and for small and medium-sized enterprises (SMEs). It has also been noted that case studies make it possible to identify the priority areas of intervention, providing useful indications for the implementation of social policies that can be promoted both by individual companies and by policy makers in the implementation of policies of welfare state.

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WASTE MANAGEMENT

Life cycle assessment applied to biofuels from sewage sludge: definition of system boundaries and scenarios

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Abstract

Europe is heavily dependent on imported oil for its mobility and transport. High population densities and an increase in sewage treatment facilities have resulted in a large increase in sludge production volumes in Europe and, consequently, disposal problems. The Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen project, acronym TO-SYN-FUEL, aims to provide satisfactory answers to both of these environmental issues. The project implements a new integrated process to produce a fully equivalent gasoline and diesel substitute starting from sewage sludge. A Life Cycle Assessment will be performed in order to evaluate the environmental performances of the new integrated process to produce biofuels. This paper illustrates the process that has led the authors to define the LCA goal and scope considering both the feedstock and the end product point of view.

1 Introduction

Wastewater treatment leads to sewage sludge production and recent restrictions on the use of sewage sludge have resulted in increased disposal problems (Bharathiraja et al., 2014). The average dewatered sludge contains approximately 65-75% water and has a low caloric value (Thinkstep, 2018). However, dried sewage sludge can be considered as a potential biogenic feedstock as a result of its considerable volatile content (30−88%) and calorific value (typically 11−25.5 MJ/kg) (Kan et al., 2016). Thermochemical conversion of sewage sludge into energy and fuel has considered as one of the most attractive technologies to handle sewage sludge (Rulkens, 2008).

The Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen project, acronym TO-SYN-FUEL, aims to validate the conversion of sewage sludge into biofuels. It is a H2020 project that runs from 2017 until 2021 implemented by twelve partners from industry and academia from five different European countries. The project implements a new integrated process combining Thermo-Catalytic Reforming (TCR©), with hydrogen separation through pressure swing adsorption (PSA), and hydrodeoxygenation (HDO), to produce a fully equivalent gasoline and diesel substitute (compliant with EN228 and EN590 European Standards) and green hydrogen for use in transport.

The aim of this paper is to illustrate how we have addressed the definition of goal and scope of the LCA of the TCR-PSA-HDO system and alternative scenarios with the study of a deep literature review and the analysis of statistical data. Two different points of view were considered: the feedstock management point of view and the fuel for road transport point of view.

2 Materials and methods

The work was carried out under the conceptual framework shown by Figure 1. As it is possible to observe, we have defined four steps: 1) analysis of the process from both feedstock and product point of view; 2) analysis of the current situation in Europe regarding sewage sludge treatment and fuel for road transport consumption; 3) analysis of the state of the art of LCA applied to both sludge management and residues biorefineries; 4) aim and scope definition of the TCR-PSA-HDO system and its alternative scenarios.

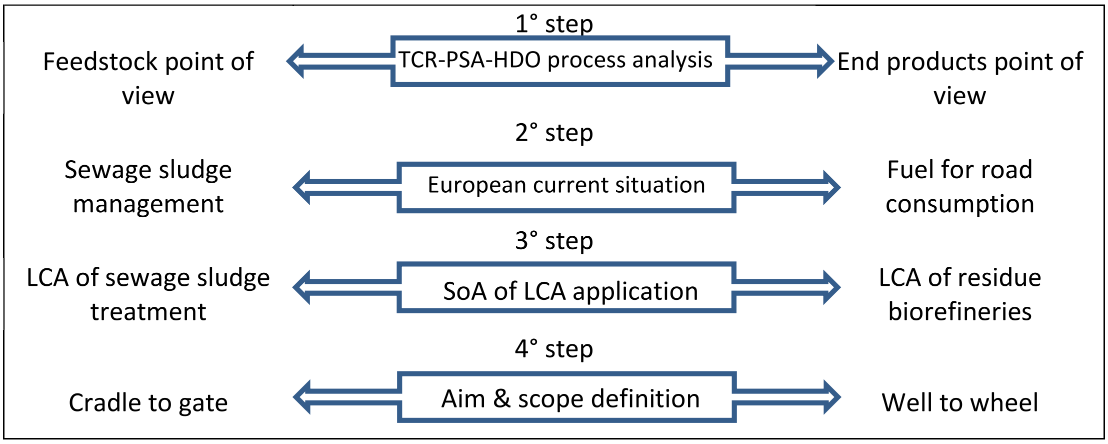

Figure 1: Conceptual framework applied in this work

2.1 TCR-PSA-HDO system

The project aims to deliver a combined TCR-PSA-HDO plant with a nominal dry feedstock throughput capacity of 500 kg/h. The core technology at the heart of the project is TCR©, which is an intermediate pyrolysis flowed by catalytic reforming. In the pyrolytic conversion of biomass by TCR© process, the following streams are generated: oil, gas, char and process water. Subsequently, during the reforming process, the char catalyses the cracking of larger oxygenated compounds present in the vapour phase and promotes reforming to synthesis gas and condensable organic vapours leading to a lower molecular weight, less viscous, non-corrosive and significantly deoxygenated oil fraction, thus avoiding the problems associated with fast pyrolysis oil (Ahmad et al., 2018; Conti et al., 2017, Jäger et al., 2017). In total, the process produces three product fractions: the thermal stable oil, char, and hydrogen rich synthesis gas. During this project the green H_2 produced will be separated from the rest of the synthesis gas by a standard PSA technology and partially utilised downstream for upgrading of TCR®-oil. The physical characteristics of the TCR®-oil (low molecular weight components, low oxygen content) enable it to be blended with fossil and biogenic fuels but there is an even greater opportunity available through the upgrading of the oil through HDO, without the need for large volumes of expensive catalyst required due to the low oxygen content. This results in a liquid which readily distils into “synthetic” fuel fractions (diesel and gasoline) that can be used directly by existing transport infrastructure (Neumann et al., 2016).

2.2 Analysis of the current sewage sludge management and fuel for road transport in Europe

The analysis is based on Eurostat web database (http://ec.europa.eu/eurostat). Eurostat produces annual data on waste generation and management. Waste statistics at EU level responds to the need for comparable and harmonised data which are collected and published every two years following common methodological recommendations.

2.3 State-of-art of LCA applied to residue-based biorefineries and sewage sludge management

The literature search was done by mean of the bibliographic databases: Scopus, ScienceDirect and Web of Science. The main analysed aspects were: goal definition, functional unit (FU), allocation procedures, and system boundaries. Twenty-six scientific papers addressing LCA and biorefineries fed with organic residues and waste were selected; they are listed and identified by a number in Table 1. The research covers both European and extra-European experiences since 2008. Nine scientific papers addressing LCA and current uses of sewage sludge were selected (see Table 2). In this case, the research covers the period 2002-2017 and focuses only on European case studies since this geographic area is interesting for the project.

3 Results

3.1 Current situation in sewage sludge management

As it is possible to observe from Figure 2 (Eurostat, 2017a), in the EU two are the most common fates of sewage sludge: land spreading and incineration. In spite of the fact that about 40% of the total sludge produced in the EU is used for agriculture purposes, the individual EU countries are very different in terms of the amount of sewage sludge that is distributed into soil. Some Member States have adopted stricter limit values for contaminants than those listed in the Council Directive 86/278/EEC and other Members have added some new contaminants. Several EU Members are taking into consideration the health and environmental risk of applying sludge to agricultural land and have even banned its use, while others use it widely and are still improving sludge management (Kacprzak et al., 2017). In Belgium, Denmark, Spain, France, Ireland and the United Kingdom, the amount of sludge used for agriculture was more than 50% in 2010. However, in other countries, for instance in Finland and Belgium, less than 5% is used for agricultural purposes. In Greece, Netherlands, Romania, Slovenia and Slovakia sludge is not used in agriculture. In Poland, a gradual decrease in landfilling of sewage sludge and an increase in their thermal conversion has been observed.

Table 1: Allocation choices used by LCA studies applied to residue-based biorefineries

		NO allocation among end-products		Allocation among end-products		
ID	Reference	One bioproduct	Multiple bioproducts	Mass	Energy	Economic
1	Adom and Dunn, 2017	✓				
2	Benoît and Gagnaire, 2008			✓		
3	Cherubini and Ulgiati, 2010	✓				
4	Ekman and Börjesson, 2011					✓
5	Falano et al., 2014		✓			
6	Farzard et al., 2017		✓		✓	✓
7	Gilani and Stuart, 2015					
8	Giwa, 2017	✓				
9	González-García et al., 2016a		✓			
10	González-García et al., 2011					✓
11	González-García et al., 2016b	✓				
12	Kimming et al., 2011	✓				
13	Liu and Shonnard, 2014			✓		✓
14	Magalhães do Na-et al., 2016			✓		✓
15	Morales et al., 2017	✓				
16	Parajuli et al., 2017a	✓				
17	Parajuli et al., 2017b	✓				
18	Piemonte, 2012					✓
19	Pourbafrani et al., 2013				✓	✓
20	Sadhukhan and Hern., 2017		✓			
21	Schmer and Dose, 2014		✓			
22	Spatari et al., 2010		✓			
23	Tonini and Astrup, 2012		✓			
24	Tonini et al., 2016		✓			
25	Uihlein and Schebek, 2009		✓			
26	Wang et al., 2013		✓			

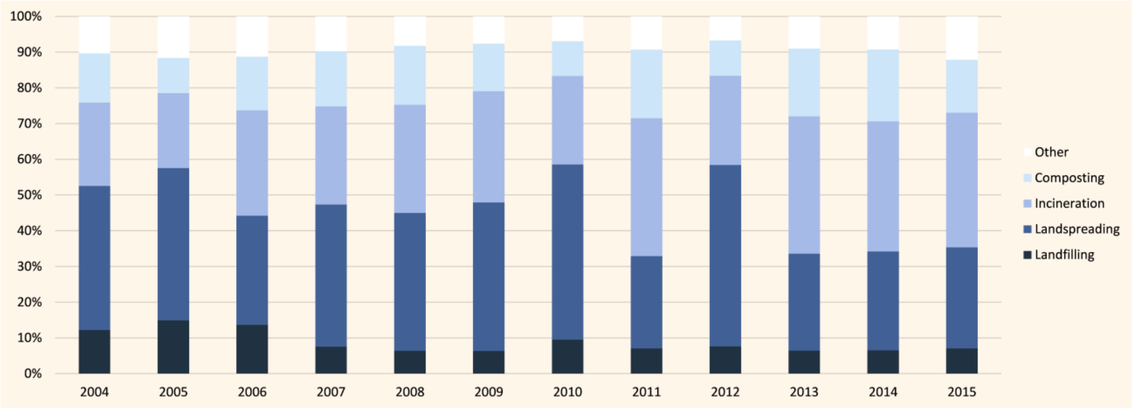

Figure 2: Sewage sludge management methods in EU

3.2 Current situation in road fuel consumption

In the transport sector, gasoline and diesel are still the main energy sources. According to the European Commission, Europe is heavily dependent on imported fossil fuels to sustain its mobility and transport system (European Commission, 2014). In 2015 by Eurostat data, diesel consumption was about 200,000 Mtoe while gasoline consumption was less than 80,000 Mtoe (Eurostat, 2017b). Gasoline demand continues to decline while diesel demand is on the rise, currently reaching a 2.6 demand ratio in 2016. Almost all diesel sold in the EU contains biodiesel, whereas 85% of petrol sold contains bioethanol.

3.3 State-of-art of LCA applied to residue-based biorefineries

As far as residues-based biorefineries are concerned, Saraiva (2017) divides the goals of LCA studies into three categories: 1) analysing environmental performances of a biorefinery as a whole, aiming at comparing different systems setups or process arrangements. These studies commonly have an input-related FU and do not perform allocation of impacts between different outputs; 2) analysing environmental performances of the production of a specific (main) product in a biorefinery, aiming at comparing this product to others with the same function. These studies commonly have an output-related FU and either perform allocation of impacts between different outputs or use system expansion, discounting impacts from goods substituted by by-products; 3) analysing environmental performances of the production of different outputs from a specific feedstock in a biorefinery, aiming at comparing use of different feedstocks for production of goods with the same function. These studies commonly have an input related FU and do not perform allocation of impacts between different outputs.

As observed by Saraiva (2017), the FU depends strongly on the type of LCA goal and can be input-related (e.g. kg of feedstock) or output-related (e.g. L of ethanol).

As far as allocation choices are concerned, the approaches are much diversified. Excluding the eight case studies where only one end-product is analysed (studies 1, 3, 8, 11, 12, 15-17), in the remaining cases nine studies use the expansion boundaries system (studies 5, 6, 9, 20-26) and the other ones show allocation. Also here the most common criterion is the economic one (studies 4, 6, 10, 13, 14, 18, 19) but also mass (studies 2, 13, 14) and energy (studies 6, 19) criteria are in some cases applied. It is noteworthy that in some cases, multiple allocation choices with a sensitive analysis have been applied (studies 6, 13, 14, 19).

The most common system boundary approach is “cradle to gate” (studies 1-7, 9, 10, 12-18, 22, 25, 26). This is the typical approach of situations in which agricultural and forest residues are the feedstock. Quite common is also the “cradle to grave” approach (studies 1, 8, 11, 13, 19, 20, 23, 24). Then, it is possible to observe rarer system boundaries choices, like as “gate to grave” by Sadhukhan and Martinez-Hernandez (2017), Tonini and Astrup (2012) and Tonini et al (2016), “well to tank” by Schmer and Dose (2014), and “gate to gate” by Wang et al (2013).

3.4 State-of-art of LCA applied to sewage sludge management

Table 2 shows the nine studies analysed in the state-of-art review; the current treatments of sewage sludge are reported for each study.

Table 2: Sewage sludge management methods in LCA state-of-art review

ID	Reference	Landfilling	Land spreading	Incineration	Compost	AD
27	Buonocore et al., 2016	✓				✓
28	Hospido et al., 2005			✓		✓
29	Houillon and Jolliet, 2005	✓	✓	✓		
30	Lombardi et al., 2017	✓	✓	✓	✓	
31	Lundin et al., 2004		✓	✓		
32	Mills at al., 2014					✓
33	Peregrina et al., 2006			✓		
34	Righi et al., 2013	✓				✓
35	Suh and Rousseaux, 2002	✓	✓	✓	✓	✓

In all cases, LCA is applied to compare the environmental performance of different scenarios for sewage sludge treatment or disposal.

With the exception of Buonocore et al. (2016), who chose 1000 m^3 of wastewater, all the cases have selected the mass of sludge as functional unit. The differences are in the content of water in the sludge.

The all case studies follow the same structure: from the dewatering to the valorisation fate (incineration, land spreading, etc.).

Very often, cases of recovered materials and/or energy produced as outputs from the systems were resolved by expanding the system boundaries to include avoided primary productions (studies 27, 29, 30, 34). In other cases, the substitution process has been selected (studies 28, 31, 32). Peregrina et al.

(2006) examine two different incineration processes and they do not have to face the issue of different product production. Suh and Rousseaux (2002) do not take into account energy and/or material recovery to avoid the expansion of the system under study.

3.5 Goal and scope definition of TO-SYN-FUEL project

Table 3 shows the most important choices resulting from the phase of “Goal and scope definition” of TO-SYN-FUEL project. The second column lists the choices concerning the sewage sludge treatment point of view in which the aim is to compare different sludge management systems. As alternative scenarios, the most common sludge treatments applied in EU were selected. The third column shows the choices concerning the biofuel production point of view. In this case the aim is to compare different type of road fuels. Gasoline and diesel were selected because they still represent the main energy sources in Europe, moreover biodiesel from dedicated crops was added as third alternative because it represents the most common road biofuel in EU Member States.

As far as the multifunctionality problem is concerned, the analysis of sludge management will be carried out applying the expansion of the system boundaries, the choice is due to the many different products in output of the analysed scenarios (power, heat, soil amendment, biofuels, etc.). In the case of biofuels perspective, the energy allocation appears the more suitable choice since all the output products of TO-SYN-FUEL have relevant energy content.

Table 3: main choices of the “Goal and scope definition” phase of TO-SYN-FUEL project

	Feedstock point of view	**End products point of view**
Goal	to compare different sewage sludge management	to compare biofuels from the project to conventional fuels
Functional unit	1 ton of sewage sludge resulting from wastewater treatment	1 MJ of fuel
System boundaries	from dewatering to valorisation treatment	from dewatering to distillation of HDO-oil to biofuel
Alternative scenarios	landfilling (worst-case scenario), incineration, land spreading	Gasoline, diesel, biodiesel from dedicated crops
Multifunctionality problem	avoiding allocation by expansion	energy allocation (completed by sensitivity analysis)

4 Conclusions

In conclusion it is possible to affirm that the state-of-art of LCA applied to biorefineries and to sewage sludge treatments has been very helpful in order to accomplish “Goal and scope definition” phase. Thank to it, we were able to evaluate pros and cons of the operational choices of the various authors and to make informed choices in relation to the different options. In the same way, the analyses of the current situation concerning sewage sludge management and road fuels consumption have been fundamental to define the most remarkable alternative scenarios

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Analysis of a recycling process for crystalline silicon photovoltaic waste

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Abstract

Despite the generation of photovoltaic (PV) waste is expected to grow exponentially, current base case PV recycling processes have a low efficiency and, in some cases, are not even in line with legislative targets. The article analyses the resource efficiency of a novel process for the recycling of crystal silicon (c-Si) PV panel waste. The life cycle impacts related to this recycling and the potential environmental benefits related to the recovered materials are investigated. It is estimated that over 80% recycling rate (in mass) of the PV panel can be achieved. Moreover, this is one of the first processes developed for the recycling of silicon (one of the EU critical raw materials) from PV waste. Benefits derived from the production of secondary raw materials largely outperform the impacts for all the considered categories. The article also discusses some improvement measures at the product level and at process level.

1. Introduction

Since 2012, photovoltaic (PV) panels have been included within the scope of the Directive 2012/19/EU on Waste of Electrical and Electronic Equipment (WEEE). The Directive established a minimum target of 80% of PV waste to be prepared for reuse or to be recycled starting from August 2018. Although several LCAs of PV panels have been published in the literature, the end-of-life (EoL) phase of this product has been generally excluded or neglected (Sherwani et al., 2010). This was due to various reasons, such as the low amount of PV waste collected, the complexity of their recycling, and the lack of data concerning the EoL stage.

On the other hand, the number of PV power plants largely increased in the last decade. The cumulative PV installations worldwide rose from 6 GW in 2006 up to 303 GW in 2016 (IEA, 2017). Crystalline-silicon (c-Si) PV dominates the market, accounting for 85–90% of the PV technologies (IEA, 2014). The long operational life of the c-Si PV panels (20-25 years or even more) implies that PV waste generation will grow exponentially in the next decades. This implies the need of further research on new technologies for PV waste processing and on the assessment of their efficiency in materials recovery and their related environmental impacts. Moreover, PV panel production is also a key sector in terms of use of Critical Raw Materials (CRMs). In particular, it is estimated that the demand of silicon for PV could rise from 33,000 tonnes in 2015 up to 235,000 tonnes by 2030 (EC, 2018). The recycling of silicon, alongside with other raw materials, has high potentials, and more than 95% is claimed as an economically feasible for recycling (EC, 2018). Nevertheless, the recycling of silicon metal at EoL, which the EC considers a supply risk mitigation filter when defining the list of CRMs for the EU (Blengini et al., 2017), is currently close to zero (EC, 2018).

The present article presents an assessment of a novel and high-efficient recycling process for c-Si PV waste, providing an estimation of the life cycle impacts of the processing and the potential benefits from secondary raw materials (SRMs) production. In particular, the article focuses on key aspects of the recycling process (as related to the waste transport and the PV backsheet treatment) and identifies some improvement measures at the process level and at the product level. The case-study also evaluates some methodological considerations related to the representativeness of impact categories used in the assessment, and to the accounting of the benefits derived from avoided primary materials production.

2. Recycling of PV in current practises and in a novel process

Latunussa et al. (2016) provided the average composition of a c-Si PV: glass (70%); metal frame (18%), mainly aluminium; polymer encapsulations (5.1%), predominantly ethylene-vinyl acetate (EVA); silicon cells (3.6%); backsheet (1.5%), made by polymers; cables (1%); others (2.3%), including silver (0.05%).

Based of the analysis of various WEEE recycling plants in the EU, there is little evidence of currently established recycling processes for c-Si PV waste. It was observed that the common practice, which can be considered representative of the current basic recycling route, is to dismantle the frames and cables of the PV waste, which are subsequently sorted for recycling. The remaining parts are then treated with simple techniques (e.g. hammered or grinded, to separate some glass) or directly shredded with other WEEE. However, due to the heterogeneity and complexity of the PV panel (including glass, encapsulations, silicon cells and multi-polymers backsheet), the amount and quality of materials that can be recycled in such a way is very low. However, the recycling rates achieved by such processes[24] revealed to be much below the target of 80% set by WEEE Directive.

Few examples of analyses of selective processes for PV recycling have been discussed in the literature. For example, Corcelli et al. (2018) applied the LCA to a recycling process of PV waste. The authors based the analysis on laboratory tests and ideal conditions conducted on some PV samples. Corcelli et al. (2018) also concluded that a well-designed recovery process has to focus on all high value materials, such as silicon and silver. Nevertheless, scale-up from laboratory to full-scale industrial process would be necessary to confirm the findings.

This article analyses a novel recycling process developed by the project “Full Recovery End of Life Photovoltaic – FRELP” (SASIL, 2016) (Figure 1). The process has been developed up to the pilot phase and it is currently considered ready for full application at industrial stage by the industrial operator. The follow-

[24] For the analysis of the base case process currently occurring in a WEEE recycling plant, it is estimated that following amounts are recycled: 95% of the aluminium in the frame (171 kg); 96.5% of copper in the cables (3.18 kg); and 10% of the glass of the frame (70 kg). Plastics from cables are energy recovered. All other materials are considered to be lost in the shredding residuals and landfilled. The overall recycling rates is estimated to be around 24%.

up of the FRELP project was however put in stand-by, awaiting for sufficient and constant flows of PV waste that would pay-back for the investment. After transport (1), the PV waste is unloaded (2) and transferred into an automated system for the PV dismantling (3), to remove the frames and the cables, which are further treated for copper recycling and energy recovery of plastics (4 and 5). The waste panels are then introduced into a glass separation process (6), in which the glass layer is detached from the remaining layers of polymers and cells (so-called 'PV sandwich'). Glass is then brought to a refinement process (7), while the sandwich is reduced in size (8), and later treated by an incineration plant (9). Ashes from the incinerations are sieved (10) and treated by acid leaching (11). The acid solution is then filtered (12) (to recover the silicon), and treated by electrolysis (13) (to recover silver and copper). The residues of the electrolysis are finally neutralised (14) and filtered (15), while silver metal is finally refined (16).
The analysis of the inventory flows of the FRELP process has been described in detail by Latunussa et al. (2016). In the present study, a more detailed analysis of the incineration of the PV panel has been carried out. In particular, impacts of the incinerations have been estimated according to a study by the Fraunhofer Institut (2017), which analysed the composition and EoL of different PV backsheets, including the measurement of air emissions from incineration. Emissions from incineration of EVA are estimated from Hull et al. (2002).

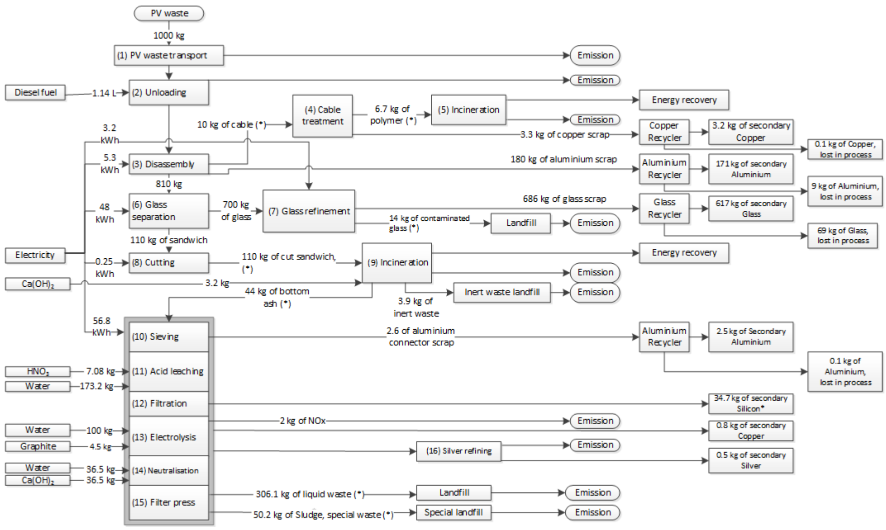

Figure 1: Input and output flows of the FRELP recycling process for C-Si PV waste (modified from Latunussa et al. (2016))

The composition of the backsheet can play a key role in the recycling of the PV waste. In particular, fluorine contained in certain polymers (as polyvinyl fluoride - PVF) can be responsible of the release of hazardous substances, such as hydrogen fluoride (HF), which is also regulated by legislation (EU, 2000). The PV backsheet is assumed to have a structure of Tedlar/PET/Tedlar (TPT) with the following composition (Fraunhofer Institut, 2017): carbon (55.6%), fluorine (5.5%), hydrogen (4.5%), oxygen (28.5%), nitrogen (0.2%). Fluorine is fully released when the backsheet is incinerated already at the temperature of 750°C (Fraunhofer Institut, 207), and HF is formed. It is also assumed that 80% of HF is neutralised by dedicated abatement system (Biganzoli et al., 2015). The following SRMs can be produced after the recycling process: glass (617 kg); aluminium (174 kg); copper (4.2 kg); silicon (34.7 kg); silver (0.5 kg). The estimated recycling rate of the process is about 83 %. Plastics in cables, encapsulations and backsheet are incinerated with energy recovery.

3. Impact assessment of the c-Si PV recycling process

The impact assessment of the novel recycling process for c-Si PV waste has been carried out according to the ILCD impact categories [EC, 2010]. Impacts are referred to the functional unit "recycling of 1,000 kg of c-Si PV waste" according to the FRELP process. However, it was observed that these categories are not capturing some relevant air emissions flows, as HF from the incineration of the backsheet. Therefore, the analysis has been extended to include two additional categories for which HF emission are characterised[25].

The potential environmental benefits related to the recycling process have been estimated according to Ardente and Mathieux (2014). In particular, the benefits of SRMs produced thanks to the recycling process are accounted as the impacts of the avoided primary raw material, at the net of the impacts for the production of the SRMs. Particular attention is given to the accounting of the effective amount of SRMs produced, on the material potentially substituted and the inventory data used. The analysis of the SRMs derived from the process (and of the potentially substituted primary materials) has been performed jointly with the designers of the FRELP recycling process. In particular, it is observed that:

- aluminium scraps from the frames and from internal connectors are separated and can be further processed for the production of secondary aluminium (assumed equivalent in quality of primary one);
- copper scraps (from cables and from interior parts of the PV panel) are sorted and can be further processed for the production of secondary copper (assumed equivalent in quality of primary one);
- glass scraps are separated through a highly selective process in order to maintain high purity. This glass also contains some valuable additives, as antinomy[26], which cannot separated further but that could be recycled together with glass in high quality applications. On the other hand, due to the low value of glass scraps, it is expected that these will be mixed with other waste glass for lower quality applications (e.g. recycled for the production of flat glass).
- silicon is separated by acid leaching to obtain a high purity material. However, a market of silicon metal scrap does not exist yet. Silicon metal in solar cell is assumed to be recovered as metallurgical grade silicon metal that will directly substitute the production of metallurgical grade silicon metal (substitution 1:1).
- silver is separated by electrolysis on graphite rods. Successively, graphite is burnt and silver is recovered (assumed of the same quality of primary silver).

[25] 'Acidification' impact as in the method "EDIP2003" (Hauschild and Potting, 2005) and 'Human toxicity' as in the method "ReCiPe" (Goedkoop et al., 2013).

[26] Antimony is used in solar glass applications to improve transmittance (Wirth and Weiß, 2016).

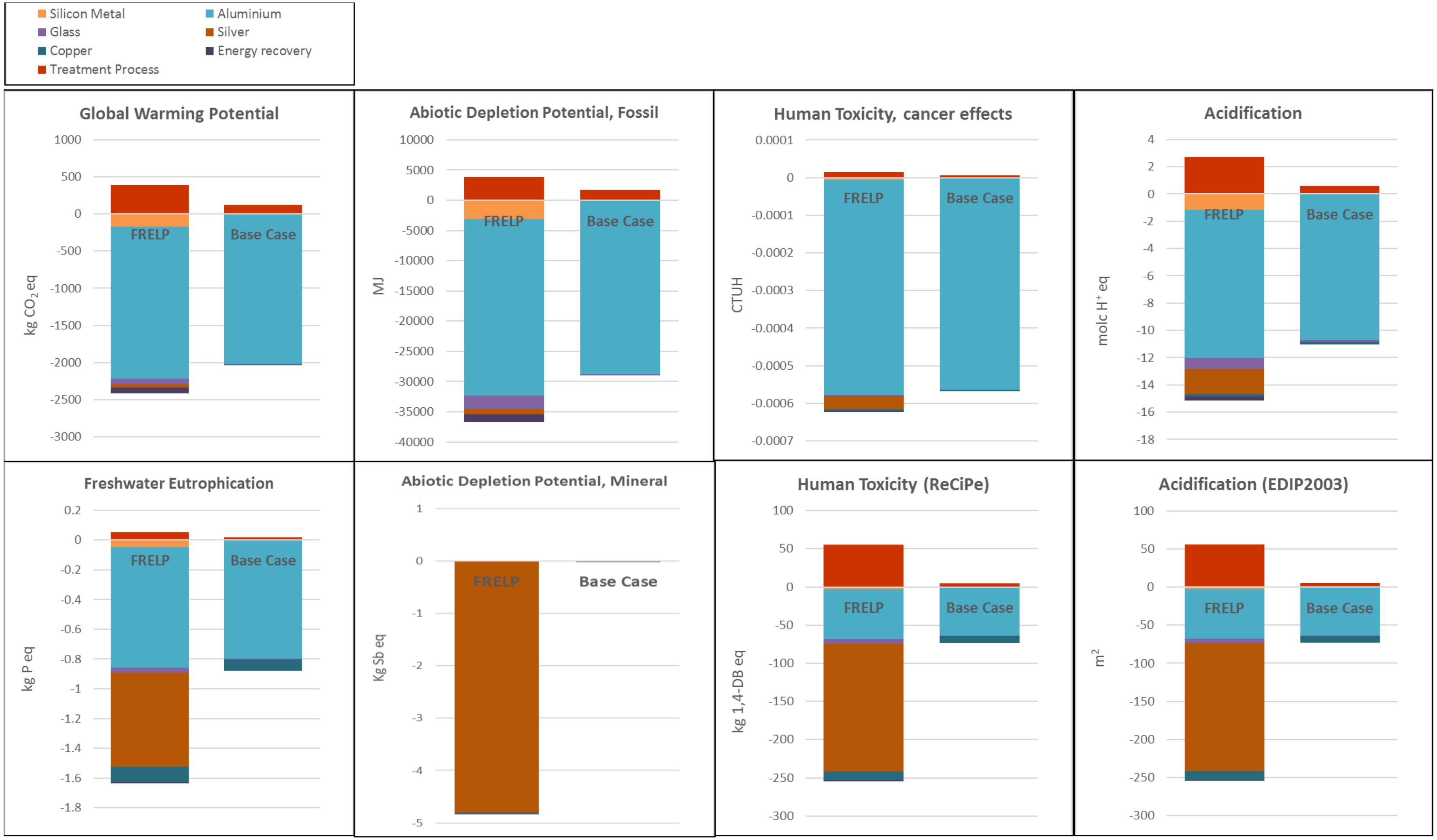

Figure 2: Impact assessment – Comparison of the FRELP recycling process with a base case recycling for c-Si PV waste

The impact assessment of the c-Si PV recycling process is presented in Figure 2. This illustrates the impacts of the FRELP process in comparison with the potential benefits due to the material recycling and SRMs production. Moreover, the Figure 2 presents the differences with the impacts (and benefits) of a base case PV recycling process (as described in section 2).

4. Discussion

The results showed that the impacts of the advanced recycling process are slightly higher compared to a lower quality recycling in a base case treatment, but the overall benefits are higher for all the considered impact categories. The benefits of the base case process are still high because of the efficient recycling of the most relevant fraction (aluminium). The difference of the impacts/benefits between the two processes are low for certain impact categories (e.g. the Global Warming Potential), while are much higher for some others (e.g. the Abiotic Depletion Potential – mineral), especially thanks to the recycling of silver.

The analysis of results proved also that transport is the main responsible of the impacts in the FRELP recycling process to several impact categories. This large incidence of the transport can be related to the heterogeneous distribution of PV plants in the geographical areas, combined with the need to transport to the specialised recycling plant. A potential improvement of the recycling could be regard the creation of decentralised recycling plants, for some pre-treatments of the PV waste.

Another key aspect of the PV recycling is related to the content of fluorinated plastics. Their processing through thermal treatments has to occur in dedicated plants provided of proper abatement systems for flue gases (especially for acid emissions as HF). On the other hand, since some valuable materials of the PV (i.e. silver and silicon) are recovered from the bottom ashes of the incineration process, it is necessary that PV waste are incinerated separately from other waste. This type of process could imply some technical problems. First of all, it is necessary to provide a certain amount of input waste to sustain the incineration in a dedicated plant. This is could represent a constraint for the full development of this type of recycling, since the amount of PV panel currently reaching the EoL are still very limited[27]. On the other hand, a large amount of fluorinated plastics incinerated all together could represent a problem for the incineration plant, which could risk to pass the legal limits for HF emissions. These emissions are also environmentally relevant. Considering the additional impact categories (as in note 2), it resulted that HF emissions are responsible for about 40% of the Acidification impact (EDIP) and about 80% of the Human toxicity (ReCiPe).

Additional metal pollutants could be emitted during the incineration of the PV waste, including arsenic, cadmium, chromium and lead (Tammaro et al., 2015). A large variability of these metal emissions is possible, mainly due to the composition of the panel, and additional research is needed on this topic.

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[27] According to Wambach (2017) the development of the FRELP pilot process was stopped in spring 2016 because of the short supply of waste modules as input to the process.

In the absence of fluorinated plastics the PV could be treated by alternative processes (e.g. pyrolysis) with several potential benefits as: avoided releases of acid air emissions; possibility to treat the PV waste in small batches, with minor losses/dispersion of ashes; reduction of the impacts due to transport[28]. The analysis of the recycling of fluorine-free PV panel can be the objective of further analysis. For this assessment is particularly relevant to select impact categories which capture HF air emissions (as those mentioned in note 2).

5. Conclusions

Basic and low-performance processes currently adopted by WEEE recycling plants for the treatment of PV waste are still not efficient in recovering high quality secondary raw materials and, in some cases, not suitable to meet legislation targets concerning the recycling rates. Still these processes are characterised by a low impact and are able to separate the metal frames and cables (which are some of the most valuable components). These processes are instead not efficient for the recovery of the glass (the main component, in mass, of the PV panel) and other valuable materials (e.g. silver and silicon).

A novel and high efficiency recycling processes for c-Si PV waste has been analysed in a life cycle perspective. This process entails some additional environmental impacts (mainly due to transport, thermal treatment, use of reagents), which are however largely compensated by the benefits due to additional material recovery (including high quality glass, silicon and silver).

Some aspects require still additional research as: the analysis of the emissions released to the incineration, the use of alternative processing (in case of non-fluorinated plastics used in the PV), and the assessment of the impacts of the recycling compared to other life cycle phases.

The article also highlights some methodological aspects. The assessment of the benefits of recycling (i.e. credits derived from SRMs productions and avoided primary raw materials) requires a detailed analysis of the outputs. In this analysis, the reliability of the assumptions have been cross-checked and validated with the industrial counterpart, taking into account the composition and quality of the material fractions derived from the recycling.

Moreover, this analysis showed the relevance of a proper selection of the life cycle impact categories. Although the relevance of this phase is clearly recommended by the standards of the series ISO 14040, LCA practitioners sometimes overlook this aspect. In particular, one of the major impact of the process was represented by the potential emission of HF air emissions. This impact was not captured by any of the impact categories initially selected. It is certainly difficult to check all the elementary flows and if/how these are captured by the selected impact assessment methods. However, it is recommended to cross check at least the major direct emissions released by the studied process.

[28] In this scenario, there is no need to send the PV waste to a specialized incineration plant with the abatement of the acid emission. The waste could be treated in small pyrolysis plant located close to the PV dismantling facility.

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Environmental comparison of two organic fraction of municipal solid waste liquid digestate's management modes

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Abstract

The study was realized to examine the environmental impacts related to two possible ways of managing the Anaerobic Digestion (AD) liquid digestate of the organic fraction of municipal solid waste (OFMSW). The comparison, in terms of managing 1 tonne of liquid digestate, was made, using the Life Cycle Assessment (LCA) methodology, between the treatment in a civil Wastewater treatment plant (Wwtp) and the spreading on landfarms. Environmental impacts were evaluated with both a Mid-point and an End-point method. The results showed higher impacts for the Wwtp in relation to the Use-on-land for the majority of the analyzed categories with the Mid-point method. The End-point method considered reported higher damages for the Wwtp compared to the Use-on-land.

1. Introduction

A great amount of AD digestate was produced in Europe during last recent years (Tampio et al., 2016). A significant quantity of solids remain in the digestate that is a liquid to thick slurry withdrawn from anaerobic digester. Great amounts of digestate produced daily can represent an issue related to the movement of it since a big amount of fuel is used for transporting it. As a consequence the solid-liquid separation of raw digestate is often performed onsite. The two fractions follow different paths in terms of treatment; the solid one can be composted or applied directly on land as organic fertilizer (Tambone et al., 2015), while the liquid one is usually treated in a waste-water treatment plant or spreaded on farmlands. The two digestate's disposal applicable ways above mentioned are exploited differently within the countries of European Community in consequence of the diverse emission values on which digestates must conform in order to be no more considered as a waste (Saveyn & Eder, 2014). Both available treatments have advantages and drawbacks. The use on land of digestate causes problems such as pollution of rivers and deterioration of the acquatic life principally due to the nitrogen leaching and penetration into the groundwater (Svoboda et al., 2013). On the other side the application on soils generates an increase in the organic matter on soil (Odlare et al., 2011) as a result of long-term nutrient release (Abubaker et al., 2012). The Wwtp is mostly used to treat civil wastewaters but it is also largely adopted for treating leachates resulting from biological treatments i.e. A.D. and composting. The functioning of these plants guarantees a treated effluent that can be discharged on water bodies, but it is required also the disposal of the sludge produced that represents an important cost item on the overall operating cost of the plant (Wei et al. 2003). In order to better understand which are the environmental impacts related to the treatment of OFMSW's liquid digestate a L.C.A. was conducted, in this study, with reference to two possible treatment paths; Wwtp and Use-on-land. In particular the study focuses on differences due to use-on-land in soils with different characteristics as the percentage content of clay, silt and sand. Different studies were conducted in order to understand the effects of the use on land on diverse types of soil. Bruun et al. (2006) performed an analysis on which values related to N-leaching result variable depending on the soil type considered. Sogn et al. (2018) determined, for the silt and loam soils, a replacement value for the ammonium N fraction in digestates equal to that of mineral fertilizer N, whereas the replacement value was higher in the nutrient poor sandy soil. With regard to Phosphorus, Albacete et al. (2014) found the potential P losses connected to digestate application not to be significantly dependent on soil type, but more related to digestate characteristics. As for the Potassium, Sogn et al. (2018) detected a strong K adsorption in the loamy soil while for the other soils investigated varying degress of leaching were observed.

2. Materials and methods

The study was performed comparing two different scenarios; the first one consisted in the treatment of the OFMSW digestate directly in the wastewater treatment plant (Fig.1) while in the second one the OFMSW digestate is spreaded on farmlands as organic fertilizer (Fig. 2).

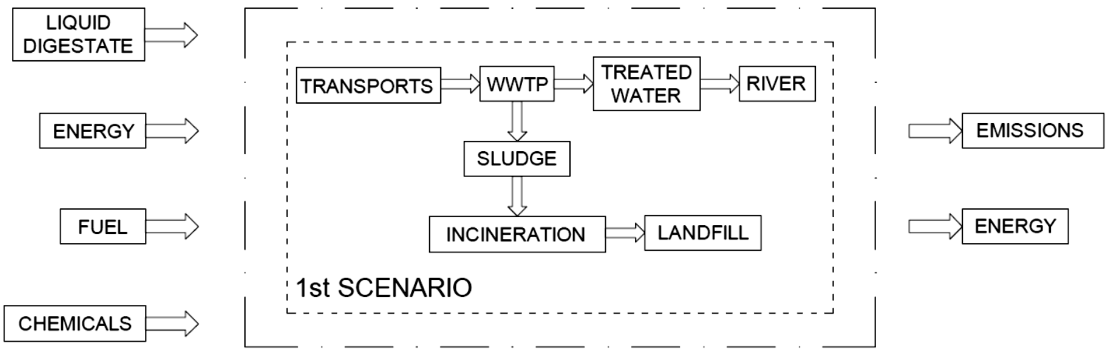


Figure 1: System boundaries of the first scenario

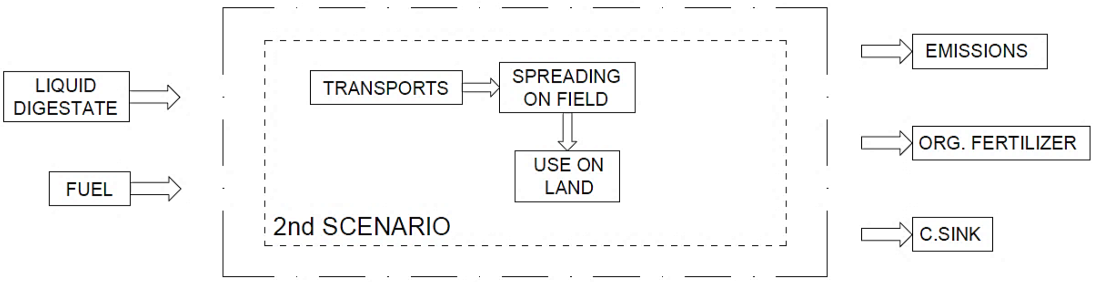


Figure 2: System boundaries of the second scenario

Table 1: Chemical characterization of the OFMSW digestate considered in the study

Parameter	Value	Unit Measurement	References
Moisture Content	68.05±17.06	(kg/kg w.b.)	Di Maria et al., 2016 Di Maria et al., 2013 Di Maria et al., 2013 Schievano et al., 2010 Tambone et al., 2010
Volatile Solids	0.252±0.105	(kg/kg w.b.)	
Total Organic Carbon	0.118±0.074	(kg/kg w.b.)	
Total Kjeldal Nitrogen	0.005±0.0014	(kg/kg w.b.)	
$N\text{-}NH_4^+$	0.0011±0.001	(kg/kg w.b.)	
COD	13130±3822.4	(mg O_2/L)	
Total P	$8.2E^{-4}$±$4.4E^{-4}$	(kg/kg w.b.)	
Total K	0.0023±$5.9E^{-4}$	(kg/kg w.b.)	
Total Ni	$1.31E^{-7}$±$2,45E^{-7}$	(kg/kg w.b.)	
Total Cu	$1.63E^{-5}$±$8.96E^{-6}$	(kg/kg w.b.)	
Total Zn	$3.59E^{-5}$±$2,43E^{-5}$	(kg/kg w.b.)	
Total Hg	$1.61E^{-7}$±$3,26E^{-7}$	(kg/kg w.b.)	
Total Pb	$8.75E^{-6}$±$5,41E^{-6}$	(kg/kg w.b.)	
Total Cd	$2.11E^{-9}$±$2,59E^{-10}$	(kg/kg w.b.)	
Total Cr	$3.31E^{-6}$±$5,40E^{-6}$	(kg/kg w.b.)	

Table 2: Main features of the first scenario

Parameter	Amount	Unit
Diesel	4.74	kg
Wastewater treatment	1	Mg

2.1. The first scenario

In the first scenario 1 tonne of OFMSW liquid digestate (Table 1) was transported 130 km away from the AD plant and treated in a WWTP (Table 2). Three stage wastewater treatment (mechanical, biological, chemical) including sludge digestion (fermentation) was adopted as standard technology, since it is well applicable for European plants. Two outputs exit from the plant; treated water and sludge. The treated water was discharged in a river and the sludge was incinerated in a Waste to Energy (WtE) plant. As a result of the incineration process the solid slags were disposed in a landfill. The energy produced both from landfill and WtE plant was assumed to be sold to the grid.

2.2. The second scenario

In the second scenario 1 tonne of OFMSW liquid digestate (Table 1) was spreaded on landfarms, located near the AD plant (Table 3). The digestate was transported by a slurry-tanker on landfarms and consequently spreaded with a tractor on fields. In order to study the impacts due to the digestate spreading on different soils (clayey, sandy-loamy, coarse-sandy) (Table 4), the same scenario (the second) was applied to each of the soils above mentioned. In particular different use-on-land emissions were identified for each type of soil: Use on $Land_1$=clayey (UL_1), Use on $Land_2$=sandy-loamy (UL_2), Use on $Land_3$=coarse-sandy (UL_3).

Table 3: Main features of the second scenario

Parameter		Amount			Unit
Diesel		1.19			kg
Use-on-land		1			Mg
		UL_1	UL_2	UL_3	
Org. fertilizers	N	2.18	2.56	2.86	kg
	P	0.81	0.81	0.81	kg
	K	2.31	2.31	2.31	kg
Carbon sink		13.4	15.6	15.2	kg

Table 4: Definition of soil types adopted in the study

Soil type	Clay <2µm	Silt 2-20µm	Fine Sand 20-200 µm	Total Sand 20-2000 µm	Org. Mat. 58.7%C	Lime $CaCO_3$
Coarse-Sandy Soil	0-5	0-20	0-50	75-100	≤10	≤10
Sandy-Loamy Soil	10-15	0-30	0-40	55-90	≤10	≤10
Clayey Soil	25-45	0-45		10-75	≤10	≤10

2.3. Environmental analysis

From the environmental point of view, the goal of the present study was to determine the impacts related to the OFMSW liquid digestate treatment on two different scenarios. The functional unit was the treatment of the OFMSW liquid digestate as it comes out by an AD plant after the liquid/solid separation. Based on this, the reference flow adopted was 1m^3 of liquid digestate. Life cycle inventory (LCI) framework was consequential. The backgrounds of the systems were liquid digestate, fuel, energy and chemicals for the first scenario while for the second scenario the backgrounds were liquid digestate and fuel only. The foregrounds of the system for the first scenario were energy and emissions while for the second scenario were only nutrients and emissions. LCI was retrieved from the Ecoinvent 3.3 database (Wernet et al., 2016), Agribalyse (Koch et al., 2016), Easetech database (Clavreul et al., 2014), agroecosystem model Daisy (Hansen et al., 2012) and adjusted on the basis of the experimental and literature data. The foregrounds were not able to influence the backgrounds for which average market values were used.

2.4. Impact assessment method

The ILCD Midpoint (EU, 2012) impact assessment method was used. Impact categories considered in the present study were (Table 5): Global Warming Potential at 100 years (GWP); Human Toxicity, non-cancer effects (HTnc); Human Toxicity, cancer effects (HTc); Particulate Matter (PM); Photochemical Ozone Formation (POF); Acidification (A); Eutrophication Terrestrial (ET); Fresh Water Eutrophication (FWE); Fresh Water ecotoxicity (FWec); mineral, fossil and renewable Resource Depletion (RD). In addition the Endpoint IMPACT 2002+ (Jolliet et al., 2003) method was adopted to evaluate the damages to the human health and to the natural ecosystem.

Damage-oriented impact categories considered in the study were: Human health and Ecosystem quality (Table 6).

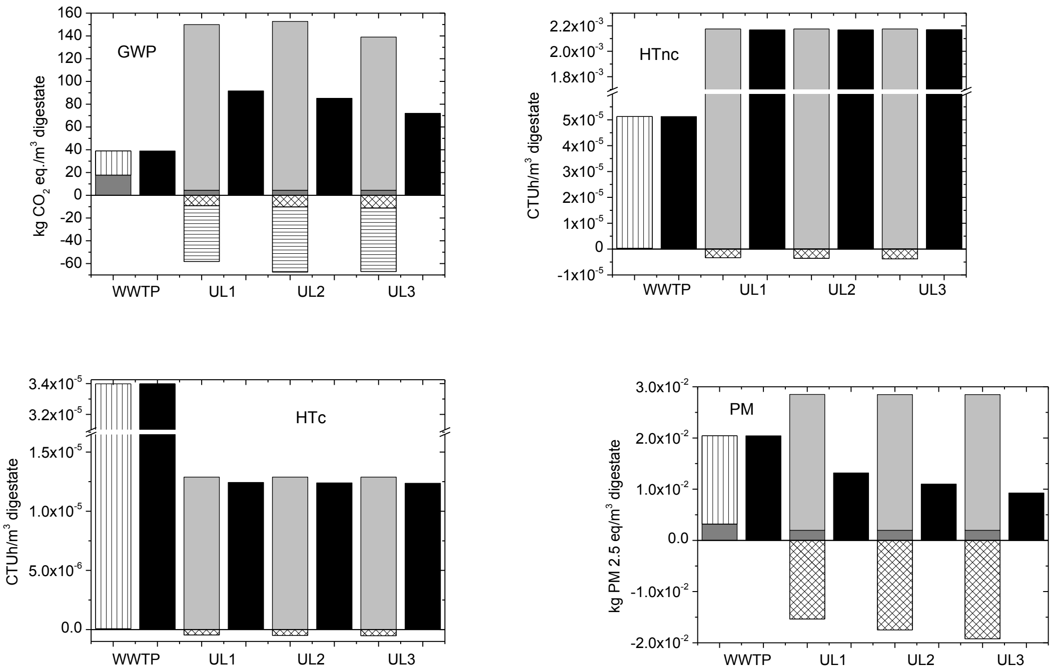
Table 5: Impact assessment categories considered for the ILCD Midpoint method

Imp.Cat	GWP	HTnc	HTc	PM	POF	A	ET	FWE	FWec	RD
Unit	kgCO_2 eq	CTUh	CTUh	kg$PM_{2.5}$ eq	kgNMVOC eq	molcH+eq	molcN eq	kg P eq	CTUe	kgSb eq

Table 6: Impact assessment categories considered for the IMPACT 2002+ method

Impact category	Unit
Hh	DALY
Eq	PDF*m²*yr

3. Results and discussion



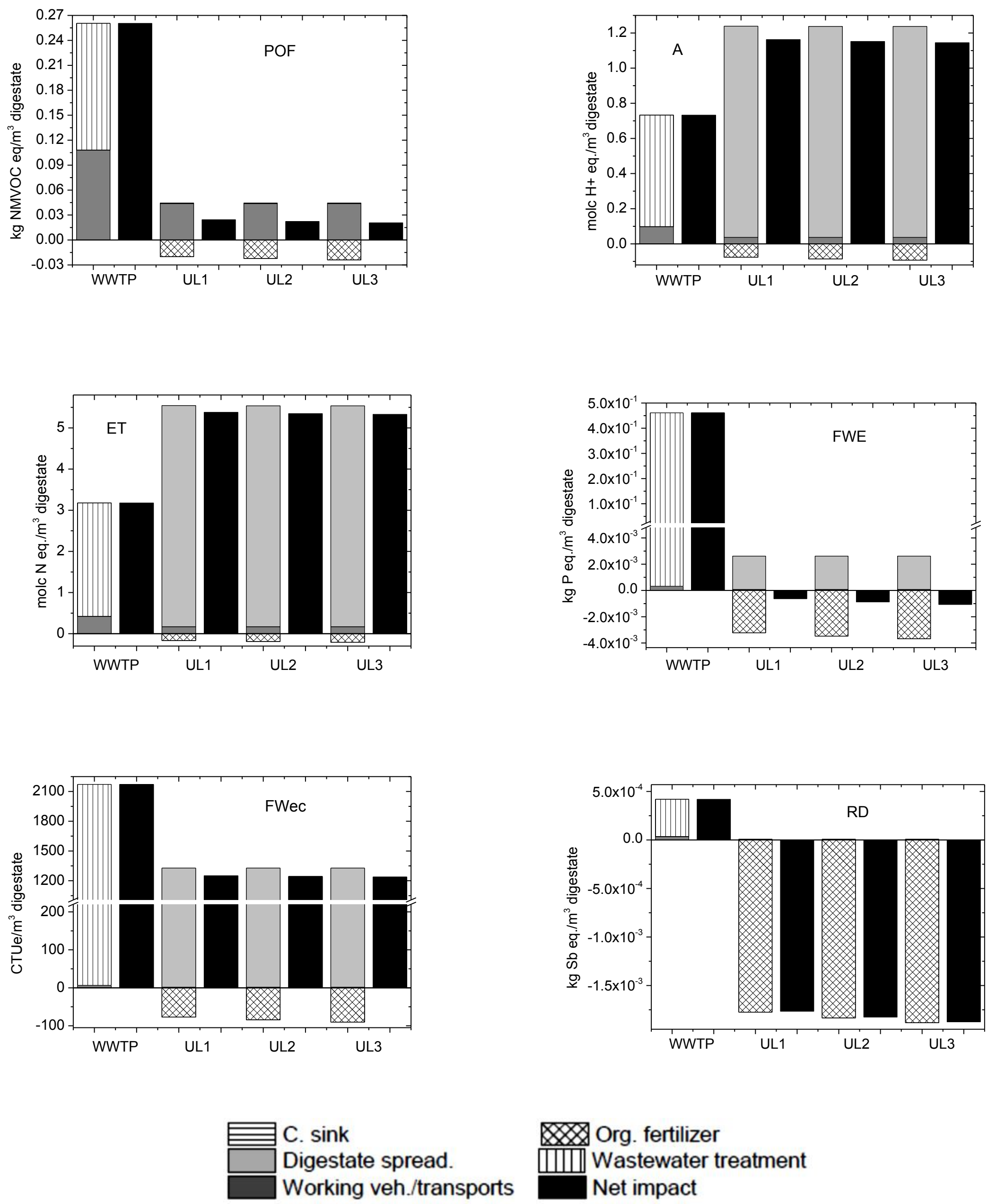


Figure 3: Impacts broken down by the different activities involved in the two scenarios for the categories analyzed with the ILCD Midpoint method

It is worth noting that different values of the N-content were taken up by the plants, depending on the type of soil considered (Table 3). Contrary to the nitrogen, considering that most of the phosphorus and potassium in the processed organic waste is in mineral form, their use from the plants is similar to that of the corresponding commercial fertilizers and the quantities of

Phosphorus and Potassium spreaded on land are considered to be almost completely taken up by the plants (Bundgaard et al., 1993).

The characterization step gave lower values for the first scenario related to the following impact categories: GWP, HTnc, A and ET. The categories A and ET result to be higher in the second scenario compared to the first one because of the bigger emissions to air of nitrogen compounds (mainly NOx, NH_3, N_2O). On the whole PM and RD impacts were found to be smaller for the second scenario due to the positive contribution of mineral fertilizers's substitution.

The evaluation of the Endpoint indicators (Human health and Ecosystem quality) analyzed (Fig. 4) showed that the contribution, in terms of damages, related to the spreading of liquid digestate has proved to be higher compared to treatment in a Wwtp.

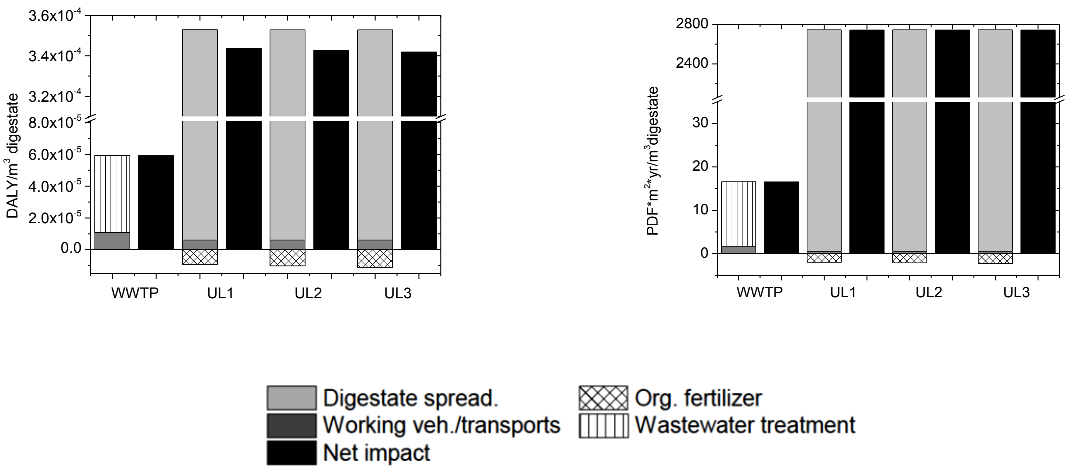


Figure 4: Impacts related to the activities referred to the two scenarios for the Endpoint IMPACT 2002+ method

In the present study, an assumption that mostly influence the results is the adopted agroecosystem model (Daisy), based on which the emissions due to the Use-on-land of the liquid digestate were calculated.

Another assumption potentially influencing the results was the choice to incinerate all of the Wwtp's sludge; this option was chosen in order to avoid confusion between the two scenarios and so the Wwtp Ecoinvent model was adapted to this case (given that in the standard Ecoinvent Wwtp model a part of the sludge is used on land and a part of it is incinerated).

4. Conclusions

The results of the present study show that the treatment of the AD OFMSW's liquid digestate in a Wwtp leads to higher impacts compared to the Use-on-land for the majority of the categories considered in the ILCD Midpoint method. The Endpoint method adopted provides as result of the analysis that the Use-on-land of the digestate causes higher damages to the Human health and to the Ecosystem quality than the Wwtp.

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Life Cycle Thinking for food waste management alternatives, an experience in Costa Rica

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Abstract

Climate change and Food Waste (FW) are relevant matters in the agenda of national governments and international organizations. Together, they have motivated the assessment of FW management and valorization alternatives. This experience aimed to evaluate FW management scenarios through LCA and E-LCC at Instituto TEcnológico de Costa Rica, through a consequential approach. The functional unit was defined as FWkg/year and system boundaries from grave to cradle. Currend disposal, FW biodigestion and FW co-digestion scenarios were assessed, resulting in evident emission savings in the biodigestion scenarios, and similar overall costs in comparison to the current scenario due to the susbstitution of external inputs provided by the digestion processes. The use of this methodology within this context of FLW management is one of the firsts in Costa Rica, in order to achieve systematic yet holistic analysis.

1. Introduction

Climate change remains a relevant issue in the agenda of national governments and international organizations. Food Losses and Waste (FLW) management have gained attention as well, due to its economic, social and environmental effects, including the misuse of production resources and increase of greenhouse emissions (FAO, 2014). Goal 12.3 of the Sustainable Development Goals promotes to halve food waste by 2030 (FAO, 2017), reinforcing the need to embrace a hierarchy in which prevention and valorization is preferred before disposal and landfill options. Efforts have been made in the Latin American and Caribbean Region; however, limited scientific literature is available in this part of the world. Recent inter-sectorial efforts and reseach begun to address FLW, particularly when the estimates in the region suggest that 15% of its food production is lost or wasted (FAO-RLC, 2015). Costa Rica has been a key player in this Region through case studies and networking in FLW, specially in specific agri-food chains and operations (Brenes-Peralta et al., 2015) (Brenes-Peralta, et al.,2017). In parallel, the Country´s legislation has promoted waste management (Asamblea Legislativa de Costa Rica, 2010) and lower carbon emissions (Dirección de Cambio Climático, 2018), hence evaluation of alternatives remains of interest.

The scientific, international, public and private sectors concensus on promoting climate change and FLW actions through evidence-based interventions has led to the constant revision of methodologies (FAO-SAVE FOOD, 2015) (WRI, 2016). The interest to comply with the environmental legislation, and proper FLW management encouraged reseachers to consider technical scopes to asses organic waste management alternatives (Rojas Soto, 2017), including those originated from food waste (Ramírez Ramírez, Campos Rodríguez, Jiménez Morales, & Brenes-Peralta, 2016). However, most papers usually focus on technical scopes, creating a motivation to move forward into more holistic interventions like those possible by Life Cycle Thinking (UNEP/SETAC Life Cycle Initiative, 2011). The later displays an inmense potential and suitability to address several subjects and processes, including waste management (Hunkeler, et al.,2008), (Cleary, 2010) (Bernstad, la Cour Jansen, 2012) and FLW (De Menna, et al., 2018).

Principles of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) for waste management systems have been introduced by Martinez-Sanchez et al (2015); however, the use of LCC is somehow new to assess environmental and societal costs of FW management (De Menna, et al.,2018). Specifically, in the Latin American and Caribbean case, only two conference proceedings from the same researcher were found regarding the use of Life Cycle Thinking in FLW (Giraldo, 2016) (Giraldo de los Ríos, 2017). Therefore, the aim of this work is to evaluate FW managing scenarios, treating the FW within a system delimited to a University campus in Costa Rica, through the application for Life Cycle Thinking in the mentioned context.

2. Methodology

The Administration from the public university called Instituto Tecnológico de Costa Rica (TEC) located in Cartago Province, is interested in pursuing its own waste management system. This case was developed through the Environmental Life Cycle Costing (E-LCC) methodology and the system boundaries were established from grave to cradle, consisting of the collection of the waste once its generared at the institutional restaurant, the transport to a treatment facility, processing and use (or disposal) of the obtained product (fig 1).

(Generation) → collection/transport treatment for FW disposal/ use

Figure 1: System boundaries for the developed study within TEcnológico de Costa Rica Campus to manage FW

Observations and experimental exercices supported the definition of a flow chart for each FW treatment alternative, wich permitted the inventory of imputs and outputs inside the system boundaries. The cost modeling was based on a consequential approach, considering FW kg/year as the functional unit. The obtained results from the inventory correspond to the cost (USD) and emissions (ton of CO_2e) for the yearly treated FW, considering the possible substitution of external imputs if the FW treatment generated product that could be used within the campus.

Data from prior studies in 2016 and 2017 indicated that the Institutional Restaurant generates 229 kg/day of food waste from edible or inedible discards (Brenes-Peralta, et al., 2017), which are currently disposed through conventional and authorized third parties. The suitable alternatives for TEC after empirical results were:

- Biodigestion (BD): a mixture of FW with an inoculant would have the potential to generate biogas and treat the food waste (Ávila-Hernández, Campos-Rodríguez, Brenes-Peralta, & Jiménes-Morales, 2018).
- Compost production (CP): experiments allowed the researchers to select the option that presented best performance, consisting of a composting method known as Takakura, which would have an inoculated substrate that receives the food waste and degradate it into compost. It achieved a higher mass reduction than other methods, adecquate pH, moisture and no presence of leachates during the process (Chaves-Arias, Campos–Rodríguez, Brenes-Peralta, & Jiménez-Morales, 2017). Its use in experimental plots showed superior plant growth, weight and diameter (Ramírez Ramírez, Campos Rodríguez, Jiménez Morales, & Brenes-Peralta, 2016).
- Animal feed production (AF): it consisted of a fermentation stabilization process at a lower cost than commercial animal feed, and possibilities for adecquate diet balances with revenues due to a positive yield in meat production (González-Rojas, Brenes-Peralta, Jiménez-Morales, Vaquerano-Pineda, & Campos-Rodríguez, 2017).

Since BD showed the lowest operational cost of the three possible treatment options, the LCA was applied with a particular focus in the biodigestion alternative. Consequently, LCA and E-LCC is executed for three scenarios: current disposal (CD), Biodigestion scenario 1 (BD1) and Biodigestion scenario 2 (BD2). BD1 consists of FW digestion within the premises with the assumption of transporting cattle manure from a nerby farm to start the digestion process, and BD2 supposes the co-digestion of FW and catlle manure in a ratio of 2, ratio according to Cunsheng, G. et al (2013). The manure has to be transported because there are no current cattle activities within the premises to support this input. The quantity of obtained products from BD1 and BD2 are based on literature reviews regarding biogas production and calorific potentials (adapted from Steffen, R., et al. 1998). Its substitution is considered for local inputs like LPG used for commercial and domestic purposes in Costa Rica and market price (RECOPE, 2018), as well as commercial compost and its market price (Brenes-Peralta, L; & Jiménez-Morales, M. , 2013). The emissions factors are calculated under current Costa Rican data provided by the official competent institution (IMN, 2017). Information from scientific papers, environmental declarations, Costa Rican public services intuitions, market prices and questionnaires were also used to generate this case.

3. Outcomes

The primary data from 2017, allowed obtaining inputs for the LCA inventory, such as materials, costs, yield and product composition, as well as a technical overview of the potential of each alternative. These preliminary results showed that three FW treatment alternatives different from the current disposal action were technically fit, due to satisfactory results for pH, temperature, moisture, and microbiological indicators for composting, biodigestion and animal feed production (annex 1). The operational costs per kilogram of treated waste were higher than the landfill disposal value, however CP was the most expensive one, followed by AF and BD. Environmentally, the three alternatives would avoid CO_2 emissions from landfill disposal but that study did not include the emissions of each treatment options. The LCA and E-LCC done in this case to compare among the CD scenario and two biodigestion scenarios (BD1 and BD2) allowed the display of a more detailed assessment, as seen in Figures 2 and 3.

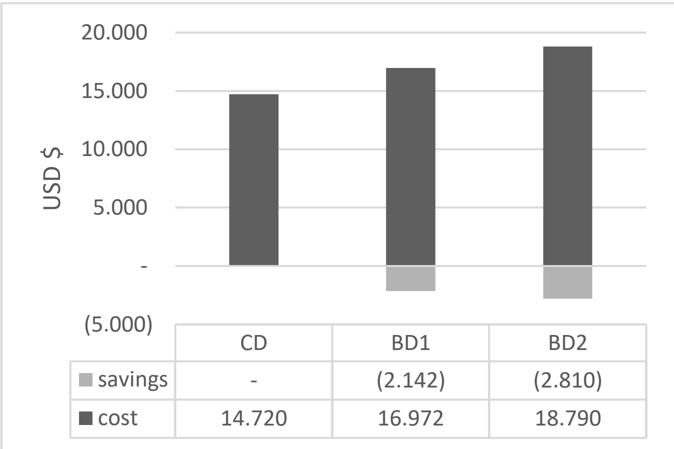

Figure 2: Cost of each FW management scenario

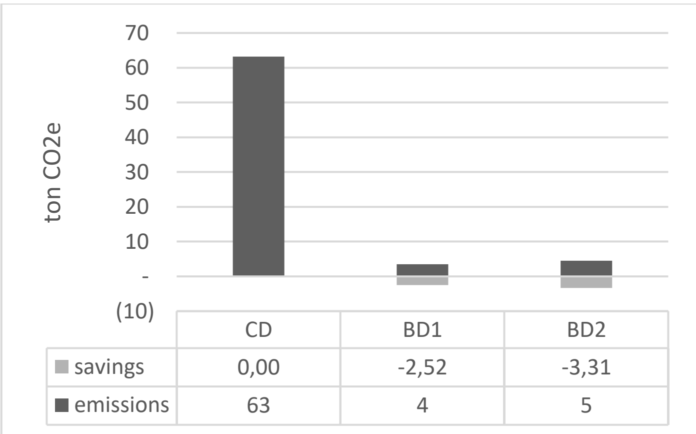

Figure 3: Emissions of each FW management scenario

Table 1: Preliminary evaluations from 2017 for current and alternative scenarios

Alternative	Assessment		
	Technical	**Cost**	**Environmental**
Current scenario	Neutral pH which may lead to pathogens growth, vectors growth, leachates, unpleasant odors, and others.	Current cost represents the amount charged to TEC by the Municipality: 0,96 USD kg/year.	Expected CO_2 emissions from landfill disposal would be maintained, however the calculations did not include associated emissions from transport and other environmental effects.
BD	Temperature during the process and initial pH suggest biodegradation and biogas production was possible. Gas production was observed constantly. C/N relation has to be observed for further gas production.	Most of the costs are due to laboring (collection of FW, biodigestors charge and monitoring) and the inoculant acquired commercially. It sums 3,2 USD kg/year.	Avoided 44,7 ton of CO2/year from landfill emissions. It is necessary to consider that gas will be used as energy source and digestate as soil amendment.
CP	Temperature and pH during the process were correct for proper composting, resulting in no soil pathogens. Final pH and moisture present an adecqute range for soil amendment.	Costs include the substrate price and laboring costs due to collection of FW, addition and mixing with inoculated substrate, and monitoring. Total cost of 24,32 USD kg/year, lower than most chemical fertilizers in Costa Rica.	Avoided 44,7 ton of CO_2/year from landfill emissions. It is necessary to consider that CO_2 emissions from the composting process as well, not calculated in this excersice.
AF	The fermentation process allows the stabilization through a lowering of the pH, inhibiting pathogens. The obtained product offers more energy/kg than fresh FW and was able to be inserted in a balanced diet according to NCR (*1).	Costs include laboring costs for collection of FW, silos filling and monitoring. Fermentation inoculants and semoline acquisition should be added; summing 10,56 USD kg/year, lower than the similar energy based commercial feed in the local market.	Avoided 44,7 ton of CO_2/year from landfill emissions. It is necessary to consider the emissions of the process itself, but from its anaerobic nature it is believed to be lower than other alternatives.

*1 National Research Council, Committee on Nutrient Requirements of Swine, Board on Agriculture and Natural Resources, Division on Earth and Life Studies

Due to potential savings in the purchase of LPG used at the institutional restaurant and commercial compost for the Agricultural Department of TEC, BD2 is the scenario with highest monetary savings; however, the cattle manure transportantion increases the costs and emissions compared to BD1. This later presents an overall cost (including savings) similar to the current disposal, with an evident decrease in emissions that are not transferred by the disposal price at the landfill from the CD scenario.

This is preferred by the administration, motivated mostly by the current legislation and the National Policy for Carbon Neutrality (Dirección de Cambio Climático, 2018). The biogas use is reflected by the substitution of LGP purchases and not by electricity generation since the Costa Rican electrical grid is already supported by more than 90% of renewable energies (ICE, 2015). Consequent with the previous statements, the Agricultural Deparments from TEC have also began the purchase of organic fertilizers; therefore, the digestate obtained from BD1 and BD2 would substitute this external supply with the correspondent monetary and emissions savings.

4. Conclusions

The available information after this work allows future modelling of possible scenarios for each management alternative, offering a more robust backround and support for the decision-making process at TEC for FW valorization.

Composting, biodigestion and animal feed production can be considered suitable FW management alternatives. Biodigestion appeared as one of the most feasible; and the evaluation of digestion and co-digestion of FW scenarios presents a wider assessment on cost and environmental implications of each situation.

The use of LCA and E-LCC for FW presented in this work is one of the firsts of its kind in Costa Rica and the Region of Latin America and the Caribeean. In this way, it leads a process towards more sistematic yet holistic approaches for the reduction and valorization of FW in a future, once more studies apply this methodology.

Further research should be carried out to also monetize externalities and include Societal Costing (S-LCC) that could later on aid in policy construction, execution and evaluation for TEC, as well as for related institutions dealing with health services, environment and public funding, at a local, national or regional level.

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The way towards sustainable policies: combining LCA and LCC for construction waste management in the region of Flanders, Belgium

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Abstract

The lack of specific recycling quality standards for Construction & Demolition Waste (CDW) recycling product, led some countries (like The Netherlands, Belgium, Germany) to invest for low-grade recycling, for instance as road base and filling materials in road construction. CDW can, however, replace virgin natural aggregates in structural concrete production. The objective of the study is to combine LCA and LCC models to identify the environmental and economic driving factors in CDW management for the region of Flanders, in Belgium. The results of the two models can provide useful information for policymakers to promote the aspects contributing to sustainability and to limit the ones creating a barrier. Although LCA and LCC led to some discordant conclusions, the CDW recycling represented an interesting case for environmental and economic analysis integration, due to the dynamic and complexity of the system.

1. Introduction

The choice for the most efficient and cost-effective policy decision can prove to be challenging, as the decision making involves trade-offs between economic and environmental aspects. To ensure the environmental gain and the economic success of policy instruments, policy-making should be supported by decision tools which analyse (i) caused & avoided environmental impacts, and (ii) economic cost & benefits (Yilmaz et al., 2015). The use of Life Cycle Thinking (LCT) in decision making offers a way of providing policy support following the three pillars of sustainable development. Within the LCT framework, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are two well-known tools. Since both methodologies use an LCT approach, the goal and scope, the functional unit and the system boundaries of the study could be similar. Thus, the results from both methodologies may be combined. However, due to the differences in metrics, temporal scale and weights, a combined environmental/economic analysis can lead to confusing and conflicting results and the integrated approach is seldom used to solve policy issues (Hoogmartens et al., 2014).
The development of effective policies is fundamental to improve the sustainability of waste management. Therefore, the combination of LCA and LCC to highlights the environmental and economic drivers in waste management is gaining more and more attention to stimulate waste recycling. In particular, construction and demolition waste (CDW) is a waste occurring during buildings construction and demolition activities. In 2011, CDW represented the 35% of waste generated globally (Schrör, 2011).

Even though CDW composition varies across countries, due to the variety of materials used, the most common fractions consist of crushed concrete, bricks, tiles, and small traces (<3% in total) of wood, glass, plastic and cardboard (Llatas, 2013). Furthermore, the CDW generation rate has a strong regional character. Hence it is not homogeneous among the different EU members. By some estimates, France, England, Germany and The Netherlands together account for approximately 70% of all CDW generated in Europe.

The Waste Framework Directive 2008/98/EC has set the goal of 70% CDW recycling by 2020. However, today only a few countries (e.g. Germany, Denmark, Belgium and The Netherlands) have already reached in 2012 the minimum requirement of 70% recycling indicated by the Waste Framework Directive 2008/98/EC. In other countries, sustainable CDW management it is still a rudimentary policy stage, and simple landfilling remains the most common end-of-life fate of CDW.

The lack of specific quality standards and specification for CDW recycling product led some countries (like The Netherlands, Belgium, Germany) to invest for more low-grade applications, for instance as road base and filling materials in road construction (Mulder et al., 2007). The low-grade application is also known as downcycling. CDW can also represent valuable material for the construction industry, since it can replace virgin natural aggregates in structural concrete production (Behera et al., 2014). The use of Recycled Aggregates (RA) from CDW in concrete production may decrease the amount of CDW to be managed, increase the economic value of the recycled material and reduce the quantity of natural aggregates employed in concrete production. On the other hand, there are technical and economic barriers limiting the use of CDW in the high-grade application. In comparison to natural aggregates, the quality of the recycled CDW is considered to be low, due to the presence of impurities and its poor size distribution (Behera et al., 2014). Advanced recycling techniques have been developed to minimise the presence of impurities without losing the integrity of the original CDW aggregates. However, the cost and the early development stage of these advanced recycling processes negatively affect the large-scale application of CDW aggregates in concrete production.

The study aims to combine environmental and economic analysis to highlight the driving factors in CDW management. Results from both analysis can then be used in policy-making to strive on the factors promoting sustainability and to limit on the ones representing a barrier to sustainable development.

2. Methods

2.1. Combing LCA and LCC

Despite some similarities in their approach, LCA and LCC are designed to answer different questions. While LCA evaluates the environmental performances of alternative product systems, LCC compares the cost-effectiveness of these alternatives from the perspective of the economic decision makers (Norris, 2001).

The goal of the presented LCA study is to compare the environmental performances of alternative scenarios in CDW management.

Accordingly, the goal of the LCC is to determine the costs and benefits related to the considered alternatives, from the perspective of the various actors involved. Data for both LCA and LCC studies are based, whenever possible, on local data from the region of Flanders, in Belgium. The LCA and LCC share the same system boundaries for each scenario, and they are based on the same assumptions and functional unit.

Four scenarios are analysed, representing four possible alternatives in CDW end-of-life: (i) S1-Landfilling; (ii) S2-Downcycling; (iii) S3-Recycling and (iv) S4-Recycling after selective demolition (Recycling_Sel Dem).

All four scenarios supply the demands of two market: high quality, coarse aggregates for concrete production and low-quality, fine aggregates for road construction. In each scenario, both demands are supplied by natural aggregates (NA) and RA in a complementary way. Hence, when RA supplies one of the two markets, the demand from the other market is supplied by the NA, more specifically river sand as fine NA for road construction and crushed stones as coarse NA for concrete production.

The chosen functional unit refers to a high-capacity CDW recycling plant (CDW-RP), able to treat 350 tonnes/h. The chosen CDW-RP works for 300 days per year, 8h each day, for a total capacity of 840,000 tonnes of CDW per year. Therefore, the functional unit of the study, common for all scenarios, is the management of 840,000 tonnes of CDW.

In S1-landfilling, the CDW is directly landfilled, and the road construction and the concrete market are directly supplied by fine and coarse NA.

In S2-downcycling, the CDW is used to produce low quality fine aggregates for the road construction market. Therefore, a traditional "*basic CDW-RP*" is used, composed of a vibrating feeder, a magnet, a crusher and a horizontal screen, as described in Ding et al. (2016). This simple configuration is sufficient to remove some of the impurities from the CDW and to produce fine RA for low-quality applications.

In S3-recycling, the CDW is used to produce high-quality coarse aggregates to be used in concrete production and, consequently, a more advanced recycling treatment is required. Therefore an "*advanced* CDW-RP" is used, composed by a vibrating feeder, a magnet, a manual separation step, a crusher, a first horizontal screen, an air sifter, an eddy current separator, a second horizontal screen and an air jig, as described in Oliveira Neto et al. (2016).

In S4-recycling after selective demolition, the selective demolition allows segregating recyclable materials before demolition (especially wood and various metals). It is therefore assumed that all the impurities are removed during selective demolition, and only clean inert material is contained in the CDW. The sorted materials (4% metals and 1% wood) are sold in the recycling market. As all impurities are removed from the CDW during selective demolition, a *"basic CDW-RP"* is then sufficient to produce high-quality coarse aggregates to be used in concrete production. Therefore, in S4, the CDW-RP presents the same configuration as already described for S2. According to Coelho and de Brito, (2013) and Symonds Group (1999), the basic CDW-RP consumes 2.2 MJ of electricity per ton of CDW treated, while the advanced CDW-RP consumes 8.8 MJ per ton of CDW.

2.2. Environmental and economic LCI

During Life Cycle Inventory phase, data are collected for each unit process, regarding all relevant inputs and outputs of energy and mass (in the case of LCA) and monetary cash flows (in the case of the LCC).

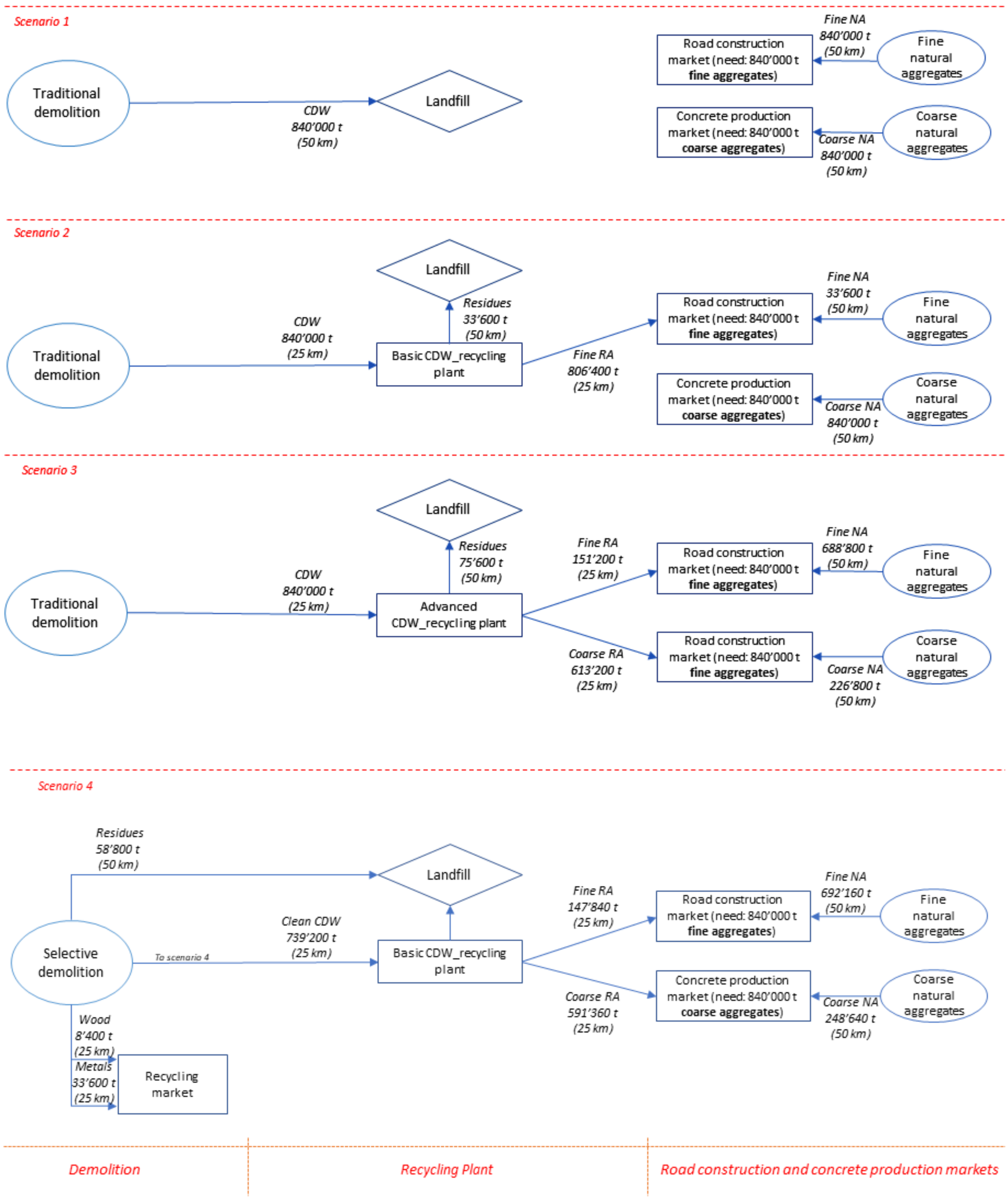

Figure 1: Mass flows and distances for the four considered scenarios (S-1: landfilling; S-2: downcycling; S-3: recycling; S-4: recycling after selective demolition

The inventory data used in this study reflects, whenever possible, the current CDW management conditions in Flanders, as it was collected through Belgian

sectorial reports on CDW and direct communications with Flemish CDW managers. Whenever data were not available for Flanders, data obtained from similar projects, published in the scientific literature or foreigner sectorial reports are considered.
Figure 1 describes the mass flows for each scenario, which are used as inputs for the environmental and economic analysis. Table 1 describes all economic input used to build the economic inventory for the LCC.

Table 1: Economic data

Common economic data				
Transport costs	0,12	€/t/km		
Landfill Tax	55	€/t	Landifill tax in Flanders	
Concrete production and Road construction sectors				
Price of NA for concrete production	10	€/t	Current market prices in Flanders	
Price of NA for road construction	5	€/t		
Scenario 1				
<u>Demolition</u>				
Average work hours per ton of C&D produced (traditional demolition)	0,16	t/h	Average among differently skilled worker	(Coelho and de Brito, 2011); Personal communication with demolition companies in Flanders
Cost per hour of labour in demolition	20	€/h		
Scenario 2				
<u>Demolition</u>				
Average work hours per ton of C&D produced (traditional demolition)	0,16	t/h	Average among differently skilled worker	(Coelho and de Brito, 2011); Personal communication with demolition companies in Flanders
Cost per hour of labour in demolition	20	€/h		
CDW Recycling Plant				
Work hours per year (300d/8h)	2400	h/year		
<u>Revenues</u>				
Gate fee for mix CDW	3	€/t	Current price in Flanders	Personal communication with CDW recycling plant managers in Flanders
Selling Low-Quality fine RA	3	€/t		

Costs				
Investment costs_Basic CDW plant (CAPEX)	8’121’138	€/20y	Initial investment costs to be divided by 20 years	
Operating costs per year_Basic CDW Plant (OPEX)	4’174’260	€/y	Including maintenance costs, labour costs and landfilling of residues	(Coelho and de Brito, 2013; Symonds Group ltd, 1999)
Scenario 3				
Demolition				
Average work hours per ton of C&D produced (traditional demolition)	0,16	h/t	Average among differently skilled worker	(Coelho and de Brito, 2011); Personal communication with demolition companies in Flanders
Cost per hour of labour in demolition	20	€/h		
CDW Recycling Plant				
Work hours per year (300d/8h)	2400	h/year		
Revenues				
Gate fee for mix CDW	3	€/t	Current price in Flanders	Personal communication with CDW recycling plant managers in Flanders
Selling high-quality coarse RA	8	€/t		
Selling low-Quality fine RA	3	€/t		
Costs				
Investment costs_Advanced CDW plant (CAPEX)	10.096.696	€/20y	Initial investment costs to be divided by 20 years	
Operating costs per year_Advanced CDW Plant (OPEX)	5’902’521	€/y	Including maintenance costs, labour costs and landfilling of residues	(Coelho and de Brito, 2013; Symonds Group ltd, 1999)

Scenario 4				
<u>Demolition</u>				
Average work hours per ton of C&D produced (selective demolition)	0,96	h/t	Average among differently skilled worker	(Coelho and de Brito, 2011); Personal communication with demolition companies in Flanders
Cost per hour of labour in demolition	20	€/h		
Revenue from recovered metals	150	€/t		(Coelho and de Brito, 2011)
Revenue from recovered wood	22.5	€/t		
CDW Recycling Plant				
Work hours per year (300d/8h)	2400	h/year		
<u>Revenues</u>				
Gate fee for CDW from selective demolition	2	€/t	Current price in Flanders	Personal communication with CDW recycling plant managers in Flanders
Selling high-quality coarse RA	8	€/t		
Selling low-Quality fine RA	3	€/t		
<u>Costs</u>				
Investment costs_Basic CDW plant (CAPEX)	8’121’138	€/20y	Initial investment costs to be divided by 20 years	
Operating costs per year_Basic CDW Plant (OPEX)	4’174’260	€/y	Including maintenance costs, labour costs and landfilling of residues	(Coelho and de Brito, 2013; Symonds Group Ltd, 1999)

2.3. Life cycle impact assessment and results analysis

In life cycle impact assessment (LCIA) phase, the environmental releases are accounted and weighted to deliver an environmental profile that can be expressed in terms of contributions to several impact categories. Environmental impacts for the present study are evaluated using the Recipe 1.08 methods, with a midpoint hierarchic perspective (Goedkoop et al., 2009). Following the purpose of using LCA for policy support purposes, the environmental results from the different scenarios must be easily comparable and understandable. Recipe 1.08 midpoint provides results for several impact categories.

Therefore, a normalisation procedure in Recipe allows to add up results for the different categories, since they have the same units. The results of the LCA for the current study are normalised to person-equivalent (PE).
In economic terms, the total yearly economic profit (revenues-cost) is calculated for each sector. For the demolition sector, the costs are represented by the labour cost for demolition, the landfill tax, the transport of residues to the landfill and the gate fee to pay to the CDW-RP. The only accounted source of revenue during the demolition phase is represented by the metals recovery from selective demolition, occurring in S4.
The total yearly profit for the recycling sector (ProfitRecSect /y) in each scenario has been calculated according to the following equation:

$$\frac{Profit_{CDW_{RP}}}{y} = \frac{Revenue}{y} - (OPEX) - (\frac{CAPEX}{20})$$

Where $Profit_{CDW\_RP}$ represents the yearly revenue for the CDW_RP, OPEX is the yearly expenditure, and CAPEX is the initial investment. Because of the yearly based functional unit, the CAPEX is divided by 20 years, which represents the average lifetime of the CDW recycling plant.
For concrete and road construction sector, only the price for the purchasing and transport of RA and NA is considered. The results for the LCA and LCC are presented in Figure 2.

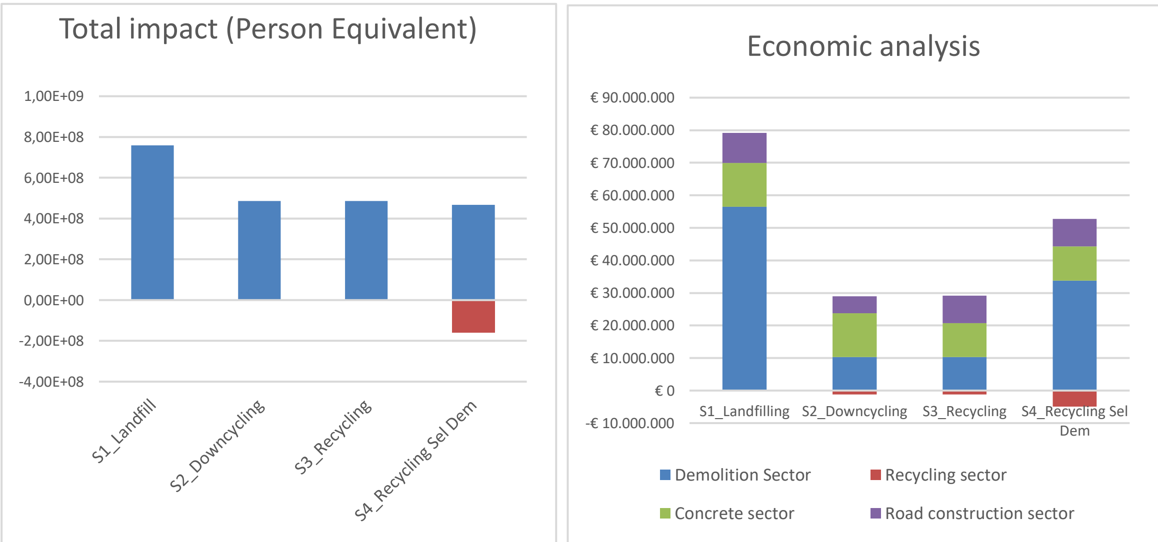

Figure 2: Environmental (left) and economic (right) results

Results from the environmental analysis in Figure 2 (left) show that the scenario 4 (selective demolition) is the one bearing the least environmental impacts, while scenario 1 (landfilling) is the one with the highest environmental impacts. The red part of the column in S4 represents the avoided impacts of metals and wood recycling, recovered during selective demolition. The key factors driving these results are the transports of aggregates and CDW to landfill or the recycling site, and the production of natural aggregates for concrete production. The results from the LCC in Figure 2 (right) show that scenario 1 has the highest costs, due to the landfill tax. Scenario 4 is the second most costly scenario, due to the higher cost of the selective demolition compared to the traditional demolition. Revenues for the CDW recycling plant come from the gate fee (paid to the CDW recycling plant to accept CDW) and from the selling of the RA. Transport results also demonstrated an important role regarding environmental and economic aspects.

3. Conclusions

The combined analysis of LCA and LCC results highlight the environmental and economic key factors which need to be reached to attain a more sustainable CDW management. The scenarios that substitute natural aggregates with recycled aggregates from CDW sensibly reduce the overall environmental impact of the system. However, the investment costs for the CDW recycling plant and the cost of selective demolition may be the economic factors limiting CDW high-quality recycling. Landfill tax, gate fees to recycling plant and tax on natural aggregates mining are the most effective elements for policy strategies to drive the CDW management system towards sustainable practices.
The CDW recycling represented an interesting case for environmental and economic analysis integration, due to the dynamic and complexity of the system: (i) different actors involved, (ii) high variability of quantity and prices due to volatile market conditions, (iii) market effects of policy decisions (mandatory recycling targets, mining and landfill taxes, recycling subsidies, etc.).

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Highlighting food waste in school canteens: a preliminary assessment of the associated environmental and economic impacts

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Abstract

Food demands is increasing as the population grows, but paradoxically food loss and waste is raising as well unless actions are taken with urgency by all stakeholders, including public sector. A way of address food waste by public institutions are in public school canteens, which involves final consumers where most of the waste is produced and implies an educational approach. This research aims to assess the environmental and economic impact of a meal eaten at school canteen, by quantifying and highlighting the food waste impact. The study combines methodologies: Life Cycle Assessment, Environmental Life Cycle Costing; and Visual assessment; collecting primary data from the catering service and secondary data from literature and software. The functional unit has been defined as the meal eaten by nursery school students. Results revealed that the biggest environmental impact is produced at food level due to its production and packaging. The biggest cost is embedder in the preparation phase, due to workforce involved. Visual assessment exposes side dish as the most wasted (about 80% of it).

1. Introduction

The rise of global population will cause a projected 71% increase of food demand by 2050 (United Nations, 2017). This will represent a challenge for food security in a world where about 815 million people are undernourished and the additionally 2 billion will face this risk within 2050 (UN SDG, 2018). Food systems will be able to meet food demand by 2050, only by implementing simultaneous multiple measures (Conijn *et al.*, 2018), as recognized as well by United Nation with the promotion of selected interventions targeting specific goals within 2030 (Sustainable Development Goals, SDG) (United Nations, 2015). The SDG 12.3 target “halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”. FAO 2011 (FAO, 2011) estimated that approximately one-third of food produced for human consumption (or 1.3 billion tons) was lost or wasted globally, with a total carbon footprint of ab. 4.4 Gt $CO_{2\,eq}$ per year (FAO, 2015), and a blue water footprint of ab. 250 km^3 (FAO, 2013). In addition, the economic impact of food waste is estimated in USD 2.6 trillion (FAO, 2014), and social impacts might be considered as well. The complexity of this matter led government and international agencies to take different positions causing the development of different definitions and methodological approaches to assess food waste. Due to the lack of a harmonized framework, policies and strategies addressing Food Loss and Waste (FLW) are actively implemented only in a limited number of countries (Burgos *et al.*, 2016).

In developed countries, food waste is mainly generated at household level (European Commission and Report, 2010; Janssen *et al.*, 2016), therefore policy interventions further raise awareness are difficult to find. But, on the other hand, there are institutions, as school canteens, often managed by public entities where policy actions can cover the wider spectrum of the food waste issue directly targeting consumers and providing as well an educative approach for next consumers generation.

Food waste at school canteens are being studied by implementing different approaches. The following four approaches have been identified. On one hand, there are studies mainly focused on food **waste quantification** (Hanks, Wansink and Just, 2014; Falasconi *et al.*, 2015; Costello, Birisci and McGarvey, 2016; Eriksson *et al.*, 2017, 2018; Biltoft-Jensen *et al.*, 2018; Boschini *et al.*, 2018) by applying weighting, visual techniques or life cycle assessment. There are studies focused on **raise awareness** between the students by using the canteen as the way of reach them (United States Department of Agriculture, 2016; Derqui and Fernandez, 2017; Pinto *et al.*, 2018). Another approach is focused on **nutrition** and diet, considering food waste an issue of undernutrition or overnutrition (De Silva-Sanigorski *et al.*, 2011; Clarke *et al.*, 2013) and studies focused on address **policy makers** by highlighting food waste hotspots (by quantifying) and suggesting actions to correct them (Cerutti *et al.*, 2016, 2018). All studies mentioned are recent, since the oldest cited is from 2013. Therefore, food waste at school canteen is a novelty topic, but there is a need of holistic approaches to deal with this multi-stakeholder and multi-impact threat.

A way of bringing a holistic approach is by applying to the food waste issue life cycle thinking, as life cycle assessment (LCA), life cycle costing (LCC), and visual assessment methodologies. The combination of methodologies identify hotspots on the environmental and economic dimension of food and food waste, from its production and consumption, and from raw materials to waste (Steen, 2005; Hunkeler, Lichtenvort and Rebitzer, 2008).

Thus, this research aims at assessing the environmental and economic impact of food waste at school canteen level, by using a mix of methods such as LCA, LCC and visual assessment. The outcome will allow to understand, highlight and communicate the issue of food waste to the different stakeholders, from students to policy makers and business, in environmental and economic terms.

2. Methodology

This research has been conducted in the nursery public schools of Cento (Bologna, Italy) in 2017-2018. Data from 13 nursery school canteens has been addressed to assess the environmental and economic impact of the meal eaten at lunch.

The methodology selected to reach the aim of the research has been LCA and E-LCC. In this preliminary study, the meal eaten has been considered as the functional unit (FU).

FU is mass based and is equivalent to the average grams of food eaten by students in a meal. It was calculated considering the meal prepared according to pediatric guidelines, which contain the amount of nutrients needed by nursery school students, plus a 10 percent added by the catering service (and requested by the public procurement contract) minus the food that is not consumed at the canteen (food waste). The selection of this functional unit was selected because it represents the real students' food intake during lunchtime at school. All the impacts of the food supply chain, including food waste disposal, were allocated on this functional unit.

Data from a catering service preparing more than 1270 meals per day has been collected, considering for this research the 95864 meals per year with a specific composition, origin, and weight, to feed nursery school students. Therefore, those menus have been allocated on an average menu. This means that starting from several menus for 180 days of school, it was possible to reach one menu containing the average of all. Eaten meal was identified by knowing the composition and weight of each dish: first dish, second dish, side dish, bread and fruit; its frequency along the year, adding the 10 percent extra of each ingredient provided by the canteen, net of the food waste along the different phases.

