CENTER FOR INDUSTRIAL ECOLOGY

2nd DISCUSSION FORUM ON

INDUSTRIAL ECOLOGY AND LIFE-CYCLE MANAGEMENT

Proceedings

UNIVERSITY OF COIMBRA
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PREFACE

Coimbra, March 2015

This book contains abstracts and short-papers of the **2nd DISCUSSION FORUM ON INDUSTRIAL ECOLOGY AND LIFE-CYCLE MANAGEMENT**, held on March 5-6 2015, in Coimbra, Portugal.

This discussion forum is organized by the **Center for Industrial Ecology (CIE)** at the University of Coimbra. It addresses current research in Industrial Ecology and Life-Cycle Management. The forum brings together faculty, researchers and doctoral students to discuss methodological developments and extended approaches in Life-Cycle Assessment (LCA). Applications to bioenergy, electric vehicles, buildings and urban environment, among others, are also addressed. The forum includes two keynote lectures, by **Prof. Roland Clift** and **Prof. Paulo Ferrão**, and five working sessions.

Like the first edition, we hope that this discussion forum will be a success, and we trust that future editions will be recognized as important technical and scientific events. We are extremely grateful to all our colleagues, authors and everyone else involved in organizing and promoting the event, namely Prof. Roland Clift, Prof. Paulo Ferrão, and all the session chairs. Lastly, we also thank ADAI-LAETA and the Department of Mechanical Engineering of the University of Coimbra for hosting the Forum.

Fausto Freire and the Organizing Committee

ORGANIZATION

CHAIRPERSON

Fausto Freire

ORGANIZING COMMITTEE

Carla Caldeira

Carla Rodrigues

Érica Castanheira

Joana Bastos

João Malça

Rita Garcia

VENUE

The Discussion Forum takes place at the Department of Mechanical Engineering, Polo II Campus, University of Coimbra.

REGISTRATION DESK

The registration desk is located at the venue (at the entrance of the auditorium) and will be open as follows:

- Thursday, March 5th, 10:00 – 13:45
- Friday, March 6th, 8:45 – 9:15

LUNCH & COFFEE-BREAKS

The cost of lunch is included in the registration fee (both days). Lunch will be served at Casa da Pedra, Polo II Campus, and coffee-breaks near the main auditorium of the Department of Mechanical Engineering.

PROGRAM

Thursday, March 5th

10.00	Registration	
10.30	**Opening Session**	
10.45	**Introduction to the Energy for Sustainability Initiative**	**António G. Martins**
11.00	***KEYNOTE LECTURE*** **LIFE CYCLE SUSTAINABILITY ASSESSMENT: EXTENDING THE SCOPE OF LCA**	**Roland Clift** ***University of Surrey*** **Chair: Fausto Freire**
12.00	**Introduction to the sessions**	**Fausto Freire**
	Session 1 - Extended LCA approaches I	**Chair: Luís Dias**
12.10	Building an impact assessment method for green water flows	Paula Quinteiro *(University of Aveiro)*
12.30	Virtual water transfers via the power grid: water embodied in electricity trade between regions	Elliot J. Cohen *(Columbia University)*
12.50	Definition of mid-point and end-point categories in social life cycle assessment	Miguel Simões *(University of Lisbon)*
13.10	Environmental and social impacts of sugarcane production in São Paulo considering different harvesting systems	Chongyang Du *(University of Coimbra)*
13.45	**Lunch**	
	Session 2 - Bioenergy	**Chair: Érica Castanheira**
15.00	LCA of the biodiesel production in Spain driven by optimization criteria	Neus Escobar *(Polytechnic University of Valencia)*
15.20	Do methodological choices really matter in the life cycle assessment of bioenergy systems?	Miguel Brandão *(IEA Bioenergy Task 38)*
15.40	Energy requirements for the continuous biohydrogen production from spirogyra biomass in a sequential batch reactor	Joana Ortigueira *(LNEG)*
16.00	LCA of rapeseed methyl ester addressing uncertainty	João Malça *(Polytechnic Institute of Coimbra)*
16.30	**Coffee break**	
	Session 3 - Extended LCA approaches II	**Chair: Luiz Kulay**
17.00	Supply chain optimization accounting for life cycle assessment – the impact of product environmental footprint	Bruna Mota *(University of Lisbon)*
17.20	Cost optimization of biodiesel blends of waste and virgin oil addressing feedstock compositional variability and life cycle impacts	Carla Caldeira *(University of Coimbra)*
17.40	Improvement of the toxicological assessment based on limits imposed by REACH regulation	Carlos Ferreira *(University of Coimbra)*
18.00	The fossilization of the Brazilian electric matrix under the life-cycle assessment perspective	Ricardo Dinato *(Getúlio Vargas Foundation)*
18.30	**Closing remarks**	**João Malça**

Friday, March 6th

8.45	**Registration**	
9.00	***KEYNOTE LECTURE*** **URBAN METABOLISM**	**Paulo Ferrão** ***University of Lisbon*** **Chair: Carlos H. Antunes**
	Session 4 - Urban systems	**Chair: José Costa**
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10.20	Integrating user transportation in the life-cycle assessment of buildings	Joana Bastos *(University of Coimbra)*
10.40	A dynamic fleet-based life-cycle approach to assess greenhouse gas emissions from electric vehicle adoption	Rita Garcia *(University of Coimbra)*
11.00	**Coffee break**	
	Session 5 - Forest and agri-food systems	**Chair: Luís Arroja**
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11.50	Synergies for decentralized biogas and fertilizer production	Luis Ferreira *(University of Lisbon)*
12.10	Barriers and opportunities of waste valorisation in rice agroindustry	Nuno Lapa *(Nova Univ. of Lisbon)*
12.30	Integrated simulation-optimization approach for ecodesign of food manufacturing processes	Alicja Sobantka *(French National Institute for Agricultural Research)*
12.50	End-of-life management strategies for natural cork stoppers through life cycle assessment	Martha Demertzi *(University of Aveiro)*
13.30	**Closing remarks**	**Roland Clift and Paulo Ferrão**
13.45	**Lunch and networking**	

KEYNOTE LECTURE: Prof. Roland Clift

Life cycle sustainability assessment: Extending the scope of LCA

Life Cycle Assessment is well established as a tool for estimating the environmental impacts (usually negative) associated with providing a product or service. However, to provide a tool for assessment of sustainability, LCA needs to incorporate other impacts beyond environmental. Based on the "three pillars" model of sustainability, life cycle sustainability assessment must consider economic and social impacts, both negative and positive. Environmental and economic impacts are already considered together in some forms of Value Chain Analysis but incorporating social impacts within life cycle assessment is more problematic. The UNEP/SETAC Guidelines approach this problem by attempting to record social impacts within the same framework as environmental impacts, but this approach is by no means universally accepted.

This talk will outline some of the problems which have been encountered in extending the general LCA approach to social impacts. Some fundamental questions are raised:

- Is it possible to apply an approach derived from risk estimation without empirical validation of outcomes?
- Can impact pathways be identified?
- Can Life Cycle Sustainability Assessment be carried out without a normative discussion on social objectives?

Professor Roland Clift

Emeritus Professor of Environmental Technology and founding Director of the Centre for Environmental Strategy at the University of Surrey; visiting Professor at Chalmers University, Sweden; Adjunct Professor at the University of British Columbia, Canada; past President and Executive Director of the International Society for Industrial Ecology; past member of the UK Royal Commission on Environmental Pollution, Ecolabelling Board and Science Advisory Council of the Department of the Environment, food and Rural Affairs (DEFRA). Prof. Clift's research is concerned with system approaches to environmental management and industrial ecology, including life cycle assessment and energy systems.

KEYNOTE LECTURE: Prof. Paulo Ferrão

Urban Metabolism

Urban metabolism provides a framework for analyzing the technical and socioeconomic processes that occur in cities. This includes assessing the inputs, outputs, and stores of energy, water, and materials of an urban area. The concept is grounded on the analogy with the metabolism of living organisms, as cities can transform raw materials into infrastructure, human biomass, and waste.

The material dimension of the economic activities in cities presents an opportunity for analysis. While the material dimension is only one component of understanding the metabolism of cities, it allows the development of reliable metrics for the assessment of urban material flows and stocks. The consumption and transformation of materials is crucial for assessing the sustainability of a city in terms of efficient functioning, resource availability, and environmental protection.

Urban metabolism concepts and its associated toolset will be discussed together with a set of international case studies, that demonstrate how urban metabolism can contribute to promote urban sustainability.

Professor Paulo Ferrão

Was born in Lisboa in 1962, graduated in Mechanical Engineering in 1985 at IST-Instituto Superior Técnico of the Technical University of Lisbon, where he obtained the prize for the best student of the year in his field. He obtained a Master in Heat Transfer and Conversion in 1998 and a PhD and "habilitation" in Mechanical Engineering at IST in 1993 and 2004, respectively. He concluded a graduation in Strategic Management in the Context of Innovation at ISCTE in 1988.

He is the National Director of the MIT-Portugal Program, the major international partnership on Science and Technology in Portugal, in the field of Engineering Systems, and he is also the focus area lead for Sustainable Energy Systems. He is Full Professor at IST. He is co-founder of IN+, Center for Innovation, Technology and Policy Research.

His scientific career has evolved within the areas of "Laser diagnostics for turbulent combustion systems", "Analysis of Energy Systems" and "Industrial Ecology", where the principles of Thermodynamics have been complemented with social and economic fundamentals in order to promote the analysis of the complex systems that characterize the major issues that are relevant for sustainable development of modern societies. He has been active on the area of "Sustainable Cities", where he is publishing a book at MIT-Press on "Sustainable Urban Systems" co-authored with John Fernandez from MIT.