The following environmental impacts were considered and characterized: global warming (assessed by using Global Warming Potential, GWP), photochemical oxidation (assessed by using Photochemical Ozone Creating Potential,PQO), acidification (assessed by using acidification potential, AC), and eutrophication (assessed by using eutrophication potential, EU). These impact categories have been selected because they are the minimum requested to be published in an Environmental Product Declaration (EPD), which contains the relevant impacts affected the different ecosystems (International EPD ® System, 2015). The economic indicator used was the cost paid for each item or service considered in the phases detailed below in Table 1. This indicator is expressed in euro of the paid menu.

The environmental and economic impacts were calculated and analysed in the phases and sub phases indicated in figure 1. Those are the phases needed to provide a meal in an Italian school canteen. Therefore, the perspective adopted was "cradle-to-grave".

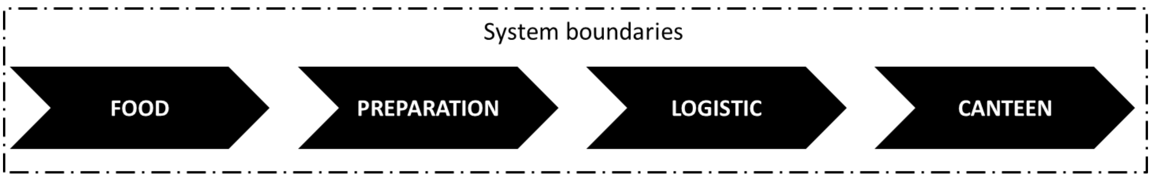

Figure 1: System boundaries and phases for this research

The LCIs have been based mainly on data from the literature and primary data from the catering company referring 2016. Table 1 shows the phases and sub-phases considered and the sources of the information.

Table 1: Phases, sub phases and data sources

<table>
<tr><th></th><th>Subphrases</th><th>Environmental data source</th><th>Economic data source</th></tr>
<tr><td rowspan="3">Food</td><td>Food production</td><td rowspan="7">Bibliography
Environmental Product Declaration (EPD 2013 version 1.03)
SimaPro (PRe’ consultants, 2016)
Ecoinvent (Wernet et al., 2016)
Primary data: Catering service and kitchen visit</td><td rowspan="10">Catering service</td></tr>
<tr><td>Food packaging</td></tr>
<tr><td>Transportation (from the grocery to the kitchen)</td></tr>
<tr><td rowspan="5">Preparation</td><td>Energy, gas and water (*)</td></tr>
<tr><td>Cleaning products</td></tr>
<tr><td>Disposal: organic and non-organic</td></tr>
<tr><td>Waste water</td></tr>
<tr><td colspan="2">Labour</td></tr>
<tr><td rowspan="2">Logistic</td><td>Vehicles</td><td rowspan="4">Bibliography
Environmental Product Declaration (EPD 2013 version 1.03)
SimaPro (PRe’ consultants, 2016)
Ecoinvent (Wernet et al., 2016)
Catering service and school visiting</td></tr>
<tr><td>Km (route)</td></tr>
<tr><td rowspan="3">Consumption</td><td>Energy and water (**)</td><td rowspan="2">Bibliography</td></tr>
<tr><td>Disposal: organic and non-organic</td></tr>
<tr><td colspan="2">Labour</td><td>Catering service</td></tr>
</table>

(*) Consumption from appliance, lighting and heating.

(**) Consumption from appliance.

The following food waste flows were considered:

- Preparation waste, which represent a percentage in every product of the total amount purchased. It is defined as preparation waste and it includes non-edible parts of food.
- Consumption waste, which include serving waste and plate waste (food left in students’ dishes).

Data from preparation waste was provided by the catering service, while plate and serving waste were assessed at the school by using a visual analysis technique.

Visits to schools with students from 3 to 10 years old were performed in a school with two refectories for a week. A quarter-waste visual assessment carried out to analyse the amount and composition of plate and serving. This technique has been validated and is recognized as a reliable and accurate visual technique comparing others time-consuming (Hanks, Wansink and Just, 2014). Figure 2 shows the template used to assess plate and serving waste.

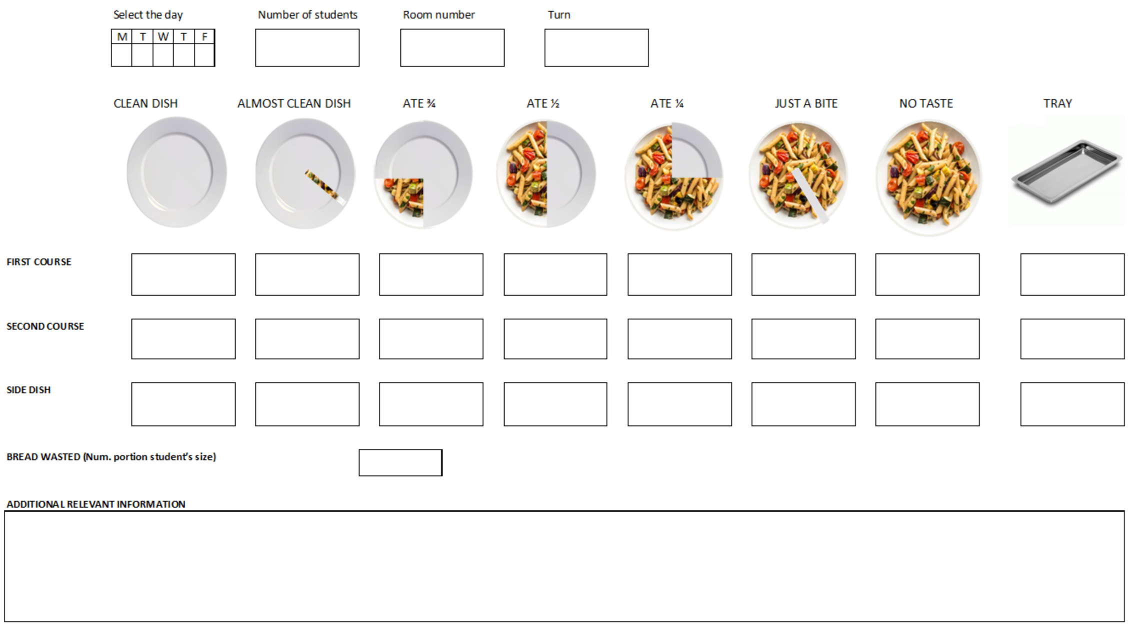

Figure 2: Template to perform visual assessment. Author's elaboration based on literature

3. Results and discussion

A representation of results is provided in figure 3 and table 2. They show the environmental and economic impact of the meal eaten from a LCA and LCC perspective.

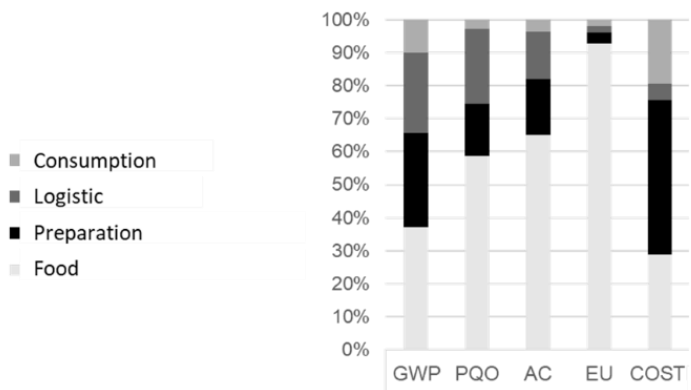

Figure 3: Results of each impact category in % from a meal eaten at the nursery school

Table 2: Environmental and economic impact by category from nursery school meal eaten by students

Phase	GWP (kg CO_2 eq per kg)	PQO (kg C_2H_4 eq per kg)	AC (kg SO_2 eq per kg)	EU (kg PO_4^{---} eq per kg)	Cost (%) menu paid
Food	$6{,}13\times 10^{-01}$	$4{,}30\times10^{-04}$	$8{,}20\times10^{-03}$	$1{,}42\times10^{-02}$	28,78
Preparation	$4{,}70\times10^{-01}$	$1{,}20\times10^{-04}$	$2{,}10\times10^{-03}$	$0{,}50\times10^{-03}$	46,91
Logistic	$4{,}02\times10^{-01}$	$1{,}70\times10^{-04}$	$1{,}80\times10^{-03}$	$0{,}30\times10^{-03}$	4,97
Consumption	$1{,}65\times10^{-01}$	$0{,}20\times10^{-04}$	$0{,}50\times10^{-03}$	$0{,}30\times10^{-03}$	19,33
Total	$16{,}51\times10^{-01}$	$7{,}30\times10^{-04}$	$12{,}70\times10^{-03}$	$1{,}53\times10^{-02}$	100

Figure 3 represents in percentage the impact of each environmental and economic indicator in each phase; while detailed data about the amount of impact in each phase are disclosure in table 2.

Most of the environmental impacts occurs at food level, this is also observed in other research as the one conducted by Cerutti (2018). This happens principally because the presence of meat and fish (mainly in the second dish), and those ingredients using packaging made of steel or plastic. Regarding cost, the major impact comes from the preparation phase, as it contains the workers' salaries, which account the most in this study. It is remarkable the environmental impacts of logistic, since the schools are close to the main kitchen (average of 5km). Since all dishes have to be supplied at the same time (or close), the service needs several vehicles to make the transportation at least twice a day, one to provide the food and the second to pick up the containers. As LCA and LCC are regarded, results indicate relevance of raw materials, packaging and transport in LCA and of indirect costs in LCC. The fact that there is not a standardized measure to serve the meal, since kitchen workers prepare the portions by hand could cause a small error in the functional unit. Table 3 offers the percentage of food wasted per dish.

Table 3: Percentage of food waste per dish in the school canteen

Dish	Food waste per dish (%)
First	11,65
Second	37,23
Dish side	79,56
Bread	22,02
Fruit	28,08

Visual assessment shows that food waste is mainly produced in the side dish and second dish. Bread is often wasted, maybe due to the size of bread, and fruit waste could be due to the fact that is provided right after the second when the students might be food satisfied.

These percentages were then used to allocate all the impacts and cost among eaten food and consumption waste, with the exception of food waste disposal that was entirely attributed to the latter. Table 4 shows that the impact of the waste is over 32 percent of the global warming potential. While more than 33 percent of the economic costs sustained are wasted.

Table 4: Global environmental and economic impact of the menu eaten and food waste

	GWP kg CO_2 eq	PQO kg C_2H_4 eq.	AC kg SO_2 eq.	EU kg PO_4^{3-} eq.	Cost (%) menu paid
Meal eaten	1,10	$4{,}30 \times 10^{-04}$	$8{,}52 \times 10^{-03}$	$9{,}85 \times 10^{-03}$	66,42
Waste	0,54	$2{,}96 \times 10^{-04}$	$4{,}08 \times 10^{-03}$	$5{,}50 \times 10^{-03}$	33,58
% waste	32,86%	40,55%	32,41%	35,87%	33,58%

As the LCA shows, major environmental and economic impacts occur at second dish, and it is the dish that causes more waste after the side. Side dish is composed by vegetables and after the first dish the student are not as hungry as when the first dish is served and it is not either as tasty as the first (mainly composed by carbohydrates from pasta or rice).

4. Conclusion

This study aimed to assess the impacts of food waste at school canteens, regarding the eaten meal by students, by using LCA, E-LCC and Visual assessment technique. The outcome of this research provides information to be used by decision-makers, highlighting in every meal phase (from ingredient to waste) the environmental and economic impact. The major environmental impacts are occurring on the food phase, in both environmental and economic side; due to the process to produce the food, transportation involved and packaging contain. From the food waste side, results revel that from the meal prepared, food waste accounts about 33 percent of global warming potential, 40 percent photochemical ozone creation, 32 percent acidification and 35 percent eutrophication. The cost of this food waste represent the 33 percent of the total expenses of the meal (from food purchase to waste disposal).

The mix of methods presented on this preliminary research brings new analytical tools providing the foundations to design interventions and evaluations and new policy options including the development of agreements among the engaged stakeholders and the delivery of targeted information days. Final results will be extended to design a broader local food plan based on the involvement and on the needs of all the local actors, providing a dialogue between the scientific community and policy makers. Setting the baseline information thanks to LCA and LCC results might help policy makers and other stakeholders to establish the mediations needed to reach SDG 12.3.

The role of teachers is fundamental to fight against food waste, from small actions as taking the bread to the class in case during the afternoon some student want to eat, to the motivation to try new aliments. Consequently, some activities with teachers together with catering workers have to be made in order to address this issue. As proposed measure, due to the amount of food waste generated in the side dish mainly composed by vegetables is to have the second course at the beginning since the students are hungry when they arrive at the canteen, and the first course after that which is mainly composed by carbohydrates (pasta or rice) and it is the most liked by students. Workshops with parents are fundamental in order to facilitate the introduction of new aliment to students, not only for nutritional purposes but to reduce the identified impacts of food waste at home as well.

This case can be extended to different public canteens from different levels (from elementary to university), in order to assess, identify and modify those environmental and economic hotspots found for a better performance.

Finally, in order to have a meal eaten close to meal paediatrics which guarantee the best nutrient ingestion, it is important to address seriously food waste.

Some limitations have to be considered, for example, the application of a sensitive analysis is highly recommended by design different food scenarios. In order to identify ingredients, only the transportation from the wholesaler to the kitchen has been considered, and the distance might be higher. Further research beyond food waste prevention, as revalorization routes could be addressed. A zoom in on the nutrition side might be interesting in order to understand if students are eating enough or not nutrients. It would be interesting to perform the study at primary school level in order to see differences.

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LIFE CYCLE THINKING METHODS AND TOOLS

The Constructal Law to optimize performances of energy systems through the Life Cycle approach

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Abstract

The aim of the paper is to explore how geometry optimization contributes to a technology's ecological evolution. The article develops this concept through a new methodology that applies the Constructal law to account for the "evolution" of technologies design (configuration, shape, structure, pattern, rhythm), and Life Cycle Assessment (LCA) for quantifying the environmental consequences of the design choices.
The combination of these two approaches is incorporated into a new "Overall Performance Coefficient", that investigates the trade-offs to identify the best technical and environmental configuration. This coefficient can show the results both in graphs and in analytically form.
The method is applied to a real biomass boiler. The study analyses a base case and a series of alternative scenarios, guaranteeing the same thermal power production.

1. Introduction

Decarbonization, reduction of environmental impacts of the economy and energy efficiency are all fundamental aspects to be addressed in the energy sector, through an integrated approach to the design of technologies in order to ensure that i.e. improvements to energy efficiency do not involve increases in environmental impacts.

In the last decades, the generation and evolution of technologies design have been influenced by the natural phenomena, since the features of "design" (i.e. configuration, pattern, rhythm, scaling rules) of the energy technology are observable in analogy to the behaviour of nature, animate and inanimate (Bejan and Lorente, 2011).

This approach is inspired by the Constructal Law, which was proposed by Bejan, as "the law of physics that accounts for the natural tendency of all flow systems (animate and inanimate) to change into configurations that offer progressively greater flow access over time" (Bejan, 2016).

The application of Constructal Law involves the transfer of heat and mass in various fields: engineering, biology, geophysics, social dynamics and even economics.

In literature Constructal Law is widely discussed for the design optimization of heat exchangers (Chen et al., 2015; Manjunath and Kaushik, 2014; Tescari et al., 2011; Yang et al., 2014) and for the optimal shaping of fins with application to heat exchangers (Lorenzini and Rocha, 2009).

The development and diffusion of new optimized shapes or configuration of the energy technologies affect, in addition to energy performance, the surrounding environment in different ways, changing the nature and extent of the environmental impacts of the original industrial processes. In fact, performing an optimization in the energy design of a technology does not ensure that the system would be more environmentally friendly.

To avoid that the potential benefits connected to the design choices in the operation stage could be offset by increasing of the energy and environmental effects of the other stages, it is necessary to extend the point of view to the whole life cycle.

This consideration suggests supporting performance-based metrics or optimization methodologies like the Constructal Law with a more comprehensive approach, able to target the complexity behind the object in a life-cycle oriented approach, encompassing materials extraction, system production, transports and end-of-life as well as the mere use phase. In such a way, energy and environmental impacts are viewed in an integrated way and not shifted from one step to another.

In such a context, merging methodological combination of Constructal geometric optimization and the Life Cycle Assessment (LCA) (ISO 14040, 2006; ISO 14044, 2006) allows to assess the energy and environmental performances of the design optimization processes during the whole life cycle of energy systems (Cellura et al., 2014; Hiloidhari et al., 2017; Moslehi and Arababadi, 2016).

Although literature presents several case studies, separately, on the Constructal Law (Chen et al., 2015; Manjunath and Kaushik, 2014; Tescari et al., 2011; Yang et al., 2014) and LCA (Cellura et al., 2014; Hiloidhari et al., 2017; Moslehi and Arababadi, 2016) applied to energy systems, there is a limited availability of studies on the specific topic of eco-oriented design optimization that combines Constructal Law and LCA applied on the thermal performances of energy systems.

The following paper presents the results of a research aimed at developing a methodology able to encompass both the Constructal Theory oriented optimization of the use stage and the Life Cycle oriented assessment of environmental impacts, to avoid the shifting of burdens from the use stage to the others. A case study is presented, in which the proposed methodology is applied to the eco-design of an existing biomass boiler. A set of scenarios, in which the original design is modified, is investigated and the related variation in energy performances is calculated. A scenario analysis is carried out through a life cycle-oriented approach to determine the most sustainable alternative.

2. Methods

The following paragraphs discuss the assumption, the mathematical model implemented and the methodology chosen for the study.

The methodology proposed requires to follow different stages:

- Constructal Law for the re-design optimization.
- Application of the LCA approach.
- Investigation of the trade-offs to identify the best technical and environmental configuration with the Overall Impacts Performance Coefficient.

2.1. Constructal Law re-design

The Constructal Law identifies potential optimizations of an energy system, such as minimizing the heat and fluid flow irreversibility (Bejan and Lorente, 2004) and maximizing the energy performance, by means of determining mathematical correlations to investigate the optimal configuration.

From an analysis of the available literature (Gulotta et al., 2017), the application of Constructal Law is based on the use of the generic mathematical optimization techniques. These types of problems can be formulated for finding a maximum or minimum value of a function of several variables subject to a set of constraints, as linear programming or systems analysis.

In many cases, an energy system is usually a complex element that requires the interconnection between different variables/parameters, and the optimization of one variable can be to get worse another.

For this reason, the "Overall Performance Coefficient", implemented in (Lorenzini and Moretti, 2014) is a parametric tool able to determinate the best design when, at every step of the optimization procedure, it is necessary to satisfy two conditions at the final point of the design process. If such conditions are the minimization of the pressure loss and the maximization of the heat removed, the following formulation is adopted for the Overall Performance Coefficient:

$$P_1^* = \alpha \tilde{Q}_i + (1-\alpha)\frac{1}{\Delta P_i^*} \tag{1}$$

where P_1^* is the Overall Performance Coefficient, Q and ΔP_i^* are respectively the ratio of the heat removed and the pressure drops in the i^{th} case respect the real case, α is a weigh, called relevance. However, it is possible to adapt the concept of the Overall Performance Coefficient to the different energy system, based on different assumptions.

2.2. Life cycle Assessment (LCA)

In order to optimize the eco-design of an energy system or process, it is necessary to assess the energy and environmental impacts arisen from the performance optimization, including the whole life-cycle of the system or process. In such a context, LCA allows investigating direct and indirect impacts throughout the life-cycle steps of the system: supply of raw materials and energy, transport, manufacturing, installation, operation, and end-of-life.

Considering that the main goal of this study is to link the Constructal Law concept to a wider perspective of the life-cycle of an energy system and that the previous formulation (Eq.1) of the Overall Performance Coefficient does not take into account the energy and environmental impacts connected to the optimization process, the Eq.1 is adapted to LCA approach. In particular, the design optimization process of the boiler is linked to the respect of two conditions: minimization of the energy consumption and minimization of the environmental impacts.

As such, with regard to an energy system the Overall Performance Coefficient formulation can be reworked as in Eq. 2.

$$P_3^* = \varepsilon \frac{1}{\sum_j I_j} + (1-\varepsilon) \frac{1}{\sum_j E_j} \qquad (2)$$

where:

- P_3^* is the Overall Impacts Performance Coefficient, which is implemented within the scope of minimizing the environmental impacts *I* and the energy *E* required during the whole life cycle of the assessed system. The subscript *j* refers to the life cycle stage of interest. The parameter ε can be defined as relevance of impacts, varying between 0 and 1, and represents the weight of impacts minimization with respect to energy minimization.

- E_j is the energy-related indicator of the j^{th} stage and is calculated as the ratio between the global energy requirement of the alternative case studies and the global energy requirement of the reference case.

- I_j is a global index calculated with reference to all the assessed environmental indicators for the j^{th} stage of the alternative case studies respect to the original energy system or process. It is calculated by means of a normalized aggregation of all environmental indicators.

The Overall Impacts Performance Coefficient, calculated as in Eq. 2, represents a parametric tool, which allows evaluating the implications that a design optimization process involves in the life-cycle of an energy system, as one solution can be more energy efficient, but it can cause larger environmental impacts than another alternative. Although having a single index causes a loss of specific information (Beccali et al., 2003), it gives a depth of analysis that is particularly useful and effective, among experts and in specific applications, with local issues, in a decision-making support context.

3. Case study: a biomass boiler

The methodology proposed above is applied to a biomass boiler. In detail, a mathematical model of such a biomass boiler is implemented in Matlab environment and a set of scenarios is identified to perform a redesign as shown in (Gulotta et al., 2017). The existing boiler (Cellura et al., 2014) is a smoke tubes typology with 16 tubes arranged in a staggered configuration with a thermal power of 46kW. The combustion process of the biomass pellets occurs in the combustion chamber seated in the lower section of the boiler, then hot smoke enters in the tubes and leaves from a chimney placed on the back of the boiler. Cold flow is water and it exchanges heat through the tubes, entering from the left in a cross-flow configuration. To perform a redesign of the boiler through the application of the Constructal Law, a scenario analysis is carried out on the main geometrical features of the boiler.

The degrees of freedom of the study are the number of tubes and their configuration. In particular, the tubes layout is varied into staggered and aligned arrangement and the number of tubes (N) is varied between five discrete values (8, 12, 16, 20 and 24). Nine alternative scenarios are defined. The scenarios are proposed to not change the boundary geometrical characteristics of the reference case. In fact, the height, the depth, and the width are not modified. For all the 10 cases analysed the optimal diameter (D_i) able to obtain the thermal nominal power of 46 kW is determined (Table 1). In detail, Table 1 shows that the optimal geometry, the number, and arrangements of the tubes affect both the pressure drops and the amount of heat exchanged in the boiler, generating significant variations in the energy performance.

The application of the LCA methodology allows assessing the energy and environmental impacts caused by the scenarios previously defined in the whole life cycle of the system. In particular, the energy and environmental impacts induced by a variation in steel use (due to variations in diameters and in the heat exchanger's configuration) and by a variation in energy use for pumping (due to different pressure losses alongside the fluid flows) are assessed.

Table 2: Geometrical features of the optimal redesign scenarios

		Ref. Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Di	[mm]	50	96	73	38	37	104	98	91	84	78
Do	[mm]	55	101	78	43	42	109	103	96	89	83
Number of tubes	-	16	8	12	20	24	8	12	16	20	24
Pressure Drop shell side	105 [MPa]	119.70	302.48	143.14	119.75	90.26	1256.5	352.53	76.11	21.09	6.71
Pressure Drop tube-side	105 [MPa]	60.33	4.59	12.35	188.40	185.06	3.12	3.00	3.41	4.18	5.16
Overall pressure drop	105 [MPa]	180.02	307.07	155.49	308.15	275.33	1259.6	355.53	79.52	25.27	11.87
Thermal Power	[kW]	46.00	46.16	46.13	46.06	46.08	46.55	46.24	46.17	46.01	46.08
Energy Efficiency	%	88.53	88.84	88.77	88.65	88.68	89.59	89.00	88.85	88.55	88.68

One biomass boiler designed to guarantee a 46kW of nominal thermal power is selected as functional unit (FU). The main methodological assumptions and the results of the LCA study are taken from (Cellura et al., 2014).

Global Energy Required (GER) is calculated according to the Cumulative Energy Demand method (Frischknecht et al., 2005). The environmental impacts categories are assessed according to the "Environmental Product Declaration" method (EPD, 2008).

Table 2 shows the energy and environmental impacts of the reference case.

Table 3: Energy and environmental impacts of reference case (Cellura et al., 2014)

Impacts category	Unit	Manufacturing	Operation use	End-of-Life	Total
Global Energy Required (GER)	GJ	$1.48\ 10^{1}$	$6.06\ 10^{2}$	$4.70\ 10^{0}$	$6.26\ 10^{2}$
Acidification (AP)	kg $SO_{2\ eq}$	$4.23\ 10^{0}$	$4.84\ 10^{1}$	$5.40\ 10^{-1}$	$5.32\ 10^{1}$
Eutrophication (EP)	kg $PO^{4---}{}_{eq}$	$2.34\ 10^{0}$	$1.96\ 10^{1}$	$1.10\ 10^{-1}$	$2.20\ 10^{1}$
Global warming (GWP_{100a})	kg $CO_{2\ eq}$	$8.97\ 10^{2}$	$4.53\ 10^{3}$	$3.24\ 10^{2}$	$5.77\ 10^{3}$
Photochemical oxidation (POPC)	kg $C_2H_{4\ eq}$	$3.50\ 10^{-1}$	$2.12\ 10^{0}$	$7.00\ 10^{-2}$	$2.55\ 10^{0}$
Ozone layer depletion (ODP)	kg CFC-11 $_{eq}$	$5.07\ 10^{-5}$	$2.50\ 10^{-4}$	$2.04\ 10^{-5}$	$3.21\ 10^{-4}$
Abiotic depletion (AD)	kg Sb_{eq}	$1.36\ 10^{-2}$	$9.01\ 10^{-3}$	$1.03\ 10^{-4}$	$2.27\ 10^{-2}$

From the outcomes of the life-cycle impact assessment, the following considerations can be made:

- the contribution of the operation step varies from 40 (AD) to 97% (GER);
- the manufacturing step accounts for more than 50% in AD, while it is lower than 20% in the other impact categories;
- the end-of-life step accounts for less than 1% in all categories except for ODP and GWP (about 6%).

Introducing the results connected to the Constructal Law analysis for the alternative scenarios, Table 3 shows the impacts variations generated by the parametric analysis of the operation stage.

The Case 5 results the worst case, since it has the highest impacts in all the categories. In particular, it generates the following increases: 21% in POCP, 2% in GER, and 13% in GWP. Significant reductions are traced (around 5%) for ODP for cases 4 and 9 while case 7 induces a 3% reduction. Some cases show worse performances for all indicators (Case 6), while others report mixed results among the impact indicators. The impacts of the cases 2, 7, 8 and 9 are lower than the reference case, except for AD, for which such cases involve an increase of 0.06, 1.72, 2.13 and 2.82 %, respectively.

Table 4: Effects generated by Constructal re-design in the assessed alternative scenarios

	GER	AP	EP	GWP	POPC	ODP	AD
	GJ	kg SO2 eq	kg PO4--- eq	kg CO2 eq	kg C2H4 eq	kg CFC-11 eq	kg Sb eq
Case 1	2.40 100	6.86 10-1	1.69 10-1	1.43 10+2	2.84 10-2	1.27 10-5	1.74 10-4
Case 2	-3.44 10-1	-9.93 10-2	-2.05 10-2	-2.04 10+1	-3.09 10-3	-1.92 10-6	9.13 10-6
Case 3	2.23 100	6.38 10-1	1.59 10-1	1.33 10+2	2.67 10-2	1.18 10-5	1.70 10-4
Case 4	1.75 100	4.97 10-1	1.32 10-1	1.05 10+2	2.30 10-2	8.99 10-6	2.06 10-4
Case 5	2.04 10+1	5.80 100	1.46 100	1.22 10+3	2.48 10-1	1.07 10-4	1.72 10-3
Case 6	3.71 100	1.05 100	2.89 10-1	2.22 10+2	5.11 10-2	1.88 10-5	5.18 10-4
Case 7	-1.20 100	-3.56 10-1	-4.52 10-2	-7.07 10+1	-4.03 10-3	-7.43 10-6	2.69 10-4
Case 8	-2.00 100	-5.88 10-1	-8.79 10-2	-1.18 10+2	-1.00 10-2	-1.20 10-5	3.33 10-4
Case 9	-2.06 100	-6.10 10-1	-7.98 10-2	-1.21 10+2	-7.51 10-3	-1.27 10-5	4.40 10-4

The above outcomes do not make possible to clearly identify an optimized solution, either through an optimal performance in the use phase from a thermodynamic point of view or from a LCA perspective, if a hierarchy is not clearly identified between the indicators, following a site-specific logic.

The application of Overall Impacts Performance Coefficient to the assessed case study allows to aggregate, through a procedure of normalization, all the environmental impacts thus allowing the definition of a single environmental index to be compared with the energy-related indicator. In addition, a single environmental indicator and its effects on two processes or stages, influenced by the design optimization, could be analysed.

Figure 1 shows the Overall Impacts performance coefficient applied to the boiler and its alternative scenarios. In particular, the graphical representation reports that:

- if the relevance ε is equal to 0, the hotspots to identify the best alternative case depend only on the energy uses *E;*
- if the relevance ε is equal to 1, the best case is identified from the normalized environmental impacts *I* along the whole life cycle.

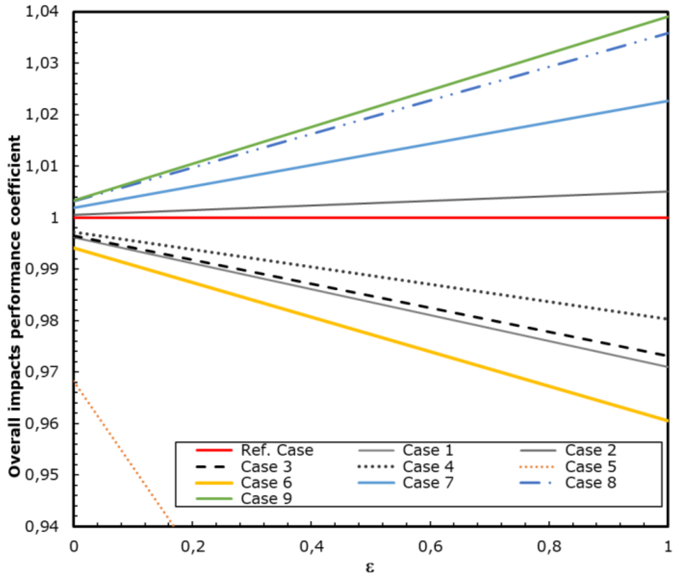

Figure 7: Overall Impacts Performance Coefficient

Considering that the trade-offs to choose the most sustainable design are the minimization of the energy and environmental impacts, it was chosen an ε equal to 0.5 as relevance. It is worth of note that all the effects of the Constructal design of the boiler are included in these two indicators: the choice of the optimal design is thus shifted to a wider level, including the mere use phase optimization in a larger life cycle perspective. The analysis clearly identifies an optimal solution in case 9. In particular, the life-cycle energy use of the case 9 decreases of 2GJ, and the normalized environmental impacts of 4%. For both these scenarios, the environmental impacts and the overall energy use during the life cycle are the lowest ones.

4. Conclusions

The paper proposes a methodology to assess the best design optimization under multiple points of view considering the Constructal Law, as main inspiration for the design variation, and using the LCA methodology as decision support tool.

The Constructal parametric analysis is applied to the design of an existing biomass boiler in order to improve its energy performances during the operation stage. Most geometrical features as the diameter size, the configuration and the numbering of the tubes are varied while keeping the boiler volume constrained to the existing one. Alternative scenarios are proposed to simplify the analysis of the results. For each case, the optimal diameter is calculated to satisfy the thermal load of 46 kW.

LCA is evaluated for each case; then to lead a comprehensive perspective on the results and a coherent formulation, the authors introduce the Overall Impacts Performance Coefficient. This allows analysing the optimization performed on a wider perspective, by combining the very different effects of the optimization (reduced use of energy, increased/reduced pumping needs and use of materials).

However, while the Constructal optimization identifies some potential good solutions, the application of the life cycle oriented integration approach has a twofold contribution: the scope of the optimization is extended to the whole life cycle (thus taking into account the analysis of the secondary effects caused by a design choice) and a potential support tool to decision making can be developed, by introducing both a wide availability of indicators, which target a large range of issues and a normalized index, in the extension of the Overall Performance indicator. While being well known to authors that having a single index causes a loss of specific information (Beccali et al., 2003), it is arguable that in a decision support context, having a single index as the Overall Impacts Performance coefficient might be very effective.

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Walk-the-talk: Sustainable events management as common practice for sustainability conferences

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Abstract

Several events and conferences on environmental and sustainability management have been organized in the last decades. If on the one hand, this has a huge importance for spreading knowledge on sustainability and in engaging companies and organizations towards a more sustainable production and manufacturing, on the other hand, these conferences or events can cause lots of environmental impacts. In fact, they bring together hundreds of participants from every part of the world to the same location and food, drinks, transport and all services have to be guaranteed for 3-4 days. That means lots of resources and energy use and consequent emissions in air, soil and water. The question is: shouldn't a conference on sustainability be sustainable and what does that entail in terms of carbon neutrality?

A case study, the Life Cycle Management conference (LCM), is presented here to show some figures on the environmental impacts created by a sustainability event/conference and relative offsetting that can be done. The LCM is a leading forum worldwide in life cycle sustainability and circular economy, bringing together 600+ scholars and practitioners from 40+ countries working in the domain. It takes place once every two years and as is the case with the delivery of events, each LCM results in environmental and socio-economic impacts.

1. Introduction

Increased demand and interest in delivering sustainable conferences has driven the development of a number of sustainability and environmental guidelines and standards to assist event organisers in implementing sustainability measures during the preparation and staging of an event. Some guidelines are universal for all types of organisations such as the ISO 14000-14006 series 'Environmental Management Systems' (ISO, 2014a) or ISO 26000 'Social Responsibility' (ISO, 2014b). Others, such as ISO 20121 (ISO, 2012) were developed specifically for the events management industry *(Parkes, Lettieri, & Bogle, 2016)*. These standards provide some useful recommendations for event organisers on addressing sustainability issues linked to the delivery of events. Consequently, environmental sustainability aspects, notably greenhouse gas (GHG) emissions accounting and carbon neutrality programs are being incorporated in the organisation of a growing number of conferences.
In the case of GHG accounting and carbon neutrality of conferences, an ex-ante evaluation of the associated carbon dioxide equivalent (CO_2e) emissions and monitoring during the event is followed by offsetting of unavoidable GHG emissions to achieve carbon neutrality. Offsetting of GHG emissions entails the purchase and retirement of verified/certified CO_2e emissions reductions generated from projects whose environmental and social integrity has been demonstrated according to standards such as the Clean Development

Mechanism, Gold Standard and Voluntary Carbon Standard which are increasingly incorporating sustainable development aspects in carbon reduction projects[29]. These are emissions reductions that fall under the voluntary carbon market, available for voluntary offsetting by organisations, businesses and individuals.
In 2015, the events industry, took center stage as top buyers of carbon offsets edging out previous champions from transportation, finance and energy sectors. This shows that organisers are taking responsibility for their environmental impact and building the business case for carbon accountability through calculating, reducing and offsetting carbon emissions related to events/conferences (Forest Trends' Ecosystem Marketplace, 2016). For more than a decade, businesses, in particular multinationals, have been engaged in offsetting CO_2e emissions related to their meetings. First movers include the former Italcementi Group which calculated CO_2e emissions related to flights, accommodation, commuting and other meeting related activities of its 2008 Sustainable Development Annual meeting held in Cairo. The Group offset the carbon emissions by purchasing equivalent Gold Standard credits from a biomass power production project in India (Italcementi Group, 2009; Suez Cement & HeidelbergCement, 2008).

In recent years the organization of international sports events has increasingly been associated with sustainable event management practices. In particular, sustainability requirements have been included in recent Olympic games such as the London Green Olympics held in 2012 (Karamichas, 2013). Starting from the bidding and pre-event – preparatory phase, sustainability is exemplified in the different constituting parts of the International Olympic Committee Council strategy (Martin & Verbeek, 2006). Environmental impact assessment studies have also been carried out on some of these major sports events, highlighting the potential benefits in adopting sustainable event management to waste generated (Lou et al., 2015), post-event site redevelopment (Parkes et al., 2016) and sport facility transformation towards environmental sustainability (Mallen & Chard, 2012). Full life cycle assessments have also been conducted which highlight GHG emissions reduction opportunities (Scrucca, Severi, Galvan, & Brunori, 2016) and the important share of impacts related to the preparatory and disassembling stages of events in general (Toniolo, Mazzi, Fedele, Aguiari, & Scipioni, 2017).

We find few examples of sustainability conferences organised by the academic or research sector which have implemented event sustainability management systems or measures to attain carbon neutrality. The *UN Climate Change Conferences organized by the* UNFCCC in Marrakesh, Paris and recently in Bonn had a strong emphasis on sustainable conference management, implementing the ISO 20121 (ISO, 2012) and obtaining a carbon neutral status. However, despite the direct link with carbon emissions and sustainability, the CARBON EXPO obtained carbon neutrality only for the 2010 edition organised

[29] https://globalgoals.goldstandard.org/

in Cologne (World Bank and International Emissions Trading Association (IETA), 2010). For the UNEP/SETAC Life Cycle Initiative program, the SETAC North America 34th Annual Meeting in Nashville used carbon offsets to reduce related carbon footprint (Sharma & Malizzi, 2014).

As it can be seen there are some front runners in establishing carbon neutral and energy efficient events, while the sustainable community stays behind common standards. This becomes even more relevant considering the increasing number of these conferences organised each year, a trend which is destined to continue. There are impacts related to direct conference activities and for all that is required for the smooth running of the conference such as accommodation, transportation services and post-conference activities. Therefore, these issues have to be addressed by adopting sustainability as an overarching concept all through the event's life cycle, from event planning to delivery (Stoyanova-Bozhkova, 2017). The carbon neutrality of conferences on sustainability should be a minimum requirement for organisers. Sustainability conferences should have zero CO_2e related impacts and mitigate as much as possible energy related ones.

2. Life Cycle Management conference: a case study on carbon neutrality in sustainability conferences

The Life Cycle Management conference (LCM) is a conference series focusing on environmental, economic and social sustainability. Once every two years, international decision makers from science, industry, NGOs and public bodies gather in a designated location to share knowledge on practical solutions in implementating life cycle approaches into strategic and operational decision-making.

The first LCM conference was held in 2001 and since then 7 editions have followed, totaling about 3,000 participants so far, from more than 40 countries worldwide. Besides the huge financial implication, organising each LCM edition entails significant pressure on mobility, energy related and material resources, as well as on the local hosting community. Informed decision making is needed in order to reduce potential negative impacts on the environment, communities and local economy while maximizing positive ones. To manage these impacts there is need to understand the baseline situation. This is usually an ex-ante measurement or assessment of impacts which is important to identify hotspots and can reveal opportunities for less impacting alternatives. Therefore, this case study implements the life cycle assessment (LCA) methodology to create a baseline measurement of CO_2e emissions and primary energy resource use associated with the hosting of LCM in 2021. For this analysis, Taormina, a city in the Sicily Region of Italy is assumed to be the venue of the fictitious LCM conference. Information are provided on above impacts related to hosting an LCM in the south of Europe. The city of Taormina was selected as a suitable hypothetical location following previous hosting of meetings of international importance such as the G7 Summit in 2017.

2.1. Methodological approach

Besides the LCA series of standards ISO 14040/44 (ISO, 2006a, 2006b), carbon footprint accounting guidance is provided in the ISO 14064 (ISO, 2006c) and Greenhouse Gas Protocol standards (World Business Council for Sustainable Development (WBCSD) & World Resources Institute (WRI), 2011). On determining what to measure for computing CO_2e emissions associated with an event organisation, these standards break down GHG emissions into scope 1, scope 2, and scope 3. Scope 1 emissions are those directly occurring from sources that are owned or controlled by the organisation (in this case the event organiser), such as work vehicles. Scope 2 emissions are emissions generated in the production of electricity consumed by the event related activities. Scope 3 emissions are all the other indirect emissions that are indirect consequences related to activities of the event, but occur from sources not owned or controlled by the event´s organiser. These include air and ground travel, hotel stays, emissions of the production and transportation of purchased goods, outsourced activities, and so forth.

Consequently, measuring Scope 1, 2 and 3 ensures a full coverage of the event's life cycle. This is the approach implemented in this work, to define the system boundaries for evaluating CO_2e emissions. A similar definition is applied to evaluate the energy footprint.

All calculations were based on a total number of 800 participants, attending the conference for 4 days. The number of participants was calculated considering a 7% increase between LCM´s consecutive editions, recorded from previous LCM conferences. Based on available information of the 2015 LCM distribution of participants by region, the type of mobility and the average distance were calculated. This resulted to 793 participants flying into Taormina of which 75% with short-haul and 20% with long-haul flights. No space heating is considered in Taormina in the summer months while space cooling is provided by electrical energy only. Paper consumption was based on an average number of 50 sheets per participant in the form of handouts and notepads. A waste generation rate corresponding to half of the world average per capita was considered due to the waste reduction measures implemented at the conference. The figures for catering are based on average empirical values per capita consumption of meals and beverages while data for accommodation is based on the type and number of recommended hotels on the official website of the 2017 LCM in Luxembourg. A total of 4,800 meals are considered for lunch and dinner, including 25% vegetarian meals while 4,000 snacks are served.

Data resulting from the above considerations were calculated for the various life cycle phases of the event, identifying relevant unit processes involved. The CML impact category assessment method was applied with the aid of the Simapro LCA sosftware to calculate the carbon (Global warming potential, 100a, GWP) and energy (Cumulative energy demand) footprints of the LCM in tCO_2e and MJ respectively. GHG emissions of catering and accommodation services were calculated using the myClimate CO_2 online calculator due to the non availability of suitable processes in simapro and GaBi (MyClimate, n.d.).

2.2. Results and interpretation

Figure 1 shows the relative contributions to the GWP from resources, energy and transportation, catering, accommodation and waste disposal services related to the delivery of the LCM. The results are in line with similar studies on events (Niccoluci et al., 2017). The single biggest contributor to an event's carbon footprint results from participants´ travelling to and from the event´s location, which accounts for about 70% of the carbon emissions. GHG emissions from accommodation, catering and energy consumption follow with about 25% of total global warming impact while contributions from waste and paper are minor.

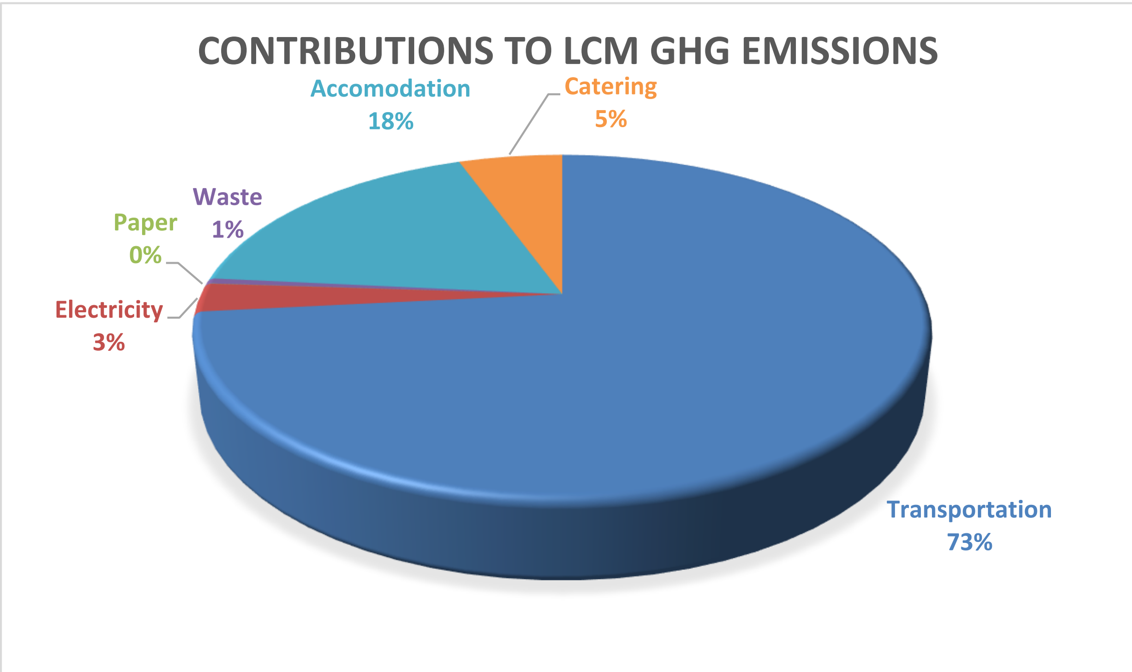

Figure 1: Share of GHG emissions for hypothetical LCM conference in Taormina

On primary energy resource use, Figure 2 shows relative contributions from transportation, material and energy related resources used and waste disposal to non-renewable (99%) and renewable cumulative energy demand. And here also the weight of transportation is clearly seen as a confirmation of GHG results as these two are closely connected.

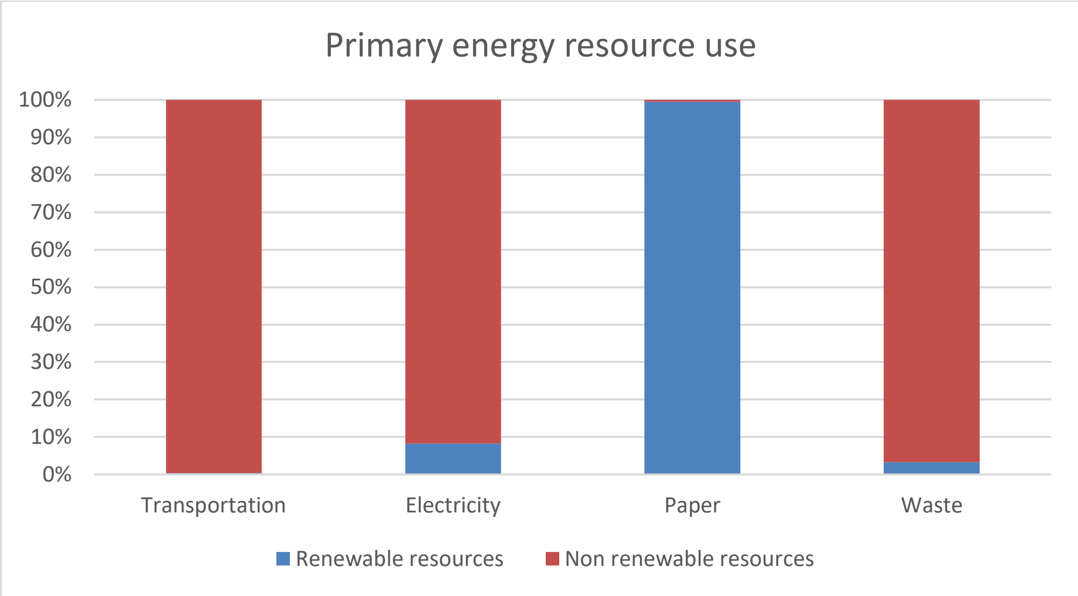

Figure 2: Share of cumulative energy demand for hypothetical LCM conference in Taormina

2.3. Offsetting of calculated impacts

Currently, various possibilities are available to offset GHG emissions generated by an event through investing in projects that reduce GHG emissions. The voluntary carbon market (VCM) supports a range of carbon offset projects that also deliver various socio-economic and environmental co-benefits. For example, supporting a local carbon reduction project could bring an additional 538€/t CO_2e to the community, according to research by Imperial College London in partnership with the International Carbon Reduction and Offsetting Alliance (Imperial College London and International Carbon Reduction and Offset Alliance (ICROA), 2016).Therefore, purchasing carbon credits could create economic development opportunities, aid environmental conservation, help deliver health benefits and improve water resources, among other benefits. When choosing an emission reduction project, it is important to tie together carbon accountability and the non-carbon related impacts of the event. So, the goal of the project should go beyond carbon emissions reduction to cover social co-benefits and sustainability in general. Furthermore, one should consider the credibility of the chosen offsetting option/project. Typical offsetting projects range from renewable energy projects passing through initiatives for the avoidance of methane emissions to reforestation projects.

In the case of the LCM conference, a renewable energy project with a strong social component can be selected to account for the primary energy resource used and ensure sustainable development opportunities. An example of such a project is the “Wind energy project in Maharashtra, India” launched in 2011 by the UNFCCC. The project reduces GHG emissions while meeting the growing demand of power in the region. New jobs are created securing livelihood to the local population and improved infrastructural developments are triggered in and around the project area (United Nations Framework Convention on Climate Change (UNFCCC), 2011)

Verified emissions from these projects can cost up to 20€/t CO_2e (Forest Trends' Ecosystem Marketplace, 2017). Offsetting the LCM calculated CO_2e emissions will amount to roughly 15,000 € which corresponds to less than 5% of the overall LCM budget.

3. Conclusions

Conferences and events are great opportunities for sustainability professionals from all sectors to share knowledge and promote action on related topics. Although these conferences usually boost local economies, they have significant impacts on the environment and communities through consumption of energy and release of greenhouse gas emissions, as illustrated in the LCM case study presented in this paper. As such, these conferences do have an inherent responsibility to be sustainable, incorporating best practices in measuring and mitigating related negative impacts on the environmental and socio-economic sphere. It is no longer enough to talk and share knowledge on sustainability issues, action is required to trigger change. Thus, conferences on sustainability topics should bring along a change in mindset by establishing impact assessments and offsetting as minimum requirements for their organisation.
Furthermore, carbon offsetting begins with the computing of GHG emissions and this requires reliable input data and representative processes in the various LCA software. So far, some activities linked to event organisation, such as catering and accommodation services have not been modelled, hence their impacts are quite challenging to compute. A possible further research topic could be the modelling and calculating of various impact categories of these services using primary data. This would provide useful data on the actual contributions of catering and accommodation services to the event industry, allowing for effective offsetting.

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A Preliminary LCA Analysis of Snowmaking in Fiemme Valley

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Abstract

Modern ski resorts have been using systems of technical snow for many years: initially they were used to compensate the limits of natural snow but today it is actually the natural snow that is used as an integration to artificial snow and not vice versa. This paper aims to identify and evaluate the environmental impacts associated to the production of artificial snow, comparing two very different winter seasons in terms of snowfalls. The results of LCA analysis shows that the production of artificial snow primarily implies impacts on natural land transformation and fossil depletion, and that more snowfalls cause more onerous skiing resorts management, due to high consumption of diesel fuel for piste machines used for snow grooming.

1. Introduction

The Alps zone is particularly vulnerable to climate changes. Twentieth century temperatures in the Alps region have generally increased at higher speed compared to the global average temperatures (Böhm et al, 2001) and, although there is a lot of uncertainty over future scenarios, it is estimated that the increase will continue also in the coming years. IPCC estimates a temperature increase between 0.3 and 4.8 degrees (under different representative concentration pathway (RCP) emission scenarios) by 2100 (IPCC, 2014) indicating that this will be more prominent in the Northern hemisphere, especially during the winter season. Due to the temperature increase, the time of snow remaining on the ground has shortened, and the decrease of the global surface of Alps glaciers has already been registered. Moreover, a gradual decrease of rain in the summer and a rain increase in winter is highly predictable, but this will be accompanied by a snowfalls reduction (Guidetti, 2008). Natural snow was assured for 91% of skiing resorts in Alps at the beginning of the 21st century, but an average of 1°C temperature increase would take the percentage to 75%, and to 61% and 30% with an average increase of 2°C and 4°C respectively (Abegg et al, 2007). At present, the big challenge for skiing resorts is being able to guarantee the best possible snow conditions for winter sports lovers over a long period of time, while facing this lack of “raw material”. Skiing resorts have been using systems of artificial snow for many years: initially they were used to compensate the limits of natural snow (i.e. unpredictability), but today it is actually the natural snow that is used as an integration to technical snow and not vice versa. The reason is that artificial snow allows ski facilities not only to be less dependent from whether conditions, but also to stretch the skiing season, from late autumn until early spring. In Italy,

about 40% of ski territory (9,000 hectares) is covered by technical snow (Guidetti, 2008).
The best conditions for the production of artificial snow are very dry air and cold water. When these conditions are lacking, snowing process is uneconomic and many skiing resorts use additives which impact on temperature needed for water to ice. Therefore, what is needed for the production of artificial snow are water, air and energy. Water plays a fundamental role: one water cubic meter produces between 2 and 2.5 snow cubic meters. When considering basic snow level (about 30 cm) on one hectare of sky run, at least 1 million liters of water is necessary and then much more water for further snow production (Hahn, 2004). According to a study conducted in France (Marnezy, 2008) artificial snow can require up to 4,000 cubic meters of water per hectare of slope. If these data are applied to the Alps (23,800 hectares ski area), around 95 million cubic meters of water would be necessary to produce technical snow, which is equivalent to annual water consumption in a city with 1.5 million inhabitants. There is also the problem that the water needed for technical snow is taken from creeks, rivers, basins or even drinkable water in periods of great water shortage (technical snow is done especially in November and December, a bit less in January and February). A lot of energy is also needed, although energy consumption depends on technical systems, location, water supplying and weather conditions. Another study conducted in France in the 2001/02 season (SEATM, 2002) showed that for artificial snow covering a ski area of 1 hectare, energy consumption was more than 25,000 kWh. Applying these numbers to the Alps area the global energy consumption would be no less than 600 million kWh, which is equivalent to the annual energy consumption of 130,000 families with 4 people (Hahn, 2004). This study aims to identify and evaluate the environmental impacts associated to the production of artificial snow, considering two very different winter seasons in terms of snowfalls, 2016/17 and 2017/2018. To the best of our knowledge, no study has applied the LCA methodology to evaluate the environmental impacts associated with artificial snow production except for a Norwegian study (Ragnhild, 2017), dealing with identification and quantification of the resources consumption.

2. Materials and methods

In this study a Life Cycle Assessment (LCA) approach has been applied to identify and evaluate the environmental impacts of the artificial snow production in a ski resort located in Trentino Province. The analysis refers to two different tourist seasons characterized by different weather conditions, 2016/17 characterized by a very dry winter with low snowfalls and 2017/18 with a particularly wet winter and plenty of snowfalls, allowing to highlight how the weather affects the environmental impacts associated with snow production.

System boundaries. A “cradle to gate” analysis for the snow production system has been designed including the different activities considered in snowmaking (Figure 1). At the facility examined the process is divided in two parts depending on the place of water supply: water coming from the valley floor or water coming from the mountain. The former requires purification (by ozone), filtration and cooling; while the latter requires only the cooling phase, if needed. Afterwards, all the water is collected in a single basin and pumped to the snow guns for the artificial snow production. Finally, snow grooming and auxiliary services required are taken in account. The phases of use by ski tourists and snow disposal are not taken into consideration because of the difficulty in identifying the inputs and collecting the data.

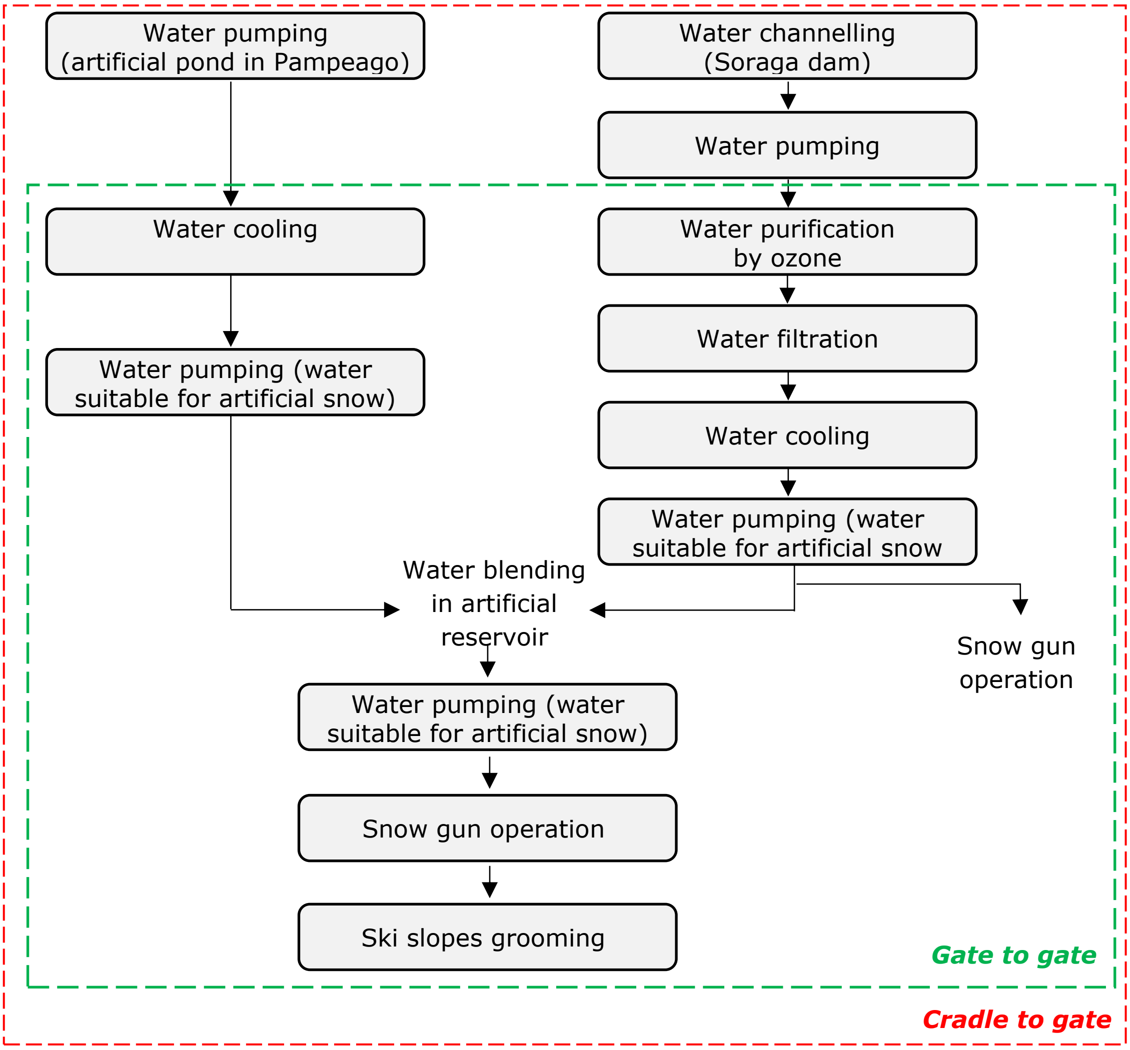

Figure 1: System boundaries and process chain of artificial snow production under assessment

Functional Unit (FU). The FU chosen is 1 m³ of artificial snow (corresponding at 0,4 m³ of water) and refers to the artificial snow used to cover approximately 3 m² of ski slope with a snow height of 30 cm.

Data collection. The primary data were gathered through personal interviews with the technicians of ITAP S.p.A. (the company that manages the ski resort of Pampeago, in Fiemme Valley) and were referred to activities carried out in 2016/17 and 2017/18 winter seasons. The data concern water consumption (referring to freshwater taken from the artificial lakes of Pampeago and Soraga), the energy consumption of all the machinery involved in snowmaking processes (including the phases of water purification, filtration, cooling and pumping) the number of snow groomers and their diesel fuel consumption, the wastewater treatment process etc., no chemical additives are used in this plant. Secondary data derive from EcoInvent 3.3 database included in the SimaPro 8.3 software (PRè, 2016). The inventory table (Table 1), obtained from the data collected at the Pampeago facility, highlights all the inputs and outputs associated with the analyzed process. The input factors considered in the study were: hydroelectric energy (for pumping, ozonization, filter washing, cooling, cannon use, auxiliary services); water (for the washing of the filters and total water for snow production); diesel fuel (for snowcats operations). The output factors were: 1 m³ of artificial snow (functional unit of the analysis) and waste water (from water purification and filtration processes).

Table 1: Summary of inputs and outputs of 1 m³ artificial snow production in the 2016/17 and 2017/18 seasons

INPUT				**OUTPUT**			
	Units	**2016/17**	**2017/18**		**Units**	**2016/17**	**2017/18**
Electric Energy pumps	kWh	2.0635	2.7288	Waste Water	m³	0.0404	0.0694
Electric energy ozonization	kWh	0.0179	0.0148	Artificial snow	m³	1	1
Electric energy filters washing	kWh	0.0002	0.0003				
Electric energy cooling	kWh	0.0888	0,1022				
Electric energy snow guns	kWh	1.5123	1.6160				
Electric energy auxiliary services	kWh	0.1157	0.1542				
Water for filters washing	m³	0.0021	0.0017				
Water pumped	m³	0.4404	0.4694				
Diesel fuel	L	0.1549	0.2635				

3. Results and discussion

Data regarding 2016/17 season were taken into consideration, in order to correctly assess the environmental impacts related to 1 m³ artificial snow production. In fact, that season was really unusual, since there was no snowfall at all, therefore all the data are entirely ascribable to this specific production. Table 2 shows the contribution values of each activity to the impact categories. Figure 2 shows the relative contribution (in percentage) of the different inputs to the environmental impact categories. The processes that contribute most to the various impact categories are: diesel fuel consumption and waste water treatment which mainly affect 16 out of the 18 impact categories.

Table 2: Data of the processes contribution to the impact categories for the artificial snow production in the 2016/17 seasons

Impact Categories	Unit	Water	Waste water	Filter washing water	Electric Energy	Diesel Fuel	Total
Climate change	kg CO_2 eq	0	0.010444	0	0.001354	0.048628	0.060427
Ozone depletion	kg CFC-11 eq	0	6.99E-10	0	2.68E-11	9.36E-08	9.43E-08
Terrestrial acidification	kg SO_2 eq	0	0.000128	0	2.17E-07	0.000448	0.000576
Freshwater eutrophication	kg P eq	0	4.26E-05	0	8.48E-09	1.47E-06	4.41E-05
Marine eutrophication	kg N eq	0	0.00083	0	5.1E-09	9.51E-06	0.00084
Human toxicity	kg 1.4-DB eq	0	0.005695	0	5.04E-06	0.005079	0.010779
Photochemical oxidant formation	kg NMVOC	0	5.37E-05	0	9.6E-07	0.000365	0.000419
Particulate matter formation	kg PM10 eq	0	4.47E-05	0	7.17E-08	0.000122	0.000167
Terrestrial Eco toxicity	kg 1.4-DB eq	0	5.29E-06	0	2.29E-09	4.7E-06	9.99E-06
Freshwater Eco toxicity	kg 1.4-DB eq	0	0.000251	0	1.7E-07	0.000243	0.000494
Marine Eco toxicity	kg 1.4-DB eq	0	0.000223	0	1.29E-07	0.000113	0.000336
Ionising radiation	kBq U235 eq	0	0.001131	0	1.06E-05	0.033783	0.034925
Agricultural land occupation	m^2a	0	0.000394	0	5.37E-07	0.000354	0.000749
Urban land occupation	m^2a	0	4.29E-05	0	7.9E-08	5.32E-05	9.62E-05
Natural land transformation	m^2	0	3.35E-07	0	3.49E-05	1.16E-07	3.54E-05
Water depletion	m^3	0.4404	-0.03628	0.0021	0.110996	0.0007	0.517912
Metal depletion	kg Fe eq	0	4.2E-05	0	5.6E-08	4.09E-05	8.3E-05
Fossil depletion	kg oil eq	0	0.002107	0	5.1E-05	0.172687	0.174845

Diesel fuel consumption for snowcats operations contributes, as expected, almost entirely to fossil depletion, ozone depletion and ionising radiation (respectively 98%, 99% and 97%) and partially to photochemical oxidant formation (87%), climate change (80%), terrestrial acidification (78%) and particulate matter formation (73%). All these impact categories are related to atmospheric emission from fossil fuels combustion. Likewise, wastewater treatment contributes mainly to freshwater and marine eutrophication (respectively 97% and 99%) as well as to marine toxicity (66%). Conversely, it negatively contributes to water depletion impact category (-7%) corresponding to an avoided impact in terms of water withdrawal from nature.

Another important process to be considered is the electric energy production. In the specific case studied, electrical energy comes wholly from the hydroelectric power plants of the Trentino Province. It contributes almost entirely to the natural land transformation (99%) due to the construction of the water accumulation basins that determines a long term modification of the territory. In addition, hydroelectric production contributes for 20% to the water depletion, whereas remaining percentage is obviously attributable to water withdrawal for snowmaking.

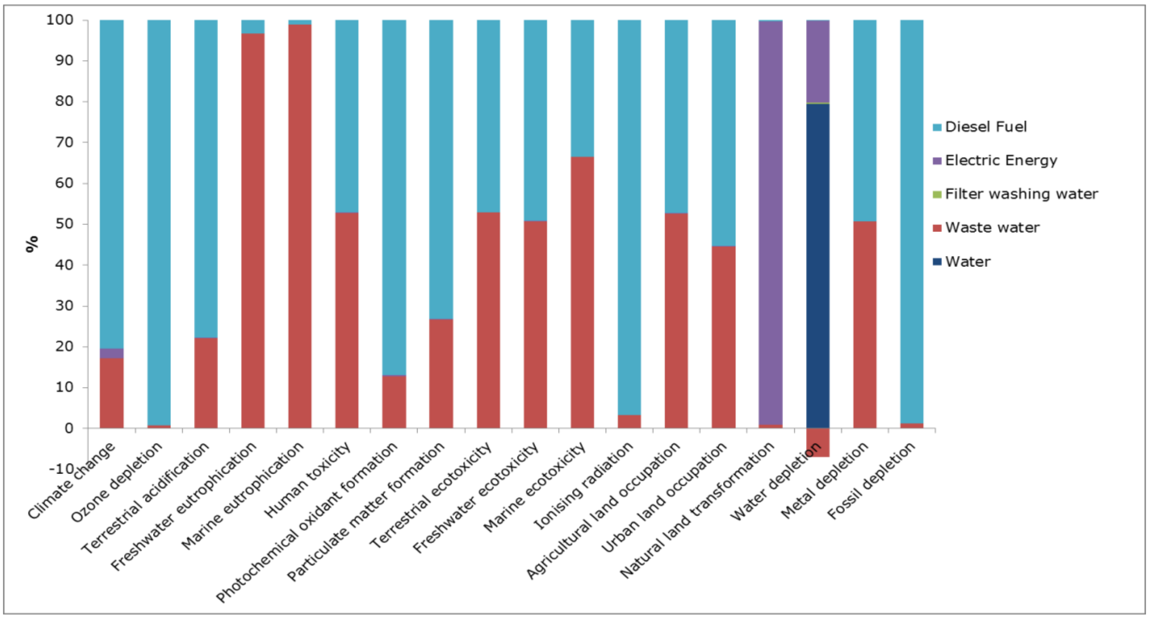

Figure 2: Relative contributions of inputs for 1 m^3 of artificial snow production to environmental impact categories in 2016/17 season. The term "water" (see the key) refers only to the amount withdrawn from the two reservoirs

Data normalization allows to evaluate the actual weight of the environmental impacts related to 1 m^3 artificial snow production.

Figure 3 shows how the midpoint impact category mostly involved in the production of artificial snow is the "transformation of natural soil", caused above all by the production of hydroelectric energy. It follows the category "depletion of fossil fuels”, due to the high consumption of diesel oil for the ski slope grooming. Since SimaPro does not calculate normalization for water depletion a water footprint analysis (Simapro method: Pfister et al 2010 (ReCiPe)) was performed to evaluate the impact related to the water consumption. This analysis highlights that water withdrawal for snowmaking is the phase that generates the most important impact both for “ecosystem quality” and for “resources” damage categories contributing to each of them for 79.6%. Moreover, the consumption of water for the production of electricity contributes to the two categories of damage for 20%.

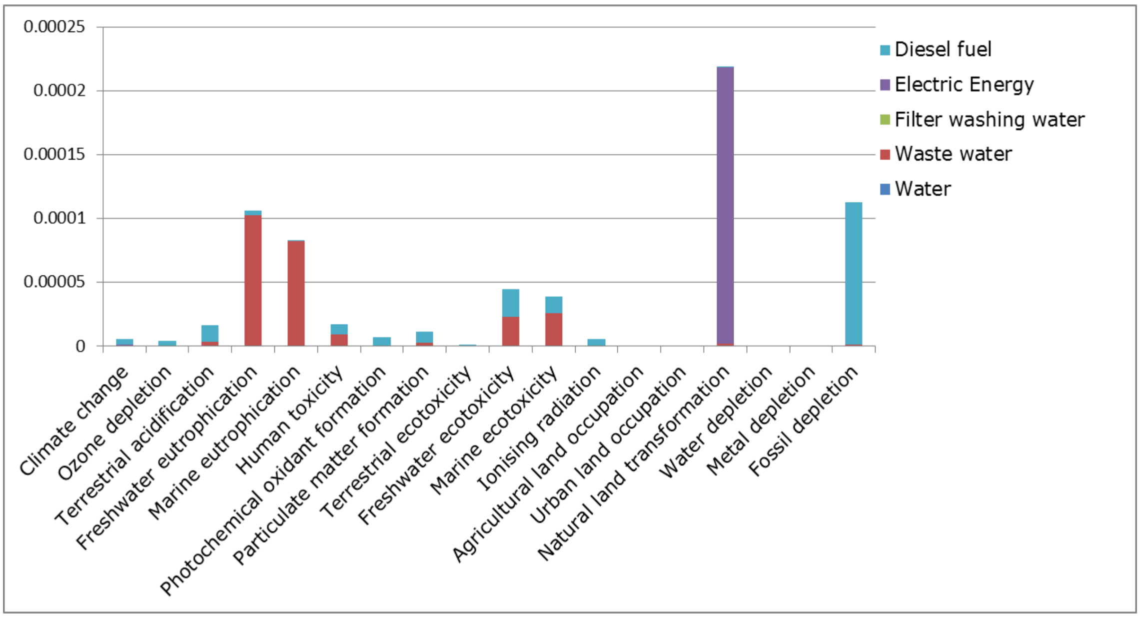

Figure 3: Normalized results for 1 m³ of artificial snow production in Fiemme Valley in 2016/17 season

The overall result of the analysis shows that energy production, both from fossil fuels and renewable sources, is the most important cause of environmental impacts to produce 1 m^3 of artificial snow in Fiemme Valley. It follows that the activities involved are the pumping for the collection and transport of water from the catchment basins to the purification plant and to the snowguns (electricity) and the use of machinery to groom the skiing slopes after snowmaking.

Finally, the environmental impacts associated with the total snow production in the two different seasons, characterized by different weather conditions, were compared in order to highlight how the weather conditions can affect the environmental impacts. In fact, total snowfalls for the 2017/18 season were abundant. Therefore, only 460,040 m^3 of technical snow were produced with respect to 776,910 m^3 produced for the 2016/17 season. The different types of impacts generated are shown in the graph of Figure 4. It clearly emerges from the analysis carried out that the impacts are very similar for all the categories considered but for “water depletion” and “natural land transformation”: for these categories the values regarding the 2016/17 season are definitely higher due to greater water and electric energy consumption. On the contrary, the impact categories related to diesel consumption do not show significant differences because the heavy snowfalls of the 2017/18 season required an intense activity of ski-slope grooming. Therefore, the different weather conditions in the two seasons on one hand has allowed savings in terms of water and electricity consumption but, on the other hand, has not helped to reduce the consumption of energy from fossil fuels.

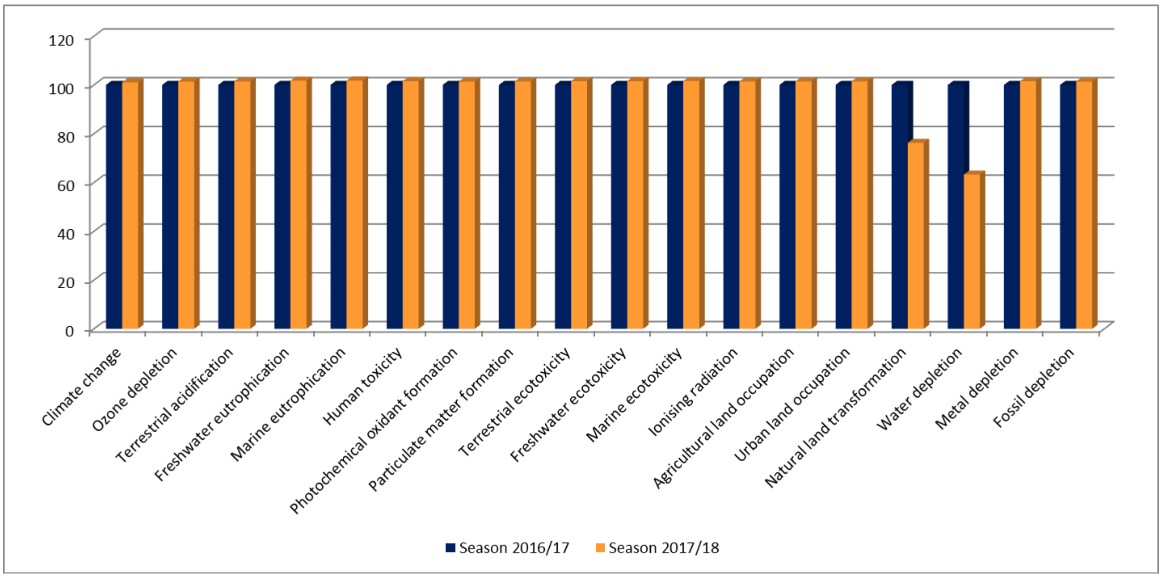

Figure 4: Comparison of the midpoint impact categories analysis of the 2016/17 and the 2017/18 winter seasons

4. Conclusions

On the basis of this study's results (which refer to a specific Alps area and therefore not necessarily applicable to other winter resorts), it is possible to state that the environmental impact associated to the production of 1 cubic meter of artificial snow is primarily attributable to two categories: fossil depletion caused by the use of diesel fuel for machinery to groom the skiing slopes and natural land transformation. In reference to the last category, the reason lies on the fact that the energy used for the production of artificial snow comes from certified renewable source, specifically hydroelectric. Therefore, the result is definitely a lower environmental impact related to energy consumption, compared to the use of non-renewable sources, but nevertheless the impact is not negligible because of the water basins exploitation for energy production. Moreover, it is quite interesting to see, when comparing the two winter seasons 2016/17 and 2017/18 very different in terms of snowfalls, how the environmental impact is overall almost unvaried, even a bit higher in the 2017/18 season with more snowfalls. This can be explained by considering that some cubic meters of artificial snow were produced before the natural snowfalls (between October and November). In addition, in the 2017/18 winter season,

skiing runs were groomed many times as a consequence of plentiful snowfalls, which caused an increase in diesel fuel consumption. This increase partially diminished the environmental benefits of a lower quantity of artificial snow. However, as expected, the two impact categories “water depletion” and “natural land transformation” show higher values for the 2016/17 season due to greater water consumption (see above in “Result and discussion” section).
Therefore, in terms of global managing of skiing resorts, it is possible to paradoxically conclude that winter seasons with favourable snowfalls do not necessarily involve a lower environmental impact.

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Life Cycle Assessment of a calcareous aggregate extraction and processing system

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Abstract

The Life Cycle Assessment methodology is increasingly used by companies to assess environmental loads connected to production processes. The objective of the present work is to apply this method, to assess the environmental impacts of a calcareous aggregates extraction and processing system of a multi-sector company in the Taranto Province. The study takes into account all the phases of the system life cycle starting from the extraction of raw materials up to the final treatment of the produced waste. The life cycle impact assessment highlights the system's critical points, namely, the electricity consumption of the production plants, the diesel fuel use of machinery and the use of explosives in the quarry front cultivation phase.

1. Introduction

The strategic importance of adopting the Life Cycle Assessment (LCA) methodology as a basic tool for identifying significant environmental aspects of a product/service is widely recognized at European level. LCA is a standardized procedure that evaluates a set of interactions that a product or service has with the environment, considering its entire life cycle (ISO, 2006 a, 2006b). Many organizations today use this tool to identify the hotspot of their production systems.

The Italcave S.p.A. company engaged in numerous and diversified production activities in the Taranto Province has shown particular interest in the application of this tool to its economic activities in order to evaluate and monitor the environmental performance of its production systems. The purpose of this paper is to apply the LCA methodology to quantify the environmental profile of a calcareous aggregates extraction and processing system managed by the company. This plant complies with the eco-management and audit scheme EMAS III (Regulation (EC) No 1221/2009) and is equipped with an Integrated Management System regarding quality, environment and safety (Italcave, 2017). The LCA study of this system will in the future be integrated with the LCA studies of the company's other production processes (non-hazardous industrial waste treatment system, goods handling facilities on the dock of the Taranto port and a temporary storage of solid fuel products), with the aim of implementing an Organisation Environmental Footprint (OEF) study for reducing the supply chain activities environmental impacts and improving resource efficiency and business competitiveness (EC, 2013).

2. Goal definition, scope and basic assumptions

The study stems from the need of the Italcave company to investigate the critical points, from an environmental point of view, of its limestone aggregate extraction and processing system with the intent of intervening with appropriate technologies to reduce environmental impacts. The function performed by the system is the extraction activity and the processing of inert materials, for which the extraction and processing of a ton of calcareous aggregates is defined as the functional unit.

The study considers "cradle to grave" approach and includes the following steps within the system boundaries: supply of auxiliary raw materials, the cultivation of the quarry front, loading and transport phase of inert materials, primary crushing and sifting, secondary crushing and sifting, ordinary maintenance of plants and vehicles. Figure 1 shows the flow chart of the system with reference to the year 2016, during which 869,725 tonnes of limestone aggregates were extracted and partly sent to crushing.

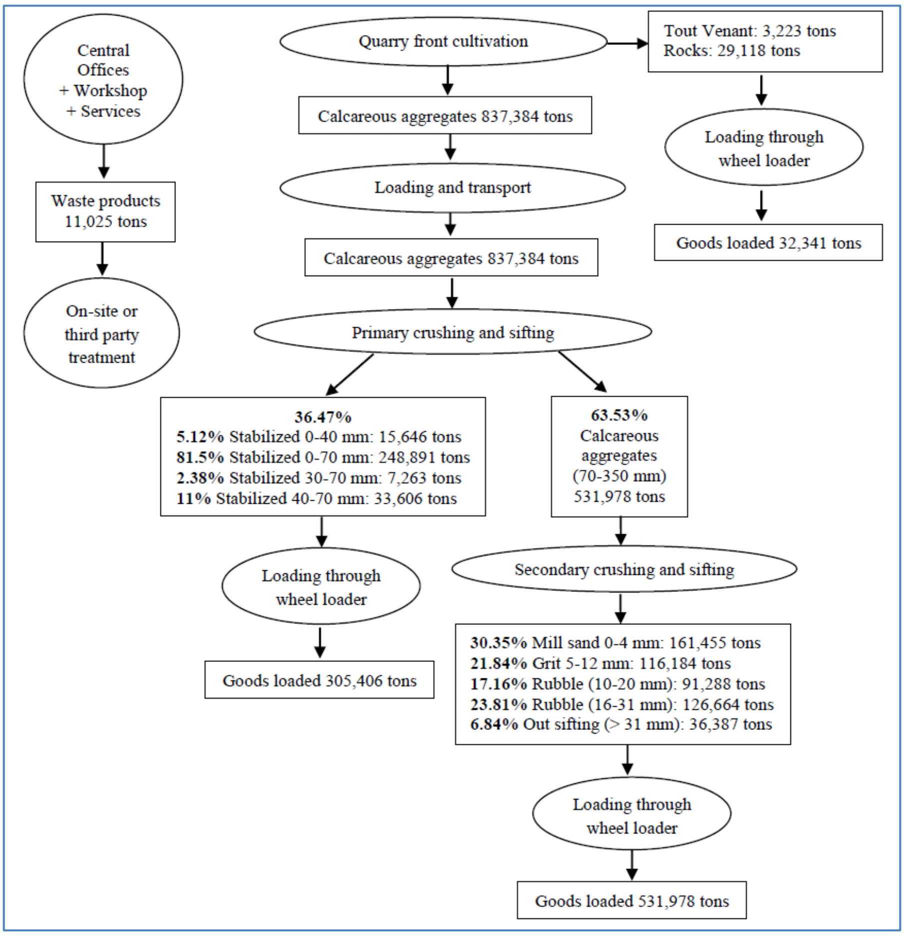

Figure 1: Flow chart of the calcareous aggregates extraction and processing system (year 2016)

The study also considers the environmental impacts of on-site or third-party treatment of process waste and its transport to the treatment site. The central offices and workshop are at the service of the various company activities namely, a landfill, the calcareous aggregates processing plant and a site for the temporary storage of bulk goods. For this reason, the inventory data of administrative and maintenance activities have been allocated taking into account the volumes of goods managed. As the landfill and quarrying activities deal with the management of about 90% of the company's goods, it was decided to allocate 45% of the energy and water consumption of the central offices and workshop both to the quarry and to the landfill, thus assigning only 10% of this consumption to the temporary storage of bulk goods.

Regarding the quarry front cultivation phase, the estimation of the air emissions deriving from the explosion is particularly complex. The type of explosive used in this phase is a mixture consisting of ammonium nitrate, fuel oil and aluminum (explosive ANFO). The scientific literature indicates that the use of ANFO explosives in this life cycle phase is responsible for nitrogen oxides and dust emissions. For the estimation of nitrogen oxides emissions, this study considers scientific literature data according to which an average emission factor of 5 kg of nitrogen dioxide per tonne of explosives can be considered (Oluwoye et al., 2017). The calculation of dust emissions caused by blasting activity considers estimates from other literature (Appleton et al., 2006) according to which the total quantity of dust, in the form of suspended particulate matter, released by a typical blast is 1,900 kg with reference to 25,000 tonnes of material extracted.

The case study in question is a multi-product system, so another important problem to be addressed in the study concerns the allocation of the environmental impacts among the different products obtained from the crushing and sifting plants. In this regard, when considering the impacts due to the distribution of energy loads between the various products, particle size of the aggregate must be considered (Tassielli et al., 2006). For the sake of brevity, in this paper the potential environmental impacts related to the primary and secondary crushing plants are assessed allocating all the impacts to the aggregate extraction and processing service as a whole.

The foreground data were provided directly by the company and refer to the year 2016. For the background data, Ecoinvent database and other bibliographic sources were used. Particular attention was paid to the quantification of the component materials and mixtures of exploding materials used in the blasting phase, considering the specific data supplied by the suppliers. For the electricity consumption inventory modelling of the system, the Italian electricity mix was taken as reference (MISE, 2015).

The environmental impact assessment methodology adopted is the one defined in the International Reference Life Cycle Data System (JRC, 2010) - ILCD 2011 Midpoint+. In this study, the main impact categories have been integrated by Cumulative Energy Demand (CED) (Hischier et al., 2010) since it allows a direct understanding of the system primary energy consumption. Normalisation was conducted on a European basis (Benini et al. 2014), whilst weighing of the results was carried out with equal weights for all the impact categories.

3. The inventory and the assessment of the system environmental impacts

In the inventory phase of the present study all the input and output data of each process considered within the system boundaries were collected. In the next phase the environmental impacts were calculated, referring to the entire life cycle of the calcareous aggregates extraction and processing system.

3.1. Life Cycle Inventory (LCI)

This section presents the inventory data, aggregated for the entire inert materials extraction and processing system, used for the life cycle impact assessment phase. Table 1 shows the principal input and output data of the system for the year 2016.

Table 1: Main Input and output data of the calcareous aggregates extraction and processing system (year 2016)

INPUT		
Materials	Limestone aggregates (tons)	869,725
	Industrial water (tons)	9,519
	Tap water (tons)	853
	Explosive ANFO (kg)	91,550
	PETN (kg)	801
	PVC (kg)	454
	Explosive transport (t.km)	11,261
	Lubricating oil (kg)	681
Fuels	Diesel (L)	349,281
Electricity/heat	Electricity (kWh)	1,087,638
OUTPUT		
Materials	Processed limestone aggregates (tons)	869,725
Air Emissions	Nitrogen dioxide (kg)	458
	Suspended Particulate Matter (kg)	66.100

3.2. Life Cycle Impact Assessment (LCIA)

Following the problem-oriented approach, the inventoried physical flows were correlated to the relevant environmental impact category. The life cycle phases analysed relate to the following activities or resources/materials used as input for the calcareous aggregates extraction and processing activities:

- Extraction activity in the strict sense;
- Use of industrial water;
- Use of tap water;
- Use of explosive ANFO;
- Use of other explosives;
- Explosive transport;
- Diesel fuel use;
- Electricity use;
- Use of lubricating oil.

Table 2 illustrates the results of the characterization phase with the indication of the absolute values of the potential impact indicators with reference to one ton of limestone aggregates. Figure 2 shows the same indicators reported in percentage terms. The most impacting activities of the system are represented by the electricity consumption of the production plants and related services and the use of diesel fuel of the transport and quarry machines. The third most impacting activity, in terms of environmental impact, is the use of explosive ANFO in the quarry cultivation phase.

Table 2: Absolute values of the potential impact indicators for each of the processes of the system (year 2016) referring to one ton of limestone aggregate (FU)

Impact Category	Unit	Total	Extraction activity	Industrial water use	Tap water use	Explosive ANFO use	Other explosives use	Explosive transport	Diesel fuel use	Electricity use	Lubricating oil use	Lubricating oil use
Cumulative energy demand	MJ eq	36.1	0	0.00312	0.00638	3.07	0.0801	0.107	20.2	12.5	0.044	0.0203
Climate change	kg CO2 eq	2.42	0	0.000277	0.000299	0.328	0.00342	0.0066	1.38	0.696	0.000543	0.00025
Ozone depletion	kg CFC-11 eq	1.38E-07	0	2.22E-11	3.52E-11	3.07E-08	4.93E-10	1,18E-09	1.61E-08	8.83E-08	5.11E-10	2.36E-10
Human toxicity, non-cancer effects	CTUh	1.62E-07	0	1.2E-10	9.29E-11	6.19E-08	7.84E-10	1,71E-09	1.28E-08	8.42E-08	1.58E-10	7.31E-11
Human toxicity, cancer effects	CTUh	3.51E-08	0	5.58E-11	3.24E-11	1.21E-08	1.7E-10	2,98E-10	1.11E-9	2.14E-08	2.84E-11	1.31E-11
Photochemical ozone formation	kg NMVOC eq	0.0149	0.000527	8.64E-07	7.17E-07	0.00074	1.24E-05	4,55E-05	0.0121	0.00146	8.11E-06	3.74E-06
Acidification	molc H+ eq	0.0152	0.00039	1.31E-06	1.89E-06	0.00182	2.0E-05	4,28E-05	0.00928	0.00363	5.6E-06	2.58E-06
Freshwater eutrophication	kg P eq	0.000244	0	8.86E-08	2.33E-07	4.36E-05	7.64E-07	6,89E-07	4.74E-06	0.000193	1.81E-07	8.37E-08
Freshwater ecotoxicity	CTUe	5.4	0	0.00388	0.00308	1.49	0.0193	0,0418	0.0545	3.78	0.00384	0.00177

The electricity consumption of the production activities is responsible for 79% of the Freshwater Eutrophication (FEU) and for 70% of the Freshwater Ecotoxicity (FEC) due to phosphate and metal emissions in the background part of the system respectively. This phase also contributes to 64% of the Ozone Depletion (OD), 61% of the Human Toxicity Cancer effects (HTC) and 52% of the Human Toxicity Non-Cancer effects (HTNC). Diesel fuel-use contributes to 81% of the potential Photochemical Ozone Formation (POF) and 61% on the Acidification (AP) mainly due to the nitrogen oxides air emissions. This fuel consumption is also responsible for 57% of the potential Climate Change (CC) due to carbon dioxide fossil emissions and for 56% of the Cumulative Energy Demand (CED).
Explosive ANFO impacts in the HTNC (38%), HTC (34%), FEC (28%), OD (22%), FEU (18%), especially due to emissions of background processes related to the production of ammonium nitrate, the main constituent of the explosive mixture.

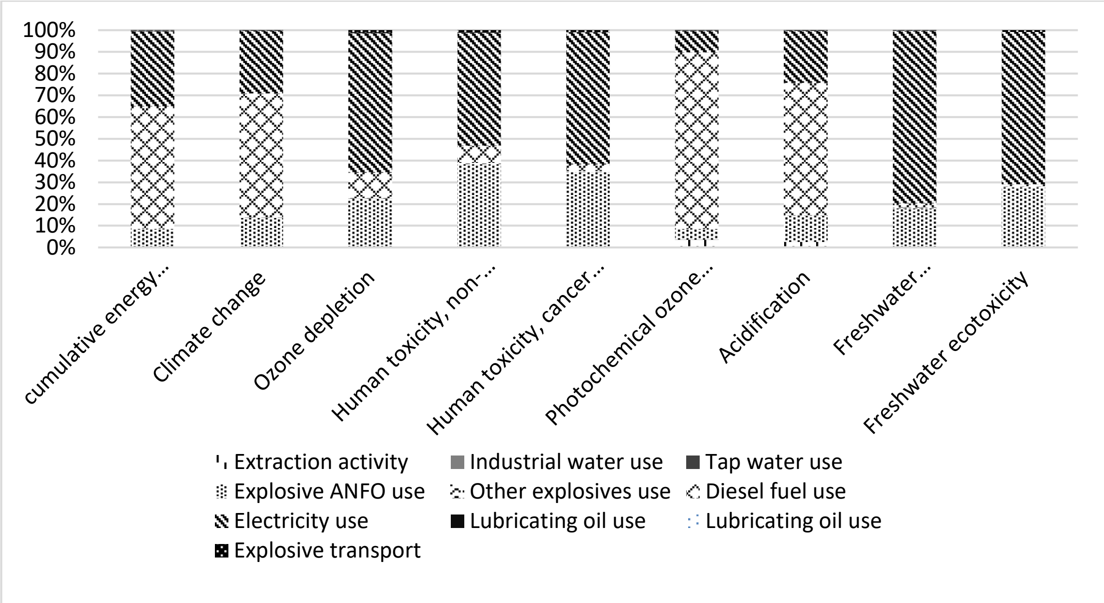

Figure 2: Characterization results in terms of the contribution (%) of each life cycle phase to each impact category (year 2016) referring to one ton of limestone aggregates (FU)

Figure 3 shows the normalized profile of the calcareous aggregates extraction and processing system with reference to one ton of extracted limestone aggregates. The normalised results indicate that the impact categories most affected by the system are the HTCE, FEC and POF.

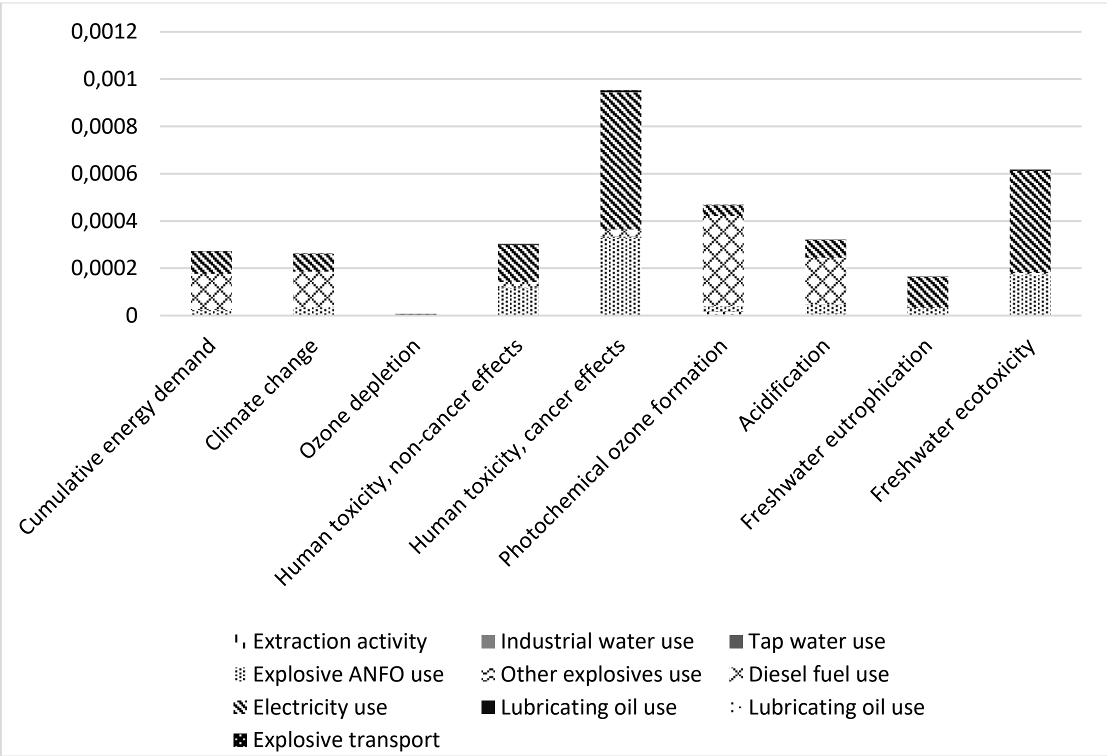

Figure 3: Normalised characterisation results in terms of the contribution of each life cycle phase to each impact category (year 2016) referring to one ton of limestone aggregates (FU)

The weighting phase, carried out with a set of equal weights, illustrated in Figure 4, confirms how the most impacting processes are the electricity use, the diesel fuel use and the explosive ANFO use.

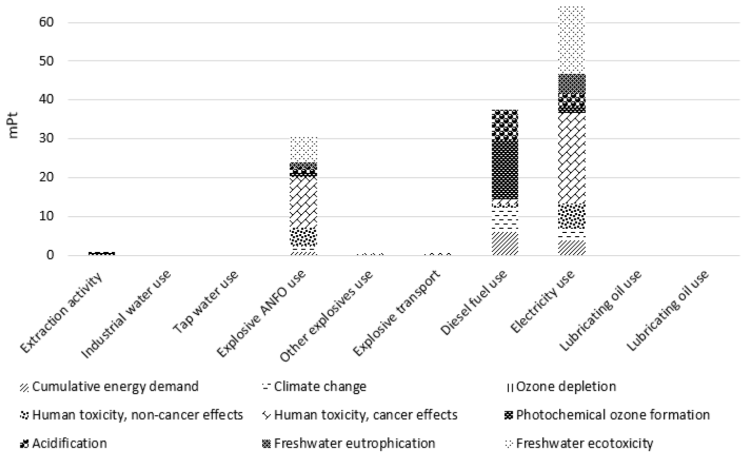

Figure 4: Normalised and weighted characterisation results in terms of the contribution of each impact to each category life cycle phase referring to one ton of limestone aggregates (FU)

4. Conclusions

The application of the LCA methodology to the calcareous aggregates extraction and processing system has identified the critical points of the system from an environmental point of view. The main environmental impacts are connected to the electricity consumption of the primary and secondary crushing and sifting plants and to the diesel fuel-use of the machinery used in the quarrying activities. In terms of environmental impact categories, electricity consumption contributes mostly to the ozone depletion and the human and aquatic ecosystems toxicity categories. Diesel fuel use mainly contributes to the photochemical ozone formation and acidification impact categories. In this regard, a more detailed analysis of the various sub-phases that make up the system is recommended to adopt the appropriate improvement interventions. It is important not to neglect the environmental impacts linked to the use of the explosive ANFO that, due of the background processes related to the production of ammonium nitrate, contribute considerably to the human and aquatic toxicity categories. In this case an alternative method, such as mechanical excavation, could be evaluated to reduce the environmental impacts of quarry front cultivation.

Finally, the present study will in future be integrated with those of the other production activities of the company and will thus make it possible to assess the environmental profile of the entire organization in terms of an OEF.

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Efficient Integration of Sustainability aspects into the Product Development and Materials Selection Processes of Small Businesses

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Abstract

To integrate sustainability aspects into product development, a lot of large companies established whole departments that foster the integration of eco-design tools. For small businesses, however, this is often not feasible due to a lack of capacity or available money. To define applicable tools, they cannot search through the extreme amount of eco-design tools that are currently available (Lindahl and Ekermann, 2013). In order to support these small companies, this research shows an efficient way to make an objective decision on which tool is the best considering their framework and preferences. To set limits, only the materials selection within the concept design phase is considered. Four main tools are identified and presented in this paper, each comprising a different depth of sustainability aspects during the product development process.

1. Introduction

"The first step is the most important. It is the most crucial and the most effective as it will initiate the direction you have chosen." (Backley, 2012). As plausible as this statement might be when it comes to a journey, as underrated it is when it comes to product development. Although it is well known that the design engineer already defines 70 % of the product´s cost within the "Development and Design"-phase of product development, most companies lack a focus especially in this stage of concept development (see Figure 1).

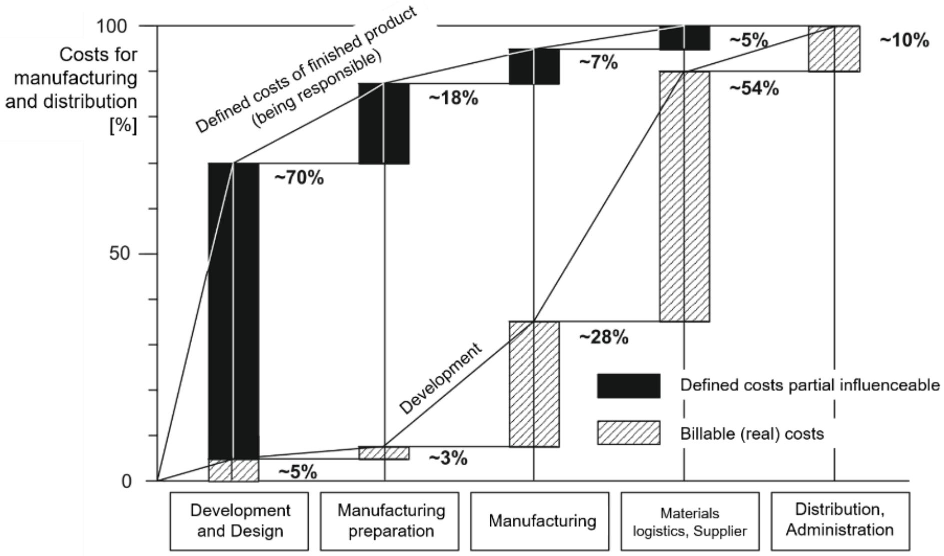

Figure 1: Generated and defined costs of the different steps of a product´s lifecycle (Ehrlenspiel, 2013)

Usually the daily business forces engineers to deliver other designs first, keeping them from taking enough time for the first steps of a new product. Standardised Product Development Processes (PDPs) like the German VDI 2221 (VDI, 1993) or VDI 2206 (VDI, 2004) (developed standards of the German Engineers Association “VDI”) pick up that issue, offering a very generic support for the engineer. Unfortunately, these processes are quite strict and a customization for the requirements of a specific company is difficult and time-consuming. When it comes to sustainable design or eco-design, these problems do intensify. The usual approach of companies to evaluate the sustainability of their products is to hire another company to do an LCA of the finished product. By then, the freedom of action to influence the product costs which highly correlate to the sustainability of the product is less than 12 % (see Figure 1, Manufacturing and Materials Logistics, Supplier). Even if the companies want to use eco-design tools on their own, they often fail to select the right design tools within the many eco-design tools that are currently available (Lindahl and Ekermann, 2013).

What most companies need is an objective, pragmatic way to quickly decide which eco-design tool is most relevant for them and when it should be implemented within a methodical product development process. In this research a pairwise comparison of 18 different attributes of a product - conducted by the management of a small business - is used to choose the most feasible product development process as well as the most suitable eco-design tool. Therefore, the choice is limited to all eco-design tools that are related or can be implemented into a methodical material selection process. The choice of material is a major influence on the sustainability of a product (Ashby, 2013). Besides many other attributes, the material defines the weight, the manufacturing and the joining strategy of the product. These factors have a huge impact.

In the end, four different eco-design tools are identified. They deliver four different depths of sustainability focus within the PDP of a product. The focus of sustainability in this case means an allocation of time and resources within the PDP to increase the sustainability of a product. The highest focus of sustainability for example results in 66 % of time and resources allocated to the improvement of the sustainability using a predefined eco-design tool. These different tools are then implemented into a methodology that allows a quick decision on which material should be used to develop a more sustainable product.

2. Method

To consider aspects of sustainability in materials selection, several interfaces between materials selection and eco-tools need to be considered. Concerning eco-tools, LCA is predominantly used and established in literature and public. It forms a reasonable basis to start from. Since LCA has a very wide range of forms and applications, its use in materials selection is elaborated here.

In theory, the optimal way of considering sustainability aspects in materials selection is treating them similar to all other restrictions and objectives. This would allow materials selection without the need of additional tools such as LCA. Data on environmental aspects, however, is not as easily obtainable as other material properties like density or Young´s modulus. At this point in time, such direct implementation is restricted to estimated values, derived indicator figures or expression via other database entries already available.

A way of enabling solution-neutral estimation of environmental consequences is by key indicator figures. Ashby promotes the embodied energy and the carbon emissions to estimate environmental consequences of a design, (Ashby et al., 2009). Estimating both figures for raw materials is accurate enough to use the data (standard deviation of about 10% according to (Ashby, 2013)). Even estimating them for the use phase is often possible, especially if it is linked to the product´s weight. Regarding manufacturing, however, the ideal of staying neutral towards different solutions is difficult to uphold. Materials can be manufactured in many different ways, resulting in many different environmental implications. Similarly, the end of life and transport phases can have different environmental impacts depending on material, location, and economical situations.

As a result, integrating sustainability considerations via direct use of material properties is only possible in specific cases. Such integration is possible under circumstances allowing the comparison of all candidate materials. If the product´s materials extraction phase and/or the use phase dominate the environmental impact, a formulation of this phase´s energy use or carbon emission can be used as relevant estimation. Ashby refers to domination of a phase from about 80% environmental impact share (Ashby, 2013), a common scenario among products as Figure 2 illustrates. Also, the candidate materials can be compared if they share the same framework conditions. For example, if all candidate materials are woods and their manufacturing process is alike, the environmental impact of the manufacturing phase can be compared. In other cases, a different approach is needed since the derivation of a material index for an environmental impact is nearly impossible then.

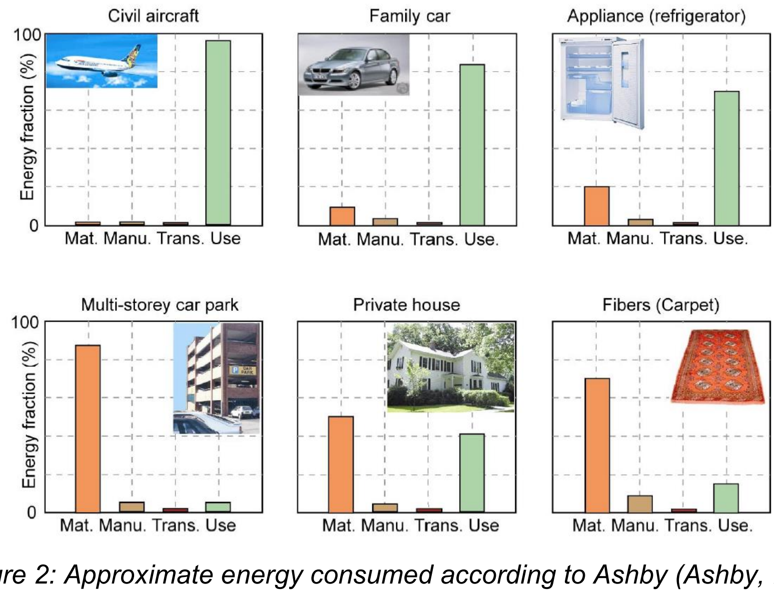

Figure 2: Approximate energy consumed according to Ashby (Ashby, 2009)

Ideally, the formulation of LCA in a solution-neutral way would be targeted. In this hypothetic case, LCA for every possible material option could be conducted. To enable this within a reasonable timeframe, a database containing all relevant LCA information would be needed. Unfortunately, conducting LCA is far too complex to be able to express all relevant data in a database since there are too many factors of influence unable to be generalized. Therefore, reasonable estimation is the next best alternative. The environmental impacts of a materials selection cannot be estimated without appropriate data. In many cases, narrowing down the range of candidate materials or choosing representative material options is necessary to access such data. Due to that, every form of LCA can only take place after preselecting materials. Since the screening of options as described by Ashby is often too broad yet, choosing an amount of representative options after the ranking step is advisable. One of the fastest forms of LCA is the so-called Eco Audit as described by Ashby (Ashby et al., 2009). It skips the impact assessment entirely. It even shortens the inventory characterization by focusing on two factors only. As an indicator of used resources, embodied energy (measured in MJ) is utilized. Its counterpart for emissions is the carbon footprint (measured in kg). The two figures are closely related in a roughly linear dependence. Those indicators were chosen due to one of the rare international agreements on the matter: “a commitment to a progressive reduction in carbon emissions” as formulated in the Kyoto protocol of 1997 (Ashby, 2013). At national level, energy consumption is a greater focus. It is also the easiest environmental indicator to monitor (Ecotec, 2001). Both figures, commonly understood by the public and increasingly standardized as indicators for environmental performance, are suitable as early indicators in the design process (Ashby et al., 2009).

If carbon emissions and used energy are not sufficient for the given task, a less radically simplified form of LCA is advisable. Still, every simplification makes the LCA faster. Too much detail is neither necessary nor beneficial because product design is still at an early stage at this point and most environmental data quality is subject to high uncertainties. Furthermore, the LCA should focus on the aspects defined in the task. By tracing the result back to its cause, critical points of attack can be identified. If possible, new restrictions can be formulated based on the findings.

3. Results

For each level of sustainability focus, this chapter proposes suitable tools. The target is to provide a tool with adequate depth and minimal resource requirements for each level.

3.1. Low Level

Life cycle approaches require a certain basic amount of time. Since time is very limited for a low level of focus, these are not suitable here. No matter how simplified its form may be, LCA exceeds the timeframe granted to this level of sustainability focus. A faster alternative is needed. In eco-design literature, several forms of checklists are promoted (Allione et al., 2012; Knigh and

Jenkins, 2009; Lindahl and Ekermann, 2013). Allione´s checklist for eco-design featuring a multi-criteria system is a great fit, providing a clear structure with a low entry level. Although the level of detail in checklists is very limited, they support the identification of relevant constraints and objectives for materials selection. Therefore, checklists are the tool of choice for a low level of sustainability focus. Allione´s checklist is adapted to the materials selection process, following a simple structure. First, a decision which of the objectives are worth considering is made. Then the relevant objectives are quantified, or otherwise defined if quantification is not feasible.

3.2. Medium Level

The medium level aims at balancing the degree of detail and the required effort. A suitable structure to support dependable decisions needs to be provided by the tool of choice, however without exceeding the timeframe devoted at a medium level of focus. Simplifying the LCA approach to a point where it can be conducted without specific knowledge in sustainability assessment is the sweet spot here. Ashby´s so-called Eco Audit is suitable for the targeted scope (Ashby et al., 2009). Its simplified methodical structure is shown in Figure 3:

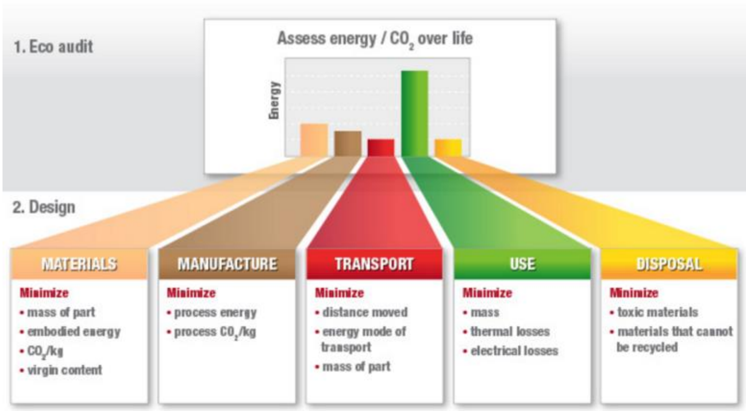

Figure 3: Eco Audit concept according to Ashby (Ashby, 2013)

Eco audits split a product´s life cycle into the sections materials, manufacture, transport, use and disposal. The tool only covers the embodied energy and the carbon footprint of products. The speed of Eco Audits qualifies them for this level. The limitation of only showing embodied energy and CO2 emissions is relevant, but not inhibiting its functionality as a rapid tool for estimating environmental impacts.

3.3. High Level

Impacts on the environment are regarded in further detail for a high focus on sustainability. Life cycle impact analysis (LCIA) provides a great benefit in this concern. This requires dedicated LCA software. According to Speck (Speck, 2014), GaBi and SimaPro are suitable options. Although precise modelling is important, the timeframe cannot be expanded too much. Thus, the more detailed expert functions of LCA software are not suitable here. A generic model compatible to the database used for materials selection, however, enables a resource-efficient integration of LCIA. There are several approaches to LCIA, therefore the options are evaluated in the following. In 2011, the Joint Research Centre (JRC) of the European Commission published a handbook on LCIA methodologies (JRC, 2011). This so-called ILCD (international life cycle data system) handbook recommends a current best practice for each mid- and endpoint category. The score criteria used comprise the completeness of scope, environmental relevance, scientific robustness and certainty, transparency and reproducibility, applicability, and stakeholder acceptance. For most impact categories, using endpoint approaches is not recommended by ILCD due to fact that the scientific relations are too soft and not mature enough yet. For this reason, midpoint categories are focused in this work.

Not all methodologies are considered in the pairwise comparison. If the scope of a methodology does not cover the three fields of human toxicity, eco-toxicity and resource depletion, it is not included. A famous example is the USEtox methodology, which features one of the best scientific foundations but does not take resource depletion into account. Furthermore, the methodologies should cover Europe relevantly, preferably the entire world. Methodologies focusing on a different specific region are excluded. Moreover, methodologies already published but not available in LCA software applications yet (e.g. ReCiPe 2016, IMPACT World+) are not considered. The criteria of excellence are scope, scientific certainty, acceptance and update frequency.

All criteria except for update frequency are based on the analysis in the ILCD handbook (JRC, 2011). They are expanded if necessary. Scope defines the range of impacts covered, as well as the regional scope of the methodology. This does not mean the highest number of considered categories tops the charts, but rather takes the broadness of scope into account. The coverage of details is considered by the criterion of scientific certainty. Additionally, the criterion rates the scientific relevance and robustness of a methodology. Acceptance refers to the “Degree of stakeholder acceptance and suitability for communication in a business and policy contexts” (JRC 2011: 8). It also reflects the public acceptance. Update frequency refers to the data used in the considered models implemented in LCA software. Furthermore, the regularity and quality of updates to a methodology is taken into account. This is a very important factor for the future applicability of a method. Table 1 shows the results of a pairwise comparison conducted corresponding to Beitz et al. (Beitz, 2013), where every methodology is compared with every other methodology using the aforementioned criteria. The methodology with most “victories” is ranked the highest.

Table 1: Ranking of impact assessment methodologies

	IMPACT 2002+	ReCiPe 2008	EDIP 2003	CML 2001
Scope	4.	1.	2.	3.
Scientific certainty	3.	1.	4.	1.
Acceptance	3.	1.	3.	1.
Update frequency	2.	1.	4.	2.
Total rank	3.	1.	4.	2.

Among the considered methodologies, ReCiPe is the choice. Although it may be dethroned by other methodologies in the future (for example a holistic approach featuring the USEtox methodology), it is the most viable option at this point in time. In the medium-term future, the use of ReCiPe will provide state of the art impact assessment. The inclusion of LCIA provides a major advantage in depth over the eco audits used for the medium level of focus. Especially detailing the use phase specifications and energy sources grants this form of simplified LCA valuable relevance. Also, the generic model can be refined and tailored to the intended application. This justifies the additional complexity that goes hand in hand with the use of another software tool. Figure 4 shows an exemplary generic plan for the analysis of car parts.

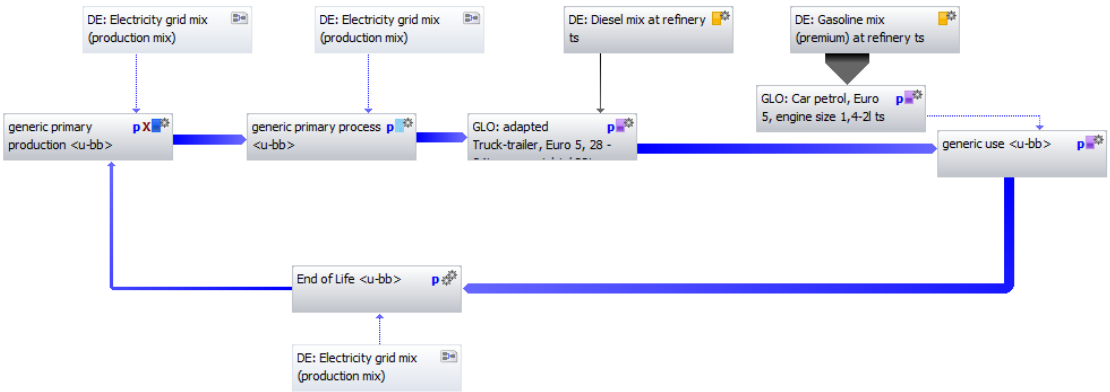

Figure 4: Generic plan for simplified LCA modelled with GaBi

3.4. Maximum Level

Even better consideration of sustainability aspects is achievable by modelling the life cycles of the material options individually. Such individual investigation is not restricted to generic structures or a main database, allowing the use of every available information. This can be useful, yet the resource requirements should not be underestimated. Especially in the case of material options from different material families (e.g. wood versus metal versus plastic), the individual models can differ greatly and demand more effort as well as knowledge in life cycle modelling. Limiting the options may be advisable if data precision is essential.

4. Discussion

These four levels of sustainability allow an allocation of eco-design tools during the materials selection process for small companies under consideration of their preferences defined by a pairwise comparison. The method used to narrow down the available Eco-design tools is based on standardised scientific design validation tools (Beitz et al., 2013; Ehrlenspiel and Meerkamm, 2013; Lindemann, 2009) and experience with the implementation of eco-design at small companies. However, one of the questions that remain is how comprehensive a partly experienced-based methodology is. The efficiency of each possible eco-design tool highly depends on the user, the use-case, the timeframe and the restrictions. With every simplification conducted within this research, a potentially superior tool is disregarded. However, the motivation of this research was to find a way to narrow down the variety of available tools. This way should be as objective as possible. According to Speck, when it comes to sustainability almost everything is relative (Speck et al., 2016). An absolute conclusion which tool is the best for different use cases can never be made.

The other question that remains is which innovation strategy the small businesses should use. If a company wants to consider environmental aspects, the usual approach is to hire another company to conduct an LCA of the almost finished product. The introduced methodology within this paper does not allow such an approach, since the material selection process is a very early step within the PDP and has a huge impact on the design of the part. Hence, the company has to decide whether to build up the competences for the tool recommended by the methodology itself or to find another company that supports these steps even in the early phase of a product development process.

5. Conclusion

The methodology developed within this research is an honest attempt to give small companies the opportunity to use the eco-design tool that is most efficient for the product development within their specific framework. Therefore, a pairwise comparison of 18 attributes of a product assigns one of four different eco-design tools and allocates that tool to a specific place within the individualised PDP. These four tools were narrowed down from the many available tools by assessing their potential on supporting the decision with the highest impact on sustainability within the product development process – the materials selection process. This decision is the foundation for the factors primary production of the raw material, geometry, manufacturing technique, weight, product architecture, fixing strategy and many more that all influence the sustainability of the finished product heavily. The eco-design tools that are compatible with a methodical materials selection process were evaluated regarding input, output, resource requirements and accessibility. Four different levels of depth were developed, resulting in a simple checklist (low level), an Eco Audit (medium level), a simplified and standardized LCA (high level) and a full LCA (maximum level).

The result is a methodology that gives an unexperienced designer the opportunity to implement eco-design tools related to the materials selection process within the PDP.

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Bioplastics in designing beauty and home packaging products. A case-study from Aptar Italia SpA

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Abstract

This article describes the main role of bioplastics materials in the packaging sector considering their potential for enhancing the sustainability of production and consumption activities. With the aim of promoting the practical application of life cycle thinking approaches an tools, this study highlights the experience of Aptar Italia SpA in the eco-design - substitution of conventional plastics with bioplastics - for the production of Beauty + Home packaging products focusing on the principal activities concluded for qualifying these materials. The results obtained reveals the possibility to replace oil-based plastic with bioplastics, which have undergone technical certification. A preliminary assessment also highlights that this solution is capable of generating a reduction in the carbon footprint of the product considered.

1. Introduction

Bioplastics include a broad range of materials and products that are biobased, biodegradable/compostable or both. Biobased means a material or product that is derived from biomass whereas biodegradable/compostable identify materials which can be transformed by a natural chemical process into natural substances such as water, carbon and biomass with the help of microorganisms (Doi, 1990; Kalia et al, 2000). The process of biodegradation depends on the surrounding environmental conditions (e.g. location or temperature), on the material and on the application (European Bioplatics, 2017).

The family of bioplastics is divided into three main groups (European Bioplatics, 2017):

1. *bio-based or partly bio-based, non-biodegradable plastics* such as bio-based polyethylene (PE), polypropylene (PP), or polyethylene terephthalate (PET) (so-called drop-ins) and bio-based technical performance polymers such as polytrimethylene terephthalate (PTT);
2. *plastics that are both bio-based and biodegradable*, such as polyactalacid (PLA) and polyhydroxyalkanoates (PHA) or polybutylene succinate (PBTS). This group includes starch blends made of thermo-plastically modified starch and other biodegradable polymers.
3. *plastics that are based on fossil resources and are biodegradable*, such as polybutylene adipate terephthalate (PBAT).

At present, bioplastics represent about one percent of the approx. 320 million tons of plastics produced annually. In 2017, the global bioplastic production capacity amounted to around 2.05 million tons. However, demand is rising, with more and more sophisticated bioplastic materials and products entering the market. By 2022, the production capacity is expected to increase to 2.44 million tons, with most of these new volumes being converted to innovative packaging solutions (European Bioplatics, 2017). Today, there is a bioplastic alternative for almost every conventional plastic material and corresponding application (Figure 1).

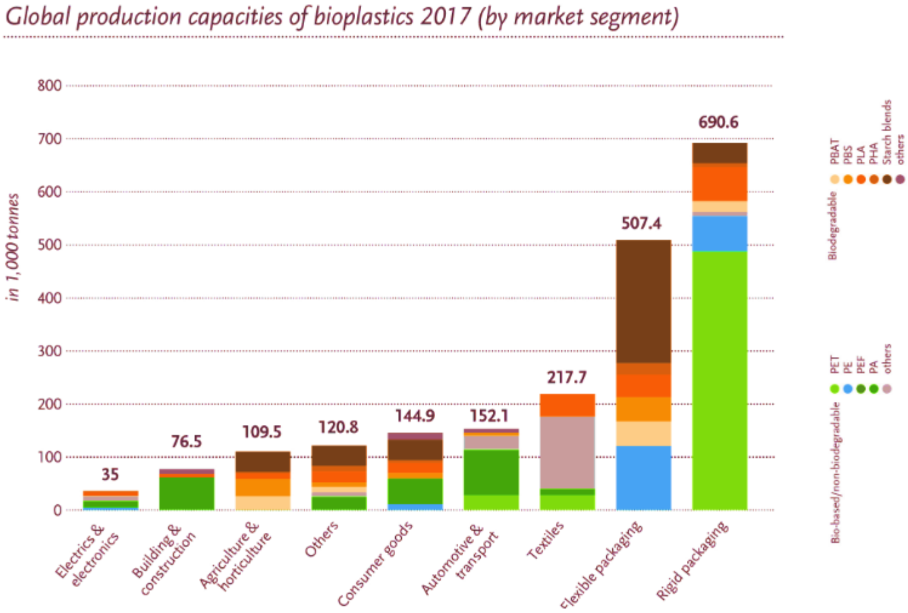


Figure 1: global production capacities of bioplastics 2017 by market segment (Source: European Bioplastic)

1.1 The use of bioplastics in the packaging sector

Packaging from bio-based plastics has developed over the past 10 years. New materials such as PLA, PHA, cellulose or starch-based materials create packaging solutions with completely new functionalities, such as biodegradability/compostability.

Packaging made from bioplastics can be processed with all customary plastics processing technologies. No special machinery is required. Depending on the type of bioplastics used, only the processing parameters have to be adjusted. A wide range of products suitable for numerous and varied applications have been developed within a short period, and nowadays the quality of bioplastics packaging can easily match that of traditional products (Cooper, 2016).

Bioplastics packaging solutions in the market can be identified as (European Bioplatics, 2017):

- *Rigid packaging:* rigid bioplastics applications are available, e.g. for cosmetics packaging of compact powders, creams and lipsticks, a well as beverage bottles. Materials such as PLA, bio-based PE, or bio-based PET are used in this section.

The high percentage of bio-based material in these products and the ability to combine them with recyclates from conventional PE and PET has resulted in a decisive increase resource efficiency and a reduction of CO_2 emissions. As a potentially mechanically recyclable material, PLA has been gaining market share in the rigid packaging segment. With growing volumes, a separate recycling stream will become economically feasible, and the beneficial environmental potential of PLA will be further increased.

- *Flexible packaging*: many different bioplastics are used for flexible packaging solutions. Biodegradability is a feature often sought when it comes to food packaging products for perishables. Biodegradable food packaging certified as industrially compostable was the first successfully commercialised bioplastic product. Films and trays are particularly suitable for fresh produce such as fruit and vegetables as they enable longer shelf life. In addition, confectionary, such as chocolate and biscuits, or dry food, such as tea or muesli, are now increasingly being packaged with bioplastics.
- *Service packaging:* food service packaging is another large growth segment. Whether it is cups, plates, cutlery or carrier bags, the entire product spectrum can be made from bioplastics. These products are used at sports events, street festivals, on planes or on trains. They can be made of biobased non-biodegradable plastics or of biobased biodegradable plastics, depending on the end-of-life solution envisaged for the individual product.

The biodegradability of certain types of bioplastics enables the joint recovery with food residue via composting or anaerobic digestion, provided that conventional plastics do not contaminate this recycling stream.

At present, the scientific literature shows that major application of bioplastics in packaging are in the agro-food industry (Peelman et al, 2013) this guarantees a novelty for this study, which, instead, is applied to the beauty and home industry.

2. Methodological approach

The study here presented has been developed in a perspective of ecodesign, recognized as a process of design aimed at reducing the environmental burden of products throughout their whole life cycle stages (Fiksel, 1996; Luttropp and Lagerstedt, 2006). The application of eco-design can include defferent aspects and solutions, which can be summarized in the following three areas:

• Correct use of materials based on the required performance and reduction/replacement of toxic or more polluting materials;

• Optimization of production processes;

• Improvement of the product during the use and end-of-life phase.

These perspectives can be pursued individually or jointly (Byggeth and Hochschorner. 2006; Bovea and Pérez-Belis, 2012).

Packaging is a field where numerous applications of ecodesign can be found; the main aim is to reduce weight, volume and, therefore, costs and impacts of transport and storage of products; for secondary packaging efforts are also directed to make them as reusable as possible, while for primary packaging to optimize the end-of-life stage (Billon, 2008; Wikström and Haag, 2014).

More specifically, in the project here analysed a "*material substitution*" solution is aimed to be adopted, looking for non-oil based plastics providing the same production and utilization performances as conventional plastics, and, at the same time, allowing the company to reduce the environmental load of its product both in terms of exploitation of resources and end-of-life management.

The methodological approach followed by Aptar Italia to identify the potential replacement of oil-based plastics started from the investigation of the technical features and properties of bioplastics and the comparison with those of conventional plastics (based on safety data sheets). After this initial step, the company's Expert Center tested the bioplastic materials by means of various lab and molding tests in order to compare the quality and features of these raw materials. The results here presented do not include what is currently considered as confidential information for industrial and commercial reasons.

3. Context of the study: Aptargroup and Aptar Italia SpA

Aptar is a leading company in the dispensing solutions niche of the packaging industry, with a market focus on three business segments (Beauty + Home, Food + Beverage and Pharma). Aptar operates in different countries with 12,700 employees and 48 facilities located in different world regions. Aptar Italia, the operating context of the study presented, produces micro-pumps and dispensers for liquids and operates two facilities located in the provinces of Chieti and Pescara, Italy. Pescara's production site covers an area of 18,000 square meters, of which 13,000 for manufacturing (moulding and assembling processes). The production types are cartridges for fragrance pump and lotion dispensers. Chieti's production site covers an area of 13,252 square meters, of which 7,892 for manufacturing (assembling process). The production types are dispensing systems and micro-pumps for fragrance. The assembly department presents 122 machines with a daily average production rate of 3.1 millions of pieces. Aptar has been involved for several years in sustainability aspects, with special focus on environmental and energy issues and is currently considered a sectoral benchmark on those issues and can provide theoretical, methodological and practical feedback to the community of scholars in the life cycle management field.

The study presented in this article falls within a set of actions conducted by Aptar in recent years, including: an initial cradle-to-gate LCA on a sample product, then extended to other items; the development of simplified tools for the dynamic assessment of the environmental impacts of transports, materials and energy use; the analysis of end of life scenarios of their products, based on EU-wide databasesorganizational and managerial actions (ISO 14001 for EMS and ISO 50001 for EnMS); research actions: (partnership with Pescara University: "Aptar Italia awards" and Industrial PhD); plant actions (energy efficiency); product actions: (materials and weight optimization, logistic aspects); wastes and scraps actions (reuse and recycling, internal Landfill Free certification); supply chain actions (intermodal project for logistics and LCA on full aerosol packaging); marketing and communication actions: (labels such as ISO 14025 EPD, ad CDP and GRI reports).

4. Description of the project

4.1 Products involved

The products focused on in the present study are the GS and GSA dispensers, produced by Aptar Italia. Those products are made of ten (for GS) and eleven (for GSA) components and five different materials: Polypropylene (PP), Low Density Polyethylene (PE-LD), Linear Low Density Polyethylene (PE-LLD); Polyoxymethylene (POM) and Stainless Steel. More in detail, the potential replacement of oil-based plastics regards specific components, such as closure, actuator and dip tube (Figure.2). Closure and actuator are currently produced by injection moulding process using hydraylic presses, while the dip tube component is produced by extrusion process. The main reasons behind the choice to focus on those components are based on the following aspects:

- those components represent more than 50% of the total weight of a dispenser;
- the module (engine) is composed of sensitive parts requiring mechanical properties and technical features.

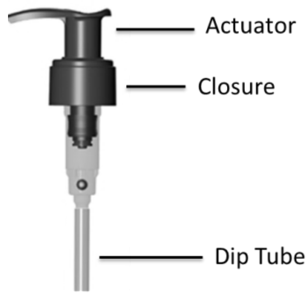


Figure 2: Dispenser GSA with focus on the potential bioplastic components

4.2 Bioplastics considered

Aptar Italia investigated different typologies of bioplastics considering their technical features and properties. More specifically, the following bioplastics, produced by different suppliers, have been tested:

1. Bio HDPE (determined according to ASTM D6866);
2. Blend of Bio LDPE (30%) and Bio HDPE (70%);
3. Blend of Bio LDPE (20%) and Bio LLDPE (80%).

The bio-blends have been considered only for the production of the dip tube component.
According to the ASTM D6866 standard, the minimum biobased content of the resins above mentioned is considered in a range from 94% to 95%.

As regards the features and properties of these bioplastics, the technical datasheet released by suppliers confirmed a good similarity with standard oil-based plastics, such as Polypropylene in terms of control properties (e.g., melt flow rate and density).

4.3 Tests conducted

Aptar Italia tested, in collaboration with the Expert Center department, various bioplastics typologies considering the following activities (Figure.3):

1. molding of two types of specimens (rectangular and dog bone) in order to complete the following lab test:
   - environmental stress cracking on rectangular specimen (with the use of surfactant);
   - tensile module on dog bone specimen (with the use of Lloyd dynamometer);
   - impact strength on dog bone specimen (with the use of Charpy pendulum);
   - melt flow rate index (with the use of extrusion plastometer);
2. molding test of components to complete the “First Article Inspection (FAI)”;
3. assembling test with the use of high speed machine in order to obtain the finished product;
4. functional test based on:
   - scratches resistance of actuator and closure;
   - esthetic analysis;
   - drop test;
   - sun test;
   - e-commerce test;
   - other test useful for the qualification of material

SUPPLIERS	SUPPLIERS CONTACT	ALTERNATE MATERIALS	MATERIAL CHECK	PROCUREMENT	SPECIMENS MOLDING	LAB TESTS	COMPONENTS MOLDING	DIMENSIONAL TESTS (FAI)	ASSEMBLY TESTS	FUNCTIONAL TESTS	QUALIFICATION TEST
Supplier 1	●	Bio HDPE	●	●	●	●	●	●	●	●	⇨
		Bio HDPE	●	●	●	●	●	●	●	●	⇨
		30% LDPE SPB208 + 70% HDPE SHA7260	●	●	●	●	●	●	●	●	○
Supplier 2	●	PCR	●	●	●	○					
		PCR	●	●	●	○					
Supplier 3	●	PIR	●	●	●	●	●	●	●	●	○
Supplier 4	●	Resin 1	○								
		Resin 2	○								
		Resin 3	○								
		Resin 4	○								
		Resin 5	○								

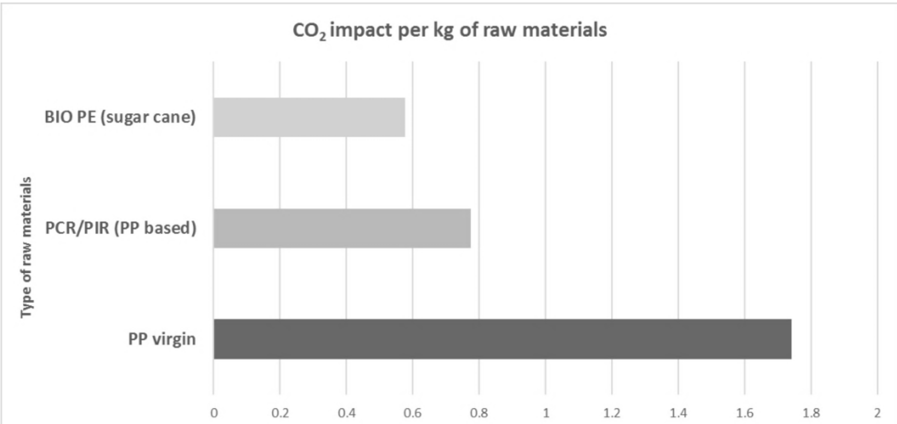
Figure 3: A snapshot of test details

4.4 Results obtained

The main results obtained from the test of bioplastics did not highlight particular differences about the technical properties compared to the standard oil-based plastics as Polypropilene used for the finished components (Figure.4).

Figure 4: GS and GSA with closure, actuator and dip tube in bioplastic

After the test conclusion, Aptar Italia qualified the use of Bio HPDE (biobased content 94%) for all types of closures and the actuators K2H and Q3H for dispenser GSA (further investigation ongoing for GS). About the results for bio-blends (used for the dip tube extrusion) the internal test developed in the Aptar's R&D department confirmed the suitability of blend of Bio LDPE (20%) and Bio LLDPE (80%) that allowed Aptar Italia to finally qualify a new supplier. In terms of the environmental performance about the use of bioplastic in the products, Aptar Italia carried out a preliminary comparative analysis based on the raw materials' carbon footprint (upstream processes) based on the LCA commercial database sources. Figure 5 shows the impact in terms of kg CO_2 eq. considering the materials used for the test (Figure 5):



	PP virgin	PCR/PIR (PP based)	BIO PE (sugar cane)
kg CO2 / kg	1.74	0.78	0.58

Figure 5: Carbon footprint impact per kg of raw materials

Considering this type of raw material substitution, Aptar Italia can identify an estimation of the total carbon footprint reduction of 21% on the single product that means, in terms of yearly volume, about 374 tons of CO_2 saved (Gabi LCI Database, 2017). Presently Aptar Italia is carrying out more specific investigations on the GS and GSA dispensers by means of product-LCAs using a commercial database for the analysis of raw materials' impact based on the production of bioplastics.

5. Conclusions

The activities carried out by Aptar Italia concerning the testing and qualification of bioplastics highlighted that it is technically viable to replace oil-based plastics with bioplastics for some GSA components: actuator, closure and dip tube; however, at the moment the market price of those materials is higher than that of oil-based plastics, so, this issue could play a crucial role for Aptar's customers. As regards the environmental impact of these materials, a preliminary analysis confirmed that the substitution of conventional plastics with bioplastics can potentially reduce the GHGs emissions of the product considered. The analysis of regulatory aspects related to the use of bioplastics confirmed that the use of these materials is in compliance with the main European regulation on the food and cosmetic packaging. At the moment, also considering the market emphasis on sustainability issues, Aptar Italia is sharing these results and experiences with the other Aptargroup plants and segments in order to build a green portfolio of dispensing systems with sustainable materials (biobased contents considering first, second and third generation).

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POSTER

Life Cycle Sustainability Assessment (LCSA) and Optimization Techniques. A conceptual framework for integrating LCSA into designing energy retrofit scenarios of existing buildings

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Abstract

According to the international reports, building sector is an important responsible for energy consumption and environmental impacts. Beside this fact, the numerous buildings constructed before 1950s with low energy and environmental performance indicate a possible research focus for resource, energy and environmental protection studies in future. Compared to the huge number of research papers in the field of building life cycle sustainability assessment, few studies have focused on the role of LCSA as a decision making support for designing energy retrofit scenarios of existing buildings and fewer have considered optimization techniques (as computational techniques for optimizing design goals) within an integrated LCSA-Design process. This paper aims to review the recent studies and discuss the challenges and barriers in existing research works and propose a conceptual framework which is capable to integrate a whole building life cycle sustainability assessment during design process of energy retrofit scenarios for existing buildings.

Keywords: *Life cycle sustainability assessment, Buildings, Energy retrofit, Optimization techniques*

1. Introduction

Based on technical and environmental reports, construction sector is known as the main responsible for raw material extraction and energy consumption among other sectors. It is estimated that 60% of raw materials are being consumed in this section, also the building sector is responsible for around 40% of the total energy consumption and 36% of CO_2 emission in Europe (Sesana and Salvalai, 2013; Iribarren et al., 2015). By improving the energy efficiency in operating phase of nearly zero-energy buildings (NZEBs), the environmental burdens of buildings are shifted to other stages of buildings life cycle. Therefore, the future question is how we can control and mitigate the energy consumption and environmental impacts during other phases of a building life cycle such as production, construction or dismantling phase. The application of Life Cycle Sustainability Assessment (LCSA) methods which are capable to quantify the environmental impacts, economic and social aspects of products or services in a whole life cycle perspective are growing fast in the building sector as well as other industries and are being used to evaluate life cycle impacts of buildings or infrastructures (Geng et al., 2017).

Back to the reports and statistics, it is stated by the European Commission that the renovation rate in building sector is only 1.2% per year (European Commission, 2015), a large proportion of existing buildings in Europe were constructed before 1950s and most of them cannot meet the new building codes especially energy efficiency standards, this fact indicates a huge potential of reducing energy consumption and environmental impacts of building sector by energy retrofitting of existing buildings especially in the European countries (Vilches et al, 2017).

The integration of LCSA and design process of energy retrofit scenarios is a complex issue since a LCSA study is highly dependent on availability and quality of data, while during the design process the materials and their quantities are not defined exactly. Also the buildings consist of various and numerous components and materials with different functions and requirements, these facts will add a complexity to the life cycle study of a product or a scenario within a design process. To resolve these complexities researchers have increasingly paid attention to use of optimization techniques in life cycle assessment studies (Hollberg and Ruth, 2016).

This paper aims to review the current trends and methods for the life cycle sustainability assessment and optimization techniques with a focus on energy retrofit of buildings, and considering the lack of an integrated framework for optimizing different criteria of sustainability such as life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (SLCA), will propose a conceptual framework for an integrated LCSA-Design process.

2. A review and analysis on application of optimization techniques in life cycle sustainability assessment studies

There are many studies that aim to conduct a life cycle analysis on a building but they eventually have been limited to one dimension of LCSA. For instance, most of them included only few environmental impacts. These limitations and

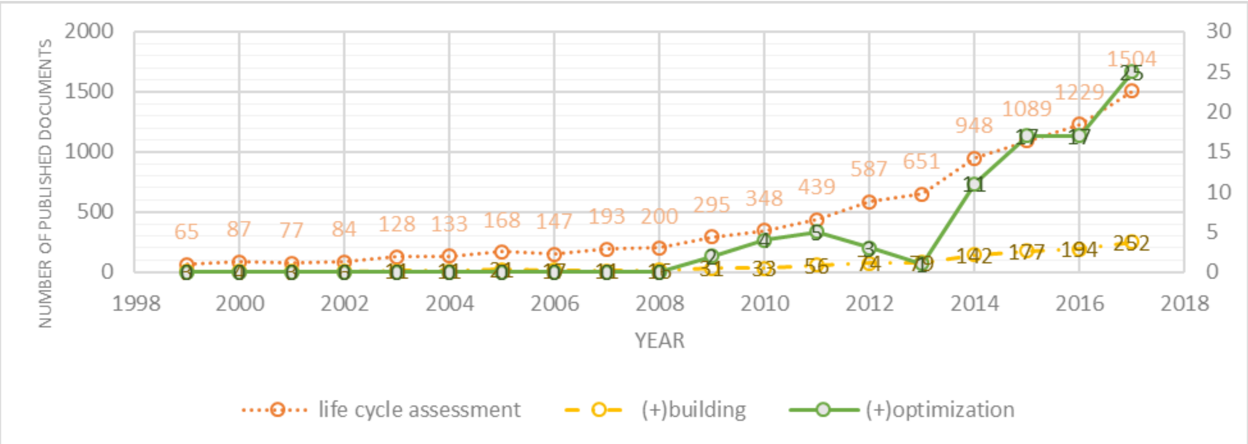

Figure 1: The number of scientific documents related to life cycle studies published between 1999 to 2017 in sciencedirect database (Authors)

simplifications are mainly due to the lack of data, tools limitations or difficulty and complexity of predicting future scenarios and research boundary system (Oregi et al, 2017).

Figure 1, shows the number of scientific documents published in the science direct data base between 1999 to 2017 in three fields: *life cycle assessment, building life cycle assessment* and *application of optimization techniques* in building life cycle assessment studies. It is clearly shown that however the number of published documents in life cycle assessment and optimization techniques is very few (right axis), a considerable growing rate of scientific research in this field has been started from 2013.

Table 5: Recent studies in building LCA and optimization techniques (Authors)

Authors/Year	Variables	System boundaries	Functional unit	Optimization method	Optimization targets/ LCA goals
Azari et al/2016 (Azari et al. 2016)	Insulation material/ Wall R value/ Window frame material/ Window to wall ratio/ Glazing type	All stages of a building envelope life cycle (cradle to grave)	1 ft^2 of a vertical envelope of the case study building with a service life of 60 years and R value equal to 2.36 m^2K/W	Two step optimization: **1.** Modelling by artificial neural network **2.** Multi objective optimization by genetic algorithm	Environmental performance (OE, GWP, AP, ODP, EP, SFP)
Antipova et al./ 2014 (Antipova et al. 2014)	Windows types, wall and roof insulation, solar collector types and area	All the stages in the energy supply chain	The amount of energy demanded for heating, cooling and hot water	Combined use of multi objective optimization and LCA principles	Environmental impacts and total costs associated with the operation of building
Pal et al./ 2017 *(Pal, Takano, Alanne, & Siren, 2017b)*	Envelope insulation thickness, windows types, heating system, heat recovery unites, PV area	Production to operation (cradle to gate) maintenance and repair for energy systems are excluded	-	Multi objective building optimization using NSGA-II	Life cycle carbon footprint and life cycle cost
Holberg and Ruth/ 2016 (Hollberg and Ruth 2016)	Insulation material type and thickness, heating system, window glazing type	Production, Use, end of life. Construction phase and some sub stages in use and end of life phase are excluded	-	Multi objective optimization	Total primary energy, total non-renewable primary energy, global warming potential, ozone depletion potential, acidification potential, eutrophication potential, Photochemical ozone creation potential, Abiotic resource depletion potential for elements
Ramin et al./ 2017 (Ramin et al. 2017)	Insulation thickness	Operation phase	-	Multi objective optimization	Energy, CO_2, cost, water
Lolli et al./ 2017 (Lolli, Fufa, and Inman 2017)	Insulation thickness, window glazing type, north & south window area	Initial production stages, operating phase (cradle to gate)	per m^2 of heated floor area per year of building lifetime	Parametric assessment tool	Operational energy and embodied energy
Amini Toosi/ 2016 (Amini Toosi 2016)	Insulation type and thickness	Whole life cycle (cradle to grave)	Weight of insulation material needed to achieve minimum energy consumption	Single objective optimization	Operational energy, embodied energy

In a recent study Mostavi et al. (2017) developed a model to optimize life cycle costs, environmental impacts and occupant satisfaction in a research project at Pennsylvania state university. They used a harmony search-based algorithm to minimize the Life Cycle Costs (LCC) and Life Cycle Energy (LCE) and maximizing thermal comfort in a commercial building. For energy analysis they included pre-use stage to end of life and excluded the end of life stage from the system boundaries in the LCC analysis. They inserted different building components including walls, floors, ceilings, glazing systems and doors as the optimization variables and LCC, LCE (over 50 years) and TCI (Thermal Comfort Index) as the optimization targets. Their method is interesting since they have implemented a multi objective optimization on three targets which are not convertible to a unified measuring unit and they have finally reported a three-dimensional view of results and found eight optimal solutions on a pareto frontier. Undoubtedly this research is a forward step in LCSA optimization studies since this is one of the few studies which used optimization techniques for optimizing LCA, LCC and other performances such as comfort which can be considered as social aspects of life cycle studies. But there are still some gaps such as missing the other life cycle impact categories, incomplete coverage of life cycle stages and also exclusion of energy systems and their contribution to life cycle impacts.

As it is discussed in the previous paragraphs and shown in table 1, most of research works and published papers have only focused on few numbers of life cycle impact categories and do not cover the whole building life cycle. Also the social life cycle assessment is still a research gap, there are few studies which addressed to social aspects of a building over its life cycle. This fact indicates that there are still unsolved problems in application of LCSA in optimizing building design and retrofit scenarios which might be mainly due to lack of input data and complexity of assessment methods and design process nature.

3. A conceptual framework for Integrating LCSA into designing energy retrofit scenarios by using optimization techniques

Compared to the number of research papers published in the field of LCA, LCC or even SLCA, there are very limited and few research works related to life cycle sustainability assessment and optimization techniques and almost all of them do not cover a wide range of life cycle impact categories or a complete system boundary of a building or a building product. This fact indicates a need for providing a conceptual framework for integrating LCSA and optimization techniques into design process of new building or retrofit scenarios of existing buildings. We already have general standards and guidelines at framework level for different aspects of life cycle studies such as ISO 14040:2006, ISO 14044:2006, EN 15643-1:2010 *Sustainability Assessment of Buildings- General Framework*, EN 15643-2:2011 *Framework for the assessment of environmental performance*, EN 15643-3:2012 *Framework for the assessment of social performance*, EN 15643-4:2012 *Framework for the assessment of economic performance*, and other standards at the building and building products level such as EN 15978, EN 15804 which have already been designed, widely accepted and implemented by researchers in the academic and professional environment. These standards can be kept as the starting point and the basis of future frameworks and directions.

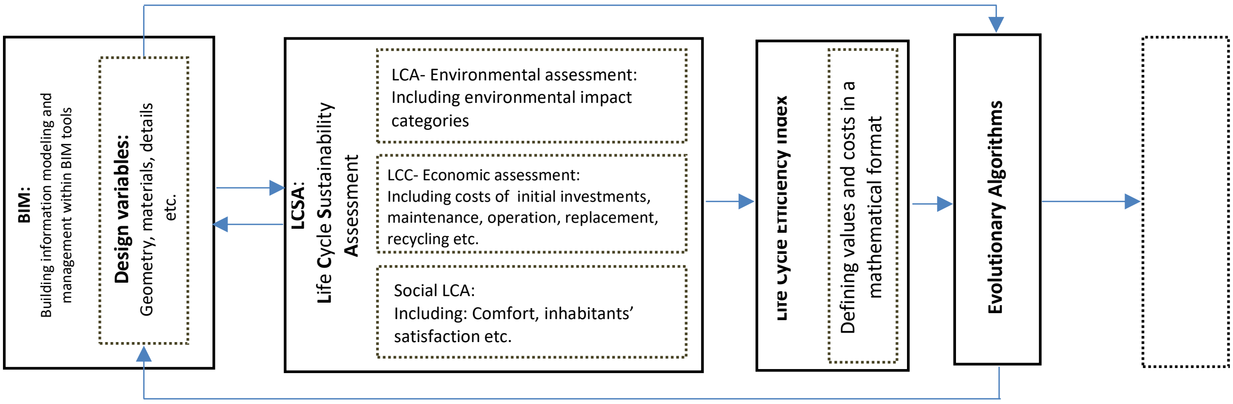

Figure 2: Conceptual framework for integrating LCSA into designing optimal energy retrofit scenarios for existing buildings (Authors)

Here we only present a framework for the interconnection between a LCSA method and optimization techniques, applicable in a design process. As it is shown in Figure 2, the framework consists of four major parts and each part has sub-parts interconnected to the other parts.

The first step is to define design variables, this step could be defined during the conceptual or technical design phase of a building or after performance analysis of an existing building (as possible interventions), then these variables will be used as input data for the life cycle sustainability assessments. For instance, in an energy retrofit design process, the insulation material type and thickness, the size and position of openings, glazing to wall ratio, the construction layers of wall assemblies etc. could be defined as design variables. In order to overcome the complexity of data management during the design phase, we propose to perform all design steps within a BIM environment.

The second part is choosing the assessment methodology. The goal, scope and system boundaries as well as life cycle inventory data base and impact assessment methodology should be defined and chosen in this stage based on one of the accepted standards and according to the design variables as the inputs of the assessment system. In the overall picture of this framework the first step and second steps are totally interconnected. Based on the project targets, goal and scope of the assessment and life cycle system boundaries, the design variables (as the optimization variables) as well as values and costs (as the optimization targets), will be defined. Therefore, it is clear that these two steps will be defined and developed in parallel. The values and costs such as energy efficiency, environmental performance, life cycle costs, health and comfort etc. will be defined to be implemented in the LCSA model and as optimization targets.

The next step is to define a dimensionless index in order to be used within a comparative evaluation by evolutionary algorithms. The life cycle efficiency index could be defined as one single index or multiple (two or more) indexes according to the types and numbers of selected values and costs and the optimization algorithm type (single or multi objective optimization). Then, the index will be optimized by using single or multi objective optimization algorithm. Obviously the best alternative is the one with the highest values and the lowest costs. Equation 1, shows an example to calculate a life cycle efficiency index.

Equation 1: Life Cycle Efficiency Index (Authors)

$$Life\ Cycle\ Efficiency\ Index_{\,j} = \frac{\sum_{i=\,Production\ Phase}^{End\ of\ life\ Phase} Values_{ji}}{\sum_{i=\,Production\ Phase}^{End\ of\ life\ Phase} Costs_{ji}}$$

Where: I: the different stages of the building's life cycle J: the building, product or scenario in assessment

Many of values in a building life cycle are qualitative parameters especially those which are related to social aspects. In our proposed equations it is required to take into account only the parameters which can be translated to a quantity such as thermal comfort and health. For those which are not possible to be measured by quantitative methods, such as inhabitants' satisfaction or aesthetics aspects, it is necessary to define a comparative numerical index in order to assign a numerical value to each design alternative.

In order to use equation 1, a mathematical definition of values and costs is needed. The values and costs could cover a wide range of physical and non-physical parameters of a design alternative. Since there could be different measuring units for each type of values or costs, it is necessary to have dimensionless inputs in order to make the mathematical operations possible in equation 1. For this purpose, values and costs should be divided by a baseline quantity which could be achieved by evaluating a baseline building or product (based on current praxis). Equation 2 and 3, are simple examples for describing values and costs mathematically.

Equation 2: Values (Authors)

$$\begin{aligned}\mathrm{Values_j} = \Bigg[&\mathrm{DrbltyWt}\left(\frac{\mathrm{Duarability_j}}{\mathrm{Baseline\ durability}}\right) + RPWt\left(\frac{\mathrm{Reuse\ Possibility_j}}{\mathrm{Baseline\ reuse\ possibility}}\right)\\ &+ CFTWt\left(\frac{\mathrm{Comfort\ factor}}{\mathrm{Baseline\ Comfort\ factor}}\right)\\ &+ HlthWt\left(\frac{\mathrm{Health\ factor}}{\mathrm{Baseline\ Health\ factor}}\right) + \cdots\Bigg]\end{aligned}$$

Equation 3: Costs (Authors)

$$\mathrm{Costs_j} = \Bigg[\mathrm{EnvWt}\left(\frac{\mathrm{Environmental\ impacts_j}}{\mathrm{Baseline\ environmental\ impacts\ value}}\right) + \mathrm{EnergyWt}\left(\frac{\mathrm{Energy\ Consumption_j}}{\mathrm{Baseline\ energy\ consumption\ value}}\right) + ICWt\left(\frac{\mathrm{Initial\ costs_j}}{\mathrm{Baseline\ initial\ costs\ value}}\right) + \mathrm{MCWt}\left(\frac{\mathrm{Maintenance\ Costs_j}}{\mathrm{Baseline\ maintenance\ costs\ value}}\right) + \cdots\Bigg]$$

Where: DrbltyWT, RPWt, CFTWt, HlthWt, EnWt, EnergyWt, ICWt, MCWt: weight factors for Durability, Reuse Possibility, Comfort, Health, Environmental, Energy, Initial costs, Maintenance costs, respectively. (DrbltyWT + RPWt + CFTWt + HlthWt= 1), (EnWt + EnergyWt + ICWt + MCWt = 1)

In the last section, according to the complexity level of problems and assessment model, an appropriate computational strategy and evolutionary algorithm should be opted. After defining the optimization targets in a building retrofit design process, according to numbers and types of the optimization objectives, the appropriate computational method will be selected. The optimum solution will be achieved from an automatic iterative process. Each result will be checked with the requirements and optimization targets and if it cannot satisfy the optimization purposes, the optimization loop will be repeated in order to reach the best solution.

4. Conclusion

Life cycle thinking approach has become an important research trend during the last decade. These days, architects and building engineers are more aware of the environmental impacts and economic values of their designs not only during use phase but also over the whole life cycle of their design products. One of the direct results of these awareness is more research works related to this topic. As it is shown and discussed in the present paper most of these research works have only focused on limited number of environmental impacts or excluded some life cycle stages. Among the numerous published research papers related to building LCSA there are only few numbers oriented to building LCSA and optimization methods. Here we proposed a conceptual framework for integrating LCSA and optimization techniques into designing energy retrofit scenarios of an existing building also applicable for designing new building from early design stage to technical design phase. There are some barriers and challenges in the application of this framework such as: the problem of availability and reliability of input data, the need for a basic knowledge about technical design phase of energy retrofit scenarios by designers, the high level of dependency of results on the accuracy of optimization algorithms, the definition of a representative baseline scenarios and the measuring method for some values and costs especially in social LCA criteria. These barriers should be resolved in future studies in order to make the framework easier for the implementation in design process.

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Comparison between conventional and organic rice production in Northern Italy

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Abstract

Italy is the most important European rice producer with about 230000 ha. In the last years, the area dedicated to organic rice production is rapidly growing. Differently than conventional rice where a quite standardised cultivation practice is carried out, in organic rice farming several different cultivation practices are performed, leading to a wide variability of productive performances. However, compared to conventional rice production, the organic system is usually characterized by lower yields and, above all, by considerable yield variations over the years.

The aim of this study is to compare, using the Life Cycle Assessment (LCA) approach, the environmental performances of rice production in Italy considering both conventional rice production than organic rice production.

1. Introduction

In Europe, rice is grown on about 425,000 ha and Italy, accounting for about 55% of European rice area, is the major rice producer. In 2015, the Italian rice production was 1,518,000 t while the rice area was 227,300 ha (+3.5% than 2014), mainly in the Po Valley (Northern Italy). The conventional rice production (CRP) is by far the most common agricultural system; however, over the year, the organic one (ORP) is becoming more and more important. In 2015, the organic rice area was 12,425 ha (5.4% of the overall rice area), with remarkable increase in respect of 2015 (+13.9%) (SINAP, 2015).

Differently than conventional rice, where a quite standardised cultivation practice is carried out, in organic rice farming several different cultivation practices can be performed, leading to a remarkable variability of yields. It is not possible to define one rice organic production system, since the management of organic paddy must take into account the different sito-specific agro-ecological environment and pedo-climatic conditions. The ORP can vary as regard to: fertilisation, sowing, soil tillage, water and weed management. However, compared to conventional rice production, the organic system is usually characterized by lower yields and, above all, by a huge yield variation over the years (Bacenetti et al., 2016). Although several studies investigated the environmental impact related to rice production, little attention has been paid to the comparison between organic and conventional production systems (Hokazono et al., 2009; Tuomisto et al., 2012).

The aim of this study is to compare, using the Life Cycle Assessment (LCA) approach, the environmental performances of rice production in Italy considering both CRP than ORP.

2. Material and methods

The selected functional unit is 1 ton of paddy rice at the commercial moisture (14%). The study was carried out with a “cradle to farm gate” approach; therefore, all the processes from raw material extraction to grain drying were included in the system boundary while rice processing, packaging and distribution were excluded.

The inventory data were primarily collected by means of surveys in the rice farms located in Northern Italy. The survey included 69 farms, 20 for ORP and 49 for CRP. The organic farms were identified taking into account the compliance with the organic cultivation guidelines and the absence of sprayers in the farm machinery fleet. No mixed farms (organic and conventional) were considered. After the surveys, 4 different cultivation practices were identified for ORP and 9 for CRP. The paddy rice yield ranges from 3 to 4.6 t/ha for organic production and from 6 to 9 t/ha for the conventional one. The main charachteristichs of the 4 ORP and the CRP systems are reported in Table 1.

With regard to secondary data, methane emissions from paddy field were estimated according the IPCC guidelines (IPCC, 2006) that consider the flooding duration, the number of aerations, the amount of organic matter introduced into the soil and the straw management. N emissions (nitrate, ammonia, and nitrous oxide) were computed following the IPCC Guidelines (2006) while P emissions, were calculated according yo Prahsun (2006) and Nemecek and Kägi (2007). Table 2 reports the main emissions for the different ORP and CRP.

Background data concerning the production of the different inputs (e.g., seeds, pesticides, fertilizers, diesel, tractors and implements) were retrieved from the Ecoinvent Database v.3. (Weidema et al., 2013).

The following impact categories were evaluated using the ILCD method: Climate Change (CC), Ozone Depletion (OD), Human toxicity, non-cancer effects (HTnoc), Human toxicity, cancer effects (HTc), Particulate matter (PM), Photochemical ozone formation (POF), Acidification (TA), Terrestrial eutrophication (TE). Freshwater eutrophication (FE), Marine eutrophication (ME), Freshwater ecotoxicity (FEx) and Mineral, fossil & ren resource depletion (MFRD).

Table 1: Description of the different rice production systems

<table>
<tr><th>Code</th><th>Fertilization</th><th>Sowing</th><th>Weed control</th><th>Flooding</th><th>Yield</th></tr>
<tr><td>ORP 1 Water</td><td>Not applied</td><td>In flooded fields, 270 kg/ha of seed</td><td>Thanks to the flooding</td><td>1 aeration 104 days</td><td>3.0 t/ha</td></tr>
<tr><td>ORP 2 Mechanical weeding</td><td>Horn meal (0.6 t/ha)</td><td>In dry paddy fields with 220 kg/ha of seed</td><td>5 mechanical weedings</td><td>1 aeration 101 days</td><td>4.6 t/ha</td></tr>
<tr><td>ORP 3 Cover crop</td><td>Cover crop (legume crop)</td><td>In dry paddy fields with 220 kg/ha of seed</td><td>Thanks to the flooding</td><td>1 aeration 110 days</td><td>4.2 t/ha</td></tr>
<tr><td>ORP 4 Compost</td><td>Green manure and compost (21 t/ha)</td><td>In dry paddy fields with 220 kg/ha of seed</td><td>5 mechanical weedings</td><td>1 aeration 95 days</td><td>5.1 t/ha</td></tr>
<tr><td>CRP 1</td><td>70 kg N mineral/ha</td><td>In dry or flooded fields, 185 kg/ha of seed</td><td>Herbicides (1.8 kg/ha) Fungicide (1.3 kg/ha)</td><td>1 aeration 112 days</td><td>6.3 t/ha</td></tr>
<tr><td>CRP 2</td><td>Horn meal (0.15 t/ha), 148 kg N mineral/ha</td><td>In dry or flooded fields, 165 kg/ha of seed</td><td>Herbicides (4.5 kg/ha) Fungicide (1.9 kg/ha)</td><td>0 aeration, 123 days</td><td>6.6 t/ha</td></tr>
<tr><td>CRP 3</td><td>Horn meal (0.15 t/ha), 193 kg N mineral/ha</td><td>In dry or flooded fields, 165 kg/ha of seed</td><td rowspan="2">Herbicides (3.5 kg/ha) Fungicide (1.5 kg/ha)</td><td>1 aeration 122 days</td><td>8.5 t/ha</td></tr>
<tr><td>CRP 4</td><td>Horn meal (0.15 t/ha), 193 kg N mineral/ha</td><td>In dry or flooded fields, 172 kg/ha of seed</td><td>0 aerations 123 days</td><td>9.0 t/ha</td></tr>
<tr><td>CRP 5</td><td>Horn meal (0.20 t/ha), 82 kg N mineral/ha</td><td rowspan="2">In dry or flooded fields, 115 kg/ha of seed</td><td>Herbicides (2.14 kg/ha) Fungicide (0.6 kg/ha)</td><td>2 aerations, 113 days</td><td>7.7 t/ha</td></tr>
<tr><td>CRP 6</td><td>Horn meal (0.20 t/ha), 172 kg N mineral/ha</td><td>Herbicides (5.1 kg/ha) Fungicide (1.6 kg/ha)</td><td>2 aerations 130 days</td><td>7.1 t/ha</td></tr>
<tr><td>CRP 7</td><td>Horn meal (0.20 t/ha), 82 kg N mineral/ha</td><td>In flooded fields, 210 kg/ha of seed</td><td>Herbicides (1.8 kg/ha) Fungicide (0.6 kg/ha)</td><td>2 aerations 118 days</td><td>6 t/ha</td></tr>
<tr><td>CRP 8</td><td>Horn meal (0.23 t/ha), 150 kg N mineral/ha</td><td>In dry or flooded fields, 165 kg/ha of seed</td><td>Herbicides (2.8 kg/ha) Fungicide (1.5 kg/ha)</td><td>1 aeration 115 days</td><td>7.3 t/ha</td></tr>
<tr><td>CRP 9</td><td>Horn meal (0.23 t/ha), 155 kg N mineral/ha</td><td>In dry or flooded fields, 165 kg/ha of seed</td><td>Herbicides (2.8 kg/ha) Fungicide (1.5 kg/ha)</td><td>1 aeration 88 days</td><td>6.1 t/ha</td></tr>
</table>

Table 2: Emissions per ton of paddy rice (14% moisture)

Code	Methane	Ammonia	Nitrate	Dinitrogen Oxide
	kg CH_4/t	kg NH_3/t	kg NO_3/t	kg N_2O/t
ORP – 1	107.64	0.00	1.87	0.19
ORP – 2	153.64	1.93	10.59	0.81
ORP – 3	124.78	7.52	41.12	0.69
ORP – 4	232.71	87.84	16.07	1.48
CRP – 1	17.83	3.94	26.02	0.40
CRP – 2	31.25	3.55	51.52	0.48
CRP – 3	16.36	4.96	34.13	0.51
CRP – 4	26.40	4.81	32.87	0.49
CRP – 5	13.92	4.71	37.83	0.56
CRP – 6	16.91	5.68	45.48	0.66
CRP – 7	16.92	5.98	42.15	0.62
CRP – 8	16.82	6.21	45.66	0.67
CRP – 9	14.34	7.03	50.87	0.75

3. Results and Discussion

Table 3 reports the absolute environmental impacts for the different cultivation practices. ORP4, where compost (22.5 t/ha) is spread for fertilization, shows by far the worst environmental performance, considerably higher also compared to the other ORP systems. More in details, for ORP4, the CC is 3 times higher than the other ORPs and 4 times higher than CRPs. ORP shows worst environmental performances for 9 of the 12 evaluated impact categories and respect to CRP presents higher variability of the environmental results (Figure 1).

Table 3: Absolute environmental impacts for the different rice production systems

	CC	OD	HTnoc	HTc	PM	POF	TA	TE	FE	ME	FEx	MFRD
	kg CO_2 eq	mg CFC-11 eq	CTUh x 10^{-4}	CTUh x 10^{-5}	kg PM2.5 eq	kg NMVOC eq	molc H+ eq	molc N eq	kg P eq	kg N eq	CTUe	mg Sb eq
ORP 1	1069	39.57	7.83	1.32	0.159	2.545	3.75	16.3	0.012	2.41	747	7.21
ORP 2	1192	32.47	5.53	1.13	0.639	2.048	25.89	115.2	0.022	11.81	573	5.48
ORP 3	1251	43.41	4.84	1.85	0.378	2.645	9.75	40.9	0.079	4.48	1667	80.02
ORP 4	3498	73.41	5.50	2.50	1.312	7.207	52.44	235.4	0.141	9.97	864	7.61
CRP 1	942	50.90	2.22	1.63	0.643	2.613	21.59	94.2	0.115	11.25	2661	80.28
CRP 2	935	40.85	1.83	1.42	0.583	2.277	20.14	88.1	0.093	11.80	1603	67.62
CRP 3	807	43.04	1.84	1.57	0.547	2.399	17.62	76.5	0.102	10.08	1900	79.42
CRP 4	898	33.66	1.63	1.16	0.616	2.032	21.64	94.8	0.092	11.70	1706	52.18
CRP 5	893	37.85	1.90	1.30	0.697	2.309	24.37	106.9	0.108	13.11	1952	58.25
CRP 6	1276	42.02	2.04	1.60	0.453	2.691	14.29	61.9	0.111	13.21	11105	110.0
CRP 7	825	42.76	1.51	1.21	0.515	1.909	17.61	76.7	0.080	9.01	7022	59.66
CRP 8	1027	29.39	1.38	1.02	0.485	1.862	16.86	74.0	0.074	8.65	7913	55.96
CRP 9	829	40.06	1.86	1.44	0.478	2.190	14.90	64.5	0.109	7.29	1914	95.58

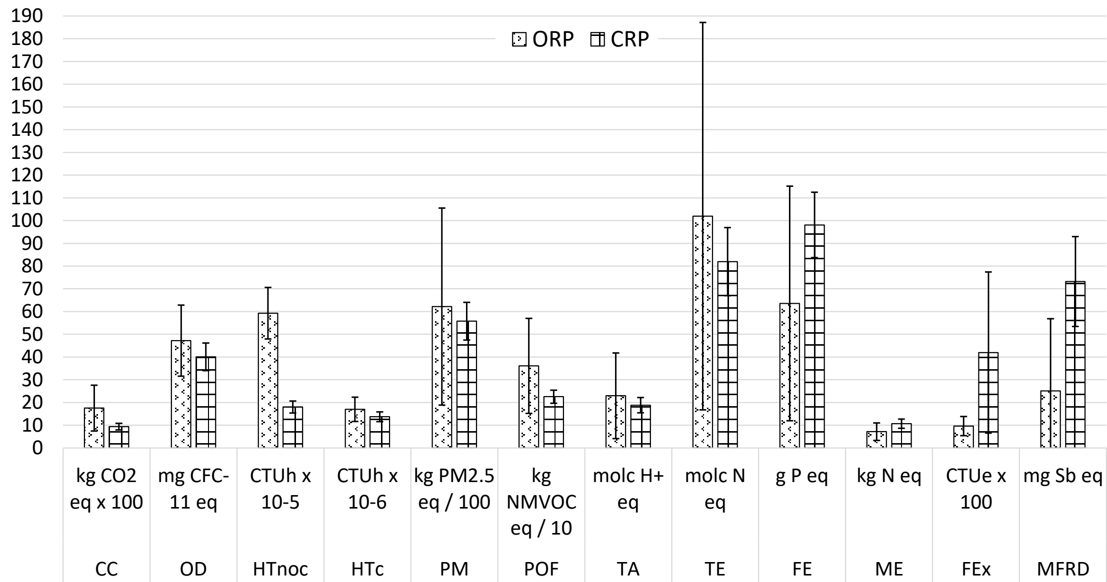

Figure 1: Environmental impacts for ORP and CRP (The error bars represent the average value ± the standard deviation)

Both for ORP and CRP: i) CH_4 emissions are the main hotspot for CC (from 40 to 65% of the total impact), ii) the emissions due to fertilizers application for TA, PM, FE, TE and ME, iii) the mechanization of field operations is a hotspot for MFRD, OD and HTc mainly due to emission from fuel combustions; for CRP the MFRD is amost completely due to (> 90%) to mineral fertilizer production. For FEx, the main hotspot is seed production for ORC and the emission of pesticides into the soil for CRP. In particular, for ORP 4, the consumption of compost as organic fertilizer and its transport (60 km) are the most important contributor to CC, OD, HTc and POF (Figure 2).

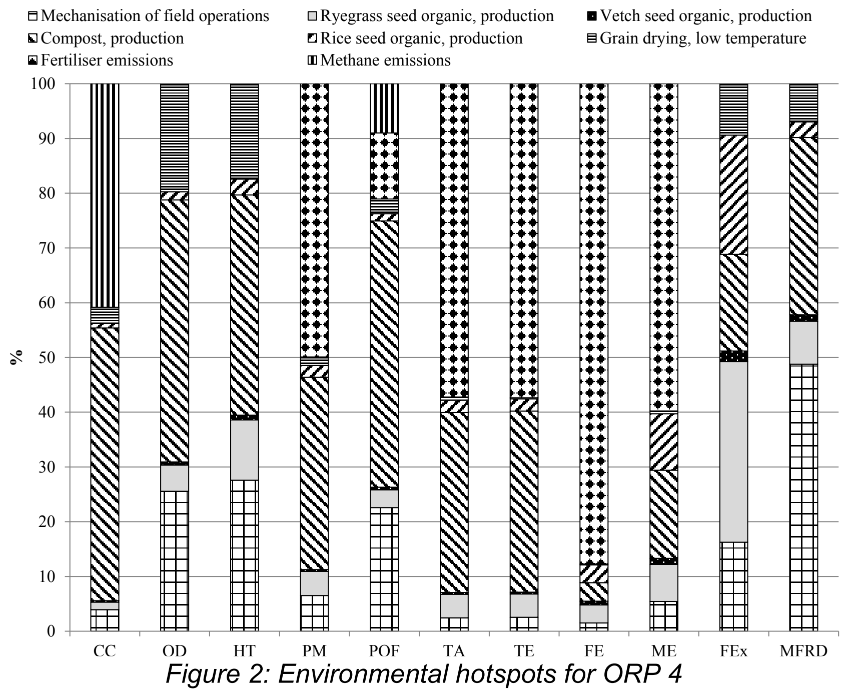

Figure 2: Environmental hotspots for ORP 4

Among the ORP, excluding ORP4 that is by far the more impacting, the ORP2 (where weed control is achieved by mechanical weeding) presents the higher impact for CC, OD, HTc and MFRD mainly due to the higher fuel consumption while for all the impacts related to the emission from fertilizer applications (PM, TA and the eutrophications), the ORP1 (where not fertilizations take place) shows the lower impacts while the ORP 3 (where fertilization is carried out by means of green manure) the higher impact.

4. Conclusions

This study focuses on the environmental impact assessment of rice production in Italy taking into account conventional and organic production systems. The achieved results highlighted how the best cultivation practice depends on the evaluated impact category and by the specific cultivation practices. On average the impact for ORP are higher than for CRP but, above all, for ORP, there is a wide variability of the environmental performances. CRP usually performs better than ORP mainly due to higher average yield (+50-300% respect to ORP), fertilization with mineral fertilizer instead of organic one (such as application of compost or green manure), lower seed rate at sowing, and higher possibility to control pests and diseases thanks to the use of pesticides (herbicides and fungicides).

Further analysis through the environmental Life Cycle Costing (eLCC) methodology will be carried out in order to verify the economic sustainability of the different cultivation practices. By monetising environmental loads, the most sustainable cultivation practice will be identify.

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Wood-based construction systems and Life-Cycle Assessment – a review

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Abstract

The AEC (Architecture, Engineering, and Construction) sector is a great consumer of energy and resources. Statistical data attest its responsibility on 40% of energy consumption and 1/3 of CO_2 *emission, causing a huge environmental impact. Moreover, the built environment status is old and obsolete and extremely needs an architectonical and technological renovation. In front of this scenario, wood-based technologies, as an example of dried construction systems, seem to represent one of the best solutions for retrofit strategies, according to current market trends. This paper aims to be the first step to evaluate if this response could really answer the issue, in terms of environmental impact, according to an LCA perspective. A literature review is performed, to define the state of the art about LCA and wood-based construction systems (processes, products, and projects), and to discover which indicators and parameters are interesting for this field of the AEC sector.*

1. Introduction: background and motivations

During the last years, the environmental issue and the transition of the society to a more sustainable and eco-friendly approach become increasingly relevant. The current 2030 Agenda for Sustainable Development of United Nations gathers in its 17 Sustainable Developments Goals several targets that address environmental aspects (United Nations, 2015).

Focusing on the construction sectors, both global than European data records the considerable amount of energy and resources' consumption due to buildings: the EPBD (Energy Performances of Buildings Directive) 2010/31/EU (European Parliament, 2010) testifies that European constructions account for 40% of overall energy consumptions, and 36% of greenhouse gasses emissions. The current built environment is, indeed, old, lacks the high-energy performances of its components (Cresme, 2014 and Corrado et al., 2011) and its operation phase would last, at least, by 2050 (Eurostat, 2016). Therefore, an overall retrofit strategy is becoming the next design approach, as the current market trends are highlighting within the so-called "First cycle of the built environment" (Sybola-Cresme, 2017).

In front of this scenario, wood-based construction systems, as examples of dried construction technologies, seem to be a reasonable solution, thanks to the good performances of the raw material. E.g., wood is naturally a good insulating material, and so its derived products. Moreover, timber structural elements gain a very good ratio between the mechanical resistance and their total weight. Hence, its technological and mechanical performances help wood products to achieve a positive standing if compared to products based on other construction materials.

However, in order to address also the environmental issues related to the AEC sector, an evaluation of the wooden-based technical solutions through the ecological perspective is needed.

Referring to timber products and components, indeed, their use is usually and easily associated with a “green design choice”, because of the naturally renewable resource: wood. Nevertheless, rigorous considerations on environmental benefits require a qualitative/quantitative, reliable evaluation, according to the most widespread and validated certification programmes, and metrics tools, such as those of the Life-Cycle Assessment (LCA) approach.

Boyd in 1976 and Ressel in 1986 already focused on wooden products, when the two oil-crisis moved the first researchers to investigate just the energy consumption issues affecting the production processes (Werner and Ritcher, 2007). Puettmann and Wilson (2006) confirm that several studies focused on the environmental performance of wooden products, addressing the data inventory and performing first assessment about the life-cycle energy consumption, from raw material extraction to product manufacturing (Perez-Garcia et al., 2005; Lippke et al., 2004). Nowadays, the scientific developments push to newer and more detailed criteria, to measure the environmental burdens of products both building elements and prefabricated components and buildings themselves. According to Villa et al., wood has the most positive environmental profile, thanks as first to its carbon neutrality (balance between the stored gasses during the life of a tree and the produced ones during the factory processes). Moreover, Federcostruzioni (2011) reports that 1.1 tons of stocks CO_2 emissions per cubic meter of wood. Besides, within the academic literature, most of the papers and publications approaching this topic seem to perform a global positive evaluation; however, these studies often present some critical issues in defining first assumptions and boundaries, or specific analyzed products. Therefore, in order to fully assess this material and its building products, all the environmental benefits and costs have to be weighted for each case, e.g. through comparative assessment approaches.

2. Scope and methodology

This paper aims to be the first step of a comparative evaluation of wood-based construction systems, according to an environmentally sustainable perspective.

It addresses the need to elaborate the current state of the art of environmental analysis and assessments, which have been collected among the scientific literature. In this first phase, the final goal is to define which are the biggest challenges regarding this field of the AEC sector. Among those analyses, this paper aims to detect which environmental indicators could affect more the decision-making process, inside the wood buildings industry.

The literature search involved several databases, including Science Direct, Google Scholar, ResearchGate, and ReteItalianaLCA web sources, using keywords such as “wood”, “product”, “building”, “environmental”, “LCA”, “Life-Cycle assessment”, “Forest management”, and combination thereof. The resulting list of references varies according to the nature of the source: they are both literature review of several LCA, performed on wooden and complementary products (Werner and Ritcher, 2007), and LCA themselves, for the most innovative wooden technologies (Villa et al., 2012). Some of the results refer to those areas of wooden industry that are far away from this building sector, such as the paper production. Therefore, the present review does not consider this kind of results, focusing only on publications that deal with the evaluation of construction products (insulations, panels), technologies (e.g. CLT), processes and buildings.

Finally, the comparison of the quantitative results of those studies is not a part of this review, because of different reasons. They refer to both LCA methodology issue (different scope, functional units, system boundaries, allocation methods, which could drive to different results for the same analyzed product) and its application to the wooden sector (see ch. 4) and the consistency of the investigated references. Thus, this paper does not focus on quantitative data and records, but it seeks to an overview on the environmental issue within the wood-based constructions and environmental criteria for their evaluation, according to validated sustainability metrics.

3. Environmental impact of wooden products, components, and buildings: the Life-Cycle Assessment approach

The Life-Cycle Assessment is, by definition, an objective and rigorous evaluation process to assess accurately the environmental loads associated with products, processes or activities, considering their burdens, from the raw material extraction to the end-of-life phases (Fava et al., 1991 and Fava et al., 2014). Transferring this approach to the wooden-based construction sector, many issues have to be considered, according to the scientific literature and performed LCA studies that have been analyzed.

The first important consideration concerns the breakdown structure of the whole production process and comes from the comparison between wooden building products and those ones belonging to different chains, based on other construction materials (e.g. steel or concrete industries). Indeed, the life cycle of wooden construction elements and components started with the tree growth and harvesting. The environmental data and the information about the processes and loads’ balances of these phases are very difficult to be available, as shared and reliable information, and therefore evaluable through a consistent approach. This is the first task that bothers the LCA when it is specifically addressed to the field of wooden constructions (Sathre and Gonzalez-Garcia, 2014).

Strictly related to this first point, another issue has to be stressed: the gap between the LCA and forestry management certifications[30], where the latter ones are common and well-known tools to approach sustainability within the use of the primary resource, addressing the problem of deforestation.

Inside the reviewed literature, just few studies are addressing this gap, enhancing the difficulties related to the assessment of forestry management through the LCA methods: from the long-lasting processes to the lack of reliable data (Bosner et al., 2012), and therefore of a spread and consolidated methodology, with clear flows, system boundaries and functional units (Heinimann, 2014). Indeed, the existing LCA on wooden-based construction products completely misses the evaluation of the benefits and costs balance related to forest management. However, the current environmental policies move the construction industries to be always more aware of the necessity to address the environmental issue, with an overall perspective, both including the LCA and the forestry management. According to that, the Active House Alliance, e.g., proposes a new evaluative approach to guide the design and assessment of a sustainable building project, integrating the requirement of forestry management certifications for wooden-based products with EPDs and the LCA on the whole construction (www.activehouse.info).

Aftereards, moving the focus on the breakdown processes of the wooden industry's production, other issues could be underlined, considering the specific structure of LCA methodology, as defined by UNI EN ISO 140140:2006 and 14011:2006[31]. In relation to the availability of trustable data for the inventory stage, indeed, the definition of the system boundaries is the first matter, both in the performing of the LCA and in the comparing of different LCA reports. Whereas in North Europe and the US the reliability of data has become a standard point since the last decade (Puettmann and Wilson, 2006), in Italy the newer technologies (such as CLT panels, e.g.) suffer the variability of forestry management operations, transport policies and local procedures for wood waste. Because of these reasons, standardized and complete data are not fully available, and those of the existing LCI databases are quite different from real products features of specific EPDs (Villa et al., 2012). This scenario implies

[30] The major worldwide forest certification programs are the American Tree Farm System (ATFS), the Sustainable Forestry Initiative (SFI), the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). They attest the sustainability of forest management and fibre sourcing systems, and the chain of custody (Southern Forest Product Association, 2018). The development and global diffusion of these tools is due to governments' pushing for eco-friendly policies of harvesting reduction and introduction of reliable methods to assess and attest the sustainability of management practices. The pressure on this aspect of the wood industry, besides the environmental studies on wood as a construction material, aims to contrast the non-technical information available to the public that discourages its harvesting and use. As testified by several researches, the overly reduced exploitation of forests prevents their proper management and maintenance, leading to an impoverishment of the wooden heritage and damaging the natural environment (Federcostruzioni, 2011 and JFS, 2003)

[31] The LCA methodology structure has four steps: (i) Goal and scope definition, (ii) Inventory analysis (LCI), (iii) Impact Assessment, and (iv) Interpretation.

different hypothesis (related to geographical and technological differences) in including/excluding processes and Life-cycle stages from an LCA, or in considering dataset from databases or performing a local data survey.

Another consideration about system boundaries deals with the definition of the end-of-life scenarios (cradle to cradle), for both wooden construction products and wooden-based buildings. This definition, indeed, is not possible as a global and standardized hypothesis for the classified wooden-based construction systems. Two main options are reported in the analyzed papers: down-cycling (for newer products derived from recycling processes) and energy recovery (heat production by the incineration of wooden waste), that inevitably involves CO_2 emissions. These scenarios are equally probable, therefore a general assumption in the LCA of a wooden-based technology is not possible; it has to be specifically considered, performing the LCA on the technology, with a specific reference to the final product.

Moreover, as the wood factory develops co-products processes, the LCA of wooden products is inevitably affected by the problem of allocation. As already introduced, from the manufactory stage of all the wooden products, the wooden waste could be used both as a recyclable content in a secondary process (being the raw material for chipboard, plywood or glued panels) than as biomass to produce heat, instead of fossil fuels. LCA is very sensitive to methodological decisions, including the selection of allocation procedures. Different methodological approaches to the allocation issue (e.g. system boundaries expansion, mass allocation or economic allocation) provide different results in quantitative records of environmental indicators. Thus, even if the ISO standards suggest the “system expansion” method, it is strictly recommended to provide at least two different allocation methods, for the transparency of the performed LCA (Villa at al., 2012).

3.1. LCA indicators for the wooden construction sector

Besides the enhancing of the main issues of a Life-cycle assessment plied to the wooden-based construction field, the aim of the current review is to collect the indicators used to assess the environmental profile of wooden construction products and wood-based buildings. The analysis of the reviewed studies is resume in Tables 1 and 2, in order to give an overall perspective, as a guide to establish how an LCA (or evaluation approaches such as the Active House Radar, e.g.) is allocated among the literature.

An observation has to be pointed: the tables report just which environmental indicators[32] have been used to assess specific products, elements, components or building projects, without any references to quantitative values. This choice

[32] Abbreviations reported in Table 1 and 2: NonR – Non-renewable energy; Ren – Renewable energy; CED – Cumulated Energy Demand; EE – Embodied Energy; EC – Energy Consumption; GWP100 – Global Warming Potential (100 years); AP – Acidification Potential; EP – Eutrophication Potential; POP – Photochemical Ozone formation Potential (photo-smog); ODP (stratospheric) – Ozone Depletion Potential; ETW – Eco-toxicity Potential Water; ETS – Eco-toxicity Potential Soil; HT – Human Toxicity Potential; RA – Radio Activity; CS – Carcinogenic Substances; HM – Heavy Metals.

derives from the co-product issue and the allocation problem. The LCA practice, indeed, attests how the quantitative results could be affected by changing the allocation method, making the resulting values not easily comparable (Villa et al., 2012).

Table 1: Comparison between LCA performed studies on wooden products.

			Solid wood	Glulam	Plywood	Chipboard	MDF panels	CLT panels	Wood frame	Laminated timber board
LCA	Energy	NonR	x	x		x				
		Ren	x	x		x				
		CED					x	x		
		EE	x	x		x				
		EC	x	x		x				
	Cml 92 / Ecoindicator 95	GWP	x	x		x		x	x	x
		AP	x	x		x			x	x
		EP	x	x		x			x	x
		POP	x	x		x			x	x
		ODP	x	x		x			x	x
		ETW							x	x
		ETS							x	x
		HT							x	x
		RA								
		CS								
		HM								

Table 2: Comparison between LCA performed studies: wooden-based construction elements, components and wooden technologies-based buildings.

			Insulation materials		Door/windows			Residential buiding	
			Wood fibre board	Cellulose fibre	Wood/Alu	Particleboard	Solid wood	Cold climate	Warm climate
LCA	Energy	NonR	x	x		x	x		
		Ren	x	x		x	x		
		CED			x	x	x	x	x
	Cml 92 / Ecoindicator 95	GWP	x	x	x	x	x		
		AP	x	x	x	x	x		
		EP	x	x	x	x	x		
		POP	x	x	x	x	x		
		ODP			x	x	x		
		ETW	x	x	x				
		ETS							
		HT	x	x	x				
		RA				x	x		
		CS				x	x		
		HM				x	x		

4. Conclusions and further developments

According to all the analyzed papers and reports, wood as construction material is considered to have a positive environmental profile, thanks to its favorable contribution to the greenhouse effect reduction (CO_2 storage capacity), the lower required energy, and the potentially re-use of waste as recycled content for other production chains (down-recycling) or as biomass, reducing the non-renewable resources consumption (energy recovery). However, the global balance between benefits and costs presents often several critical aspects, such as the punctual and not-reliable definition of boundary conditions. A different end-of-life scenario, e.g., implies a shift on the global equation of positive/negative quantities of gas emissions (incineration of wood products could cause, indeed, higher impacts on acidification and eutrophication if compared to other material-based products).

Finally, we have to consider improving the current LCA practices, in order to cover all the aspects that are related to the specific assessment of the wooden-based production chain. From the results of the literature review, those implementations mainly involve (i) the integration between the LCA and forestry-management evaluation tools, and (ii) the deeper investigation of the end-of-life scenarios, accounting the gas emissions in the global balance that defines the environmental profile of the material. The improvement of these two aspects could strengthen effectively the LCA methodology applied to wooden-based construction technologies.

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LCA methodology to compare alternative retrofit scenarios for historic buildings: a review

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Abstract

According to the latest Directives related to energy efficiency, retrofitting the existing built environment is fundamental. In this context, historic buildings represent the 30% of the existing stock and require a special attention for planning retrofit solutions, considering protection needs and constraints given by the Authorities. Life cycle assessment (LCA) methodology is adopted to assess both the environmental and energy impact of retrofit scenarios, guiding the design choice. However, in the case of historic buildings, this method involves different results in relation to the chosen parameters (goal and scope definition, functional unit, life span, system boundaries and impact categories), conservation constraints and protection goals. This work presents a literature review on a selection of publications related to the LCA method applied on heritage buildings. The final goal is to identify differences on assumptions or simplifications and define finally, some key findings for the next future.

1. Introduction

In the last decade, plan of actions and Directives (as last EPBD 2010/31/EC) have been promoted by United Nations and European Union, aiming to reduce construction sector impact, considered one of the most energy consumer. On its side each government has set ambitious goals to reduce energy needs and emissions, not only focusing on new buildings, but also on the existing ones.

According to latest UNEP (United Nations Environment Program, 2016), in fact, built environment would be responsible for 30% of solid waste production, for 1/3 of the pollutant emission in the atmosphere (about 35% of the total) and 39% of global energy consumption - mainly related to heating and cooling systems. Historic buildings represent about a quarter of the existing building stock: more than 22.3% of European constructions dating before 1946 (in Italy the percentage is slightly higher - 30%) (Eurostat, Census hub HC53, 2011). Built heritage is a unique and unrepeatable cultural value testimony to be preserved over time for our society (Code of Cultural Heritage 42/2004). Even thought, it doesn’t have to comply with minimum energy performance requirements, it is well-known that preservation aim could be guarantee thanks to refurbishment and management actions during its whole life. Nevertheless, refurbishment interventions shouldn’t compromise the uniqueness of existing constructions for achieving excellent performance values and cost savings. Hence, for each building, a specific design approach is required to ensure its usability and protection, avoiding damage problems (e.g. moisture problems, thermal bridges, etc.), reducing energy use and environmental impact without compromising its value (Pracchi, 2016).

Due to the need for a tool to address the retrofit project of built heritage, in June 2017 a new standard has been approved by the European Union: the ‘Guidelines for improving the energy performance of historic buildings’ (EN 16883, 2017). This document is a collection of recommendations, not mandatory, for help stakeholders (whether designers or protection Authorities) in the retrofitting planning process for architectural heritage. A suggest procedure is explain in it, moving from the data collection phase to the selection of preservation criteria and compatible retrofit measures. According to the Guidelines, a life cycle perspective must be adopted to truly understand possible consequences of the decisions taken during the planning process, assessing the best sustainable solutions from the economic, energetic and environmental point of view. In this term, it’s fundamental to carry out a multicriteria approach to quantify and compare benefits and impacts of different measures, as Life Cycle Assessment (LCA) methodology does on the environment (such as evaluating global warming potential, embodied energy, air and water pollution, toxic releases in landfills, natural resource depletion, etc.).

Extensive literature has been published in recent years adopting LCA on the building sector, but not many examples of LCA on built heritage are still available. In this specific research area one problem is the lack of comparable and replicable studies: LCA method, in fact, can involve dissimilar results in relation to the parameters chosen (functional unit and reference flow, goal and scope definition, impact categories, system boundaries, life span). When we talk about architectural heritage, we refer to a broad range of buildings with different constructive and materials characteristics, linked to territorial, climatic and cultural factors (Franco et al., 2017). It means that an LCA requires assumptions which might derive into inaccurate results (e.g. difficulty in defining boundaries which includes the whole life of the building, lack of data on raw materials, etc.).

The focus of this study is to have a broadly overview of the LCA studies related to the evaluation of different scenarios for the retrofit of historic buildings. Available literature is here collected to highlight which are the parameters and assumptions adopted in LCA in the international context and which are the results. A selection of studies, which consider not only the environmental impact, but also the energy assessment of single options, will be discussed. Finally, some considerations on single case process will be extracted, underlining related criticalities and potentialities.

2. Methodology

The aim of this paper was to provide an overview of the LCA criteria applied to historic building refurbishment. First operation was to select an anthology of recent papers, published all around the world, applying an LCA method to assess alternative retrofit scenarios for historic buildings, such as: wall insulation, roof substitution, windows refurbishment, etc. The collection of publications has been based on a customized search, through two web databases: Web of Science and Scopus. In each web portal, a set of authors’ keywords (LCA AND Building AND Retrofit AND Historic*), differently combined, has been used. A limited range has been fixed also for the articles publication year (2010-2018), language (English), subject area (Engineering and Energy) and document type (Article, Review). In this way, it has been limited the amount of studies not related to the specific topic. After analysing their abstract and contents, the only articles related to build heritage retrofit were selected to be reviewed and to elaborate some considerations. Parameters identified for this study are: LCA goal and scope, research area, database adopted, building typology, functional unit, life-span, system boundaries, life cycle inventory, impact indicators and results themselves.

3. Result analysis

Some difficulties have been met in finding the more related papers to the selected topic. This research has led to 42 studies on Scopus, all related to LCA method applied for existing buildings, but just 3 on historic buildings. The same happens in Web of Science: 54 results, but just 6 related to this topic.

3.1. LCA goal and scope

In all the selected papers the LCA scope is clearly defined: 100% of the papers perform a comprehensive energy and environmental Life-Cycle Assessment of different retrofit scenarios to guide the decision-making. There are two ways in which it is expressed: in most of the cases it’s a life cycle evaluation of materials and packages of measures; in just two cases it’s an analysis on the overall process of the building construction: Binet et al. (2012) study the different impact between the original building and the actual one after renovation and Ming (2017) estimates different impacts for the same building if considered as original, as renovated or as a new equivalent construction. Just 4 papers integrated also this analysis with a Life-Cycle costing evaluation. Two papers elaborate also an Ecological footprint analysis (Dotelli et al., 2013 and Bin et al., 2012).

According to that, defined LCA scopes are slightly diverse among selected publications and it can be difficult to compare them. This is reasonable as each study was performed following a personal target. Comparison feasibility among adopted strategies would still be possible if a proper FU is defined from the beginning. Other differences may contrast studies comparability, as the adoption of different impact categories.

3.2. Research area, building typology and retrofit measures

Papers come from all around the world: Canada, Australia, USA and Europe. The majority are from Portugal (4 papers on 9) because the authors come from the same research group. Although there is a shortage of papers on the specific topic, the provenance of studies from so many different Countries indicates that this sector is wide-ranging, but it’s low possible to compare results.

Most of the case studies are houses (13 in total – of which 8 are in the paper Iyer-Raniga et al., 2011). The others building typologies are different, as explanation of the topic extents: a XIII century church (Bortolin et al, 2015), a former silk spinning (Dotelli et al., 2013), a XIX century monument (Ming, 2017).

Retrofit measures are quite repeated: different insulation material or insulation thickness; window, roof, plants refurbishment. Specific differences are here referred: while Rodrigues et al. (2014), Freire et al. (2017), Tadeu et al. (2015) assessed 27 scenarios (adopting different insulation materials, different thickness, windows refurbishment), Iyer-Raniga et al. (2011) assessed 15 and Binet et al. (2012) just 2 options (a baseline scenario and a post-intervention one); in Rodrigues et al. (2017) are evaluated different occupancy scenarios (residential and office, leading to different consumption needs and equivalent different set-points); Dotelli et al. (2013) evaluated the impact of wall insulation with 3 retrofit options (present, conservative retrofit, deep retrofit) and 2 material options (synthetic and natural); Bortolin et al. (2015) assessed the same package of retrofit measures with 5 different impact methods and Ming (2017) assess three adaptive reuse scenarios (historic preservation, renovation and new building). Different parameters adopted don't allow making easily comparison among different papers; however, it can be useful to understand each strategy to make it replicable or not.

3.3. Functional unit and life span

Functional unit express the kind of impact we want to measure. In 7 cases on 9 the functional unit is considered one square meter of living area, very common for buildings according to the willing to evaluate the impact given by a generic and equivalent amount of retrofitted area. In another case the functional unit is the entire surface adopted for the insulation, because the assessment of the wall insulation only (Dotelli et al., 2013). Just in one case it is considered the impact of different adaptive use on the whole building (Ming, 2017), but this generic assumption limits the comparison with the other studies because it doesn't allow to assess the effect of measures on each building component.

Life-span ranges between 30-75 years (the majority assumes 50 years), making the results uncertain, because there is low reliability on the assumptions for the prices, technologies (if including cooling and heating energy consumptions), disposal, as well as the energy mix that would be available in the following years. Additionally, the amount of maintenance or replacing activities can vary depending on the strategy.

3.4. System boundaries

A life cycle approach is important to evaluate the impact of the whole chain of a retrofit intervention. However, 5 on 10 LCA results include as system boundaries just the phases of removal of the existing components - replaced during the retrofit operation (e.g. old window frame), construction and use phase of the retrofit measure adopted (e.g. new window disposition), excluding the previous and later phases (e.g. building construction phase, end of life of the retrofit components as recycling or waste treatment phase).

Two studies, Iyer-Raniga et al. (2011) and Binet al. (2012), consider the system boundaries from cradle to grave, including the entire life cycle of the ancient construction, adopting many approximations on the historic building products' chain. Other two studies considered just the operational phase of the retrofit measure (Ming, 2017 and Dotelli et al., 2013). The assumption of a reduced life cycle approach leads to an uncertainty in the evaluation of the scenarios impact. The "pre-use" phase (cradle to site) involves embodied energy consumption and concomitant carbon emission during material extraction, transportation, manufacturing and installation which need to be considered for a good life cycle assessment. Because such information in many cases are poorly documented or available (especially in the case of renovations during the life of the building), it is very difficult to track each one of them.

In some studies, it is important to notice that a corrective maintenance strategy was assumed, including the conservation of the retrofit measures: in Freire et al. (2017) a gradual deterioration of interior and exterior finishes of the building is considered; in Iyer-Raniga et al. (2011) sensitivity studies evaluating the influence of variable residential component lifetimes (e.g. lower maintenance when compared to the baseline scenario) on the results were conducted.

3.5. Life cycle inventory

For the life cycle inventory, many of the researchers adopt databases (such as Athena, EcoInvent and ECOshopping) or data available from literature, evaluating only the retrofit technologies. But the central problem is related to the lack of significant data for specific locations (e.g. Athena is related to Canada products but most of the papers used it) and different age of materials. As mentioned before, two cases (Iyer-Raniga et al., 2011; Bin et al., 2012) had tried to get information on historic building materials, communicating with the architecture historians and by examining the historiography on ancient materials, considering the whole life of ancient buildings until now. As known, it's almost impossible to have accurate data on all the stages of historic buildings materials and it's also clearly impracticable to create a database which includes all existing ancient materials.