WORKING SESSIONS

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Building an impact assessment method for green water flows
Paula Quinteiro, Ana Cláudia Dias, Bradley Ridoutt and Luís Arroja

Virtual water transfers via the power grid: water embodied in electricity trade between regions
Elliot J. Cohen and Anu Ramaswami

Definition of mid-point and end-point categories in social life cycle assessment
Miguel Simões, Ana Carvalho, Carlos Lucas de Freitas, Ana Paula F.D. Barbosa-Póvoa

Environmental and social impacts of sugarcane production in São Paulo considering different harvesting systems
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Do methodological choices really matter in the life cycle assessment of bioenergy systems?
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Energy requirements for the continuous biohydrogen production from spirogyra biomass in a sequential batch reactor
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Session 5 - Forest and agri-food systems

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Synergies for decentralized biogas and fertilizer production
L. Ferreira and E. Duarte

Barriers and opportunities of waste valorisation in rice agroindustry
C. Carvalho, N. Lapa and F. Pinto

Integrated simulation-optimization approach for ecodesign of food manufacturing processes
A. Sobańtka, C. Azzaro-Pantel G. and Gésan-Guiziou

End-of-life management strategies for natural cork stoppers through life cycle assessment
M. Demertzi, A. Dias and L. Arroja

BUILDING AN IMPACT ASSESSMENT METHOD FOR GREEN WATER FLOWS

Paula Quinteiro[1]*, Ana Cláudia Dias[1], Bradley Ridoutt[2] and Luís Arroja[1]

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Keywords: *Eucalyptus globulus*, green water flows, life cycle assessment (LCA)

Abstract The growth of short rotation forestry is largely dependent on local precipitation. The portion of rainwater used by soil and vegetation that is evaporated or transpired back to atmosphere (green water flow) contributes to the regulation of the hydrological cycle as well as to regulation of biomass/food production. Therefore, when assessing the potential environmental impacts of forestry and agriculture resulting from changes in green water flows due to land use, the interactions between forest plantations/crops and freshwater should be considered at both green water/soil and green water/atmosphere interfaces. The interface green water/soil analyses how a change in green water use affects the regional long-term availability of surface blue water, whereas green water/atmosphere focus on how land use affects the evapotranspiration that is recycled to the atmosphere, and then, the precipitation that returns to the regional terrestrial ecosystem. Despite the crucial relevance of green water flows for the long-term sustaining ecosystem services, a life cycle assessment (LCA) method focusing both on terrestrial green water flows and on reductions of surface blue water production caused by green water deficits, due to land use remains a substantial gap

This study proposes a LCA method for assessing impacts on terrestrial green water flows (TGWI) and addressing reductions of surface blue water (river) production (RBWP) – caused by reductions of surface runoff – due to a land use-production system. The method considers the effective net green water flow at life cycle inventory phase, allowing the consideration of two alternative reference land uses: 1) quasi-natural forest; and 2) grasslands/shrublands. The method also proposes regional- and species-specific characterisation factors at life cycle impact assessment phase. The applicability of this method is illustrated by using *Eucalyptus globulus* stands located in Portugal. The TGWI and RBWP results have shown that, depending on the alternative reference land use, different impacts on terrestrial green water flows and on surface blue water production are obtained. Moreover, the method supports the sustainable freshwater use of forestry demystifying the idea that biomass production and forest-based products present a huge consumptive use of green water, leading to a severe depletion of soil moisture, groundwater and surface resources.

1. INTRODUCTION

Over the last years, methodological efforts have been carried out with the purpose of including water-related issues in life cycle assessment (LCA). Studies have been addressing water abstraction and human appropriation [1-3], the potential impacts of blue water use on ecosystems [3,4] and water pollution linked to the discharge of eutrophying, acidifying and ecotoxic compounds into freshwater systems [5,6]. However, less attention has been paid to green water use and green water flows. Green water use refers to precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. It also refers to the rainwater incorporated into harvested crops or forest biomass. Green water flow refers to the portions of green water used by soil and vegetation that is evaporated or transpired. At the interface between green water/atmosphere, changes in ET have an influence on terrestrial ecosystem quality both on a regional (watershed or sub-watershed) and continental scale [7,8]. At the interface between green water/soil, the increase of green water flows to the atmosphere, due to direct green water use caused by agriculture and forest practices, leads to reduced regional surface runoff, affecting surface blue water production. This can reduce the regional long-term blue water availability for ecosystem services. A decrease of green water flows can lead to more water available for runoff, which may disturb stream flows and cause groundwater table lifting.

This study proposes a LCA method for assessing impacts on terrestrial green water flows (TGWI) and addressing reductions in surface blue water (river) production (RBWP) caused by reductions in surface runoff due to a land-use production system. This method encompasses the life cycle inventory, which accounts for green water flows recycling into the atmosphere due to specific types of land use, and proposes regional- and species-specific characterisation factors (CFs) in the life cycle impact assessment phase. The applicability of the proposed method is illustrated by using *Eucalyptus globulus* stands located in Portugal.

2. MATERIALS AND METHODS

2.1. Life cycle inventory

The net green water flow inventory is performed taking into account the basin internal evaporation recycling ratio (BIER) (adimensional) [7], i.e. the share of the water evaporated or transpired through plants to the atmosphere that returns to the same watershed. Therefore, the inventory explicitly accounts for the effective net green water flow, NGW_{eff} [9], which leaves the land-use production system (system boundary) towards downwind sink regions due to atmospheric moisture transport [10]. It represents the difference between the effective ET of the land-use production system, $ET_{act,eff}$, and the effective ET of the alternative reference land use, $ET_{PNV,eff}$ (equation 1).

$$NGW_{eff} = ET_{act,eff} - ET_{PNV,eff} \qquad (1)$$

The $ET_{act,eff}$ is determined by subtracting the portion of ET_{act} that is recycled within the watershed (equation 2), whereas the $ET_{PNV,eff}$ is determined by subtracting the portion of ET_{PNV} that is recycled within the watershed (equation 3).

$$ET_{act,eff} = ET_{act} - ET_{act} \times BIER \quad (2)$$

$$ET_{PNV,eff} = ET_{PNV} - ET_{PNV} \times BIER \quad (3)$$

The method proposed allows the consideration of two alternative reference land uses: 1) near-natural forests and 2) grasslands/shrublands. On the local or regional scale, depending on the specific location of a crop or forest, both near-natural forests and grasslands/shrublands can co-exist. Therefore, in situations in which two reference vegetations are appropriate, the ET_{PNV} should be calculated for both [11].

2.2. Life cycle impact assessment

The TGWI and RBWP are calculated according to equations 4 and 5, respectively.

$$TGWI = NGW_{eff} \times CF_{TGWI} \quad (4)$$

$$RBWP = NGW_{eff} \times CF_{RBWP} \quad (5)$$

where CF_{TGWI} is the characterisation factor for the assessment of TGWI and CF_{RBWP} is the characterisation factor for the assessment of RBWP. CF_{TGWI} is proposed as a function of both $ET_{act,eff}$ and $ET_{PNV,eff}$, which are indicators of water available for the interface green water/atmosphere. CF_{RBWP} is proposed as a function of both $ET_{act,eff}$, and $ET_{EWR,eff}$, which are indicators of water available for surface blue water production. $ET_{EWR,eff}$ refers to the effective threshold evapotranspiration level of the land-use production system that guarantees the environmental water requirement (EWR) [11]. When a crop or forest species evaporates or transpires the same effective volume of water as the reference land use, CFs are set to zero ($CF_{TGWI} = CF_{RBWP}= 0$). When $ET_{act,eff}$ is lower than $ET_{PNV,eff}$, the green water flow that returns to the atmosphere is reduced, which has an impact on the precipitation levels that return to the terrestrial ecosystem. The CF_{TGWI} is given by equation 6. However, the land-use production system does not reduce surface runoff to surface blue water production, i.e., $CF_{RBWP} = 0$.

$$CF_{TGWI} = 1 - \frac{ET_{act,\ eff}}{ET_{PNV,\ eff}}, \text{ when } ET_{act,eff} < ET_{PNV,\ eff} \quad (6)$$

When $ET_{act,eff}$ is higher than $ET_{PNV,eff}$, the crops or forest species do not cause disturbances to terrestrial green water flows. Therefore, $CF_{TGWI} = 0$. When $ET_{act,eff}$ is higher than $ET_{PNV,eff}$, reductions in surface runoff occur, leading to reductions in surface blue water production until a critical level of $ET_{EWR,eff}$ is reached. CF_{RBWP} is given by equation 7. When $ET_{act,\ eff}$ is equal to or higher than $ET_{EWR,\ eff,}$, the critical level is achieved. The reductions in surface blue water production may lead to high impairment of regional long-term blue water availability, so that not all aquatic ecosystems services can be fulfilled. CF_{RBWP} is set to 1.

$$CF_{RBWP} = \frac{ET_{act,\,eff}}{ET_{EWR,\,eff}},\ \text{when}\ ET_{PNV,eff} < ET_{act,\,eff} < ET_{EWR,\,eff} \quad (7)$$

3. CASE STUDY: E. GLOBULUS STANDS

3.1. Functional unit, description of the system and ET_{act} calculation

The functional unit (FU) is defined as one hectare of land occupied by *E. globulus* during a complete rotation of 12 years, with a tree density ranging from 833 to 1,904 trees per hectare. The system boundary considers the full *E. globulus* growth during its first 12-year coppice rotation, following a gate-to-gate approach. The nursery stage (first year before the stand installation) was excluded from the system boundary.

To calculate ET_{act} of *E. globulus*, a modified version of the 3-PG model (Physiological Principles Predicting Growth), originally developed by Landsberg and Waring [12], and adopted to Portuguese E. globulus growth conditions [13] was used.

3.2. Results

For both alternative reference land uses, it was found that the *E. globulus* produced in the Northern littoral area has the highest mean annual wood volume growth increment (MAI) (around 21 $m^3_{wood}.ha^{-1}.yr^{-1}$). These stands cause a minimal or no TGWI, and although they present the highest average RBWP (Figures 1 and 2) – being the region with the highest potential to reduce surface blue water production – the effective threshold evapotranspiration level of the land-use production system that guarantees the Environmental Water Requirement, $ET_{EWR,\,eff}$, is not reached, meaning that aquatic ecosystem functions stay fulfilled.

The national strategy for the Portuguese forest [14] recommends the reordering of the forest occupation based on precipitation levels and tree productivity, as a strategy to maximise the MAI of *E. globulus*. According to this strategy, *E. globulus* stands should be mainly located in Northern littoral and Central littoral areas, which is supported by the results of this study.

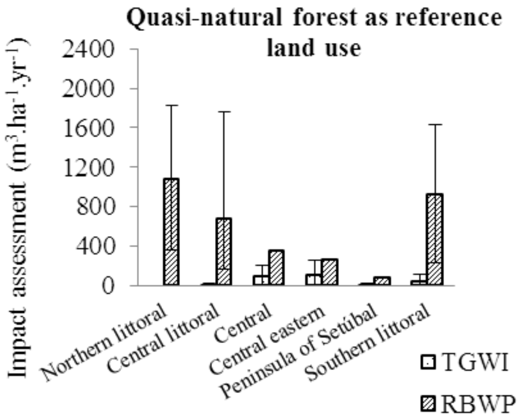

Figure 1. TGWI and RBWP of each region of *E. globulus*, considering the quasi-natural forest as an alternative reference land use. The error bars indicate the variation range obtained for the TGWI and RBWP within each region.

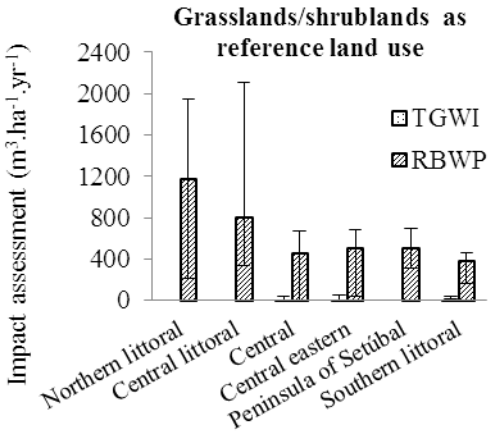

Figure 2. TGWI and RBWP of each region of *E. globulus*, considering the grasslands/shrublands as an alternative reference land use. The error bars indicate the variation range obtained for the TGWI and RBWP within each region.