3.6. Impact indicators

Roughly all papers presented environmental impacts at the midpoint level (except for Bortolin et al, 2015), avoiding the high uncertainty associated with impacts damage oriented (e.g. Human Health, Biodiversity, Ecosystem). The results are evaluated for the all retrofit packages, not on the single component. GWP and Non-Renewable Primary Energy (NRPE) are the main analysed impact categories; all studies calculated either one or both. Other impact factors are alternatively used (photochemical oxidation, terrestrial acidification, and eutrophication) and in two cases ecological footprint is also evaluated. No one of the studies applied normalization.
Methods adopted for LCIA are different, but mainly Cumulative Energy Demand (CED) - to measure the non-renewable life cycle primary energy requirements -

and ReciPe (Endpoint or Midpoint level) – to assess life cycle impacts. In Bortolin et al. (2015) they tested same retrofit packages adopting 5 methods to test different results (IMPACT 2002+, EDIP2003, EPS2000, ReCiPe, IPCC). Each method has different impact categories. It is interesting because leads to understand how different results can be presented depending on different assumptions. For the energy assessment of each scenario, dynamic simulation software (mostly EnergyPlus and TRNSYS) has been adopted in the 90% of the studies.

3.7. Results

Results are very different, depending on many factors: different building typology and construction materials, different location and different assumptions on the retrofit measures adopted. In some studies on Portugal area, which are further comparable, the retrofit strategies that maximize LC benefits depend on the type of use and occupancy level: in Freire et al. (2017) and in Rodrigues et al. (2017) it is underlined that operational energy needs (heating and cooling) are higher for residential use with an high occupancy profile and lower for office use (in the first paper, in the base case without retrofit insulation strategies, energy needs values are respectively 49.9 kWh/sqm*yr for residential and 40 kWh/sqm*yr for office; in the second paper they are 55.3 and 23.3 kWh/ sqm*yr); consequently, this gap between different uses is reflected also in LC impacts values: considering the impact over a period of 50 years, in Rodrigues et al. (2017) NRPE is 1250 kWh/sqm for office use, 1800 kWh/sqm for residential high occupancy use. In all studies, the use phase results in the highest environmental impact in all studies (55-80% of total LC impacts), followed by the production phase (20-40%). The results show that for higher insulation thicknesses (from 0 to 120 mm for roof, 0–80 mm for wall), the reduction in primary energy is not significant (5% or less - NRPE in the base case is 1340 MJ/sqm, whilst it's 1270 kWh/sqm when it's considered the package of measures 120 mm roof insulation + 80 mm wall insulation, but on the contrary there is a small increase in construction and maintenance primary energy), while the LC impact increase from 6 to 20%.

In the same paper and in Tadeu et al. (2015), it is also interesting to see how the same problem is addressed performing a Life-cycle costing: a sensitivity analysis was done to assess different retrofit insulation strategies, assuming the already quoted three alternative occupancy scenarios. Without entering in-depth in the cost assessment topic, it's important to notice that the annual cost savings are considered negative for office and low residential use in the base case (-1500 €) and they worsen in the retrofit scenario with higher insulation thickness (for 120 mm expanded polystyrene the annual net saving of exterior walls is 10% lower), but they are positive in the case of high residential occupancy (480 € in the base case, 70 € in the second scenario). In other studies, it is interesting to see how different retrofit insulation materials can have different results both in terms of energy requirements and embodied energy: in Rodrigues et al. (2014) rock wool (RW), XPS and polyurethane foam (PUR) are compared (all with an 80 mm thickness). The comparison between embodied and operational impacts shows that PUR80 has the lowest impact in four LCI categories (climate change, terrestrial acidification, ozone depletation and freshwater eutrophication), but not in primary energy, in which XPS80 has the LCE lower value (3100 MJ) counter the other two materials (3500 MJ) and in marine eutrophication. As demonstrated in Bortolin et al. (2015) and Dotelli et al. (2013), the comparison among materials is not straightforward, as different methods give different results: comparing XPS and wood-wool insulation with IMPACT 2002+ and EDIP 2003 method, for example, the results are completely different: the first method considers the natural material worse than the synthetic one for the higher land use, whilst in the second method it's the reverse, since XPS affects more the GWP.

3.8. Conclusions

The expressed results explain how different assumptions, adaptive use and LCIA methods could influence the choice of retrofit solutions, in terms of life-cycle environmental, energy and cost assessment. However, it is important to not forget that we are dealing with historic buildings and it's fundamental to consider the heritage significance value to decide in terms of sustainability which retrofit solutions is more suitable and compatible. According to that, some key findings from the study are listed in the following:

- Assumptions and simplifications led to several limitations. Usually a life cycle approach on the whole life of the building is needed, but in the case of architectural heritage it's not possible to evaluate the building pre-use phase because it's not possible to improve inventory data considering all existing materials. Typically, LCA methodology is applied to retrofit interventions considering the existing construction as "a zero-impact datum". According to that, good data quality for retrofit products is needed for specific locations and different age of materials, considering maintenance operations to reduce natural decay of components and ensure long-term strategies. Furthermore, in determining the rate at which building materials will be replaced, additional information on material durability and compatibility with the heritage significance would make this input more precise;
- In the built heritage field, demolition scenario should not be considered because preservation needs. LCA is not the correct tool to demonstrate whether this kind of intervention can be convenient or not, but it should be decided by conservation constraints. In any case, the only LCA selected paper that try to evaluate if demolishing is less impactful than restoring the building (Ming, 2017) demonstrated that demolition-reconstruction has more impact on the environment (+50%) that benefits in reducing the operational energy demand (-40%);
- Lastly, a proper choice of impact indicators, normalization and weighting factors should address the objectives of the decision-makers. In addition, it can be useful to adopt also qualitative factors, to capture differences among different options.

	Reference	LCA goal and scope	Location	B. typology	Retrofit variables	FU	Life span	LC Inventory source		System boundaries	Impact indicators	LCIA method
								Materials	Energy			
1	**Tadeu et al., 2015**	LCCA+LCEA+LCIA+RS	Portugal	House - XX century 119sqm	9 packages for 3 location (diffent insulation materials, different thickness, windows refurbishment) 4116 energy simulations	1 sqm of living area	30 yr	Lit.	DS	A1-B7*	NRPE, CC	IPCC
2	**Bin et al., 2012**	EF+LCCA+LCEA+LCIA+RS	Canada	House - XX century 140sqm	Baseline scenario and after retrofit intervention	1 sqm of living area	50 yr	IE4B Athena (Canada) + Atlas	DS	A1-C4**	GWP, EE, EW, EF, EC	-
3	**Bortolin et al, 2015**	AIM+LCEA+LCIA+RS	Italy	Church - XIII century	3 insulated material, 7 thickness	1 sqm of living area	50 yr	ECOshopping + EcoInvent	DS	A1-B7	Human Health, Biodiversity, Ecosystem, CC, NRPE, ODP, EU, GWP, EP, EW, TA, FE, ME	5 impact methods: IMPACT 2002+, EDIP2003, EPS2000, ReCiPe, IPCC
4	**Dotelli et al., 2013**	LCEA+LCIA+RS	Italy	Former silk spinning - XIX century	wall insulation with 3 retrofit options (present, conservative retrofit, deep retrofit) and 2 material options (synthetic and natural)	the entire surface adopted for the insulation	50 yr	EcoInvent	DS	A4-B7	GWP, EF, EI99	
5	**Freire et al., 2017**	LCCA+LCEA+LCIA+RS	Portugal	House - XX century 279sqm	27 scenarios (3 insulation levels, 3 thickness, 3 materials)	1 sqm of living area	50 yr	Lit.	DS	A1-B7*	NRPE, CC, ODP, EU, TA, GWP,FE, ME	CED+ReciPe
6	**Iyer-Raniga et al. 2011**	LCEA+LCIA+RS	Australia	8 houses - different age and envelope	15 scenarios (insulation, windows replacement, UV films, adding secondary glazing, new plants)	1 sqm of living area	50 yr	IE4B Athena (Canada) + EcoInvent	SS	A1-C4**	GWP, PO, EP, EW, EF	-
7	**Ming, 2017**	EE+LCCA+LCEA+LCIA+RS	USA	Monument - XIX century 2136 sqm	3 adaptive reuse (historic building, renovated, new building), 6 energy performance targets	the whole building	75 yr	IE4B Athena (Canada)	CBES data	A4-B7	GWP, ODP, SP, HHP	-
8	**Rodrigues et al., 2014**	LCEA+LCIA+RS	Portugal	House - XX century 279sqm	27 scenarios for roof to have the same U-value (3 insulation levels, 3 thickness, 3 materials)	1 sqm of living area	50 yr	Lit.	DS	A1-B7*	CC, ODP, EU, GWP, TA, FE, ME	CED+ReciPe
9	**Rodrigues et al., 2017**	LCCA+LCEA+LCIA+RS	Portugal	Office - XX century 438 sqm	9 occupancy scenarios, 3 insulation levels, two set-points combination	1 sqm of living area	50 yr	Lit.	DS	A1-B7*	NRPE, CC, ODP, EU, GWP, EP, EW, TA, FE, ME	CED+ReciPe

AIM= assessment of impact methods; CC= climate change; DS=Dynamic Simulation; EC=embodied carbon; EE= embodied energy; EE=Eco- efficiency; EF= Ecological footprint; EI99= ecoindicator 99; EU= eutrophication; EW= embodied water; GWP= global warming potential; LCCA=Assess costs/net savings; LCEA= life cycle energy analysis; LCIA=Assess environmental impact; Lit=from literature; LU= land use; ME= marine eutrophication; NRPE= non-renewable primary energy; PO=photochemical oxidation; RS=assessment of different retrofit strategies; TA= terrestrial acidification. System boundaries (EN 15804:2012): A1-A3= Production/raw material; A4-A5= Installation process; B1-B7= Use processes; C1-C4= End-of-life; *=it includes also the demolition of existing components; **=it includes the whole life of historic building components (A1-C4) and the whole life of retrofit interventions.

Table 1: research synthesis

4. References

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Evaluation of environmental sustainability in additive manufacturing processes for orthopaedic devices production

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Abstract

Sustainability impact assessment of additive manufacturing represents one of the work packages (WP5) of the European Union Horizon 2020 project “Driving up Reliability and Efficiency of Additive Manufacturing” (DREAM). Additive manufacturing is a versatile technology consisting in melting metallic powders to produce objects from 3D data, layer upon layer. Additive manufacturing applications in industry range from automotive, biomedical (e.g. prosthetic implants for dentistry and orthopedics), aeronautics and others. One of the main target of WP5 is to assess the environmental sustainability of DREAM products and processes, conducted with laser-based powder bed fusion additive manufacturing systems through Life Cycle Assessment (LCA) methodology. Environmental impacts on different impact and damage categories due to manufacturing, use and end of life of the designed solution have been assessed adopting IMPACT 2002+ method.

1. Introduction

Additive Manufacturing (AM) is a rapidly growing technology that seems to be limitless. Its strengths are the capability in creating high geometrical complexity objects, precluded to traditional manufacturing, and the flexibility in meeting customer’s requests, avoiding the increasing of productive costs.

Powder bed fusion (PBF) is one of the latest terminology for the designation of an AM process in which a metal powder is laid in a bed and sintered by high-energy beam, often a laser. AM technologies are used in a wide range of industries from aerospace, consumer electronics to medical applications.

A cooperation study between EADS IW, the aerospace and defence group’s research and technology organisation, and EOS, the worldwide technology supplier for industrial 3D printing of metals and polymers, (EOS, 2015) provides a comparison, in terms of energy consumption, between traditional manufacturing and AM in an aerospace application (a bracket) over the whole life cycle. In the same study, a comparison focused on the static phases between rapid investment casting and an EOS platform is carried out, too.

Burkhart and Aurich (2015) presented a framework to assess the environmental impact of PBF in commercial vehicle production and identify product components/assemblies with high impact on vehicle performance and potential for improvements.

The present study is realized in the context of the DREAM project (H2020-FOF-2016) that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 723699. Its aim is to significantly improve the performance of laser PBF of titanium, aluminum and steel components in terms of speed, costs, material use and reliability, also using a LCA approach, whilst producing work pieces with controlled and significantly increased fatigue life, as well with higher strength-to-weight ratios. DREAM targets the development of a competitive supply chain to increase the productivity of laser-based AM and to bring it a significant step further towards larger scale industrial manufacturing.

This article is focused on the study of environmental damage of a medical application of AM, femoral stems, over the whole life cycle. In particular, an environmental performance comparison between two different production routes of titanium alloy powder is performed, namely gas atomization (GA) and plasma atomization (PA) processes.

2. Life cycle of a femoral stem produced with PBF

In the last decade and in the field of the prosthetic components, PBF processes have been applied to the production of titanium alloy parts, such as femoral stems. The entire life cycle of femoral stems produced with AM consists in Ti6Al4V powder production, femoral stems production, use phase and end of life.

Femoral stems production is realized by laser sintering of titanium alloy powder layers. End of life step analyses exhausted gas treatment and waste Ti6Al4V recycling processes. During the production process indoor emissions have been taken into account, for this reason air filters and personal protective equipment (PPE) have been included in this study. The main steps of the life cycle of femoral stems production are described below.

2.1 Ti6Al4V powder production

Ti6Al4V powder production is examined for gas atomization and plasma atomization. The main differences between these productive processes consist in alloy feeding and atomization technology. PA process uses a Ti6Al4V wire feedstock, straightened and positioned at the apex of three plasma torches. The plasma flow melts the wire, which droplets solidify in spherical particles during the fall through the atomization tower.

GA process uses a Ti6Al4V bar feedstock that gets rotated and, at the same time, lowered in an inductive coil that melts the bar without contact. Then the melt gets atomized by high-pressure argon jets. Both atomization processes are supposed to work 16 hours/day (EOS, 2017) and are characterized by indoor emissions of argon and metals. Since, IMPACT 2002+ method does not taken into account indoor emissions, characterization factors for argon and metal indoor emissions are calculated and introduced in the Life Cycle Impact Assessment (LCIA) method. This allows to evaluate and include the indoor emissions in the impact assessment stage.

2.2 Femoral stems production

Femoral stems production is realized by EOS M290 machine, where sintering takes place with a 400 W laser (EOS, 2017). The whole production cycle lasts 61 hours and 21 minutes with a production capacity of 20 femoral stems (Poly-Shape, 2017) per cycle. After a set-up phase, powder is fed by the dispenser system platform and then a 30 m thick layer is stretched on a titanium plate with a recoater. Laser fusion involves selective melting of cross-sections, previously defined by CAD model. The powder bed is lowered progressively in order to allow a new layer deposition that, in turn, will be sintered.

In order to avoid the development of explosive atmospheres due to the raising of powder particles during sintering and to control N/O pick-up, argon flow is insufflated over the powder layer. An air recirculating filtering system works continuously to purify argon. At the end of the productive process, the parts are extracted by workers. Extraction considers the separation of solidified parts from the remaining loose powder, that will be reused in the following productive process. Indoor metals emissions that occurs during the machine cleaning and parts extraction are considered.

2.3 End of life

Femoral stems end of life consists in archiviation, prior sterilization. This information was obtained through direct interviews with technicians. Prosthesis average lifetime is supposed to be about 15 years (value obtained with weighted average of lifetime reported in Wyatt et al., 2014). The rate of deceases before stem’s revision is equal to 25% of total implantations (rate of deceases within 10 years from stem’s implantation, Wainwright et al., 2011). If death occurs before removal, the prosthesis will not be removed from the patient.

3. Life cycle assessment

3.1 Goal definition

The goal of the study is to assess the environmental impacts of Ti6Al4V based femoral stems produced with AM over their entire life cycle in order to identify the hot spots of the system considered in agreement with UNI EN ISO 14040-14044 regulations.

3.2 System, functional unit and function of the system

The system studied is the additive manufacturing process with powder bed fusion of Ti6Al4V alloy powder. The function of AM is the application for biomedical devices, such as femoral stems. For the aim of the present study, 20 femoral stems produced with AM are analyzed.

3.3 System boundaries

The system boundaries cover the entire life cycle of the analyzed system. The analysis includes the Ti6Al4V alloy production, Ti6Al4V powder production with both plasma atomization and gas atomization, femoral stems production with EOS M290 machine, use and end of life phases. The production, maintenance and disposal of facilities as well as other auxiliary materials are also included in the present study. Emissions to air and indoor emissions as well as solid and liquid waste produced in each step are considered and quantified.

Moreover, the following assumptions are fixed:

- The transport of raw material, facilities, systems and machines has been supposed for an average distance of 100 km from the producer to the user;
- The distance of transport of femoral stems from the producer to the final customer has been fixed to 100 km and partitioned for 40% by rail and 60% by road;
- The electricity energy production has been assumed to be the European mix electricity energy created by Ecoinvent;
- The use of 99,97% efficiency HEPA air filter during femoral stems production and powder production steps;
- The use of 99% efficiency personal protective equipment (filter category P3) during EOS M290 machine cleaning, powder production and exhausted argon treatment steps.

3.4 Impact assessment methodology

The analysis is conducted using the SimaPro 8.3 software (Prè Consultants, 2014) and IMPACT 2002+ evaluation method (Jolliet et al., 2003), then modified (Ferrari et al., 2015). The following additions are implemented in order to consider a wider and more representative scenario of the considered system:

- For emissions of Ti6Al4V in indoor environment and inhaled by workers, the substance Metals, unspecified indoor is introduced in Carcinogens, indoor impact category with a calculated characterization factor (Pini et al., 2016).
- For emissions of argon inhaled by workers, the substance Argon, indoor is introduced in Non-carcinogens, indoor impact category with a calculated damage factor. The limit of concentration of argon in a working space, considered to be 500 m^3, is equal to 0,18 kg/m^3 and it is calculated considering the increased percentage of argon (up to 10%) in air. Considering a breath rate of 2,5 m^3/h and 8 working hours per day, indoor argon limit of emission is calculated ad it is 3,57 kg. Referring to Europe (with population density of 386 millions, Goedkoop et al., 2001) and

considering average lifetime of 80 years and 50 year old man exposed to emissions, the damage factor on human health results 2,18E-6 DALY/kg and the resulting characterization factor is 0,78 kgC_2H_3Cl eq.

3.5 Life cycle inventory

The compilation of inventory data is conducted using primary data collected from DREAM project partners where possible, otherwise literature data are included. Eco-invent database (Ecoinvent Centre, 2014) included in SimaPro 8.3.0 software is used, too. The more representative data used in Life Cycle Inventory of femoral stems production with EOS M290 machine are reported in Table 1.

Table 1: inventory input data for 20 femoral stems production with EOS M290

Setup phase argon	Operative phase argon	Ti6Al4V powder	Energy
1700 l	4 l/min	20 kg	88,8 kWh

4. Impact assessment and concluding remarks

The environmental loads at the damage categories level of each step of 20 femoral stems production with EOS M290 machine is reported.
Fig. 1 represents the use of Ti6Al4V powder produced with GA technology. The analysis of the results highlights that the single score damage for 20 femoral stems manufacturing process with GA Ti6Al4V powder usage is 5,72E-1 Pt, where the phases with the highest environmental loads are Ti6Al4V powder production (61,13%) and electrical energy consumption (22,22%). The damage assessment analysis show that Human health category contributes with 46,16% of the total damage, in particular with the substance Particulates, <2,5 m (air) (50,86%, partitioned for 72,04% for powder production and 8,8% for electrical energy consumption).
Resources category provides 25,03% of the total damage, mainly for the substance Coal, hard (27,95%, due especially for energy production for primary titanium production used in alloy powder). The damage to Climate change (21,43%) is generated almost entirely by the substance Carbon dioxide, fossil (93,93%) due to a quantity of 1215 kg CO2 eq., emitted for 56,51% during gas atomization process and for 28,35% during electrical energy consumption. Occupation, industrial area affects the category Ecosystem quality (7,55% of the total damage) and is linked to the furnace used in Ti6Al4V bar production process.
Finally, Human health indoor category contributes to total damage with 6,71E-5% due, mainly, to argon indoor emissions (3,75E-7 Pt, 6,55E-5% of total damage) during exhausted argon treatment and Ti6Al4V powder production processes, and then to metals indoor emissions (9,36E-9 Pt, 1,63E-6% of total damage) occurring in exhausted argon treatment, Ti6Al4V powder production and femoral stems production processes.

Femoral stems production with PA powder (Fig. 2) highlights total damage of 6,2E-1 Pt as result, where the phases with the highest environmental loads are Ti6Al4V powder production (66%) and electrical energy consumption (19,44%). In this hypothesis, Human health category provides 45,34% of total damage, Resources category 26,06%, Climate change category 21,84% (with 1341 kg CO_2 eq. emitted), Ecosystem quality 6,91%, Human health indoor 0,018% (3 orders of magnitude higher than GA hypothesis for the higher quantity of exhausted argon sent to treatment during powder production).

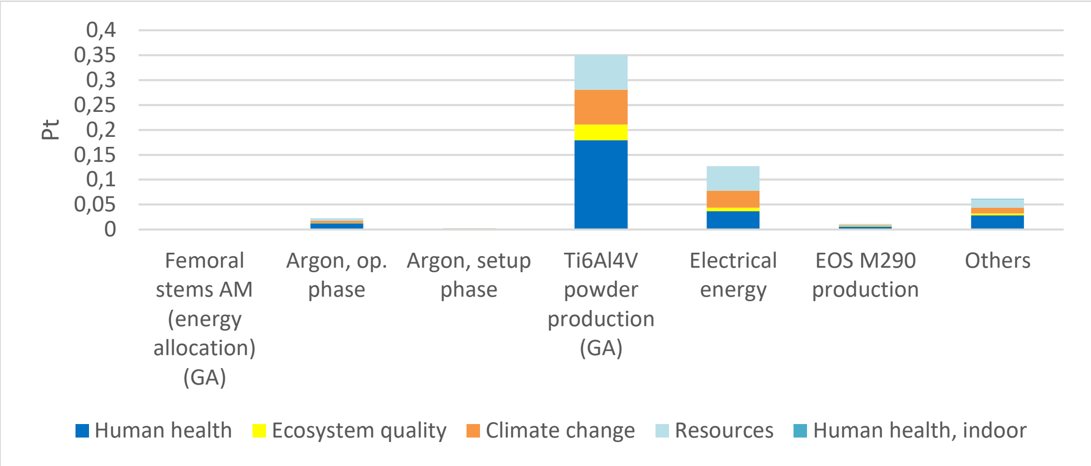

Figure 1: Femoral stems manufacturing process with GA powder

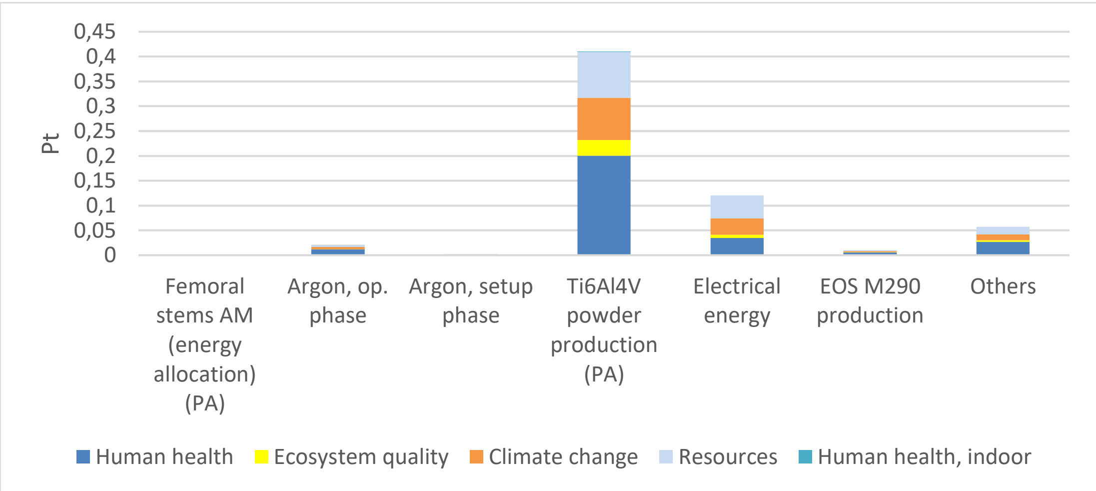

Figure 2: Femoral stems production with PA powder

Femoral stems production with PA powder presents a higher damage (+7,69%) compared to GA powder. In fact, Ti6Al4V powder production process provides a higher contribution to total damage compared to the GA powder hypothesis because of the greater use of argon for PA (2,56 kg of argon to produce 1 kg of powder) compared to GA (0,007 kg for 1 kg of powder) and because of the lower atomization productivity of this technology (80 kg of powder produced in

16 hours) compared to GA productivity (500 kg in the same time) (EOS, 2017). The damage category with the highest increase is Resources (+11,22%), followed by Climate change (+9,33%) and Human health (+5,92%).
An analysis of entire life cycle of 20 femoral stems produced with GA powder is reported below. Total damage is 6,94E-1 Pt (Fig. 3) and is due mainly for 82,5% to stems production, for 17,46% to the use phase (consisting in stem's implantation and medical examinations during patient lifetime) and for 0,02% to end of life (previously described). Damage in use phase is due almost to surgery (68% of total damage), in particular for damage caused by surgery sterilized towels produced with polyethylene terephthalate.

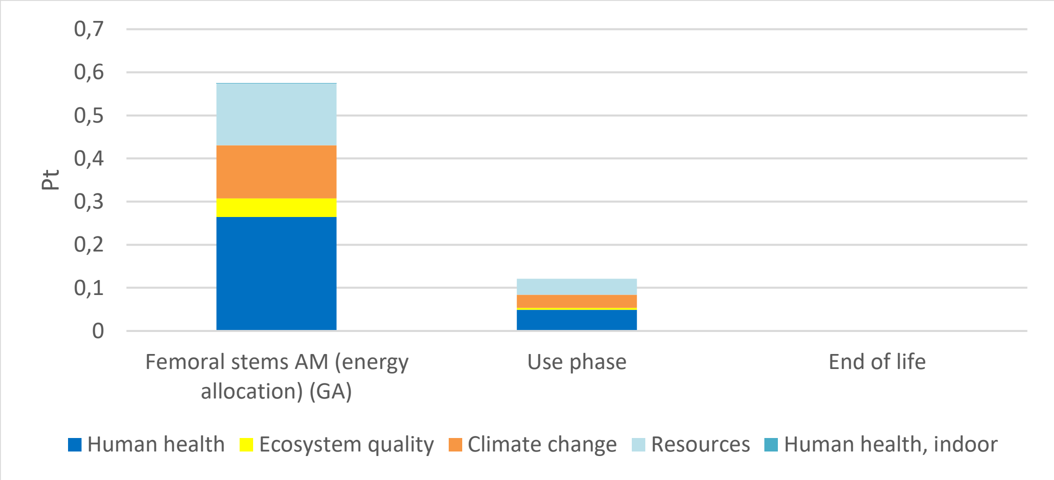

Figure 3: LCA of 20 femoral stems with GA powder

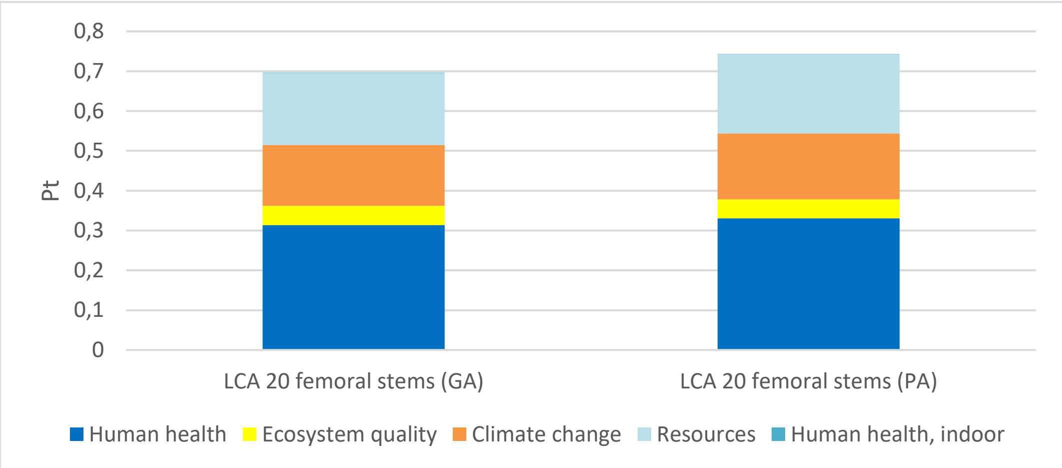

Figure 4: Comparison between entire LCA femoral stems (realized with GA powder) and entire LCA femoral stems (realized with PA powder)

The analysis of the comparison (Fig. 4) highlights that femoral stems produced with PA powder presents a higher impact (7,41E-1 Pt) during all life cycle compared to the GA powder hypothesis (+6,36%) due to higher damage of powder production with PA compared to GA. The damage category with the highest increase in LCA 20 femoral stems with PA powder is Resources (+9,12%), followed by Climate change (+7,61%) and Human health (+5,04%).

Acknowledgment

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Life Cycle Assessment methods and tools in Eni: Green Refinery case study

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Abstract

This paper describes how LCA plays an important role in Eni business both in the design and in the decision-making phase of processes, produtcs and services. LCA methods and tools are useful for all Eni processes (Upstream, Downstream, Renewables). In particular for biofuels, LCA is compulsory for certification and it is important in the design phase too. This paper reports some examples of application in Eni business related to Green Refinery (GHG calculation of H_2 production at Venice Biorefinery, support to Venice Biorefinery during audit for certification, different scenarios for the conversion of Gela refinery following Venice model). Each case study identifies critical environmental points to be managed for continuous improvement and respect of EC directives.

1. Introduction

Reducing the environmental impact of technologies, processes and products is an important challenge in private and public business.

Eni, as an energy major, is engaged to reduce its environmental footprint both reducing the impact of traditional processes and introducing new renewable energy carries.

Life Cycle Assessment (LCA) is a widely applied methodology that helps Companies to estimate the environmental impacts/effects on natural resource use, natural environment and/or human health for a process. In particular, LCA returns an assessment of the *Greenhouse Gas* (GHG) emissions.

LCA is an ISO standardized methodology that gives a comprehensive overview of the system (life cycle). The assessment includes all material and energy flows inside the defined system boundaries starting from raw material extraction to disposal at the end of life (*from cradle to grave*). System boundaries must be definined and taken in account when defining the LCA model. Governed by ISO 14040 - ISO 14044, the methodology has been widely applied in various sectors.

Being an energy company Eni focuses, in particular, on the substitution of fossil fuels with renewable biofuels, for sxample produced from biomasses. This path must be framed in the Renewable Energy Directive (RED, 2009/28/EC and 2009/30/EC) and following updates.

In order to reach this important environmental goal, the conversion of traditional refineries in Biorefineries is a key point. Eni did this conversion in Venice site and now is going to do the same virtous action in Gela site.

The case studies described in this paper have been assessed using the software GaBi (Thinkstep) and its databases (*GaBi Thinkstep ts* and *Ecoinvent*). The environmental impact is expressed in terms of *Global Warming Potential* (GWP calculated on a period of 100 years, *CML method*).

2. Life Cycle Assessment of transport fuels: *Well to Wheel* approach

Talking about environmental assessment of fuels, Well-to-wheel (WTW) approach is an application of the LCA methodology to transport fuels.

The WTW approach differs from a Life Cycle Analysis (LCA), as it does not consider energy and emissions involved in building facilities and the vehicles, or end of life (EoL) aspects.

Therefore, the WTW analysis focuses on:

- fuel production (Well-to-Tank, WTT)
- vehicle use (Tank-to-Wheel, TTW)

Both these two phases are the major contributors to lifetime energy use and GHG emissions. *Fig.1* shows a short description of WTW path.

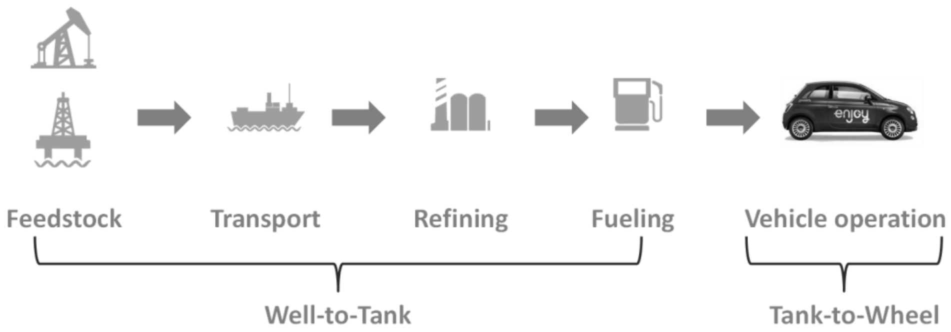

Figure 1: Well to Wheel

Following the 2009/28/EC methodology (Annex V, C 1-2), the assessment of greenhouse gas (GHG) emissions from the production and use of transport fuels, biofuels and bioliquids shall be calculated as:

$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee},$

Greenhouse gas emissions from fuels, E, shall be expressed in terms of grams of CO_2 equivalent per MJ of fuel, gCO_2eq/MJ.

The fossil fuel comparator shall be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the EU Community as reported under Directive 98/70/EC. If no such data are available, the value used shall be 83,8 gCO2eq/MJ. *Fig.2* shows the sustainability criteria for biofuels along the time. A new release of RED is going to be published in 2018.

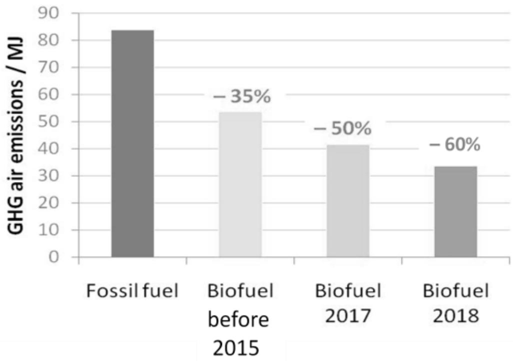

Figure 2: Sustainability criteria for biofuels

3. Eni's Green Refinery

Since the second half of 2005 Eni and UOP decided to launch a R&D project to identify a new technology to produce high quality biofules. This project had excellent results and in 2007 a new technology was invented by Eni and UOP, called *Ecofining*^{TM}. In 2011 the Venice refinery was shut down to be converted in an oil depot, due to its simple process scheme and low capacity. Eni was able to turn a critical situation into a great opportunity by investing in the innovative Green Refinery project for the conversion of a petroleum refinery into a Biorefinery.

The Green Refinery idea is focused on the application of Eni/Honeywell UOP Econfining^{TM} technology and results from the long term Eni Green Strategy. Eni entered the biofuels market, producing a new generation of very high quality biofuels starting from renewable feedstock.

The conversion of an oil refinery to a bio-refinery is not only of environmental and technological significance, but also of economic and social importance, since it allows us to give new life to the plant and guarantee continued employment through innovation.

Fig. 3 draws the path followed to reach this challenge site conversion and biofuels production.

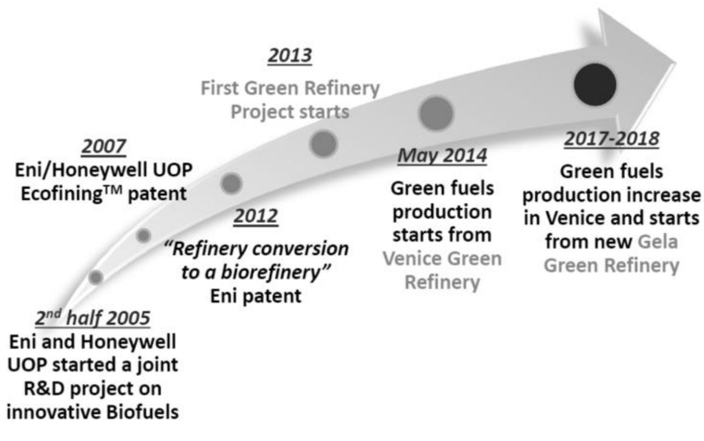

Figure 3: Eni Green Refinery

A detailed descrition of Ecofining™ process can be found in *Kalnes et al. 2007. Fig.4* reports some key information about the Ecofining™ process path.

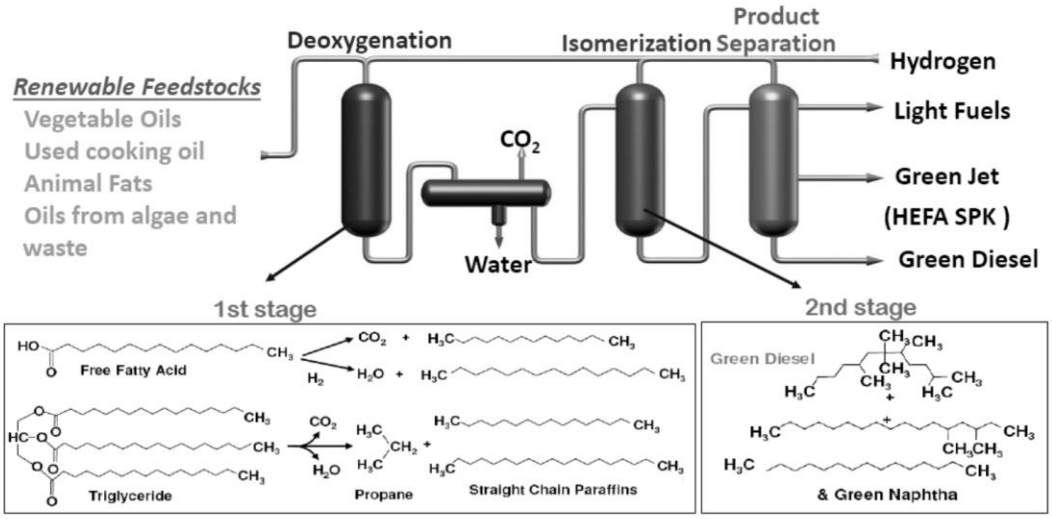

Figure 4: Ecofining™ process

3.1. LCA of H_2 production at Venice Biorefinery

In the Biorefinery of Venice, Eni reused an existing structure instead of building a new one. This strategy offers considerable savings at the initial capital expenditures and converts an old traditional industrial site into a more environmental-friendly one.

UOP developed a preliminary LCA of the process, as described by *Kalnes et al. 2007.*

An updated LCA assessment has been elaborated on the basis of mass&energy balance of the Biorefinery, after the start. In particular, most of the *Impact Factors* related to the process streams were available in the used databases, for the exception of hydrogen.

Eni carried out an evaluation of GHG impact for the hydrogen production with the actual data from the refinery, for different semester (2nd 2014, 1st 2015, 2nd 2015, etc.). The collaboration is still ongoing and this assessment gives support to Eni Venice Biorefinery for its annual environmental certification.

The LCA methodology applied to this case study follows as usual the ISO standards (ISO 14040 – ISO 14044) and it is structured as shown in *Fig.5*.

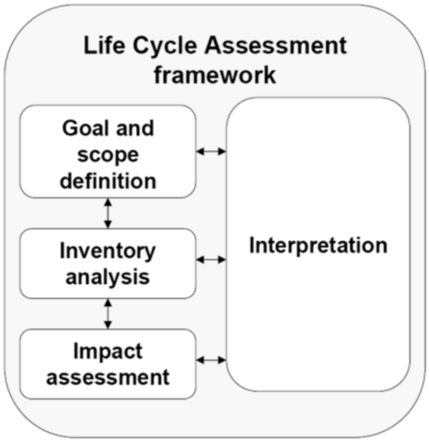

Figure 5: LCA phases

In details:

- **Goal and scope definition:** choice of the system boundaries and the functional unit (for example 1 kg of H_2 for H_2 production in reforming unit or 1 kg of Green Diesel for Ecofining^{TM} process);
- **Inventory analysis**: collection of the necessary data to meet the objectives of the LCA study by inventorying (LCI) the input and output data of the studied system**,** data (mass&energy balance) are given by refinery;
- **Impact assessment**: convert the LCI into the related environmental impacts/effects on natural resource use, natural environment and/or human health; the tool for LCA simulation is GaBi Thinkstep and the database used is Ecoinvent 3.

The following *Fig.6* shows system boundaries of the H_2 production via catalytic naphtha reforming and *Fig.7* reports the LCA results of the environmental impact (GWP-100 years), in percentage, calculated by energy allocation.

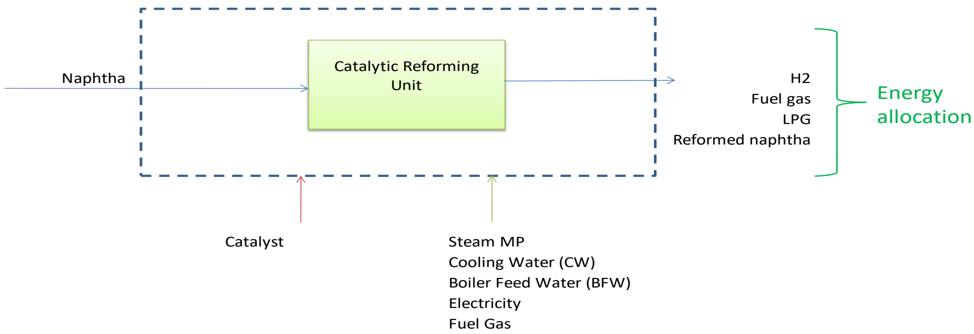

Figure 6: H_2 production LCA system boundaries

H_2 production environmental impact has been calculated every 6 months based on refinery actual data. The result is used in the assessment of the Ecofining^{TM} process for Green Refinery certification.

As shown in *Fig.7*, H_2 production causes about one third of the total GWP of the Green Refinery.

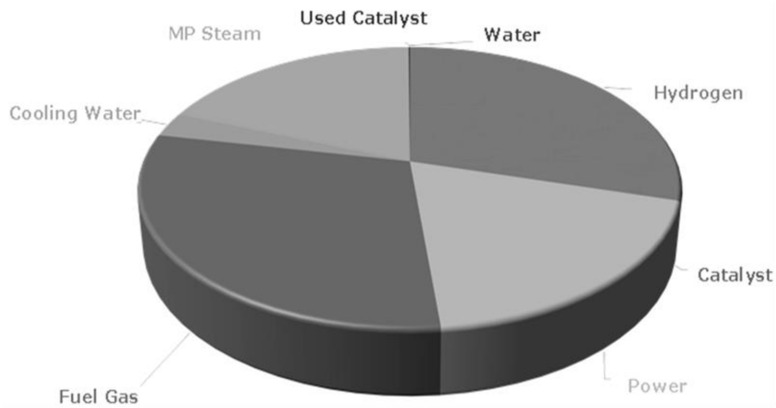

Figure 7: H_2 production environmental impact contribution in Green Refinery

An alternative process than catalytic reforming to produce H_2 is steam reforming. A rough existimation about the environmental impact of H_2 production via steam reforming shows that it is much higher than the one of catalytic reforming path in terms of $kgCO_2/kgH_2$.

The difference between the GWP results for these two paths of reforming is due to the advantage of energy allocation in catalytic reforming (distribution of the environmental impact over other products on energy basis, in particular weighted on their LHV).

4.2 LCA of HVO production at Gela Biorefinery

The second case study here described is the production of Green Diesel (HVO, hydrotreated vegetable oil) in the new Gela Biorefinery. Since the succeful results archieved by Eni in Venice, a similar conversion of Gela site is going to be defined.

In this case the in-house LCA analysis comprises not only the contribution of H_2 unit production but also the entire conversion of a vegetable oil (palm oil) into HVO.

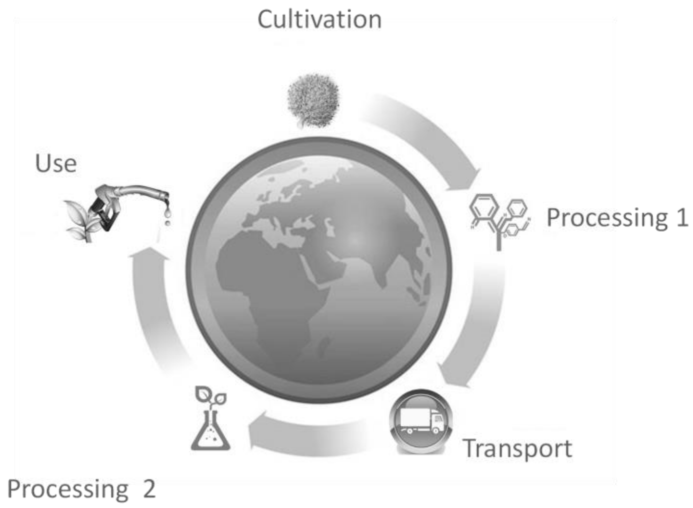

Figure 8: HVO LCA system boundaries

The phases (*Fig.8*) to take in account for HVO production are the followings:

- Cultivation: this step considers the cultivation of palm oil fruits and the relevant use of raw materials, the impact is reported on *Proof of Sustainability* (PoS) certificates;
- Processing 1: palm oil production from fruits, the impact is lower if the methane is captured at the oil mill;
- Transport: includes the transport of raw materials and the intermediate (palm oil);
- Processing 2: production of hydrotreated vegetable oil (HVO) from palm oil to HVO, with the data for the Gela case (Ecofining™)
- Use: combustion phase, GHG emissions for biofuels are zero, as reported in RED (Renewable Energy Directive).

The following picture (*Fig.9*) shows the system boundaries of Ecofining^{TM} process. H_2 from catalytic naphtha reformer (NR) and treated palm oil (POT) are the process inlet. The environmental impact of H_2 is calculated as in Venice case.

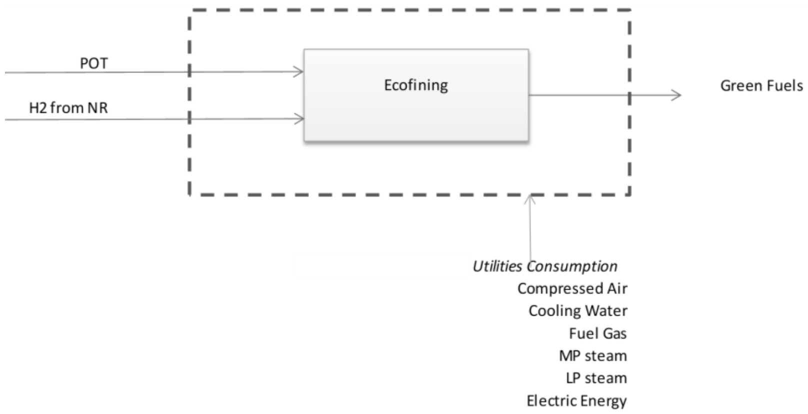

Figure 9: HVO LCA system boundaries

Following the RED instructions, as in *Fig.2*, new plants have to respect a reduction on CO_2 equivalent emissions of at least 60% than fossil fuels (fossil diesel 83,8 gCO_2 eq/MJ): HVO must have an environmental impact less than 33,52 gCO_2 eq/MJ.

The new Green Refinery respects this reduction and the highest contributions on the environmental impact are:

- the biggest impact is due to palm oil: it is crucial to have PO with low emission certificate
- hydrogen has a considerable impact too
- electricity is the third, an alternative to reduce its impact is the use of green electricity (for example from solar energy or renewables in general).

The LCA is extremely useful in the design phase of a project: it has the capability to underline the prevalent source of impact and to give some tips to reduce it before building a plant. Moreover, LCA is an important and crucial tool in gaining environmental certification.

4. Conclusions

LCA methods and tools are useful for all Eni processes (Ustream, Downstream, Renewables).

In particular for biofuels, LCA is compulsory for certification and it is important in the design phase too. LCA methodology can be applied to processes, products and services.

Some examples of how LCA is important in Eni business have been described in this paper:

- GHG calculation of H_2 production at Venice Biorefinery
- Support to Venice biorefinery during audit for certification
- Different scenarios for the conversion of Gela refinery (pretreatment of palm oil, different electricity sources including electricity from renewables).

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Web-site:

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Some lessons learned and highlights from the working group on tourist services to position the Italian LCA Network in the context of SDGs

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Abstract

Pursuing achievement of the Sustainable Development Goals requires immediate action and empowerment of stakeholders, provided the ambitious policy timeline ending in 2030. In order to stimulate discussion on the role of the Italian LCA Network in the context of the SDGs, a survey was conducted within the working group on tourist services. A questionnaire was disseminated (a) to map relevant projects having an influence on tourism LCA, (b) to share major lessons learned from project implementation and stakeholder dialogue, (c) to identify challenges in mainstreaming application of LCA and LCT, (d) to brainstorm ideas to position the work of the working group on tourist services in the context of the SDGs and to highlight topics for a research agenda and action of the broader Italian LCA Network. This paper presents all contributions received from the 4 research groups that took action and responded to the questionnaire.

1. Introduction

"Tourism can make a significant contribution to address economic, climate and poverty imperatives. Tourism represents up to 45% of the exports of services of developing countries and is often one of the few entry possibilities into the job market. It is also one the most viable and sustainable economic development options given its significant impact on related areas of economic activity", Taleb Rifai, former Secretary-General World Tourism Organization (UNWTO) in his address in the flagship UNWTO report positioning tourism in the context of the Millennium Development Goals (MDGs) in 2010. The substancial contribution of tourism towards the achievement of Millennium Development Goals (MDGs) by the year 2015 made this sector at the core of many policy discussion at the time of the Sustainable Development Goals (SDGs) release. By 2030, UNWTO forecasts international tourist arrivals to reach 1.8 billion (UNWTO, 2017). The significant amount of GHG emissions associated to travels poses a threat to climate. Global action was called in the context the United Nations Framework Convention on Climate Change (UNFCC) in order to pursue the objectives of the Paris Agreement andthe key role of tourism in the UN agenda for an inclusive and sustainable economic growth was hence confirmed through the launch of "the International Year of Sustainable Tourism for Development 2017".

Life Cycle Thinking (LCT) is a mainstream perspective enabling to drive sustainable consumption and production through its tools. Sustainable sourcing of raw materials and services, environmental communication and reporting schemes, environmental management and eco-design are a few application contexts for LCT. LCA and other LCT tools has great potencial to play a major role in achieving the SDG #12 as well as SDG#2 and a few others. However, gaps in research, application and governance still exist.

This paper is an attempt to collect ideas to prioritize research efforts in LCT and sustainable tourism, and to position the working group on tourist services and the broader Italian LCA Network in the context of the SDGs, whose timeline is ambitious as it comes to end in 2030.

To come up with research priorities and proposals for action, a questionnaire was initially circulated to working group members to realize how many experts in the group are working on topics affecting tourism LCA and SDGs. The questionnaire started with a description of the research group and continued with a short description of those projects generating knowledge for sustainable travel and tourism. Experts were requested to provide detail of all projects relying on LCA and complementary tools. The questionnaire continued with a short description of the challenges the experts envisage in mainstreaming usage of LCA and LCT tools in support of strategies for sustainability, thus supporting both public and private businesses in making more informed decisions. Experts were then requested (a) to describe what role they see for LCA and LCT in the context of the SDGs, and (b) to propose must-have topics for the research agenda of the Tourism working group or the broader Italian LCA Network so that challenges in application and dissemination can be overcome and the impact of the Italian LCA Network is maximised with regard to the achievement of the SDGs and national targets on sustainable transport and tourism. In order to accelerate the pathway towards the SDGs, the experts were eventually requested to propose topics around which new working groups could be set up within the Italian LCA Network.

This paper includes contributions from 4 research groups involved in the working group on tourist services. The authors of this paper are solely responsible for their own contribution[33]. Co-authors might not necessarily agree on the content of all sections, accordingly.

Chapter 2 focuses on results, lessons learned and highlights from a research project led by the University of Padua aiming at supporting environmental management and local development through a methodological framework based on territorial LCA. Chapter 3 provides a short overview of the project presented by the University of Catania and ENEA Casaccia in the proceedings of this annual meeting of the Italian LCA Network. Such a contribution focuses on green marketing tools and techniques, applied into different hotels located in

[33] References of each contribution can be requested making use of the contact details provided for each chapter.

eastern Sicily. The University “G. d’Annunzio” focuses on sustainable soucing and sustainable consumption in chapter 4. In particular, it is presented a new study aiming at integrating the concept of sustainability within online booking platforms for tour operators and tourists. The contribution from UNINT in chapter 5 focuses on methodology challenges for sectoral environmental reporting and continuous improvement, and provides elements to discuss priority research items for the LCA community in view of supporting countries to work on eco-friendlier transport and tourism.

2. Contribution from the Department of Industrial Engineering, University of Padova, Padua, Italy[34]

Projects. *Application of a life cycle management system in a touristic destination*

Introduction: Proper management of a territory and local development are strictly linked each other and there are several interconnections between the sustainability territorial management and sustainable tourism policy (Cucculelli et al., 2015).

Research gaps: LCA has been evaluated as one of the most promising methodology to assess a territory as a whole (Loiseau et al., 2012) and has been applied on a theoretical case study for local authorities involved in urban planning (Loiseau et al., 2013). However, it has not been applied to highlight environmental burdens of a tourist destination.

Project objective: In this context, our project aims at investigating how LCA methodology can be applied to support public administrations in touristic sites to manage the environmental aspects of their territory and reduce the environmental impacts, through the identification and quantification of environmental burdens of a tourist destination as a whole.

Results: The methodological framework based on territorial LCA was developed focusing on the typical environmental aspects of touristic territories. In particular, the defined reference flow was identified as the studied territory, enlarged including the administrative activities. The reference unit was defined as the execution and provision of touristic and administrative activities by the territory during one year.

Lessons learned. A public administration, through the application of this framework, can identify the environmental aspects systematically, can gain a complete vision and a proper quantification of the related impacts and can finally use the obtained results to take decision with increased awareness.

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Challenges. (i) Development of a suitable inventory embracing data from different sources (data from public administration under study, but also data from territorial/regional agencies and from private organisations); (ii) Inclusion of legislative aspects and evaluation of legal compliance; (iii) Assessment of aspects not yet in Life Cycle Impact Assessment (LCIA) methods, e.g. the presence of underground tanks or asbestos in building

Benefits will be: better policies with clear environmental and social objectives.

Perspectives. Role LCA and LCT in the context of the SDGs: (i)Development of frameworks to embrace life cycle aspects; (ii) Provide a calculation method to evaluate quantifiable aspects; (iii) Setting a baseline to define improvement goals.

Topics for the research agenda of the working group or Italian LCA Network: (i) Development of a common Italian framework to embrace life cycle aspects for touristic destinations; (ii) Development of a common Italian framework for social aspects for touristic destinations.

3. Contribution from the Department Economics and Business, University of Catania, Italy[35]

Projects. The aim of this research is to analyze the environmental impact of the tourism industry through green marketing tools and techniques, applied into different hotels located in eastern Sicily, in order to allow strategies based on bio-economy. Some analyzes will be carried out in this regard: the applicability of the water footprint by the ISO 14046 standard, on inbound and outbound water monitoring; The implementation and therefore the certification of the Ecolabel label, an eco-label that aims to reward the best products and services from an environmental point of view, so as to inform the final consumer about the business's ecosystems. Lately, the tourism sector has spread and it offers different services such as transport, hospitality and entertainment. The instrument LCA, internationally standardized by the ISO 14040 and 14044 standards, is a technique that studies the environmental effects of all the stages of a service considering changes in the ecosystem, consumption of natural resources and the damage to human health. These instruments represent sustainable development techniques that enable the company to implement them to protect the environment and preserve ecosystems and biodiversity.

Further analysis will be conducted on the economic benefits that sustainable tourism and green marketing strategies can generate, so the impact of such tools on tourism demand will be studied.

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Lessons learned. The aim is to analyze how back up instruments for tourism, in our case the LCA, can become strategies of the application of the circular economy. The firm that we are studying is a hotel facility in the territory of Catania which had a lifelong experience on the sector.

Challenges and perspectives. The main advantage of this research in the field of international literature of the sector is to underline the social advantages exploitable from an economic perspective. Through the LCA tool, it is possible to highlight the inefficiencies of the various phases and to improve them from the environmental point of view by reducing consumption and emissions among other positive economic consequences.

4. Contribution from University "G. d'Annunzio", Pescara, Italy[36]

Projects. The group has recently started a new study on sustainability in tourism (Raggi et al., 2018). The first objective regards the integration of the concept of sustainability within online tourist reservation platforms and tour operators, one of the most common means of booking in tourism. The literature review performed, showed that this issue has not been adequately adressed. A detailed analysis of selected online booking platforms confirmed this statement, with few exceptions where "green" accommodation was either proposed or awarded. The second objective of the study was to identify life cycle-based indicators suitable for the selection of sustainable accommodation within the aforementioned websites. Once again, this has been poorly dealt with. The promotion of a life-cycle indicator emerged only via the proposal of a single indicator (e.g., Filimonau, 2011; Kalbar et al. 2017). The preliminary results confirmed that the concept of sustainability has been so far inadequately introduced in online booking platforms and there is still much to be discussed. >The future outcome of this research could be a basis for supporting tourists when selecting a more sustainable accommodation through online booking platforms, thus helping to reduce the overall environmental impact of tourism.

Lessons learned. Although most of sustainability challenges depend on human behaviour (Baddeley and Font, 2011), it is this behaviour that can be aided and/or guided when it comes to making the right choices, a "nudge" as described by the Nobel laureate Thaler (Thaler et al., 2014). Most users of the online booking platforms are used so as to make free choices regarding, for instance, price, location, luxury and so on, of their accommodation. It is this choice, e.g., selecting an environmentally friendly (throughout its life cycle) or so-called "green" hotel service, through the interface of an online booking platform that can make the difference towards a sustainable tourism.

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Challenges. The challenges for the definition of strategies for sustainability, from the perspective of the ongoing project, would include an effort by online booking platforms, towards more sustainable strategies. Indeed, the inclusion of the concept of sustainability would require the use of LCT tools (even simplified ones) for the single accommodation in order to identify its environmental and social performance to be displayed in terms of the identified indicators. Furthermore, another challenge would regard the level of interest and sensitivity of tourists towards the environmental performance characteristics of tourism services, especially of hotel accommodation. In other words, would they pay more or be willing to accept less attractive accommodation features in order to improve the environmental performance? Is sustainability an actual priority for tourists?

Perspectives. As soon as the various life-cycle indicators are identified and/or selected, the working group on Tourism could be requested to provide an assessment of the suitability of the indicators in tourism and in online booking platforms, in particular (expert judgements).

5. Contribution from the University of International Studies - UNINT, Rome, Italy[37]

Projects. The following is a short list of projects deemed relevant for the working group on tourist services:

- School of Advanced Studies, "G. d'Annunzio", Chieti, 2007-2010. The PhD project focusing on Life Cycle Thinking approaches and tools for sustainable transport and tourism involved (a) a review of LCAs in the tourism sector, (b) an LCA of hotel services, and (c) exploratory research on how to integrate Life Cycle Thinking into tools enabling to design, assess and improve the environmental performance of tourist products and to boost sustainable consumption through communication vehicles and integrated tools (De Camillis et al., 2010a; 2010b; 2010c; 2012). The PhD project was conducted in collaboration with the Centre for Sustainable Transport and Tourism, Breda University of Applied Science, NL.

- European Commission, Joint Research Centre, 2011-2012. In the context of a project supported by Eurostat, it was developed a life cycle assessment framework enabling to assess and monitor resource use and potential environmental impact from tourism and all other sectors (Lundie et al. 2012).

- UN Environment, 2016-2017. In the context of the Life Cycle Initiative, in collaboration with UNESCO chairmanship in Life Cycle and Climate Change,

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consensus was built on Recommended Key Environmental Indicators for The Tourism Private Sector (Shurland et al., 2017). The project involved an expert workshop, a consultation meeting and a public review. The technical report informed the UNFCCC COP22 and the International Year of Sustainable Tourism

- FAO, 2014-present. In the context of the Livestock Environmental Assessment and Performance (LEAP) Partnership, consensus building is on-going for understanding, assessing and improving the environmental performance of livestock supply chains (De Camillis, 2016). Nearly 450 experts have been contributing to guideline development on GHG emissions from feed and livestock supply chains, and on biodiversity, water use, nitrogen and phosphorus cycle modelling, soil carbon stock changes, and feed additives.

- UNINT, 2015-present. While teaching Food Quality Management, food and catering are presented as a major component of holiday packages. Sustainable sourcing of foods and drinks through LCA is part of tour operators' and hotel chains' strategy for business sustainable management. Last, food is presented as core component of agri-tourism and eno-tourism.

Lessons learned. - Tourism is a continuously growing sector. GHG emissions land use impact on biodiversity and ecosystem services, water use and waste production are major environmental aspects for the tourism sector. While land use impacts on landscape, biodiversity and ecosystem services can be addressed through policies on land use planning and environmental management, while policies for water allocation and infrastructure development are able to address water scarcity issues, the sector growth and viability is indeed threatened by its tremendous carbon footprint. Depending on the reference study comparing the potential environmental impacts from all sectors a policy maker might pick up, tourism can be found or not as one of the sectors having the highest contribution to global warming. Indeed, the vast majority of these studies rely on GWP100, which is one of the indicators recommended by IPCC. However, IPCC and other authoritative bodies such as the Life Cycle Initiative also suggest usage of GTP500. CH4, a short-lived GHG, is a major contributor to global warming according to GWP100, while it is far less prominent its contribution if GTP500 is picked up. Depending on the indicator chosen by the practitioner, assessment results change drastically. Policy focus and research efforts can be easily diverted from a sector to another, accordingly.

While mitigating GHG emissions from agriculture is acknowledged as a measure to tangibly advance the climate agenda in the short run, focusing research and policy efforts in cutting down GHG emissions from tourism is likely to result as an effective action also in the long run.

- The choice of impact assessment method indicator is just one choice out of many made by an LCA practitioners. Also other methodological choices drastically affect LCA results. Harmonization of environmental assessment methods is necessary to make informed choices, prevent green washing and help sectors to focus on environmental improvement.

- The interpretation of LCIA results is fundamental to support policy making and policy monitoring. An in-depth knowledge of LCIA methods is a pre-requisite for interpretation and before any conclusion is drawn. Similarly, to figure out the potential of a given environmental improvement proposal to be adopted by users, socio-economic implications should be always assessed.

- As the sector growth is mainly constrained by its contribution to global warming, research efforts should be primarily intensified on solutions for carbon neutral or low carbon air transport. LCA-based tools supporting eco-design and environmental management of hotels, resorts and other tourist facilities can support mitigation of GHG emissions from tourism.

- A wide array of tourist products exist. However, very few LCAs have been conducted in the sector. This impedes identification of hot spots and best practices.

- Accommodations and many other tourist products can be assessed through LCA either focusing on the product system of the buildings providing tourist services or on the life cycle of the tourist experience.

- While consequential assessments are becoming prominent in the LCA community, policy makers often rely on ex-ante attributional assessments and consultations. Consequential modelling in LCA was found by ISO advisory as an interesting research topic, which is at current stage of conceptualization unsuited for broad application for policy making. While importance of grasping effects tied to knock-on effects is acknowledged by all stakeholders, assessments of policy implications are often conducted through dialogue with stakeholders.

- Water availability, soil degradation, habitats of wild species and biodiversity corridors, species richness and diversity, pests presence and spreading, soil quality and nutrients loss are all major elements for environmental management in agriculture. The abovementioned are all dependant on local conditions and pose a challenge for comparing the environmental performance of agricultural products belonging to the same category, but produced by different farms. Should environmental performance be integrated into market mechanisms, favourable environmental local conditions will result in competitive advantages.

- If used in combination with GIS, LCA has much potential to be used in support of land use planning and, hence, to drive industrial, rural and tourism development following an integrated landscape approach.

- LCA is acknowledged by platforms such as LEAP and Life Cycle Initiative as a tool in support of decision making. In order to drive continuous environmental improvement of food systems – food is a major input for the tourism sector –

more research efforts are necessary both at the inventory and impact assessment level.

Challenges. In order to disseminate best practices in environmental management of tourist services, more LCAs are necessary to identify hot spots and potential measures to improve the environmental performance of tourist products. Only if knowledge produced by LCA is translated into action, the tourism sector can advance towards achievement of relevant SDGs. In order to make findings from LCAs usable by tour operators, hotel chains, accommodations, shops, museums and so forth, environmental improvement and adoption of best practices should always be translated into business opportunities, revenues or at least savings. Boosting sectorial sustainable development through dissemination of best practices requires not only additional research, but also proactive engagement in policy dialogue as stakeholder and setting up an enabling environment for capacity building and best practice dissemination at global level.

Perspectives. To reconcile sector growth with its environmental sustainability, research could seek for solutions enabling to drastically lower the carbon footprint of passenger transport. For example, LCA could focus on comparing latest concepts for biofuels whose production does not exacerbate competition for land with those sectors securing food, housing and other products. Research could also focus in conducting LCAs instrumental to identify hot spots and best practices for each tourist product identified by UN Environment in the technical report on Recommended Key Environmental Indicators for The Tourism Private Sector. Some of the research gaps to fill in order to enhance usage of LCA for policy dialogue on tourist products and all bio-economy sectors are the following: 1) land occupation and land use efficiency, 2) ecosystem services, 3) variability of herds and crops in a given timeframe, 4) eco-toxicity and soil quality, 5) assessment of policy options, 6) desertification and soil quality.

In order to upscale the usage of LCA in support of SDGs, environmental policies and a multi-stakeholder governance are necessary to ensure uptake of best practices and make the policy implementation an opportunity for economic growth and conservation of nature.

In order to increase its impact on the SDGs, the Italian Network on LCA could consider setting up: (a) ad hoc working groups to address the abovementioned methodology shortcomings, and (b) a task force in charge of setting up a strategy to position the Italian Network on LCA in the context of national governance mechanisms instrumental to the Paris Agreement and SDGs.

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Life Cycle Assessment for the evaluation of the organic waste management: a literature review

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Abstract

In the Italian urban waste management, the organic fraction is the most relevant among all the separately collected materials with 107 kg per inhabitant in the year 2016. This waste fraction can be subjected to various management alternatives. The most important differences are related to the typology of treatment (aerobic composting or anaerobic digestion). Also the disposal in landfill and incineration are possible destinations of organic waste if not separately collected. These management alternatives lead to important differences from the environmental point of view, which can be evaluated by applying the Life Cycle Assessment (LCA) methodology. In this paper, a review of recent publications related to the LCA of organic waste management systems is performed in order to evaluate their main features and differences.

1. Introduction

According to the European Waste Framework Directive 2008/98/EC, bio-waste or organic fraction includes biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers, retail premises, and comparable waste from food processing plants (EU, 2008). Bio-waste is generally the largest fraction of municipal solid waste (MSW) with an average 37% share in the EU-27 countries (excluding Cyprus and including Norway and Switzerland) (EEA, 2013), ranging from 29% to 48% in the EU-15 (Karak et al., 2012). When a separate collection is performed, bio-waste can be subjected to:

- anaerobic digestion, i.e. a degradation in absence of oxygen in which waste is converted into biogas (source of energy) and digestate (possibly subjected to post-composting), which can be used as a soil improver in agriculture;
- composting, i.e. an aerobic degradation with the production of compost, which can be used as a soil improver.

Approximately 30 million tonnes of bio-waste are composted or digested yearly in about 3,500 treatment plants across Europe (Siebert, 2016). Despite the increasing amount of dedicated plants, 14 out of the EU-28 countries treat less that 10% of MSW (that means less than one third of the organic fraction) in composting or anaerobic digestion plants (ISPRA, 2017). Moreover, also where developed waste management systems and separate collections have been in place for many years, a high proportion of bio-waste (60-70 kg/inhabitant/year) remains within the residual waste stream (Siebert, 2016). This assertion is confirmed by waste composition analyses in northern Italy (where about 65% of waste is separately collected) in which 10-20% by weight of residual waste is classified as food waste (Tua et al., 2017). When organic waste is collected together with other fractions, it is usually subjected to the following treatments:

- mechanical biological treatments (MBT), i.e. a variety of mechanical separation systems and biological treatments applied to residual waste;
- landfilling;
- incineration.

Focusing on the legislative context, the European Waste Framework Directive (EU, 2008) indicates that Member States shall take measures to encourage the separate collection of bio-waste with a view to its composting and digestion and its treatment in a way that fulfils a high level of environmental protection. Moreover, the following waste hierarchy is stated: prevention, preparing for reuse, recycling, other recovery, disposal. However, Member States shall take measures to encourage the options with the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by Life Cycle Thinking on the overall impacts of the generation and management of such waste (EU, 2008). Accordingly, the ISO standardized Life Cycle Assessment (LCA) methodology (ISO 2006, a, b) can be performed for the assessment and the comparison of the environmental benefits and trade-offs of the different waste treatment options.

2. Literature review

The objective of this work is to review previous LCA studies related to bio-waste management that:

- assess food or organic waste management excluding other MSW fractions;
- compare two or more management alternatives;
- were published after the year 2010.

All the examined studies, characterized by these features, were selected according to the keywords organic waste / food waste management + LCA.

Accordingly, the following eight papers are reviewed: Padeyanda et al. (2016) [1]; Ahamed et al. (2016) [2]; Jensen et al. (2016) [3]; Buratti et al. (2015) [4]; Evangelisti et al. (2014) [5]; Kong et al. (2012) [6]; Colón et al. (2012) [7]; Bernstad and la Cour Jansen (2011) [8]. Table 1 reports the main features of these studies. They analyze and compare the treatment technologies described in Section 1 and, in addition, two studies evaluate the production of animal feed and biofuel from food waste. Five studies are related to the European geographical context while three are focused on extra European situations.

As regard the typology of assessed waste, [1, 2] evaluate the management of food waste while in all the remaining studies the organic fraction of municipal solid waste (OFMSW) is considered, i.e. the household bio-waste. This fraction is mainly composed by food waste but also includes yard trimmings and others minor components (only [3, 6, 8] report the considered waste composition).

2.1. Functional unit

As shown in Table 1, the functional unit is 1 tonne of waste in all the studies excluding [5] that considers the yearly amount produced in the examined area and [8] in which the yearly per capita amount is assumed. In addition, one study [7] introduces a functional unit able to include the real performance of each biological treatment based on the achieved level of organic matter stabilization[38].

Table 1: main features of the reviewed studies: technologies, geographical context, functional unit, stages included into the system boundary, characterization method, and impact categories.

*<u>System boundary</u>: C: collection; T: transportation; TR: treatment; UWDM: use of waste-derived materials. * Only for some waste-derived materials (see Section 2.2).*

<u>Impact categories</u>: CC: climate change; AC: acidification; EU: eutrophication (T: terrestrial, F: freshwater, M: marine, A: aquatic); PO: photochemical oxidation; CED: Cumulative Energy Demand; OD: ozone depletion; IR: ionising radiation; HT: human toxicity (C: cancer effects, NC: non-cancer effects); ET: ecotoxicity (F: freshwater, A: aquatic, T: terrestrial); PM: particulate matter; RES: resource depletion (mineral and fossil); AA: aquatic acidification; RI: respiratory inorganics; TA: terrestrial acidification/nutrification; LO: land occupation; NRE: non-renewable energy; ME: mineral extraction; NE: nutrient enrichment; AD: abiotic depletion

#	Technologies	Geograp. context	Functional Unit	System boundary	Characteriz. method	Impact categories
1	• Composting • Animal feed production (4 scenarios)	Korea	1 tonne of food waste	• C • T • TR • UWDM*	CML 2002 (Guinée et al., 2002)	• CC • EU • AC • PO
2	• Incineration • Anaerobic digestion • Biofuel production	Singapore	1 tonne of food waste	• C • T • TR • UWDM*	• CML 2 baseline 2000 • CED (Frischknecht et al., 2007)	• CC • EU • AC • CED
3	• Incineration • Anaerobic digestion / MBT / incineration	Denmark/ Germany	1 tonne of organic household waste	• C • T • TR • UWDM	ILCD (EC-JRC, 2011)	• CC • AC • OD • HT (C,NC) • IR • ET (F) • PO • PM • EU (T,F,M) • RES
4	• Composting • Mechanical biological treatment + landfill	Italy	1 tonne of organic fraction	• C • T • TR • UWDM	IMPACT 2002+ (midpoint + endpoint) (Jolliet et al., 2003)	• CC • AA • OD • RI • IR • PO • EU (A) • TA • HT (C,NC) • LO • NRE • ET (A,T) • ME
5	• Landfill • Incineration • Anaerobic digestion	UK	35,574 tonnes of OFMSW	• T • TR • UWDM	• CML • EDIP 97 (NE) (Wenzel et al., 1997)	• CC • PO • AC • NE
6	• Landfill • Composting (2 scenarios) • Anaerobic digestion	USA	1 tonne of wet organic matter	• C • T • TR • UWDM	Intergovern-mental Panel on Climate Change model (IPCC, 2007)	• CC

[38] It is calculated as the reduction of the Dynamic Respiration Index (DRI) between input and output materials. DRI is expressed as mgO_2 consumed / $g_{organic\ matter}$ / hour (Colón et al., 2012).

#	Technologies	Geograp. context	Functional Unit	System boundary	Characteriz. method	Impact categories
7	• Composting (4 scenarios) • Anaerobic digestion	Spain	• 1 tonne of OFMSW • 1 DRI unit reduction in 1 t of OFMSW	• TR • UWDM*	CML 2001	• CC • AC • PO • EU • HT • AD • OD
8	• Composting • Incineration • Anaerobic digestion	Sweden	24.9 kg of organic waste/ person/year	• C • T • TR • UWDM	characteriz. factors from Lindahl et al. (2001)	• CC • AC • NE • OD • PO

2.2. Analyzed system

In this section, the main aspects and stages included in the system boundary of the examined studies are evaluated.

Input material: five out of the eight studies [1, 2, 3, 5, 8] indicate the assumed organic waste elemental composition and characteristics. This aspect is relevant because the carbon content influence many factors with impact on greenhouse gases emissions (Bernstad and la Cour Jansen, 2012). Also the nutrients content is relevant when the use of compost and the substitution of chemical fertilizers are evaluated.

Collection: this stage is included in the system boundary of all the studies excluding [5] where it is not considered because identical in the three analyzed scenarios and [7] that is focused on the waste treatment processes.

Pre-treatment: energy consumption for pre-treatments is generally considered. On the contrary, in some studies the residues generation during this stage and above all the subsequent management of these scraps are not assessed: only in [1, 4, 8] these aspects are described in detail.

Treatment: this stage is related to the bio-waste treatment processes. In addition to materials and energy consumptions and emissions, the main inputs and outputs are landfill gas / energy / biogas and digestate / compost / animal feed / biodiesel respectively for landfill, incineration, anaerobic digestion, composting, feed production, and biofuel production plants. All these aspects are generally considered in the examined studies although the accuracy in their estimation and description varies largely. [2] gives few details about the considered emissions; on the contrary, in [3, 4, 5, 7, 8] a detailed description of input and output data is provided.

Use of the waste-derived material: most of the studies considers the use of the waste treatment products (Table 2) even if there are some exceptions: [1] where the use of compost and animal feed is considered only for the climate change impact category in addition to the baseline scenarios, [2] where the digestate is assumed to be treated in a wastewater treatment plant, and [7] where the use of compost and digestate is excluded. When the use of biogas, compost, and digestate is considered, the emissions from their use vary largely. In particular, focusing on the carbon sequestration[39], according to Bernstad and

[39] A fraction of the carbon content in waste is bound in soil for longer periods. This can be seen as a sink of CO_2, credited as an avoided emission.

la Cour Jansen (2012) there is no consensus whether a carbon sink approach should be used or not and therefore the assumptions vary: in [4, 5, 8] the carbon sequestration for the use of compost and digestate is not considered or is evaluated with a sensitivity analysis (see Section 2.5); on the contrary, in [3, 6] it is taken into account.

Compensatory system: in all the studies where the use of the waste treatment products is considered, the substitution by system expansion is performed avoiding the alternative production of electricity, heat, fuel (for incineration, biogas, and landfill gas use), chemical fertilizers, soil improver (for compost and digestate), and animal feed. Both the substitution ratio and the environmental impacts of the substituted product or energy vary largely and are not always clearly defined. More details are reported in Table 2.

Table 2: use of the waste-derived materials and compensatory system in the reviewed studies.

#	Waste-derived product or energy considered	Data considered for the substitution by system expansion
1	• compost • animal feed	not defined
2	• electricity from incineration / biogas / biodiesel	performed in terms of equivalent calorific value and emissions
3	• electricity and heat from incineration / biogas • compost	marginal data
4	• electricity from landfill gas • compost	average data
5	• electricity from landfill gas • electricity and heat from incineration / biogas • digestate	average data (marginal in sensitivity analysis)
6	• energy from landfill gas / biogas • compost	typology of substituted energy not defined (substitution by system expansion not performed for compost)
7	electricity from biogas	typology of substituted electricity not defined
8	• electricity and heat from incineration • heat and fuel for vehicles from biogas • electricity and heat from biogas • digestate / compost	average data (marginal in sensitivity analysis)

2.3. Input data

Data sources and their quality are very different among the studies. The use of primary data is relevant in [3, 4, 7, 8] while [5, 6] are mostly performed with data from literature or database. Only in [3] the data quality is quantitatively assessed with the method developed by Weidema and Wesnæs (1996).

2.4. Impact Assessment

Table 1 reports the characterization methods considered in the reviewed studies and the corresponding assessed impact categories. In one situation [6] only the climate change is evaluated while only two studies [3, 4] consider a wide selection of impact categories in the attempt to cover all the potentially relevant environmental issues. In the calculation of results, five studies [1, 2, 3, 4, 8] apply the normalization step. Figure 1 shows the potential impacts of the baseline scenarios (see Table 1) analyzed in the eight reviewed studies for the climate change impact category. A similar comparison was performed by Bernstad and la Cour Jansen (2012) in a review of 25 comparative LCAs of food management systems published between the years 2000 and 2010. Both Figure 1 and the comparison provided by Bernstad and la Cour Jansen (2012) clearly show that the difference between the studies is large. In Bernstad and la Cour Jansen (2012), the reason was found to be mainly related to differences in system boundary settings, methodological choices, and in used input data more than to actual differences among the systems. As detailed in Sections 2.1, 2.2, and 2.3, these differences can be also recognized in the examined studies.

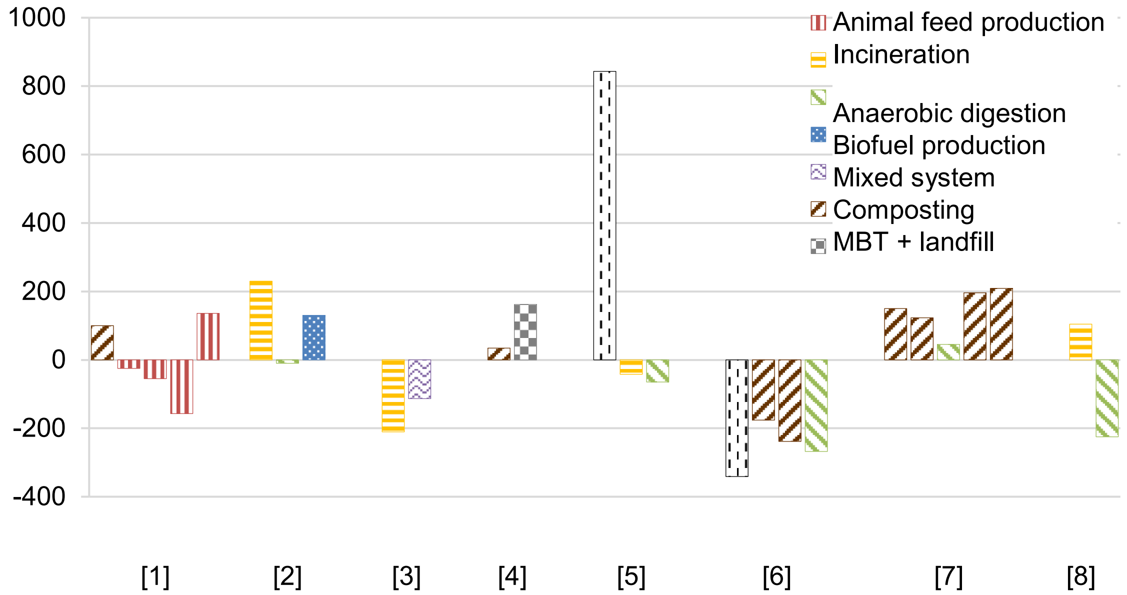

Figure 1: potential impacts of the baseline scenarios (see Table 1) analyzed in the reviewed studies for the climate change impact category[40] (kg CO_2 eq/tonne). For [1] the figure reports the results when the use of the waste-derived products and their substitution is considered

2.5. Sensitivity analysis

In the review of comparative LCAs performed by Bernstad and la Cour Jansen (2012), the most commonly assessed assumption through sensitivity analyses was related to the eco-profile of substituted energy when the treatment process resulted in a net energy production. This aspect showed an important influence on the overall results, principally in relation to the climate change.

In most of the reviewed studies, in addition to baseline scenarios, a sensitivity analysis was performed. The evaluated assumptions are:

- Input material: food waste oil content [2];
- Pre-treatments, treatments, and use of the waste-derived materials:
  - electricity consumptions [1];

[40] All the studies consider the baseline 100-years model of the IPCC with the exception of [4] where a 500-year time horizon is considered. Characterization factors derive from IPCC (2007) for [3, 6], IPCC (2001) for [2], and are not indicated in [1, 4, 5, 7, 8].

- screening waste amount [1];
- landfill gas collection efficiency [4, 6];
- fugitive emissions of methane from the anaerobic digestion plant [5, 8];
- transportation distances [6];
- origin of electricity used in the composting process [8];
- air emissions from the composting process [8];
- energy efficiency in incineration [3] and anaerobic digestion [3, 5] plants;
- emissions from compost [8] and digestate use [5, 8];
- carbon sequestration from the use of compost [4] / digestate [5] / landfilled waste [4];

- Compensatory systems:
  - technology for the substituted electricity / heat in relation to the energy production from incineration [3, 5, 8] and anaerobic digestion plants [3, 8];
  - energy efficiency in the substituted facility [3];
  - substitution ratio of nitrogen from compost and digestate compared to chemical fertilizers [8];
  - production technology of fertilizers substituted by compost and digestate [8].

3. Conclusions

This paper reviewed eight LCA studies, published after the year 2010, in which different bio-waste treatment processes are analyzed and compared. The analysis showed numerous differences in system boundary settings, methodological choices, used input data, and consequently in the results leading to a not well defined hierarchy between alternative treatments.

The studies focused their attention mainly on treatments but there are other aspects that can have an influence on the environmental performances of the organic waste management system. For example, focusing on the separate collection, it can be performed by means of bioplastic bags (typical Italian situation) or paper bags. This leads to differences not only in the collection stage but also in the waste management. As indicated in Bernstad and la Cour Jansen (2012), previous studies showed important weight reduction in food waste collected in paper bags, mainly due to the evaporation of water. On the contrary, with bioplastic bags losses are generally lower. Such differences have consequences not only on the amount of waste sent to treatment plants but also on the concentration of carbon, nutrients, and pollutants in the collected waste. Moreover, the collection bag can have an important influence on the subsequent waste treatment. Considering bioplastic bags, they are generally discarded by anaerobic digestion plants during pre-treatments, dragging by them part of the organic waste and leading to non negligible amounts of residues while this aspect may be quite different when using paper bags.

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Use of LCA to support symbiosis paths for the valorisation of agrifood residues

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Abstract

After the milling process, wheat bran's oil content can be higher than 5% if the germ is not completely removed. Therefore, a de-oiling process would contribute to the valorization of waste in a circular economy approach. A Life Cycle Assessment study according to ISO 14040 (2006) was performed to compare the environmental impacts of two technologies for bran's oil extraction: supercritical fluid (SFE) extraction techonology and solvent technology. Primary data were used for the SFE technology, whereas literature data were used for the solvent technology. Despite having several environmental advantages, results show that the environmental impacts of SFE techonology are higher than those of solvent technology for a percentage ranging from 61% to 95%, mainly due to higher electricity consumption. Improvement options for the SFE technology could be the efficiency optimisation, the use of renewable electricity and the recovery of heat produced.

1. Introduction

Every year, over 650 million tons of wheat are produced in the world, 69% of which for food purposes (Pruckler et al., 2014). After the milling process, bran is about 25% of the milled wheat weight (150 million tons), which is mainly used in the feed industry (Pruckler et al., 2014; Neves et al., 2006). However, in the last decade, it has also been used for human nutrition because it is rich in dietary fiber and bioactive compounds. Since bran's oil content can be higher than 5% if the germ is not completely removed (Apprich et al., 2014), a de-oiling process would contribute to the valorization of waste in a circular economy approach, with the aim to increase the overall environmental sustainability of wheat supply chain.

Food-Crossing District project, coordinated by CIRI AGRO (Interdepartmental Centre of Industrial Agrifood Research of the University of Bologna) and funded by the POR FESR 2014-2020 of the Emilia-Romagna Region, has been developed in this context. The project aims at developing and promoting circular economy by means of the valorization of two by-products from tomato and wheat processing. As regards wheat supply chain, the objective is to define, analyse and evaluate both the industrial scale up and profitability of bran valorisation to obtain the following products: 1) defatted and roasted bran which can be used as feed in the livestock sector or as litter for pets; 2) wheat germ oil for cosmetic products. Supercritical fluid extraction (SFE) technology has been evaluated for the wheat germ oil extraction in comparison with the solvent extraction technology used for the production of vegetable oils. Supercritical extraction is already widely used for matrices of different origins. The efficiency of oil extraction (80-93%), which is generally comparable to that obtained by solvent extraction (Kuk and Dowd, 1998; Sparks et al., 2006), depends mainly on the chemical-physical characteristics of the milled material (size and water content) and process variables (pressure, temperature, extraction time) (Durante et al., 2012; Panfili et al., 2003). The use of CO_2 eliminates the risks associated with the use of organic solvents (toxicity, flammability, etc.) and does not leave any residue in the extracted products. Further advantages are the wide availability, at low costs, and the possibility of recycling it, minimizing its consumption. In addition, SFE technology, differently from solvent extraction, preserves the polyunsaturated fatty acids and bioactive compounds contained in the extracted oil from oxidation (Krings et al., 2001), thanks to the chemical inertia of CO_2. The environmental sustainability assessment of these technologies to valorize the wheat bran has been performed within the project by applying the Life Cycle Assessment (LCA) methodology according to the ISO 14040/44 (2006a,b).

2. Life cycle assessment - case study

2.1. Goal and scope

The goal of the LCA study is to compare the environmental performance of bran de-oiling using SFE technology (innovative technology) and solvent extraction technology (conventional technology), both at industrial level.

The function of the system is the de-oiling of wheat bran, produced during the processing and milling of wheat, to obtain wheat germ oil and defatted bran. The functional unit is the treatment of 500 kg of wheat bran, to obtain 22.5 kg of wheat germ oil and 477.5 kg of defatted bran (yield of 4.5% in wheat germ and 94.5% in defatted bran). The reference flow is 500 kg of treated bran. An attributional approach was applied according to the goal of the study (EC JRC, 2011).

System boundaries in both cases are “from gate to gate” assuming that bran is processed fresh (i.e. just produced) in situ, thereby not requiring storage, packaging or transport. The extraction phase with SFE technology includes energy consumption for oil extraction, the production of defatted bran, the production of liquid CO_2 and the airborne emissions from plant’s CO_2 losses. Solvent extraction technology includes energy consumption for oil extraction and defatted bran production, water consumption, solvent production and airborne emissions due to solvent losses.

In accordance with ISO 14044 (2006b), in case of multifunctional processes, such as the studied system, in which wheat germ oil and defatted bran are produced, allocation procedures were avoided expanding the system boundaries, thus including the additional functions related to the co-products. As regards the SFE technology, primary data supplied by the SFE plant were used referring to 2017. The bran’s oil content (4.5%) was experimentally determined (Cardenia et al., 2017). As regards the solvent extraction technology at industrial level, data on the extraction of soybean oil for food purposes contained in the Fediol report (European Vegetable Oil and Proteinmeal Industry) (Schneider and Finkbeiner, 2013) were elaborated, considering them as representative for an average European seed oil extraction technology and recalculating them for an oil yield of 4.5%.

Ecoinvent 3.3 database was used for background data (Ecoinvent Center, 2007). The medium voltage Italian electricity mix for 2012 was used for electricity consumption.

The following assumptions were used in the study:

- SFE and solvent extraction systems were assumed to be able to extract 100% of the bran's oil. According to the data provided by the SFE plant technicians, no waste is produced, therefore the yield in defatted bran was assumed to be 95.5%;
- The defatted bran yield was assumed to be equal to 95.5% for the industrial solvent extraction plant as well;
- According to data from the technicians of the SFE plant, CO_2 losses per working cycle with the SFE technology are 3% of the extractor volume.

The refining of wheat germ oil was not considered since it is not necessary for cosmetic applications. Midpoint methods recommended by ILCD were used for the impact assessment phase (EC JRC, 2012).

2.2. Inventory

As regards SFE extraction at industrial level, data on energy consumption (methane and electricity) and liquid CO_2 from the de-oiling of 5,500 kg of bran with a volume extractor of 22,000 liters were used, which were linearly scaled with respect to data from a pilot plant processing 500 kg of bran (Table 1). The liquid CO_2 is completely recirculated within the plant; according to the data from the SFE technicians, CO_2 losses per working cycle were estimated to be 3% of the extractor volume, with a liquid CO_2 density of 0.1 kg/l. These losses were accounted for as airborne emissions. The consumption of both methane for the heater and electricity for the pump and the chiller were calculated on the basis of machinery power and the processing time per cycle (Table 1).

As regards industrial solvent extraction (with hexane), data on energy and materials consumption referring to the extraction of soybean oil contained in Schneider and Finkbeiner (2013) were used, referring only to the crushing phase only (solvent extraction) and considering an oil content of 4.5% (Table 1). The hexane losses (equal to 0.58 g/kg of bran) were accounted for as airborne emissions.

Table 1: Consumption of electricity, methane and steam for the analysed extraction plants

Consumption	Unit of measurement	SFE	Solvent extraction
Electricity	kWh/kg bran	1.0E+00	2.9E-02
	kWh/kg wheat germ oil	22.7E+00	6.5E-01
Methane	kWh/kg bran	2.6E+00	-
Steam	kg/kg bran	-	2.5E-01

3 Results and discussion

Table 2 shows the characterization results of the comparison between the SFE technology scenario and the solvent extraction technology scenario.

Figure 1 displays the percentage contributions of the different phases of the life cycle of bran de-oiling by SFE technology, for each impact category. The electricity consumption for the SFE plant operation is the main hotspot: its contribution varies from 56% for Ozone depletion to 87% for Freshwater Eutrophication. The contribution of heat production ranges from 11% to 44%, whereas the production of liquid CO_2 contributes for 15% in Mineral, fossil and renewable resource depletion. The percentage contribution of CO_2 losses to Climate Change is not remarkable.

Figure 2 shows the percentage contributions of the different phases of the lifecycle of bran de-oiling by solvent technology, for each impact category. Results highlight that the main hotspot is the steam production, with a contribution higher than 48% for all impact categories, with the exception of Photochemical Ozone formation, in which the most significant environmental impacts are due to hexane airborne emissions from plant losses. The contribution of electricity varies from 5% to 43% in all impact categories. The contribution of hexane production is 11% in Mineral, fossil and renewable resource depletion and is negligible in the other categories.

The comparison between the environmental impacts of the bran de-oiling with SFE and solvent technologies (Figure 3), reveals that in the former case they decrease from 61% (Photochemical Ozone Formation) to 95% (Mineral, fossil and renewable resource depletion). In all impact categories, this is mainly due to the lower electricity consumption of solvent technology (Table 1).

Table 2: Characterisation results of the life cycle of bran de-oiling process (FU: 500 kg of bran): comparison between SFE technology and solvent technology

Impact category	Unit of measurement	SFE	Solvent extraction
Climate change	kg CO2 eq	4.48E+02	3.21E+01
Ozone depletion	kg CFC-11 eq	5.59E-05	3.42E-06
Particulate matter	kg PM2.5 eq	1.23E-01	1.61E-02
Photochemical ozone formation	kg NMVOC eq	7.65E-01	2.98E-01
Acidification	molc H+ eq	1.70E+00	1.54E-01
Terrestrial eutrophication	molc N eq	2.43E+00	1.76E-01
Freshwater eutrophication	kg P eq	7.88E-02	4.61E-03
Marine eutrophication	kg N eq	2.34E-01	1.67E-02
Mineral, fossil & ren resource depletion	kg Sb eq	1.83E-03	9.46E-05

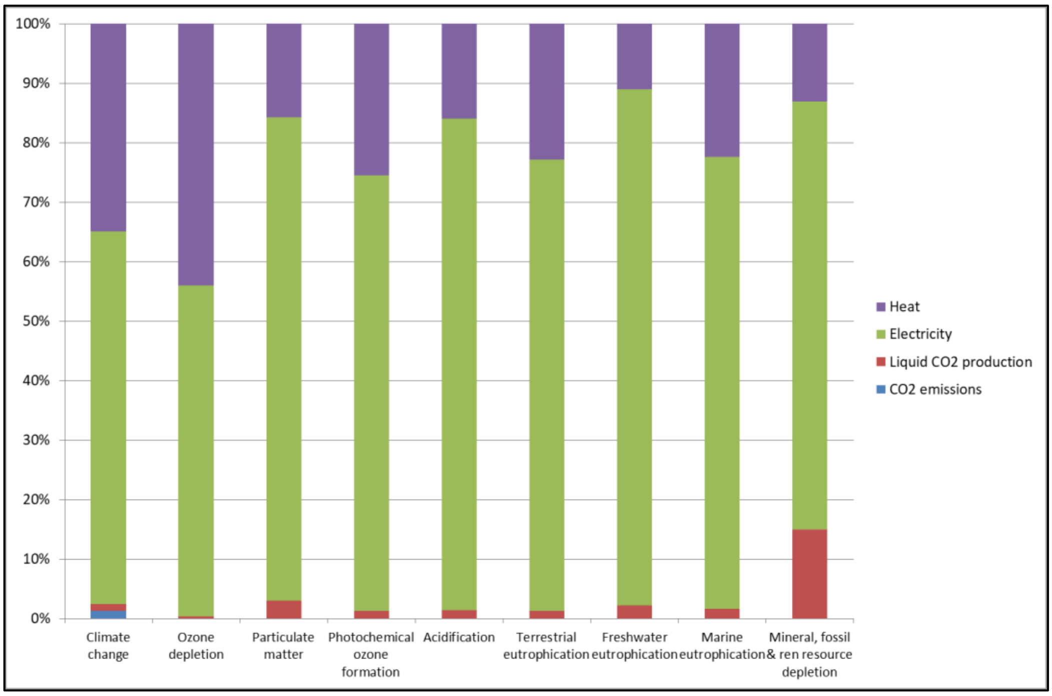

Figure 1: Percentage contribution to each impact category of the different life cycle phases of bran de-oiling with SFE technology (FU: 500 kg of bran)

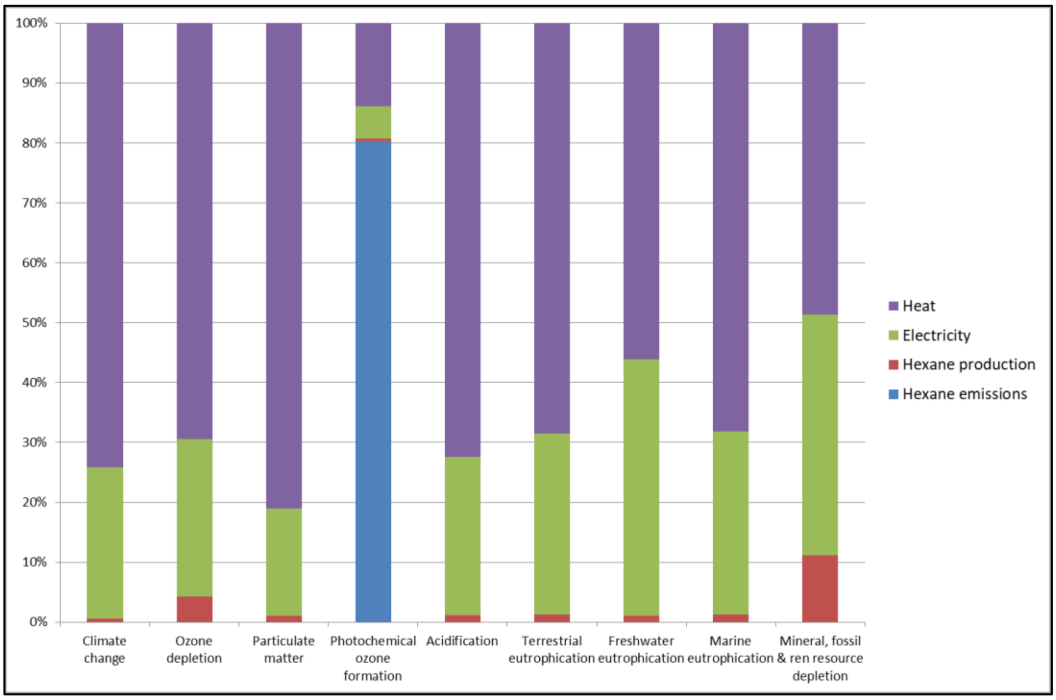

Figure 2: Percentage contribution to each impact category of the different life cycle phases of bran de-oiling with solvent technology (FU: 500 kg of bran)

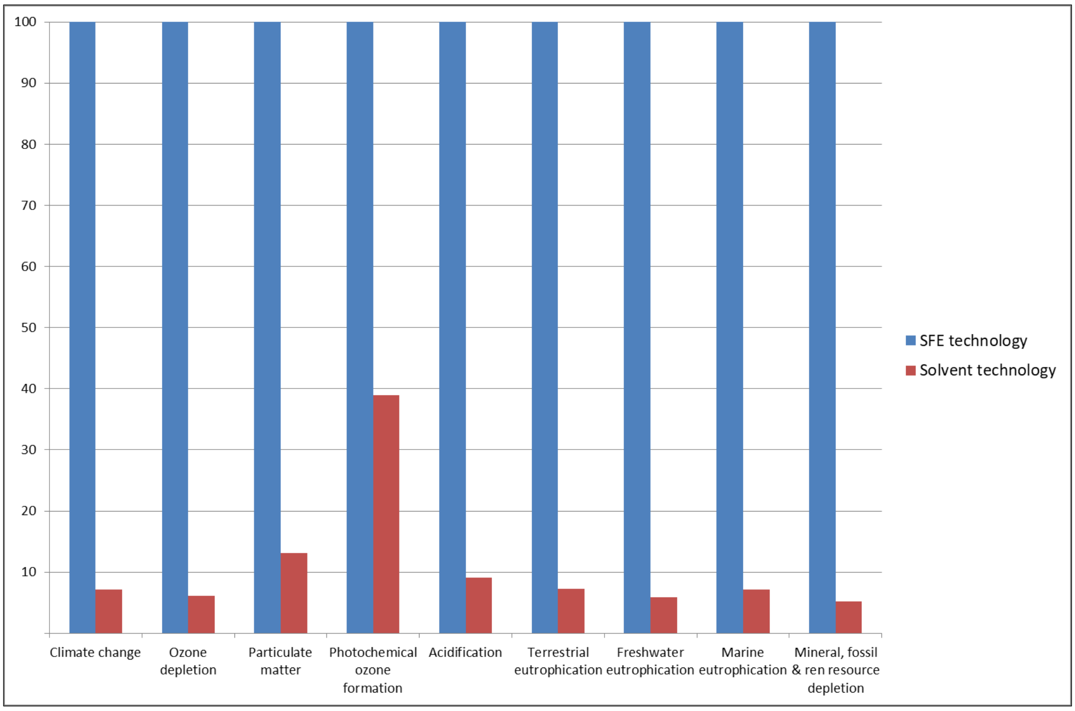

Figure 3: Characterisation results of the life cycle of bran de-oiling (FU: 500 kg of bran): comparison between SFE technology and solvent technology

4 Conclusions

The comparison between the bran de-oiling by SFE technology and by solvent extraction technology highlighted that the environmental impacts of solvent technology are much lower than those of SFE technology for a percentage ranging from 61% to 95%, mainly due to the lower electricity consumption. However, SFE technology has some environmental advantages, such as the absence of organic solvents, and the risks associated with their use, the lack of residues in the extracted products, the possibility of CO_2 recycling thereby minimizing its consumption. Therefore, in order to reduce the environmental impacts of the supercritical extraction technology, the efficiency of the extraction technology must be increased, optimizing the process from the energy consumption point of view, and using electricity production systems with a better environmental performance, such as electricity from renewable sources. Furthermore, the design of a system for the recovery of heat produced by the chiller, to be used in the water pre-heating for steam production, could decrease the system's methane requirements.

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Preliminary LCA study of Cobalt-based fibrous anode material for Lithium Ion Batteries

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Abstract

In this study the Life Cycle Assessment methodology is utilized in order to analyse the environmental burdens (from raw material extraction to manufacturing process) of nanofibrous materials employed as active materials in electrodes for Lithium ion batteries (LIBs).
In order to assess the associated environmental impacts, simplified comparative LCA studies are conducted for two electrodes, at the same cell performance, by defining inputs and outputs of the system and evaluating the associated impact categories.

1 Introduction

LIBs have made significant progress in the last decade and are now a mature and reliable technology with still significant improvement potential (Van Noorden, 2014). For mobile applications, they are already the dominating technology and their share in stationary energy systems is steadily increasing (U.S. Department of Energy; 2016).

An improvement of energy efficiency and a rational use of energy of LIBs can be achieved through the sustainable development of innovative electrode materials. Low environmental impact, long life, high energy density, great charge rate, large number of charge/discharge cycles and safety are the main requirements of the considered materials (Andreopoulou, 2012).

Recently, nanostructured metal oxides MO_x (M=Cu, Fe, Co) have been studied as anode materials for LIBs owing to their high energy capacity (Zhang Q et al., 2013; Zhang M. et al., 2013, Zhu et al., 2015, Jung e al., 2016, Mei et al., 2015).

Our research group using a non-conventional technique as electrospinning has produced cobalt-based fibrous anode materials for LIBs. In particular, self-standing and flexible paper-like electrodes consisting of nano-sized Co_3O_4-based fibrous membranes to be used as active anode materials in electrode for flexible LIBs are produced by electrospinning using graphene oxide as additive (Pantò et al., 2016).

Due to the environmental challenges to produce more sustainable materials it is mandatory to conduct a comprehensive environmental assessment of new anode active materials for LIBs, considering that the addition of graphene oxide in face of a modest increment of the of electrodes performance could cause significant environmental impacts (Pantò et al., 2016).

In fact, from an environmental point of view, graphene has potential advantages: i) replacing rare metals could alleviate resource scarcity problems, ii) improving the feasibility and competitiveness of novel energy technologies could reduce the overall environmental impact of human activities. However, this material could also have negative environmental impacts (Arvidsson et al.,2014)

There are several LCA studies on LIBs and principally those works comparing them with other a kind of batteries (Ager-Wick Ellingsen et al., 2016; Li et al., 2014; Vandepaer et al., 2017). Among the currents assessments on batteries, it is possible to found several lines of research and methodological choices to carry out an environmental evaluation. The majority of studies conduct cradle-to-grave assessment focused on different set of impact categories.

This study is focused on environmental assessment of new active anode materials for LIBs in order to increase the information on achieving sustainable development of future batteries and also because previously studies showed that the majority of life cycle environmental effects in the anode production is caused by the anode material production phase (Peters et al., 2016; Padashbarmchi, et al., 2015).

2 Methodological assumptions and procedure

The goal of this study is to compare associated life cycle environmental impacts of the electrode for LIBs with different anode active nanomaterials.

In particular, two materials have been investigated:

- Cobalt oxide nanofibers (code C6)
- Cobalt oxide nanoparticles/graphene oxide-based composites encapsulated in carbon nanofibers code (PCG26)

The materials differ for the presence of graphene oxide and for post electrospinning thermal treatments. The spinnable solution was prepared by dissolving polymer polyacrilonitrile (PAN (6.5 % wt/wt)) in the solvent dimethyl formammide (DMF), adding the metal precursor cobalt acetate tetrahydrate (38.5 % relative to the polymer concentration, if any), and stirring until a clear solution was obtained. Solution feeding rate, applied potential and distance between the tip of the syringe needle and the grounded collector were 1.14 ml/h, 15kV, and 15 cm, respectively. The thermal treatment after electrospinng of C6 consisted in a single-step; instead, PCG26 was obtained from two-steps thermal treatment.

The functional unit was defined relatively to storage capacity of active anode materials; the target value is 600 mAh/g, that is approximately twice commercial electrode with graphite (Lee and Lee, 2002).

The system boundaries are defined as cradle to gate and include four phases, as showed in the flowchart of Figure 1.

In details the production process of active anode materials involves:

1) Phase I: raw materials production (cobalt acetate and graphene oxide),
2) Phase II: cobalt-based solution mixing,
3) Phase III: electrospinning process
4) Phase IV: thermal treatment of active materials.

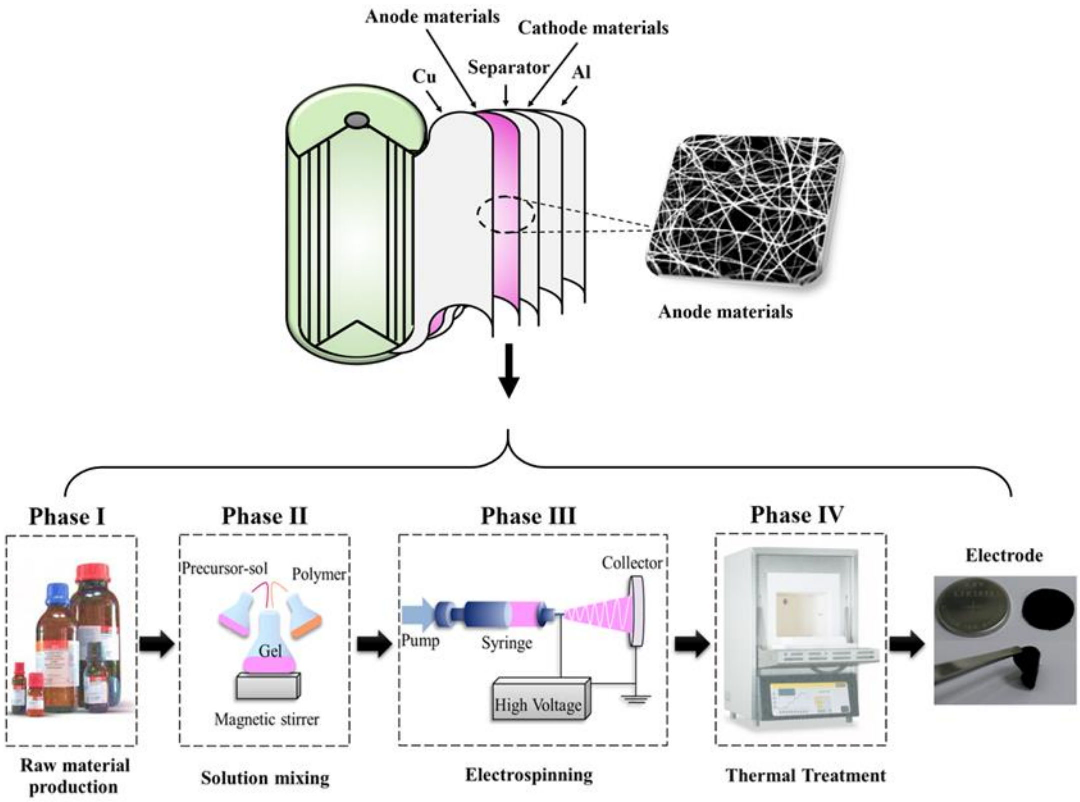

Figure 1: Flowchart of production of anode active materials

The life cycle inventory was compiled with some manufacturing data collected from our laboratory experimentation. The primary data are mainly used in the phases of solution mixing, Electrospinning and thermal treatment and are related to the known material and energy quantities consumed by the operating devices (vacuum pump, magnetic stirrer, syringe pump, high voltage supply, etc.).

The other data, related to the raw materials production, are retrieved from Gabi Professional database or modeled from similar processes conditions.

The electrode material production requires the use of different raw materials. The manufacturing processes of polymer and solvent used are already in the database. Nevertheless, the metallic precursor (cobalt (II) acetate) and graphene oxide here used are not directly available in the GaBi database. For this reason, it is necessary to create the production processes starting from raw materials, processes and energy involved. The process considered for the cobalt acetate is based on the reaction of metallic cobalt and acetic acid:

$$\mathrm{Co} + 2\,\mathrm{C_2H_4O_2} \rightarrow \mathrm{Co}\,(\mathrm{C_2H_3O_2})_2 + \mathrm{H_2}$$

In the reaction, the amount of reagents per product kg are stoichiometrically calculated. Thermal energy involved per producted (1 MJ) has been roughly estimated.

Also the process for graphene oxide has been created reffering to a metod described in the literature (Marcano et al., 2010). Compared to the classic Hummers' method, the procedure does not generate toxic emissions and allows an easy control of reaction temperature. Thanks to these features, such method may be applied to large-scale production and to the composite device manufacturing.

Life cycle impact assesment was carried out with Gabi ~~6~~ 8 using its standard impact categories and characterization factors.

3 Results and Discussion

As well known, there are many life cycle impact assessment methods for quantifying the environemental impacts.

In this study the impact assessment method Eco-Indicator 99 with cultural perspective of hierarchical view (base case) was used; its provides the single score indiceses which are a simple format as environmental impact data.

Here the LCA impacts are categorized as belonging to one of three categories: damage to human health, damage to ecosistem quality, and damage to resources. The relative importance of each category can vary.

The overall scores of the two active anode materials analyzed were compared according to their environmental performance, as shown in Figure 2.

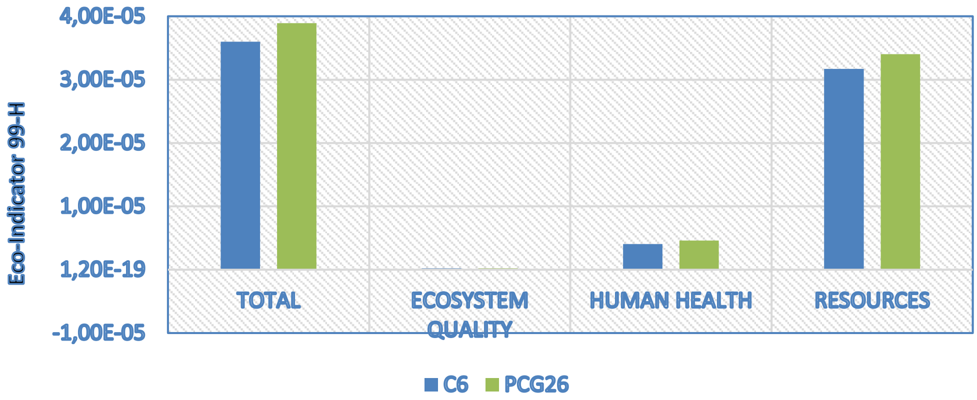

Figure 2: Environmental impact of C6 and PCG26 anode materials

The impact groups for all environmental area are similar for both active anode materials, very little differences occur; the resources are the most dominant group, instead the lower impact is ascribed to ecosystem quality. This effect should be ascribed to the material extraction stage in agreement with other LCA results (Paadashbermchi et al., 2015, Peters et al., 2016).

For a better understanding of the effects of each phase production, all impact categories have been scaled to 100%.

In Figure 3 each pie plot represents the impacts arising from the different active anode materials.

The cradle-to-gate production impacts of anode active materials are mainly caused by phase I (raw materials production); despite the complexity of graphene production, its synthesis does not affect sensibly the groups of impacts. This is probably due to the limited quantity used in the anode materials.

After the phase I for C6, the phases III and IV contribute in a similar way at all impact categories; the impacts correlated with phase II are not significant. Instead this phase has more impact in the production of PCG26; this is probably due to the lowetr solubility of graphene oxide in the spinnable solution, that requires a larger driven source in order to obtain a suitable viscosity which however allows a more facile spinning to the solution.

For PCG26 phase IV (thermal treatment) is the second important hot spot in terms of environmental impacts in the production phases with a contribution of about 12-20% of the total impact associated with the production phases; this is could be explained considering the two steps of thermal treatment carried out in order to obtain a carbonized membrane.

The graphene synthesis has a lower impact in the production of PCG26, on account of two factors: the low amount of added graphene and the graphene production method implemented (Marcano et al., 2010).

4 Conclusions

The environmental analysis carried out in this cradle to gate LCA allows the evaluation of impacts associated to the production of active anode materials prepared by electrospinning technique, resulting in higher impact due to consumption of resources with respect to the manufacturing steps.

However, nanomaterials may have potential toxic effects and will be better investigated in the further studies. Future assessments will include the use phase and the end of life of electrode materials, with a more depth-analysis of the nanowastes and nanoparticles emissions derived from the nanomanufacturing process.

Future assessments will take also in consideration the new category rules of European Commission that recently approved the reccomendations for batteries based on the Product Environmental Footprint methodology.

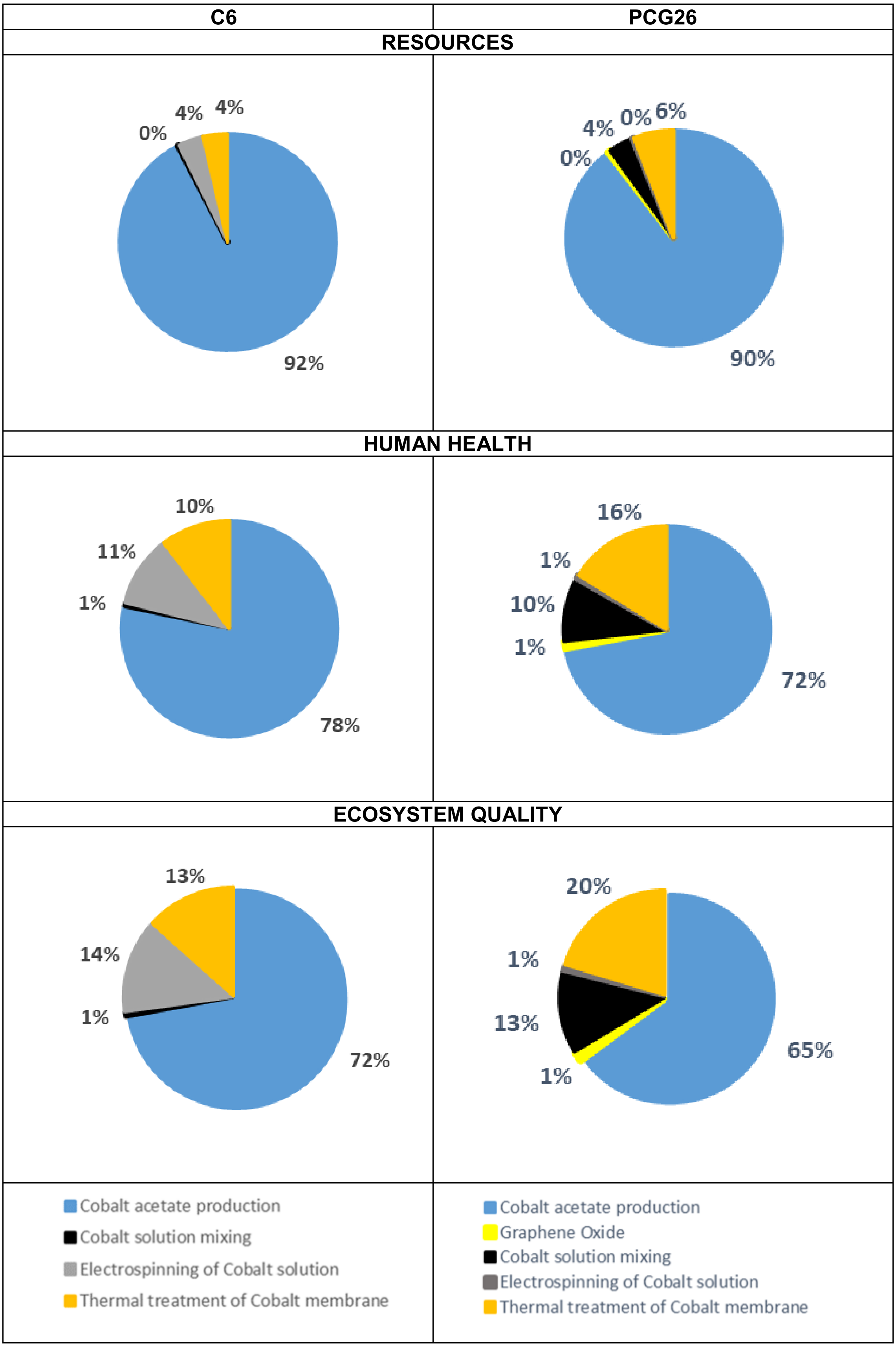

Figure 3: Environmental impacts of different phases production of C6 and PCG26

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LCA and Normalisation of environmental LCA based benchmarks for construction materials

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Abstract

The paper elaborates environmental data of seven construction material categories (cement, brick, steel, gypsum plasterboard, glasswool, stonewool, ceramic tiles) and it sets normalised environmental benchmark values based on Life Cycle Assessment (LCA) impacts indicators. LCA data of construction materials are collected through Environmental Product Declarations (EPDs) and are statistically analysed, obtaining Limit, Reference and Target benchmark values for seven LCA impact categories. Then, the benchmarks are normalised through the EU25+3 and World(2000) normalisation methods contained in the CML-IA methodology. The normalised environmental benchmarks obtained are set to communicate information about the relative significance of the impact category indicators that can be used to interpret and understand which environmental impact categories are relevant in the construction sector.

3 Introduction

In the construction sector, the definition of the best environmental performance based on the Life Cycle Assessment (LCA) between similar materials is often performed through the comparison between the impacts of a selected number of products chosen by practitioners. This approach could be replaced using objective environmental threshold values (benchmarks) which can set sustainable environmental levels for different construction product categories and are more reliable than a random comparison between products. The environmental benchmarks can be considered as thresholds based on the average of representative data and can refer to the LCA impact categories. Nowadays, LCA based benchmarks are often used in the construction sector to fix an environmental sustainable evaluation scale, which is introduced in many building certification schemes, such as the Green Building Rating Systems (GBRSs), and the energy certifications (Ganassali et al., 2016). From literature, there are several examples of LCA based benchmarks fixed in order to measure the environmental performance levels of buildings and materials. The evaluation scale is often composed by three benchmarks: the *Target* value, which is the highest environmental performance linked to a specific construction technology; the *Reference* value, which represents the average value of the scale and the current construction practices of a context; the *Limit* value, which is the lowest value in the evaluation scale and it represents the highest environmental impacts value accepted (Ganassali et al., 2017). LCA benchmarks for the construction sector shall change according to the different benchmarking methodology applied. Moreover, they are influenced by the reference samples or LCA assumptions; in facts, the benchmarks could be based on the normative prescriptions (i.e. national construction standards), the political values (i.e. European targets EU2020) the statistical values or a reference building. The LCA benchmarks of different impact categories cannot be compared with each other, because every category expresses different midpoint impacts. The normalisation step in LCA allows the interpretation of LCA benchmark values, providing a reference situation of the pressure for the environmental impact categories (Junbeum et al., 2013). After the normalisation of benchmarks, the LCA results can be used in a decision-making process concerning construction products.

The study aims to provide normalised LCA based benchmarks obtained through the statistical analysis of reference samples, each of which are related to the seven construction product categories. Moreover, the study discusses the relative significance of the environmental impact linked to the product categories analysed. The paper is divided in three parts: the first one is the "Methodology", in which the benchmarking approach is analysed and the resulting LCA benchmarks values are fixed. The second part is the "Normalisation", in which the normalisation methods are applied to the LCA benchmarks, in order to obtain comparable values and the relative percentage values of the impacts in each product category. The third part is the "Conclusions", in which the results are summarized and a possible use of normalised LCA benchmarks is suggested, focusing on future adjustment of the references.

4 Methodology

a. Study sample

The LCA benchmarks used in this study are fixed through the application of a benchmarking process based on the statistical analysis of LCA data of construction products, which belong to seven different categories typically used in the building sector. The construction product categories are: bricks, cement, ceramic tiles, gypsum plasterboard, glass-wool panels, stone-wool panels and steel. The construction materials have European boundaries and they are manufactured and sold in the European market. The LCA data of different products categories are collected through Environmental Product Declarations (EPDs) of different products, which are provided by nine European Program Operators, and the final LCA based benchmarks are fixed for seven LCA impact categories. The benchmarking process readapts the statistical analysis of environmental data used in recent studies, which set LCA benchmarks for healthcare buildings in Portugal (De Fàtima et al., 2015), for school buildings in South Korea (Ji et al., 2016) and for residential buildings in Italy (Moschetti et al., 2015), France (Lasvaux et al., 2017) and Germany (Köning and De Cristofaro, 2012). The LCA benchmark are performed through the statistical analysis and interpretation of LCA data of materials. The reference sample is composed by construction products manufactured and sold in Europe, with Environtal Product Declaration (EPD) in compliance with the standard EN 15804. These environmental labels are provided by eleven European Program Operators and they represent all the available EPDs of products in the market. The Program Operators are: EPDItaly (Italy), FDSE INIES (France), International EPD® System (Sweden), BAU EPD (Austria), IBU (Germany), GlobalEPD (Spain), DAPHabitat System (Portugal), EPD Danmark (Denmark), EPDNorge (Norway), Bre (UK) and ITB (Poland).

b. LCA procedure and LCA benchmarks

The environmental data collected from the EPDs refer to the LCA stages A1 (raw materials extraction), A2 (transport) and A3 (manufacturing), in order to ensure LCA data comparability. The other LCA stages cannot be analysed, due to the lack of data; indeed, the EPDs collected had not all “cradle-to-grave” system boundaries, but some of them have “cradle-to-gate with options” system boundaries (in which the LCA phases accounted were not the same). Then, the LCA data are converted in a unified declared unit equals to 1 kilogram of material. The LCA benchmarks are set for seven LCA impact categories provided in the EPD certifications. The environmental impacts considered are the Global Warming Potential (GWP), the Ozone Depletion Potential (ODP), the Acidification Potential (AP), the Eutrophication Potential (EP), the Photochemical Ozone Creation Potential (POCP), the Abiotic Depletion Potential for Non-fossil resources (ADNP) and the Abiotic Depletion Potential for fossil resources (ADP).

The benchmarking methodology is based on the statistical analysis of LCA data and it set an evaluation scale with three benchmark levels (Limit, Reference and Target) for each construction product category. The reference value is fixed with the median value of the sample; it is a robust value and it is not sensitive to the presence of outliers in a sample with a small number of data. The target value (the best practice) is fixed by the 1° quartile and it represents the upper value of the 25% better environmental performance values of the sample. The limit value (the worst practice) is fixed by the 3° quartile, which represents the value of the 75% highest environmental values. The Table 1 shows the three LCA benchmark obtained for the GWP impact category and an excerpt of descriptive statistics for the product categories.

Table 1: Limit, Reference, Target LCA benchmarks and standard deviation for Global Warming Potential (GWP) of seven construction product categories

GWP (kg CO_2 eq)				
Construction products	**L**imit	**R**eference	**T**arget	**SD**
Bricks	2,50E-01	1,95E-01	1,24E-01	8,36E-02
Cement	8,22E-01	7,48E-01	6,02E-01	2,39E-01
Ceramic tiles	5,58E-01	4,19E-01	3,28E-01	3,36E-01
Gypsum Plasterboard	2,64E-01	2,19E-01	2,02E-01	7,31E-02
Glass-wool panels	3,94E-02	4,81E-01	1,01E+00	4,81E-01
Stone-wool panels	1,30E+00	1,21E+00	1,09E+00	3,65E-01
Steel	1,18E+00	5,72E-01	5,13E-01	6,64E-01

c. Normalisation

According to the ISO 14044, the normalisation is a voluntary step in the Life Cycle Assessment and it allows the expression of the LCA results using common reference impacts, or zero-dimensional values (Breedveld et al., 1999). The ISO 14044 defines the normalisation as "the calculation of the magnitude of the category indicator results relative to some reference information" (ISO, 2006). The normalisation factors express the total impacts occurring in a reference region for a certain impact category (i.e. global warming) within a reference year. Since the study sample is composed by EPDs and the CML-IA methodology is required in the EN 15804 to characterize the environmental impacts, the normalisation methods used to normalise the LCA values are the "EU25+3" and the "World (2000)" provided by the CML-IA methodology (Table 2). The first one accounts the impacts related to the economic systems composed by 25 European countries plus Iceland, Norway and Switzerland in the year 2000 (Wegener Sleewik et al., 2008), while the second one accounts the impacts related to the world economic system in the year 2000. The use of two normalisation systems shows the uncertainty issue of the normalisation process, related to the differences between the geographical boundaries of the normalisation system and the boundaries of the environmental impacts (European or Global boundaries, depending on the materials dataset used to assess the product life cycle in the EPDs). EU25+3 system is suitable because the EPDs include European product system and the LCA benchmarks could be used for policies or companies operating on EU levels. Furthermore, the World (2000) system is suitable because the manufacturers acts on world levels and it is useful to see how the European products (and the LCA benchmarks) are put in relation with the Global impact results.

Table 2: EU25+3 and World2000 normalisation values for GWP, ODP, AP, EP, POCP, ADNP and ADP environmental impacts (Database CML-IA, Version 4.8 updated in August 2016)

Environmental impacts	EU25+3	World 2000
GWP (kg CO2 eq / year)	5.22E+12	4.22E+13
ODP (kg CFC11 eq / year)	1.02E+07	2.27E+08
AP (kg SO2 eq / year)	1.68E+10	2.39E+11
EP (kg PO4-3 eq / year)	1.85E+10	1.58E+11
POCP (kg C2H4 eq / year)	1.73E+09	3.68E+10
ADNP (kg Sb eq / year)	1.62E+08	3.61E+08
ADP (MJ / year)	3.51E+12	3.80E+14

The World(2000) normalisation values show a proportional increase than the Europe25+3 normalisation values, which can be expressed as a percentage value for each impact category. The normalisation step is applied to the reference LCA benchmarks, which can represent the median values of the current European manufacturing processes for the construction products categories analysed.

5 Results and discussion

Table 3 illustrates the normalized LCA benchmarks obtained through the normalisation EU25+3 and World (2000) systems. Figure 1 shows the relative significance of the LCA environmental impacts for each product categories, where the percentage values show the importance of each LCA impact category in the seven construction product categories, highlighting the lowest or the most significant impact category in this construction sector field.

Table 3: Normalised LCA benchmarks. The column "Benchmarks (R)" reports the LCA reference benchmarks of each environmental impacts of the seven product categories; the values normalised through EU25+3 and World (2000) systems are illustrated in the columns "Normalised Values", respectively.

Materials	Benchmarks (R)	Normalised values EU25+3		Normalised values World (2000)
Bricks				
GWP	1,95E-01 *(kg CO_2 eq)*	3,74E-14	+ 12.37%	4,62E-15
ODP	1,03E-10 *(kg CFC11 eq)*	1,01E-17	+ 4.49%	4,54E-19
AP	6,21E-04 *(kg SO_2 eq)*	3,70E-14	+ 7.03%	2,60E-15
EP	5,00E-05 *(kg PO_4^{-3} eq)*	2,70E-15	+ 11.71%	3,16E-16
POCP	4,71E-05 *(kg C_2H^4 eq)*	2,72E-14	+ 4.70%	1,28E-15
ADNP	6,67E-08 *(kg Sb eq)*	4,12E-16	+ 44.88%	1,85E-16
ADP	2,84E+00 *(MJ)*	8,09E-14	+9.24%	7,47E-15
Cement				
GWP	7,48E-01 *(kg CO_2 eq)*	1,43E-13	+ 12.37%	1,77E-14
ODP	6,16E-09 *(kg CFC11 eq)*	6,04E-16	+ 4.49%	2,71E-17
AP	1,09E-03 *(kg SO_2 eq)*	6,49E-14	+ 7.03%	4,56E-15
EP	2,75E-04 *(kg PO_4^{-3} eq)*	1,49E-14	+ 11.71%	1,74E-15
POCP	1,10E-04 *(kg C_2H^4 eq)*	6,36E-14	+ 4.70%	2,99E-15
ADNP	2,51E-07 *(kg Sb eq)*	1,55E-15	+ 44.88%	6,94E-16
ADP	3,03E+00 *(MJ)*	8,63E-14	+9.24%	7,97E-15
Ceramic Tiles				
GWP	4,19E-01 *(kg CO_2 eq)*	8,02E-14	+ 12.37%	9,92E-15
ODP	2,16E-08 *(kg CFC11 eq)*	2,12E-15	+ 4.49%	9,51E-17
AP	1,31E-03 *(kg SO_2 eq)*	7,81E-14	+ 7.03%	5,49E-15
EP	1,57E-04 *(kg PO_4^{-3} eq)*	8,46E-15	+ 11.71%	9,91E-16
POCP	9,88E-05 *(kg C_2H^4 eq)*	5,71E-14	+ 4.70%	2,68E-15
ADNP	5,15E-06 *(kg Sb eq)*	3,18E-14	+ 44.88%	1,43E-14
ADP	4,57E+00 *(MJ)*	1,30E-13	+9.24%	1,20E-14
Gypsum Plasterboards				
GWP	2,19E-01 *(kg CO_2 eq)*	4,20E-14	+ 12.37%	5,19E-15
ODP	1,59E-08 *(kg CFC11 eq)*	1,56E-15	+ 4.49%	7,01E-17
AP	6,13E-04 *(kg SO_2 eq)*	3,65E-14	+ 7.03%	2,56E-15

EP	1,18E-04 *(kg PO_4^{-3} eq)*	6,36E-15	+ 11.71%	7,45E-16
POCP	4,24E-05 *(kg C_2H^4 eq)*	2,45E-14	+ 4.70%	1,15E-15
ADNP	3,41E-07 *(kg Sb eq)*	2,10E-15	+ 44.88%	9,44E-16
ADP	3,71E+00 *(MJ)*	1,06E-13	+9.24%	9,76E-15
Glass-wool panels				
GWP	4,81E-01 *(kg CO_2 eq)*	9,22E-14	+ 12.37%	1,14E-14
ODP	8,52E-08 *(kg CFC11 eq)*	8,35E-15	+ 4.49%	3,75E-16
AP	6,31E-03 *(kg SO_2 eq)*	3,75E-13	+ 7.03%	2,64E-14
EP	9,45E-04 *(kg PO_4^{-3} eq)*	5,11E-14	+ 11.71%	5,98E-15
POCP	8,97E-04 *(kg C_2H^4 eq)*	5,18E-13	+ 4.70%	2,44E-14
ADNP	4,48E-07 *(kg Sb eq)*	2,77E-15	+ 44.88%	1,24E-15
ADP	1,68E+01 *(MJ)*	4,79E-13	+9.24%	4,43E-14
Stone-wool panels				
GWP	1,21E+00 *(kg CO_2 eq)*	2,32E-13	+ 12.37%	2,87E-14
ODP	1,01E-09 *(kg CFC11 eq)*	9,91E-17	+ 4.49%	4,45E-18
AP	7,52E-03 *(kg SO_2 eq)*	4,47E-13	+ 7.03%	3,15E-14
EP	5,96E-04 *(kg PO_4^{-3} eq)*	3,22E-14	+ 11.71%	3,77E-15
POCP	5,34E-04 *(kg C_2H^4 eq)*	3,09E-13	+ 4.70%	1,45E-14
ADNP	3,44E-07 *(kg Sb eq)*	2,12E-15	+ 44.88%	9,53E-16
ADP	1,68E+01 *(MJ)*	4,78E-13	+9.24%	4,41E-14
Steel				
GWP	5,72E-01 *(kg CO_2 eq)*	1,10E-13	+ 12.37%	1,36E-14
ODP	4,89E-08 *(kg CFC11 eq)*	4,79E-15	+ 4.49%	2,15E-16
AP	2,59E-03 *(kg SO_2 eq)*	1,54E-13	+ 7.03%	1,08E-14
EP	5,00E-04 *(kg PO_4^{-3} eq)*	2,70E-14	+ 11.71%	3,16E-15
POCP	4,00E-04 *(kg C_2H^4 eq)*	2,31E-13	+ 4.70%	1,09E-14
ADNP	1,32E-07 *(kg Sb eq)*	8,12E-16	+ 44.88%	3,65E-16
ADP	8,75E+00 *(MJ)*	2,49E-13	+9.24%	2,30E-14

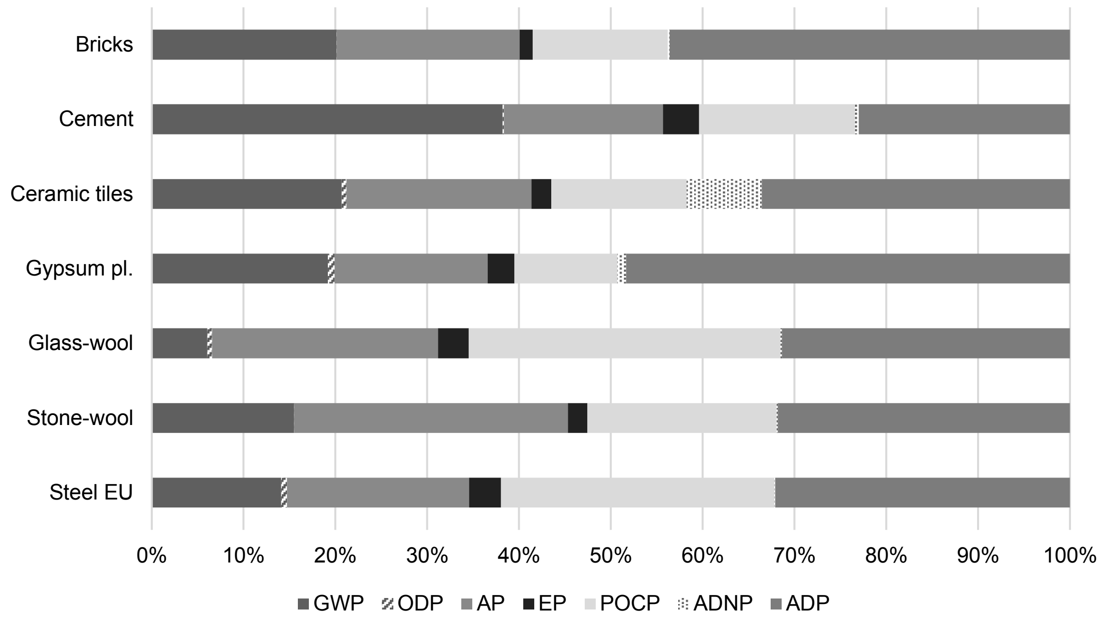

Figure 1: Percentage distribution of impact categories' relative significance for each construction product category

The Figure 1 shows the percentage distribution of all the impact categories in each product category. The Global warming potential (GWP), the Acidification potential (AP), the Photochemical ozone creation potential (POCP), and the Abiotic depletion potential for fossil resources (ADP) are the environmental impact categories with a significant role for the specific construction materials selected. Besides, the Ozone depletion potential (ODP), the Eutrophication potential (EP) and the Depletion potential for non-fossil resources (ADNP) have the lower role in the seven product categories analysed.

The main impact categories in brick category are the ADP, the GWP, the AP and the POCP, with percentage values equal to 43.60%, 20.13%, 19.91% and 14.68%, respectively, while the EP (1.46 %), the ADNP (0.22%) and the ODP (0.005%) have a less relevant role. The cement category has GWP (38.20%), ADP (23.01%), AP (17.30%) and POCP (16.95%) as relevent impact categories, while EP (3.96%), ADNP (0.41%) and ODP (0.16%) are the lower significant impact categories. In ceramic category, the ADP, the GWP, the AP and the POCP are the main three impact categories with percentage values close to 20% (33.57%, 20.67%, 20.12% and 14.72%, respectively). The ADNP, EP and ODP impact categories have lower significant values equal to 8.20%, 2.18% and 0.55%, respectively. The gypsum plasterboards category has the ADP as the most relevant impact category (48.34%), while the others with higher significant values are the GWP (19.19%), the AP (16.68%) and the POCP (11.20%) impact categories. The EP (2.91%), the ADNP (0.96%) and the ODP (0.71%) are the impact categories with lower relevant values. The relative significant impact categories in glasswool are the POCP (33.94%), the ADP (31.37%) and the AP (24.58%), while the impact categories with a lower relevance are GWP, EP, ODP and ADNP, with values equal to 6.04%, 3.35%, 0.55% and 0.18%, respectively. The stonewool category has ADP, AP, POCP and GWP as main relevant impact categories, with a value of 31.82%, 29.82%, 20.58% and 15.49%, respectively. The EP (2.15%), the ADNP (0.14%) and the ODP (0.01%) impact categories have the lower relative significant values in this product category. The steel material category has four significant impact categories, which are the ADP (32.09%), the POCP (29.76%), the AP (19.84%) and the GWP (14.11%), while the EP (3.48%), the ODP (0.62%) and the ADNP (0.10%) impact categories have value with lower relevance.

d. Weighting step

The weighting step is an optional procedure in Life Cycle Impact Assessment and it is used to establish an overall indicator of environmental impacts. In the study, the binary weighting method is assumed for the midpoint indicators (Castellani et al., 2016; Pizzol et al., 2017) and all the environmental impact categories have equal weight (equals one). In a possible future application of LCA benchmarks to environmental policies, a different weighting method (i.e. panel methods, monetisation method or distance to target method) could be applied.

6 Conclusions

The LCA benchmarks elaborated for this study are statistically based and specific for seven construction product categories. They reflect industrial and building practices and the normalisation of LCA values helps the stakeholders in the identification process of the relevant environmental impact categories and their variabilities in the construction sector, highlighting the significant impacts categories for each product categories. The main aim of LCA benchmarks for construction materials is to increase environmental knowledge in the construction sector, in order to lead future stakeholders toward a sustainable built environment. Moreover, the LCA benchmarks could help the stakeholders in the target thresholds definition in the construction sector (i.e. in Green Public Procurement). The study could be improved adding new environmental impacts, which are accounted in different characterization and normalisation models (i.e. the ILCD- International Reference Life Cycle Data System- developed by the EU Joint Research Centre for the implementation of the Environmental Footprint), in order to analyze different LCA impacts and find other impact categories, which can be relevant in the construction sector.

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Assessing the use of neodymium alloys in wind turbines from a Life Cycle Assessment perspective: a literature review

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Abstract

Direct drive permanent magnet generators are the most powerful and reliable alternative for kinetic-to-electrical energy conversion in wind turbines. The magnetic rotor is made of a metallic alloy containing neodymium, dysprosium and praseodymium, three rare-earth elements. The 2010 price bubble of rare-earth oxides increased the notoriety of these materials, which came out to be very impacting on the environment of the producing countries. Nevertheless, the great performances related to the use of these materials result in an environmental trade-off between the production and use phase. To make clarity on the subject, we critically review the literature on Life Cycle Assessments of wind turbines including rare-earths in the material inventory.

1. Introduction

Wind power has been the most exploited renewable energy source in the last years: in 2005, wind energy accounted for only 6% of the total installed power capacity in Europe; in 2016, it was 16.7%, corresponding to 154 GW (Nghiem and Mbistrova, 2017). In the same year, wind power was the generation technology with the highest share of new installations in Europe, more than half of the total new energy capacity (12.5 GW vs. 24.5 GW; Nghiem and Mbistrova, 2017). The European wind power capacity is expected to double to 324 GW by 2030 (Nghiem and Pineda, 2017). Kinetic-to-electrical energy conversion is driven by wind turbines (WTs): aerodynamic blades exploit wind to provide torque to a central rotor. The rotation is transmitted (sometimes through a gearbox) to a generator, to convert it into electric power (Chen et al., 2009). In 2016, about 340,000 WTs were spinning all around the world, with more than 480 GW of total installed global capacity (GWEC Global Wind Energy Council, 2017).

1.1. Neodymium magnets in wind turbines

In the last decade, direct drive wind turbines have gained increasing importance compared to geared systems. Introduced in the market in 1991, direct drive generators had a rapid growth in the last years due to their reliability and low maintenance requirements (Ivanovski, 2011). The largest share of operation and maintenance costs for geared turbines is associated with the gearbox itself, which is the component with the major number of moving parts, featuring contacts and wearing due to friction. Direct drive turbines, gearless, avoid this risk of blocking and reduce wear. Energy companies well appreciate this feature, especially for off-shore applications, where human intervention is complicated and expensive. Direct drive turbines are also superior to geared ones in terms of energy yield, while geared turbines are cheaper, lighter, and smaller (Ivanovski, 2011).

The main part of direct drive generators is a magnetic rotor (5 to 10 m diameter, up to dozens of tonnes in weight). The rotor can be made up of permanent magnets (PMs) or electrically excited electromagnets. Between the two solutions, the PM generator is the most reliable and the one with the highest energy yield (Ivanovski, 2011; Polinder et al., 2006), making it the most suitable solution for high-cost, high-performance applications as offshore wind farms. PM rotors are made of $Nd_2Fe_{14}B$, an alloy which exploits the magnetic properties of neodymium (Nd). Commercial alloys are drugged with other elements, resulting in an average composition of 65% Fe, 25% Nd, 6% Pr, 2% Co, 1% B, 1% Dy (Gambogi, 2016). PMs are also used in geared turbines, but in negligible quantities.

e. Rare-earth elements

Neodymium, as well as Praseodymium (Pr) and Dysprosium (Dy), is a rare-earth element (REE). REEs include seventeen chemical elements in the periodic table, specifically the fifteen lanthanides, scandium, and yttrium. Used in several technological products, REEs have been the subject of hot debate after the price bubble occurred between 2010 and 2011 (Fernandez, 2017). China, world leader in REEs production with a market share greater than 85%, actuated a restrictive export policy during 2009-2012. This policy generated an exponential increase in market quotations of these elements. The visibility brought by economic constrictions put the whole REEs context under attention, highlighting some criticalities. The production of rare-earth oxides is a complex process: the very low concentration in ores results in very aggressive chemical treatments; in addition, ores may be contaminated by radioactive elements as thorium and uranium (Laurent, 2014). Campbell (2014) states that one of China’s competitive advantages to impose its market leadership in REEs mining is most likely its willingness to accept the associated environmental damage over the years.

The European Commission labelled REEs as critical raw materials, extremely strategic for the manufacturing industry but with a very vulnerable supply chain (European Commission, 2010). Efforts have been made to reduce the use of REEs to mitigate their economic and environmental impacts (Alonso et al., 2012; Massati and Ruberti, 2013). As for WTs, studies have been done to reduce the use of REEs in turbines generators (Pavela et al., 2017). Moreover, important WTs manufacturing companies adopted strong policies to avoid the use of PMs generators (like Vestas, market leader in WTs production; Vestas, 2014). While the 2010-2011 REEs price bubble retreated after the reopening of China’s market (2012), REEs’ environmental issues are still at the centre of a hot debate, influencing scientific opinions and companies’ production policies.

2. Scope of the research and methods

There is a clear trade-off between performances of PMs direct drive WTs and environmental impacts related with the use of neodymium alloys. Materials whose extraction causes serious toxic emissions allow the creation of high-performing generators to better take advantage of renewable energy sources. Structured methods to evaluate benefits and burdens of different alternatives are required to quantitatively assess the related environmental impacts, from the production stage, through the use phase to the final dismantling.

2.1. Environmental impact analysis of wind turbines

Life Cycle Assessment (LCA) is a methodology to evaluate the environmental impacts associated with a given product or process over its full life cycle. By mapping unit processes in the different production steps and assessing resource consumptions and environmental pressures associated to each of them, LCA provides a comprehensive assessment framework of the environmental burdens related to a product (ISO, 2006).

Many LCAs regarding WTs are available, comparing wind power generation with other energy sources or contrasting the environmental performances of different wind turbine types. Exhaustive literature reviews provide aggregated information and results (see e.g. Arvesen and Hertwich, 2012; Davidsson et al., 2012). Nevertheless, the role of neodymium in turbines' overall environmental impact has been poorly investigated. Concerns regarding the impacts associated with the use of neodymium PMs in wind turbines have risen years ago, but the problem has rarely been analysed quantitatively, trying to make a balance of the overall costs and benefits of this material.

f. Environmental impact analysis of rare-earth elements

After 2010, the growing awareness about the environmental burdens of REEs' exploitation encouraged the research community to try to quantitatively assess the impacts related to these elements. In many cases, LCA has been used because of its systematic approach and the transparency of the procedure. Literature reviews are available on this topic too (Kossakowska and Grzesik, 2017). These studies show that the environmental impacts related to REEs can vary dramatically in different extraction and refining contexts: Weng et al. (2016) estimated the Gross Energy Requirement (GER) and Global Warming Potential (GWP) of the mining, beneficiation and refining processes of REEs in 26 REEs mining facilities. For instance, the GWP of neodymium oxide production can vary between 1000 and more than 10,000 kgCO_{2eq} per tonne of oxide depending on the geological and mineralogical features of the deposit. Schreiber et al. (2016) compared the environmental impacts of neodymium extraction from a new plant to be realized in Sweden with the Bayan Obo process (Bayan Obo is the biggest Chinese REEs deposit and with its facilities represents the world's biggest REEs production site). Better emissions control, as well as waste and sludge treatment forced by Swedish legislation, guarantees environmental impacts that are 60% lower for the Swedish process (11 midpoint impact categories analysed).

g. Research scope

This work reviews the studies that assessed the use of neodymium alloys for WT construction according to LCA standards. The study aims to shed light on the current knowledge on the topic, highlighting existing results and knowledge gaps, suggesting a research path to increase the scientific awareness about the environmental impacts and trade-offs of different WT generators. The final goal of the study is to make clarity about the environmental impact that the use of REEs alloys have on the overall lifecycle of a WT, to understand how deeply this impact is related with the mining context of REEs and to highlight if it is possible to clearly identify a best solution between the exploitation or avoidance of neodymium PMs in WTs. In the end, the authors provide an overview on the opportunities to implement circular economy strategies to recover neodymium PMs from WTs and dilute their environmental impact over several life cycles.

h. Research methods

The study has been carried out by identifying existing scientific publications on LCA studies of WTs including the environmental impacts associated with the use of neodymium alloys. To this end, the Scopus engine has been used with the following research query: (TITLE-ABS-KEY (“wind turbine”) AND TITLE-ABS-KEY (lca) OR TITLE-ABS-KEY (“life cycle assessment”) AND ALL (“rare earths”) OR ALL (“neodymium”)).

3 Results

19 publications satisfied the query limitation. The oldest was from 2012. Some of them were not directly relevant: three are the literature reviews previously mentioned (Arvesen and Hertwich, 2012; Davidsson et al., 2012; Kossakowska and Grzesik, 2017). Two are conference proceedings in which WTs, LCA and REEs are considered separately. Five are studies specifically focusing on REEs and do not provide any quantitative information directly related to WTs (Graf et al., 2013; Harmsen et al., 2013; Haque et al., 2014; Schreiber et al., 2016; Weng et al., 2016).

Some studies investigate the production of neodymium alloys for wind industry applications. They do not provide final quantifications about the use of PMs and their contribution to determining the overall environmental impacts of WTs, but it seems good to mention them here because they can provide a valuable reference for future, broader studies. Wulf et al. (2017) developed a cradle-to-gate Life Cycle Sustainability Assessment (the combination of a LCA, a Life Cycle Costing and a Social Life Cycle Assessment) to compare the production of $Nd_2Fe_{14}B$ exploiting REEs from the three main commercial mining and refining alternatives: the already mentioned Chinese Bayan Obo, the Mount Weld chain (extraction in Australia, refining in Malaysia) and the Mountain Pass chain (extraction and refining in USA). The Chinese alternative was the worst in all environmental midpoint impact categories, worst in 14 out of 15 social midpoint impact categories and best in all the economic midpoint impact categories. Holger et al. (2017) developed a more detailed Social Life Cycle Assessment to compare the three above cited alternatives. Again, the Bayan

Obo production chain resulted to be the most impacting on the social conditions of stakeholders. Jin et al. (2016) developed a LCA to compare virgin (Chinese) and recycled (through a hybrid mechanical-chemical process) neodymium PMs: recycled PMs were 40% to 70% less impacting than virgin ones, depending on the specific midpoint impact category.

Bonou et al. (2016) analysed an eco-design framework (a tool to design or re-design products to improve their sustainability through their entire life cycle) and its alignment with LCA standards. Ortegon et al. (2013) compared different dismantling processes for WT components, without applying a full LCA approach. Kouloumpis et al. (2013) proposed a combination of LCA and an On Site Environmental Impact Assessment (focusing on local effects and impacts on the biosphere) to evaluate the burdens of a wind farm in the UK. The analysis was based on secondary data from the Ecoinvent database. Ji and Chen (2016) developed a LCA of a Chinese wind farm. In all these studies, REEs were only mentioned but were not the subject of specific analyses.

(Adibi et al., 2017) developed a new endpoint impact category (called Global Resource Indicator, GRI) to assess the resource depletion potential of a product from a broad perspective (including recyclability and supply risk of the material). The study applied this impact indicator to the case study of 3-MW WTs. Datasets of two different types of WTs were obtained from Crawford (2009), and complemented using a permanent magnet Life Cycle Inventory (Adibi, 2016). In this study, the quantity of REEs inside the turbines is declared (415 kg of Nd, 15 kg of Dy) and their environmental impacts are assessed with the LCA methodology. Results are interesting: REEs are shown to contribute for more than half of the total GRI of the turbine, making turbines containing REEs more impacting than those based on different materials. However, the use of PMs allows a much lower consumption of copper (more than one tonne less). A reason of the high GRI of REEs is that their recycling rate (the fraction of a material that is recyclable) is set to 10%.

Lloberas-Valls et al. (2015) carried out a LCA to compare the environmental impacts of a 15-MW PM direct drive generator and a 15-MW second-generation high-temperature superconductor direct drive generator (a new rising electromagnetic technology). The analysis had cradle-to-gate boundaries (i.e. it included only the production phase) and considered only the generator (not the whole turbine). Results indicate that REEs account for the majority of the Ozone Layer Depletion Potential (OLDP) and a non-negligible proportion of the Eutrophication Potential (EP), while they have minor impacts on other indicators. Despite the OLDP of the PM generator is more than twice that of the other generator type, a normalization analysis (based on the EU25+3 year 2000 CML ReCiPe method) showed that the OLDP is the less relevant impact category (magnitude 10^{-9}). With respect to the most relevant impact category, the non-Fossil Abiotic Resource Depletion Potential (magnitude 10^{-5}), the PM generator is less impacting than the superconductor generator.

4 Conclusions

This review points out a general lack and lateness (nothing before 2012) in structured studies on the environmental impacts of Nd alloys used in the production of WTs. The LCA methodology, a mature and standardized assessment framework, has rarely been applied to assess those impacts. Some hints to develop further studies may be to (i) extend the analysis to a wider number of turbines and generators; (ii) broaden system boundaries to embrace the whole cradle-to-grave horizon and to consider not only the generator but the whole turbine (or the entire wind farm); (iii) base LCA analyses on primary data on REEs production in different contexts, in order to underline the role of mining and refining processes on the overall environmental burdens of a WT.

The available studies highlight the impossibility to identify a best solution between the use or avoidance of REEs in WTs: direct drive PMs WTs are the more effective alternative for offshore applications. Nevertheless, REEs usage has a serious influence on the sustainability of this choice. The high impact that REEs have on the OLDP indicator is easily ascribable to the slags released in atmosphere during chemical processes in mining. Moreover, REEs emerge to be the most impacting materials on the GRI despite their low contribution to the total weight of the WT (less than a tonne over thousands of tonnes). Their scarcity and the complexity of the supply chain force REEs to be evaluated by this indicator as materials like silver or palladium. Energetic efficiency, toxic emissions and economic-politic complexity coexist without prevailing in this complex trade-off scenario. Nevertheless, in case the PMs can be recovered and reused in several product lifecycles, the impacts generated by their production would be spread and reduced, allowing the performance opportunities to triumph. Adibi et al. (2017) assumed a PM recycling rate of 10% (directly impacting on the GRI), while Lloberas-Valls et al. (2015) stopped their cradle-to-gate analysis to production.

To recover PMs and mitigate their environmental impact, a circular economy (CE) perspective would be advisable in order to keep these materials in the loop. CE is a cross-sectorial market paradigm aimed to implement a closed-loop product life cycle, restoring when possible the entire end-of-life product or its components, otherwise recycling its materials or recovering its embedded energy (McKinsey & Co., 2012). Neodymium PMs can be recycled: however, if alloys to be recycled have different compositions, the hydrometallurgical processes (similar to the ones used in extraction from ores) required to obtain single REE oxides suitable for reintroduction into market are very impacting in consumption of chemicals and wastewater generation (Binnemans et al., 2013). If recycling is applied to alloys with the same composition (as those used in WTs of a same production company), the closed-loop recycling process based on hydrogen decrepitation requires less energy and no waste is generated (Binnemans et al., 2013). Recycling is not the only way to recover PMs: with a modular design-for-remanufacturing of rotors, PMs composed by unit-cell magnets with standard shape and size can be demagnetized, refurbished and re-magnetized as new PMs for new wind turbines. Direct reuse provides a dramatically lower environmental footprint than production of virgin magnets or hydrometallurgical recycling (Hogberg et al., 2016). A conscious development of a manufacturer-centred circular economy approach can provide an effective way to take advantage of the benefits brought by PM direct drive turbines while avoiding dramatic consequences on the environment of REEs-producing countries. Manufacturers best know the composition of their own products and can design and implement effective dismantling, remanufacturing, and recycling routes for rotor magnets (as well as for other components). The reuse of the same material over several life cycles can provide multiple benefits: the decrease of the environmental footprint of REEs' extraction, the low energy consumption in material reprocessing (compared with production from virgin materials), and the strategic advantage of a short and safe supply chain are key elements making the CE approach an effective way to take full advantage of the embedded value of end-of-life WTs and decrease environmental impacts associated to the extraction of virgin REEs.

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Variation of Greenhouse Gases (GHG) emission related to milk production in a sample of farms, within two years

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Abstract

During the last few years the attention towards environmental sustainability of foodstuffs has increased, especially for those of animal origin that cause serious impacts on the environment mostly related to Green House Gases (GHG) emission. The aim of the study was the evaluation of the environmental impact, as GHG emission, of milk production of five bovine farms, in order to highlight the differences between 2014 and 2016. The analysis was conducted with Life Cycle Assessment (LCA) method. For the sample considered, the average value for the GHG emission for producing 1 kg of Fat and Protein Corrected Milk has increased slightly, switching from 1.5 kg CO_2 equivalent in 2014 to 1.7 kg of CO_2 equivalent in 2016. Analyzing the single farms, however, there are some differences: from one year to the other some farms have increased the sustainability of their production, others show a worsening in terms of environmental impact.

1. Introduction

During the last few years, both costumers and producers have increased their attention towards environmental sustainability of foodstuffs, especially for those of animal origin. Livestock production are considered to cause serious impacts on the environment mostly related to Green House Gas (GHG) emissions (Fantin et al., 2012; Gerber et al., 2010).

The literature reports that for milk production, at farm level, most of the contribution in terms of Climate Change is given by the emissions related to enteric fermentation of ruminant animals (Kristensen et al., 2011). In particular, in the rumen, carbohydrates are fermented in anaerobic conditions by rumen microflora with the release of carbon dioxide and methane, gases with climate change effect.

In terms of GHG emission, another activity at farm level that has a great effect is feed production (Gonzales-Garcia et al., 2013). This activity includes growing crops, processing and transportation of feed (van Middelaar et al., 2012). Within milk production, feed production contributes to GHG emissions for about 45% (Thomasen et al., 2008; van Middelaar et al., 2011), while, for example, in swine and chicken meat production feed production concurs to GHG even for 60% and 80%, respectively (Basset- Mens e Van der Werf, 2005; Pellettier, 2008).

Another big contribution to GHG emissions at farm level is given by emissions related to manure management and distribution (Gonzales- Garcia et al., 2013). In particular, during manure management and even more with manure spreading, N_2O is emitted in environment .

2. Scope

The aim of the study was the evaluation of the GHG emission of milk production of five dairy cattle farms, in order to highlight the differences between 2014 and 2016. All the farms sold their milk to the same cheese factory, that produces Grana Padano cheese.

3. Material and methods

The methodology used in this case study for quantifying GHG emission related to milk production is Life Cycle Assessment (LCA).

The aim of the study was the evaluation of the Green House Gases emission of 1 kg of FCMP (Fat and Protein Corrected Milk), according to IDF directions (2015). System boundaries were defined (Figure 1) in a *from cradle to farm gate* point of view, considering both the production process and all the inputs and outputs involved.

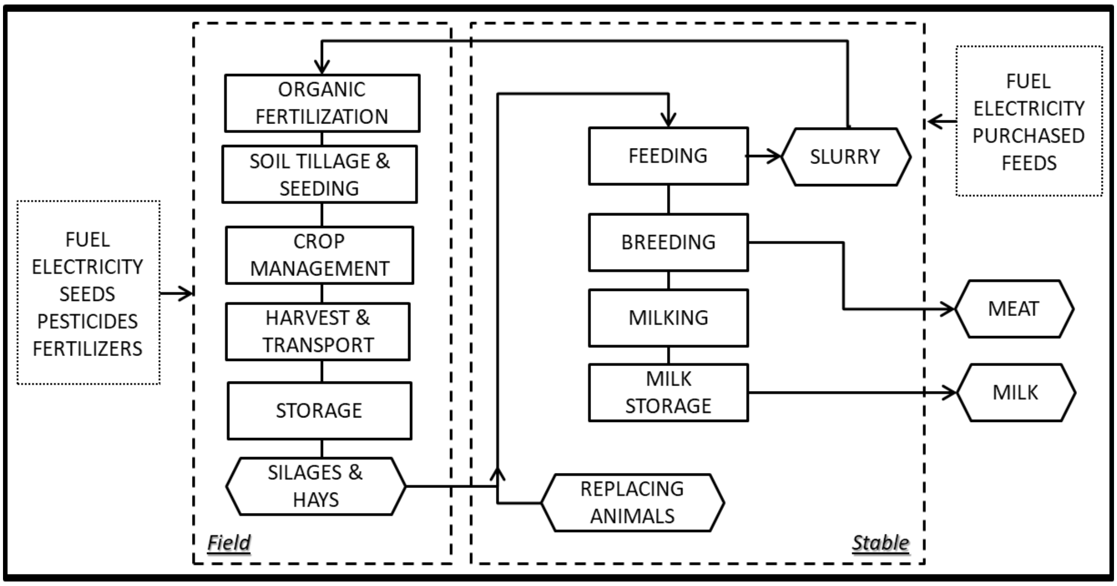

Figure 1: System boundaries

During the inventory analysis primary data were directly collected, through interviews to the farmers: data recorded were about farming system, manure management, fertilizing, purchases, etc.

Main features of the studied farms were analysed, first of all the self-sufficiency, based on Dry Matter (DM) produced and purchased at the farms and calculated as: $DM\ produced / (DM\ produced + DM\ purchased)$

in which DM produced and DM purchased are referred to the animal rations.

Furthermore, for the 5 farms the dairy efficiency was evaluated, that is the ability of the cows to turn the DM ingested (Dry Matter Intake, DMI) into milk produced. Dairy efficiency is calculated in the following way:

$$Milk\ (\frac{kg/\ head}{day}) \Big/ DMI\ (\frac{kg\ /head}{day})$$

With the support of the software CPM Dairy the composition of the animal rations was deduced on the basis of the ingredients and the amount declared by the farmers. The GHG emissions were estimated using the equations developed by IPCC (2006) and Moraes et al. (2014). The emissions considered were enteric methane, and emissions of methane and N_2O related to manure management and spreading. To estimate gas emission during this analysis it was held a TIER 2 level of details.

Using the Software Simapro GHG emissions were quantified for 1 kg of FPCM, using IDF allocation (2015): the environmental impact was divided between the two main farm's products (milk and meat). The ILCD-Midpoint calculation method was used.

4. Results

Tables 1-3 report some features and productive results of the studied farms in the years 2014 and 2016: some important differences can be noted in terms of general characteristics and management.

Table 1: Main features of the studied farms: crop production and feed self-sufficiency

	Cultivated Area (ha)		**Meadow (%)***		**Chemical Fertilizers (t)**		**Self-sufficiency** (%)**	
	2014	**2016**	**2014**	**2016**	**2014**	**2016**	**2014**	**2016**
1	315	299	22	25	108	54	48	68
2	46	46	43	47	9	10	69	75
3	40	40	100	100	0	0	77	72
4	70	76	41	39	25	19	79	81
5	98	79	18	20	22	20	82	93

* Permanent meadows and alfalfa field

** Based on DM produced and DM purchased

Table2: Main features of the studied farms: herd composition and dairy efficiency

	Lactating cows (n)		**Milk production/head (kg)**		**Dairy efficiency**	
	2014	**2016**	**2014**	**2016**	**2014**	**2016**
1	760	785	33	33	1.5	1.5
2	94	100	28	29	1.2	1.2
3	55	60	35	32	1.6	1.3
4	140	145	34	32	1.7	1.6
5	120	120	29	27	1.4	1.2

Table 3: Main features of the studied farms: Milk IDF allocation

	Milk production (t FPCM/year)		**Meat Production (t/year)**		**Milk IDF allocation (%)**	
	2014	**2016**	**2014**	**2016**	**2014**	**2016**
1	9019	9290	199	226	90	85
2	955	1022	16	21	86	87
3	683	657	18	14	84	87
4	1818	1753	41	51	87	82
5	1297	1188	34	35	84	82

Some differences between 2014 and 2016 are evident, in particular in term of crop production management (use of chemical fertilizer, DM produced).

For the sample of farms considered, the average value of GHG emission for producing 1 kg of FPCM has increased slightly in the two years, switching from 1.5 kg CO_2 eq in 2014 to 1.7 kg of CO_2 eq in 2016.

Analysing the single farms, however, it's possible to highlight different trends: in fact from 2014 to 2016 some farms have increased the sustainability of their production, while others showed a worsening in terms of GHG emissions (Figure 2).

For the Farm 2, despite the increasing of feed self- sufficiency (Table 1) and milk production/head (Table 2), GHG emission goes from 1.7 to 1.9 kg of CO_2 equivalent for FPCM kg. This could be due to management choices like for example the type of raw materials purchased.

Also in the third farm, there is a significant increase in environmental impact in terms of GHG emission (29%): the farm shows, indeed, a lowering of the feed self-sufficiency (Table 1) and of the milk production/head (Table 2), with a consequent growth in the impact related to milk (Table 3).

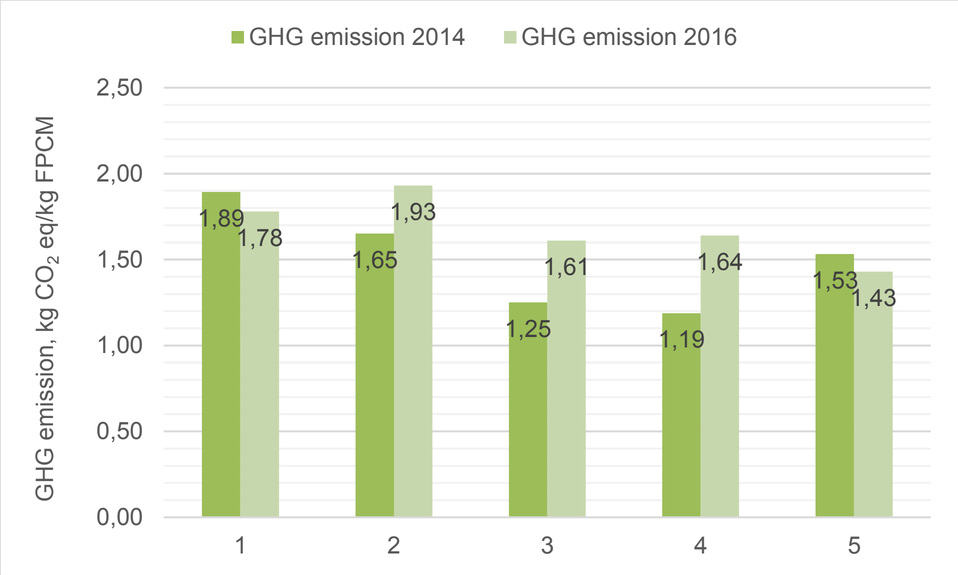

Figure 2: Variation of Greenhouse Gas Emission per kg Fat and Protein Corrected Milk in the studied farms within the twoyear period

For the farms of the sample, was also analysed the detail of GHG emissions calculated on LU (Livestock Unit) (Figure 3).

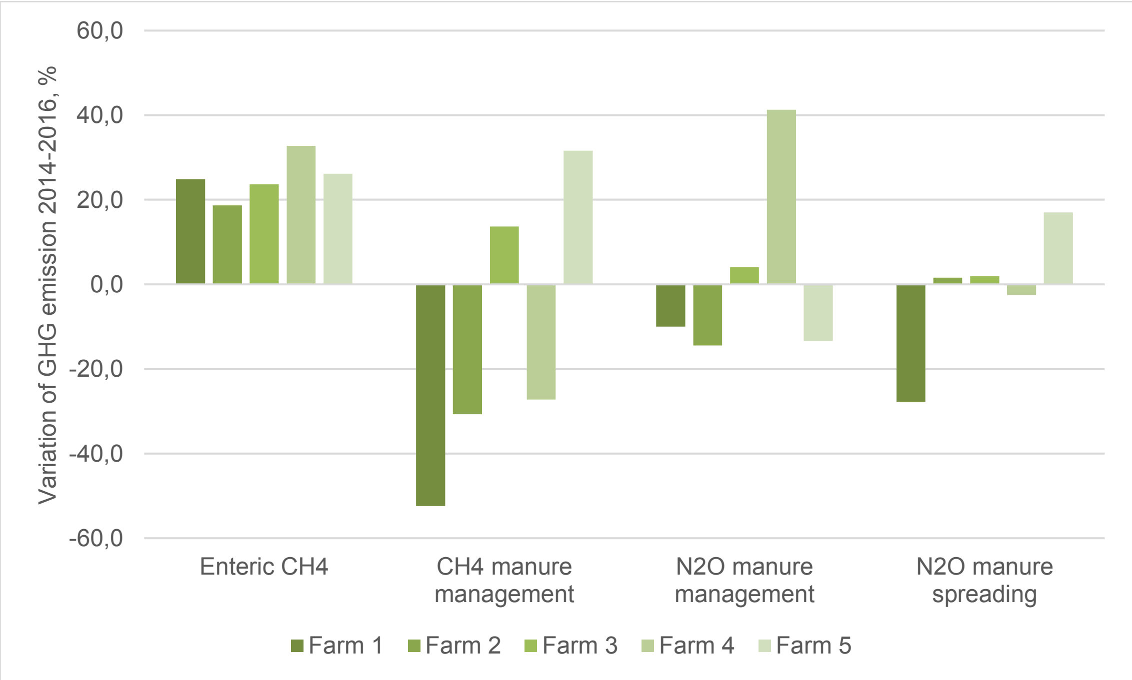

Figure 3: Emissions from enteric fermentation, manure management and spreading

The feed self-sufficiency is related to environmental sustainability: the aim of a sustainable agriculture, indeed, is to reach a farm management that allows to reduce chemical products, but especially to reduce the purchase of products from the outside, in order to maximise a re-employment of farm's products (manure, feed, etc.) (Guerci et al., 2013).

The feed self- sufficiency is also connected to LUC (Land Use Change): to produce directly animal feed in the farm implies a reduction in the purchased of product from abroad, for example soy, for whose cultivation have been knocked down many forests. Thus, on the impact of soy production is added an impact related to LUC.

In Farm 4, an increase of 38% of GHG emission was estimated. This is due both to a reduction in animal dairy efficiency (Table 2) and in the meadow areas (Table 1).

On the other hand, in the case of Farm 1 there is 6% reduction of the GHG emission; this is related mainly to the increase of feed self-sufficiency (Table 1) and numbers of sold animals, that has involved a reduction in the impact allocated to milk (Table 3). Furthermore, there is a reduction in gas emissions at farm level, especially in terms of methane from manure management and also in N_2O related to manure spreading (Figure 3).

Finally, farm 5 shows also a reduction in environmental impact of the 7%. This result is related to the fact that there is an increased feed self-sufficiency and meadow areas (Table 1) and also to the lower impact allocated to milk, thanks to an increase of the number sold animals (Table 3).

5. Conclusions

The monitoring of the variations over time in farm management and productive results and the evaluation of the consequent changing in environmental impact seems to be a good method in order to identify some mitigation strategies of the environmental impact due to milk production.

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Wood pellet as biofuel: a comparative life cycle analysis of a domestic and industrial production chain

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Abstract
This study focuses on the environmental impact assessment of wood pellet production through Life Cycle Assessment (LCA). In particular, the aims are to compare the environmental impacts of ''A1 premium'' wood pellet manufacturing in a large industrial plant with "domestic" wood pellet manufacturing in a small pelletiser, and to identify the environmental hotspots of these two pellet productive chains. The results underline the fact that electricity consumption due to machinery used for the compressing phases of pelletising process plays a key role in the environmental profile, together with pellet burning. The production of the wood (forest stage) has a low impact (no more than 20%) if compared with the other main stages of the pellet life cycle (pellet production and pellet use). The comparison between the domestic and industrial model shows that, the domestic model performs better on 6 of 8 impact categories.

1 Introduction
Since long times, biomass has been a convenient and renewable energy source for humanity. Thanks to its easy supply and relatively high heating value, biomass was used for a long time in many applications, from cooking to spatial heating, lighting, and steam production (Cespi et al., 2014). As described in the study of Calderón et al. (2016), more than two thirds of biomass used in Europe consists of solid biomass (69%); biogas and biofuels represent only 12% and 13% of gross inland energy consumption of biomass and biowaste. Solid biomass is the market driver for biomass, and is generally represented by compressed wood, although woody biofuel includes logs, chips and pellets. Domestic usage of wood as energy source, is the main consumption (27%), followed by the industrial use (22%) and domestic small scale use of wood chips (14%), pellet consumption is constantly growing, and it currently represents 6% of the total EU wood energy consumption (Calderón et al., 2016).
In Europe, the Directive 2009/28/EC incentivizes the use of woody biomass as fuel in combustion plants to generate heat or power and aims to reduce fossil resource consumption (Cleary and Caspersen, 2015).
In this study, life cycle assessment (LCA) methodology is applied to compare the environmental impacts of two types of pellets: a class A1 plus pellet produced by a large pellet industry, and a pellet produced in laboratory to simulate a local production plant. A sensitivity analysis was performed to check the robustness of results and their sensitivity to uncertainty factors of the model.

2 Materials and methods

2.1 Goal and scope definition

The main goal of this study is to perform a comparative life cycle assessment of the domestic and industrial production chain of wood pellet, for a better knowledge of the feasibility and the environmental impacts of both the production systems, following the European directives (such as 20-20-20 package) that aim to reduce the consumption of non-renewable energy resources.

The functional unit selected is 1 ton of wood pellets with a moisture level of 7% and a LHV of 17 MJ (Vicente et al, 2015). This study analyzes two systems: a) an industrial pellet production chain; b) a domestic pellet production chain. The system boundaries of both production chains include: Forest operations, Pellet production (and sawdust production in the domestic model), Pellet use (see Fig. 1 and 2). The environmental impacts resulting from the two investigated systems were assessed using the ReCiPe 2008 v.1.12 method for the following midpoint categories: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, photochemical oxidation, particulate e matter formation, metal depletion, fossil depletion.

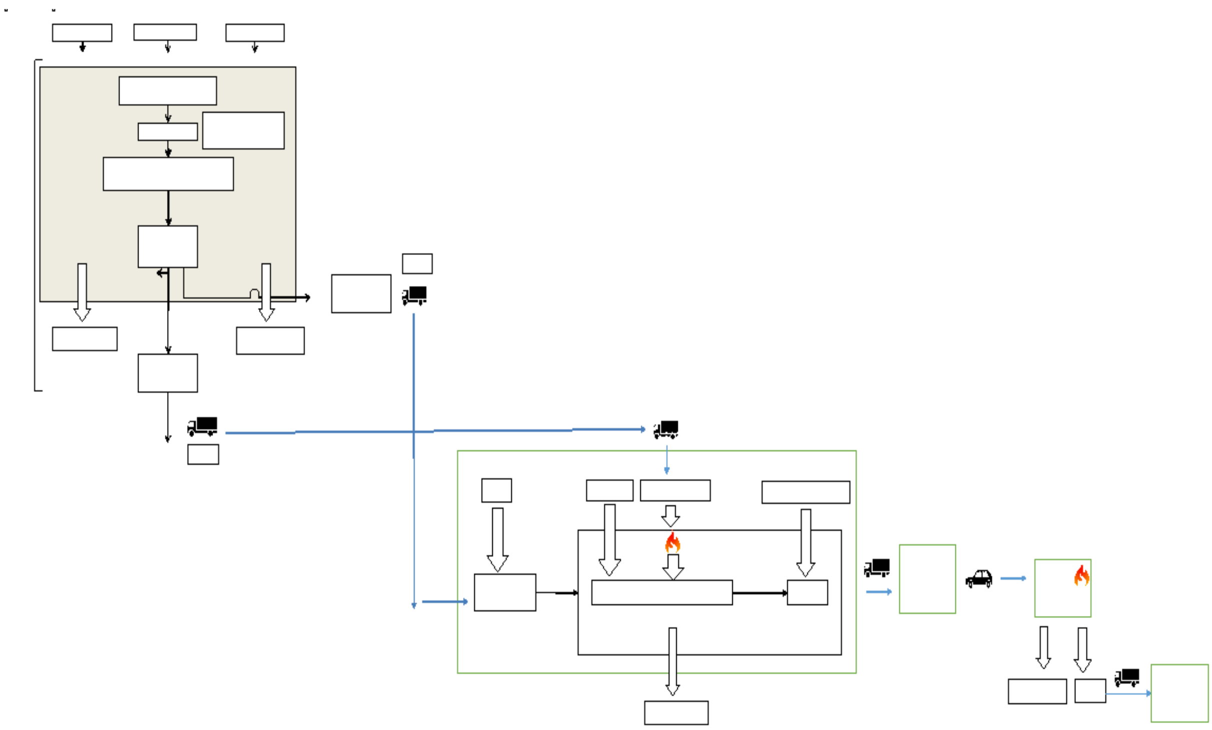

Figure 1: System boundaries of the Industrial pellet productive chain

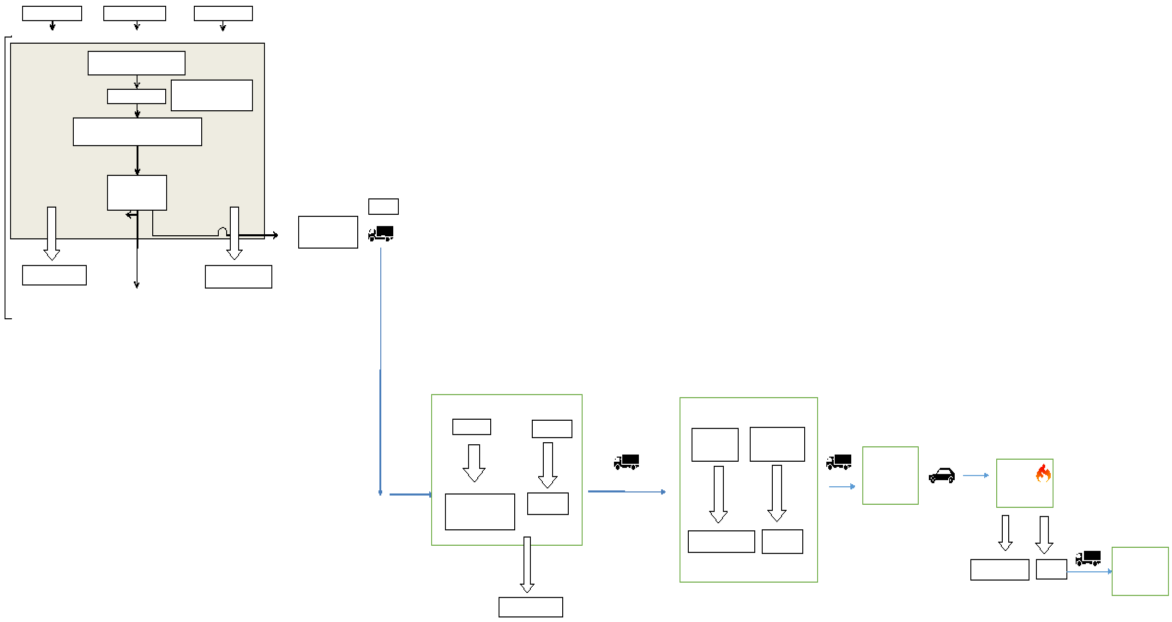

Figure 2: System boundaries of the domestic pellet productive chain

2.2 Scenario analysis

As explained in the section 2.1, two different systems were analyzed: 1) industrial pellet production chain; 2) domestic pellet production chain. For both of them two different scenarios regarding the forest management were considered: intensive model and extensive model. The intensive model is the default model. It requires high intensity management of maritime pine forest, and is characterized by the adoption of time-consuming management practices. The extensive model represents low intensity management. Moreover, two scenarios regarding pellet burning were studied: a) highest emissions in the combustion process; b) lowest emissions in the combustion process.

2.3 Inventory Analysis

Inventory data for forest operations are taken from the study of Dias and Arroja (2012) which studied in details the maritime mine wood production in Portugal. The inputs from the technosphere for forest stage operations include: fuels, lubricants and fertilizers, which were quantified for each operation. Inputs from nature, such as CO_2 assimilated due to forest growth and land occupation, were not taken into account. The amount of CO_2 assimilated during forest growth was assumed to be equal to the amount of CO_2 that will be released back to the atmosphere due to wood oxidation along the downstream life cycle stages of wood.
The first process in the pellet production is the storage of raw material. Following Silva (2009) it was assumed that the movement of raw materials, inside the storage area, is carried out by a hydraulic excavator. The data for the pellet industrial production were provided by a Portuguese factory. Forest residues are burned in the pellet factory for thermal energy. This energy will be used for drying the sawdust, this process has emissions taken from IPCC

(2006), EMEP/EEA (2016a). The data for the local pellet production were developed in the laboratory of the University of Aveiro in a Pellet Machine (MOKIL 225 2015 model) with a power of 7.5 kW. For a domestic production the best option due to cost reductions is the natural drying that is performed by leaving the raw material at atmospheric condition. Data for pellet packaging materials and respective amounts are taken following the study of Laschi et al. (2016). In the local production chain, the raw material is maritime pine sawdust, that comes from the forest and goes to a local sawmill (15 km from Aveiro).
Pellet use stage is equal for both industrial and domestic model. The pellet is bought from a local market and is burned in a pellet stove. From the market to the house, a car is assumed to be used for the transport. This stage includes also the ashes disposal and its transport in a municipal waste collector truck. For an estimation of the emissions to air, emissions factors are used (IPCC (2006), EMEP/EEA (2016b)).
Transport distances (from the forest to the pellet plant) are taken using an average value from other LCA applied to pellet studies (Laschi et al., 2016; Magelli et al., 2009). Following Nunes (2016) it is known that in Portugal the maximum distance when no one wants the raw material due to high transport costs is 70 km, for the domestic model, travel distances are based on the distance from the sawmill (Aveiro) to the university of Aveiro (that is simulating a local producer).
In this model it is assumed that the ashes are trashed by the user and collected by a municipal waste truck. Wood ashes of pine wood could be used as a potassium fertilizer, but the ashes composition is very variable, depending on the combustion system and the material: different combustion systems can produce very different types of ashes, making a specific analysis necessary to determine it. Ashes are thus considered as an inert residue disposed at landfilling facilities.

3 Results

Figure 3 show the relative contributions of the four main stages (forest operations, pellet production, pellet use and transportations) to the total impacts.
The key stages in the production chain are the pellet production and the pellet burning, although pellet burning only affects some impact categories. Contributions of pellet production are due mainly to machinery high energy consumption during the pelletisation processes.
The analysis shows also that transport processes generally do not have a large environmental impact. Transportation phase affects significantly only ozone depletion and fossil depletion categories). It is possible to notice that, if compared to the other main stages, the forest stage is the less impacting phase (no more than 20%).

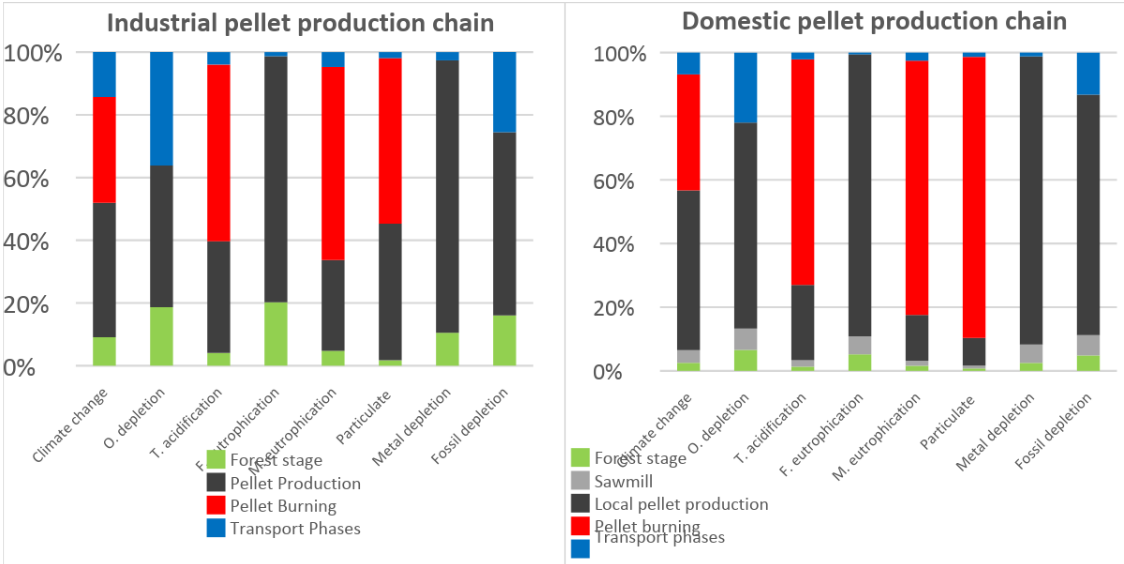

Figure 3: Industrial and domestic pellet production chain hotspots

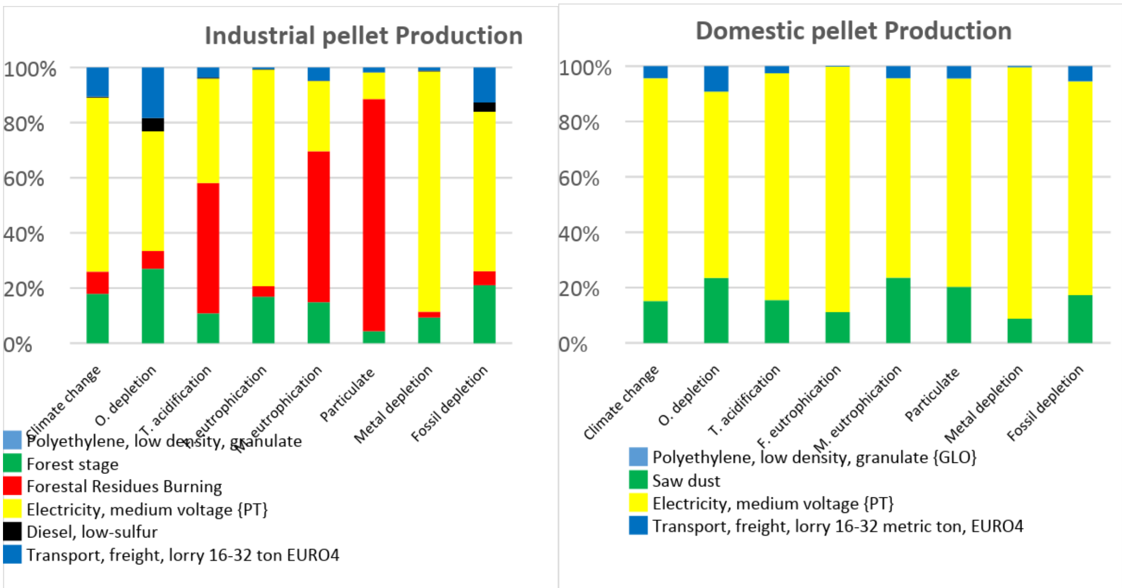

Figure 4: Processes of the industrial and domestic pellet production stage

The production stage consumes a large amount of energy, and as showed in figure, the biggest environmental impacting process in the industrial pellet production factory, is the electricity consumption, used for the pelletizing machineries, also the burning of forestal residues, needed for a more intensive drying procedure (compared to the domestic model) for the pelletization process, has a relevant environmental impact, but both of those stages are fundamental steps for an industrial wood densification process.
The scenario analysis was applied to pellet burning, due to the fact that the emissions of pellet burning can vary in a certain range, due to several reasons, such as a different model of domestic pellet stove used by the final user, or a

wood pine pellet produced by a different company, or different parameters settled in the stove, like the heating output etc.

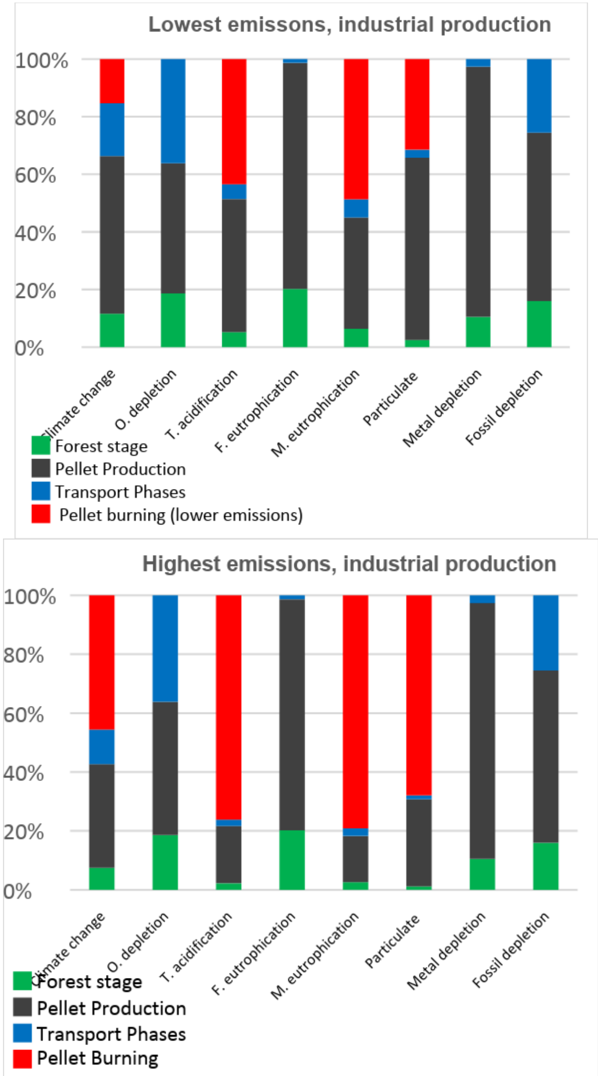

Figure 5: Sensitivity analysis applied to pellet burning stage, industrial model

In the highest emission scenario, it is possible to notice that the impact of the pellet burning becomes the key phase in the production chain with a minimum overall impact that ranges from 50% to 90% in the affected categories. If the emissions are at the lowest, the pellet production phase has the most impacting environmental profile. It’s interesting to notice that despite the lower emissions scenario, pellet burning still accounts for 15% of the climate change impact of the overall production chain and from 30% to 60% in the categories were the burning process has an impact.

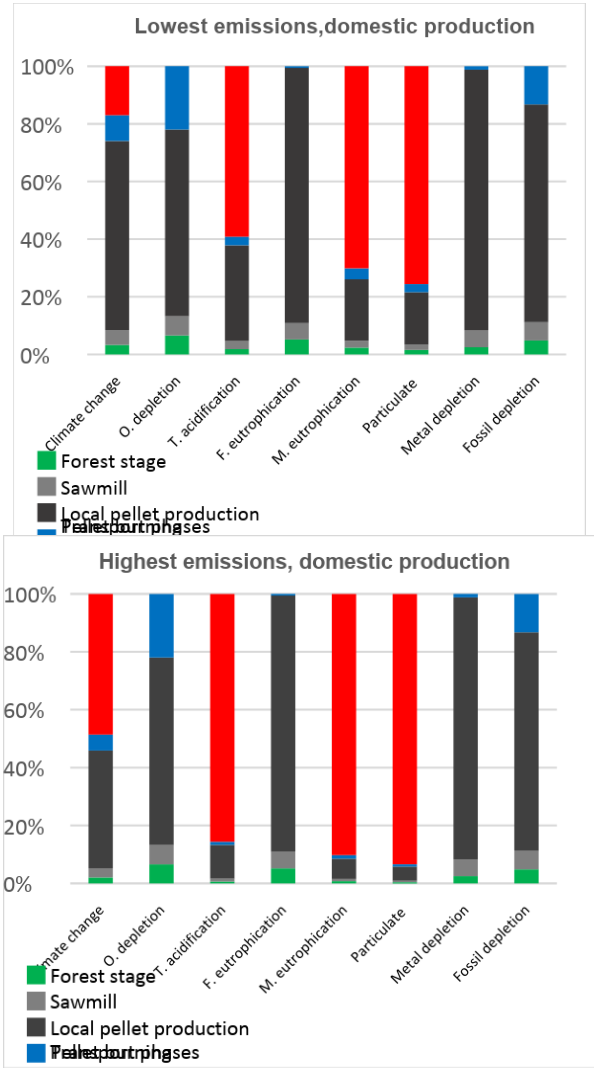

Figure 6: Sensitivity analysis applied to pellet burning stage, domestic production model

Figures 7 and 8 compare the results of all eight scenarios concerning climate change and particulate matter formation, respectively. The first impact category has been chosen because biofuels are often considered a solution to climate change. Indeed, one of the main purposes of biomass use, instead of fossil fuel, is to reduce the GHG emissions. Particulate matter has been selected because particle emission factors from woody biofuels can be relatively high in comparison to other fuels used for energy production (Bolling et al., 2009). Indeed, one of the most problematic issues related to biomass use is the particulate matter formation that can lead to a worsening of air quality.

The main contributors (for all the models) to climate change are CO_2 followed by CH_4 and N_2O, where about 65.1 kg of CO_2 eq. were emitted to air only by electricity used in the pelletizing process (emissions derived from electricity production). A large quantity of CO_2 eq. is emitted during pellet combustion process (54.6 kg). Thus, if we consider the industrial model, highest emission scenario, is the most impacting model for climate change analysed in this work.

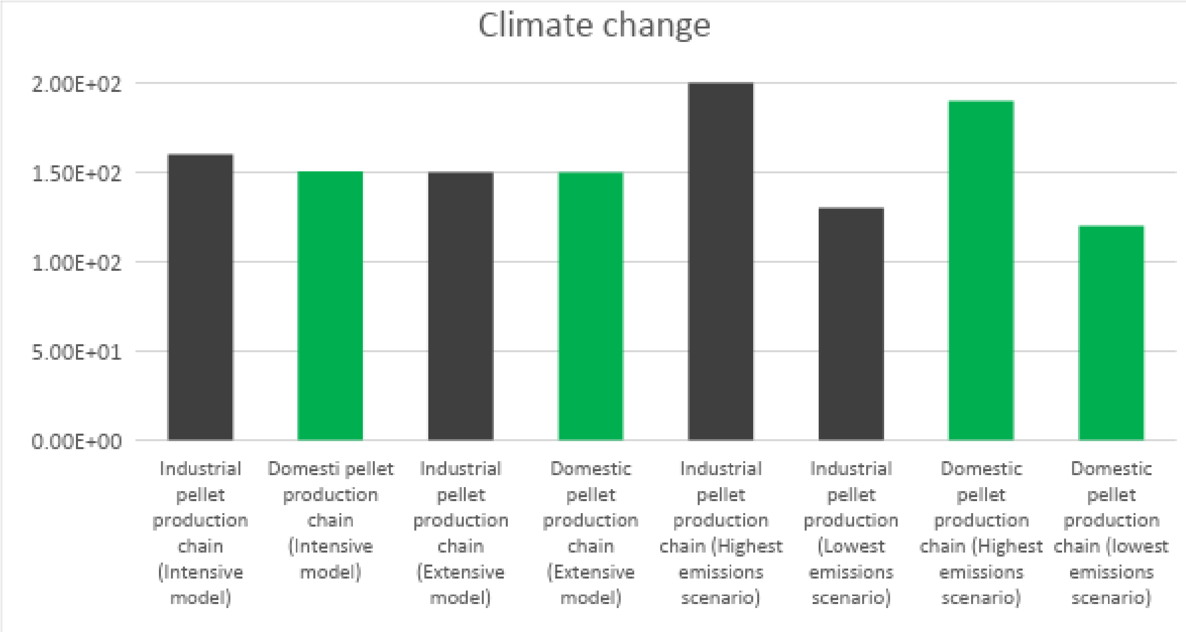

Figure 7: Comparison between all the scenarios analysed in this study for the impact category climate change

If compared to the default industrial model 25% more of CO_2 eq. is emitted. In details in this scenario 89.8 kg of CO_2 eq. are emitted to air in the combustion of 1 ton of pellet. The less impacting is the domestic production chain model, with lowest emissions scenario (19.5 kg of CO_2 eq. for the pellet burning).Most of the PM10 comes from burning processes, 1.33 kg of PM10 eq. comes from pellet burning with 2.3 kg of PM10 and 0.473 kg of PM2.5 and 0.981 kg of PM10 eq. comes from forest residues burning. Also a percentage of PM10 derives from the coal used in the electricity production. We can conclude that the most impacting model in particulate matter formation is the industrial model with high emissions scenario, which leads to an increase of 48% in PM10 eq. respect to the default model.