4. CONCLUSIONS

The proposed model embodies mature and robust principles and requires a modest amount of input data, easily accessible to stakeholders and non-LCA practitioners. The results of the case study show that, depending on the alternative reference land use, different impacts on terrestrial green water flows and on surface blue water production are obtained. Moreover, the developed method can be a useful tool to assist in improved national *E. globulus* forest planning, maximising MAI and minimising potential impacts on ecosystems.

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VIRTUAL WATER TRANSFERS VIA THE POWER GRID: WATER EMBODIED IN ELECTRICITY TRADE BETWEEN REGIONS

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Keywords Water Footprints, Embodied Water, Virtual Water, Life-Cycle Analysis

Abstract *Allan (1998) observed that water-scarce regions in the Middle East and North Africa import water intensive agricultural goods to compensate for lack of local water resources. Hoekstra and Hung (2002) built on the insights of Allan by computing the water requirements of global food crops and applying import-export data to assess water embodied in international crop trade. The water footprint concept can be extended to the analogous case of water embodied in energy infrastructure (Cohen and Ramaswami 2014). Cohen and Ramaswami (2014) show that 93% of U.S. counties have little to no in-boundary electricity generation and thus rely on grid electricity produced outside the city/county boundary. Since energy (like food) is highly water intensive, cities therefore rely on external water resources to meet local energy demand.*

This research combines detailed urban energy use, energy production and energy exchange data with estimates of the water intensity of power generation to compute a spatially- and temporally-delineated water footprint of energy supply for a global mega-city. The result is a geo-referenced look at the water inputs to the energy system of Delhi, India over a one-year period. Borrowing the language of Allen (1998), this represents virtual water transfers embodied in electricity trade between regions.

Potential applications of a spatially- and temporally-delineated water footprint of energy supply include (1) season-ahead forecasting of regional water demand vis-à-vis energy outlooks; (2) optimization of electricity supply dispatch models with respect to water use minimization and directionality of virtual water transfers between regions; and (3) identification of potential water scarcity hotspots when used in conjunction with drought severity maps and/or regional water balance models.

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DEFINITION OF MID-POINT AND END-POINT CATEGORIES IN SOCIAL LYFE CYCLE ASSESSMENT

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Keywords Social Life Cycle, Mid-Points, End-Points, Framework

Abstract *Attempts to establish an accepted method to evaluate social aspects have been a concern amongst academics and industry. However, there is still a lack of consensus on what is the best approach to adopt regarding social assessment. As recommended by the European Commission, a standardisation of the available methods remains crucial to a sustainable development in the Life Cycle Assessment field. The aim of this work is to identify the mid-point social impact categories for assessing products and services on a Social Life Cycle Assessment (S-LCA). This work is based on an extensive literature review covering scientific articles, which are focused on social responsibility and social sustainability. This literature review has provided a database composed of 1450 social indicators. A content analysis has been performed in order to aggregate the indicators into different areas of protection, leading to standardized mid-point categories. A set of sixteen social mid-point categories has been proposed. The selection of these categories was validated through the application of a set of face-to-face semi-structured in-depth interviews. The interviews were conducted at companies from different industries in the European Union, positioned at various levels of the supply-chain. The corporate managers in charge of sustainability were the persons interviewed.*

To summarize, this work aims to reinforce the foundations of S-LCA and proposes the definition of a new taxonomy for the social mid-points, which improves upon and systematises the existing literature on the area. This work contributes into an essential topic, providing valuable information on critical criteria for decision-making.

ENVIRONMENTAL AND SOCIAL IMPACTS OF SUGARCANE PRODUCTION IN SÃO PAULO CONSIDERING DIFFERENT HARVESTING SYSTEMS

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Keywords life cycle assessment, social impacts, sustainability, sugarcane

Abstract *Brazil is nowadays the world largest sugarcane producer accounting for nearly 40% of the world production, and a main sugar and ethanol exporter. The world has witnessed Brazil´s success in the growth of sugarcane, sugar and ethanol industries. However, the Brazilian sugarcane sector has been criticized for its environmental impacts mainly due to the pre-harvest burning and the poor working conditions of sugarcane field workers in manual harvesting systems. To meet the requirements of the international markets on sustainable products, Brazil is promoting the mechanization of the sugarcane industry. In the State of São Paulo, pre-harvest burning is planned to be ruled out by 2017. This paper assesses the environmental and social impacts of sugarcane production in Sao Paulo considering different harvesting systems. A comparative LCA study was conducted to evaluate the environmental impacts of manual harvesting system with pre-harvest burning, and mechanical harvesting system without burning. A comprehensive desktop research is conducted to qualitatively analyse the social impacts of sugarcane production in the trend of mechanization of the sugarcane sector. The LCA results show that sugarcane product system with mechanical harvesting has higher environmental impacts on all the selected impact categories compared to manual harvesting system mainly due to the higher consumption of fertilizer and diesel. In terms of social impacts, mechanical harvesting system has a better performance on public health and working conditions of field workers. However, it may result in job loss and social exclusions on small sugarcane producers. Recommendations in supporting policy-making are made based on the analysis to improve the sustainability performance of the sugarcane sector in Sao Paulo and in Brazil.*

LCA OF THE BIODIESEL PRODUCTION IN SPAIN DRIVEN BY OPTIMIZATION CRITERIA

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Keywords Biodiesel supply chain, Economic modelling, Life Cycle Assessment, Land Use Change

Abstract *The implementation of the European Union's Renewable Energy Directive (RED) has led the biodiesel market to take into account not only production costs but also the associated Greenhouse Gas (GHG) emissions. In the Spanish biodiesel sector, this is seen as an opportunity to increase domestic production and enhance a well-integrated supply chain. A model of the agro-industry biodiesel sector is developed based on mathematical programming. Two versions of the model are presented, with two different objectives: firstly, to determine the optimal capacity of a hypothetical biodiesel plant using only domestic oilseeds; secondly, to determine the optimal combination of feedstock for the entire biodiesel sector, given its nameplate capacity. An emissions module allows for a life cycle assessment of each production option to be carried out, although optimal industry configurations are only driven by economic principles.*

The optimal capacity of a biodiesel plant in the Spanish context is 300,000 t/a, minimizing unit production costs (around 850 €/t). For the second goal, the optimal oil mix is the one that maximizes the industrial surplus under different import scenarios, with an increased presence of domestic feedstock. As a result, biodiesel is mainly manufactured from domestic sunflower oil and imported palm oil in different proportions, while residual oils are also used in the plants operating with second-generation technology. Increased levels of domestic feedstock generally translate into lower impacts, except for acidification. Reducing the share of palm biodiesel clearly benefits the GHG balance, since this chain causes an emission increase of 216% (relative to the reference fossil fuel), mainly due to the emissions from land use change. Biodiesel from domestic sunflower delivers a 51% emission saving, while only 42% is saved with rapeseed. In this way, the proposed model constitutes a tool for verifying the compliance with the RED's emission reduction targets.

1. INTRODUCTION

The implementation of the European Union's Renewable Energy Directive (RED) has led the biodiesel market to take into account not only production costs but also the associated greenhouse gas (GHG) emissions. Specifically, the RED establishes a 10% target for biofuel consumption by 2020 in combination with minimum emissions reduction targets. The major part of this target is expected to be met with biodiesel. Emission constraints provide an opportunity to promote the presence of domestic feedstock in biodiesel blends and enhance national supply chains in the Member States, since imported vegetable oils are generally related to heavy life cycle carbon footprints, due to land use change (LUC), as well as long transport distances. For instance, [1] and [2] found that considering the conversion of carbon-rich ecosystems into bioenergy production leads to much higher GHG emissions than fossil fuels. In the Spanish biodiesel sector, the RED may foster the contribution of domestic sunflower and rapeseed in addition to waste feedstock, if certification and double-counting schemes are finally implemented. The installed capacity, around 4.5 Mt/a, almost doubles the target demand and far exceeds the current production. Given the low profit margins of biofuel production, optimization models are necessary to determine optimal industry configurations [3][4][5]. Although there are studies addressing the economic viability and environmental performance of the biofuel supply in Spain [6][7], to the best of our knowledge, there is no multi-chain optimization model of the biodiesel sector in the Spanish context. The objective of this study is twofold: on the one hand, to determine the optimal capacity of a hypothetical biodiesel plant using only domestic oilseeds; on the other hand, to determine the optimal combination of feedstock for the entire biodiesel sector, given its nameplate capacity.

2. METHODOLOGY

The model is written in General Algebraic Modeling System (GAMS) and couples the farm sector to the biodiesel industry. The optimal capacity will be the one that minimizes unit production costs, while the optimal oil mix will be the one that maximizes the industrial surplus, calculated as the sum of the individual producers' surplus. To this end, two versions of the industry model have been defined, at plant and sector level, based on identical price and cost information gathered from [6] and three Spanish biodiesel plants. All the costs are linear, depending on the biodiesel capacity, except investment cost, for which an exponential function has been introduced, following expert opinion. For the sector model, the overall supply of first (1G) and second-generation (2G) biodiesel is defined following a step-function and switching technologies is not allowed. The agricultural model is the same in both approaches; a region-based model including those provinces that concentrate the bulk of oilseed production in Spain, built on area, yield and variable costs data for 2009 gathered from [8] and official reports from Autonomous Communities. Resource, rotation, policy and quota constraints have been included, based on regional differences. Prices are assumed to be constant and set exogenously. Under the first approach, the set of activities that maximizes the total agricultural surplus in each province is selected, and oilseed output becomes the input for the industrial biodiesel production. In the second model, the expected biodiesel demand for 2020 triggers the supply of oilseeds and the import of oils. An emission module, built on environmental information from [7] and the Ecoinvent v2.2 database, allows for a life cycle assessment (LCA) to be simultaneously carried out, although optimal industry configurations are only driven by economic principles. LUC emissions from imported virgin oils are included based on [1][9][10]. Partitioning is applied in accordance with the energy content of co-products, as recommended by the RED.

3. RESULTS

3.1. Results from the plant model

In order to determine the optimal capacity of a biodiesel plant operating with available sunflower and rapeseed in Spain, supply curves are defined for each feedstock by taking different price levels into account. The prices of the vegetable oils are dependent on the seed prices and follow a linear relationship. Unit production costs are determined by iteration, decreasing the prices of sunflower and rapeseed separately, although the oils are subsequently mixed in the biodiesel plant. The optimal capacity is found for a plant manufacturing 300,000 t/a of biodiesel. The minimum production cost, 848.8 €/t, is reached when the price of sunflower is 181.3 €/t, for baseline prices of rapeseed (239.9 €/t). On the contrary, when the rapeseed price reaches 215.9 €/t, with the price of sunflower at the starting point (241.8 €/t), the minimum unit cost reaches 859.0 €/t of biodiesel. In both cases, the feedstock cost represents 78% and the investment cost only 3% of overall unit costs, the rest being transport, operational and other fixed costs.