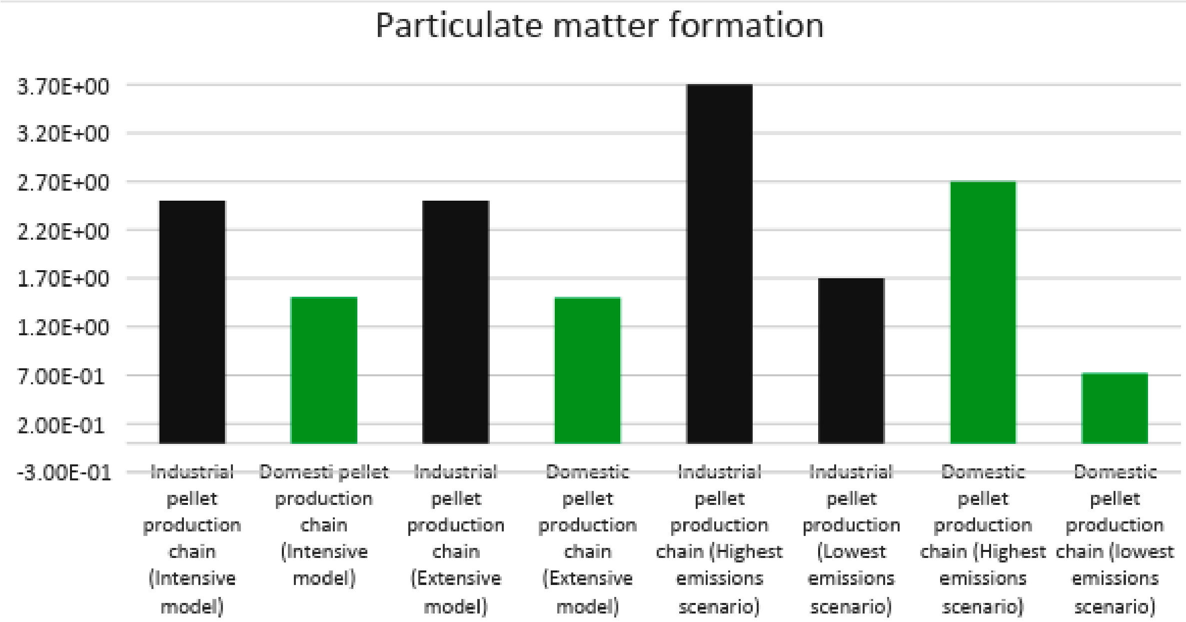

Figure 8: Comparison between all the scenarios analysed in this study for the impact category particulate formation

If we compare the intensive and the extensive forest models, considering only the operations taken inside the forest, (excluding the transport phase of the wood logs), the intensive one has generally impacts higher than the low management one. However the disadvantage of the low intensity model is a reduction in the wood productivity.

4 Conclusions

Based on the finding of this study, the development of local productive chain of wood pellet holds potential in reducing environmental impacts of pellet production, especially in climate change, particulate matter formation, ozone depletion and fossil depletion impact categories. This is mainly due to reductions in the transport distances, and the avoidance of forest residues burning for raw material drying. The results underline the fact that the energy used in the machines used in pelletizing process is the most impacting process during the production chain, followed by the pellet burning. This important contribution is mainly due to the non-renewable source of the electricity consumed. The energy consumption used in the domestic production chain is higher than the industrial-scale requirements due to less efficiency of the process, and for the lack of quality control that a big scale industry can perform on the raw material, especially on the moisture level that has a key role in the energy that will be consumed during the pelletisation process. The phases related with wood production (forest stage) are the stages with the lower environmental impacts, which comes mostly from the phases of forest management stage.

We can conclude that the pellet burning phase is a key phase even when the stove with the lowest emissions scenario is considered. When emissions are assumed to be maximum, the contribution of some critical substances such as

NOx, CO, and particulate, leads to a great worsening of the environmental performance of the model.

5 Acknowledgements

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Life cycle assessment in improving the sustainability of existing buildings: some issues in historic buildings

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Abstract

Buildings account for 41% of total end-use energy consumption and 18.4% of total anthropogenic GHG emissions. Energy saving and emission reduction targets are urgent to be achieved. Historic building is a substantial proportion of existing building stock and its sustainability is critical for the whole building sector. This review summarises recent contributions related to the evaluation of sustainability of existing building using LCA methodology, with a special attention to historic buildings. Key points in methodological options are outlined and compared, such as system boundary, calculation methods, etc. Based on these review, future challenges and improvement needed are analysed.

1 Introduction

Building sector consumes the largest proportion of energy in Europe: 41% of the total final energy consumption (Enerdata, 2012), in which space heating constitute 71% of the total end use. Regarding to greenhouse gas (GHG) emission, building sector contributes 18.4% of total global anthropogenic GHG emissions with both direct and indirect emissions (IPCC, 2015). Historic buildings represent a substantial part in total European building stock: more than 14% buildings were built before 1919, 12% were built between 1919 and 1945 (Troi, 2011), and more than 40% were built before 1960 (BPIE, 2011). The construction year suggests that most of the historic buildings are not regulated by any energy performance certificate. In particular, their obsolete equipment and envelope lead to low energy performance (BPIE, 2011; Fabbri et al., 2012).

To restrain climate change and delay the depletion of scarce energy resources, EU commission released associated legislations to address energy efficiency. In Directive 2010/31/EU (EU, 2010), Europe 2020 strategy was underlined: commitment to reduce at least 20% of overall GHG below 1990 levels by 2020 and to reduce 20% the Union's energy consumption. Considering the abundant stock and energy consumption of historic buildings, it is urgent to improve the sustainability. Life Cycle Assessment (LCA) is generally used in the construction sector to assess the sustainability of buildings or relative activities in building's life cycle (Chau et al., 2015; Vilches et al., 2017). The review presented in this study aims at summarising recent contributions in reducing the environmental impact of historic buildings using LCA methods, to explore the barriers in practice, and indicate future development. Although there are social and capital aspects in the conservation and retrofit activities of historic building, literature adopting Social Life Cycle Assessment (SLCA) and Life Cycle Costing (LCC) are not included in this review.

2 LCA practice in historic building sector

The EN 16883: 2017 (EU, 2017) defined historic building as historically, architecturally or culturally valuable buildings, which referred to historic buildings of all types and ages. In LCA research, analysis of buildings dating back before 1945 is very limited, so the scope is expanded to buildings built before 1960s, which is one of the criteria of culture property in Legislative Decree no.42 of 2004 of Italy(MiBACT, 2004).

a. Retrofit of historic buildings

Due to the low energy performance of historic buildings, energy efficiency and emission targets could only be achieved with the replacement of these buildings. However, this replacement implies of demolishing and reconstructing new buildings (Boardman et al., 2005) or implementing retrofit solutions in the existing stock. In the debate of "demolish" or "retrofit", several studies adopted LCA methods to prove the environmental benefits in the retrofit of historic buildings (Itard & Klunder, 2007). From a sustainability point of view, existing buildings already embody the energy used in constructions. The energy used in resource extraction, transportation to the plant and manufacturing of construction materials is known as embodied energy (Dixit, 2017). The embodied energy of construction process could amount up to 30% of the whole life cycle energy consumption (Itard & Klunder, 2007). With demolition, the embodied energy would be discarded. In Munarim's review of feasibility of heritage buildings rehabilitation (Munarim & Ghisi, 2016), the application of LCA was analysed regarding how to establish the correct indicator of environmental impacts. To determine whether a retrofit would be a feasible solution, the LCA should be applied in comparing: a) the environmental impact associated with the retrofit interventions and operational phase after the retrofit and b) the environmental impact arising from demolishing and, reconstructing plus operational phase after the rebuild.

Aforementioned studies emphasise the importance of environmental loads in retrofit interventions. On this base, other studies assess the sustainability and energy efficiency of different retrofit strategies to select the optimal solutions. Invasive retrofit interventions are often not allowed considering on the aesthetic and historic value of the buildings. Usually, retrofit strategies comprise internal insulation, glazing replacement, heating/cooling system upgrade, solar integration, etc. In the applications of LCA, insulation is assessed most frequently: The assessments look into selections of types, thickness and position (Bortolin et al., 2015; Rodrigues & Freire, 2017). Previous research confirm that both insufficient and excessive insulation cannot achieve energy efficiency or sustanability. Using a LCA method, the optimum insulation thickness and type could be determined. At the same time, conservation of historic characteristic could be ensured with the retrofit. Considering the specific features of historic buildings, a framework combining on-site survey and, building energy simulation with life cycle modelling is emerging. A throughout building survey is necessary to understand the performance of the building in detail while providing recommendations for retrofit (Alajmi, 2012). Since the properties of historic materials are complex and often unknown, on-site surveys also serve as a method to collect enough information for the energy simulation (e.g. thermal conductivity)(Genova et al., 2017). Energy simulation is applied to calculate the operational energy consumption for the life cycle inventory. For example, a dynamic simulation was implemented for a historic building retrofit (Rodrigues & Freire, 2014), in which researchers considered a realistic use of the building with occupancy and other internal heat gains, exact schedule of lighting and appliances.

Overall, LCA application in historic building retrofit is fairly limited: usually just single retrofit solutions are studied. There is a lack of environmental impact comparison between different retrofit packages. For example, previous research involving multiple retrofit solutions evaluates the efficacy of different interventions as single process (Iyer-Raniga & Wong, 2012), or compares the solutions by economic assessment instead of environmental one (Tadeu et al., 2015).

b. Maintenance and repair of historic buildings

Maintenance is known to be crucial for the survival and in-service use of historic buildings. However, it also has considerable environmental impact. In the study of existing traditionally built Dutch buildings (Blom & Itard, 2007), found that the environmental impact of façade maintenance is 5-43% of the impact of producing a new building façade over a period of 50 years. Additionally, when extending the maintenance impact to the whole building level and longer service years, the maintenance impact would be higher. Therefore, reducing the environmental impact of maintenance will contribute to increase historic buildings' sustainability.

Some researchers focus on maintenance material in historic buildings such as natural stone (Chishna et al., 2010), addressing the importance of the stone source, which will lead to significant increment of impact because of transportation. Based on data generated from aforementioned literature, Kayan uses LCA methods to assess the embodied carbon expenditure of maintenance techniques with a special focus on historic masonry buildings (Kayan, 2013). The results show that the embodied carbon expenditure is highly influenced by the number of maintenance interventions, longevity of repairs, and total wall surface repaired. Guidance for the selection of maintenance interventions could be provided following this approach. In the calculation procedures (Kayan et al., 2016), the system boundary includes the manufacturing of natural stone, transportation and all repair processes. Single and combination of repair techniques are evaluated and, among these scenarios, the LCA results show that replacement of the stone is the most eco-efficient solution within 100 years maintenance profile.

3 Simplification and assumptions in literature

LCA method has proved to serve as a tool supporting in energy retrofit of historic buildings. Since building system involves large amount of products, processes and multidisciplinary perspectives, full LCA is extremely complex. Hence, simplifications are usually adopted in practice related to data input, system boundary, calculation method, etc. These simplifications could results in uncertainty and therefore it is important to clarify the boundaries.

a. System boundary

EN 15978:2011 (EU, 2011) establishes modules (A to C) to describe the different phases in building life cycle[41]. These modules cover all the environmental impact and aspects related to processes in buildings: from construction material production to building's "end of life". For the existing buildings, the standard addresses that the system boundary should include the stages in the remaining service life of the building (from intervention to end of life stage).

Table 1: Summary of system boundary for existing buildings

Literature		gi et al., 2015	s & Freir e	eu et al., 2015	olm et al.,	mbo et al.,	ga & Won g	& Park er,	oran o et al.,
A1-5 Pre-retrofit stages								x	
B5 REFURBISHMENT	Demolition	x	x	x		x	x		x
	End of life stage of replaced components	x	x	x	x	x	x		x
	Components production	x	x	x	x	x	x	x	x
	Transportation	x	x	x	x	x	x	x	x
	On-site construction	x	x	x			x		x
	Waste management					x			
B2 MAINTENANCE		x	x	x		x	x		
B3 REPAIR									
B4 REPLACEMENT		x				x	x		
B6 OPERATION		x	x	x		x	x	x	
C1-4 END OF LIFE						x	x	x	x

In historic building retrofit studies, very few studies include all stages. Table 1 summaries the system boundaries of reviewed literature. The most assessed stages are B5 Refurbishment (with varied options), B2 Maintenance and B6 Operation stage. Research in (Oregi et al., 2015) aims at verifying the capability of LCA methods in selecting retrofit solutions for a multi-family building in San Sebastian (Spain) from 1962. Three LCA methods are investigated: full LCA (showed in Table 1), simplified LCA (product, replacement and operation) and operational energy use assessment. Results indicate that simplified LCA could

[41] A1-3: Product stage; A4-5: Construction Process Stage; B1-7: Use stage; C1-4: End of life stage.

substitute full LCA sufficiently, while operational energy use assessment cannot reflect whole life cycle energy use effectively. Based on those results, Oregi et al. conclude that building life cycle phases relate to transport, on site construction or end of life are generally negligible regarding resource use and environmental impacts. Building use and products manufacturing phases are sufficient for retrofit decision making. In the study of existing buildings, environmental impacts of the end of life stage represents less than 1% of whole life cycle (Ortiz-Rodrã-Guez et al., 2010), while impacts of maintenance vary largely in the whole life cycle (Proietti et al., 2013; Winistorfer et al., 2005). In the case of historic buildings, end of life stage also holds very small share. For maintenance and construction stages, most research emphasise their importance due to specific technique and materials needed.

b. Calculation method

Three LCI methods are applied in reviewed literature: Process Analysis, the Input-Output analysis and Hybrid Analysis. In Process Analysis inputs and outputs are limited outside the system boundary to simplify the calculation. This traps the results in “truncation errors”. This error is case-dependent and the magnitude could reach 50% (Lenzen & Manfred, 2001). It could be adequate in comparing different options for the same product or service, where the truncation will have the same border (Vilches et al., 2017). Input-Output method is an adaptation of a technique to express the financial interactions between different economic sectors of a nation (Menzies, 2011). It is accurate in quantitative assessment, but the comparability is relatively low since the economic sectors differentiate in definition and numbers. The hybrid method combines the former two methods with the intention to break the limitations. It extends the outside inputs and outputs by including input-output data for some procedures, while uses process analysis for the others. Most studies under review are using the Process Analysis method. Input-output method can hardly been applied in historic buildings, because the economic input-output data during building construction period are rarely available (Menzies, 2011). When applying Process Analysis, small items and ancillary activities (e.g. administration) are usually excluded.

c. Data gap for historic buildings

Most studies use environmental data from commercial databases to calculate environmental inputs and outputs in each process due to the lack of data describing environmental impact of traditional materials (Kayan, 2013). In maintenance phase, values like embodied carbon coefficient are summarised for new buildings and materials (Kayan et al., 2016). Production industry of traditional materials is declining due to craft loss and decrease of market demand, so environmental impact value of common materials cannot be accurately calculated for historic buildings. In the construction phase, there is also a lack of data quantifying the energy consumption (Pombo et al., 2016). When assessing the life cycle energy consumption, the operational energy use is typically simulated with numerical software. The material and products of the building will deeply influence the energy performance. Moreover, historic buildings have unique characteristics regarding construction and materials. So they present specific energy performance when comparing to modern buildings. These data can only be defined with a detailed survey. To fulfil these data gap, some studies (Chishna et al., 2010) are aiming at collecting necessary data from historic material industry. However, a wide range of materials and crafts are still lacking information about thermal properties, environmental impact, or economic coefficient etc. Once the inventory is complete and accurate, an integrated LCA could be applied in historic building sector. Until then, academics have to select data based on careful analysis, in terms of manufacturing details and properties of construction elements. (Bortolin et al., 2015).

d. Building lifespan and components service life

Building and components service lifespan influence the overall environmental impact greatly. Durability and longevity of building and components would change the overall result since the impact will be distributed in their lifespan. In the reviewed studies, the lifespan is usually defined according to standards (Pombo et al., 2016) and materials' service life are selected based on Environmental Product Declaration (EPD) or databases like National Association of Home Builders (NABH). However, in the case of historic building, the durability data is often lacking (PGL, 2011). Another aspect to highlight is that unsuitable retrofit of historic building could reduce the durability and longevity of the materials, increasing maintenance and retrofit cycles (Menzies, 2011). Further analysis is needed to define the different service life assumptions for each specific case.

4 Conclusions

This paper has outlined the application of LCA method for the environmental assessment of activities in historic buildings. The use of LCA method allows retrofit and maintenance solutions assessed and compared so as to contribute to a better informed decision-making. It is found that the number of studies in historic building sector is relatively low and inventory is incomplete to a large extent. A number of databases exist, but cannot be applied to historic buildings due to the lack of historic materials and construction techniques. A comprehensive system boundary results in a relatively high precision calculation, while in practice some process could be simplified. For historic buildings, the manufacture of specific building products, construction and maintenance could make a great difference on whole life impact. An accurate LCA relays heavily on the inventory quality and the robustness of the methodological assumptions. In future research, more historic inventory should be collected and tested the sensitivity to environmental impacts. Durability and other properties of historic materials should also be further studied and evaluated. Historic buildings are culture heritage, therefor the feasibility of the upgrade solutions should consider not only their whole life cycle impact, but also their influence on historic characteristics. More conservation compatible retrofit packages should be investigated by LCA method to explore the actual performance, as well as maintenance planning.

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LCA overview on different post-combustion carbon capture applications

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Abstract

The aim of this paper is to compare, from a technical environmental point of view, different post-combustion capture technologies applied to a supercritical pulverized coal power plant. All the selected technologies are based on chemical absorption using different solvents. In particular, two of them are amine-based technologies, while the other two are inorganic solvents using aqueous ammonia and aqueous potassium carbonate. This paper presents the results of a comparative LCA among the four different technologies and the reference case without CO_2 capture. The benefits of the inorganic solvents compared with amines are principally due to avoidance of emissions from amine degradation along with a cleaner footprint during the production and transport process of the solvent maintaining almost the same global warming potential and energetic performances.

1 Introduction

One of the most important sources of global anthropogenic carbon dioxide emissions is the combustion of fossil fuels for power generation. Power plants contribute more than 40% of the worldwide anthropogenic CO_2 emissions and more than 24% of total GHG emissions (Stern, 2006). Scenarios about the future global energy requirements forecast an increasing demand for electricity, which in 2040 is predicted to be 40% higher than the current demand (IEA, 2018). In particular, in many countries, coal is a convenient raw material for power generation because it is cheap, and the technologies based on coal are well developed (Zhao and Chen, 2015). As a consequence, the capacity of the coal-fired power plants will increase by approximately 40%, and the carbon dioxide emissions derived from those plants are inevitably expected to rise (H2-IGCC, 2010).

The International Panel on Climate Change (IPCC) have suggested that carbon dioxide (CO_2) equivalent levels should be estabilished at 490–535 ppm in an effort to contain human induced global warming to between 2 °C and 4 °C over the next century to prevent catastrophic climate change. In order to meet these aggressive targets, a suite of solutions for reducing CO_2 emission is necessary including energy efficiency, renewable, nuclear and carbon capture and storage (CCS). CCS is a recognised part of this solution as it has potential to provide deep cuts in CO_2 emissions from large stationary sources such as power generation, which will continue to be dominated by burning fossil fuels (IEA, 2018).

Post-combustion capture has the large benefit of being readily applicable to already existing power plants, both coal or natural gas-fired. The carbon capture can be accomplished by adsorption or chemical absorption. The use of amine aqueous solutions for the chemical absorption is widely used in other industrial sectors, such as the oil&gas or the urea industries.

The most studied post-combustion technology is the chemical absorption. In particular, monoethanolamine (MEA) represents the reference chemical for this purpose (Giuffrida et al., 2013;Wang et al., 2011;Sanchez Fernandez et al., 2014). Other amines have been proposed such as methyl diethanolamine MDEA (Oyenekan and Rochelle, 2003) and piperazine (Sanchez Fernandez et al., 2014;Kvamsdal et al., 2014) in order to decrease the energy impact of the carbon capture plant on the net power produced by the power plant.

As an alternative to the amine, aqueous ammonia solvent (Valenti et al., 2012;Bonalumi and Giuffrida, 2016; Bonalumi et al., 2016) and potassium carbonate solvent (Nejad et al., 2015; Grant et al., 2014) are examples of inorganic solvents with promising energetic performances. The third generation solvents are not far from the theoretical minimum (Kim and Lee, 2017), so in addiction to the energetic efficiency of the capture process other parameters must be considered in order to lead to the application of the best technology.

The aim of this paper is to compare, from a technical environmental point of view, different post-combustion capture technologies applied to a supercritical pulverized coal power plant. All the selected technologies are based on chemical absorption using different solvents. In particular, two of them are amines technologies with MEA and MDEA, while the other two are inorganic solvents using aqueous ammonia and aqueous potassium carbonate.

LCA is an internationally recognised methodology for comparing alternative products and processes taking into account the impacts from cradle to grave and over a range of relevant environmental indicators. This paper presents the results of a comparative LCA among the four different capture technologies cited before and the reference case without CO_2 capture.

The LCA analysis will return the results considering the following environmental impact indicators: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Abiotic Depletion Potential (ADP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Human Toxicity Potential (HTP), Photochemical Oxidation Potential (PCOP), Terrestrial Ecotoxicity Potential (TEP), Marine Aquatic Ecotoxicity Potential (MAETP). Indicators such as GWP and ADP are related more on the energetic efficiency of the capture process which influences the specific emissions of greenhouse gasses and the Abiotic depletion potential (which is related to the fossil and chemical consumptions). The other environmental indicators such as the acidification potential or the human toxicity potential are maily influenced by the solvent used for the carbon capture and the related emissions.

2 Methods

a. Process modelling and technical evaluation

The coal, transported pneumatically using pre-heat air, is fed to a boiler. Coal combustion occurs here and hot flue gases are formed in the combustion process. The hot flue gases are used to pre-heat the primary and secondary air streams and to generate steam, which is then expanded in the steam turbine for power generation. The NO_x emission control is done by Selective Catalytic Removal (SCR) using ammonia. In the study (Petrescu et al., 2017) was considered that SCR unit will decrease the NO_x limit to below 20 ppm as required for downstream CO_2 capture plant. The cooled flue gases are sent to the Flue Gas Desulphurization (FGD) in order to remove sulphur. Limestone is used as raw material for desulphurization, and gypsum is formed in the process.

The carbon capture processes differ among them by the chemical absorption reactions of the carbon capture section. The different processes have different feedproduct, different bypoduct and different emissions. The description of the MDEA and ammonia technologies are presented in the paper by (Petrescu et al., 2017), while the MEA and potassium carbonate technologies in the work by (Grant et al., 2014). In Figure 1 there is the schematic layout of the coal power plant including the CO_2 capture; all the analysed cases are considered with a CO_2 capture efficiency higher than the 85% on the total CO_2 flow at the stack.

Where considered, the captured carbon dioxide stream is dehydrated using tri-ethylene-glycol (TEG) in a standard absorption and desorption cycle and then compressed to 120 bar. The compression is done in four stages with inter-cooling.

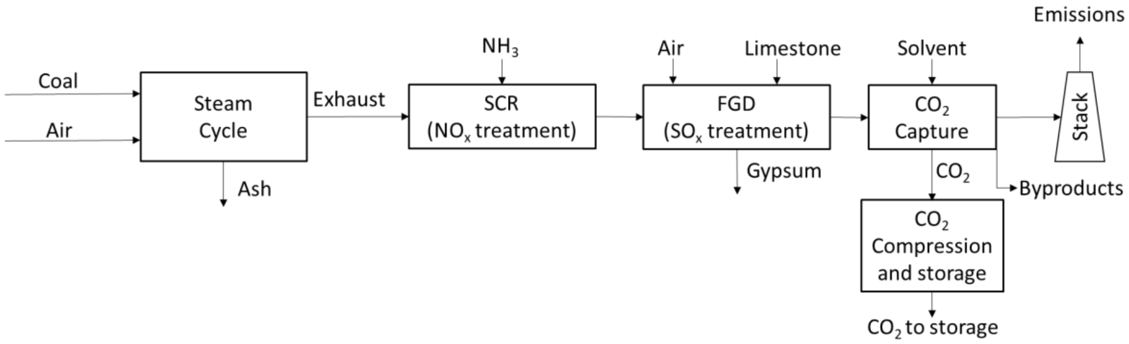

Figure 1: Generic plant layout of the coal power plant with the CO_2 capture

b. LCA analysis and assumptions

The primary goal of this study is to quantify and analyze the total environmental aspects of power production using SC pulverized coal power plant with/without post-combustion CCS technologies. To this purpose, the present work analyses the results, taken from the literature, of different technologies, as mentioned above. There are two comparative analyses: (i) the first between aqueous ammonia solvent technology and the MDEA technology with respect to the coal plant without CO_2 capture and (ii) the second between the K_2CO_3 technology and the MEA technology. Finally, a third paragraph reports a sensitivity analysis focused on MEA capture plant in order to present the parameters that maily impact on the LCA indicators.

In the first comparison (NH_3 vs. MDEA) the functional unit proposed is one MWh of net power produced. The net power produced is obtained, for each case, by subtracting the auxiliary power consumption from the gross electric power. The material and energy balance are available from the modeling and simulation phase. A “cradle-to-grave” LCA approach is adopted in the study by (Petrescu et al., 2017).

A detailed assessment of each pathway step, from raw materials extraction to power production, including CO_2 transport and storage, is presented. The LCA study by (Petrescu et al., 2017) is based on the energy and material consumption of each unit process. Several assumptions have to be considered in the LCA. A requirement of the study is that the plant is self-sufficient in all its utilities, which means that electricity must also be produced to drive the machinery (Figure 1). The midpoint impact categories considered in CML 2001 method are: GWP, AP, EP, ODP, ADP, FAETP, HTP, PCOP, TEP, MAETP. These indicators are widley described in the literature (Korre et al., 2010).

In the second comparison (Grant et al., 2014), the functional unit proposed is one tonne of CO_2 separated by the capture plant. The analysis considers the pathway steps of the plant construction, the raw material exstraction and the emission related to the power production until the carbon separation process. Both the CO_2 compression and the CO_2 transport and storage are not taken in to account. The same midpoint impact categories are considered because the same method is selected, i.e. CML 2001. LCA boundaries adopted in different papers are illustrated in Figure 2.

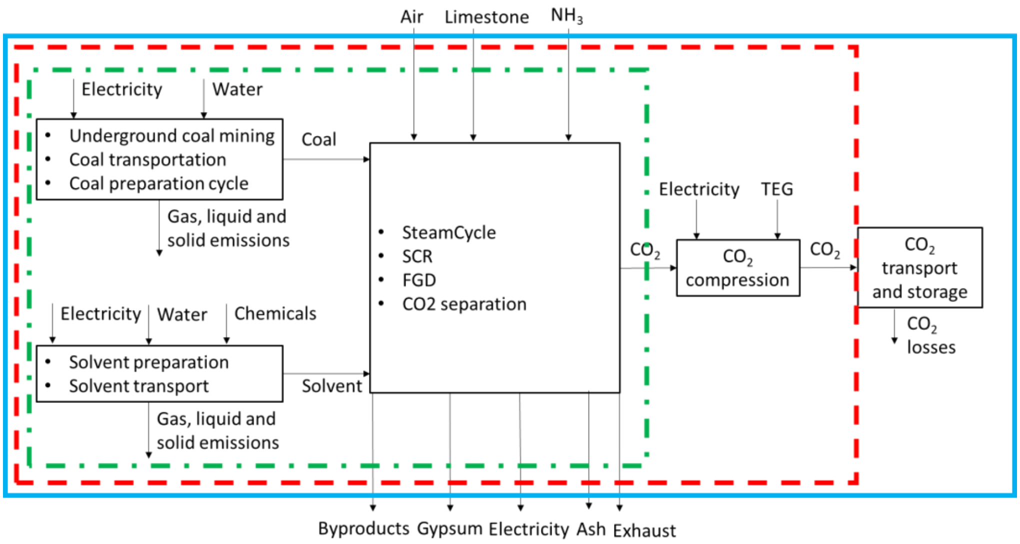

Figure 2: Boundary conditions for the cited works: (i) in blue solid line the boundary of the work (Petrescu et al., 2017), (ii) in red dashed line the boundary of the work (Schreiber et al., 2009) and (iii) in green dashed-dotted line the boundary of the work (Grant et al., 2014)

Finally, a concise sensitivity analysis taken by (Schreiber et al., 2009;Grant et al., 2014) for a MEA capture case is presented to show in brief the main parameters that influence the LCA. The parameters considered in the (Schreiber et al., 2009) are only six (Primary energy PE demand, GWP, HTP, AP, POCP, and EP). The system boundaries are from the raw material extraction processes to the CO_2 compression and liquefaction, while the CO_2 transport and storage are not considered.

3 Results and discussion

In this paragraph the three analyses taken from the literature are presented. The results cannot be directly compared because the system boundary, the life cycle inventory and the functional unit are different. Anyway, qualitatively the results return common conclusions that help in the comprehension of the LCA applied to coal plant with carbon capture.

a. MDEA capture plant vs. aqueous ammonia technology

All plant concepts evaluated generate about 385-545 MWe net power, with a net plant electrical efficiency of about 43.33% for the case without CCS and about 34-36% for CCS cases (Petrescu et al., 2017). The CCS cases investigated are the aqueous ammonia capture plant and the MDEA plant, both compared with the standards SC coal plant without CCS.
Figure 3 *Figure 3* reports the LCA indicators for the three cases, while Figure 4 reports four of the main indicators, where are highlighted all the contributions of the different processes.
The GWP value for SC coal plant is 970.37 $kg_{CO2eq.}$/MWh. Looking deeper into the details (Figure 4) the total GWP is mainly due to two processes: (i) 801 $kg_{CO2eq.}$/MWh is coming from the SC pulverized coal power plant operation, (ii) 154 $kg_{CO2eq.}$/MWh is coming from coal mine operation. For MDEA case the total GWP value is 495.93 $kg_{CO2eq.}$/MWh. The SC power plant with MDEA capture represents 91 $kg_{CO2eq.}$/MWh of the total value which is 88.66% lower than the benchmark case without capture. On the other hand, coal mine operation has a contribution higher that in the benchmark case (e.g.195 $kg_{CO2eq.}$/MWh vs. 154 $kg_{CO2eq.}$/MWh) due to the fact that a lower electric efficiency is correlated to a higher quantity of coal extracted and transported in this case. Significant contribution to the total GWP value is also brought, in the present case, by other steps, e.g. CO_2 losses in transport and storage (71.4 $kg_{CO2eq.}$/MWh), MDEA production (e.g. 65 $kg_{CO2eq.}$/MWh) and CO_2 pipelines commissioning (e.g. 52 $kg_{CO2eq.}$/MWh), steps that are not present in the benchmark study. The considerations for the MDEA case are valid also for the ammonia case. Indeed, the small differences are due to a lower carbon capture ratio (85% vs. 90.2%), which leads to a higher emission of CO_2 from the power plant, but less in the CO_2 capture, transport and storage section and less emissions for the solvent production. Anyway, the GWP of this two technologies are very similar (500.33 $kg_{CO2eq.}$/MWh vs 495.93 $kg_{CO2eq.}$/MWh).
As a final result, it is important to highlight that, despite a carbon capture ratio higher than 85% in both the cases, the overall carbon footprint decreases less than 50%.
Considering the other indicators, as Figure 3 shows, the MDEA case has the highest value for almost all the indicators. In particular, MDEA case differs from the ammonia case for the indicatiors like AP, FAETP, HTP, PCOP, TEP, MAETP.

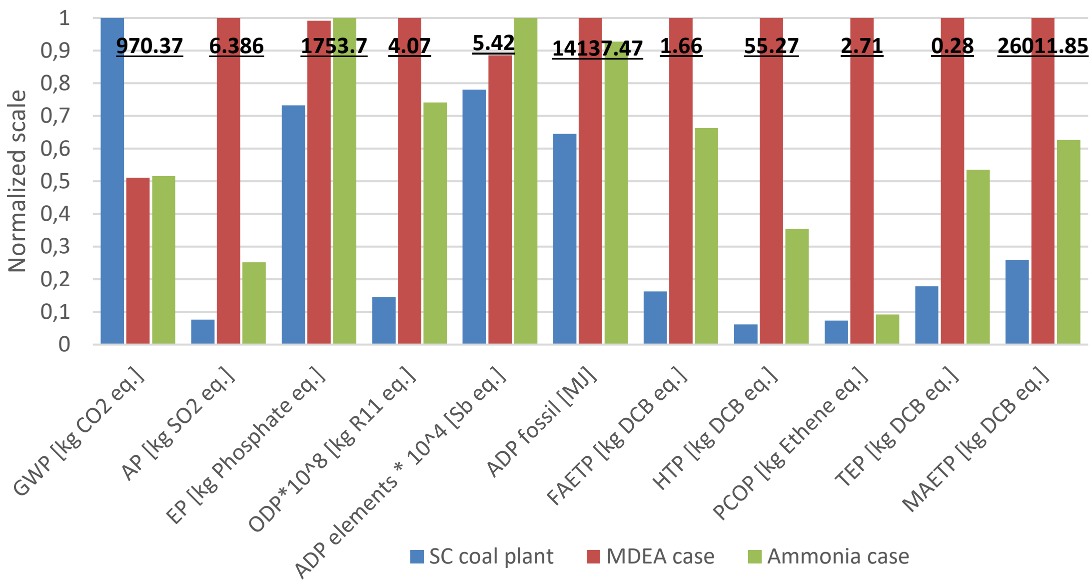

Figure 3: LCA indicators values for the three cases analysed by (Petrescu et al., 2017) specifics on the MWh of electric power produced. The results are normalized on the higher value of each indicator, which value is reported with the number on the top of the columns

Analysing deeply the contributions of the different processes for some indicators in Figure 4, the results state that the main reason of the higher toxicity and pollution of the MDEA case is related to the MDEA production and transport process. Hence, since there are not important benefits in terms of CO_2 capture and energy efficiency, MDEA technology has a higher environmental impact with respect to aqueous ammonia technology. The reason is mainly due to the production, transport losses and degradation of the solvent.

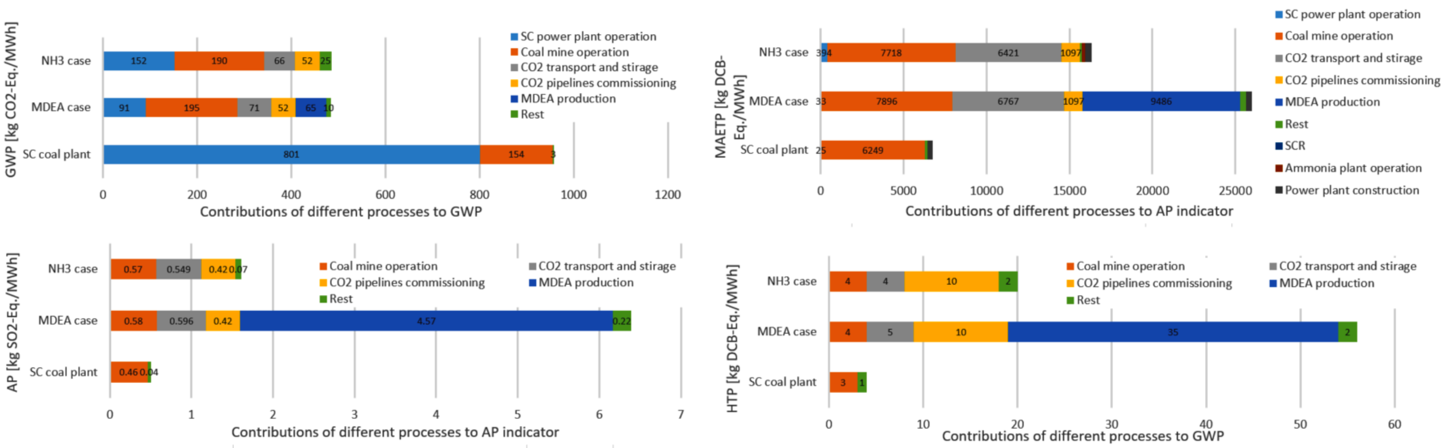

Figure 4: Significant environmental indicators for SC pulverized coal power plant with/without CCS with the explicit contributions of the different processes by (Petrescu et al., 2017)

b. MEA capture plant vs. Potassium carbonate technology

The comparison here presented is taken from (Grant et al., 2014). The functional unit assumed in this study is 1 tonne of CO_2 captured. Results for MEA and the potassium carbonate technology UNO MK3 are presented in Figure 5.

The global worming potential and the embodied energy are lower for the K_2CO_3 technology mainly due to its higher energy efficiency and the lower energy intensive solvent production process. For example, UNO MK3 uses 36% less electricity and heat than MEA and it has also higher consumptions in the solvent production. This results in lower greenhouse emission specifics on the tonne of CO_2 captured (142 $kg_{CO2eq.}$ vs. 223 $kg_{CO2eq.}$)

The toxicity, acidification and eutrophication indicators are higher for the MEA case supposing a recovery of the 95% of degradation products back in to the solvent and not emitted into waterways. Indeed, MEA degrades upon contact with flue gasses impurities such as SOx and NOx forming toxic compounds such as nitrosamines and formaldehyde, which may be emitted within the decarbonized gasses. UNO MK3, on the other hand, is based on an inorganic solvent which is not degradated by the impurities and does not emit degradation products with a lower environmenta impact and toxicity.

The higher value of photochemical ozone creation potential (PCOP) in the MEA case is led by the production of the ethylene and other organic compounds, which are precursors of the MEA production.

Considering both the results of this comparison and the comparison presented in the previous paragraph, the amine production, transport and degradation during carbon capture have a very strong impact on the environmental indicators with respect to other inorganic solvents like NH_3 or K_2CO_3.

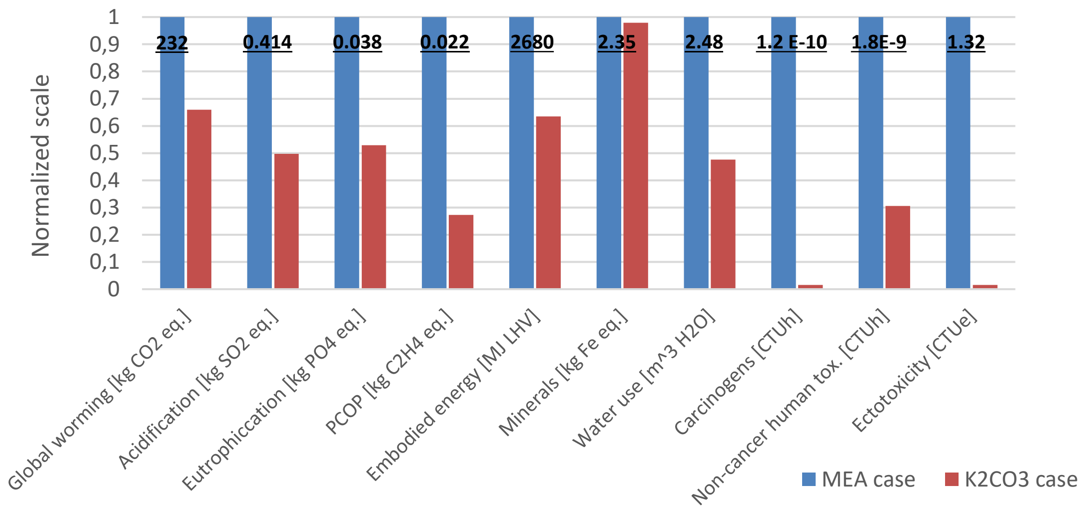

Figure 5: LCA indicators values for the three cases analysed by (Grant et al., 2014) specifics on the tonne of CO_2 separated. The results are normalized on the higher value of each indicator, which value is reported with the number on the top of the columns

c. Sensitivity and scenario considerations on CCS technologies

This paragraph aims to cite some sensitity analysis from the literature in order to identify and brefly discuss which parameters have more impact in the LCA indicators results.
Sensitivity analyses are undertaken by (Schreiber et al., 2009) for a MEA capture case to determine the effect on the total life cycle impacts. The parameter considered with the higher impact is the coal origin. As coal origin, in the reference case, the German hard coal mix is assumed. For variations, Western Europe, Australia, South Africa, and Russia are chosen. In our calculation, the origins do not affect the coal quality for combustion, which is assumed to be Pittsburgh No. 8 for all the analyses, but it affects the supply of raw coal, which depends on the upstream processes “mining” and “coal transport”. The influence of the origin of imported coals on the life cycle impact results.

For the selected origins, inventories for extraction and for transports are very different. If the coal exclusively originates from Australia (AUS) or South Africa (ZA) all impact potentials increase except greenhouse gas potential, due to the energy consumption of the long-distance transports (diesel fuel for ships). The slight decrease for greenhouse gas potential is caused by much lower methane emissions during the extraction of coal in Australia and South Africa. If Western European or Russian coal is used, only marginal alteration is observed. Therefore, if a chosen technology needs higher coal inputs, the coal origin with its necessary transports is gaining increasing importance.

In the sensitivity analysis conduced by (Grant et al., 2014) the results highlight that another important parameter is the recovery rate of MEA in the waste water stream is an important parameter as it has a large effect on the ecotoxicity results. A reduction of 5% in recovery from the default of 95% to a 90% recovery rate almost doubles the impact on ecotoxicity. However, if the recovery rate can be increased from the default of 95% up to 99% it would be reduced by a factor of 4. All the same, even at 99% recovery, the ecotoxicity indicator is still ten times higher than the results with K_2CO_3 technology. The sensitivity analysis to the fraction of MEA that breaks down into nitrosomorpholine results in a 3% rise of the carcinogens indicator for the case where the nitrosamine emissions increase by a factor of 350. This relatively small rise is because the indicator is still dominated by formaldehyde and ethylene oxide in the baseline scenario. This problem does not happen with inorganic solvents like NH_3 or K_2CO_3 because they do not degrade in other toxic or carcinogenic substances and their production processes do not include chemical with high toxicity.

4 Conclusions

The environmental impacts of different technologies for separating CO_2 from the flue gas stream of a coal-fired power station have been compared. In particular, two comparisons between amine based solvents and inorganic based solvents are presented.

The benefits of the inorganic solvents (such as NH_3 and K_2CO_3) compared with amines (such as MEA and MDEA) are principally due to avoidance of emissions from amine degradation along with a cleaner footprint during the production and transport process of the solvent.

For what concerns the energy saving and the specific CO_2 emission, the benefits of the inorganic solvents are less evident. Indeed, the NH_3 case has a different CO_2 capture efficiency, so the carbon footprint cannot be directly compared with the MDEA case. The K_2CO_3 technology, compared at the same capture ratio with MEA case, return better results also in terms of energy afficiency and carbon footprint.

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LCA of different devices for pollutants emission reduction on agricultural tractors

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Abstract

Agricultural mechanisation plays an important role on the environmental sustainability of crops cultivation. Commonly, not much attention is paid to the different tractors to be used for carrying out field operations. Although only one average tractor is available in the Ecoinvent database, several models can be identified, characterised by differences in: (i) engine power, (ii) dimensions and mass, (iii) fuel consumption and, (iv) technologies for the reduction of exhaust gases emissions. This study shows how just one difference in the selected tractor, i.e. the solution for reducing exhaust gases from the combustion in the engine, brings to different environmental outcomes quantified by means of the LCA approach. In particular, a comparison is made among three tractors characterised by different solutions for emissions reduction: tractor A, equipped with Exhaust Gas Recirculation (EGR), tractor B, equipped with Selective Catalytic Reduction (SCR) and tractor C, with no-emission-control device.

1. Introduction

Agricultural mechanisation is responsible for a considerable share of the environmental impact attributed to agriculture. Although there is availability of standardised and extensively accepted methods for environmental impact assessment, their application to mechanical field operations is still restrained. The main reason for this reduced applicability is linked to the difficulties in the data collection; in particular, inventory data for agricultural-related processes are often characterised by site and time variability as well as by mechanical and operative specificities that make their general and uncritical use unadapt. However, it is essential to get valid, updated and reliable data to quantify appropriately the environmental impacts and the effective environmental benefits to be achieved with new machines and innovations in technologies.

In particular, it is important to highlight that some data have a deep effect on the environmental outcomes but they depend on pedo-climatic (e.g., soil texture and water content), site-specific (e.g., field shape, slope) and logistic (e.g., machinery, annual working time) variables. To overcome this problem database have been developed but the processes available not always consider the same pedo-climatic and logistic conditions and, therefore, do not permit to achieve trustful results.

Depending on soil texture, for example, which is field-specific, mechanical and agronomic choices of a farmer vary. It is widely known that soil tillage is more energy-consumptive when carried out on clay rather than sandy soils, but on an environmental perspective also other variables must be considered, such as the engine power of the tractor for ploughing on a clay soil in respect to one on a sandy soil. This, consequently, reflects on the dimension and mass of the tractor to be produced, maintained and disposed of, on the fuel and lubricant consumed during the life span as well as on the common average working time of the tractor.

Additionally, to fuel consumption are associated engine exhaust gases released during combustion and emitted to the atmosphere. When the engine power needed to carry out the operation (generally lower than the maximum engine power of the tractor) is very low respect to the maximum one, the coupling tractor-implement is inefficient, the engine works unproductively and both the specific fuel consumption and the specific exhaust emissions increase (Lovarelli et., 2017). In this case, a smaller tractor could be used, making its activity more efficient under several environmental points of view (i.e. lower fuel consumption and pollutants emissions, smaller tractor to be produced). Moreover, similarly to cars, also tractors need to respect Emissive Standards from EU Directives, and the newer is the tractor, the more efficient is the technology to reduce pollutants emissions. Of course, this affects substantially the environmental sustainability of the field operation.

This study focuses on the application of Life Cycle Assessment (LCA) approach (ISO 14040 Series) to the environmental impact assessment of three tractors. More in detail, a comparison is made among two tractors that belong to two different emissive stages (EU Directives 2010/22/EU, 2010/26/EU) that permit a reduction in exhaust gases emissions with different technological solutions and a third tractor that is an old model (about 20 years old) characterised by no-emission-control technology. The outcomes will:

- show how LCA can be useful to analyse, from an environmental perspective, the same field operation performed with similar tractors, thus taking into account the site-specificity and the technological improvements of tractors for controlling exhaust gases emissions;
- discuss limits and unsolved issues of this approach applied to mechanisation aiming to the identification of possible solutions.

This study brings also interesting information helpful to policy makers and stakeholders. In particular, understanding the effect of machinery choices due to legislative restrictions on both the economic and the environmental point of view has impact on the circular economy and on the life cycle thinking approach, on the effectiveness of the technological improvements that are highly sought after and on understanding how LCA can help improve and support business strategies.

2. Materials and methods

2.1. Goal and scope

The Life Cycle Assessment (LCA) approach was used for quantifying the potential environmental impacts of ploughing carried out with three tractors belonging to different emission stages for controlling the pollutant emissions produced during combustion in the engine.

2.2. Functional unit and system boundary

The selected Functional Unit (FU) is 1 ha of soil properly tilled.

A cradle-to-farm gate approach was considered and, consequently, the system boundary (Figure 1) includes all inputs (e.g., machinery, fuel, lubricant, organic and mineral fertilisers, pesticides, water) and outputs (emissions to air, soil and water).

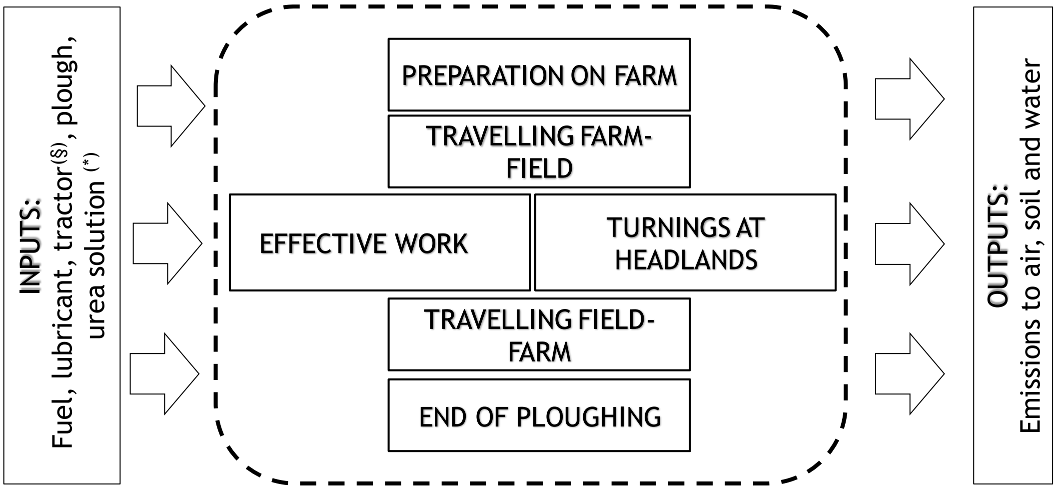

Figure 1: System boundary for ploughing. (§) Three tractors are studied, one equipped with EGR, one with SCR and one without pollutant technologies. (*) Only the SCR-equipped tractor is considered for urea solution

2.3. Description of the system and data collection

For ploughing, a 4-furrow mouldboard plough on a medium texture-clay soil was considered. With regard to the tractor, three tractors belonging to different emission stages were taken into account:

- tractor A, engine power 179 kW, minimum specific fuel consumption 213 g kWh^{-1}, emission Stage 3A, equipped with EGR (Exhaust Gas Recirculation),
- tractor B, engine power 191 kW, minimum specific fuel consumption 196 g kWh^{-1}, emission Stage 3B, equipped with SCR (Selective Catalytic Reduction) in which a urea solution is used at 3.4% volume of the fuel consumed,
- tractor C, engine power 135 kW, minimum specific fuel consumption 235 g kWh^{-1}, previous to emission Stage limits, therefore no equipment for pollutants reduction is included. Moreover, at that time more powerful tractors were not available on the market, therefore was selected this less powerful tractor in respect to A and B.

Table 1: Emissions limits for the Emission Stages of Tractors A (Stage 3A), B (Stage 3B) and C (previous to Stage 1). (EU Directive 97/68/EC and the amending ones 2010/22/EU, 2010/26/EU)

Pollutant	Unit	**Stage 1 (*)**	**Stage 3A**	**Stage 3B**
CO	g kWh^{-1}	5.0	3.5	3.5
HC	g kWh^{-1}	1.3	4.0 (#)	1.19
NO_X	g kWh^{-1}	9.2		2.0
PM	g kWh^{-1}	0.54	0.20	0.025

Note: (*) Stage 1 is the first emissions restriction, introduced after to tractor C. (#) for Stage 3A the limit is related to HC+NO_X together.

The consumption of fuel (and of urea solution on tractor B) were measured for all three tractors, while pollutants emissions were quantified by referring to the emission limits of the emission Stage of belonging reported in Table 1.

In particular, this calculation foresees knowing for each tractor: (i) the engine power, (ii) the power absorbed during ploughing (that depends on the work variables of type of plough, working speed and soil texture), (iii) emission limits per emission Stage, and (iv) correction factors due to the engine load (Schäffeler and Keller, 2008; Lovarelli et al., 2017). For all three cases, secondary data about diesel and urea solution production as well as tractor and implement manufacturing, maintenance and disposal were retrieved from Ecoinvent 3 (Weidema et al., 2013). Concerning the production of the urea solution, the energy consumption was 0.07 kWh of electricity and 1.71 MJ from natural gas per 1 kg (Yara, 2017).

For what regards the technologies available, thanks to EGR, the conversion to nitrogen oxides (NOx) during the combustion in the engine is reduced up to 90%. The EGR consists of a valve that allows recirculating part of the exhaust gases as intake air in the engine. This means that the oxygen content per unit volume of intake air is lowered and that intake air has already high temperatures, hence NOx formation is lowered. However, EGR shows some disadvantages, among which an increase in fuel consumption (4-10%) (Volvo, 2010) mainly due to the filter regeneration for the high soot production. In this study, an increase of 5% in fuel consumption was considered. The SCR, instead, removes NOx using ammonia (NH_3) as reducing agent, which is present on the tractor as an aqueous solution containing 32.5% urea. In the after-treatment system, urea injected is converted to NH_3 through thermolysis and hydrolysis. Respect to EGR, SCR presents some advantages among which a higher specific power output, improved engine life and lower fuel consumption due to an increase in fuel efficiency (4-5%; Maiboom et al., 2009; Volvo, 2010). Nevertheless, urea solution is consumed and LCA is fundamental to evaluate if the reduction of pollutants and the increase in fuel efficiency achieved with SCR offsets the environmental impact related to urea solution consumption.

Conversely, tractors that are still present on the market that were produced more than 20 years ago are characterised by the absence of emission control technologies because emission limits were still not introduced for agricultural tractors. The pollutants released during the combustion of fuel were very high in quantitative terms and dangerous for human health. However, although such tractors are outdated, they are still common on average Italian farms. For this tractor, it must be underlined that since engine power is lower, to perform the same operation of tractors A and B, ploughing with tractor C must be carried out at a lower working speed respect to A and B. Working speed is, accordingly, 6.0 km h^{-1} for tractors A and B and 4.3 km h^{-1} for tractor C. This difference affects the total time to perform ploughing on 1 ha and, consequently, the annual use of tractor C and of the plough used with tractor C (i.e. for the inventory, the machinery consumption in kg ha^{-1}).

Table 2 reports the main inventory data used.

Table 2: Main inventory data for the ploughing operations

Variables		Unit	Tractor A, Stage 3A with EGR	Tractor B, Stage 3B with SCR	Tractor C, with no emission control
Fuel consumption		kg ha^{-1}	40.3	38.4	39.4
Urea solution consumption		dm^3 h^{-1}	--	1.08	--
Mass of tractor		kg	7200	8140	6665
Mass of plough		kg	1280	1280	1280
Working time per year	Tractor	h y^{-1}	500	500	500
	Plough	h y^{-1}	130	130	160(*)
Consumed mass	Tractor	kg ha^{-1}	1.53	1.74	1.01
	Plough	kg ha^{-1}	1.04	1.04	1.16

Note: (*) because the engine power is lower and the pedo-climatic characteristics are the same the working speed must be lower, therefore working time is higher.

2.4. Impact assessment

The following 12 environmental impacts were considered by using the ILCD characterisation method (ILCD Handbook, 2011):

- Climate Change (CC, kg CO_2 eq),
- Ozone Depletion (OD, kg CFC-11 eq),
- Human toxicity, non-cancer effects (HTnoc, CTUh),
- Human toxicity, cancer effects (HTc, CTUh),
- Particulate Matter Formation (PM, kg $PM_{2.5}$ eq),
- Photochemical Oxidant Formation (POF, kg NMVOC eq),
- Acidification (TA, molc H^+ eq),
- Terrestrial eutrophication (TE, molc N eq),
- Freshwater eutrophication (FE, kg P eq),
- Marine eutrophication (ME, kg N eq·10),
- Freshwater ecotoxicity (FEx, CTUe),
- Mineral, fossil and renewable resources depletion (MFRD, kg Sb eq).

3. Results

Table 3 reports the absolute environmental impact for the ploughing carried out using the three different tractors.

Table 3: Absolute environmental impacts for the 3 studied tractors

Impact category	Unit	Tractor A Stage 3A	Tractor B Stage 3B	Tractor C - no emission control
CC	kg CO_2 eq	162.69	158.37	162.99
OD	kg CFC-11 eq $\cdot 10^{-5}$	2.64	2.55	2.64
HTnoc	CTUh $\cdot 10^{-5}$	4.96	5.09	14.80
HTc	CTUh $\cdot 10^{-6}$	3.72	3.95	4.61
PM	kg PM2.5 eq	0.0677	0.0411	0.1266
POF	kg NMVOC eq	1.2145	0.3623	1.8572
TA	molc H+ eq	1.0604	0.4354	1.5441
TE	molc N eq	4.4619	0.8445	7.0982
FE	kg P eq	0.0130	0.0142	0.0165
ME	kg N eq	0.4082	0.0774	0.6493
FEx	CTUe	349.67	380.06	487.77
MFRD	kg Sb eq	0.0133	0.0150	0.0174

For all the environmental impact categories analysed, the tractor without emission control strategy (tractor C) has the worst environmental performance. However, regarding the best solution, not univocal results are obtained, and this is mostly due to the specific engine and operative characteristics of the tractors.

The environmental relative comparison between the ploughing carried out with tractor A (Stage 3A EGR), tractor B (stage 3B SCR with urea solution) and tractor C (no emissions control) is reported in Figure 2. Tractor C has the highest environmental impact on all impact categories, especially on those affected by pollutants emissions. On CC and OD, the environmental outcomes are very close to each other for tractor A and C, due to the fuel consumption. Tractor B shows the best environmental behaviour on 7 of the 12 evaluated impact categories, especially on those affected by the pollutants emissions; in respect to tractor C, the impact reduction for PM, POF, TA, TE and ME ranges between 68% and 88%. On HTnoc, HTc, FE, FEx and MFRD, instead, tractor B behaves worse than tractor A because the SCR technology is characterised by a more complex system that involves a substantial increase in the mass of the tractor. In any case, tractor C is still the worst on these categories due to the higher working time per ha that affects the data of tractor and plough consumption.

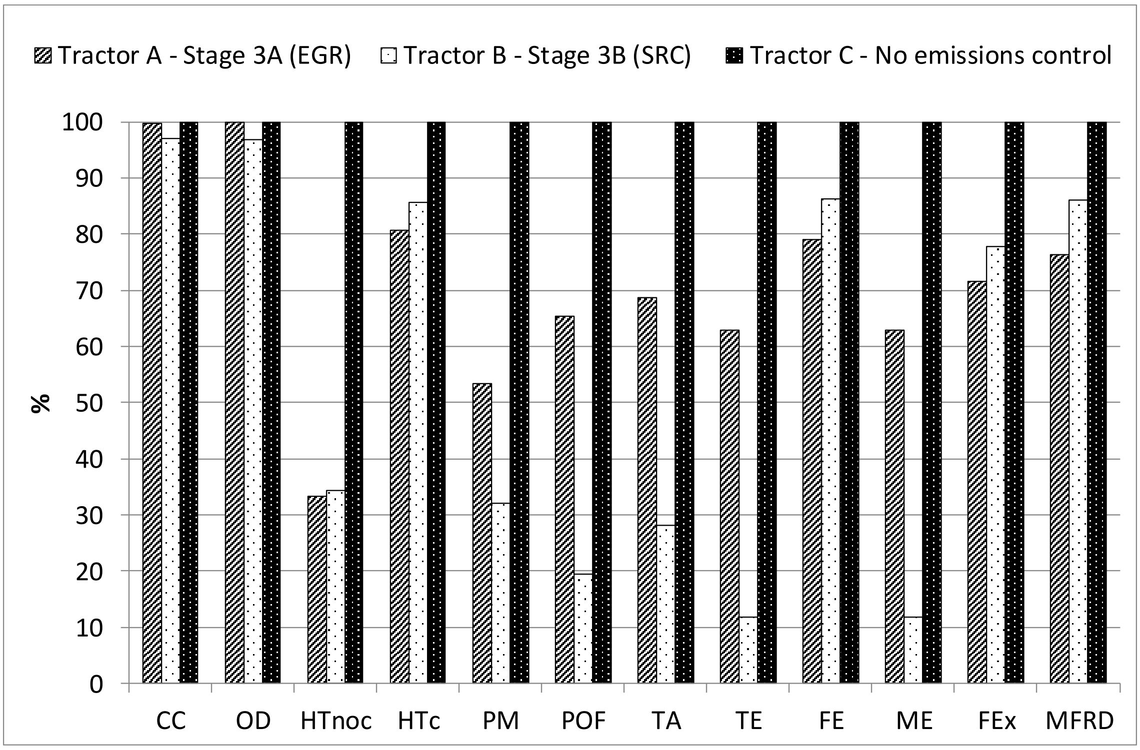

Figure 2: Comparison among the ploughing operations performed with the three tractors

The use of urea solution in tractor B has a negligible effect on all the evaluated impact categories (<2% - Figure 3) but allows to reduce considerably the environmental impact affected by NOx and NMVOC emissions (i.e. TA, TE, ME, POF, PM), while, for the other impact categories, the reduction is almost completely related to the reduction of fuel consumption. The ploughing carried out by the tractor equipped with SCR shows a higher impact on HTnoc, HTc, FE FEx and MFRD than the one performed by the tractor with EGR mostly because tractor B has a higher mass than tractor A.

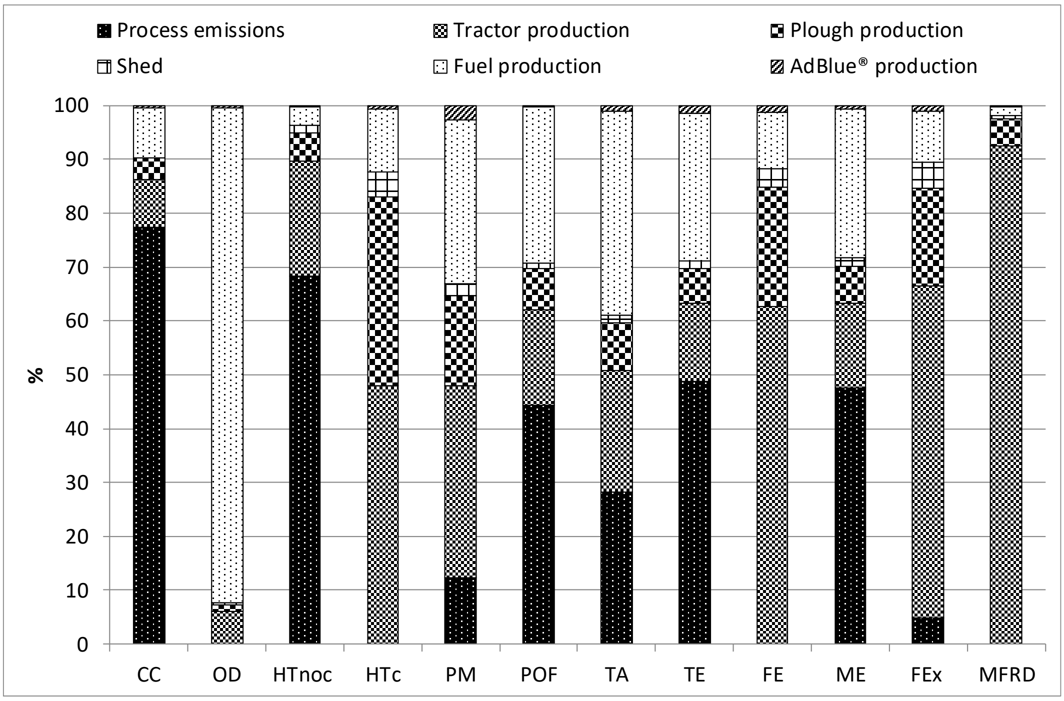

Figure 3: Hotspot processes for ploughing carried out with tractor B (Emissive stage 3B, with SCR and consumption of urea solution)

Figure 4 highlights the hotspot processes of tractor C, from which can be retrieved the high role of pollutants emissions on the impact categories of PM, POF, TA, TE and ME.

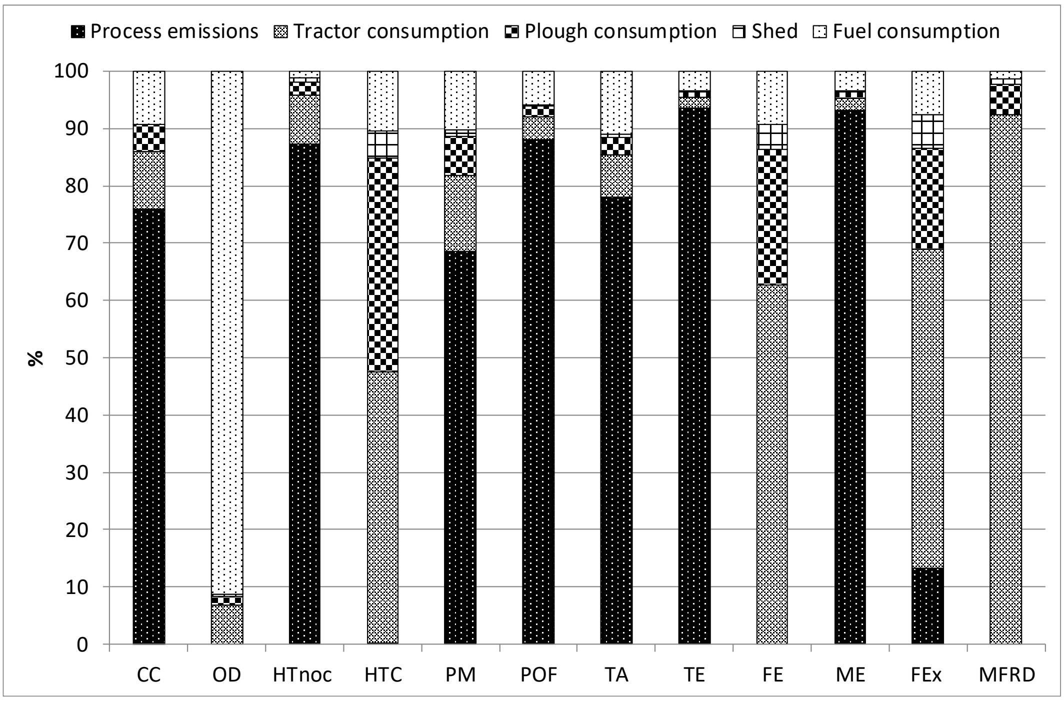

Figure 4: Hotspot processes for ploughing carried out with tractor C (no emission control)

4. Conclusions

The outcomes of this study show how the LCA approach can be useful to highlight, from an environmental perspective, the performances and benefits arising from the development of new technologies. As shown in the comparison among modern tractors equipped with EGR (tractor A) and SCR (tractor B) and old ones without emission control strategies (tractor C), it is interesting to underline that the technological improvement has brought also to environmental benefits. Although these results refer to the case study analysed and for some categories the achieved benefit is marginal, the most recent tractor B (with SCR and urea solution) shows the best performance for 7 of the 12 evaluated impact categories. On these categories are shown significant benefits due to the emissions control strategies, while on the remaining ones, the environmental effect is mostly related to tractor production, for which the heavier tractor involves a worsening of the environmental impact. Tractor C performs the worst due to the lack of technologies for reducing emissions and to the high working time.

Introducing efficient technological innovations on agricultural tractors allows for important environmental benefits that should be considered when studying the environmental effects of the technological improvements achieved. In particular, the agricultural sector is characterised by several conditions similar to those analysed and the value for human health and the environment is not at all negligible. Finally, these outcomes represent relevant information for the accuracy of LCA studies about agro-food productions in which mechanisation plays an important role. On a strategic point of view, the life cycle thinking approach permits to evaluate the applicability and effectiveness of public policies.

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Life Cycle Thinking approach applied to the Sustainable Tourism Sector

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Abstract

The bioeconomy is a new economic strategy that underlines environmental opportunities, through the concepts of the circular economy or thanks to some tools such as LCA, a technique that studies the environmental effects of all the stages of a service considering changes in the ecosystem, consumption of natural resources and the damage to human health.
The aim of this paper is to analyze the environmental impact of the tourism industry through the LCA analysis. Lately, the tourism sector has grown and offers different services such as transport, hospitality and entertainment. The LCA (Life Cycle Assessment), internationally standardized by the ISO 14040 and 14044 standards, is a technique that studies the environmental effects of all the stages of a service considering changes in the ecosystem, consumption of natural resources and the damage to human health.
The functional unit of this study is a "Trip and overnight stay in a hotel during mid- season with the arrival and departure of the tourist at Fontanarossa Airport in Catania, Sicily".
The tourism sector is important for the development of a country's economy. There is a strong relationship between the two elements of tourism and the environment because, on the one hand, for tourism, the environment is a fundamental resource but, on the other hand, it must be deeply analyzed because an uncontrolled spread of tourism could cause serious environmental damage.

1 Introduction

The circular economy is viewed as a promising approach to help reduce our global sustainability pressures. The Ellen MacArthur Foundation has helped popularize the move to a circular economy with businesses. Also, the European Commission associates the move to a more circular economy with strategies such as: boosting recycling and preventing loss of valuable materials; creating jobs and economic growth; showing how new business models, eco-design and industrial symbiosis can move Europe toward zero-waste; and reducing greenhouse emissions and environmental impacts (Ellen Macarthur Foundation, 2012).

Tourism represents one of the driving sectors of the economy on a global scale and, in order to promote its sustainable development, it's necessary to observe and analyze its environmental impact. Negative impacts occur because tourism, both international and domestic, causes an intermingling of people from diverse social and cultural backgrounds, and also a considerable spatial redistribution of spending power, which has a significant impact on the economy of the destination. Tourism consequences cannot be prevent, but need to be planed and managed to minimize the negative impacts and accentuated the positive impacts of tourism.

Sustainable tourism activities principally cover the environmental, economic, social and cultural aspects of development. Since natural resources may be intensively exploited in the tourism business, tourism activities would sometime pose major impacts on the environment, ecosystems, economy,society and culture. The UNEP and UNWTO (2005) conceptually defined sustainable tourism as "development of tourism activities with a suitable balance between these the dimensions of environmental, economic, and sociocultural aspects to guarantee its long-term sustainability."

The term ecotourism was originally proposed in the late 1970s. It is seen as a type of nature-based tourism, and has been becoming as away to protect the natural landscapes of a specific region. Ecotourism is now defined as: "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" (TIES, 2015). Ecotourism should be regarded as a suitable industry for promoting economic development in developing countries with capital scarcity and natural resource abundance (Wunder, 1999; Viljoen, 2011). A community-based approach to ecotourism recognizes the need to promote both the quality of life of people and the conservation of resources. Even where ecotourism results in economic benefits for a local community, it may result in damage to social and cultural systems thus undermining people overall quality of life. (Scheyvens,1999).

At the same time, the respect towards tourism refers to both citizens and tourists because ecotourism is based on respect for values by tourists themselves, without which there is no reason to exist. But it is also a rational behavior of the same local populations that sustainably manage their natural and cultural heritage, which ensures long-term economic activity in the long run.

The evaluation of the activities performed using both methods could provide more extensive and comprehensive results and could lead to a more reliable evaluation of the system providing better support for decision making (Castellani and Sala, 2012). Tourism development and management would encounter a multitude of significant sustainability-related challenges for policy-makers and planners. In fact, the challenge of sustainable tourismis to mitigate the negative impacts by enhancing the tourism's benefits into the right directions (ETE, 2009).

Tourism is a significant contributor to the increasing greenhouse gas (GHG) emissions in the atmosphere at the global scale, being attributed fromtravel, transport, accommodation, and its related activities. In fact, the tourism sector accounts for about 5% of global CO2 emissions but, considering the radiative forcing of all GHGs, the overall contribution of tourism activities to global warming potential is estimated to be 5.2–12.5% (UNEP and UNWTO, 2012;

Peeters and Dubois, 2010). The increased number of tourism industry has resulted in an increase of waste generation (UNEP and GPA, 2006). So, tourismactivities (e.g., construction ofmassive transport and building infrastructure) could bring severely negative consequences to natural environment (Hashemkhani Zolfani et al., 2015), such as degradation of landscapes, destruction of habitat, and pollution of coastal zones.

Sustainable tourism can provide effective resource management, while simultaneously minimizing negative externalities to an area's environmental and cultural integrity. In addition, sustainable tourism can generate "green" income or become an important source of export growth especially in developing countries.

Sustainable tourism has a direct connection with the Life Cycle Assessment method. The LCA is the evaluation of the environmental impact related to the entire vacation. This can include but not limit the following aspects: trip, transport, overnight stay, etc. Tourist services can be interpreted as a series of consequential processes which, when viewed together, trace the life cycle of the tourist service.

Since tourism is a composite product, when the tourists begin their trip, the life cycle of the ''tourism product'' starts; and when tourists finish their trip, the life cycle of the ''tourism product'' ends. Accordingly, every sector of the whole trip including transportation, accommodation, and recreation is all considered and the environmental impacts of the whole trip can be inventoried under such approach (Kuo and Chen, 2009).

The general process can be schematized through a stream of activities that characterize the distinct phases which are common to the different forms of tourism. This process, from a life cycle perspective for its implementation, requires that inputs are taken from environment and territory.

Taking into account the wide panorama of the companies in the tourist sector, the LCA method applied to this sector can be used as a lever of green marketing. This, in turn, allows the company to distinguish itself from its competitors thanks to the possibility of obtaining an eco-label. The Eco label represents an element of prestige in the eyes of tourists increasingly sensitive to these issues.

The aim of this paper is to suggest circular economy strategies in an hotel located in Etna Volcano, where principal environmental impact were analysed trhought a Conceptual LCA**,** a strategic way only in the early stages; it omits therefore many aspects of the life of the product /service and does not go into detail on the differences with other output. The firm that has been studied is a hotel facility in the territory of Catania with a lifelong experience in the sector.

The main advantage of this research in the field of international literature about the sector is to underline the social benefits exploitable from an economic perspective. Through the LCA tool, it is possible to highlight the inefficiencies of the various phases and to improve them from the environmental point of view by reducing consumption and emissions besides other positive economic consequences.

2 Methods

The LCA methodology has continued to develop and has become to some extent mature during recent decades. From the first conceptualizations, LCA is now an internationally standardized methodology (ISO 14040:2006; ISO 14044:2006) recognized by the European Commission (2003) as the best tool for assessing the life cycle environmental impacts of products. While general guidelines for LCA have been issued by the European Commission (2010), many initiatives have been developing ad hoc sector- and product-specific methodologies. According to a preliminary survey on the use of LCA in the tourism industry, LCA is still uncommon within the tourism industry and for researchers in the field of Sustainable Tourism.

According to Judd (2006), the actual product of tourism is the tourist's experience which is generated by several social and economic actors. Middleton (1989) observes that the term "tourist product" is used at two different levels: the "specific" level (i.e. a discrete product offered by a single business, such as a sightseeing tour or an airline seat) and the "total" level (i.e. the complete experience of a tourist from the time one leaves home to the time one returns). From these considerations, it can be deduced that a tourist's experience is the outcome of a tourist product at a "total" level. Such a product can be seen as a system whose components (products and services) are the tourist products at a "specific" level, which are provided by different actors and may be incidental to "non-economic" activities.

Tourism is a complicated system due to the large number of goods and supporting services involved in it. Furthermore, describing the sector is complicated as, scientifically, there is an on-going debate about the definition of tourism.
Therefore, applying LCA to calculate the environmental performance of tourist products is often problematic. In particular, these drawbacks have major implications in the "goal and scope definition" step (De Camillis et al., 2012).

In an effort to promote Life Cycle Thinking (LCT) principles and approach characteristic cases of all-sized hotels in the areaIn this paper, the assessment of the impact generated by one tourist during a one day holiday in hotel was assessed using early stages LCA.

LCA applied to a holiday aims at: identifying which holiday phases are responsible for the largest environmental impacts; identifying of the most significant impact categories; and defining potential improvement actions that can be implemented by stakeholders in order to reduce the environmental impacts of the holiday.

LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

• compiling an inventory of relevant energy and material inputs and environmental releases;

• evaluating the potential environmental impacts associated with identified inputs and emissions;

• interpreting the results to help make a more informed decision about the human health and environmental impacts of products, processes, and activities (Castellani and Sala, 2012).

For a typical product, LCA takes into account the supply of raw materials needed to produce the product, the manufacturing of intermediates and finally the product itself, including packaging, transportation and the disposal of the product after it has been used. This sequence, as depicted below, is called "Cradle to Grave" assessment.

In particular, this study applies "Goals and Scoping" phase of the LCA process

The scoping step determines which processes will be included, which environmental concerns will be taken into account, what economic or social good is provided by the goods or services in question, it resolves any technical issues and defines the audience for the LCA.

Later, we identify a preliminary Life Cycle Inventory (LCI), which provides information about all environmental inputs and outputs from all parts of the product system involved in the life cycle assessment. This involves modeling of the product system, data collection and verification of data for inputs and outputs for all parts of the product system.

Inputs include: materials, energy, chemicals and 'other'.

Outputs include: air emissions, water emissions and solid waste.

Finally, the last step is an analysis of the impact data, which leads to the conclusion whether the ambitions from the goal and scope can be met.

3 Experimental

The study of a preliminary LCA of a service or product analyzes each phases from "cradle to grave", in order to establish which are the steps and moments in which the environmental concerns develop. In this paper, two phases of LCA analysis are applied to the Hotel Primavera dell 'Etna.
This Hotel is in Zafferana Etnea,Catania, Sicily in a tourist road Mareneve Sud located between the Mediterranean sea and Mount Etna.
The facility was renovated in 2002 with the aim to improve the costumer comfort and satisfaction and to reduce the energy consumption and its environmental

impacts. The functional unit taken into consideration is a "Trip and overnight stay in a hotel during mid- season with the arrival and departure of the tourist at Fontanarossa Airport in Catania, Sicily".
The ambit of the study goes from the transfer of the client from the airport to the check out in the hotel, which means: transfer from the Fontanarossa airport to the Hotel Primavera dell 'Etna, overnight stay, dinner, breakfast, check out .
The consumption analyzed in this study are:
Consumption of fuel (gasoline) needed for the transfer by car from the airport to the Hotel; Consumption of the overnight stay: water, sheets, towel, courtesy kit, breakfast and the energy's consumption associated to the services used by the client such as television, bar service, hairdryer and toilette.
Consumption related to the check out: Dishwashing utensils, bedroom cleaning and laundry service. The inventory analysis of the life cycle is the main phase of the study and it is represented by quantitative data of all the material and energy flow at the beginning and at the end of the entire process.
The output of the inventory analysis results in the filling out of a table which shows the use of the resources, the emission associated with the functional unit such as energy flow, air, water and waste. The input and output data was provided directly by the Hotel.

4 Results and discussions

The first phase considered is the transfer to the hotel which is located 38.6km from the airport. The main input of this phase are gasoline, oil and tire. The average of the gasoline used is 2.72 liters which generate an emission of 7295g of CO_2, oil and tires are used for 0.13% generating respectively emission of NH_3 and the attrition of the tire.
The second phase analyzed, concerns the overnight stay of the costumer in the Hotel; the relevant data are: Consumption of 0.528 m^2 of methane gas which generate emission of CO_2; Consumption of energy of the bedroom for a overnight stay of 14 hours per a total of 1.42 kW divided into:
Hairdryer 0.08 kW;Television 0.51 kW; Minibar 0.40 kW; Lighting 0.40 kW; CPU 0.028 kW; Consumption related to the toilet ;Water:150 l; Shampoo: 20 g; Bubble bath: 50g; Soap: 13 g; Consumption related to breakfast;Water bottle: 0.5l;Coffee: 7 g; Cracked slice: 17g; jam :25 g; Butter: 8g; sugar: 5g; napkin: 2 pieces .

The energy consumption of this Hotel is considerably lower than other hotel facilities, which do not operate in a green economy, thanks to the investment made by the company. In 2002 the heating system VRV-CLIMATIZZATOR MULTIZONA was installed. The system is equipped with centralized control so every room and floor of the whole hotel has heating, cooling and ventilation necessary without the need to waste energy to air-conditioning non-temporarily inhabited areas. In addition, these systems operate with intelligent energy management by optimizing seasonal performance. In addition, in 2014, a 63 kwp photovoltaic plant was installed on the roof of the building, meeting the needs of 21 private rooms, exploiting for solar power generation, clean and renewable energy as well as reducing energy costs. Connected with the photovoltaic system and with the concept of energy saving, a process of energetic qualification of the structure has started, beginning with energy efficiency, thanks to the replacement of energy-saving lamps with LED technology lamps. In the last phase, check out, all the waste generated during the check-in and stay phase is analyzed. Waste generated for the sanitary facilities include: pvc bottles for the use of shampoo and bubble bath and paper packaging for the use of soap.

The waste generated for breakfast is: glass bottle, pvc pack for cookies, jam jar, butter wrapping, sugar paper bag and paper napkins. Speaking of waste management, with a view to carrying out its activities with the least environmental impact and also following the initiatives of the municipality of Zafferana Etnea, the management is committed to reducing waste incineration as much as possible, reducing the amount of undifferentiated donation, and carrying out a very accurate differentiated collection. In this way, at present, the hotel can differentiate between 80% and 85% of its waste.

5 Conclusion

The preliminary application of the LCA in the Hotel Primavera dell'Etna showed that the main emissions caused by Italian tourism, tourism in southern Italy, is the CO_2 emissions caused mainly by the use of private means of transport. The paper showed, however, that the amount of energy used by the structure (1.42 kW) for one night, is relatively low compared to other tourist facilities. As a matter of fact, that amount is less than that consumed by other hotels in different nations; for example, the average of energy consumption in a hotel room in Hong Kong is: 32% of total energy were consumed for air conditioning, 12% for lighting, 5% for lifts and escalators, 23% for other systems/appliances, and 28% for cooking and water heating (the latter based on gas and diesel) (Deng and Burnett, 2000). A study (electricity only) of hotels in Hong Kong indicated a very high average electricity consumption of 10.9 MJ per bed night (Burnett, 1994, quoted in Jim, 2000). However, this may underestimate total energy consumption by one-quarter, and such low values will generally only be the case in city hotels. Hotels investigated in the Seychelles indicated an energy use of 36–108 MJ per bed night, excluding the use of fossil fuels for cooking etc. (UK CEED, 1994). Hotels with self-supporting power generation may even use more energy per bed night (Gossling, 2002). Finally, the amount of energy consumed is low compared to other hotels in southern Italy thanks to the investments made by the hotel, or through the installation of the VRV-CLIMATIZZATOR MULTIZONA system. This preliminary attempt to applied LCA in tourism sector represents a relevant step towards a comprehensive sustainability assessment of tourist activities and accommodation.

LCA highlights strengths and weaknesses, from a point of view of the effects on the environment, of the chains, identifying the phases that have a greater environmental impact. The advantage of this analysis is that it allows for each of the environmental impact factors (emissions, waste, discharges, etc.) to specify its origin by attributing it percentage to the distinct stages of the life cycle. The inventory analysis makes it possible to highlight the energy resources and products needed for the training process of the offered service, quantifying the resources needed during the consecutive lifecycle impact assessment phase. LCI is a very detailed, simple compilation tool but it is quite difficult to find individual data, very schematic and capable of quantifying the data sought. In the case of the tourist service examined, the choice of functional unit was crucial in identifying the environmental impacts attributed to a single tourist because it made it possible to locate exactly where it is possible to intervene to make tourism more sustainable. Improvement proposals based on inventory results or impact assessment can help decision-makers identify and evaluate ways to reduce impacts on the environment of products or services. Since LCA studies are long, expensive and complex (as it is necessary to acquire a large amount of environmental data during each stage of the production process), more and more “simplified LCA” tools are being developed. They enable a quick review of the life cycle and environmental performance of products, even to those which do not have all the skills and resources needed to carry out a detailed study. Given the importance of reliable data availability for the success of an LCA study on an international and European level, it is important to promote accessibility, availability and free exchange and Small and Medium Businesses Free LCA data through The development of Public Data Banks, protected, compatible, transparent and accredited.

The main advantages can be summarized as follows:

• Significant economic savings characterized by an initial investment but savings in the medium term.

• Competitive advantage as they show a reduced environmental impact

• Identification of environmental issues during the life cycle of products or processes.

• Information and training for consumers and stakeholders.

• As a tool for certification of corporate environmental management systems (SGAs) for both ISO 14000 and EMAS Community Regulations. The LCA methodology allows the integration of the environmental variable with the core business functions in order to develop environmental management policies. This also helps to improve relations with institutions.

• Definition of eco-compatible strategies for urban solid waste management. The LCA methodology should made it possible to compare environmental loads with different alternatives by facilitating the choice of the disposal method that minimizes cost and environmental impact.

Therefore, despite the criticalities that can be found in the application of the LDA both from a technical (data acquisition) and economic (initial investment) point of view, the implementation of LCA is a useful tool and competitive for companies that apply it.

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Emerging trends of Life Cycle tools in agrifood sector

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Abstract

The Life Cycle tools, such as Life Cycle Assessment, Product Carbon Footprint, and Water Footprint, are widely used in the agri-food chain to know environmental hotspots related to agrifood products throughout the supply chain. Our research aims to deepen the use of life cycle studies in the agrifood sector, identifying the most used tools, the goals pursued and the boundaries chosen to analyze the products. From a systematic review of scientific papers related the adoption of LC tools in agrifood sector, we studied 299 papers published in 30 journals, concerning 412 life cycle studies related agrifood products. The statistical analysis of data collected highlights which life cycle tools are more frequently used, which objectives are mainly pursued and which boundaries are privileged.

1 Introduction

Coherently with a continuous demographic increase, the demand for food is constantly growing in the world. On the othe hand, the global food system a vital component of food security. So, one of the most urgent challenges of economic policies and market is to increase food production by maintaining safe and sustainable environmental operating conditions (The Lancet, 2017; Rockström et al, 2009).

The production and consumption of food is among the main causes of environmental impacts. The environmental hotspots related to agrifood products are widespread throughout the supply chain, involving the activities of cultivation and breeding, processing of products, transport and consumption (Sala et al, 2017; Tilmann et al, 2011; Notarnicola et al, 2017/b).

The environmental impacts of agrifood sector are also linked to the increasing spread of the western diet, which is characterized by a high consumption of products of animal origin, such as meat, dairy products, eggs and vegetables, which require a lot of energy for their production (Stehfest et al, 2009; van der Goot et al, 2015).

The Life Cycle tools (LC tools), such as Life Cycle Assessment (LCA), Product Carbon Footprint (PCF), and Water Footprint (WF), more and more widespread in the analysis of the environmental loads of products, are widely used in the agri-food chain, analyzing and improving production and transformation, packaging and consumption of products (Notarnicola et al, 2017/a).

Several companies choose to conduct life cycle studies to get to know the environmental impacts of their products considering the entire agri-food chain. Furthermor, companies can adopt LCA, PCF and WF with the aim of promoting their products, through comparative studies, as well as of evaluating environmental convenience of innovative products or processes.

Our research aims to deepen the use of life cycle studies in the agrifood sector, identifying the most used LC tools, the goals generally pursued in the studies and the boundaries chosen to analyze the products.

Through a systematic analysis of scientific papers published in recent years, the research observes the distribution of LCA, PCF and WF studies over the years and by the type of agrifood products studied. The statistical analysis of data collected from the papers studied highlights which objectives are mainly pursued by these studies and which system boundaries are privileged.

2 Methodology

To investigate the research topic, we conducted a research based on a systematic literature review, exploring the life cycle studies in agrifood sector in scientific papers published during the period 2012 – 2017.

To verify which papers concern life cycle studies in the agrifood sector, a bibliographical survey was conducted with international databases (ISI Web of Knowledge and the main editors' libraries) using the following research keywords: "life cycle", "life cycle assessment", "carbon footprint", "water footprint", "agrifood", "food", "food and beverage".

In order to include in the literature analysis all the relevant papers, we selected them in two steps (coherently with Luederitz et al, 2016 and Mazzi et al, 2016):

- Data Screening, which concerns the search in the established databases through the established keywords;
- Data Cleaning, which concerns the evaluation of each papers selected in the previous step (Data Screening), in order to decide their inclusion in the research sample, based on the coherency of the title, abstract and full text with the research topic.

Each paper has been categorized through the following variables: year of publication, journal of publication, product analyzed, goal of the study, LC tool used, and system boundaries adopted.

Table 1 explaines all variables adopted in the literature review.

Table 2 proposes as example the categorization of some of 299 papers selected by data screening and cleaning.

Then, a descriptive analysis of the selected papers was conducted in order to know in the recent scientific papers the statistical distribution of products studied, year and journal of publication, LC tools adopted, goals and system boundaries assumed.

Table 1: Variables considered in order to categorize selected papers

Variables	**Possible values for each variable**
Year of pubblication	2012, 2013, 2014, 2015, 2016, 2017
Journal	Name of the journal
Products	Bread, Cereals and Rice, Cheese and dairy products, Eggs, Fruit and vegetables, Meat, Milk, Pasta, Oil, Tomato sauce and tomato products, Wine and alcoholic drinks, Packaging, Seafood, Soft drinks, Sugar and coffee, Others
LC tools	Life Cycle Assessment (LCA), Product Carbon Footprint (PCF), Water Footprint (WF), Others
Goals	Environmental Marketing, Environmental Innovation, Environmental Consciousness, Methodological Objectives
Boundaries	Cradle to Grave, Cradle to Distribution, Cradle to Consumers, Cradle to Gate, Gate to Gate, Cradle to Cradle, Gate to Grave, Others

Table 2: Example of table used to categorize selected papers

Autors	**Title**	**Year**	**Journal**	**Products**	**LC tools**	**Goals**	**Bounda-ries**
Arcese et al	Analysis of Sustainability Based (…)	2012	J Environ Science Eng	Wine and alcoholic drinks	LCA	Environ. Consciou-sness	Cradle to Grave
(…)							
Röös et al	Can carbon footprint serve (…)	2013	Ecol Ind	Meet	PCF	Method. Objectives	Cradle to Gate
(…)							
Almeida et al	Carbon and Water Footprints and Energy Use (…)	2014	J Ind Ecol	Fruit and vegetables	PCF, WF, Other	Environ. Innovation	Cradle to Distribution
(…)							
Manfredi and Vignali	Comparative Life Cycle Assessment (…)	2015	J Food Eng	Packaging	LCA	Environ. Innovation	Cradle to Grave
(…)							
Vazquez-Rowe et al	Carbon footprint of pomegranate (…)	2016	Int J LCA	Fruit and vegetables	PCF	Environ. Consciou-sness	Cradle to Grave
(…)							
Filimonau and Krivcova	Restaurant menu design (…)	2017	J Clean Prod	Other	PCF	Environ. Marketing	Cradle to Grave

3 Results

The papers selected from the literature analysis are 299, published in several scientific journals from 2012 and 2017. The distribution of the 299 selected papers within the time period is represented in figure 1, and their distribution within the journals is represented in figure 2.

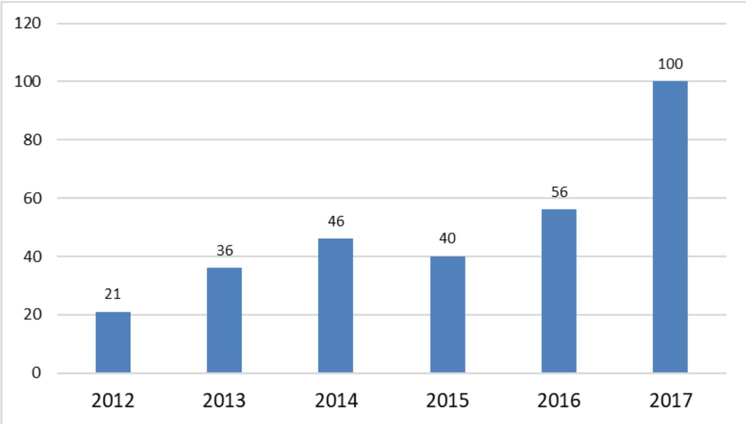

Figure 1: Distribution of papers based on the time of pubblication

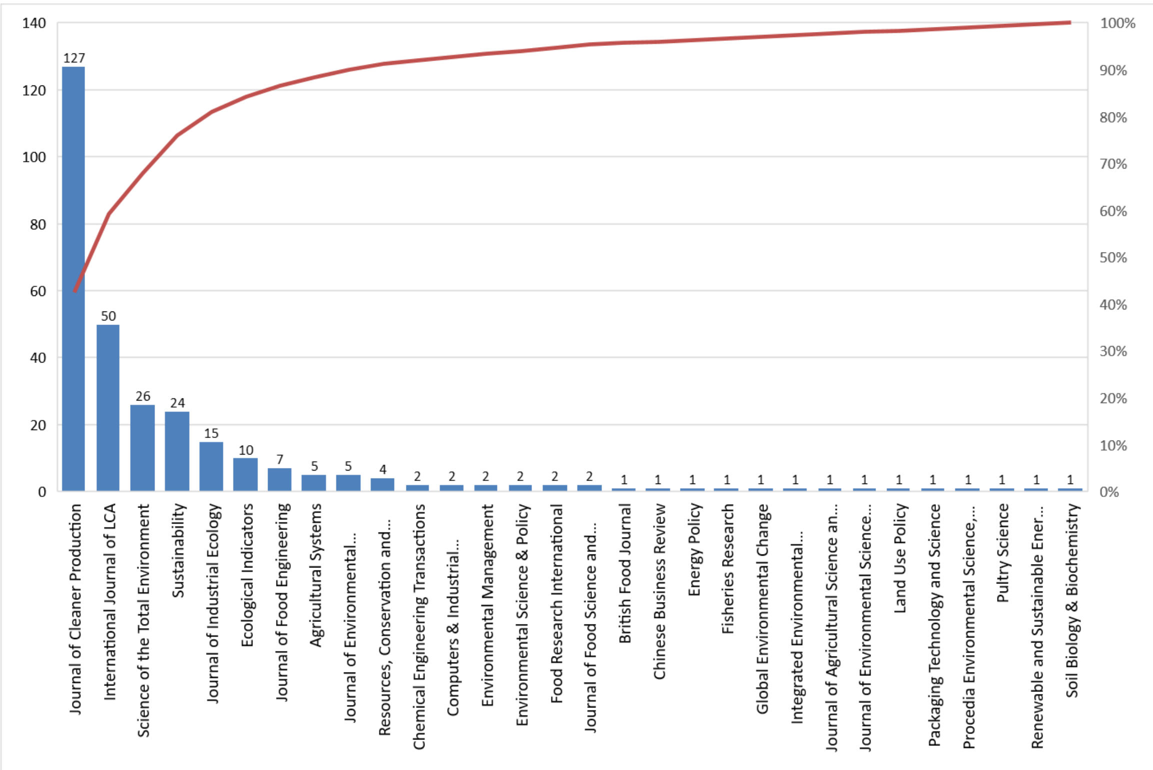

Figure 2: Distribution of papers based on the journal of pubblication

We underline that the analysis of the agrifood sector through LC tools is growing, with a more and more relevant number of published studies from 2012 to 2017. The journal with the higher number of publications is the Journal of Cleaner Production, followed by the International Journal of LCA. Several journals demonstrate an increasing interest of this topic, instead the life cycle approach can be a new topic (as in the 20 journals which only 1 or 2 papers related this topic). On the other hand, 4 journals have published more than 80% of papers in this period.

With the aim to analyze not simply the published papers, but more precisely the life cycle studies conducted during the year in the agrifood sector, we must consider that several of the selected papers were formed by more than one life cycle study. Then, these papers were divided into singular observations; consequently, 412 studies are assessed.

Figure 3 summarizes the distribution of 412 studies in terms of products analized. We can see that “Fruit and vegetables”, “Meat” ad “Wine and alcoholic drinks” are the most studied categories. Moreover, there are numerous studies concerning “Packaging”, “Cereals and rice”, “Milk” and “Seafood”. From the literature analysis, we can also affirm that from 2012 to 2017 the range of products analyzed has increased. The group “Others” includes a growing number of studies that have considered complex products, as ready meal, catering service, vegetarian and vegan diet, home made meal, and so on.

Figure 4 represents the distribution of selected studies in terms of LC tools adopted. The LC tool more frequently used is LCA, followed by PCF. Instead, WF remains the less frequently used tool, despite in this economic sector the water availability represents a felt problem. In the group “Others” there are a consistent number of studies that have adopted other LC tools, as partial LCAs, Environmental Product Declaration, Ecological Footprint, Life Cycle Costing.

Figure 5 represents the distribution of 412 studies based on the goal. The great majority of life cycle studies were conducted pursuing goals of environmental consciousness, for example to know environmental hotspots within the supply chain. Instead, the number of studies conducted with objectives as environmental marketing and environmental innovation is lower. On the other hand, several studies discuss methodological questions, frequently related the impact assessment methodologies.

Finally, figure 6 shows the distribution of selected studies with different boundaries adopted. Cradle to Gate are the most widespread framework, meaning that the majority of the studies focus on the production only. This is somewhat limitative as they leave out later phases of the life of a product, such as transformation, distribution, consumption and end-of-life, as well as food-waste-related issues, thus not considering important causes for environmental impacts. More comprehensive system boundaries, as Cradle to Grave, can be found in second place. Together Cradle to Gate and Cradle to Grave approaches make up to 80% of the total. We can also affrim that during the years a decrease in Cradle to Distribution approach is accompanied by an increase in Cradle to Consumers approach. The group named “Others” includes all the studies that have adopted other boundaries, as Gate to Distribution, Gate to Consumers, and so on.

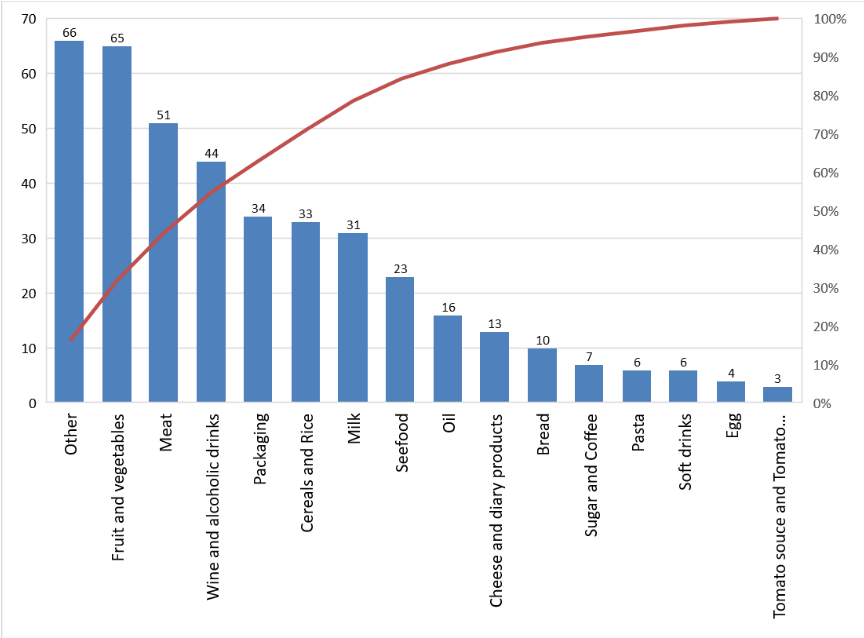

Figure 3: Distribution of studies base on products analyzed

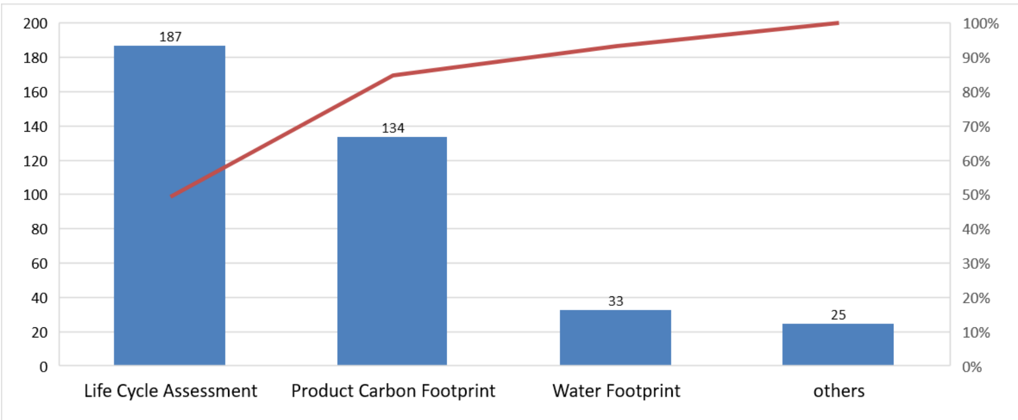

Figure 4: Distribution of studies based on the LC tool adopted

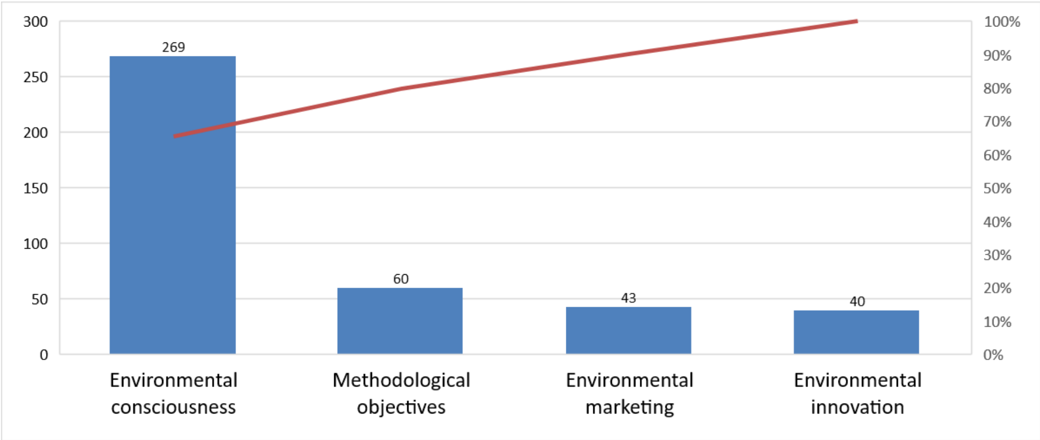

Figure 5: Distribution of studies based on the goals assumed

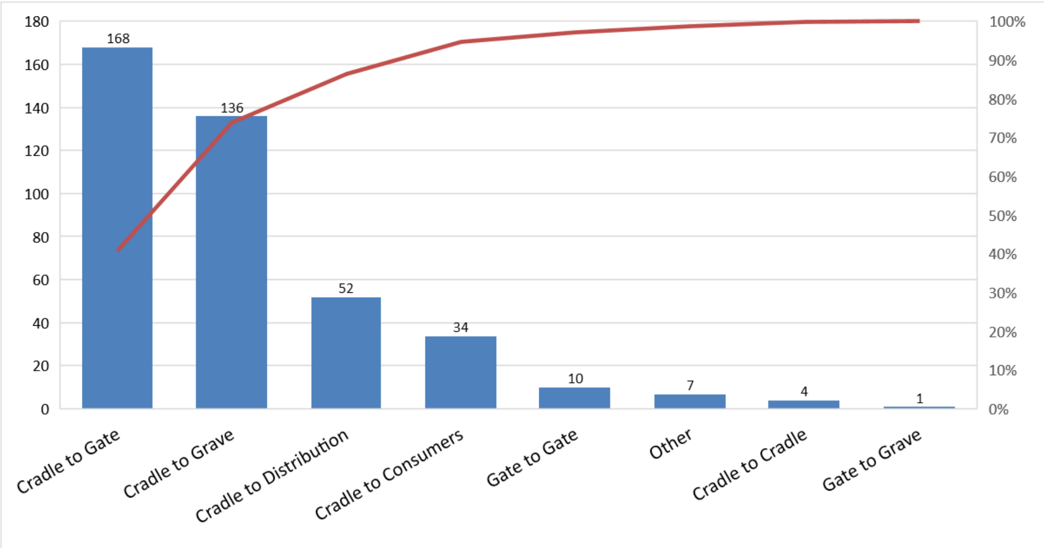

Figure 6: Distribution of studies based on the boundaries adopted

4 Conclusions and recommendations

From a systematic review of scientific papers related the adoption of LC tools in agrifood sector, we studied 299 papers published in 30 journals, concerning 412 life cycle studies related agrifood products. Thanks to this research, it is possible to reach the following conclusions.

The adoption of LC tools in the agrifood sector is constantly growing in recent yaers, mainly with the aim of increasing environmental awareness.

The products more frequently studied are related fruit and vegetables, meat and wine. An increasing number of studies regards packaging and innovative solutions in a supply chain perspective.

The LCA is the preferred tool, following by the PCF, instead the Water Footprint is still rarely adopted.

The LC tools are more frequently adopted with a Cradle to Gate perspective, and the production phase (including cultivation, breading or fishing, and transformation) is the mainly studied. Furthermore, in recent years several studies consider the entire life cycle of products, adopting a Cradle to Grave approach (including distribution and consumption phases).

From these results, next research perspectives open up. We will investigate if there are statistical correlations between types of studies (as LC tools and agrifood products) and methodological choices (as goals and boundaries), in order to deepen tendencies related the adoption of LC tools in agrifood sector.

Moreover, the research results can be enriched with an analysis of other reports and publication in agrifood sector, as EPDs. Besides the spread of environmental product certifications represents other comparison element with results obtained in this research.

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Environmental and Social LCA as tools for inclusive overview of SME sustainability and marketing strategy: the case of a farm in Maremma (Tuscany)

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Abstract

Business strategies of companies in the agro-food sector should be supported by effective evaluations, such as Environmental and Social Life Cycle Assessment (E-LCA and S-LCA), to have an overview of the sustainability level of supply chains, also oriented to marketing strategies. E-LCA and S-LCA were applied to a small farm in Tuscany (Italy) whose production of wine, olive oil and honey is based on environmental wellbeing principles. E-LCA results (focused on Carbon Footprint) highlight high performances for all products and farm emissions are completely "compensated" by ecosystem uptakes. S-LCA evidences a proactive farm behavior towards stakeholders and subcategories. Both analyses valorize the positive aspects of an aware management and reveal how specific "sustainability-oriented" choices can be relevant in terms of overall farm impacts.

1 Introduction

Very often, companies in the agro-food sector limit their mission to guarantee the quality of products, adopting innovative technologies (e.g. photovoltaic installations) or complying to specifications (e.g. organic) and promoting their virtuosity only in a qualitative way. But it is not enough to demonstrate their sustainability. Private businesses should systematically monitor their environmental and social performances (not only economic ones) to enhance awareness of their sustainability level, adopting continuous improvement pathway. This approach leads not only to better understand where it is necessary to intervene, but also to be competitive in market. It is advisable to start this process from a preliminary screening, based on standardized methods (i.e. Life Cycle Assessment, LCA; ISO, 2006a,b).The Environmental LCA (E-LCA) focuses on environmental implications of any human action, by quantifying potential impacts, as a snapshot, in a specific period. It is widely used practical tool, but it is not sufficient as a "stand-alone" evaluation. Further investigation must in fact includes other aspects. The Social LCA (S-LCA; UNEP SETAC, 2009) gives information about the farm "status" and company behavior through interactions with different actors along the supply chain. These two complementary methods allow for identifying and valorizing positive actions to be adopted along the supply chain. These also show hotspots and inspire supporting programs for future improvements. This is particularly effective in companies that manage the whole production chain.

In this article we present E-LCA and S-LCA applied to a small farm in Tuscany (Italy), highlighting both environmental and social aspects, to have a more complete overview of its sustainability level. S-LCA is applied using the

Subcategory Assessment Method (SAM), adapted to the characteristics of the case study, starting from Salvi, 2018.

2 Materials and methods: case study, Environmental and Social Life Cycle Assessment

LCA has been applied to Fattoria La Maliosa, a small farm in Maremma (South Tuscany, Italy). The farm is 158 ha large (of which: 6 ha is vineyard, 16 ha is olive grove and the remaining area is forest and grassland) and it is self-sufficient for electricity supply, thanks to photovoltaic installations. The farmers pay attention to tradition and, at the same time, innovation, social aspects around products and connections to the environment. The human expertise plays a crucial role and the farmer is considered as a craftsman that interacts with environment to produce goods, while respecting the territory and its originality. Wine, olive oil and honey are produced according to the organic and vegan specifications. In particular, the agronomic processes focus on minimizing the use of chemicals (i.e. small doses of S and Cu only) and machineries, maximizing the vitality of soil (no fertilizer, but auto-produced hay applied to fields), as well as the respect of the territory of origin by the use of autochthonous species. The agricultural practices relative to grape production, are registered patent and trademark. Data for both analyses are referred to average values of the last three years and collected by direct interviews with the farm owner and workers. System boundaries (i.e. from cradle to grave approach) include field management (i.e. vineyard, olive grove and beehive), transformation (i.e. cellar operations, oil milling and honey extraction), bottling and packaging end of life, excluding the distribution and use phase. The yield was about 150q of wine per ha, 0.8q of oil per ha and 10 kg of honey per beehive.

Relative to E-LCA, allocation was not performed for wine production (i.e. reuse of co-products in field, e.g. stalk and march), while economic allocation was performed for olive oil (according to Notarnicola et al., 2015) and mass for honey. Functional Units (FU) were referred to 1 bottle of wine (red and white, 0.75L), 1 bottle and 1 steel can of olive oil (0.25L and 3L respectively) and 1 honey jar (300g). In order to have a consistent evaluation to S-LCA at farm level, FUs were then multiplied for the total amount yearly produced (three year average, i.e. about n.1750 bottles of white wine, n.4590 bottles of red wine, n.1720 olive oil bottles, n.138 olive oil cans and n.990 honey pots). E-LCA was calculated by using SimaPro 8.0.4 software (PRè Consultant, 2014), selecting the method IPCC 2007 (100 yrs) (IPCC, 2013). In fact, this study is focused to the Carbon Footprint (CF), as commissioned by the company to be even included in its communication strategy. The Carbon Uptakes within the farm were estimated using equations proposed by 2006 IPCC Guidelines (IPCC, 2006) and dynamic model elaborated with STELLA 8.1.4 software (STELLA, 2005). The “farm GHGs balance” was quantified by subtracting the uptakes to the whole farm CF.

S-LCA was performed by adapting the UNEP/SETAC framework (UNEP/SETAC 2009; Benoit et al., 2013) to the case study. As the existing method is set for big companies (e.g. multinational corporations that hardly have the whole production chain under their direct control), it has been here modified according to the characteristics of a small farm. This influences the set of subcategories chosen for stakeholder investigation. For example, the subcategories "*prevention and mitigation of armed conflicts*" and "*secure living conditions*" were deleted, because not pertinent or applicable to the case study; other subcategories and a new stakeholder (i.e. *environment*) were added, as detailed in Fig.1. in order to highlight other aspects that E-LCA and S-LCA do not usually take into consideration or valorize and to better appreciate the peculiarity of the farm.

STAKEHOLDER	SUBCATEGORY	BASIC REQUIREMENT	LEVEL C	LEVEL D
Consumers	**Quality of the product**	The organization has a procedure regarding quality standards and % of its production is organic, according to CE 889/08	The organization has no proven cases that violate quality standards and is considering an organic conversion of several processes	The organization has proven cases that violate quality standards and does not consider an organic conversion at any process level
	Care to consumer needs	The organization offers a set of product alternatives	The organization has different sizes of the same product	The organization has no alternative products
Society	**Safeguard of cultural difference of the product**	The organization use methods of cultivation and production that recall the tradition, opting for usual methodologies	There is no evidence that the organization breaks the traditional methodologies	The organization does not take into consideration traditional processes, opting for social and environmental impactful methodologies, concerning only to the quantity produced
Environment	**Biodiversity protection and conservation**	The organization adopts solutions for the protection of biodiversity e.g. organic farming, soil vitality, buffer zones	There is no evidence in action aimed at limiting or damaging the biodiversity	The organization does not adopt any policy for the protection of biodiversity, mono-species farming is preferred
	Waste management	The organization operates in compliance with waste disposal guidelines of the country where it is located (d.lgs. 205/10)	The country where the organization is located has no policy for waste disposal, however the company is interested in applying waste recycling	There is the evidence of disinterest in correct waste disposal
	GMO free	The organization operates in compliance with national law relative to GMO use and cultivation (2001/18/CE)	The country in which the company operates has no policies against the use of GMOs	The company uses and cultivates GMO , despite GMO are banned in its country
	Use of autochthonous species	The organization uses autochthonous species for cultivation and breeding	The organization uses autochthonous (small %) and non autochthonous species for cultivation and breeding	Non-autochthonous species are used for cultivation and breeding
	Soil erosion	The organization carries out actions for organic matter conservation	There is no evidence of action aimed at soil deterioration and the country, where the company operates, has low risk of desertification	There is evidence of action aimed at soil deterioration and the country, where the company operates, has high risk of desertification
	Forest conservation/ sustainable use	The organization has a cutting plan , according to national law and regional agreement	There is no evidence of cuttings without the regional agreement	The organization operates cutting without regional agreement in a country with high deforestation risk
	Water withdrawal by local aquifers	The organization has a internal water management system and monitors consumption by local resources	There is no proven cases of overexploitation and the company is implementing a plan for water reduction use	There is evidence of local resources overexploitation

*Figure 1: BR (basic requirement), level C and D assigned for stakeholders and subcategories introduced ad-hoc in this study, with regard to UNEP/SETAC guidelines; *subcategory by Serrelli et al., 2016*

Ad-hoc questionnaires were elaborated and submitted to the farm owner and to all workers. Additional information was obtained indirectly during in farm visit, supported by evidences (e.g. presence of "buffer zones" for biodiversity protection). The characterization of each subcategory was based on SAM (Sanchez Ramirez et al., 2014), by developing the following phases: identifying the unit process (the organization); defining the basic requirements to assess each sub-category; definition of levels based on the environmental context; assignment of a quantitative value to each level. According to Sanchez Ramirez et al. (2014), the level A indicates that the organization exhibits proactive behavior by promoting basic requirements (BR) practices along the value chain (4 scores assigned). Level B means that the organization fulfils the BR (3 scores assigned). Levels C indicates that the organization does not fulfill the BR (2 scores assigned) and D when the organization does not fulfill the BR, even if operating in a positive context (1 scores assigned). Collected data were translated in attributing levels and scores.

3 Results and discussion

E-LCA highlights the following Carbon Footprint outcomes per FU: 0.81 kgCO_2eq for a bottle of white wine (0.75L), 0.92 kgCO_2eq for red wine (0.75L), 0.88 kgCO_2eq for olive oil in glass bottle (0.25L), 8.9 kgCO_2eq for olive oil in can (3L) and 0.58 kgCO_2eq for honey pot (300g). In general terms, results obtained in this study are lower than European literature average (Notarnicola et al., 2015; Rugani et al., 2013). Hotspots for the wine sector are mainly constituted by packaging (i.e. glass bottle is about 50% of total CF per FU) and gasoline consumption for worker transportation farm-vineyard (about 35% of total CF per FU). The use of chemicals marginally contributes to the total CF (i.e. 11%). Regarding the olive oil sector, main contributions to the total impacts per FU derive from gasoline consumption (about 80%) for transportations to reach olive grove and oil mill, and packaging (26% for glass bottle and 10% for can). Once again, gasoline for worker transportation to control beehives (70% of total CF per FU) and the glass of pots (27% of total CF per FU) represent hotspots for the honey supply chain. The total CF at farm level (i.e. referred to the total amount annually produced) is about 9 tCO_2eq per year. Main impacts are related to wine production (i.e. 63% of total CF), in particular red wine (i.e. 47% of total CF), and marginally to olive oil production (i.e. 30% of total CF), as illustrated in Fig.2. Obviously, this result is closely linked to the annual amount produced, but highlight which supply chain needs urgent improvements.

Fig. 2 shows that energy use (i.e. gasoline in red) and packaging (i.e. glass in violet) mainly contribute to overall impacts (respectively 51% and 38%). The high impact of gasoline consumption is to attribute to the distance farm headquarter-fields (about 10 km). Recommended solutions to mitigate hotspots are certainly the substitution with more efficient vehicles for worker transport (i.e. electric cars, also possible by virtue of an electricity production surplus within the farm) and lighter packaging (390g glass instead of 430g and 0.25L cans instead of glass bottles for olive oil). Nevertheless, the best practice implemented, as the use of electricity by renewable sources and the substitution of lighter bottles for white wine, allowed saving 30% and 7% of emissions respectively, as well as the use of stalk and marc instead of fertilizer, hay to regenerate the organic content in soil and cans for olive oil packaging (3L).

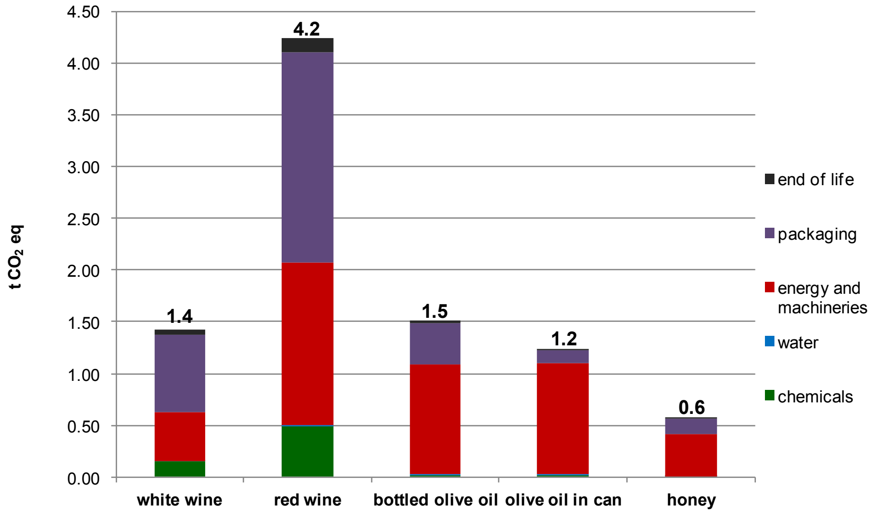

Figure 2: Carbon Footprint of total wine, olive oil and honey annually produced

Carbon Uptake by local ecosystems is illustrated in Fig.3. Oak woodland represents the bigger carbon sink within the farm. The best practice implemented to maintain grass in vineyard and olive grove also contributes to uptakes.

type of woodland/crop	area (ha)	uptake (tCO_2/yr)
oak woodland	72.13	564.03
olive trees	16.18	104.34
grassland*	74.24	245.77
TOTAL UPTAKE		**914.15**

*Figure 3: Carbon Uptake at farm level; *it includes area dedicated to grassland (54.24 ha) in addition to area with grass among grapevine rows and olive trees (about 20 ha)*

Total carbon uptake is about 100 times larger than farm CF (even if we consider that the former is expressed in kg CO_2 and the latter in kg CO_2-eq. Emissions from the whole farm production can be considered as completely “compensated” by CO_2 uptake by farm ecosystems.

S-LCA outcomes reveal a positive trend for most of stakeholders (i.e. 3 and 4 scores). The stakeholder “*workers*” highlights scores of 3 and 4 because the farm pays attention on worker well-being, showing the following characteristics: freedom of association, fair salary and working hours, favoring manual work instead of mechanized, absence of serious accidents on the job and limited use of chemicals in field processes, promoting refresher/training courses. The stakeholder "*local community*" scores high values because the company promotes sustainable management of resources and healthy living conditions (e.g. by monitoring the lifecycle impact of products, re-inletting in the network the surplus of electricity produced by photovoltaic installations, minimizing use of chemicals on the field and restoring the vitality of soil), supports community service and engagement (e.g. by sharing information and knowledge transfer, promoting guided tours of farm and nearby small towns), local employment (i.e. 90% of workers live close to the farm, including not Italian native) and encourages traditional production methods (both in field and transformation phases). The analysis takes into consideration also the upstream component of the supply chain, by evaluating the stakeholder "*value chain*". Results revealed high performances due to the care in selecting suppliers, according to social/ environmental responsibility and short chain, as much as possible (e.g. preferring suppliers characterized by distance below 100 km, involvement in programs aimed at supporting disadvantaged peoples, promotion of recycling/reusing projects, low environmental impacts along the production chain). The subcategory "respect of intellectual property rights" is completely satisfied by safeguarding the intellectual property of the agronomic processes by registered patent. It also allows for the repeatability and availability of the method to other farmers. The "*consumer*" stakeholder achieved high scores, because the company takes care to: healthiness of products (e.g. natural wine without sulfite added and chemicals use in field operations), its quality (e.g. 100% organic products, several quality awards: best 100 Italian wines, bioil gold medal, biomel gold medal), consumer dietary preferences (i.e. vegan label), transparency (e.g. products and farm CF communication in fairs and website, organic and vegan labels on products), consumer engagement (e.g. guided tour of the farm, organization of wine, olive oil and honey tasting), feedback mechanism (e.g. the use of social network, website, email) even if the consumer satisfaction is not tested (e.g using feedback questionnaires). The item "end of life responsibility" is the only one criticality noticed (i.e. score 2), because of the absence of information on how to dispose the packaging, even if the company has implemented the best practice recommended to using lighter glass bottles for wine. Concerning the "*society*" stakeholder, no criticalities are revealed, because of the strong farm diligence in public commitment to sustainability issues (e.g. LCAs at farm level by annual monitoring of whole production chains implemented with mitigation plans and objectives that year by year were achieved, as the use of lighter bottles), besides the safeguard of products due to the robust link among product-tradition-territory. Although the farm is a small entity, it contributes positively to generate revenue, create job and make investments, by also converting research into economic development (i.e. the patent for agricultural practices as innovative technology to produce efficiently, while safeguarding the environment). The evaluation of the subcategory corruption is strongly affected by the national background: obviously, the company has no evidence of corruption, but the national Corruption Perception Index (CPI) score (TI, 2010) is very low.

High scores obtained for the new stakeholder "*environment*" valorize the farm diligence in safeguarding the territory. In fact, enhancing the soil quality through specific agronomic processes, the use of autochthonous species and ancient variety recovery, the presence of quality indicator species and "buffer zones" maintenance, aware use of water and the circular economy approach (Fucci, 2018) to reduce wastes, clearly demonstrate the farm care in environmental issues. This stakeholder, created ad hoc, proves to be fundamental in adding values to other aspects and best practices that E-LCA does not take into account.

Detailed description of results obtained for each new subcategory and stakeholder those that scored lower values are illustrated in Fig. 4.

STAKEHOLDER	SUBCATEGORY	LEVEL	SCALE SCORE	COMMENTS
Consumers	**End of life responsibility**	**C**	**2**	Even if the company is reducing the weight of packaging (e.g. glass bottles), that can be recycled, no indications on how to dispose it are specified in label
	Quality of the product	**A**	**4**	All the production is organic. During last 5 years products were awarded for their excellent quality at national and international level (e.g. biol, biomiel). Wine, olive oil and honey are naturally produced both during field and transformation phases, without any additional intervention
	Care to consumer needs	**A**	**4**	All products have the Organic and Vegan label (certified). The company take care of dietary preference of consumers
Society	**Cultural difference safeguard of products**	**A**	**4**	Cultivation and transformation methods are based on traditional (and at the same time innovative) principles, products must have a strong identity, while respecting the territory of origin
Environment	**Biodiversity protection and conservation**	**A**	**4**	All agronomic processes are aimed at protecting and enhancing the biodiversity of farm ecosystems: the soil vitality is favored by avoiding the machineries access to vineyard and olive groves (the biological soil quality is regularly monitored); only autochthonous species are used, both plant species and yeasts, vineyard and olive grove grassland are not treated but different species are free to flourish; cultivated field are bordered by "buffer zones" constituted by wood band, that promote fauna and flora exchange. Moreover, the presence of particular species (e.g. Libelloides coccajus) indicates good health of ecosystems.
	Waste management	**A**	**4**	The company correctly dispose and differentiate wastes according to the regional law. Wastes are minimized by adopting a circular economy approach (e.g. reuse of cellar by-product, stalk and marc, as fertilizers)
	OGM free	**B**	**3**	All products are GMO free, neither GMO are using during production processes. There is no specific certification of it.
	Use of autochthonous species	**A**	**4**	The company uses only autochthonous species both for cultivation and transformation phases (e.g. autochthonous grapevines as Ciliegiolo, Sangiovese, Procanico, olive tree as Leccino, Frantoio, Leccio del Corno, bees as Apis mellifera ligustica, yeasts and indigenous bacteria in cellar)
	Soil erosion	**A**	**4**	The company limits mechanical work in fields, use organic soil cover techniques (mulching) to preserve the organic matter and enhance the quality of soil. Systematic soil monitoring are carried out to measure the organic content
	Forest conservation/ sustainable use	**B**	**3**	Even though forests within the farm are managed with regular cuts, there is no evidence of an exploitation plan to valorize the obtained wood
	Use of water	**A**	**4**	The farm adopts a water conservation plan: field processes do not require irrigation, except for rare emergency and minimal treatments. In that case, well water is used. Water use by network is limited to cellar processes.

Figure 4: S-LCA outcomes and explanation for each sub-category and stakeholder created ex-novo (in blue) and criticalities

4 Conclusions

The aim of the study was to valorize the diligence in environmental and social issues by a small farm in the southern part of Tuscany (Maremma), Italy, that produces wine, olive oil and honey. The farm pays attention to tradition and, at the same time, innovation, environmental and social aspects of the production processes. The vitality of soil, integrity of the environment and quality of products are key issues of the farm's attitude.

E-LCA and S-LCA were applied to the case study, using a *cradle to grave* approach. E-LCA results (focused on CF category) highlight high environmental performance at product level (0.81 $kgCO_2eq$, 0.92 $kgCO_2eq$, 0.88 $kgCO_2eq$, 8.9 $kgCO_2eq$ and 0.58 $kgCO_2eq$ per FU, respectively for a bottle of white and red wine (0.75L), for olive oil in glass bottle (0.25L) and in can (3L) and for honey jar (300g)) if compared to scientific literature. Whole farm emissions are completely "compensated" by ecosystem Carbon Uptake (more than 100 times greater). Obviously, the analysis should take into consideration a wider set of impact categories to have a more complete overview of potential impacts. S-LCA was firstly adapted by adding new stakeholders and sub-categories, more pertinent or applicable to the case study, than the SAM was applied for a characterization based on BR. The farm presents high performances also concerning social aspects, in most cases characterized by a proactive behavior relative to the BR. Only one criticality was identified for the subcategory "end of life responsibility", due to the lacking of specific information on how to dispose the packaging. Results obtained for the new category added ad-hoc (i.e. "*environment*") valorize aspects that are not taken into account in E-LCA; at the same time, the E-LCA annually performed, inspires best practices with effects in social terms, highlighting the positive interaction among involved actors along the supply chain.

Nevertheless, outcomes of both analyses reveal also few hot-spots, that can be mitigated (e.g. introducing lighter packaging and electric vehicles, enhance the worker awareness about energy consumption). Limits of S-LCA are obviously well known (e.g. subjectivity and influence of context environment on results), but this study highlights that it can be a useful tool, complementary to E-LCA, to have a more complete overview on the company sustainability.

Outcomes reveal how specific "sustainability-oriented" choices can be relevant in terms of overall farm impacts. The ethic mission of the company is rewarded not only by the wine, olive oil and honey quality, but also by results of this study. Results can surely contribute to express an added value in market oriented initiatives of the company, inform and address consumers towards awareness and responsible choices. Next step will provide for a Life Cycle Costing (LCC) analysis to fulfill the Life Cycle Sustainability Assessment (LCSA) perspective.

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Concrete design optimization by LCA: a critical analysis

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Abstract

In today's societies, concrete is ever more frequently used, but its production demands a large amount of power that creates environmental pollution. The main material composing concrete is cement which is made from clinker. The necessary high production temperatures cause emissions of CO_2. Simultaneously, very significant amounts of demolished concrete produced from deteriorated and obsolete structures create severe ecological and environmental issues. One of the ways to solve these problems is to use this 'waste' concrete as an aggregate. Various authors have studied the effects of mixing a portion of recycled aggregates with concrete and they found that this solution has a positive effect on environmental impacts reduction. Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development.

1 Introduction

Nowadays, concrete is the most used building material all over the world, but the presence of clinker in the concrete mixture makes this material harmful to the environment. The production of concrete requires a large amount of energy that causes environmental pollution. Cement with a lower environmental impact in terms of carbon footprint, embodied energy and water use should be utilised with the aim to design in a more ecological way. (Fantilli et al., 2015).

If we analyse the life cycle of concrete, we can see that at the end-of-life it becomes the so-called "construction and demolition waste" (C&D). This means that after its lifespan, concrete is demolished and most often disposed of in a landfill (Corinaldesi and Moriconi, 2014).

With the desire to draw the attention to this alarming and worldwide overbuilding, the main target of this work is to gather the basic principles regarding concrete, its production, its life cycle and its environmental impact. This paper wants to be a review of the previous papers concerning the concrete topic that it is possible to find in the scientific literature and it is structured as follow. In section 2 after a general description of the main concrete components, a concise definition of LCA is given with direct reference to the concrete LCA. The environmental impact of concrete is analysed in section 3 with a separate analysis of the environmental impact of each of the concrete mix design components. Cement firstly and successively the aggregates. Section 4 shows the feasible use of recycled aggregates with a description of the properties that characterize aggregates made from construction and demolition (C&D) waste and of the environmental impact own of the recycled aggregates. As a conclusion of this review work, the sustainable design is presented in section 5 with reference to a new design philosophy oriented towards the analysis of the whole life-cycle.

2 Concrete

a. A general description

Worldwide concrete consumption has increased over the years. In 2016 it rose by 1,7% and reached 3,97 billion tons, 66 million more than 2015 (AITEC, 2016). This makes concrete one of the most common building materials on the market. The main ingredients in concrete are aggregate (70-80%), cement (10-2%) and water (7-9%), and to enhance specific characteristics, chemical admixtures (less than 1%) are added (Sjunnesson, 2005). In the cement production process, which is the main component of concrete with the role of hydraulic binder, not only do natural resources such as limestone and clay become depleted, but environmentally relevant gaseous substances are also emitted during clinker manufacturing through pyro process, due to large amounts of energy use (Kim et al., 2016). Additionally, the extraction of natural aggregates can lead to soil erosion or ecosystem destruction, while the waste sludge and wastewater emitted from a concrete batch plant have harmful effects on the water ecosystem (Cucchiella et al., 2014).

b. LCA of concrete

The life cycle assessment, LCA, is the investigation and the evaluation of the environmental impacts of a product, process or service. LCA evaluates all stages of a product's life and considers each stage interdependently, meaning that one operation leads to the next (Lemay, 2011). The environmental impact assessment on concrete was based on the life cycle assessment process suggested in the ISO 14040 (ISO 14040:2006). Some environmental problems arising from concrete use are global warming, ozone depletion, photochemical ozone creation, abiotic depletion, eutrophication, and acidification.

3 Environmental impact of concrete

Concrete is the most heavily consumed material in the construction sector and the second most heavily consumed substance on Earth after water (Weil et al., 2006). As a consequence, it is obvious that the construction sector employs a lot of power and emits large amount of greenhouse gases like CO_2 into the atmosphere. Indeed, power is required for the extraction, transport, production, and manufacturing of building materials and components (Corinaldesi and Moriconi, 2014).

a. Environmental impact of cement

The fundamental raw material in the production of Portland cement is limestone. The very high temperatures of the cooking process (some phases reach 1450°C) causes the chemical reaction in which the limestone is broken down into the fundamental components: CaO and CO_2. Other CO_2 emissions come from the carbon contained into the fuel used to reach the high temperature needed to produce the clinker. 60% of the CO_2 emissions derive from the limestone decarbonisation, while the remaining 40% derives from the combustion of the fossil fuels (Corinaldesi and Moriconi, 2014).

b. Environmental impact of aggregates

Aggregates form more than 80% of the weight of a typical concrete mixture. The extraction of a ton of natural aggregates needs 20 MJ of energy by fossil fuel and 9 MJ of electric energy, while smashing a ton of aggregates needs 120 MJ and 50 MJ (Worrell et al., 1994), respectively. So, the use of natural aggregates instead of smashed aggregates in concrete production involves a lower consumption of fossil fuels and smaller CO_2 emissions, but the insufficient availability and the resulting environmental impact constitute a very difficult problem to solve.

Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development. Continuous industrial development poses serious problems of construction and demolition waste disposal (Topcu and Guncan, 1995). On the one hand, there is critical shortage of natural aggregates for production of new concrete, on the other the enormous amounts of demolished concrete produced from deteriorated and obsolete structures creates severe ecological and environmental issues. One of the ways to solve this problem is to use this ‘waste’ concrete as an aggregate (Khalaf et al., 2004; Raeis Samiei et al., 2015), the so-called recycled concrete aggregate (RCA).

Concrete debris was once routinely shipped to landfills for disposal, but recycling is increasing due to improved environmental awareness, mandatory laws and economic benefits (Wikipedia, 2018).

The cement industry has integrated sustainable development into their global operations, with the aim to create a concrete with a smaller environmental impact. They have become leaders in industrial ecology and innovators in carbon dioxide management (The cement sustainability initiative, 2002).

4 Concrete with recycled aggregates

Construction and demolition (C&D) waste has become the largest (Schachermayer et al., 2000) and increasing (Muller 2006; Hashimoto et al., 2007) waste fraction in industrialized countries. It is estimated that the annual generation of C&D waste in the EU could be as much as 450 million tons, which is the largest single waste stream, apart from farm waste. Even if earth and some other wastes were excluded, the construction and demolition waste generated is estimated to be 180 million tons per year, and considering a population of approximately 370 million, the per capita annual waste generation is about 480 kg (Rao et al., 2007).

Thus, C&D waste reuse as concrete aggregates has been considered as a valuable option to substitute the primary aggregates in concrete production as well as reducing the C&D waste deposition, where space for landfills is increasingly scarce (WBCSD, 2009). In the European Union, where the average

C&D waste recycling rate is 33% (Eurostat, 2017), the most recent waste legislation established a material recovery rate target of 70% for 2020 for this group of wastes (including reuse, recycling or other material recovery) (EC, 2008).

a. Properties of aggregates made from C&D waste

Recycled concrete aggregates can be produced from (a) recycled precast elements and cubes after testing, and (b) demolished concrete buildings. In the former case, the aggregate might be relatively clean, with only the cement paste adhering to it, whereas in the latter case the aggregate might be contaminated with salts, bricks and tiles, sand and dust, timber, plastics, cardboard and paper, and metals. It has been shown that, after separation from other waste types, and sieving, contaminated aggregates can be used as a substitute for natural coarse aggregates in concrete (Nagataki et al., 2004). As with natural aggregate, the quality of recycled aggregates, in terms of size distribution, absorption, abrasion, etc. also needs to be assessed before using the aggregate (Rao et al., 2007).

b. Environmental impact according to recycled aggregate

Kim et al. (2016) analysed, among others, the effect of recycled aggregates mixed into concrete and they concluded that there was an increase in some environmental categories.

Indeed, as the recycled aggregate portion of concrete increased, the potential for acidification (AP), eutrophication (EP), ozone depletion (ODP), and abiotic depletion (ADO) decreased, while the potential for global warming (GWP) and photochemical ozone creation (POCP) increased (Jongsuk et al., 2014).

In more detail, Kim et al. (2016) have demonstrated that, when the recycled aggregate mixing ratio was increased, GWP increased to up to about 14%~29% compared to concrete in which only natural aggregates were mixed. This was because, in the production process of recycled aggregates, major impact substances in terms of global warming potential (GWP), such as CO_2, CH_4, and N_2O, were emitted more than in the case of natural aggregate production process. On the other end, when the mixing ratio of recycled aggregate was increased to 10%, 20%, and 30%, compared to the concrete in which only natural aggregates were used, AP, EP, ODP, and ADP were reduced to about 9%~29%. A fine analysis of the reasons of this outcome revealed that in the manufacturing process of recycled aggregates, lower amounts of substances such as NOx, NH_3, SO_2, NH_4, halon, and CFC, which greatly affect the impact categories of AP, EP, ODP, and ADP, were emitted with respect to the production process of natural aggregates. In particular, as a large quantity of natural resources is not used in waste concrete recycling, it was found that also abiotic depletion potential (ADP) was significantly reduced. As the recycled aggregate mixing ratio was increased, compared to OPC (Ordinary Portland Cement), POCP was found to be reduced to about 2%~9%. CH_4, CO, S, and C_4H_{10}, the major impact materials of photochemical ozone creation potential

(POCP) in recycled aggregate production process, were emitted less than in the case of natural aggregate production process, but there was not much difference (Kim et al., 2016).

Knoeri et al. (2013) have also studied the impact assessment using two endpoint methods (Ecoindicator 99 and Ecological Scarcity 2006), and the GWP and the abiotic depletion potential (ADP) as midpoint indicators.

This study has also demonstrated that recycled concrete mixtures for structural concrete applications have significant environmental benefits compared to conventional concrete with the same cement type at endpoint level. Strongly reduced “respiratory inorganic” effects and a slight reduction of fossil fuel consumption are the main contributors to the Ecoindicator 99 reduction, while the Ecological Scarcity 2006 reduction is caused by natural resources preservation in addition to reduced emissions to air. Recycled concrete and conventional concrete have similar GWP due to higher cement content when recycled aggregates are used. On average, recycled concrete mixtures show around 30% environmental impacts reduction when assessed by Ecoindicator 99, Ecological Scarcity 2006 and ADP compared to conventional concrete mixtures, while the two options are on the same level regarding GWP (Knoeri et al., 2013).

These two results (Kim et al, 2016; Knoeri et al., 2013) could appear in contradiction with previous studies, which resulted in comparable or even higher environmental impacts of recycled concrete aggregates with respect to virgin ones (Marinkovic et al., 2010; Weil et al., 2006).

The difference might partly occur due to differences in construction practices among the countries (e.g. transport type and distances), but it is more likely to be related to different system definitions, particularly to the fact that the demolition process, C&D waste transport and landfilling, were largely excluded until that time.

5 A sustainable design

With the desire to find a solution to this alarming and worldwide pollution problem owed to the overbuilding, structural engineering could bring about profound changes in the design philosophy.

The traditional design procedure will be converted in an analysis of the whole life-cycle (Biondini and Frangopol, 2018), from the materia prima extraction to the end of the building lifespan.

One of the main issues facing sustainable building is that today’s demolition technologies do not produce directly reusable clean recycled materials. Usually, when a construction arrives at the end of its lifespan, it is demolished and transformed into demolished ruins. During this process, various materials are mixed and suitable careful procedures are needed to allow the reuse of debris (Corinaldesi and Moriconi, 2014).

It is possible to deal with this problem in two different ways:

- Designing with the aim of recycling the materials at the end of their life of service. The design procedure could include dismantling technique (DFD, design for dismantling) that allow an easier and direct reutilization of the materials and remove components after the building demolition (DFR, design for recycling).
- Adopting selective demolishing techniques for new buildings and selective destruction for existing buildings.

This kind of analysis needs to be included into an end-to-end design, previously mentioned.

To reach this ambitious goal to reduce the pollution problem owed to the overbuilding, it will be also useful to have a partnership among all the professional figures who contribute to the design and building of a structure. This would be the best way to fuse together the architectural, structural and functional needs in the aim of reducing environmental impacts that derive from the choices taken during the design phase.

The adoption of interoperable methodologies (the so call Building Information Modelling) appear to be the best way to reach this aim of new design philosophy (Fantilli et al., 2015).

6 Conclusions

The production of concrete requires a large amount of power that causes significant environmental pollution. With the desire to draw the attention to this alarming and worldwide environmental problem, the main target of this work was to gather the basic principles regarding concrete, its production, its life cycle and its environmental impact. The aim to design in a more ecological way calls for selecting cement with a lower environmental impact.

If we analyse the life cycle of this material, we can see that it belongs to the construction and demolition waste (C&D), this means that after its lifespan, it will be demolished and deposited in a landfill. One of the ways to solve this problem is to use this 'waste' concrete as an aggregate, the so-call recycled concrete.

Many authors have studied the effects of the recycled aggregates portion of concrete on resultant environmental issues. The outcomes of these studies are not conclusively in favour of the adoption of recycled concrete aggregates. As expected, with current recycling technologies some impact categories, but by no means all, are favoured by the use of RCA.

For this reason, it is important a larger degree of inter-operation between architectural, structural and functional needs during the design phase, implementing smart technologies for dismantling and recycling. To this purpose, Building Information Modelling (BIM methodologies) could reveal a highly effective tool.

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Methanol production from CO_2: comparison of the environmental impact of different processes

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Abstract

Methanol is the simplest organic alcohol and one of the most important substances in industrial chemistry. It is used as fuel, solvent and starting material to produce formaldehyde, methyl-tert-butyl ether (MTBE), acetic acid and dimethyl-ether (DME). On industrial scale it is produced using a gas mixture of H_2 and CO, also called syngas, in presence of a copper-based catalyst. Today methanol is primarily produced using fossil fuels. To improve the environmental impact new processes were developed during the years starting from different raw materials (i.e. biomass) or using different processes (i.e. photocatalysis). In this paper the environmental impact of different processes for the methanol production is evaluated using the Life Cycle Assessment (LCA) procedure. Relevant publications were reviewed focusing only on the environmental impact, while economical and social analysis were excluded.

1 Introduction

Today, methanol (MeOH) is one of the most important chemicals and its production has been continuously growing in last years reaching 70 Mtonne in 2014 and with a forecast demand of over 100 Mtonne in 2020 (Alvarado, 2016). It is used as solvent, fuel or starting material to produce several substances like formaldehyde, methyl-tert-butyl ether (MTBE), acetic acid (AA) and dimethyl-ether (DME) (Bozzano et Manenti, 2016). Methanol is an interesting alternative energy source and recently the methanol economy has been proposed as substitute to the hydrogen-economy since the alcohol transportation and storage is easier and the energy demand lower (Olah, 2005). Methanol has an octane number of 113, an energy density which is the half of gasoline and pure methanol engines can reach efficiency up to 44%. Moreover, methanol is a very flexible solution since could be coupled to "store" energy from different energy sources (photovoltaic, wind, geothermic, nuclear…). Another valuable alternative fuel is dimethyl-ether (DME), which is produced starting from methanol. It is a possible green substitute of liquified petroleum gas (LPG or GPL) due to its high calorific power, good chemical stability, high cetane number, low emissions and easiness to transport.

Nowadays, methanol is industrially produced starting from syngas, a mixture of hydrogen and carbon monoxide, in presence of a copper-based catalyst (Chinchen et al., 1988). The involved reactions are three:

$$2\,H_2 + CO \rightarrow CH_3OH \qquad \text{eq.1}$$

$$3\,H_2 + CO_2 \rightarrow CH_3OH + H_2O \qquad \text{eq.2}$$

$$H_2O + CO \leftrightarrow CO_2 + H_2 \qquad \text{eq.3}$$

eq.1 and eq.2 are reactions for methanol production respectively starting from carbon monoxide and carbon dioxide while, the third is the water gas shift reaction (WGS). The syngas composition of fed gas for the methanol synthesis is characterized by stochiometric number "S":

$$S = \left[\frac{H_2 - CO_2}{CO_2 + CO}\right].$$

under ideal conditions S should assume a value of 2, which correspond to about 2:1 ratio of hydrogen and carbon monoxide and a maximum carbon dioxide concentration of 6-8 %vol. Today the right mechanism of CO/CO_2 hydrogenation is not so clear yet, but some studies demonstrated that under industrial conditions, CO_2 hydrogenation is the favourite mechanism. The methanol synthesis is carried out at 230-250°C, 40-100 bar and catalyst is CZA ($Cu/ZnO/Al_2O_3$) (Manenti et al., 2014). Different processes are studied for the methanol synthetisis using photocatalysis, alternative raw materials for the syngas production or coupling the methanol production with traditional power plants as intensification process. The main goal of these studies is the reduction of fossil fuels consumption and the CO_2 reuse in order to improve the environmental impact.
In this work different LCA studies were presented to understand which processes or raw materials could improve the environmental impact of methanol synthesis.

2 Literature review

A literature review was performed considering only recent LCA studies of different technologies applied, or applicable, on industrial scale plants for the methanol production starting from CO_2 or using renewable sources. The research was limited to the years 2010 – 2017. The final selected 5 papers were resumed in table 1.

Table 1: List of selected papers

ID	Functional Unit	Process	Reference
STE	1 kg of H_2	MeOH production using CO_2	Sternberg et al., 2017
SLI	1 kg of MeOH 5.4 MWe	MeOH co-production using coal gasification	Sliwinska et al., 2017
REN	1 kg of MeOH	MeOH production using sugarcane waste	Reno et al., 2011
KIM	1 kg of MeOH	MeOH production using CO_2 and solar-thermal energy	Kim et al., 2011
TRU	14.3 MJ MeOH 1 kWe 14.3 MJ of CH_4	MeOH production using CO_2 and photocatalytic process	Trudewind et al., 2014

In these works, it was considered the methanol production with traditional process, with the use of bio-waste, and coupled with renewable energy. The latter is one of the most interesting topic since the environmental impact of methanol is mainly caused by hydrogen production. The system boundaries of each paper are not the same, in general a “cradle-to-gate” study was done including raw material extraction, fuel consumption, construction and disassembly of plants. Every work excludes the impact of methanol use and its disposal.

a. Methanol by intensification of traditional process

Sternberg et al. (STE) performed the LCA study of the traditional process and of the new CO_2-based process. They compared the synthesis of different C1 hydrocarbons using CO_2 as starting material. The goal of the study was to understand which hydrocarbon, between natural gas, carbon monoxide, methanol and formic acid, is more effective for the global warming reduction using as reference flow the consumption of 1 kg of H_2. Methanol production was assumed by CO_2 hydrogenation at 210-250°C and 50-75 bar and then alcohol was separated by distillation. Results show that methanol produced by CO_2-based process has a global warming impact (GW) of 7.3-8.4 kg CO_2-eq per FU, while for the traditional fossil-based process the typical value is 5.3-5.7 kg CO_2-eq per FU (Figure 1).

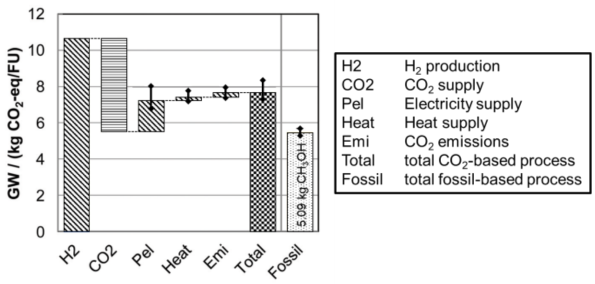

Figure 1: Methanol global warming (GW) impact per functional unit (FU = use of 1 kg of H_2). Oblique bars are supply processes with positive impact, horizontal bar is supply process with negative impact. Checkered bar is the overall new CO_2-based process while dotted bar represents the fossil-based processes.(Sternberg et al. 2017)

This is due to the high environmental impact of hydrogen production and its high energy demand. CO_2-based process could be an interesting alternative only as replacement of low efficiency fossil-based processes, in other cases the environmental impact reduction could be low or negative. In the paper, to achieve the highest global warming reduction the formic acid CO_2-based process was suggested. Methanol process CO_2-based has a positive impact on global warming, the CO_2 emissions are greater than CO_2 consumptions. Hydrogen production using renewable energy is mandatory to invert the trend (Aresta et al., 2002).

Sliwinska et al. (SLI) evaluated the environmental impact of methanol and electricity co-production starting by coal. Methanol is produced using syngas, the product of coal gasification. Unreacted gases, after the methanol reactor, are used for electric power production. In this work the impacts were allocated in function of the amount of carbon monoxide reacted (0.43 for methanol and 0.57 for electricity). GHG emissions resulting of methanol and electricity co-production were compared with total GHG emissions generated from the production of the same quantity of methanol and electric energy using alternative reference technologies (figure 2).

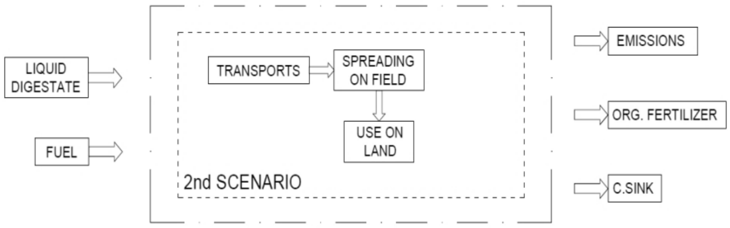

Figure 2: Greenhouse gas emissions (GHG) of co-production process. Symbols: G – analyzed technology, R – reference technology, A1 – average energy mix, A2 – subcritical coal power plant, A3 – supercritical coal power plant with CCS, A4 – IGCC power plant with CCS, A5 – nuclear power plant.(Śliwińska et al. 2017)

This new technology can reduce the GHG emissions with respect to processes that use traditional technologies (A1 and A2). Nevertheless, today development of new technologies to reduce the impact in the power sector is one of the most important goal set by IEA (IEA, 2010). For this reason, the authors considered also new technologies (A3, A4 and A5) and in these cases the co-production process result as more impactant. The co-production process could be an interesting alternative with respect to actual technologies, but the improvements are highly dependent on the alternative technology selected.

b. Methanol from biomass

Methanol production starting from biomass is another interesting way to reduce the use of fossil fuels and to promote rural development. Renò et al. studied the methanol synthesis using sugarcane bagasse as raw material (STE). Their work describes a “cradle to gate” LCA analysis considering cultivation, biomass treatments, gasification, gas cleaning, methanol synthesis and purification. Results were reported as environmental impacts and using two indicators, fuel energy ratio (FER) and life cycle energy efficiency (LCE). FER and LCE are defined by the following ratios:

$$FER = \frac{E_{fuel}}{E_{fossil}} \qquad LCE = \frac{E_{fuel}}{E_{fuel} + E_{primary}}$$

For this process, FER value is 9.4, this means that only 1 MJ of fossil fuel is necessary to produce 9.4 MJ of methanol. In other words, the methanol could be considered as renewable since the energy in the methanol is higher than the fossil energy consumed to produce it. The FER value of methanol from sugarcane bagasse is also higher than that obtained producing the alcohol starting from coal or natural gas, respectively 0.39 and 0.44 (Spath and Dayton, 2003). LCE value is 0.58 due to the high demand of primary energy (biomass energy) and the high quantity of bagasse necessary to produce methanol. The efficiency of existing biomass conversion technologies is low, 2 kg of bagasse are necessary to produce 1 kg of methanol. Methanol produced starting from sugarcane bagasse is a promising alternative to coal and natural gas based process from an environmental point of view. Moreover, its impact could be further reduced improving the gas cleaning system after gasification and minimizing the use of fertilizers. Authors also proposed regulation policies to compensate the land use for biofuels production and to guarantee land for food production.

c. Methanol from solar energy

Methanol production using solar energy is based on two different approaches, the use of solar-thermal energy and the use of photocatalysts. These processes are called "Sunshine to Petrol" S2P and "Solar2Fuel" S2F. In the first case solar energy is concentrated in a thermochemical reactor to convert CO_2 into CO. Carbon monoxide is used to produce syngas by water gas shift reaction to feed a methanol reactor. The second approach is the photocatalytic conversion of CO_2 directly to methanol and methane using dye-sensitized semiconductors according with the following reactions:

$$CO_2 + 2\ H_2O + solar\ energy \rightarrow CH_3OH + 1.5\ O_2 \qquad \text{eq.4}$$

$$CO_2 + 2\ H_2O \rightarrow CH_4 + 2\ O_2 \qquad \text{eq.5}$$

Both the processes are relatively recent and today the industrial application is limited by economical or technical issues. For the S2F process described by Kim et al. (KIM) the technical limiting factor is the thermochemical reactor which is currently under development. The S2P process is reported in Figure 3.

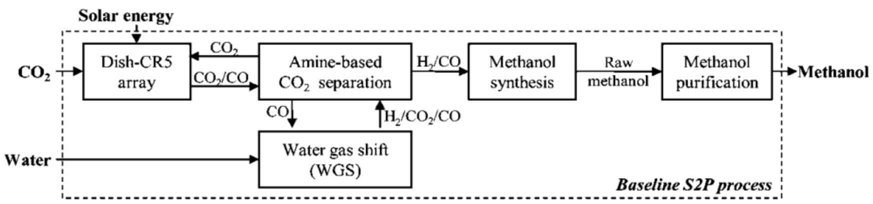

Figure 3: Flow diagram of the S2P process

CO_2 is converted into CO using Dish-CR5 array, a solar chemical heat reactor, installed on the focal of an 88 m^2 parabolic dish. The CO_2/CO mixture is sent to WGS reactor where hydrogen is produced and then, by amine treatment unit, CO_2 is removed. Syngas is sent to traditional methanol reactor and then the alchol is purified using a distillation column. The environmental impact was assessed performing a "cradle to gate" LCA, and the methanol use was not taken in consideration. Three different processes were compared: traditional natural gas to methanol plant (C-NG), S2P process with utilities (heat and electricity) provided by fossil fuels (S2P-C) and S2P process with utilities provided solar energy (S2P-S).

Results show that, as expected, the less impacting process is the S2P-S (Figure 4). S2P-C process has higher global warming and acidification potential than traditional C-NG due to the high heat demand for amine treatment unit. This is confirmed by S2P-S results, in fact using renewable energy the impacts are dramatically reduced. In the C-NG and S2P-C processes the GWP and AP are mainly due to heat and electricity production (e.g., flue gases), while for S2P-S process the impacts are due to plant construction. The work shows that methanol production with S2P-S process can produce methanol with an important environmental impact improvement with respect to natural gas-based process, the net GWP is also negative and the use of fossil fuel negligible.

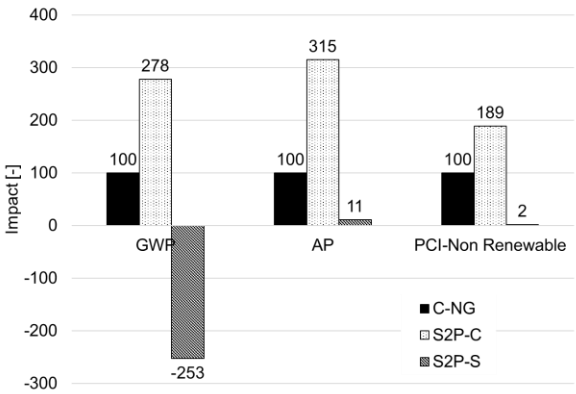

Figure 4: Environmental impact (%) of the S2P processes compared with traditional fossil fuel based process

The LCA of photocatalytic methanol and methane co-production was performed by Trudewind et al (TRU). The S2F environmental assessment was done comparing the process with traditional plant with (TR-CCS) and without (TR) carbon capture and storage. Both the traditional plants produce methanol starting from methane (Figure 5).

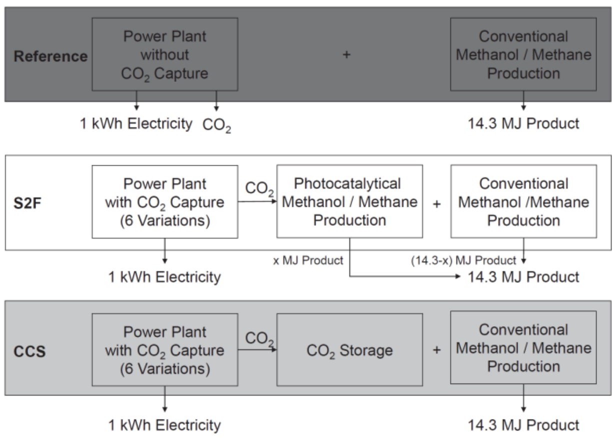

Figure 5: Configuration comparison of S2F with traditional process without CCS (Reference) and traditional process with CCS (CCS)

Results show that the primary energy demand of the traditional process without CCS (TR) is about 40% higher than photocatalytic one (S2F). TR-CCS process energy demand is slightly higher than traditional due to the capture and storage of CO_2. Nevertheless, the traditional plant has the highest GWP and TR-CCS the lowest. In the S2F process PE and GWP mainly depends on energy for methanol distillation. For all the processes the impact of power plant, utilities transport, and CO_2 storage are negligible. Acidification potential, photochemical ozone potential (POCP), eutrophication (EP) and human toxicity (HTP) are similar for all the processes. In the paper a sensitivity analysis was performed. Energy mix influence is negligible, but solar efficiency and material lifetime can double the impacts. Trudewind concludes that S2F process can reduce the environmental impacts (except POPC) with respect to traditional processes. Methanol purification section, which contributes to about 30-42 % of GWP impact, was identified to be the weakest point of S2F process.

3 Conclusions

In this work the environmental impact of different processes for methanol production from CO_2 was compared. The comparison of traditional process was performed highlighting the differences with respect to methanol produced as intensification process, starting from biomass or using solar energy. The main problem of methanol produced starting from CO_2 is that the impact is strictly linked to hydrogen production, the most impactant step. Only the use of hydrogen produced with renewable sources could produce methanol with an environmental impact lower than fossil-based processes. The synthesis starting from biomass shows interesting results, the footprint of BTL process is lower and, furthermore, it could be reduced improving some process aspects. The main issue of BTL process is the competition between land destined to fuels and to food. Finally, processes which use solar energy are the more interesting but further developments are necessary. Generally, those processes could reduce the environmental impacts, especially for global warming and fossil fuel demand, but economical and technological problems limit their application.

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O-LCA contribution to FM innovation

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Abstract

In an even-more eco-friendly world, LCA could extend its benefits to the organizations at different levels. However innovation among organizations seems to be undertaken toward the full synergy between facility management (FM) and LCA, in order to create a new product such as organizational LCA (O-LCA). This article provides a review of product/service LCA literature in its widest context and later it adds a proposal for O-LCA use. This additional step can be achieved at different FM levels, but interesting points are displayed into the inclusion of environmental issues inside invitation to tenders and contracts. So far O-LCA can become an useful item to company reorganisation with care to environmental contents.

1. Introduction

This paper aims at investigating how Life Cycle Assessment (LCA) can drive innovation within facility management (FM) service provisions.

According to IFMA (International facility management association), Facility Management (FM) is a “corporate discipline”, which coordinates the “integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities” by addressing to “Space and Infrastructure” and “People and Organization” (EN 15221-1:2006). Hence FM acts on three main levels, which later will be explained, according to the definition: strategic, tactical and operational. Product/service LCA can be an assessment tool handled by facility managers who can evaluate the single service environmental impacts, find new service optimization modes or compare different services within a service chain. This paper proposes also an innovation level of interaction between FM and LCA, which evaluates service environmental quality, and a second prompted innovation level with Organizational LCA (O-LCA), which can configure a more sophisticated tool within company boundaries. This paper promotes a hypothesis aiming at demonstrating the intersection points between product/service LCA and operational level, and O-LCA and strategic level. In paragraph 2 a product LCA literature review applied to services equipment will be exploited. In paragraph 3 O-LCA will be highlighted by putting in evidence the relations between O-LCA and FM. Paragraph 4 exhibits how O-LCA can be treated in a FM perspective.

2. Product/service LCA Literature review

Hospital technical facilities represent a field handled by FM and engaged in LCA assessments. According to ISO 14040:2006, Product-LCA can assess the environmental performances of any goods or services. Hospital is among all the infrastructure the one which involves major FM categories, because of the high number of functions within the healthcare sector, such as: Accomodation, Workplace, Technical utilities, Cleaning, Health, safety and security, Hospitality, ICT, Logistic, Other support services (ISO 15221-1:2006). Nowadays many methods of impact assessment are available for detecting environmental burderns. EI-99 results like the most used impact methods. The presented LCA cases on technical equipments are investigated according to the most recurrent environmental impacts. In the case study on trigeneration (Carvalho et al., 2010), seven spanish hospitals are analyzed to investigate how demands of heat, electricity and cooling impact on environment. Here global warming potential indicator is taken into account by exploring how the installation of particular cogeneration components can affect this impact. Moreover in this LCA comparison, characterization factors used in the EI-99 method explain the Single Scores obtained for the electricity purchased from the grid (SSe ¼ 0.0226 pts per kWh) and natural gas (SSg ¼ 0.0378 pts per kWh). Natural gas extraction is significantly disadvataged when it is taken into account the extraction of fossil fuels, resulting in a high value of damage to resources. The results for the EI-99 optimal, here used, and CO_2 optimal suggested the installation of conventional equipment for the peninsular locations: hot water boilers, vapor compression chillers and cooling towers. In the case of Santa Cruz de Tenerife cogeneration modules are installed for the considerable difference among the local electricity impacts supplied by the grid and the electricity produced by cogeneration modules, because the local electricity supply depends on fuel-gas with a higher global environmental load. Different configurations are presented for both environmental objective functions: one absorption chiller is substituted by one mechanical chiller when changing the objective function from CO_2 emissions to EI-99 Single Score.

A multi-indicators study is presented in ColdPeak case (De Falco et al., 2017), a phase changing materials (PCM) analysis, in comparison with a conventional air cooling system by assuming the same potentiality of cold energy. Here Global Warming Potential, Acidification Potential and Eutrophication Potential are studied at mid-point level, while the end-point level is investigated through Eco-toxicity, Human Health and Fossil Depletion. The PCM system integrated to a standard air conditioning implies the electricity consumption reduction by 15% on average. Then in the study for each impact category it has been considered the stand-alone conventional air conditioning system, conventional system integrated with the Cold Peak assuming an energy saving of 15% (Medium Saving Case), assuming an energy saving of 25% (High Saving Case) and assuming an energy saving of 5% (Low Saving Case). In general in all 6 impacts studied categories, PCM integrated system shows better environmental performance than the conventional one. The GWP category shows a reduction of 25% of the total kg of CO_2eq for PCM system with respect to the traditional case. Whereas considering the Acidification Potential (AP) category the medium saving case shows a reduction of 15.5% of the total kg of SO_2eq emitted in comparison to the traditional system and a reduction of 23% in the best case (25% of energy saving). The EP category presents a reduction of 18%, 26% and 10% kg of PO_{4eq} emitted, respectively in medium, best and worst case.

Another multi-impacts assessment is represented by a third study (De Santoli et al., 2005) which focuses on the requirements of LCA on HVAC system. The authors firstly show a standard comparative LCA carried out on three different heating system associated to HVAC. The environmental assessment for the single phase of material production is penalized for the metallic products. Infact they are characterized by a more elevated score in all the damage categories than the plastic ones, because of high energy consumption for extraction on raw materials. In order to yield a complete evaluation on the materials it is also necessary to analyze the damage caused by the recovery or by the dump disposal. Recycling copper with a reference flow of -3,24 Pt/kg exhibits -0,824 Pt in human health, -0,0912 Pt in ecosystem quality and -2,32 Pt in resources. For environmental balance, the values related to recovery are with negative signs, but because of the processes of transport, labour and land use necessary to reintegrate the material in the cycle and its loss of quality and weight to be considered, the benefits would be less than the avoided damage for production.

De Santoli et al. (2005) moreover show a study for a building placed in Roma, by considering three heating system (traditional, solar collectors with auxiliary heating system, heat pump with auxiliary heating system) and their linked impacts. The comparison among these different systems is made starting from the settle of the same functional unit in terms of primary energy: 67,5 MJ/m^3. Heat pumps is responsible of about 40% of thermal energy demand, because of the remaining part supplied by the auxiliary heating system. Solar plant leads to small environmental damage, about half of impact on traditional plant. The greatest electricity and materials consumption (copper used for pipelines and components) are those by the non-traditional solutions, whereas traditional configuration doesn’t result harmful for the Ecosystem Quality category. For Human Health, the traditional plant is responsible of a damage lower than the impact associated to heat pump, because of the greater electricity consumptions of the latter responsible of a greater NO_x and SO_x emissions. As normalized values on impacts are used, it has been possible to sum up each damage category, obtaining a single score for three systems. Traditional plant reaches 11,3 points, Heat pump plant achieves 9,86 points, while solar plant shows 6,16 points.

Mancini et al. (2005) highlight a HVAC’s analysis of a major hospital building in North of Italy, where Human Health, Ecosystem Quality, Resources indicators are evaluated. The study is performed to evaluate the environmental impact of individual components and their effects on the overall environmental balance of the HVAC system. Two different working conditions are here considered: 24 hours/day running at 20 ACH and 12 hours/day at 20 ACH (CASE 1) and 12 hours/day (from 20:00 to 8:00) at 10 ACH (CASE 2). The component which contributes to the total environmental damage are the ducts in galvanized plate used for air distribution. The damage is to attribute mainly to the long distance from the air handling unit to the operating rooms. The preventive process of hot galvanization releases a significative quantity of zinc (1,4 kg) in air. Moreover, the protective layer causes a reduction of the steel quality for recycling, reducing the relating environmental benefits.

Table 1: Comparison table

	Carvalho et al.	De Falco et al.	De Santoli et al.	Mancini et al.
Environmental impacts considered	Global Warming Potential	Global Warming Potential, Acidification Potential, Eutrophication Potential, Eco-toxicity, Human Health, Fossil Depletion	Global Warming Potential, Acidification Potential, Eutrophication Potential, Eco-toxicity, Land Use, Human Health, Fossil Depletion	Human Health, Ecosystem Quality, Resources
System boundaries considered	Cradle to Gate	Cradle to Gate	Cradle to Grave	Cradle to Grave
Impacts assessment methods	EI-99	ReCiPe	EI-99	EI-99
Inventory database used	IDEMAT, ETH/ESU and Ecoinvent	Gabi Database	Database for italian conditions created	Database built from past cases

Interesting points are now showed into previous analyzed cases. Carvalho et al. (2010) conducted an analysis where a facility LCA oriented methodology is set to investigate how the carbon emissions factor of the electricity, purchased from the grid, affects the configuration of the system. For example, in open market solutions, consumers can buy electricity from a range of service providers. The introduction of α factor by the authors considers the ratio CO_2 emissions associated with the consumption of natural gas to electricity. Therefore the hospital in Zaragoza has seen an analysis performed by the variation of the α factor: when α was close to 1,5, cogeneration modules were installed, and from 2.0 onwards, absorption chillers were also installed, with the consequential environmental impacts. Then, De Santoli et al. (2005) performed a trend of Technical Lifespan (LFS) in term of environmental damages over next 25 years for each heating system. In a cartesian plane on horizontal axis is represented the considered life and over the same axis are shown 6 process steps of LCA: production, pump substitution, solar collector substitution, pipelines substitution, heat pump substitution, disposal and reuse of the components. The LFS shows that after a period of 10 years the environmental damage caused by the production of components and by the energy management of the three considered systems is approximately the same. During the reuse phase, the solar collectors plant reaches a final damage score of 6,16 points after considering the recovery environmental advantage, while the traditional plant achieves a score twice higher (11,3 points). The heat pump system has a damaging effect for the production higher than the traditional one. It is therefore necessary to outline the choice of the most advantageous system considering the durability of the total life cycle of the system as well as the durability of every component. Actually core ideology of LCA and maintenance, which is a FM application, are directly linked. An effective maintenance policy provides environmental and economic advantages. It is coherent with the idea of sustainable development and makes it possible, on the one hand, to increase the availability of industrial systems and, on the other hand, to lengthen their lifecycle. It also helps to save energy, extend equipment life and increase the overall safety of any facility. So it is direct the correlation between maintenance issue and LCA, since the definition of maintenance program would be based on real-time information provided by product/service LCA in order to extend life of facility. Facility manager which faces energy issues have to consider how a LCA method can be a useful analysis during all the procurement phase related with energy such as the heat production by contractors. If all the heating is supplied on the basis of an existing contract by a district heating supplier or by a contracting party, life cycle analysis can be conducted along the entire supply chain process to detect economic and environmental impacts.

3. Operational LCA (O-LCA)

As FM concerns the management of integrated services, O-LCA in its general connotations looks as a perspective of absolute innovations into the modality of services provision. O-LCA can offer a new instrument, inside FM process, to assess how a certain provider manages its services, according specific environmental indicators. In particular O-LCA, introduced by ISO/TS 14072, is an input, output and environmental analysis of impacts associated with the organization, useful both as complement to product-based LCA studies or as FM stand-alone method. Its application is “relevant, meaningful and feasible” within the framework of LCA organization. According to Finkbeiner and König (2013), 27 out of 31 of the ISO 14044 requirements are transferable from products to facilities. So far O-LCA integrates an organization environmental toolbox especially when relevant amount of data is available. Environmental impacts occurred in internal operations of many organizations. Sectors like utilities, forestry and mining, oil and gas, are found at the top of the supply chains of other industries with direct impacts contributed over 40% of the total impacts of 19 sectors studied (Makower, 2014). As in classic LCA, O-LCA follows a four phase approach, by including goal and scope definition, inventory, impact assessment, and interpretation. The definition of clearly defined and measurable “reporting unit” allows to make processes comparable. Furthermore, by joining the definition of reporting flow with existing records in the organization control system, it is easy to enact O-LCA. A system boundaries in O-LCA can be seen as three concentric domains in which, in the inner part FM relations between organization, logistic and distributor are shown; in the middle linkings between logistics and suppliers and between distributor and retailers are displayed, with the focus on organization; in the ultimate domain, boundary is represented by the stream made by the focused organization that from one side, is connected by the chain distributor-retailer-consumer, from the other side by the chain logistics, suppliers, material producers. In SETAC’s O-LCA Guidance, four “experience-based pathways” are provided on how organizations can use LCA approach within their boundaries. The first pathway is the simplest level with limited initial environmental experience and informations. The second organization pathway is possible when existing environmental assessment gate-to-gate are available. In this case the organization offers data for direct activities and guides the identification of the targerted suppliers (ISO 14001, EMAS, etc). The third pathway is undertaken if environmental life cycle assessment at the product level exists. Here, it is possible to define important hotspots in the value chain that have to be further assesses. In this sense O-LCA may be composed by the addition of many LCAs (ISO 14044, PEF, EPDs, product carbon footprint, etc.), weighted by the amount of goods produced. The highest level of experience-based pathway for organization is the fourth, feasible when single-indicator environmental assessment at the organizational level are usable, including the value chain (GHG Protocol, ISO 14064:2012). It is generally not consistent to simply aggregate the entire set of direct inputs and outputs of the suppliers, for an O-LCA, because organizations normally don't purchase the whole product/service spectrum or the total production volume of a particular supplier. Infact a supplier could be involved just in delivering a certain facility of another organization, without being part of the analyzed organization's value chain. So, it is necessary to detect which is the respective part of supplier's direct emission to address the up- and downstream impacts associated with its activities or customer one (Rebitzer et al., 2005). This produces issues to solve using system expansion, unit process division, by using data representative for the products purchased, or by applying allocation to the supplier's inventory. At the end it is possible to measure the impacts associated to services of a specific supplier, in order to assess environmental load from its life cycle technological history placed in every LC stages and to gather appropriate data (Lewandowska, 2011). Facility Management acts on three main levels, according to the definition: strategic, tactical and operational, respectively to achieve the objectives of the organisation in the long term, to implement the strategic objectives in the organisation in the medium term and to create the required environment to the end users on a day-to-day basis. Hence strategic level has more affinity with O-LCA, for their common long-term perspective, whereas operative level has strong interaction with product/service LCA, thanks to their ready latency. Tactical level represents a linkage between O-LCA and product/service LCA, as it implements the standard LCA by bringing it to the strategic level which looks at the relationship with clients, optimising the use of resources and defining SLAs (Service Level Agreements) and interpreting KPIs (Key Performance Indicators). Facility managers, therefore, can correctly define requirements for tasks of outsourcers of particular support services within an organization and O-LCA method can perform good environmental and economic analysis for facility such as cleaning, maintenance and many other services. O-LCA can reinforce the already overdue trend of synergy bwtween environmental management systems (EMS) and life cycle assessment (LCA) within organizations (Gaudreault et al., 2009). Another bridge between LCA and FM can be also found in their field of application. According to the definition, facility management is applied to a triaxial system of space, work and capital (Somorova, 2012) which can be compared to the "triple bottom line LCA" of environment, social and economic (Elkington, 1994). However scientific literature still highlights a lack on O-LCA cases, as all the led analysis are more product-comparison oriented.

4. A Proposal for O-LCA application to FM

As tendering in FM sector involves the outsource of no core activities, mostly according the Global Service scheme, O-LCA may be applied not only to the single services but also to contracts. Contracts comparison is possible by analyzing different environmental impacts or same processes with different input and output. Moreover, the choice among different KPIs may be evaluated by a LCA, thanks to its multi-impact approach. O-LCA, actually, can evaluate both the environmental supply's optimization and the external client or tender operative conditions. Different comparisons among services may be possible thanks to the inclusion of a such innovative methodology inside contract's subsidies and incentives. So far it is possible to use O-LCA into the evaluation of alternative choices for modifying a certain support service with related environmental impacts. This allows to make the outsource activity more effective. So O-LCA could be an useful facility manager's tool to evaluate service processes for optimization in operative costs and environmental monitoring. Practioners, thanks to O-LCA, may detect environmental content of parameters to compare different services and products: a facility manager, infact, can consider services in a tender to analyze different modes of same service. Client can carry out an O-LCA on different main contractors with few defined indicators. In this way it is interesting to detect, on client side, which indicators for each service provided have to be taken into account, in order to choose a specific environmental oriented supplier. In this sense practising O-LCA inside a FM contest means developing a technical tender with environmental SLAs and KPIs definition in order to ask to the competitor providers their service specifications. From general contractor's side, O-LCA allows to verify the environmental impact of a certain service, by analyzing the entire supply-chain from an ecological view point within a predetermined target value. It can be useful for an organization to have an "environmental global index" where a provider balances out the environmental performance, similarly what happens with Eco-Management and Audit Scheme (EMAS). This kind of approach enables to an organization to ecologically push down some indicators, if a certain service needs to be offset. By doing so, a facility manager, who intends to take part to a tender can detect the environmental footprint of a specific provider. The client doesn't have the awarness of the entire supply-chain, as (s)he is just account for the services level. However outsorcing involves a set of services in which the client can investigate, through the comparison paramenters, the service package presented in the tender, in which can fall the entire organization with its environmental indicators. So "organization parameters" can have an invariant value, whereas "services provided indicators" can have variant measure. Another interesting O-LCA issue carried by facility manager is to detect how organization and supply-chains parameters impact on their services, in order to reorganise a process or product. This could take the general contractor the definition of a specific rule for its chains. Otherwise a general contractor can decide to shorten the internal process chain according to an environmental perspective.

Last but not least, as O-LCA aims to improve the organizational processes, the role of contractual documents appears as a hot point, as it represents the interface among the contractors, subcontractors and suppliers. Scientific literature LCA applications on FM currently show medium-maturation grade applications, whereas O-LCA applications represent still a virgin soil, which can represent a new opportunity for LCA practioners oriented toward FM field.

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Towards a low-carbon economy: the Clim'Foot project approach for the organization's Carbon Footprint

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Abstract

The LIFE Clim'Foot project aims to provide European policy makers with a toolkit which fosters the development of policies of organizations carbon footprint (CFO) reduction. This paper aims to present the experience of the project and its contribution to the climate governance issue. The approach followed is described, especially i) the toolbox developed (national databases of emission factors, training materials and carbon footprint calculator); ii) the description of the voluntary programme and iii) the role played by decision makers. Strengths and weaknesses of the toolbox are discussed and opportunities of replicability and transferability of the results of the project to create a dynamic European network for carbon accounting.

1. Introduction

During the United Nations Climate Change Conference (COP 21), held in 2015 in Paris, the world governments agreed about putting the world on track to avoid dangerous climate change by limiting global warming to well below 2 °C. The European Union (EU) has a road map of the transformation towards a low-carbon economy (EC, 2011), which engages the EU to achieve 80% reduction of greenhouse gas (GHG) emissions by 2050, compared to 1990, and 40% by 2030. The EU Emission Trading System (ETS) represents the cornerstone of the European policies on the Climate Change, targeting the most polluting organizations, which cover 45% of the GHG emissions. However, no common framework has been proposed yet for "non ETS organizations". The Carbon Footprint of Organization (CFO), which is currently implemented by organizations on a voluntary basis, can represent a proper scheme for GHG emissions accounting, encompassing also the indirect emissions. The methodology focuses on one single criterion, the Climate Change, and is based on a life cycle approach.

In this context, the LIFE Clim'Foot project aims to foster public policies of calculation and reduction of the CFO. The project deals with two aspects of the problem: i) the need for national policies addressing GHG emissions of non-ETS organizations and the strategic role of standardised tools, such as the national databases (DBs) of Emission Factors (EFs); ii) the relevance of organisations training to foster their commitment to account and mitigate GHG emissions. Clim'Foot brings together seven partners from five EU countries: ADEME and IFC (France), ENEA and Ecoinnovazione (Italy), CRES (Greece), HOI (Hungary) and EIHP (Croatia). ADEME coordinates the project, under a 3-year LIFE contract, from September 2015 to August 2018 (Clim'Foot, 2018).

This paper, shaped around the Italian contribution, intends to illustrate the experience acquired during the project in the development and application of an innovative approach for calculating and reducing CFO. This approach includes the creation of a national toolbox, a test phase and the involvement of policy makers to promote the CFO use and appropriate climate initiatives.

2. The LIFE Clim'Foot project approach

The Clim'Foot approach for organizations' Carbon Footprint (CF) calculation and reduction is an original concept, developed and tested during the project, which is structured along three levels: a) development of national toolboxes including national DBs of EFs and training material; b) voluntary programme, involving a selected number of organizations in each participating country to calculate their CFO with the use of the national toolboxes and the support of the project partners; c) communication to the policy makers (since the early stage of the project), to foster replicability and transferability of the approach and to implement regulations or public policies for the reduction of GHG emissions.

The next sections describe each of these elements and highlight the results of the testing phase.

3. A national toolbox for the CFO

3.1 The Italian National Database of EFs

Data currently available to perform a CFO study (such as the EF Database (EFDB) by IPCC[42]) do not match the needs of the totality of EU organizations. In fact, they have been mostly developed to fulfil the accounting duties set by the EU legislation at Member State level and for those organizations that most contribute to GHG emissions. In addition, several EFs are provided only with reference to an international scale, which raises a two-fold issue. On the policy side, the lack of national EFs does not favour the design and implementation of policies fostering the CFO accounting and reduction. On the organizations side, the use of international EFs does not encourage accounting actions, as it lowers the accuracy of the results. As a consequence of the current data availability, the CFO is mostly applied by those organizations able to afford the cost of deep studies, with the support of consultants and/or with the use of commercial DBs (e.g. LCI DB developed for Life Cycle Assessment).

In this context, Clim'Foot has developed five national DBs of country-specific EFs, with 150 EU common EFs and at least 150 country-specific EFs for each

[42] The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988.

DB. A common methodology has been defined with the aim of sharing data within the project and replicating project outcomes. The main references are the GHG protocols for Organizations[43] (GHG, 2004; 2011a; 2011b), the ISO 14064 (2006) and the IPPC guidelines (2006; 2013), but also the European initiative on Product and Organization Environmental Footprint (PEF/OEF) (EC, 2013) has been considered, in particular for the data quality definition. The methodology defines content and classification structure of the DBs, and identifies the reference greenhouse gases. Moreover it gives suggestions on data collection, including an overview of the main data sources for the development of a national DB as well as some examples of datasets production starting from different data sources such as Life Cycle Inventory (LCI) and National Inventory Reports (NIR) (Scalbi et al., 2016).

The Italian DB includes 150 EU EFs and 182 country-specific EFs (Table 1). For each EF a data description is given to guarantee comprehensive information and to support the end-user in choosing data for the CF calculation.

Table 1: Italian Emission Factors

Category	Data Source	Number of EFs
Fossil fuels consumption	Italian National Inventory Report 2017 (ISPRA, 2016)	43
Electricity consumption	ISPRA, 2015	2
Freight transport	National database on transport, elaborated (ISPRA, 2016b)	16
Passenger transport	National database on transport, elaborated (ISPRA, 2016b)	57
Chemicals	Italian National Inventory Report 2017 (ISPRA, 2016)	9
Waste	Italian National Inventory Report 2017 (ISPRA, 2016)	10
Agriculture	Leap Database (FAO, 2015) the Global Database of GHG emissions related to feed crops for the agricultural product, developed by FAO (2015)	14
Mineral water	Fantin et al., 2014	2
Fugitive emission from agriculture	Italian National Inventory Report 2017 (ISPRA, 2016)	29
TOTAL		182

Each partner prepared a report aiming to: i) share the data sources used, so as to favour the replicability of the calculation in other sectors and contexts; ii) ease the validation and update of the EFs; iii) present the data to external users such as regulators, general public or specific stakeholder groups, in order to promote the replicability of the DB in other countries. In addition, this document serves also the purpose of ensuring consistency among the Clim'Foot National EFs DBs in terms of completeness of data description, appropriateness of calculation and coherence of data quality assessment. The consistency of the input data used for calculating the EFs represented a major issue. In fact, GHG emission data are not always disaggregated: some data sources deliver a sub-set of emissions, reporting them as the most relevant ones, while others report the results in terms of CO_{2eq}, after aggregating the emissions according to the characterization factors.

[43] World resources institute and World Business Council for sustainable development

The DB structure, currently in excel format, is designed to be imported in a relational DB in order to improve its replicability and transferability. Moreover, a simplify web version of the DB is available on the Clim'Foot website http://www.climfoot-project.eu/.

3.2 Training courses

The project has proposed two targets for the training: trainers and end users. The training of the trainers has a twofold objective: i) to give information on the methodology for calculating and mitigating CFO; ii) to learn coaching tips and strategies to be used during the workshop for the end users. The objectives of the training for end users are: i) to increase awareness on the climate change impact; ii) to teach how to calculate the CFO and iii) to give an overview on how to plan and implement a carbon management plan.

Different training courses for end users have been developed within the project including: i) ***on-line training,*** which provides a general overview on climate change, the methodology for the CFO assessment and the calculator use; ii) ***specific technical modules,*** which have been used during the national workshops with the organisations involved in the voluntary programme; iii) ***dissemination materials,*** which have been used in national meetings with stakeholders such as industrial trade associations or professional orders.

4. Towards a growing use of CFO by the organizations: the voluntary programme for a bottom-up process

4.1 Calculation of CFO

Clim'Foot has developed voluntary programmes to support public and private organizations in calculating and reducing their CF. This demonstration phase has allowed the testing of the tools developed by the project. In the first phase each project partner has identified at least 150 public and private organisations for each country, and has created a DB of contacts. In Italy, a call for interest has been launched to involve a larger number of organizations. At the end, 17 Italian organizations joined the voluntary programme. ENEA and Ecoinnovazione prepared and sent a survey in order to identify the key drivers for the participation of the organisations to the voluntary programme and to map their expectations. Public organizations showed interest in the project due to the opportunity to participate in collaborative networks, to exchange ideas and experiences. For the private sectors the project was a good opportunity to share experiences and to establish new potential business relationships.

The end-users have been involved in the following activities:

- Training sessions (on-line and on-site) on climate change and CF assessment;

- Calculation of their CFO using Bilan Carbone®, a tool proposed by ADEME since the beginning of the project for the calculation of CFO. The tool, which provides calculation and data extraction for reporting in compliance with the GHG Protocol and ISO standards (ISO 14064, 2006 & ISO/TR 14069, 2013), has been translated into Italian and includes the EFs developed in the Italian national DB (both country specific and European). The results of the CFO will be shared among the Clim'Foot partners before the end of the project
- Implementation of the mitigation actions based on the CFO results (in Italy this involves 3 organizations).

Two workshops were held in Italy for the organisations involved in the national voluntary programme. They were organized in sessions of teaching and exercising and included: i) a general overview of the main challenges related to climate change and energy, and the international and national initiatives on carbon footprint; ii) a presentation of the methodological and standard principles and the main phases of a CF project; iii) a technical presentation of the Bilan Carbone® calculator and practical exercises; iv) the definition of mitigation actions for carbon reduction and the presentation of some case studies. All the developed material was made publicly available at the project website. The overall feedback received from the participants was good. Potential improvements are related to the structure of the on-line training course, which was a time-intensive activity for the users, so they have suggested to implement some more concise guidance. The participants have also highlighted that the time of the on-site training sessions (2 consecutive days) was probably too short, especially for users at their first experience with the topic.

During the calculation phase, the support of the national partners has been guaranteed by monthly contacts with the end-users and technical meetings to check the progress of the activities and to solve issues encountered. In particular the organizations needed to be supported in the following steps: i) choice of the standards (GHG and ISO); ii) definition of perimeters, in line with the organisations strategic goals, in terms of activities and processes to be included in the CFO study; iii) choice of the appropriate activity data to collect and EFs. The face-to-face meetings with the organisations, organised to better involve the end-users and to analyse into detail the major difficulties encountered, were another important element of the experimentation phase.

To date, 13 organizations have calculated their CFO. 4 organizations have analysed only direct emissions and energy indirect emissions to identify critical aspects concerning energy consumption. The others have investigated the indirect emissions too, such as materials in input, packaging, home-work transport, waste and capitals good, in order to obtain a more complete picture of their carbon footprint and to select targets and strategies for a (potential) GHG reduction.

During the voluntary programme strengths and weaknesses of Clim'Foot tools were assessed. The organizations highlighted the need to have further EFs to calculate their CFO, so new country specific EFs were implemented in the DB (waste and water treatment, minerals water, renewable energies) and further development is in progress, concerning construction, chemicals and waste scenarios. They also suggested a simplification of the Italian calculator, deleting the elements strictly related to the French context, and the development of a short calculator guide to help the users data input. All organisations highlighted that this experience increased their awareness on GHG problems and some of them decided to include the results of CFO in their quality management plan as an indicator to evaluate the efficacy of energy improvements adopted.

4.2 Implementation of a mitigation plan

The reduction of the GHG emissions is an important milestone of Clim'Foot approach. After the emissions calculation, which allows the identification of the main sources of GHG emissions, a plan of mitigation actions should be defined through the involvement of all the stakeholders and the definition of targets and timeline. The actions for the transition to low-carbon organisations may be quick-wins (short term), priority actions (mid-term) and strategic actions (long-term). A technical committee is necessary to support the definition of the criteria for prioritizing actions and the assessment of the results. To support this approach, Clim'Foot has applied a method to manage and monitor GHG data, which was already developed by ADEME (ADEME, 2017). This activity is mainly in charge of the French partners, while the other countries are committed to implement only few mitigation plans. To date, 3 Italian organizations are working to develop their mitigation plan, but no actions will be actually implemented before the end of the project.

5. The involvement of policy makers

Some policy makers from all country partners have been involved in national Technical Committees to have feedbacks on the Clim'Foot approach and its possible future applications. They showed a particular interest towards the strategy adopted, i.e. the development of standard tools that can be either directly applied or used as a basis to create country specific tools.

Policy makers from countries which are not partners of the project have been involved with a survey aimed at presenting the project results and collecting information about the carbon policies of their countries. 20 among them, coming from 9 countries, will be trained on the Clim'Foot toolbox in a workshop that will coincide with the final conference of the project.

At the end, an initial kernel of a dynamic European network for carbon accounting has been created to answer the following expectations: i) raising awareness among the policy makers at national, regional and local level; ii) exchanging best practices; iii) fostering replicability and transferability of the project.

A good example of involvement of a local public administration is the participation of the Città Metropolitana di Torino (Italy). After the training workshop they decided to apply the Clim'Foot approach by involving some schools of the territory in calculating and reducing their CFO. The following step was to train a group of students of five high schools, who have calculated their schools CF and have identified the main critical aspects. As a final result, with the participation to the voluntary programme, the public administration could fulfil the demand for increasing environmental awareness of young people, in agreement with the objectives of the Green Education initiative of Piemonte Region, and is now able to implement the CF results of the schools in the set of indicators monitored by the Energy manager of the Città Metropolitana.

6. Conclusion

The modular structure of the toolbox and the accompanying informative materials, including the documents that summarise the lessons learnt, are the strengths of the project, as factors that increase the potential of replicability and transferability of the approach inside the consortium and in other European countries. The policy makers, indeed, after considering the strategy that better fits the national and local context, can select the tool most suitable to develop specific services for the organizations or to implement national legislation and/or reward measures for the reduction of CO_2 emissions.

The voluntary programme has highlighted that the organisations were not able to calculate their CF by themselves: also when the end users already had a good expertise on the topics and clear ideas about their participation to the voluntary programme, the initial training was not sufficient and they needed to be accompanied during the experimentation phase.

Some future developments have been identified for a better usability of the tools. Currently the EFs are entered manually into the calculator. The implementation of a utility that connects the National DB with the calculator has a twofold aim: i) it would simplify the update of the calculator with the new EFs developed in the DB; ii) the end-users could choose the EFs more easily as they would have access to the description of the data. The involvement of stakeholders such as categories associations, national agencies or networks could support the EFs implementation. The integration with other projects or policy makers' initiatives could create synergies and promote the use of Clim'Foot tools. Finally, the update and the enlargement of the national database, which are time consuming and need specific expertise, are guaranteed for three years after the end of the project thanks to the commitment of the Clim'Foot partners.

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Environmental friendly transition of SMEs to Industry 4.0 through LCA. A case study of reinforced expanded polystyrene panels

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Abstract

The actual context of the environmental concern is very important in the construction sector, which is called to make the transition to the Industry 4.0, trying to reduce the environmental impacts derived from its activities. To achieve this goal, the role of the small and medium enterprises (SMEs) which produce construction materials is very important. This study – a research between the PDTA Department of the Sapienza of Rome and a family business type enterprise – analyzes a technical and innovative solution for the production of reinforced panels of expandable polystyrene (EPS), through life cycle assessment to determine its environmental profile considering a cradle-to-gate approach. The analysis demonstrated that most of the impacts could be attributed to the raw material production stage rather than to the manufacturing stage. For example, in the case of global warming potential, 90% of the emissions of CO_2 eq is attributed to the raw material production, and 10% represented the manufacturing stage. These results show the importance of empower the whole production chain with an environmental conscience and a responsibility to communicate their environmental data in an effective way to induce in the consumer environmental friendly actions in their daily decisions.

1 Introduction

Nowadays, the environment is a main subject at international, national and local level. In fact, protect the environment and mitigate climate change effects are at the top of the 2030 sustainable development goals (SDG), the global agenda of the United Nations (United Nations, 2016).

Human activities contribute in different levels with greenhouse gas (GHG) emissions and in the consumption of natural resources. Considering the built environment sector, Europe consumes more than 50% of natural resources in terms of all materials extracted from the earth's crust that are transformed into materials and construction products. Moreover, on the production of waste, mainly deriving from demolition activities (amounting to between 40% - 50% of the total production of waste generated by all other human activities), and from energy consumption during the use phase of buildings (about 40% - 45% of total consumption) (ENEA, 2017).

Due to the high demand of resources and energy in the built environment sector, the European Union has promoted energy efficiency policies (EU Commission, 2010). In Italy, some national laws and a national energy strategy (SEN in Italian) have been developed (Ministero dello sviluppo economico, 2017a), but the construction sector is divided which difficult the achievement of the proposed objectives. That is why it would be important that the whole supply-chain actors participate actively in the achievement of those objectives, considering that the construction context is constantly changing in terms of instruments, operators and laws. Indeed, the construction is going through a transition to the Industry 4.0, which means the digitalization. The new Procurement Code states the provisions of the new unified legislation for public contracts for works, supplies, services and projects, and the use of instruments as the Building Information Modeling (BIM) (Gazzetta Ufficiale, 2016). These changes seek to overcome the economic crisis that has affected the sector for 10 years, and transform it in a competitive and environmental friendly business.

In this sense, small and medium-sized companies (SMEs) that produce materials and components for the construction sector play an important role because they are the “engine” that energizes the economy of the sector. Moreover, their environmental compromise could be focused on search, communicate and teach in a correct and effective way, the importance of environmental data, digitalization of processes and the opportunity that the Industry 4.0 represents. This new social responsibility of the Industry 4.0 represents a different way than business as usual, which not only focuses on the final product; instead, it considers the whole production process taking into account energy/environment efficiency (Ministero dello sviluppo economico, 2017b; CRESME, 2017).

The best and more reliable way to transfer this information to the user is an Environmental Product Declaration (EPD). The methodology to measure and establish the environmental profile of a product is the life cycle assessment (LCA), which is standardized (ISO, 2006a, 2006b). Specifically, the EPD type III allows producers to be competitive in the international “sustainable” construction market. In Italy, the EPD cover the Minimal Environmental Criteria (CAM in Italian) (Ministero dell’Ambiente e della Tutela del Territorio e del Mare, 2015).

The CAM establishes some criteria for construction materials. For example, the percentage of recycled materials should be at least 15% (in weight) of the used materials, their compounds must not have harmful for the ozone layer and must not have a high global warming potential (GWP), possibility of been disassembled or demolished in a selective way, be recyclable or reusable, and at the end of its useful life, and at least 70% of the non-hazardous building waste should have the possibility of being sent to a recycling center.

This article aims to inquire about the opportunities and problems that SMEs of construction materials face in their attempt to make compatible their activity and the environmental conscience, considering that the measurement of environmental impacts of their activity is part of the industry 4.0. The analysis is developed through a life cycle assessment case study of a reinforced panel made of galvanized steel wire and expanded polystyrene (EPS) at high density for the realization of a construction system based on open prefabrication.

2 Methodology

This study analyzes the environmental performance of a reinforced EPS panel, intended for construction of houses from one to two stories high, along its life cycle. The panel is composed by high-density expanded polystyrene (45 kg/m^3), which is an isotropic, homogenous polymer, characterized by a high resistance to compression and high thermal and acoustic insulation; and galvanized steel wire characterized by a high mechanical resistance, plasticity and ductility (AC Engineering, 2017). The study covers the product stage information as suggested in the product category rule (EPD Italy, 2017), dividing the production process in three stages: raw material supply, transport and manufacturing. These comprises the minimum of processes that shall be required in an environmental product declaration of construction products. The functional unit, defined as the quantified performance of a system for its use as reference unit (ISO, 2006a), was 1 m^2 of panel (thickness 10cm, weight 8,6 kg) considering a 50-year durability hypothesis.

a. System boundaries

The system boundaries were considered using a cradle-to-gate approach (see Figure 1), where impacts were evaluated considering the extraction of raw materials (from the cradle), its transport to the factory, and its transformation until obtaining the panel ready for delivery (to the gate). According to Bovea et al., 2014, the cradle-to-gate stage must be included in any EPD, and should remain the same for a given manufacturing location, irrespective of where the product is used.