3.2. Results from the industry model

For the second goal, different import scenarios featuring an increased presence of domestic feedstock are defined as follows: 1) imports from major oil-producing countries are unlimited; oil input from domestic oilseeds must be 2) at least a quarter of the total amount imported; 3) at least half of the total amount imported; 4) equal to or greater than the total amount of oil imported. At the same time, used cooking oil (UCO) can be imported from the United States (US) and France, with different emission intensities; maximum UCO availability in Spain and France is set at 300,000 t and 11,000 t, respectively, according to [6]. However, using only UCO and domestic oilseeds would not allow the target demand in 2020 (2.58 Mt in [6]) to be met, given the agricultural supply and the biodiesel sector configuration, with less than 20% of the overall capacity devoted to 2G technologies. Figure 1 shows the oil mix underlying biodiesel consumption in Spain under the different scenario assumptions. In scenario 1, imports of palm oil fill the Spanish market (66.3%), as is currently the case, since it is the most competitive oil in the international market. 2G plants preferably operate with UCO from Spain (11.3%) and France (0.3%), since this feedstock entails lower transportation costs and biodiesel producers are usually responsible for them. However, UCO imports from the US are necessary and account for the largest share (22.1%), since they are widely available. The shares of UCO remain constant in the subsequent scenarios, with plants working at full capacity, since it has been assumed that UCO biodiesel is sold at a higher price than 1G biodiesel, as recommended by the RED. Scenarios 2, 3 and 4 favour the presence of domestic oilseeds, mainly sunflower (with a larger planted area), which accounts for 8.7%, 21.2%, and 37.8% of the oil mix, respectively.

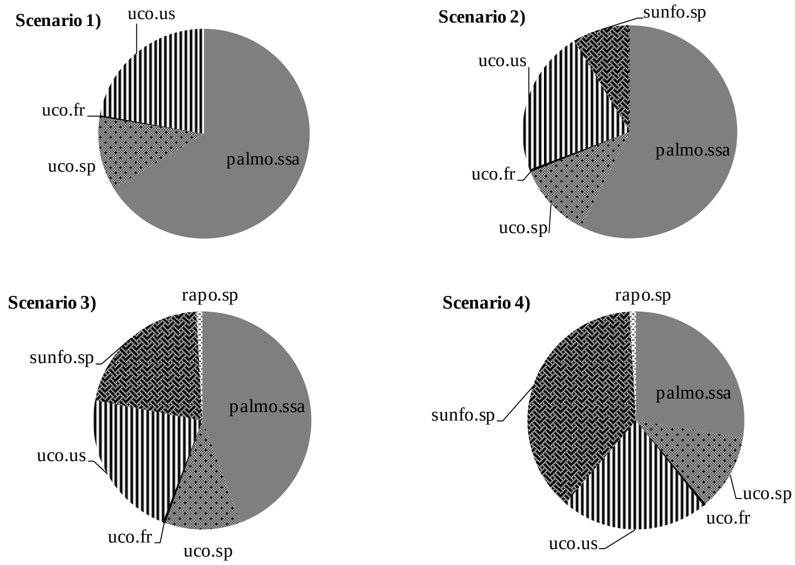

Figure 1. Oil mix for domestic biodiesel production under the different defined import scenarios. Palmo.ssa: palm oil from South-Eastern Asia; uco.sp: UCO from Spain; uco.fr: UCO from France; uco.us: UCO from the US; sunfo.sp: sunflower oil from Spain; rapo.sp: rapeseed oil from Spain.

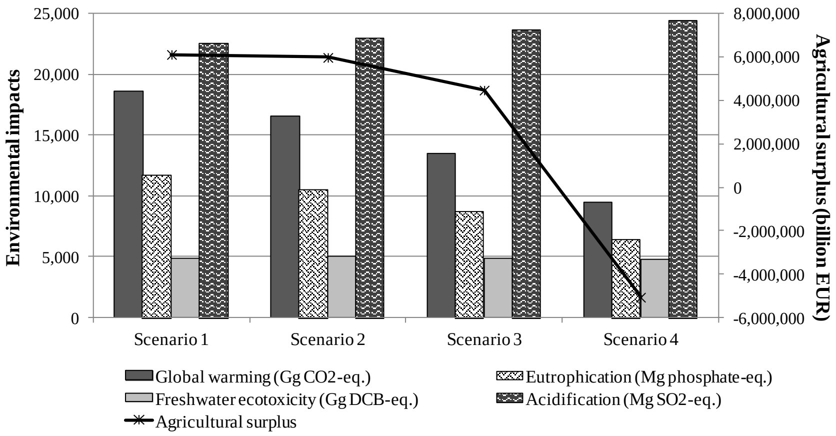

Figure 2. LCA outcomes and agricultural surplus from the production of 2.58 Mt of biodiesel in Spain.

For the LCA, the CML 2 impact assessment method has been applied. It can be observed in Figure 2 how increased levels of domestic feedstock generally translate into lower impacts, except for acidification. This is because rapeseed and sunflower have greater fertilizer needs than palm, thus causing greater emissions (e.g. ammonia). Freshwater ecotoxicity outcomes barely vary from one scenario to another, since all the 1G biodiesel pathways exhibit similar emission intensity, mostly caused by agricultural production. Greater transport distances for palm oil are compensated for by lower pesticide needs. As for global warming (GW), reducing the share of palm biodiesel clearly benefits the GHG balance, with much greater emissions from LUC, despite the fact that agricultural production is less-input intensive than for other oilseeds. The sub-stages which contribute the most to eutrophication are those of agricultural production and export to Spain; using domestic oilseeds substantially reduces emissions from transport. However, reducing impacts comes at the cost of agricultural surplus, since domestic oilseeds expand at the expense of other crops with higher margins. The overall industrial surplus of the biodiesel sector is negative (around 3,700-3,900 million EUR) in every scenario, since unit costs in some 1G plants are higher than the selling price of biodiesel. Increasing the share of sunflower oil generates greater losses, due to its higher price relative to palm and soybean oil. UCO plants are profitable thanks to a higher market price of the 2G biodiesel.

4. DISCUSSION

When comparing the GHG reduction thresholds with those in the RED, all the UCO biodiesel pathways easily meet the requirements, as can be seen in Table 1. Biodiesel from domestic oilseeds meets the 35% target, but only sunflower will meet the 50% one when it is implemented in 2017. These results are consistent with default values provided in the RED. Palm biodiesel causes an emissions increase of 216% when it involves transformation from rainforest in South-Eastern Asia. Considering peatland could lead to much greater emissions, whereas considering degraded grassland could substantially improve the GHG balance of palm biodiesel [2][10]. Emissions from LUC have been assumed to be zero for biodiesel based on domestic feedstock, according to the Tier 1 approach of the IPCC guidelines, since transformation from cropland to cropland may lead to small changes in carbon stocks.

Table 2. GHG emission reduction (%) caused by biodiesel underlying consumption in Spain, relative to the reference fossil fuel. An emission factor of 90.3 g CO_2/MJ has been considered for the reference fuel.

	% GHG reduction
Spanish UCO biodiesel	94
French UCO biodiesel	87
US UCO biodiesel	83
Sunflower biodiesel	51
Rapeseed biodiesel	42
Palm biodiesel	-216

5. CONCLUSIONS

Two optimisation models for biodiesel production in Spain have been developed with two different objectives. The plant-oriented model determines that the optimal capacity for using the oilseed feedstock currently available in Spain would be 300,000 t/a, with a unit production cost of around 850 €/t. This is higher than the selling price of biodiesel from virgin oils (780 €/t), leading plants to incur losses. Indeed, since the end of the tax exemption in Spain, most of the plants are idle, while the 1G ones that remain active mostly use much cheaper imported oils (palm and soybean). The sector-oriented model aims to estimate sector configurations so as to optimise the use of the nameplate capacity, while coupling the outcomes to environmental results from LCA.

Increasing the share of domestic oilseeds considerably reduces most of the analyzed impacts, especially GW, but causes a great decrease in surplus. Higher market prices for UCO biodiesel (1,022 €/t) help to compensate for higher operational costs, ensuring that 2G plants work at full capacity. It remains to be seen if including emission reduction as an additional criterion in the model indeed favours the presence of domestic feedstock. In this way, the proposed model constitutes a tool for verifying the compliance with the sustainability requirements in the RED; however, indirect LUC emissions are not considered, which will possibly be a future requirement according to the new European proposal on biofuels.

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DO METHODOLOGICAL CHOICES REALLY MATTER IN THE LIFE CYCLE ASSESSMENT OF BIOENERGY SYSTEMS?

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Keywords Life Cycle Assessment, Bioenergy Systems, Methodological choices

Abstract *Bioenergy systems have come under increasing scrutiny due to the urgent need for replacing fossil fuels in order to mitigate climate change impacts. The perceived benefits of bioenergy systems may not hold when a different set of methodological choices are adopted. This paper quantifies the sensitivity of climate-change results to the methods applied for time-accounting, inclusion of biogenic carbon flows, allocation, indirect land-use change, reference systems, soil carbon stocks, inventory-modelling approaches, etc., in both annual and perennial crops.*

ENERGY REQUIREMENTS FOR THE CONTINUOUS BIOHYDROGEN PRODUCTION FROM *SPIROGYRA* BIOMASS IN A SEQUENTIAL BATCH REACTOR

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Keywords Biohydrogen, Microalgae, Life-Cycle Analysis

Abstract *The current energy market requires urgent revision for the introduction of renewable, less-polluting and inexpensive energy sources. Biohydrogen (bioH_2) is considered to be one of the most appropriate options for this model shift, being easily produced through the anaerobic fermentation of carbohydrate-containing biomass. Ideally, the feedstock should be low-cost, widely available and convertible into a product of interest. Microalgae are considered to possess the referred properties, being also highly valued for their capability to assimilate CO_2 [1]. The microalga Spirogyra sp. is able to accumulate high concentrations of intracellular starch, a preferential carbon source for some bioH_2 producing bacteria such as Clostridium butyricum [2]. In the present work, Spirogyra biomass was submitted to acid hydrolysis to degrade polymeric components and increase the biomass fermentability. Initial tests of bioH_2 production in 120 mL reactors with C. butyricum yielded a maximum volumetric productivity of 141 mL H_2/L.h and a H_2 production yield of 3.78 mol H_2/mol consumed sugars. Subsequently, a sequential batch reactor (SBR) was used for the continuous H_2 production from Spirogyra hydrolysate. After 3 consecutive batches, the fermentation achieved a maximum volumetric productivity of 324 mL H_2/L.h, higher than most results obtained in similar production systems* [3] *and a potential H_2 production yield of 10.4 L H_2/L hydrolysate per day. The H_2 yield achieved in the SBR was 2.59 mol H_2/mol, a value that is comparable to those attained with several thermophilic microorganisms* [3], [4].
In the present work, a detailed energy consumption of the microalgae value-chain is presented and compared with previous results from the literature. The specific energy requirements were determined and the functional unit considered was gH_2 and MJH_2. It was possible to identify the process stages responsible for the highest energy consumption during bioH_2 production from Spirogyra biomass for further optimisation.