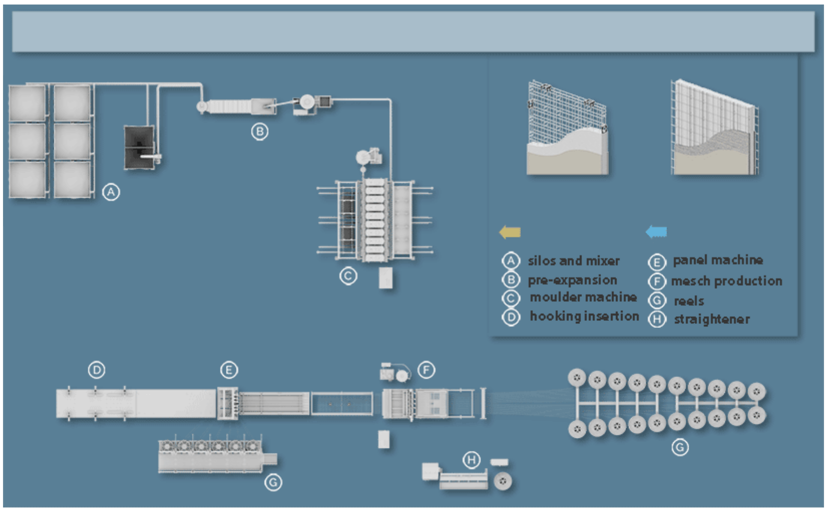

Figure 1: Layout of the enterprise. Production for 8 hour working shift (1440 m^2)

The production of the panel entails as main raw materials the use of galvanized steel wire and expandable polystyrene, which are transported from the supplier company to the production plant along 300 km and 1000 km by road, respectively. Inside the production plant, a process of expansion of polystyrene and its paneled is overcome. Afterwards, the galvanized wire is assembled in a net form and introduced in the EPS. It is important to highlight that 10% of EPS is produced as a residue, but then recycled as part of the raw material used in the next panel.

b. Inventory and key assumptions

Table 1 summarizes the life cycle inventory data used in the assessment of the panel. Raw material supply was obtained as secondary information except water datum, which was obtained as primary information; meanwhile transport and manufacturing were primary data obtained from AC Engineering *in situ*. In addition, secondary information, such as databases and scientific literature were used. In order to identify the environmental aspects associated with the panel, the Ecoinvent v.3 database, from SimaPro 8.0.4.30 library was used. It is important to highlight that the Italian energy mix from this database was used.

The following assumptions were made:

- Details of minor equipment, such as valves and pumps, were not included in this model.
- The pentane used as expansive agent was assumed in the production stage of the polystyrene pearls.

Table 1: Global inventory for panel production, categorized by each stage that conforms the product life cycle

Stage	Input	Quantity	Unit
Raw material supply	Unalloyed steel	1016	kg
	Zinc	24	kg
	Polystyrene expandable granulate	1980	kg
	Water	426	kg
Transport	Transport truck >10t, Euro3 default	2292	tkm
Manufacturing	Electric power from the Italian's national grid	668	kWh
	Output to technosphere	**Quantity**	**Unit**
	Reinforced EPS panel	400	m^2

c. Impact Assessment

The life cycle impact assessment was used to evaluate the quantity and significance of potential environmental impacts from a defined system throughout its life cycle (ISO, 2006a, 2006b).

The cradle-to-gate production process of the reinforced EPS panel was modeled in SimaPro 8.0.4.30, (PRé Consultantas, Amersfoort, The Netherlands). As specified in the product category rule, the impact assessment was carried out using baseline characterization factors from CML assessment method, considering the following impact categories: Global warming potential, ozone depletion, acidification of soil and water, eutrophication, photochemical ozone creation, depletion of abiotic resources (elements), and depletion of abiotic resources (fossil fuels). Moreover, for the energy analysis, the total cumulative energy demand (CED) methodology version 1.09 was used.

3 Results and Discussion

The way that humans design its settlements has a profound influence on society's environmental pressures. Even though it is well known that the use stage of a building tends to dominate environmental impacts, over the years technology has increased energy efficiency, shifting life cycle impacts to other stages (Goldstein and Rasmussen, 2017). That is why this article focuses on a material used in the construction sector.

LCA results strongly depend on the information quality used as input. Given this issue, when LCA is applied to provide quantitative assessments, data quality is of high relevance. In this study, the manufacturing process data was obtained *in situ*. Table 2 summarizes the LCA results of the impact categories selected in this study, for the production of 1m^2 of reinforced EPS panel.

Table 2: Potential environmental impacts from the production of 1 m^2 of reinforced EPS panel

Impact Category	Unit	Total
Abiotic depletion (AD)	kg Sb eq	6.701E-05
Abiotic depletion (AD FF)	MJ	4.836E+02
Global warming (GWP)	kg CO_2 eq	2.418E+01
Ozone layer depletion (ODP)	kg CFC^{-11} eq	3.240E-07
Photochemical oxidation (PO)	kg C_2H_4 eq	7.850E-03
Acidification (AC)	kg SO_2 eq	8.984E-02
Eutrophication (EU)	kg PO_4 eq	1.557E-02

Considering the Global Warming Potential (GWP100a) impact category, 1 m^2 of reinforced EPS panel emits 24.2 kg CO_2 eq, from which raw material entails 90% of the impact; and the other 10% is attributed to the manufacturing process (transport of galvanized steel an polystyrene pearls, expansion, panelled and assembly). Table 3 summarizes the LCA results of GWP for the production of 1m^2 of reinforced EPS panel.

Table 3: Emissions of kg CO_2 eq for the production of 1 m^2 of reinforced EPS panel

Stage	Emissions (kg CO_2 eq)	Contribution (%)
Prod. of galvanized steel	5.722E+00	23
Prod. of polyestyrene pearls	1.670E+01	67
Transp. of galvanized steel	1.951E-01	1
Transp. of polyestyrene pearls	1.040E+00	4
Expansion	6.469E-01	3
Paneled	2.376E-01	1
Assembly	2.852E-01	1
Total	2.4180E+01	100

Figure 2 shows in black the contribution of raw material to each impact category, and in gray the contribution of the manufacturing process. In all the impact categories studied, the manufacturing process contributes with less than 20% of the impacts. It is important to highlight that in AD and ODP categories, the production of the galvanized steel is the main contributor. This high impact could be mainly attributed to the zinc used in the galvanization process. Meanwhile, in the ADFF, GWP, PO, AC and EU categories, the main actor is the production of polystyrene pearls due to the high consumption of fossil fuels.

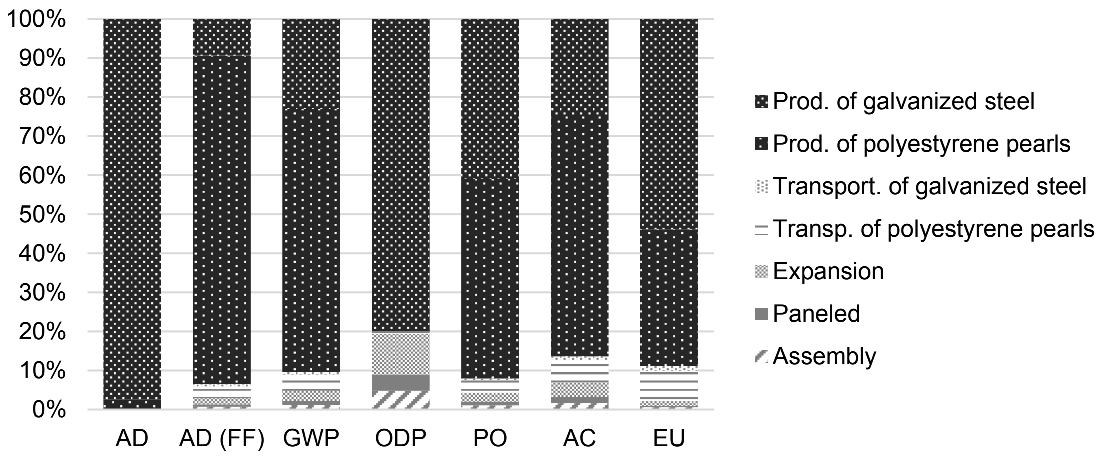

Figure 2: Contribution of each process involved in the production of reinforced EPS panel to the impact categories

The energy analysis (Figure 3) allows corroborating that the production of polystyrene pearls has a higher impact due to the high use of fossil fuels, encompassing 80% of the total energy demand. Meanwhile, the manufacturing process is responsible of 10% of the energy used. Therefore, it is important to highlight that the main environmental responsibility in the production of the reinforced EPS panels lies on the raw material extraction and transformation.

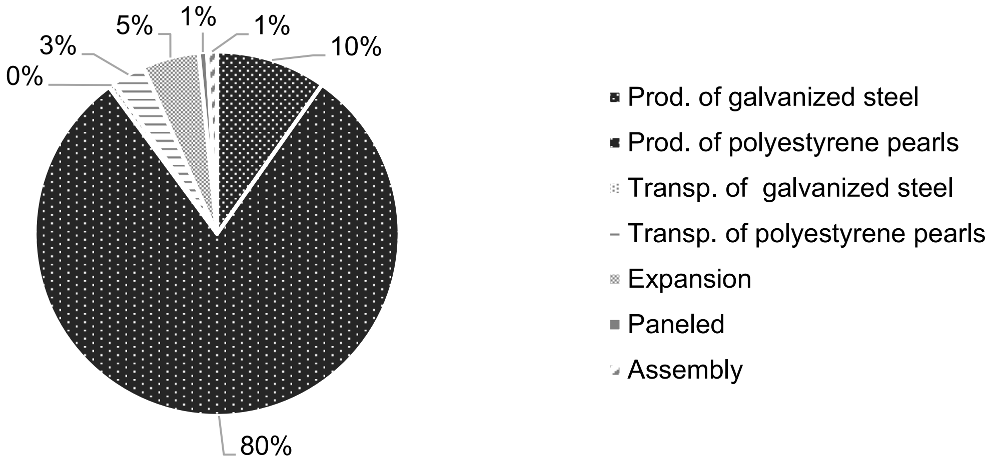

Figure 3: Energy requirements of each process involved in the production of reinforced EPS panel

4 Conclusions

The analysis of reinforced EPS panel through the “cradle to gate” life cycle assessment methodology, allows knowing how each process, implied in the production of it, impacts the environment. This kind of analysis are important to develop in order to achieve the transition of the SMEs to the Industry 4.0. In fact, it generates valuable information about the process, and let SMEs understand how their production chain is impacting the environment. Letting them know which stage of their process could be improved. With the case study analyzed in this article, it was possible to conclude that the main impact could be attributed to the extraction and production of raw material stage.

It is important to highlight that the producer is aware of the high environmental impact provoked by the galvanized steel due to the use of zinc, but in order to maintain the high technical performances of the product and its durability, this solution is considered as the most appropriate. Moreover, the low environmental burden attributed to the manufacturing stage is due to the efficiency of the machinery, the production process of fourth generation (where time, quantity and quality is constantly monitored), and the recycling of the raw material.

Therefore, the LCA of a product allows knowing the environmental profile of a product and making informed decisions to become an environmental friendly SME ensuring high technical performances.

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Life Cycle Assessment to support monetary evaluation of water related impacts

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Abstract

Increasing population growth and demand for resources has led in the last fifty years to a degradation of ecosystems with significant implications on natural capital availability. Consequently, the scientific community has started performing environmental impacts assessments adopting different tools to support the sustainable management of ecosystems. Life cycle assessment is one of the most adopted tool to perform this kind of analysis. However, to date it doesn't provide monetary information about environmental impacts. Thus, a new model has been developed for the monetary evaluation focusing on water related impacts. Specific environmental monetary characterization factors, accounting for the environmental impacts effects from water consumption in the i-th-country, have been developed and the methodology has been tested in case study in order to understand its capability to provide hotspots analysis.

1 Introduction

The increasing awareness on natural resources availability, mainly due to the ecosystems degradation of the last fifty years (Millennium Ecosystem Assessment, 2005), has led the scientific community to perform assessment on environmental impacts adopting different tools like the one of life cycle assessment (LCA), the most adopted to perform evaluation on potential environmental impacts of a product/process/organization along all the life cycle stages (ISO:14072, 2014). However, because of its intrinsic nature of tool able to provide mainly a biophysical impact characterization, the LCA methodology to date doesn't provide monetary information about environmental impacts (Pizzol et al., 2015). For this reason, in recent years the scientific community started investigating the possibility to perform assessment of environmental impacts and aspects in monetary terms, in order to allow decision makers to better understand LCA outputs (Bruel et al., 2016; Nguyen et al., 2016). Monetization of environmental impacts is mainly aimed to support organizations and in general decision makers in developing sustainable practices and strategies (ISO/DIS 14008, under development). Considering the need for a sustainable management of natural resources, water protection represents one of highest concerns, with water crisis universally recognized as a top global risk. Increased competition between water users and other demands as led to a situation where about 40% of the world's population live in water stressed areas, with an expected increase up to 50-65% by 2025 (World Economic Forum, 2016). Even if water on earth is more or less constant in absolute quantity terms, the uneven distribution of water continues to create growing problems of fresh water availability and accessibility.

Water availability is a challenge faced by a growing number of countries, with potential impacts on economic growth. Thus, considering the necessity to assess water related impacts and to implement policies for the sustainable water resources management, the object of this research is to propose an LCA based methodology to develop and test a methodological proposal to assess in monetary terms water use impacts.

2 Objective

The aim of this study was (i) the development of specific environmental monetary characterization factors ($MCF_{i\text{-}env}$) able to consider the environmental impacts effects from water consumption in the i-th country and (ii) the application of the methodology to specific case studies to investigate the capacity of the model to provide hotspots analysis.

3 Materials and methods

Considering the framework of the LCA methodology, with four main phases, the study focuses on the impact assessment stage. According to the ISO principles, this is the phase of the LCA where the LCI results are analysed to evaluate the significance of potential environmental impacts (ISO 14040, 2006). According to the fact that water use may generates potential impacts on three different endpoint areas (human health, ecosystems, resources), the proposed methodology account for exposure and effects deriving from water consumption on those area of protection (AoP) through the development of specific environmental monetary characterization factors. According to many different methods published in the last years that account for fate, exposure and effects providing fondamental impact measures, like IMPACT 2002 (Jolliet et al. 2003), USES-LCA (Huijbregts et al., 2000), Eco-Indicator 99 (Goedkoop et al., 1998), the characterization factors of the model proposed in this study are obtained multiplying a monetary base constant by an environmental intensity index accounting for exposure and effects from water consumption, according to the following equation:

$$MCF_{i\text{-}env} = MK \cdot EI_i \qquad (1)$$

MK represents a monetary base constant ($\$/m^3$) and EI_i is a dimensionless environmental intensity index. MK, assumed as a first approach equal to the world average water supply tariff, has been derived from the International Benchmarking Network for Water and Sanitation Utilities (IBNET, 2017) database. Even if this value has been considered as a good proxy for the basic economic value of water since to date no market exists for this kind of resource, the assumption is under investigation in order to check its validity. EI_i index has been developed considering exposure and effects generated by water consumption on each different area of protection (Human Health, Ecosystem, Resources) according to the following proposed equation:

$$EI_i = XF_i \cdot (HH_{i\text{-}eff} \cdot W_{HH} + ECO_{i\text{-}eff} \cdot W_{ECO} + R_{i\text{-}eff} \cdot W_R) \qquad (2)$$

Equation (2) has been developed with the aim to explain how exposure and effects have been accounted to calculate the environmental intensity index EI_i.

The exposure (XF_i), whose aim is to express the level of vulnerability to the consumption of water, has been calculated developing two dimensionless indexes multiplied together:

- the first (I_i^{WS}) was derived from AWARE (Available WAter REmaining), a method recommended by UNEP/SETAC Life Cycle Initiative for water scarcity impact assessment in LCA (Boulay et al., 2017). AWARE captures the potential impacts of water consumption by representing the amount of remaining water in a watershed after the deduction of human and environmental water requirements. AWARE method assesses thus the potential to deprive another user in a watershed. It is based on 1/AMD which is the inverse of the remaining water available after demand has been met.
- the second (I_i^{AC}), representing the capacity of a country to adapt to loss of water, was derived from the World Bank Gross National Income (GNI), according to the inverse of the GNI normalized (World Bank, 2017). GNI has been considered because of its correlation with access to an improved water source, as reported by the United Nations (2009). The normalization has been performed according to the different percapita income levels in each country considered in the study.

Considering effects of water consumption on each Area of Protection ($HH_{i\text{-eff}}$, $ECO_{i\text{-eff}}$, $R_{i\text{-eff}}$) they were accounted through the development of another three different dimensionless indexes:

- the one for Human Health ($HH_{i\text{-eff}}$) was derived from the methodology provided by Boulay et al. (2011) which expresses how the reduction in water availability potentially affects human health. This method is an endpoint indicator expressed in DALY and is obtained by modelling each water user's loss of functionality. It has been used the distribution approach, which refers to the impact assessment in which all users are competing and proportionally affected according to their distributional share of water use for off-stream users (agriculture, fisheries and domestic).
- the one for Ecosystem ($ECO_{i\text{-eff}}$) was derived from the methodology developed by Verones et al. (2013) providing impacts from water consumption on the biodiversity in wetlands. Species considered are birds, mammals, reptiles, amphibians.
- the one for Resources ($R_{i\text{-eff}}$) was derived from the combination (sum) of two adimensonal indexes:
    - $I_i^{\text{Efficinecy}}$, which indicates the efficiency of water use, has been calculated considering information (gross domestic production and total water abstracted) from World Bank Water Productivity. Normalization has been performed according to the average world value of reference, obtaining an adimensional index.

- I_i^{Supply}, derived from the IBNET tariff database in order to account for the supply of water. As for the previous index, normalization has been performed according to the average world value of reference, resulting in a final adimensional index.

Finally, considering equation (2), W_{HH}, W_{ECO} and W_R represent the weighting factor of each effect $HH_{i\text{-}eff}$, $ECO_{i\text{-}eff}$, $R_{i\text{-}eff}$, assumed equal to 1/3 for each one.

Plotting the monetary characterization factors calculated for 75 countries (Figure 1), the curve shows a trend below the assumed monetary base constant (1,41\$/m^3) for about half of the countries, mainly those characterized by lower water scarcity (Uruguay, Costa Rica, Slovenia). The curve, instead, increases for the other half of the countries, with a trend that follows more or less the increase in water scarcity (Senegal, Algeria, Tunisia).

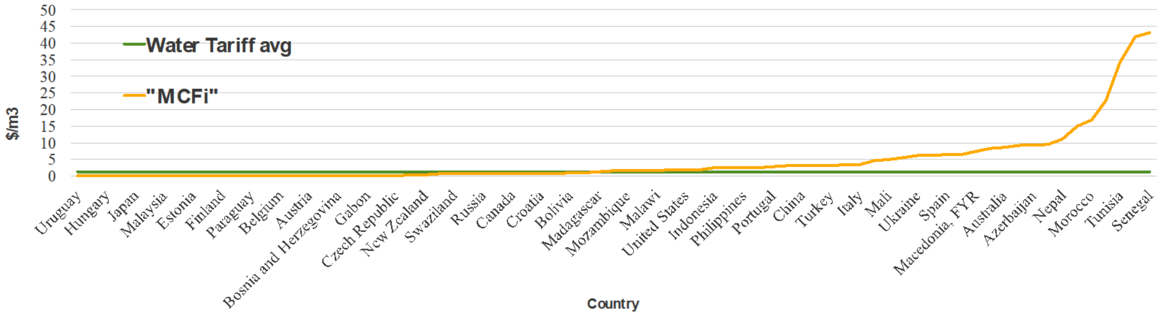

Figure 1: Resulting monetary characterization factors trend according to the different countries considered in the study

To have the final economic impact value $I_{i\text{-}eco}$ (in economic terms) of the environmental impact of the i-th country from water resource consumption, the specific environmental monetary characterization factors ($MCF_{i\text{-}env}$) of the i-th country have been multiplied by the environmental impact ($I_{i\text{-}env}$), of the i-th country obtained through the application of an already existent water scarcity assessment methodologies:

$$\sum I_{i\text{-}eco} = \sum (I_{i\text{-}env} \cdot MCF_{i\text{-}env}) \qquad (3)$$

The proposed methodology has been tested in a complete product LCA case study in the agrifood sector, according to the steps showed in Figure 2.

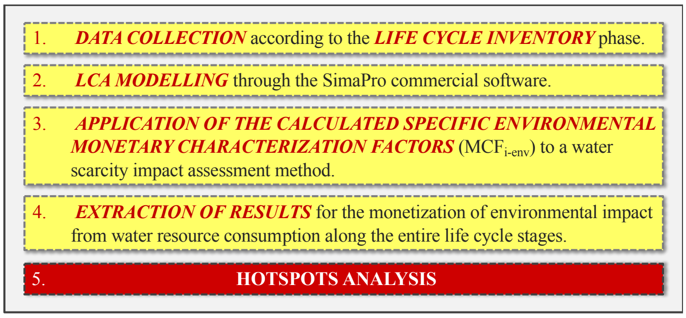

Figure 2: Framework adopted for the application of the proposed LCA based model for the monetary evaluation of water related impacts

First primary data on raw materials, chemicals for the treatment of water extracted from well, chemicals used during production, chemicals for the wastewater treatment, refrigerant charges, packaging (primary, secondary and tertiary), water consumption, electric and thermal energy consumptions, wastes and distribution of the final product to the costumers were collected to perform the complete life cycle inventory. Secondly the considered product system was modelled into the LCA software SimaPro 8.0.5.13 (Prè, 2014), adopting the widely-accepted datasets Ecoinvent v3.1 (Ecoinvent, 2014) and Agri-footprint v1.0 (Agri-footprint, 2014).

$MCF_{i\text{-}env}$ were then used according to the equation (3), applying them to an already existent water scarcity assessment methodology. For this test the chosed water scarcity method was AWARE. Resulting values were finally upload into the software SimaPro allowing the application to the modelled product system and the next extraction of the results for the monetization of impacts from water resource consumption.

4 Results and discussion

The sysyem product adopted to perform the case study deals with the production of a mozzarella cheese by a company in the northwest Italy. The functional unit is 1 kg of mozzarella cheese comprehensive of packaging and delivered to final consumer. The system boundaries have been fixed according to Figure 3, considering all input and output fluxes of farming, raw materials processing, distribution, consumption and final disposal.

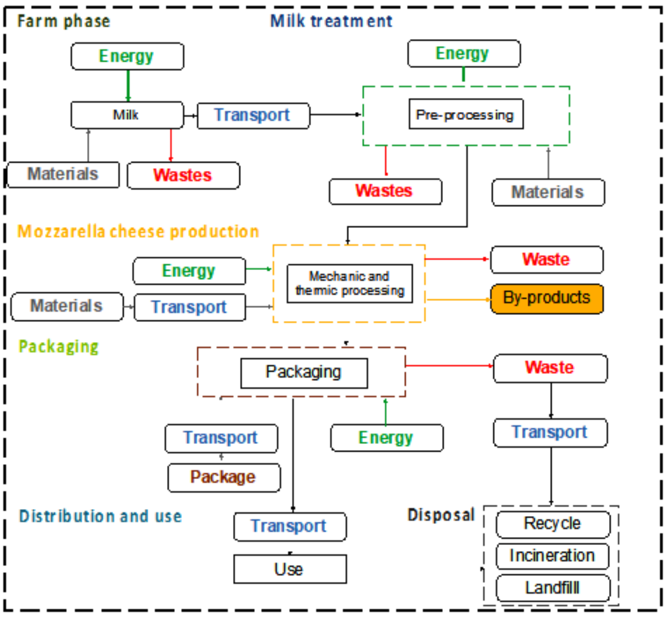

Figure 3: Semplified system boundaries

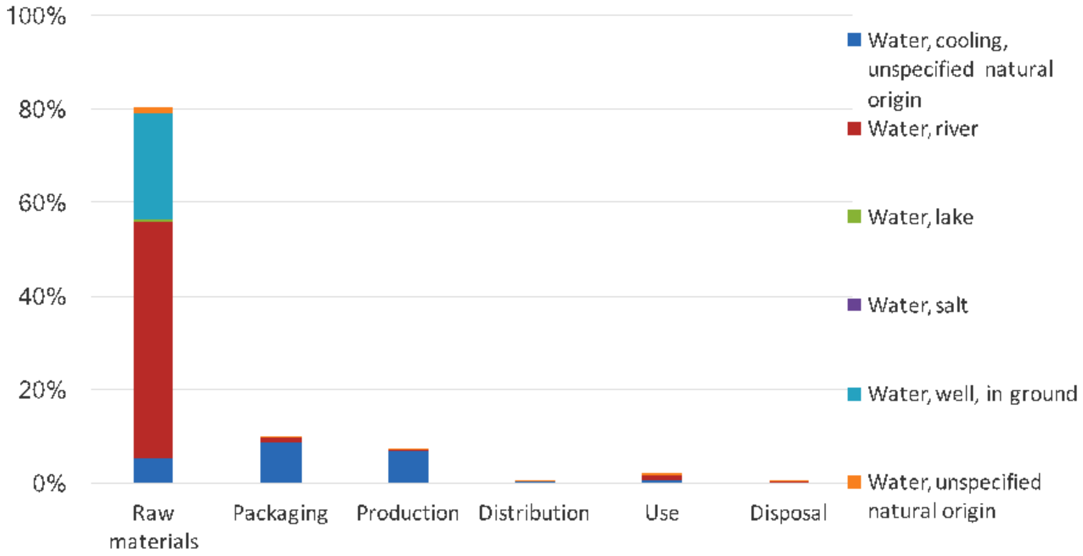

Figure 4 : Semplified system boundaries

Considering water abstractions, results in Figure 4 highlight that raw materials is the life cycle stage responsible for the most part of them, with about the 80% of the abstractions, followed by packaging and production phase with 10% and 7,5%, respectively.

The characterization of final results (Figure 5) shows that economic impact of water scarcity is mainly focused on raw materials with about 80%, followed by packaging, production and use all with about 6% of incidence on the total economic impact. Moreover, it is interesting to observe that results show a relevant percentage increment of economic impact if compared to that of environmental impact (+10%), giving even more importance to the incidence of raw materials on the whole product life cycle.

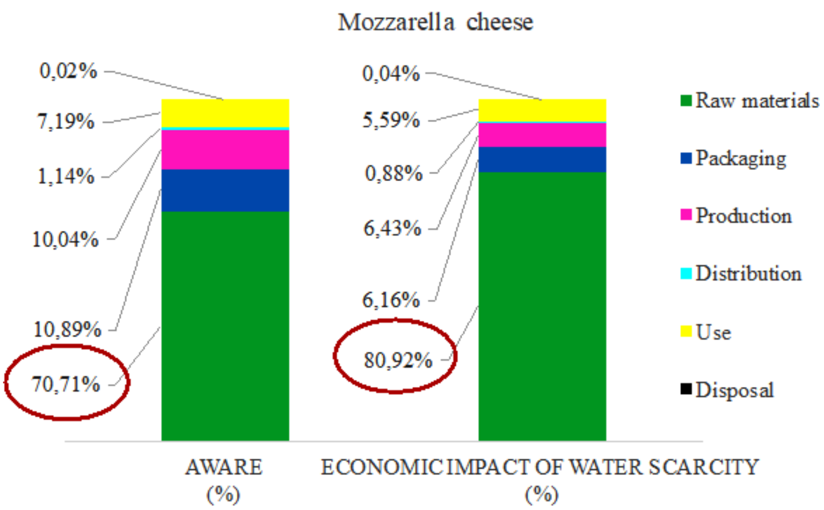

Figure 5: Results from AWARE and proposed methodology for monetization of water impacts

5 Conclusions

An LCA based methodology has been developed and tested to assess in monetary terms water use related impacts. Specific environmental monetary characterization factors (MCF_{i-env}), considering environmental impacts effects from water consumption in the i-th country, were calculated and the resulting model was applied to a specific case study in the agrifood sector. This was performed thanks to the possibility to upload the generated CSV file containing the developed characterization factors into the SimaPro software.

The hotspot analysis of results from the study highlights that the life cycle stage of raw materials is responsible for the most part of impacts, both from application of AWARE method and proposed monetary evaluation method, mainly because of the characteristics of the production system which is highly affected by the agricultural phase. Moreover, the results show a percentage increment of economic impact if compared to that of environmental impact obtained through AWARE method, of +10% for the product system investigated.

According to these information, it could be interesting to investigate how results, particularly the different incidence of the life cycle stages resulting from the comparison between water scarcity method and proposed economic monetization of water use impacts method, may be influenced by the adoption of production systems different from that from the agrifood sector, e.g. considering construction and building systems.

Moreover, even if AWARE is a methodology approved and recommended by the life cycle community, other available water scarcity footprint methods may be considered to provide a sensitivity analysis. Finally, assumption like the monetary base constant MK and the weighting factors W_{HH}, W_{ECO} and W_R need to be investigated to check its validity and increase the robustness of the proposed method in order to provide a monetization of water related impact assessment as much as possible consistent.

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Industrial symbiosis to improve zero waste production system: middle Italy wine district case study

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Abstract

This article studies the energetic potential of biogas obtainable from winery waste production through an anaerobic digestion (AD) process, within the territorial context of Emilia Romagna in Italy. The winery district produces about 5.2 million tons of grapes. These wastes are processes by anaerobic digestion in 5 biodigesters, this methodology allows to re- introduce in the production process 800,000 tons of food waste, consisting of: vegetable waste, wood chips and waste from pruning. Reusing production waste generates 12,236 million Nm^3 per year of biogas and 104,283 million kW/h per year of electrical energy. These results show that partnership between companies and the implementation of process innovations, could be reached by food manufacturers which requires a high energy needs and that produce significant amounts of organic waste, reusable by-products as raw material for biogas production.

1. Introduction

From the beginning of the 70s, the relationship and the interconnection between economy, environment and wellbeing has become more preponderant, especially for human activities and their effects on natural environment. The economic worldwide organization and productive system are based on the neoclassical linear approach, in which the intrinsic value of productive capital is dependent only on manufactured capital and does not account the environment safety, enhancing the weak sustainability vision (Pelenc and Ballet, 2015). According to this vision, the production cycle forces the economic chain in the same stages: mining, production, consumption and disposal.

Differently the circular economy approach, proposed as a sustainable alternative to our current linear economic system (Singh and Ordoñez, 2016), is a model in which the production activities are connected and organised to optimise the resources employed in the processes. The added value in this approach is related to the waste: the waste of some economic actors become resources for other stakeholders. This system is more virtuous compared to the linear economy approach, because it is based on the preferable usage of renewable resources and on the importance of sharing information among the different economic agents. Innovation and ecological design of final products are the other two variables that contribute to the enforcement of this system.

The circular economy concept is strictly linked to the industrial symbiosis model: symbiosis is a biological term referring to "a close, sustained coexistence of two species or kinds of organisms" (Encyclopedia Britannica, 1992), and in the 20th century, the symbiosis in natural systems was adopted as an analogy for

understanding how industries interact (Lowe and Evans, 1995; Harper and Graedel, 2004; Korhonen, 2004). This model used for the first time by Valdemar Christensen in 1989 to describe the Kalundborg eco-industrial park (Zhaohua W. et al., 2010), is based on the collaboration between firms in different sectors with the aim of sharing economic and social capital to optimize resources and costs. The benefit of this model is the integration of the three dimensions of sustainable development (environmental, economic and social) for the strategic management of the companies' factors of production.
More generally, a biomass is considered as any organic and decomposable material from vegetable or animal composition following a biological life cycle. The biomass can be used as energetic commodity, by converting the chemical energy present in the substances in heat, electricity or biofuels. Depending on the processing technology and the energy produced, it is possible to distinguish different types of biomass: solid (firewood, pellets, chips, agro-industrial residues and organic fraction of municipal solid waste wood and agricultural crops and residues, animal dung, herbaceous and woody energy crops, municipal organic wastes as well as manure.); liquid (biodiesel produced from oilseeds and exhausted vegetable oils); gaseous (biogas produced from livestock waste, agro-industrial residues and organic fraction of municipal solid waste) (Gracceva e Contaldi, 2004).
The employment and the consumption vary geographically according to the type of process used for the energy production. In the American continent, USA and Brazil are the leaders in the production of biofuels from corn ethanol and sugarcane ethanol respectively, with a total production in 2012 equal to 79 billion litres (WBA (2014) Global Bioenergy Statistics). In Europe (EU), the biomass is employed mainly for energy production, both heat and electricity predominantly produced from forestry products and residues in cogeneration plants (80%). Differently in Asia and Africa fuel, wood and charcoal are the most used resources, by considering that a significant part of the population do not have access to the electricity grid, but biogas and decentralised bioenergy systems are increasing.
Biomass is often defined as low-fuel carbon content or carbon neutral, indicating that burning biomass does not contribute to climate change.
In 2015 the world wine production reached 274.4 million hectoliters, a slight increase on 2014 (+ 1.3%) (Ismea, 2016). The forecast for 2016 is 259.4 million hectoliters, a marked decline compared to the previous year (-5.5%). In 2015, Italy was the first producer with a share of 18.2% of the world total, regaining the record lost in 2014 in favor of France (17.3% of the total). The advances for 2016 would confirm Italy in the position of the world's leading producer with 48.8 million hectoliters compared with 41.9 million in France and 37.8 million in Spain (Ismea, 2016). In the same year, the value of Italian production is estimated at 12.9 billion euro. The ISTAT estimates for 2015 indicate a share of DOC and DOCG wine production equal to 39% of the total, an increase of 15.8% on 2014; to it are added the IGP wines with 31.7%, + 14.7% on 2014 and, on balance, the common wines that count for the remaining 29.3% (Mediobanca, 2017). A significant share of Italian production is exported, with an operating surplus of 760 million euros in 1990 to 5.1 billion euros in 2015 (6.7 times), a

year in which volumes decreased by 1.2% and value increased by 5.4%; the average export price therefore rose from 2.49 euros to 2.66 euros per liter (+ 6.7%). Provisional data from Istat for 2016 show an increase in exports of 4.3% over 2015 (+ 2.9% in quantity); the average export price increased by 1.4% to 2.7 euro per liter. The provisional surplus in December 2016 rose to 5.3 billion (+ 4.9% compared to 2015) (Mediobanca, 2017).
The companies of this study have a location on the Italian territory that leads to a certain concentration in some regions, also called "wine district". With the caveats due to the multi-regional location, sub-aggregates can be processed on which to calculate significant economic-environmental indicators. In some regions, economic performance is relatively more brilliant than the national average.

2. **Methods**

The article is based on a quantitative analysis of the data obtained from the study of a wine district involved in the process of industrial symbiosis. The role of networking and innovation in the field of industrial simbiosis (IS) is investigated through direct research in the field with the use of specific and reliable sources. With acquired datas it as possible to investigate the whole production process by life cycle assessment (LCA) methodology. Datas were processed with data-based software such as Simapro v. 7. The study applied the systemic approach to sustainability science, which includes a comprehensive analysis for identifying potential areas for theoretical, methodological and practical progress of IS studies.
Italy has an important tradition in terms of local collaborations between companies, institutions and communities, inherited from the district model. For this work has been studied a Emilia Romagna's wine district. Main product of the district is wine, but it also produces by products that can be used and processed by other companies of the district.

2.1 Goal and scope of definition

The main objective of this study is to use LCA methodology to assess the environmental and economics impacts associated with standard biogas digesters of wine district in Emilia Romagna. For the study case the wine production wastes and energy used in a certain time frame has been defined as the functional unit to analyse the enviromental impacts.
The mission of the entire district is zero waste production, to achieve this goal all organic wastes from production are destined to anaerobic digestion. By anaerobic digestion the wine district can produce energy that can be re-used for energy needs of the production process itself.
Figure 1 describes the production process for biogas fermentation using continuous stirred tank reactor (CSTR) of the middle Italy wine district. The fermentation process is a mesophilic type. The fermentation takes place in large

tanks of 500 m3 and the fermentation temperature is kept around 35 °C with recycled hot water. About 80 tonnes of waste water passing through the fermentation process and part of the biogas produced by the anaerobic digester is used to power the wine distillation process or for heating the boiler. Most of the waste to be composted are derived from a winery in northern Italy.

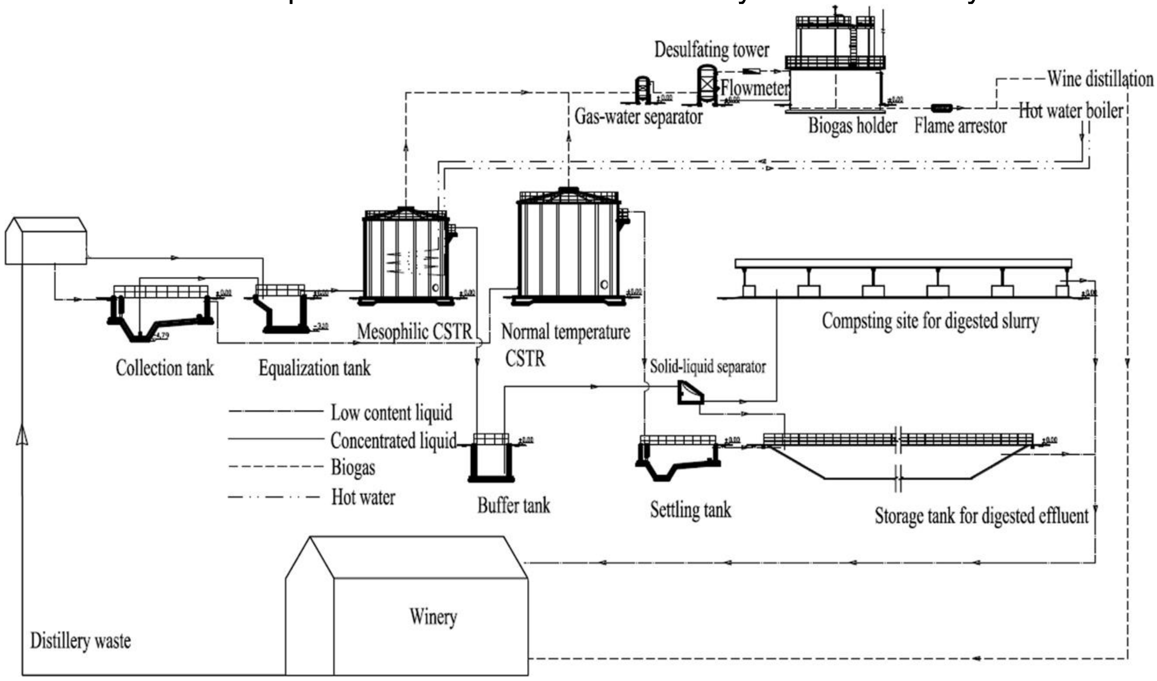

Figure 1: Process flowchart of the Faenza biogas plant

The winery district has embarked on a partnership with an energy company, with which it works in symbiosis. The energy company produces biogas resulting from the waste processing of the wineries. The energy requirements of the winery are totally satisfied by the production of electricity resulting from the biodigester. In Table 1, the energy requirements are listed.

Table 1: Winery energy requirements per year

Equipment	Electricity Consumption (KWh)
Screw pump for mesophili CSTR	12.946.500
Recycle stirring pump	12.946.500
Hot water recycle pump	3.528.000
Submerged pumps	37.663.500
Overhead stirrer	17.650.500
Submerged mixer for equilization tank	7.056.000
Solid liquid separator	12.946.500
Illumination	262.500

To calculate the energy balance, energy and biogas have been converted into electricity (kwh). The total production of 5,200,000 tons of grapes produces 220,000 tonnes of waste that are destined at the biodigester. Thanks to the anaerobic digestion process the energy company that collaborates with the winery can produce 105,000,000 kwh of biogas and 81 million kwh of electric energy. The use of renewable fuels allows an annual saving of about 35,000 tons of CO2. The total energy produced satisfy the energy needs of the winery that produces food waste.

2.2 Life cycle assessment approach and data sources

In this study, LCA was used to assess the environmental impacts of wine district's wastes management systems with and biogas digesters throughout the entire life cycle of production, from storage to field application. The methodology used is in accordance with the standards described in ISO standards ISO 14044 (ISO, 2006a) and ISO 14040 (ISO, 2006b).

The functional unit (FU) applied was the treatment of 100 kg of organic wine production wastes.

The ReCiPe 2008 impact assessment method (Goedkoop et al., 2009) was applied in this study to assess the impact in four different categories: i) global warming potential, ii) marine ecotoxicity, iii) freshwater ecotoxicity, and iv) metal fossil depletion. These categories cover the most important environmental emissions and energy resource issues and are important impacts of parameters for wine wastes.

3. Results and discussion

In this section, we will try to highlight how networking and innovation have progressively become relevant topics in IS studies and how they have been integrated in supporting EU policies and local development models.

The winery district transforms 5,200,000 tons of grapes into wine. Wastes from this transformation process are re-introduced in the production system.

Thought anaerobic digestion wastes are transformed into electric energy and biogas. Environmental and economic impacts from the transformation process has been elaborated by LCA simulation software as Simapro 7.

The following inputs were taken into consideration in the analysis process:

- Total production of grapes;
- Amount of biogas produced by anaerobic digestion;
- Amount of electric energy produced by anaerobic digestion.

The parameters analysed for this case study are listed in table 2.

Table 2: Environmental and economic parameters from biomass energy production

Parameter	Type	Total	Electricity from biomass	Heat from biomass
Climate change Human Health	DALY	20	6,73	13,60
Ozone depletion	DALY	2	2,08	0,01
Human toxicity	DALY	6	0,48	5,60
Photochemical oxidant formation	DALY	0	0,17	0,00
Particulate matter formation	DALY	9	6,02	2,61
Ionising radiation	DALY	0	-	0,45
Climate change Ecosystems	species.yr	0	0,04	0,08
Terrestrial ecotoxicity	species.yr	2	1,68	0,00
Freshwater ecotoxicity	species.yr	10	9,63	0,00
Marine ecotoxicity	species.yr	8	1,95	6,38
Agricultural land occupation	species.yr	0	-	0,01
Metal depletion	$	3	-	3,16
Fossil depletion	$	5	1,35	4,00

The results from software development show that biomass gas production has a greater environmental and economic impact than biomass electricity production. An economic analysis was conducted for the biogas plant. The biodigestion plant was built in 2009 and has an estimated life span of 20 years. The installation cost was 1,250,000 €. The annual revenue is calculated by adding up the sale of energy produced and the savings resulting from the production of energy from the biodigester. The annual costs include the cost of labor and equipment maintenance fee. The annual income is calculated from the difference between the annual operating costs and revenues. The payback period has been identified by dividing the costs for the installation of the biodigester and annual income (1).

$$Payback\ period = \frac{investment\ cost}{annual\ income} \qquad (1)$$

Il net present value (NPV) It was calculated as shown in equation (2).

$$\mathrm{NPV} = -C0 + \sum_{i=1}^{n} \frac{C1}{(1+r)^i} \qquad (2)$$

- C0: installation cost of biodigester
- C1: annual income
- *r*: rate of interest
- *n*: number of years
- *i*: discount factor at time

Table 3 shows how the payback period and npv returns positive results. Domestic production of electricity and biogas saves in a year: 3.726 € million from electricity costs and 2,195, 545.54 € from gas costs.

Table 3: *Economic analysis of the anaerobic digestion plant*

Type	Value
Installation cost	1.250.000,00 €
Annual income	5.921.545,54 €
Equipment maintenance costs	4.830.000,00 €
Payback period (months)	2,56
Net present value	5.529.082,99 €

As a source of renewable energy, biogas and other renewable energy, not only bring environmental benefits but can be economically competitive to attrack new investments.

4. Conclusion

The challenge of our century is to define and apply a new scenario where the production is *re-thought* and *re-launched* for the improvement of environmental and human safety. The territory is the pivotal element that can lead the redefinition of the economic boundaries, by achieving a more efficient process of production based on the revalorisation of waste. The new vision starts from different innovative sectors, from waste to sustainable management and recovery, from agriculture to mobility, to biochemistry, to push the supply of commodities under an innovative low carbon perspective. The process of transition must be taken together with the industrial innovation policy, territorial and environmental, to respond to the dangerous situation of pollution and to create the conditions for new investments in the renewable energy sources, as well as in the optimisation of resources allocation.

Incentives to promote the circular economy approach should be based on two variables, savings on production costs and the acquisition of competitive advantages (a consumer prefers to buy a product from circular rather than linear production process). Prolonging the productive use of materials, the reuse and increasing the efficiency, the competitiveness will be strengthened, the environmental impact and the GHGs emissions will be reduced. The sustainable collaboration will enhance the sharing initiatives between different companies operating in different sectors, with the aim to share initiatives based on common interests, in terms of economic, environmental and social value. Collaborative agreements between companies and industries will optimize the environmental preservation, amplifying the final benefits. Subsequently, collaboration for certain firms has deepened between firms exploiting new opportunities for initiating collaborative practices. Furthermore, the use of biomass in the production process is cost-competitive today, and incentives will lead the generation and the usage of this commodity. Environmental preservation, energy security and socio-economic advantages are associated with sustainable bioenergy, and transitional measure will reduce the cost of the competitiveness in the middle term. Policy frameworks at national and local level should provide the support for the implementation of production waste reuse, by achieving also other important objectives, such as greenhouse-gas reduction, energy security, biodiversity preservation, and socio-economic development.

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YOUNG RESEARCH AWARD

Environmental implications of future copper demand and supply in Europe

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Abstract

Copper is the third metal by production volume after iron and aluminium, but its wide use in modern technology can be affected by high vulnerability to supply restriction due to the anticipated mine production peak. Securing access to copper forms is of particular importance for countries highly depending on imports, notably many EU Member States. Recycling of post-consumer scrap can help to reduce Europe's reliance on natural reserves and to reduce the environmental impacts associated with primary copper production, but end-of-life management of copper scrap is far from perfect recycling performance. In this work, we combined material flow analysis, scenario analysis and life cycle assessment to explore the possible evolution of copper demand in the EU-28 to 2050 and discussed the potentials for energy savings and climate mitigation achievable under the creation of a circular economy in the EU-28.

1 Introduction

Copper is a major metal utilized in many traditional applications such as plumbing and infrastructure, but it is also essential component in emerging technologies including photovoltaics and wind turbines.

Despite modest copper deposits in the EU-28 and a strong import reliance of primary copper forms to meet the domestic demand, the European Commission has not included copper in the Critical Raw Materials list (EC, 2017). However, the decrease of ore grade and the anticipated mine production peak (Vieira et al., 2012; Northey et al., 2014), should the global copper demand keep growing at current rates, could result in limitations to access essential materials for the European copper industry.

Recycling of secondary copper sources, in particular post-consumer scrap (or old scrap) can help to reduce Europe's reliance on primary sources and to to move towards a closure of material flows in accordance with the Circular Economy (CE) approach (Ellen MacArthur Foundation, 2013).

Recycling of anthropogenic reserves has the further potential of avoiding the use of large amounts of energy, which would be required in primary metal production because recycling is often significantly less energy-intensive. However, despite a well-established industry network in the copper value chain, the EU-28 is still far from perfect recycling and margins for improvements are remarkable (Ciacci et al. 2017).

In this work, material flow analysis (MFA), scenario analysis and life cycle assessment (LCA) were combined to (i) explore the possible evolution of copper demand in the EU-28 to 2050, (ii) evaluate opportunities and barriers for improving recycling at end-of-life; and (iii) assess the potentials for energy savings and greenhouse gas (GHG) emissions reduction achievable under the creation of a circular economy in the EU-28.

This comprehensive approach merges complementary research drivers in the analysis of the metal-energy-climate change nexus to analyse (i) the potential impacts of copper recycling on future secondary metal supply to provide materials for traditional application segments and greener energy systems, and (ii) the potential for energy savings and carbon emissions reduction associated with recycling in the copper industry.

We expect that the results will be of novelty and timely to inform decision-makers addressing topics such as energy policies and climate change for enhancing the growth of an economy based on resource efficiency and recycling in the EU-28.

2 Materials and methods

a. Modeling future copper demand and supply in the EU-28

Efficient recovery of secondary resources requires quantitative estimates of total scrap generated at end-of-life and available for recycling. This pre-condition for sustainable management strategies is seldom available and builds upon characterisation of elemental cycles in modern society.

MFA is often the preferred technique to understand the anthropogenic metabolism of materials (Pauliuk and Müller, 2014) and was applied to analyse copper at different geographical levels (Bertram et al., 2002; Ruhrberg, 2006; Glöser et al., 2013; Soulier et al., 2018). Based on a systematic application of the principle of mass conservation, MFA quantifies flows and stocks of resources. Extending the analysis to a wide time span of investigation, MFA enables to simulate the annual generation of post-consumer scrap as function of historical demand (i.e., flow into use) and the useful lifetime of products in use.

In this work, MFA was applied to determine the copper cycle in the EU-28 from 1960 to 2014 (Ciacci et al., 2017). The comprehensive retrospective provided constituted the evidence-based information on which the future domestic demand for copper was built.

More in detail, regression analysis was applied to analyse the relation between historical copper demand in the EU-28 and a set of independent variables. Population, gross domestic product, the level of urbanisation, and time as a proxy for time-dependent variables (e.g., technology evolution) are often adduced as the main drivers of resource use (Roberts, 1996; Elshkaki et al., 2016; Elshkaki et al., 2018) and were used in this work as explanatory variables of annual copper inflow to use.

Copper demand was disaggreted by major application sector including building and infrastructure, transportation, industrial machinery, electrical and electronic products, consumer and general goods. The regression equation applied in the analysis is in the form:

$$Y(t) = \alpha_0 + \sum_{i=1}^{n} \alpha_i X_i(t) + \varepsilon(t)$$

Where $Y(t)$ is the copper flow into use at time t, n is the number of explanatory variables, $X_i(t)$ are the explanatory variables at time t, α_i are the regression model parameters and $\varepsilon(t)$ is the residual of the regression model. The choice for the best fitting regression equations is based on the statistical parameters describing the adequacy of the model and the significance of the explanatory variables. The confidence level was set at 95%.

Then, the domestic copper demand to 2050 was explored by applying a "business-as-usual" scenario (named Market First, MF) and a scenario that sets the United Nations Sustainable Development Goals (SDGs; UNEP, 2017) as a priority (Equitability First scenario, EF). The two scenarios are founded on the UNEP GEO-4 scenarios (UNEP, 2007) and a description of their storylines is reported elsewhere (Elshkaki et al., 2016). Each scenario models growth rates of the explanatory variables to 2050 according to its underlying dynamics and simulate a possible evolution of the copper demand in the region.

The estimated future copper demand informed the MFA model to simulate the generation of copper old scrap to 2050. Lastly, LCA was combined with copper cycle information to generate first-order estimates of energy savings and GHG emissions reduction associate with copper recycling.

b. Modeling environmental impacts from future primary and secondary copper production

Being interested in the potential environmental benefits that may derive from a closure of copper cycle in the EU-28, we discussed the results under a European-centric perspective. Thus, for both scenarios, copper old scrap was assumed to undergo recycling in the region fulfilling the principles of the CE.

The degree to which post-consumer copper can substitute for primary copper was explored for constant recycling conditions and for "optimal" end-of-life recycling. The former condition refers to the case in which the current end-of-life recycling rate (EoLRR) remains stable to 2050, while the latter one models a hypothetical improvement of EoLRR to near-perfect recycling, determined as 90% collection rate and 90% sorting and pre-processing rate.

Cumulative Energy Demand (CED) and Global Warming Potential (GWP) were selected as impact assessment indicators. According to the ISO guidelines (ISO, 2006), credit was given to recycling for offsetting the energy required to produce the same amount of copper input to fabricators from primary sources (i.e., assuming a 1:1 substitution rate for recycled and virgin material).

Energy inputs for primary copper production include primary and final energy demanded for drilling, blasting, hauling, crushing and beneficiation of virgin ores plus energy required for smelting and refining.

Energy associated to secondary production includes energy inputs for collecting and pre-processing (e.e., transport and pre-processing) of copper old scrap and was distinguished between inputs to fabricators for direct melting and to secondary refiners for cathodes production. Generally, direct melting is supplied with copper scrap of high quality, but it may require inputs of virgin copper for dilution purpose due to the presence of alloying elements in the scrap input.

The current primary production of copper in the EU-28 has almost reached the installed capacity and, based on the known domestic copper deposits, it was assumed to remain constant in the coming years. However, imports will continue to be dominant in the copper supply to the European industry. The ecoinvent processes "*Copper, primary, at refinery*" and "*Copper, secondary, at refinery*" (Classen et al., 2009) were used to compute the environmental implications from global and regional copper supply in 2015 and as a basis to model scenario transition to 2050.

For primary copper production, the future energy required was determined by ore grade declining, the metallurgical route followed (i.e., pyro- and hydrometallurgy), and worldwide implementation of best available techniques (BATs). More in detail, the relation between energy demand and ore grade declining as function of the anticipated cumulative copper production was defined by (Mudd et al., 2013) and previously applied to global copper demand evolution (Elshkaki et al., 2016).

In addition, according to several authors (Kulczycka, 2016; Norgate and Jahanshashi, 2011), between 10%-60% of current energy requirements could be saved through worldwide diffusion of BATs (e.g., flash-smelting). For the EU-28, margins for energy savings were quantified at 30% as more than 70% of domestic copper is produced in plants with best available smelting and refining technology (Kulczycka, 2016).

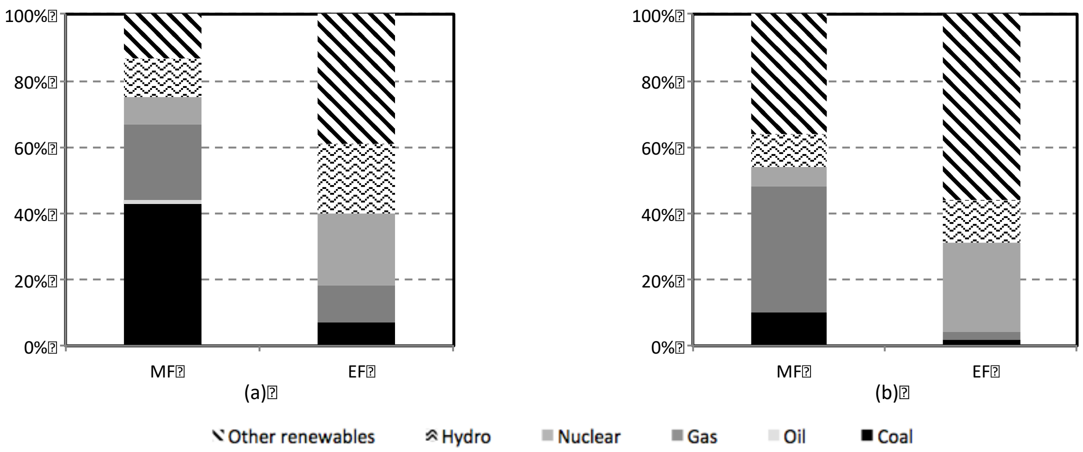

Figure 1: Electricity production mix for the world (a) and the EU-28 (b) in 2050 used in the model

For secondary copper production, it was assumed that the adoption of design for resource efficiency (e.g., design for disassembly, design for recycling) strategies offsets the additional energy requirements to improve old scrap recovery and achieve near perfect recycling. Thus, in first approximation, energy requirements for secondary copper production were assumed to remain constant to 2050.

Energy-related GHG emissions associated with primary and secondary copper production were distinguished between primary energy and final energy requirements. Carbon intensity values were set for primary energy sources (i.e., coal, heavy oil, natural gas, diesel, and blasting), while the carbon intensity associated to final energy was expressed as function of the electricity production mix in 2015 and 2050 (Figure 1). To this aim, the projections from the International Energy Agency (IEA, 2012) for the world and the EU-28, were applied to the copper scenarios. More specifically, the IEA Current Policies Scenario was set for MF, while the IEA 450 Scenario was considered for EF.

3 Results and discussion

Figure 2 displays the contemporary anthropogenic copper cycle in the EU-28. The results demonstrate that the EU Member States relies on imports of copper forms to meet the demand, with less than 20% of copper production being supplied from domestic reserves. Cumulative in-use stock amounts to 90 Tg Cu (or >200 kg Cu/capita), which almost doubles the known copper reserves in the region (~48 Tg Cu; USGS, 2017). Part of post-consumer scrap is recycled domestically, either sent to direct melting or secondary cathodes production. Part is net-exported, but the largest fraction of copper old scrap is not recovered and lost. (Ciacci et al., 2017)

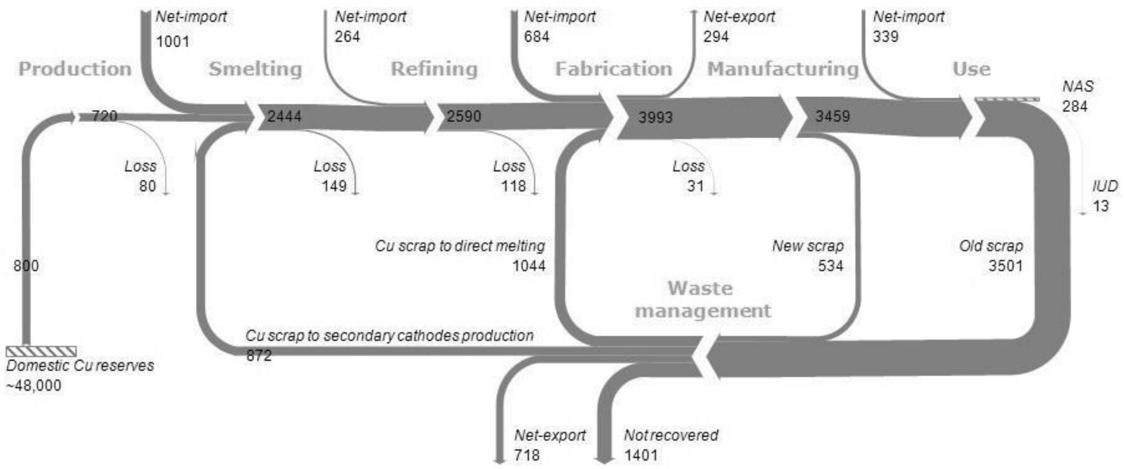

Figure 2: The anthropogenic copper cycle in the EU-28. NAS – Net addition to in-use stock; IUD – In-use dissipation. Values in Gg copper content. Reproduced from Ciacci et al. (2017)

The MFA model revealed that from 1960, the copper demand in the EU-28 has increased by about 1.6 times but, should the future follow the dynamics of a “business-as-usual” scenario (i.e., MF), the amount of copper demanded domestically will likely triple respect to current levels. This perspective implies severe constraints to a society based on secondary material sources.

As shown in Figure 3a, post-consumer scrap constituted about 50% of the copper demand in 2015. However, in case of a MF scenario, this ratio will likely decrease to less then 40% requiring more primary copper input at higher environmental costs due to the anticipated ore grade declining. Interesting to note, the increase in primary copper input would be also needed in case of “optimal” recycling.

In contrast, a world that would prioritise the SDGs will progressively result in a decrease of the copper demand to 2050. For instance, this positive situation could result from de-materialisation and decoupling strategies, which would lay the foundation for a circular economy in which the natural capital is preserved as secondary copper flows could even exceed the demand (Figure 3b).

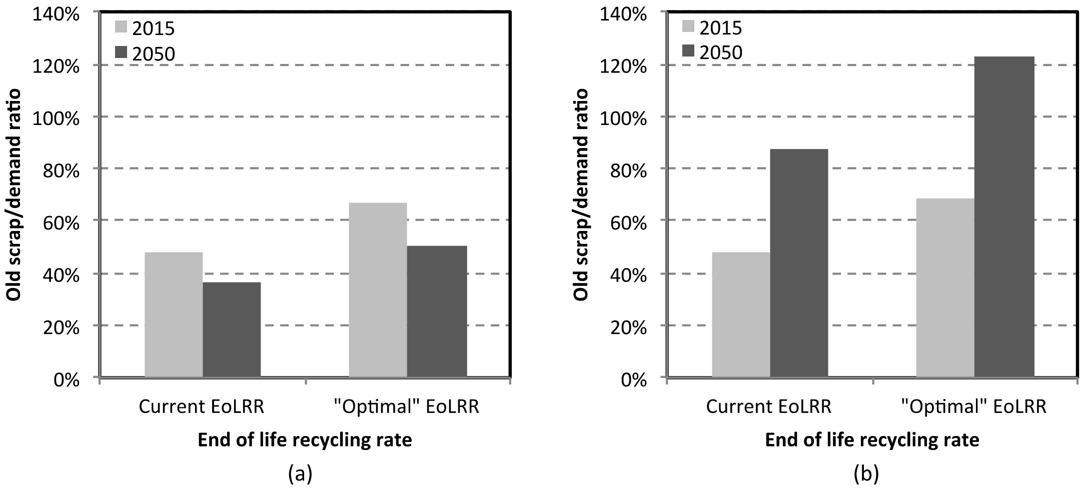

Figure 3: Recyled copper as fraction of total copper demand in the EU-28 in 2015 and 2050 for Market First (a) and Equitability First (b)

In terms of environmental implications, the results confirm that recycling can be significant in reducing primary material demand and the environmental impacts associated to virgin ore extraction and processing.

The greatest energy savings result for a EU-28 based on resource efficiency (e.g., enhanced recycling of post-consumer scrap, energy efficiency improvements in copper production, greater shares of renewable energy sources employed in electricity production), the effects of which are maximized in the EF scenario.

Interesting to note, in case of “optimal” EoLRR EF models surpluses of copper old scrap compared to the total demand, the recycling of which requires energy supplements. However, these energy increments are marginal compared to the energy savings offset from primary copper supply (Figure 4).

Potentials for reducing GHG emissions through recycling follow the same order. Putting the results in the context of the global climate challenge and assuming that each industrial sector must contribute proportionally to the 2°C target, we estimated that a world that follows the EF dynamics will likely fulfil the required reduction for GHG emissions at 50% below 2000 levels.

In contrast, the modest contribution of domestic recycling in light of the dramatic increase of future copper demand modelled by the MF scenario will determine an increase of 240-280% of the GHG emissions at 2000 levels.

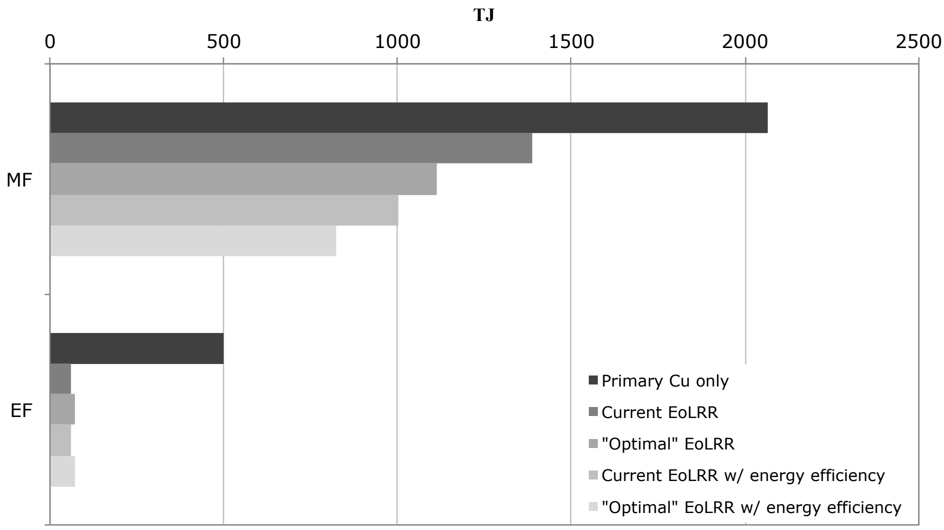

Figure 4: Energy requirements for copper supply to the EU-28 in 2050

4 Conclusions

The study constituted the first work integrating complementary life cycle thinking approaches such as MFA, LCA and scenario analysis to explore the future copper demand and supply from a Euro-centric perspective. The results can provide a foundation for complementary research lines including criticality assessments (EC, 2017), economic evaluations and environmental analysis (ICA, 2018) associated with the copper value chain.

Although the scenarios considered are not absolute predictions, but only a subset of the possible futures, the results demonstrated that secondary copper sources could cover a substantial part of the domestic demand if EoL recycling is adequately strenghtened.

However, the current recycling capability seems not enough to tackle the challenge of ensuring access to essential resources to the European copper industry while preserving the natural capital and mitigating climate change. Particularly, whether the world is expecting us is dominated by the current patterns of resource production and consumption.

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Multifunctional agriculture and LCA: a case study of tomato production

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Abstract

Agricultural activities are not limited to a food and fibre production role, but they have a multifunctional character, being also able to provide additional services to society. These services are a source of supplementary value, either for the farm itself or for the whole society and are defined Ecosystem serivices. However, when environmental analysis such as Life cycle Assessment (LCA) are performed on agricultural productions, although these additional services contribute to create economic value, they are often left out of the analysis, focusing on the physical output of the production process. In this work an economic allocation to deal with the multifunctional nature of a tomato production will be applied to the results achieved by the LCA study carried out in the Traditom project (www.traditom.com).

1 Introduction

Agriculture for a long time has been intended to serve two purposes: food and fibre production (OECD, 2009). However, although it was often out of the human perception, agriculture was carrying out also other functions than those for which it was meant to exist and still today they are observable in many agricultural activities. This capacity of agriculture to provide different functions can thus be referred to as multifunctionality. Beside these opportunities that may arise from agricultural activities, there is a number of natural mechanisms that can be activated and supported by agriculture (in particular by some kind of agriculture). These can be defined Ecosystem Services (ES), i.e. "benefits people obtain from ecosystems" and let additional utility arise from agricultural activities (Braata and Groot, 2012). Pollination and the protection from floods ensured by a healthy soil are examples of ecosystem services and they can both be supported by conscious ways of doing agriculture and foster agriculture itself. In the last decades environmental sustainability has become an increasingly discussed concept in all the fields of human activity and agriculture is not an exception. Environmental impacts associated to production processes can be assessed in several ways, following different logics and consequently with many tools. One of the most used tools is Life Cycle Assessment (LCA). Although LCA is generally considered a reliable and effective tool to describe the environmental effects of production processes, when applied to agricultural activities it faces some limitations, as it is not able to catch all the substantial aspects previously cited. As a consequence, there is some economic value coming from these activities that does not receive any counterpart among the environmental impacts, thereby leaving all the burden on the physical product. This mechanism, beside not being correct from a logical point of view, very often ends up rewarding production processes with high yields and disadvantages those with low yields, even if obtained through more sustainable practices. Indeed, the formers will allocate the total impact on a wider amount of products, assigning to the functional unit a lower burden. To get more into detail, this is exactly what happens when intensive and extensive production are compared: the latter often performs worse than the former in terms of LCA. In extensive agriculture are included many organic and local typical productions, so those that usually have a deeper connection with the territory and are more prone to respect nature end up performing worst in LCA, which seems to be a contradiction (Kiefer et al., 2015). Hence, this work aims to develop a simple framework that, although not exhaustive and precise in figures yet, includes multifunctional agriculture, ecosystem services and LCA, in order to show how they can all be brought together to assess the environmental impacts associated to tomatoes production. This issue can be faced with the inclusion in the assessment of the additional functions carried out by the agricultural systems, which are commonly more prominent in extensive cultivations. The argument of this work is that this classical LCA approach should be overtaken, to allow other functions to be considered in the assessment and, by doing so, allocating the environmental burden of the agricultural activity to a more comprehensive FU, to give a fairer description of the environmental perfomances of different product in order to better support decision making in the sustainability field.

2 LCA of tomato production: the case study of the Traditom project

The LCA study, representing the starting point for this methodological attempt, has been carried out as a part of Traditom project, funded by the Horizon 2020 programme (www.traditom.eu). Its purpose is to promote the genetic diversity of traditional tomato varieties and prevent their replacement with high-yield and typically lower-quality ones by increasing their resilience. LCA studies have been carried out on four tomatoes varieties out of the hundreds considered in the project: a Spanish traditional 'da serbo' variety (de Penjar D'Alcalà De Xivert tomato) and an Italian traditional 'da serbo' variety: Piennolo del Vesuvio tomato, both distributed to local markets; an Italian traditional variety (Pomodoro di Sorrento) reaching supermarket distribution and a Spanish variety (Palamós tomato), commercialized by Conca de la Tordera cooperative, which represents a modern production scheme. The goal of the studies has been to assess the environmental impact of tomatoes production in order to identify environmental hot spots. The study is addressed to the Traditom partners, who can benefit of the application of LCA to four of the investigated tomatoes varieties and integrate the project results with product related environmental information. The system boundaries of the studies have been set from cradle to gate of the farm. The functional unit is 1 kg of tomatoes ready for commercialization. This means that the inventory has been calculated considering the cultivation yields of the products and the discard generated during the harvesting and storage processes (35% for Piennolo, 20% for de Penjar D'Alcalà De Xivert tomato, 15% for the Pomodoro di Sorrento and 30% for the Palamós Conca de la Tordera tomato). For the impact assessment, the

ILCD (International Life Cycle Data System) *method version 1.09, recommended by the European Commission, EU-27 (2010) normalization factors* have been used. The results of the LCA studies presented in this document will be discussed only for the categories of the ILCD method considered robust and reliable by the Joint Research Centre document and ranked with a first (I) or second (II) level in the classification table of the Recommendations for Life Cycle Impact Assessment in the European context, ILCD Handbook (European Commission, 2011). The LCA study has been carried out in compliance with the 14040 and 14044 ISO standards (ISO, 2006) and the model has been built through the support of the LCA software GaBi TS and the Ecoinvent 3.1 database, for the secondary data modelling.

Table 1: Normalization results

Impact categories	Palamos Conca de la Tordera	Piennolo del Vesuvio	Pomodoro di Sorrento	de penjar D'Alcalà de Xivert
Acidification	1.07E-05	9.51E-05	2.54E-05	1.56E-04
Climate change	8.82E-06	4.01E-05	9.94E-06	5.46E-05
Eutrophication	2.13E-05	1.35E-04	3.54E-05	2.10E-04
Ionizing radiation	5.22E-06	4.79E-06	3.11E-06	2.08E-05
Ozone depletion	4.30E-07	1.57E-06	3.49E-07	4.78E-07
Particulate matter	1.00E-05	4.29E-05	1.43E-05	6.03E-05
Photoc.ozone form.	7.27E-06	1.99E-05	6.88E-06	1.60E-05
Resource depletion	5.31E-05	8.21E-05	1.94E-05	3.89E-05
Total impact	**1.17E-04**	**4.22E-04**	**1.15E-04**	**5.57E-04**

In Table 1 and Figure 1 an overview of the normalization results is proposed. All the results reported are aimed at highlighting the strict dependency of the impacts generated to the yield (inversely proportional). Looking at the very condensed information reported in the last row of Table 1, we can state that traditional varieties locally distributed (de Penjar D'Alcalà de Xivert tomato and Piennolo del Vesuvio tomato) generate higher overall environmental impacts than more widely distributed varieties (Palamos tomato and the Pomodoro di Sorrento tomato).

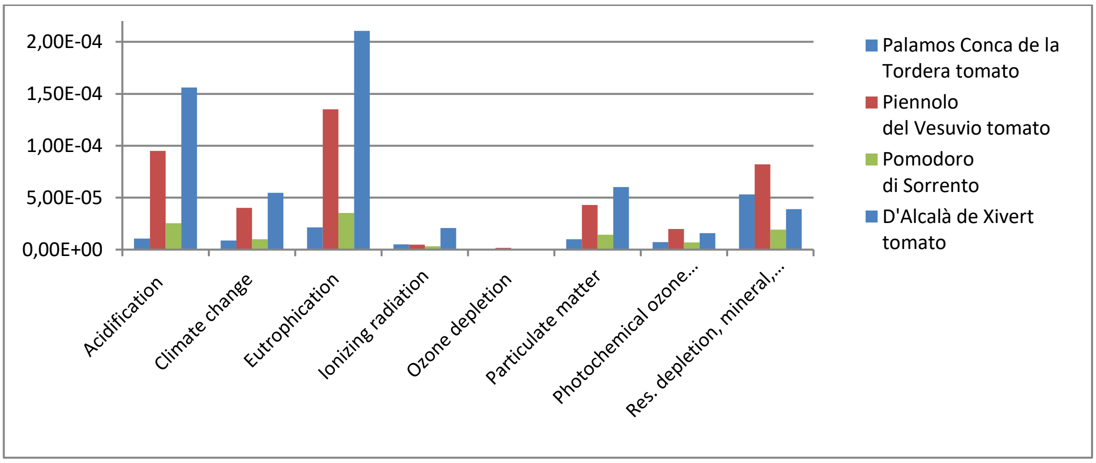

Figure 1: Graph of the normalization results

Both between the Palamos tomato and the Pomodoro di Sorrento (1.17E-04 vs 1.15E-04) and between de Penjar D'Alcal de Xivert tomato and the Piennolo del Vesuvio tomato (5.57E-04 vs 4.22E-04) there is a slight difference in this aggregated indicator (weighting factor set equal to 1). Looking at the contribution of the different impact categories to the environmental impact generated, all the tomato productions analysed show a high relative contribution in Eutrophication (for simplification purposes, the three eutrophication impact normalised values have been summed up to obtain a unique value), Acidification and Resource depletion. The Piennolo del Vesuvio tomato and de Penjar D'Alcalà de Xivert tomato register also a quite high contribution of the Global warming potential. All the results are directly related to the low yield of the traditional locally distributed tomato varieties (de Penjar D'Alcalà de Xivert tomato and Piennolo del Vesuvio tomato, respectively equal to 30 tons/ha and 16 tons/ha) compared to the 115 tons/ha yield of the Palamos tomato and the 100 tons/ha of the Pomodoro di Sorrento. The correlation between high impacts and low yield is a key aspect for a correct interpretation of the results. In general, literature studies on LCA of tomato production report a wide variation in the environmental impacts of products from extensive and intensive agriculture, which can be explained by yield differences, farmer's management choices and inaccurate modelling of specific characteristics of the studied system. For example, some authors found that estensive and organic farming can have higher impacts per unit of product, due to lower production yield (Tuomisto et al., 2012). A direct correlation between agricultural intensity and environmental performance per hectare was found for tomato production (i.e. intensive crops have higher environmental impact per hectare), whereas an inverse correlation was found between extensive crops and environmental impacts (i.e. extensive crops have higher impact per kg of product) (Hayashi, 2005). However, the assessment, for example, of organic farming is a complex issue, and several parameters can affect the final results (Cellura et al., 2012).

3 Multifuctional agriculture and economic allocation

Multifunctional agriculture (MFA) is a concept strongly related to sustainable agriculture, in that the latter provides the framework to describe and evaluate all the environmental, economic and social aims connected to the former (Renting et al., 2009). Although there is no unique definition of sustainable agriculture, Harwood (1990) described it as "an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species". According to a literature analysis made by Van Huylenbroeck et al. (2007), MFA refers to four types of function: i) green functions: landscape and biodiversity management, maintenance of animal welfare, improvement of nutrient recycling; ii) blue functions: water resource management and flood control; iii) white functions: food security and safety; iv) yellow functions: vitality of rural areas, rural amenities, historical and cultural heritage, regional identities and agro-tourism. Economic allocation shows a potential for the allocation of impacts in MFA, due to their intangible features. Economic allocation has been used by Ripoll-Bosch et al. (2013), Kiefer et al. (2015) and Salvador et al.

(2016), who showed that it can be a powerful mean to include ES and multiple functions of agriculture in LCAs of farming activities. However, to perform an economic allocation of the impacts on multiple outputs, each of these must be economically valuated. Particularly, the considered outputs are the physical product (or products) and the ES provided by the farming activities. To valuate the physical product is not a major issue, as market prices (adjusted for market oscillations) are already available to be used; on the contrary, to obtain a value for the ES is not so straightforward. The approach used by Ripoll-Bosch et al. (2013), Kiefer et al. (2015) and Salvador et al. (2016) has been to assign to the ES the value of the payments acknowledged to farmers established by the Common Agricultural Policy. The rationale behind is that these values can be used as proxies of the willingness to pay of society for those services.

4 Economic allocation of additional functions of the Piennolo del Vesuvio tomato production

In order to test the application of an economic allocation to some of the additional functions fulfilled by an extensive tomato production, the case study of the Piennolo del Vesuvio, one of the tomatoes investigated in the Traditom project, has been used. The case study considered in this work is an Italian production of tomatoes located in the Parco Nazionale del Vesuvio, in the Campania region. Since the Piennolo tomato is recognised as a D.O.P. product, its production is subject to procedural guidelines, and it can be considered an extensive production. The Piennolo tomato plantations cover an area of approximately 480 ha, with a total annual production around 4,000 t and a yield oscillating between 6,000 and 16,000 kg/ha.

The demand for this product is constantly high and an increase in the supply is likely to be well accepted by the market; yet, the complex orographical conformation of the area represents a hurdle for the development of the supply. The selling price ranges from 8 to more than 10 €/kg, which makes it difficult to estimate average revenues. Since the farm is located in a National park, farmers have the responsibility to manage portions of the park, thereby protecting the biodiversity and promoting local networks (Brookshire and Coursey, 1987). Moreover, in this specific area, where eco-criminality is an alarming issue, farmers also have the role to reduce the possibilities that this phenomenon expands even more (Legambiente Campania, 2015). The analysed cultivation is clearly multifunctional, in that, beside providing tomatoes, also provides ES such as the ones above mentioned (among others). Thereby, according to the main idea of this work, the environmental impacts generated by this cultivation should not only be attributed to its physical output (tomatoes), but should be rather shared with the ES it provides, performing an economic allocation of the impacts between the physical output and the ES. A system expansion, on the other hand, would require to expand the FU to include both the physical output and the ES. Although this would be a practicable method, a major shortcoming is that it reduces the comparability among cultivations. For these reasons, an economic allocation that takes into account the value of ES seems, in this case, to be a reasonable way to deal with multifunctionality in

LCA. In order to perform an economic allocation of the impacts on multiple outputs, an economic value must be assigned to each of these. Yet, at the moment any attempt to valuate the ES would intrinsically and inevitably bring a lot of uncertainty (Hou et al., 2013). On the one hand, because identifying the services provided by a specific cultivation requires quite strong assumptions; on the other hand, it is difficult to determine at which level the services are provided by the cultivations and, as a consequence, to attribute them an economic value. Thus, instead of using directly the value of ES, it is more practical to refer to the value of subsidies to agriculture. These are granted to farmers with the underlying assumption that, by adopting some specific agricultural practices or carrying out agricultural activities in particular circumstances, some ES are generated. In particular, the reference for the case study considered in this work will be the Rural Development Programme 2014-2020 of the Campania region (Programma di Sviluppo Rurale Regione Campania 2014-2020). Among the various measures included in the plan, some are suitable to be applied to the considered Piennolo tomato cultivation. In Table 2 are listed the ones considered in this work.

Table 2: Value of subsidies granted by the Campania region PSR

Measure	**Monetary value (€/ha)**
Cultivation and sustainable cultivation of local vegetable varieties endangered of genetic erosion	600
Conservation of local genetic resources in order to protect biodiversity	600
Compensative payment for areas subject to natural constraint	200
Compensation for areas with specific constraints	200
Total	1,600

The final step of the procedure is to allocate to these practices a share of the potential impacts estimated with the LCA. This will be carried out using the market value of 1 kg of tomatoes and the value of the subsidies computed in Table 2, the conversion rate would then be the following:

10,400 kg of tomatoes : *1,600 € of subsidies = 1 kg of tomatoes : 0.15 € of subsidies*.

In order to perform an economic allocation of the impacts, also the kg of product has to be assigned a monetary value. This is obtained from the market price, which for the Piennolo tomato is quite high, standing around 8 to over 10 €/kg. For the purpose of this work, a price of 8 €/kg has been chosen. Adding to this price the value of the subsidies, the total value of 1 kg of production raises up to 8.15 €. Applying this procedure, the results vary as shown in Table 3.

Table 3: Normalization results with the economic allocation applied

Impact categories	No allocation	With economic allocation			
		Piennolo		Subsidies	
Acidification	9.51E-05	9.33E-05	98.15%	1.76E-06	1.85%
Climate change	4.01E-05	3.94E-05		7.42E-07	
Eutrophication	1.35E-04	1.33E-04		2.50E-06	
Ionizing radiation	4.79E-06	4.70E-06		8.86E-08	
Ozone depletion	1.57E-06	1.54E-06		2.90E-08	
Particulate matter	4.29E-05	4.21E-05		7.94E-07	
Photoc.ozone form.	1.99E-05	1.95E-05		3.68E-07	
Resource depletion	8.21E-05	8.06E-05		1.52E-06	

The economic allocation of the potential environmental impacts to the two functions of the system, the physical output production and the ES provision, leads to a reduction of the 1.85% of the burdens allocated to the tomato production. It is critical to point out that the objective of this allocation is not simply to lower the environmental impacts attributed to the tomato production, but rather to highlight that these are related to two different functions of the productive system and thereby both should be allocated a share of the total impacts. In this specific case study, the reduction of the impacts attributable to the physical output is relatively low and this may be due to multiple reasons. First of all, the Piennolo tomato is a high-quality product and hence has a very high market price. Secondly, only a part of the ES provided by the cultivation has been included in the analysis.

5 Conclusion

This work has given an example of how to bring in the same framework the concepts of ES, MFA and LCA, showing how they can be connected each other. The ES provision has been considered as a function of the production system, thereby the ES supplied by the cultivation are actual outputs of the agricultural activities, worth to be assigned part of its environmental burden. This is particularly relevant for extensive cultivations, such as de Penjar D'Alcalà de Xivert tomato and the Piennolo del Vesuvio tomato examined in this work. These cultivations on one hand typically have lower yields, a feature that may penalise their environmental profile, but on the other hand they can supply higher levels of ES. In order to integrate the results of the LCA study of the Traditom project, the presented framework will be extended to the other tomato cultivation investigated, as wider test of its strenght and limitations. Of course the definition of all the ES provided by a specific agrofood product and their monetization is the key for a fair application of this approach in comparative studies. Moreover additional monetization approaches could be considered as feature development of the study. Nevertheless the framework described in this work can be included in the flourishing approaches emerging in order to reduce the distortion in the definition of the environmental profile of agrofood product generated by the Product Environmental Footprint methodology application, i.e. the additional information, also qualitative ones, required to complete the LCA results.

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Development of a method to integrate particular matter formation in climate change impact assessment

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Abstract

The concept of sustainability is nowadays one of the principal points for choices about global development and takes into account environmental, economic and social aspects. The published methods for sustainability assessment are different and have some methodological limits not yet solved: today the research field on LCSA (Life Cycle Sustainability Assessment) is differentiated on some aspects, from the definition of a methodology that consider together environmental, economic and social aspects, to the choice of adequate sets of assessment indicators. The present research focuses on an improvement proposal of an existing characterization method that allows to assess damage to Human Health (social characteristic), that actually do not take into account consequences of the respiratory problems due to the average temperature increase as a climate change phenomena (environmental characteristic).

1 Introduction

In the globalized word the concept of sustainability is one of the most discussed topics in an optics of worldwide future scenarios and developments. A consolidated sustainability assessment methodology that takes into account environmental, economic and social performances has not yet shared in the scientific community. Table 1 summarized an analysis made with the aim to check the aspects that should be improved for a development of LCSA approaches, where six critical areas have been individuated (for each analyzed publications, the red box represents topics that are relevant for aithors).

Table 1: Aspects to be improved for the development of LCSA methodology

	Topic					
Ref.	Effective communication and comprehensibility of the results	The role of LCC in LCSA	Development of S-LCA and integration inside LCSA	Sustainability assessment (calculation of indicators)	Double counting for some impact categories	Temporal dimension in the assessment
Ciroth et al., 2011						
Cinelli et al., 2013						
Jorghensen et al., 2013						
Zamagni et al., 2013						
Finkbeiner at al., 2010						
Ostemayer et al., 2013						
Vinyes et al., 2013						

One of the most relevant problems for LCSA is the definition of a well-defined sustainability methodology and specific sustainability indicators. Despite that existing assessment method allows to calculate damage to human health due to environmental impacts: Human Health indicator takes into account consequences of environmental impacts on a social dimension, and so could be seen as a coherent product performance indicator in a sustainability assessment optics. One of the most relevant environmental indicator is the “Climate Change” for its risks and effects on the social and economic sphere: one of the effects of the climate change is the global temperature rise, parameter that affects the particulate concentrations in the inhaled air. The air quality is one of the principal themes developed in all environmental policies, and particulate matters are one of the main responsible substances for the air quality degradation (Fuzzi et al., 2015). A literature research has underlined as health effects linked to climate change, in terms of respiratory problems, are not considered in the actual LCIA methods (Goedkoop and Spriensma, 2001; Goedkoop et al., 2013; Huijbregts et al., 2016, Joillet et al., 2003).

a. Research objectives

Actual LCIA model (Life Cycle Impact Assessment) for Human Helath damage are built basing on a top-down approch that consider four steps for the calculation of the damage starting from emissions: fate, exposure, effect and damage analysis (Hofstetter, 1998; Humbert et al., 2011). In particulate the “fate analysis” models the relathionship between emissions to air, surface water or soil and the exposure of humans to a contamination due to inhalated air. The aims of the study are to find formulas to estimate the relationship between temperature rise and pollutants concentration in the air and to improve the ReCiPe life cycle assessment method for the Human Health damage category assessment (Goedkoop et al., 2013), considering the changes of pollutants concentration in the air (that gives respiratory problems) due to temperature rise associated to climate change. At the end the applicability of the improved model is verified in a real LCA case study, choiced between the main sectors responible for PM emissions and impact on climate change: the transport sector.

2 Materials and methods

a. Effects of Climate change on human health damage assessment

The model is based on the definition of the following functions: $\Delta c_{pol,i} = f(\Delta T_x)$ and $\Delta HH=f(\Delta c_{pol,i})$ with ΔT_x=average temperature rise due to climate change, $\Delta_{cpol,i}$ =variation of concentration in inhaled air of pollutant “i” and ΔHH=variation of Human Health damage indicator.

i. Temperature scenarios (ΔT_x)

According with the IPCC scenarios (IPPC, 2014), considering a time horizon of 100 years and the theorem of the “marginality of impacts” (Heijungs et al., 1992; Heijungs, 1995), a temperature increase value of ΔT_x = 2°C (ΔT_2) has been considered in the research. Furthermore, a sensitivity analysis has been implemented considering other different temperature increase scenarios (with ΔT_1= 1°C;ΔT_3=3°C;ΔT_4=4°C and ΔT_5=5°C).

ii. Temperature-concentrations laws ($\Delta c_{pol,i}$=f(ΔT_x))

Primary data were not available, so these relationships have been found analyzing literature. Some studies confirmed the relationship between climate change, air quality, particulate matter formation and respiratory diseases but a unique and shared function do not exist for each of the pollutants considered in this analysis. Different formulas for the relationships come from environmental publications and results obtained are summarized in Table 2.

iii. The formulas ΔHH=f($\Delta c_{pol,i}$)

In this phase the so called "variation indexes" for each "i" substances (V-index$_i$) have been calculated, in the following way: a) Definition of $c_{i,\text{AVERAGE VALUE}}$ for each substance "i". These values, published from European Environmental Agency (EEA, 2015), are $PM_{2.5}$=25 μg/m³, PM_{10}=40 μg/m³ and O_3=120 μg/m³ in air in Europe; these are the substances considered in the study for availability of data; b) Calculation of V-index$_i$. These indexes have been calculated as follow, with the aim to quantify the absolute variation in air of pollutants linked to the variation of concentration ($\Delta c_{pol,i}$) due to ΔT_x:

$$\text{V-index}_i = \{[c_{i,\text{AVERAGE VALUE}} + (\Delta c_{pol,i} / \Delta T) * \Delta T_x] / c_{i,\text{AVERAGE VALUE}}\} - 1$$

c) Starting from the assumption that actual $c_{i,\text{AVERAGE}}$ values are due to the actual global emissions (including so the emissions coming from product inventories calculated from existing database considered in actual LCIA model), these indexes could be used to modified data inventories in LCA case study to calculate the variation in terms of mass of pollutant "i" that should be added to mass values from database to do new concentration levels ($c_{i,\text{AVERAGE VALUE}}+\Delta c_{pol,i}$). These pollutants mass variations (Δm_i) represent, for each substance "i", the absolute variation (in terms of emission in the air) that is responsible of the variation of concentration in air of the substance "i", caused by a temperature change. Mass variation is calculated as follow:

Δm_i = V-index$_i$ * m_i , where "m_i" is the value obtain from original life cycle inventory analysis of LCA study for each substance "i".

3 Results and discussion

The relathionship between ΔT_x and $\Delta c_{pol,i}$ are reported in Table 2.

Table 2: Relationship $\Delta c_{pol,i}$ /ΔT in the European scenarios

Substance «i»	Reference	Relationship $\Delta c_{pol,i}$ /ΔT (µg/m³K)
$PM_{2.5}$	Tai, 2012	(+/-)4
	Megaritis et al.,2014	(+/-)4
PM_{10}	Dias et al., 2012	1.4
	Carvalho,2010	(1-4)
Ozone	Doherty et al., 2012	(4.4-6.4)
	Carvalho,2010	(1-3)
	Jacob and Winner, 2009	(4-20)

As it is possible to see in many cases the results are a scenario represented by a range of values (both negative and positive) and not a punctual number, because the various assumptions that have been made in the different environmental studies. In this study for each pollutants "i" the highest and lower values founded for the relationships has been considered as representative, respectively, of "worst" and "best" scenarios.

To verify the applicability and effectiveness of the model on real LCA case studies three different scenarios must be studied:

a) "Base case" scenario: LCA study implemented considering ΔT_x = 0°C (ΔT_0); b) "Best Case" scenario: LCA study implemented considering a ΔT_x=ΔT_2 and the lowest V-index values of Table 3; c) "Worst Case" scenario: LCA study implemented considering a ΔT_x=ΔT_2 and the highest V-index values of Table 3.

Table 3: Reference data condidered in the upodating of the model

Substance «i»	V-index$_i$ value (Best case scenario)	V-index$_i$ value (Worst case scenario)
$PM_{2.5}$	-0.32	0.32
PM_{10}	0.050	0.20
Ozone (O_3)	0.017	0.33

The evaluation of the "best" and the "worst" cases allow to delineate a range of results that include all other intermediate values.

a. Case study: service transport by diesel lorry

The product system analyzed has been a service transport by a diesel lorry; the function of the product system is defined as "the transport of good in national and European places". The functional unit (FU) considered for the LCA study is the transport of 1 ton of goods for 1 kilometer of distance, expressed as 1 tkm. As reference value is considered a diesel lorry with an average consumption of 0.28 liters/km, considering an average load of 22.9 tons transported (Fedele et al., 2015). The processes included in the system boundaries are shows in Fig.1. The inventory data m_i of considered "i" pollutants basing on the FU are: $PM_{2.5}$=1.41E-05 kg/FU, PM_{10}=133E-05 kg/FU and O_3=6.60-05 kg/FU. Implementing the Recipe 2008 method, the result calculated for Human Health damage indicator, basing on the chosen FU, is 1.137 E-07 DALY. Considering a ΔT_2=2°C, Δm_i are calculated and results are reported in Table 4. Final results for the Human Health damage indicator are: 1,137E-07 DALY (base case), 1,118E-07 DALY (best case) and 1,156E-07 DALY (worst case).

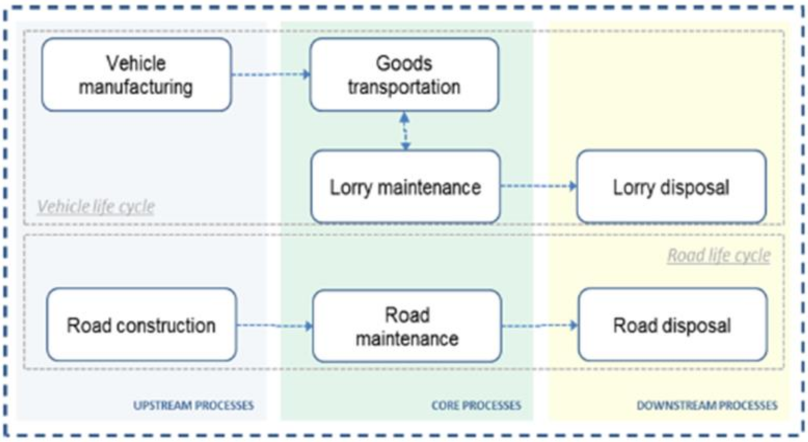

Figure 1: Service Transport by a diesel lorry: system boundaries

Table 4: Δm_i results for the best and worst scenarios

Substance «i»	**Δm_i** (kg/ FU)	**Δm_i** (kg/ FU)
Particulate matter ($PM_{2.5}$)	- 4.50E-06	4.50E-06
Particulate matter (PM_{10})	6.63E-07	2.65E-06
Ozone (O_3)	1.12E-09	2.18E-08

Considering all results obtained for the different temperature increase values analyzed and taking into account both “best” and “worst” scenarios, the follow figure shows the results of the sensitivity analisys. The dashed “orange” line represents the base scenario.

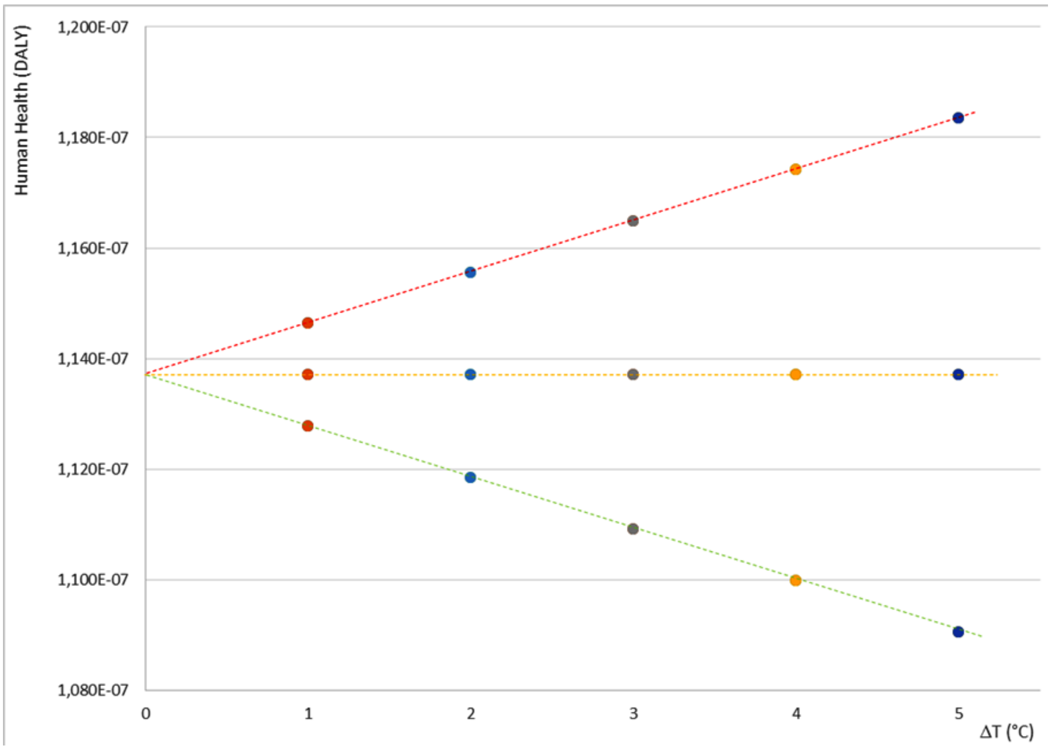

Figure 2: Results of the sensitivity analysis

4 Conclusions

Sustainability has become a main topic in the international development policies and should not takes into account only environmental aspects, but also social and economic burdens linked to the life cycle of products and services developed in the global market. Despite it, sustainability assessment is a field that needs yet improvements to make available for stakeholders and companies simply and concrete instruments for an effective and useful analysis. In line with this contest and with the actual mainly international policies trends, that gives even more focus on the climate change, air quality and human health quality, the research aimed to improve existing characterization model to assess effects of climate change (in particular temperature rise) on concentrations of particles in the air (e.g. particular matter) that cause respiratory problem and have consequences in terms of Human Health damage. The model proposed from this study must be collocated as an intermediate step through a complete sustainability evaluation, taking into account specific environmental and social problems.

Starting from a deepened environmental literature research only data on particulate matters $PM_{2.5}$ and PM_{10}, and Ozone are been taking into account. Other substances (e.g. nitrogen oxides) are not been analysed for lack of data. Moreover, only these primary emissions are been considered but some studies underlined also the great relevance of secondary emissions on the respiratory problems that affect human health. Secondary particles come from chemical reactions of gaseous and are formed in the air through primary pollutants and precursor. About the laws "pollutant concentrations"-"temperature increase" these are built interpolating published values and graphs inherent to European and national data. To better define these functions a greater number of studies could be useful, always considering that for the life cycle studies specific localized data are need. These values must be chosen in consideration with the geographical and also temporal boundaries of the life cycle analysis where these data will be used. In this research the data and laws utilized are valid only for European context, in which case studies have been implemented. Another aspect that requires attention is the choice of the average concentrations of pollutant in the air. The method proposed in this research takes into account average concentrations as an assumption, basing on data published by the European Environment Agency. It is opportune to underline that the values considered are average data although is well know how particulate concentrations on the air could change during the annual seasons but also within a single day. The choice to considered average values is in consideration to the fact that the model implemented is not a dynamic model, but in line with the implementation of an LCA analysis, is based on real, preferably primary, but average data. The updating to the existing characterization method is concentrated in the particular step of fate analysis, the first one in the entire damage analysis model. Following developments of research could be focalized attention also on exposure, effect and damage analysis. Applying this model with the aim to analyze damage to Human Health in the existing LCA software a practitioner or a company could analysed data and make correct interpretation, basing in particular on the gravity analysis. This is a procedure that identifies those data having the greatest contribution to the indicator result and so these items may then be investigated with increased priority to ensure that sound decisions are made, in an optical of product sustainability product or service development.

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