1. INTRODUCTION

Biofuels are regarded as a viable alternative to fossil fuels for the production of renewable energy. Special attention has been given to biomass-derived fuels thanks to their renewable and largely non-polluting qualities. Biohydrogen (bioH_2) is one of such fuels, being easily convertible into energy through combustion, a process which yields solely water as sub-product [5]. BioH_2 production can be attained by anaerobic fermentation of carbohydrate-containing biomass and originates a highly rich biogas containing both H_2 and CO_2 [6]. A prime example of a feedstock adequate for bioH_2 production is microalgal biomass. Microalgae are photosynthetic organisms able to assimilate atmospheric CO_2 and store both lipids and carbohydrates in their intracellular space. They are also highly productive allowing for a near daily harvest and, unlike higher plant cultures, require no arable land or potable water [7]. BioH_2 production has already been successfully achieved by the authors, using *Scenedesmus obliquus* [8], [9], *Chlorella vulgaris* [10] and *Spirogyra* sp. biomass [2]. *Spirogyra,* in particular, is able to accumulate starch, a preferential substrate for anaerobic fermentation by certain bacterial strains, at very high concentrations [2]. In this work, the production of bioH_2 from *Spirogyra* biomass by *Clostridium butyricum* was evaluated in small-scale batch reactors and a bench-scale sequential batch reactor. Both processes were compared in terms of their H_2 yield, production rate and overall energy consumption.

2. MATERIALS AND METHODS

The *Spirogyra* biomass used in this work had the following average composition (% (w/w) dry weight basis): 45.1% total sugars, 22% crude protein, 3.6% fat, 25.9% ash and 3.4% others (by difference). The microalga was cultured and harvested as already described [2]. Biomass hydrolysis was performed with H_2SO_4 1N (60 min, 121 °C). Small scale fermentation was undertaken in 120 mL serum flasks containing 20 mL of MCM medium [11]. Bench-scale sequential batch fermentation was performed in a lab scale double jacketed reactor (1.65 L) with a total medium volume of 500 mL (10 g/L of total sugars, 37 °C, 150 rpm). After the first batch assay, 250 mL of the medium were replaced with a 1:1 mixture of hydrolysate and concentrated MCM. The produced biogas was collected and stored in inverted serum flasks filled with water, and quantified by displacement of the liquid phase. Biomass dry weight was determined throughout the fermentation. Gas samples were analysed by GC and the fermentate samples by HPLC [9]. The final energy consumption inventory associated with the microalga culturing, harvesting, drying, hydrolysis and fermentation was assessed based on direct equipment energy measurements. The results are expressed in MJ/MJH_2.

3. RESULTS AND DISCUSSION

H_2 production from *Spirogyra* sp. hydrolysate was first attempted in a small set-up consisting of individual flasks with the purpose of evaluating whether *C. butyricum* was able to successfully convert the sugars made available by the acid hydrolysis. The fermentation results are displayed in figure 1.

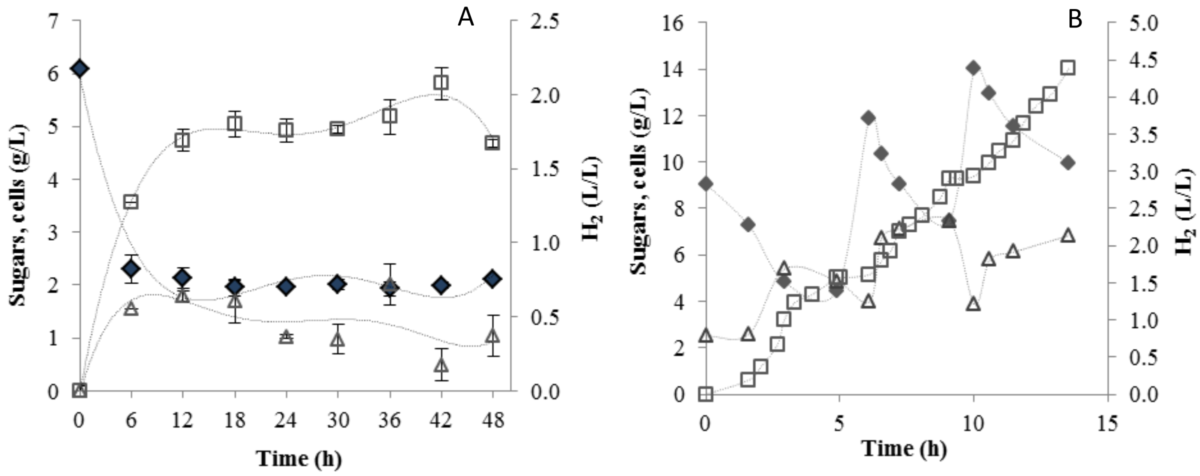

Figure 1. Time-course of H_2 production, sugar consumption and cell dry weight in: A) small-scale batch reactor; B) bench-scale sequential batch reactor (□ – H_2; ♦ – total sugars; Δ – cells).

As seen in figure 1 (A), H_2 production occurred rapidly between 0 and 12 hours of incubation with no visible lag phase. The maximum H_2 production was achieved at 42 hours of fermentation (2.1 L H_2/L). The maximum H_2 percentage in the biogas produced was 28% (v/v). The highest H_2 production rate (141 mL/L.h) was detected from up to 12 hours and corresponded to a H_2 yield of 3.78 mol H_2/ mol glucose equivalents. These results show that not only H_2 production from *Spirogyra* hydrolysate was viable as it was comparable or higher to already published results [8], [9].

With the objective of scaling-up the bioH_2 production, a sequential batch reactor (SBR) was set-up. The use of a sequential batch system maintains the concentration of biomass inside the reactor in a quasi-exponential status, virtually eliminating the lag-phase between consecutive batches and lessening the operation time of each batch. This enables to increase the number of batches per day and the overall H_2 production rate. Figure 1 (B) depicts the results of bioH_2 production from *Spirogyra* hydrolysate in SBR during three consecutive batches. In comparison to the small-scale batch reactor, the H_2production rate increased almost two-fold (324 mL/L.h) and the biogas produced was richer in H_2 (>50% (v/v)). The bioH_2 production did not change significantly during the consecutive batches, displaying a steady, uninterrupted production profile up to 4.4 L H_2/L.

Table 1. Inventory results of bioH_2 production from *Spirogyra* biomass (MJ/gH_2)

Production stage	BioH_2 production in small-scale batch reactor	BioH_2 production in SBR
Microalgae culture	0.11	0.03
Biomass harvesting and drying	1.87	0.55
Biomass hydrolysis	1.71	0.07
Fermentation	1.96	3.09

Table 1 summarises the inventory of both production processes and the energy consumption associated to each stage of H_2 production. The results are presented in MJ per g of H_2 produced.

In order to show the results in MJ per MJ of hydrogen produced, a lower heating value of 120 MJ/kg was used [1], [2]. A total energy consumption of 47 and 31 MJ/MJH_2 was obtained in the small-scale batch reactor and the SBR, respectively. Previous studies on the fermentation of dried and ground microalgal biomass achieved total energy consumption values of 88 MJ/MJH_2 with *Scenedesmus obliquus* as feedstock and 207 MJ/MJ H_2 with *Spirogyra* sp., values which are visible higher than those attained in this study [1], [2]. The use of less energy consuming harvesting and drying procedures (electrocoagulation and solar dewatering) and the use of a simpler culture medium contributed for this energy consumption decrease. In the small-scale process, the production and processing of the microalgal biomass (harvesting, drying, hydrolysis) was responsible for a considerable energy consumption (30 MJ/MJH_2), in accordance to what was already reported by other authors [12]. In contrast, the fermentation was clearly the stage which consumed more energy in the SBR. This result is directly related to the high energy consumption of the heating bath used for controlling the reactor temperature. Together, the biomass hydrolysis and the fermentation stages accounted for 85% (26 MJ/MJH_2) of the total energy consumption in the SBR.

The comparison between small-scale and bench-scale allowed us to assess that the SBR improved the cumulative H_2 production, the H_2 production rate and the global energy consumption. Although it is still necessary to reduce the ratio of energy input per energy output, the increase in the scale of bioH_2 production allowed for a reduction of 34% of the energy requirements. The comparison of the results obtained in this work with others already published [2] shows a clear improvement in the process performance, likely due to the refinement of the microalga harvesting process, the culture medium optimisation and the bioconversion efficiency.

4. CONCLUSIONS

The purpose of the current study was to evaluate the effect of scaling-up the bioH_2 production from microalgal biomass in the energy requirements and production yield of the process. The fermentation results show that *Spirogyra* biomass is an adequate feedstock for the fermentation by *C. butyricum*, achieving H_2 production yields close to the maximum theoretical value. The SBR system improved significantly the H_2 production yield (from 2.1 to 4.4 L H_2/L) and H_2 production rate (from 141 to 324 mL/L.h), while supporting at the same time the operation in a continuous mode. The energy inventory analysis revealed that the process scale-up decreased the energy consumption in 34%. It is possible that pursuing with the optimisation of the fermentation stage, the energy requirements may decrease to values which make the biological H_2 production more sustainable.

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LCA OF RAPESEED METHYL ESTER ADDRESSING UNCERTAINTY

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Keywords Agricultural practices, LCA, Renewable Energy Directive (RED), RME, uncertainty analysis

Abstract *Biodiesel has emerged as the main alternative to fossil fuels in transportation; however, important environmental concerns were raised regarding its impacts. Previous Life Cycle Assessments (LCA) of rapeseed biodiesel (rapeseed is the main feedstock for biodiesel in Europe) mainly focused on energy and GHG and often neglected soil carbon emissions and uncertainty. Moreover, performance-based regulations for biofuels in Europe ignore uncertainty, despite the inherent uncertainty in biofuel systems.*

The aim of this article is to present an LCA of rapeseed biodiesel, addressing soil carbon emissions and incorporating uncertainty sources. A "well-to-tank" approach was implemented. Cultivation data was obtained from rapeseed producers in France and industrial data was collected from biodiesel companies in Portugal. Different transportation scenarios were assessed based on alternative systems and distances. An uncertainty analysis was conducted using Monte-Carlo simulation for parameter uncertainty and scenarios for alternative co-product allocation methods (mass, energy, economic).

Main contributors to the impacts of rapeseed biodiesel were: i) cultivation (e.g. global warming: 67-74%, acidification: 87-95%) mainly due to field emissions and N fertilizer production; and ii) transesterification (abiotic depletion: 34-36%) due to methanol use. Soil carbon changes were the main contributor to global warming uncertainty (60-96%): emissions ranged from -8gCO_2eq/MJ (full-tillage cropland converted to rapeseed cultivation) to 32gCO_2eq/MJ (no-tillage cropland converted to rapeseed cultivation). Different allocation methods also influenced the results: compared to energy allocation (used in the Renewable Energy Directive, RED), mass allocation results were on average considerably lower (-24% for abiotic depletion; -35% for eutrophication), whereas economic allocation results were higher (+7% for abiotic depletion; +10% for eutrophication).

This article demonstrates the importance of incorporating different sources of uncertainty in LCA studies of biodiesel. The high level of uncertainty does not allow clear conclusions on the compliance of biofuel systems with sustainability criteria, namely those defined in the RED, which does not require assessing uncertainty. We recommend that quantification and communication of uncertainty in LCA studies should be done in future biofuel legislation, providing a basis for sound decision-making and avoiding the risk of policy failure.

SUPPLY CHAIN OPTIMIZATION ACCOUNTING FOR LIFE CYCLE ASSESSMENT – THE IMPACT OF PRODUCT ENVIRONMENTAL FOOTPRINT

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Keywords Supply Chain Optimization, Life Cycle Assessment, ReCiPe, PEF, Decision Tool

Abstract *The continued growth of the population is contributing to a depletion of resources and to what could become irreversible climate changes. This situation is pressing governments and firm managers to take measures that can somehow reverse or at least reduce the environmental impact of industries. In this context and being supply chains an important system in any organization, the design and planning of such systems accounting for these concerns is mandatory. Environmental impact evaluation of supply chains is of major importance since it allows the identification and prioritization of the most problematic activities of a product life cycle. The European Commission has recently released a new methodology for life-cycle assessment (LCA) called Product Environmental Footprint (PEF), which intends to achieve standardization amongst the pre-existent life cycle approaches. Several studies have been conducted previously to PEF applying different LCA methodologies. Therefore, decisions have been taken based on the prior LCA results. Now, it is crucial to verify if the incorporation of PEF will influence the previous decision making processes. In this work a mathematical programming optimization model for the design and planning of supply chains is developed to be used as the foundation for the decision process. In the optimization model the environmental impact of the different activities within the supply chain is assessed both through ReCiPe and the life-cycle impact assessment models defined in PEF in order to compare their results, while accounting for the economic performance of the supply chain. The model is applied to a case study of a Portuguese food distributor and the results are compared regarding two aspects of the problem. The first concerns the assessment of the supply chain structure obtained through the application of the different environmental assessment methods, which are used as objective functions as well as total supply chain cost minimization. The second is the comparison of the midpoint environmental impact values of the optimized structures. Results show that even though the same network configuration is obtained, the midpoint categories of main concern differ when measured with the different LCA methodologies. The main reasons for these results rest in the fact that the different methods used for each midpoint category translate in significantly different characterization and normalization factors (by 2 to 6 orders of magnitude). Therefore it is possible to conclude that the incorporation of PEF can introduce changes in previous assessments conducted using ReCiPe.*

COST OPTIMIZATION OF BIODIESEL BLENDS OF WASTE AND VIRGIN OIL ADRESSING FEEDSTOCK COMPOSITIONAL VARIABILITY AND LIFE CYCLE IMPACTS

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Keywords Biodiesel, waste cooking oil, blending optimization, uncertainty, Life-Cycle, Greenhouse Gas (GHG)

Abstract *This paper presents an optimization model to minimize the costs of virgin oils and waste cooking oil (WCO) blends for biodiesel production. The model incorporates uncertainty associated with oils chemical compositional and assesses the life-cycle GHG emissions. WCO have been gaining prominence as an alternative feedstock for biodiesel production due to their potential to improve the environmental performance of biodiesel compared with energy crops feedstock. The use of WCO is also attractive due to the potential cost reduction of biodiesel production: 80 to 85% of the biodiesel costs are associated with feedstock cultivation. However, two critical aspects may compromise the use of WCO: i) the high uncertainty and variability in chemical composition (high diversity of sources) hinders guaranteeing biodiesel quality and may result in significant market limitations and ii) the low availability of collected WCO. A potential strategy to deal with these issues is to blend WCO with virgin oils, such as soybean, rapeseed, and palm oil. A chance-constrained blending optimization model was developed to minimize the biodiesel blend cost (quantity of each oil feedstock multiplied by its market price) and explicitly addressing the uncertainty of the feedstock chemical composition. Prediction models for biodiesel properties (density, cetane number, cold filter plugging point, iodine value and oxidative stability), based on the fatty acid composition of the oils, were used to establish constraints of the model, allowing the compliance with biodiesel technical specifications. Preliminary results demonstrate it is feasible to use up to about 20% of WCO in the blend while still meeting technical fuel standards. However, due to the relation between the feedstock chemical composition and the technical constraints, the use of WCO implies the use of a higher quantity of rapeseed oil (the feedstock with the higher price and GHG emissions), which leads to no reduction in the costs or GHG emissions when compared to an optimal blend given by the model considering only the use of the virgin oils.*

IMPROVEMENT OF THE TOXICOLOGICAL ASSESSMENT BASED ON LIMITS IMPOSED BY REACH REGULATION

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Keywords Toxicological Assessment, REACH, USEtox

Abstract *REACH is a European Union regulation concerning the Registration, Evaluation, Authorisation and restriction of Chemicals. REACH has established limits for physicochemical properties of substances, which are related with their fate in the environment (persistence and bioaccumulation) and their effect (toxicity) in Human Health and Ecosystems. The evaluation of the fate and effect of substances is carried out independently for each physicochemical property, and if at least one of the limits is exceeded, the production and use of a substance shall be limited or banned. However, this evaluation neglects some properties of the substances and the combinatorial effect of different properties in the potential toxicity impacts.*

The goal of this paper is to show how to improve the toxicological assessment of substances based on the limits defined by REACH regulation. The limits defined by REACH that are used to calculate the toxicity characterization factors are applied in this research to create "virtual substances". A virtual substance is characterized by having one of its physicochemical properties on the limit defined by REACH to be considered persistent, bioaccumulative or toxic (PBT), or very persistence or very bioaccumulative (vPvB). The physicochemical properties of the "virtual substance" are inputted in the USEtox method to calculate the respective toxicity characterization factors. The USEtox is a Life-Cycle Impact Assessment method which, based on the physicochemical properties of substances and environmental characteristics, calculates the fraction of chemical substance that is exchanged between the different compartments (air, water and soil); the real fraction taken by the organisms; and the effect on humans and different trophic organisms (e.g. plants, microorganisms, algae, fish, etc). Therefore, the USEtox method converts the physicochemical properties into potential impacts for ecosystems and human health. The characterization factors calculated for a "virtual substance" can act as thresholds for the toxicological assessment, since they reflect the behaviour of substances that overcome the limits imposed by REACH. The thresholds calculated can be used to i) assist in the toxicological assessment in order to provide a reference for understanding the significance of the impacts and ii) to comprehend the possible effects of combining different physicochemical properties into potential impacts.

Fourteen virtual substances were defined based on the physicochemical property limits considered in the toxicity assessment (seven for the PBT limits and seven for the vPvB limits). The properties considered were: persistence in air ($t_{1/2}$ air), water ($t_{1/2}$ water), soil ($t_{1/2}$ soil) and sediment ($t_{1/2}$ sediment); octanol-water partition coefficient (k_{ow}); water solubility at 25°C (Sol_{25}) and Effect Dose for human toxicity (ED_{50}). The calculation was carried out for six different compartments: continental air, urban air, freshwater, sea water, natural soil and agricultural soil. Overall, eighty four threshold values were calculated considering the combination of the fourteen virtual substances and the six different emission compartments.

The calculated threshold impacts can be used to assist in the toxicological assessment of substances. The threshold for the virtual substances mimics the limits defined by REACH (and other regulations), so that all the substances with impacts above the calculated thresholds can be considered hazardous for Human Health. The conclusions sum-up how this approach can improve the toxicological assessment, based on limits imposed by reach regulation.

THE FOSSILIZATION OF THE BRAZILIAN ELECTRIC MATRIX UNDER THE LIFE-CYCLE ASSESSMENT PERSPECTIVE

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Keywords Brazilian Electric Matrix, grid, Life-Cycle Assessment, Brazil

Abstract *The increasing participation of fossil fuel thermoelectric plants in the Brazilian electricity grid in the past few years has led to a worsening of its environmental impact, a correlation made evident by data on CO_2 emissions divulged by the Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovação, MCTI) for the National Interconnected System since 2006. Moreover, the environmental concerns are often limited to quantifying the emissions so as to inform the country's energy planning.*
The present study assesses the environmental impact of the Brazilian electricity grid during the period 2006-2013 in order to verify the environmental effects of the use of different sources in terms of Climate Change (CC), Consumption of Primary Energy (CPE), Freshwater Eutrophication (FEu), Terrestrial Acidification (TAc), Agricultural Land Occupation (ALO), and Natural Land Transformation (NLT). It was also made a comparison between CO_2 emission data divulged by MCTI — who quantifies only the burning of fossil fuel — and greenhouse gases emission (GHG) inside the Life Cycle Thinking model.
The results show an increase in the environmental impact in almost all categories. In FEu, the 2009 impact was only 46% when compared to 2013; for TAc, 2009 emissions were 53% when compared to 2013. In face of the LCT model, the emission data divulged by MCTI are revealed to be underreported. The results of both cases, however, are compatible in terms of variation trends. It is concluded that a systemic approach of the environmental impact of electricity generation would bring more subsidies for a more efficient energy planning.

1. INTRODUCTION

The Brazilian government often fails to consider environmental impact in its decision-making process for energy planning. When it does, it is often limited to the effects of Climatic Change.
The Ten Year Plan of Energy Expansion 2023 (Plano Decenal de Expansão de Energia 2023) [1] is the main agent for future action in the field. In environmental terms, the document considers renewable sources as important alternatives for lowering environmental impact —without specific development analyses — and estimates Greenhouse Gases (GHG) emissions from established directives. Another key document is the National Energy Plan 2050 (Plano Nacional de Energia 2050) [2], whose environmental focus is restricted to

climactic change, with brief reference to effects of ionizing radiation from nuclear sources.
For these reasons, modifications in the sources of electricity supply in Brazil have led to significant changes in environmental impact. Since 2006, the Ministry of Science, Technology and Innovation (Ministério da Ciência, Tecnologia e Inovação, MCTI) has disclosed carbon dioxide (CO_2) emission data per unit of electricity generated in National Interconnected System (Sistema Interligado Nacional, SIN), revealing an upward trend. [3]
The present study analyzes the changes in the Brazilian grid, with a systemic focus made available by Life Cycle Thinking (LCT) on different kinds of environmental impact. Moreover, the paper compares data provided by MCTI — limited to CO_2 emissions from fossil fuel to generate power — with similar LCT data in order to discuss the effects of the different methodologies. It is expected that the conclusions will support a more effective energy plan for the country.

2. LIFE CYCLE MODELING

Life Cycle Modeling has a cradle-to-gate attributional focus for all modes of electricity generation of the Brazilian grid. The reference flow adopted was 1.0 MWh. Geographically, the data encompassed all the electricity available for use in Brazil, be it generated inside the country or imported. Temporally, it covered the period 2006-2013 so as to coincide with the MCTI horizon of measurement.

Table 1. Composition (%) of the Brazilian electricity grid in the period 2006-2013

Source	2006	2007	2008	2009	2010	2011	2012	2013
Hydraulic	75.7	77.3	73.2	77.3	73.3	75.5	70.1	64.1
Natural Gas	4.0	3.2	5.7	2.6	6.6	4.4	7.9	11.3
Net Imports	8.9	8.0	8.4	7.8	6.3	6.3	6.8	6.5
Sugar Cane	1.8	2.3	2.4	2.8	4.1	3.9	4.2	4.9
Coal	1.5	1.2	1.3	1.1	1.3	1.1	1.4	2.4
Nuclear	3.0	2.6	2.8	2.6	2.6	2.8	2.7	2.4
Fuel Oil	0.9	1.2	1.4	1.1	1.0	0.6	1.0	1.8
Diesel Oil	1.4	1.3	1.7	1.5	1.6	1.6	1.8	1.8
Wind	0.1	0.1	0.2	0.2	0.4	0.5	0.9	1.1
Firewood	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3
Other	2.5	2.7	2.7	2.8	2.6	3.1	3.0	3.3

Consumption and emissions data relative to each electricity source were collected from secondary data from Ecoinvent Database v.3.1 [4]. Environmental charges generated during electricity transmission, present in the Ecoinvent data, were excluded. The composition of the Brazilian grid during the 2006-2013 period was obtained through National Energy Balance (Balanço Energético Nacional, BEN) [5]. These data are presented on Table 1.

The sources under "Other" — referring to supplementary energy sources such as black liquor, gas coke, waste, renewable and non-renewable secondary sources of energy — were excluded from the analysis, because of its minimal participation (2.5-3.3%) and the high level of imprecision associated to quantifying their use.
Brazil acquires and provides electricity to adjoining countries — the net balance is under "Net Imports". The absence of official data on the provenance of these imports led to the adoption of secondary data from Ecoinvent [4]. Table 2 shows data on the electricity imported by Brazil according to country of origin, contribution percentage, and source. According to these data, 82% of the imported electricity comes from hydroelectric plants, and the remainder from natural gas thermoelectric plants.

Table 2. Origin and characteristics of the electricity imported by Brazil (2006-2013)

Country of origin	Participation (%)	Source
Paraguay	62	Hydraulic (100%)
Argentina	28	Natural Gas (66%) + Hydraulic
Venezuela	6.0	Hydraulic (100%)
Uruguay	4.0	Hydraulic (100%)

Figure 1 shows the result of the LC model. Sources were grouped into classes according to provenance of the primary energy, so as to make the presentation and analysis more concise.

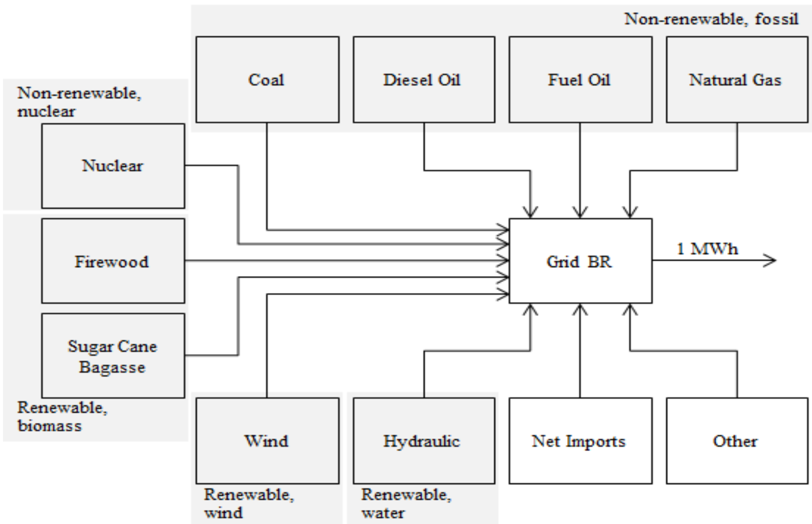

Figure 1. LC-modeling from the Brazilian electricity grid

The environmental effects on six impact categories were quantified: Climate Change (CC), Consumption of Primary Energy (CPE), Terrestrial Acidification (TAc), Freshwater Eutrophication (FEu), Agricultural Land Occupation (ALO), and Natural Land Transformation (NLT). These estimates came from the application of the following Life Cycle Impact Assessment methods: IPCC 2007 GWP 100a for CC; ReCiPe Midpoint (H) – v.1.11 for FEu, TAc, ALO, and NLT; and Cumulative Energy Demand (CED) – v.1.01 for CPE.

3. RESULTS AND DISCUSSION

Figures 2-4 show the results of the study. The impact of the generation of 1.0 MWh in Brazil has two distinct stages within the analyzed period. The first one, 2006-2011, dominated by hydroelectricity (73.2-77.3%); the second one begins in 2012 with an increase in the role of thermoelectricity, with a prevalence of 22.5% in 2013. Out of this total, the largest portion comes from fossil fuels, such as natural gas, oil, and coal, which have been taking over the hydroelectric plants. This evolution is corroborated by CPE results shown in Figure 2.

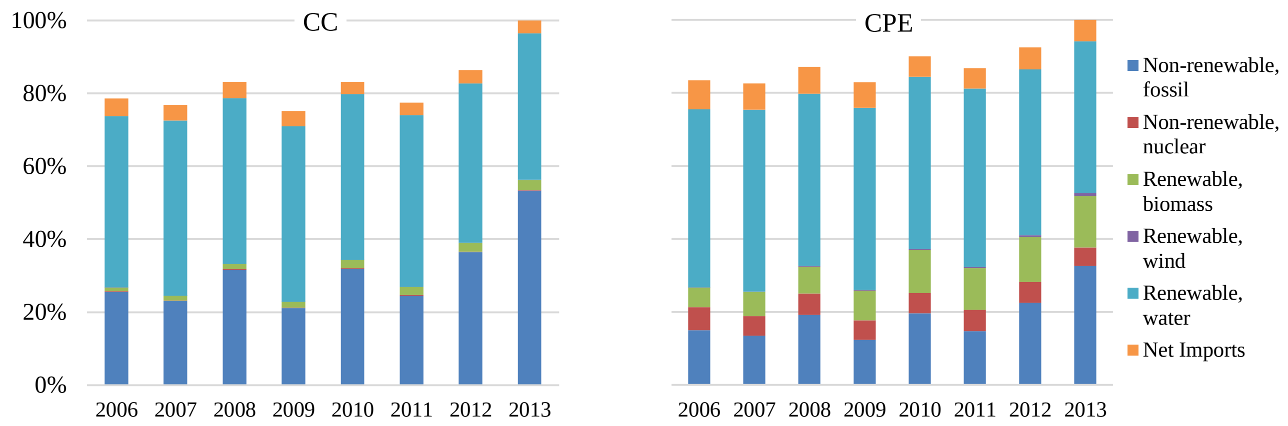

Figure 2. Impact on Climate Change and Consumption of Primary Energy

The increase in the use of "Renewable, biomass" as a primary energy source was prompted by an increase in the use of sugar cane bagasse. Under CC, the emissions in 2009 accounted for 75% of the emissions in 2013.

Figure 3. Impact on Freshwater Eutrophication and Terrestrial Acidification

The prominent use of fossil fuels leads to increases in FEu and TAc (Figure 3). The impact on FEu in 2009 was only 46% when compared to 2013; as for TAc, emissions in 2009 were 53% of the emissions in 2013.

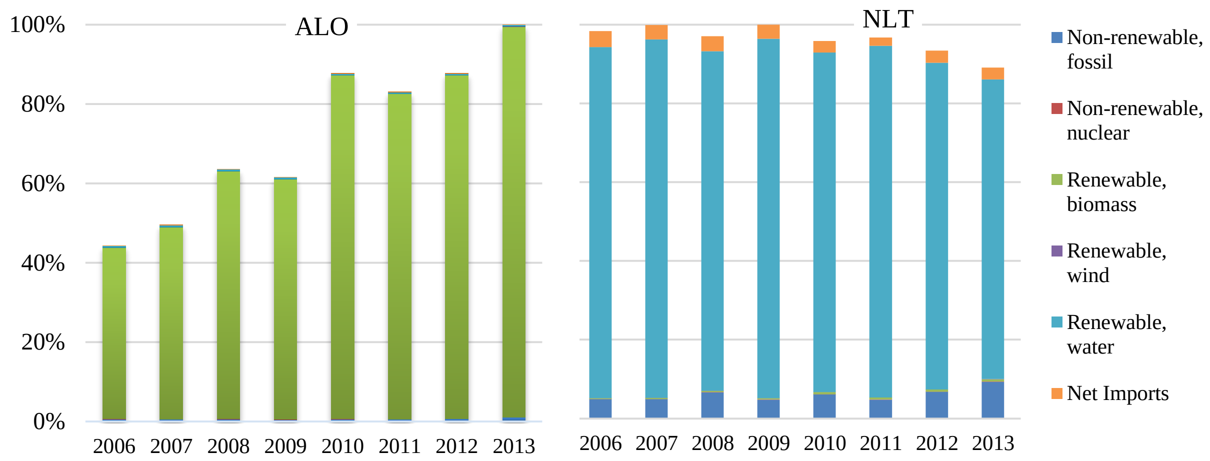

Figure 4. Agricultural Land Occupation (m^2a) and Natural Land Transformation (m^2)

According to Figure 4, the vast majority of the impact on ALO is due to the use of biomass — sugar cane bagasse (75%) and firewood (25%) — used in thermoelectric plants. This result was expected because of an increase in "Renewable biomass" in the national grid, as shown in Table 1. This occurs because of a trend in the installation of cogeneration systems in sugar and alcohol plants. NLT was the only category that showed a decrease during the period, due to a reduced reliance on hydroelectric plants.
Figure 5 compares CO_2 emissions divulged by MCTI [3] with GHG values totaled for the entire LC.

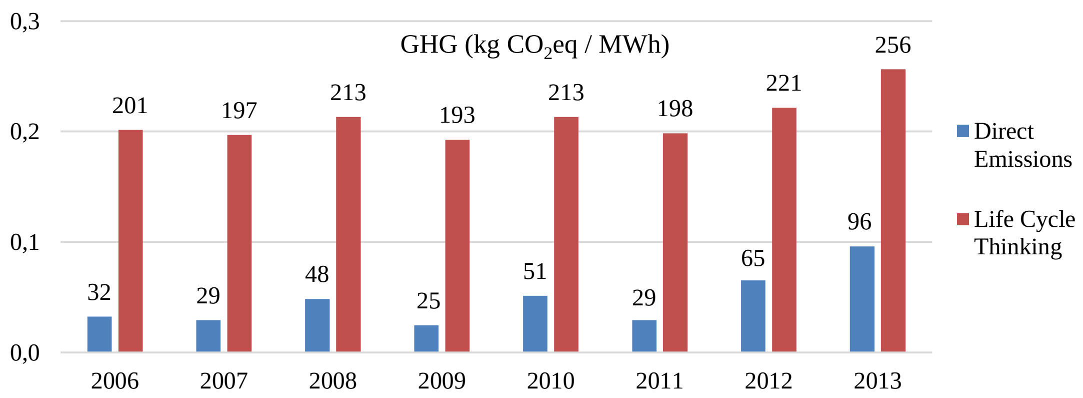

Figure 5. GHG emissions of the Brazilian electricity grid according to different approaches

It should be noted that there is a similar trend of increase and decrease in both methods, regardless of the values. This behavior shows the significant influence of "Non-renewable, fossil" in the LCT results, even during the 2006-2011 period in which hydroelectricity was prevalent. In 2008 and 2010, years in which hydroelectricity use was lowest (73.2% and 73.3%), the R coefficient — which measures the ratio of emission data between LCT and MCTI — is at a low for the period (4.44 and 4.18). In other years, when hydroelectricity ranges from 75.5-77.3%, the ratio increases, $6.28 \leq R \leq 7.72$. Thus, when the role of fossil fuels in the grid increases, the values from the two methods get closer, thus $R \rightarrow 1.0$. This occurred in 2012 and 2013, when the lowest R-values of the period were found (3.40 and 2.67).

4. CONCLUSIONS

The present study has analyzed, within a LCT perspective, the environmental impact caused by the variation in sources of electricity in the Brazilian grid. In addition, the CO_2 emission data derived from the use of fossil fuels, as divulged by MCTI, was compared with LCT data, so as to discuss specific aspects of both methodologies in terms of Energy Planning. The results have led to believe that the increase in the role of thermoelectric plants using fossil fuels in the Brazilian grid has also caused it to become more polluting. This trend, observed in terms of CC and CPE, is also seen in other impact categories: FEu, TAc, and ALO.

Comparison with the LCT model has revealed that the MCTI emission data are underreported. The results of both cases, however, are compatible in terms of variation trends. It seems that the upward trend in the role of thermoelectric plants will be confirmed. The MCTI has not yet published its 2014 report, but it can be projected from the available data the figure of 134 kg CO_2/MWh, which is 40% higher than what was reported in 2013. More detailed studies on this topic are encouraged in order to better plan reductions in environmental and economic impacts of the electricity sector.

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LIFE-CYCLE ASSESSMENT OF PASSIVE CONSTRUCTION: STRATEGIES FOR A RESIDENTIAL BUILDING

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Keywords Life-cycle assessment (LCA), construction passive options, house

Abstract *The aim of this research is to analyze the influence of simple passive construction measures and heating systems for a single-family house located in Coimbra. Using the life-cycle assessment (LCA) methodology, the following passive construction strategies were assessed: 3 alternative exterior envelope solutions (double brick, concrete and wood walls), 5 different insulation thicknesses levels (0-12 cm), and 4 total ventilation levels (0.3-1.2 ac/h). Regarding the heating system, the following alternatives were analyzed: a heat pump, a natural gas condensing boiler, and electric space heaters.*

A life-cycle (LC) model was implemented for the single-family house including 3 LC phases: construction, maintenance, and operational phase (heating and cooling) and considering a 50 years life span. The heating and cooling energy loads have been obtained using thermal dynamic simulation for a "permanent operational pattern" (100%) in order to guarantee annual interior set-points between 20ºC and 25ºC. However, based on Portuguese statistical data and actual measurements of domestic energy consumption, a more "realistic operational pattern" was considered assuming only 20% of the simulated energy results, this accounts for the so called "prebound effect" which is typical of Portuguese dwellers behavior.

The results show that the heating system selected has a high influence on LC results and on the insulation level LC benefit. A house with a heat pump system has the lowest impacts for most categories (non-renewable primary energy, GWP, Abiotic depletion and OLD). Regarding the LC energy, there is a tipping point on the insulation thickness (around 9 cm), for which the life-cycle energy is reduced, although the LC benefit of adding more insulation than 6 cm, is less that 2% for all ventilation scenarios. In contrast, the electric resistance heaters, often used in Portuguese homes, have the highest LC impact for all environmental categories, (a 20-100% increase when compared to the heat pump system).

The results also show that embodied impact of Portuguese single family houses should not be neglected. Depending on the ventilation rate, insulation level, and mainly on the heating system, the construction phase may hold the majority of impacts, which reinforces the need of using a life-cycle perspective when trying to define guidelines for new houses development and existing houses refurbishment.

INTEGRATING USER TRANSPORTATION IN THE LIFE-CYCLE ASSESSMENT OF BUILDINGS

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Keywords Environmental assessment, Commuting, Primary energy, Greenhouse

Abstract *Like most European cities, the Lisbon metropolitan area has expanded in population and in geographical scope in the last decades, and travel demand, vehicle ownership, and vehicle use has increased significantly. Transportation needs, as well as the resulting environmental impacts, are influenced by land use planning. Building locations, both work and residential, affect mobility patterns and should therefore be considered in environmental assessments. Neglecting transportation needs can result in the shifting of impacts. For example, an otherwise energy efficient building in a suburban area that has low accessibility would appear to have good environmental performance in terms of embodied and operational requirements, but the higher transportation demands of the building occupants can offset these energy savings and lead to significant environmental impacts.*

This paper explores the linkages between land use and environmental impacts associated with buildings and transportation. It draws on a life-cycle (LC) energy and greenhouse gas (GHG) analysis of inner city and suburban dwellings in Lisbon. The analysis included building construction, building operation and user transportation (commuting). The results showed a significant contribution of user transportation. In cases, primary energy and GHG emissions associated with commuting, exceeded the overall building impacts over a 50-year lifespan (including construction and operational requirements). Moreover, suburban dwellings had 50 to 130% higher LC energy and GHG emissions than those in central locations, mainly due to transportation demand, which was dominated by car use with low occupancy rates. The results highlight the need for urban development strategies and policies that jointly consider the transport infrastructure and accessibility, together with building efficiency. Due to the diversity and complexity of interlinked factors that influence environmental performance, site-specific assessments are needed to identify potential improvement opportunities. Future work should further explore the environmental impacts of commuting in Lisbon, and extend the life-cycle approach that integrates vehicle-associated emissions and associated environmental impacts.

A DYNAMIC FLEET-BASED LIFE-CYCLE APPROACH TO ASSESS GREENHOUSE GAS EMISSIONS FROM ELECTRIC VEHICLE ADOPTION

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Keywords Battery electric vehicles, fleet model, life-cycle assessment

Abstract *The adoption of electric vehicles (EVs) has been promoted as a way of reducing greenhouse gas (GHG) emissions in the transportation sector. Assessing the environmental impacts of the transition to this new technology requires a holistic, fleet-based approach, rather than a static single-product life-cycle assessment. A fleet-based life-cycle approach is able to capture the overall environmental effects of technology turnover by taking into account the set of units in service and its evolution over time, including boundary conditions (e.g. electricity mix) and technology developments (e.g. fuel consumption improvements). This is important because: the substitution of conventional vehicles by electric vehicles does not occur immediately, but rather during a considerably long period; EVs do not instantaneously gain 100% market share, which means that the production of conventional technologies may persist for a long time; and even if their production ceases, conventional vehicles do not abruptly disappear from use, as they have a long service life. This paper aims at assessing the life-cycle GHG emission reduction potential of the introduction of EVs in the Portuguese car fleet across different scenarios. Fleet LC GHG emissions will be assessed by implementing a dynamic fleet-based life-cycle model of the Portuguese passenger car fleet (up to 2030), featuring three vehicle technologies: gasoline ICEV, diesel ICEV and battery EV (BEV). The effect on the results of changing different model parameters, such as BEV fleet penetration rate, electricity GHG intensity and new ICEVs fuel consumption improvements, will also be addressed. Finally, the application of the model to derive conclusions for policy-making will be explored and recommendations for future research provided.*

INDUSTRIAL SYMBIOSIS POTENTIAL IN TRADITIONAL INDUSTRIES: THE CASE OF THE FISH CANNING INDUSTRY IN PORTUGAL

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Keywords Industrial Symbiosis, Fish Canning Industry, Portugal, Literature Review, SWOT Analysis Matrix

Abstract *Industrial Symbiosis (IS) is increasingly being recognized as a fundamental strategy for the advancement of Circular Economy across regions and countries. This is particularly evident in the European Union and among its member countries, where more ambitious waste and resource related efficiency goals and objectives demand for integrative top to bottom action, from policies to business strategies, across industries.*

The analysis of IS potential in traditional industries or established clusters could render additional positive impacts, since these are typically long-term, regionally embedded industries, with strong social and economic ties to the community. Analysing the potential for IS in these sectors/regions could open opportunities in terms of dissemination of good-practices or expansion of cluster businesses, thus shaping the context towards favouring IS as a common business operation.

The present paper takes this premise and sets out to explore the potential for IS in one of the Portuguese most traditional industries – fish canning – which in turn is embedded in one of the main industrial clusters supported by the National Government, the Sea Cluster. Based on the identification of the industry's main inputs and outputs, the researchers explore the potential for the development of new business ventures within the cluster, thus strengthening its economic impact based on improved resource efficiency.

The analysis reported in this paper indicate that there are synergies not yet identified as IS (by-product synergy: effluents turned into fishmeal) and that several IS opportunities (by-product synergy: collagen recovered from fish residues) require further study to be implemented.

1. INTRODUCTION

The limited availability of Earth's natural resources [1] coupled with a rapid increase in waste production [2], has lead researchers, practitioners and policy makers to rethink materials' networks in order to reduce impacts on the environment and on human health [3]. One of such approaches is provided by Industrial Ecology (IE), by which the economy and the industry are seen as organisms that consume the natural resources, metabolize them into goods and services, and release waste materials which are reintroduced in the natural systems, either by means of resource recovery – secondary raw materials extracted from waste – or by Industrial Symbiosis (IS) – waste flows are consumed by dissimilar industries as raw materials [3] [4].

The research presented in this paper seeks to apply the paradigm provided by IE and IS in particular, to a traditional business cluster in Portugal – the fish canning industry. Traditional industries provide interesting case studies since they are commonly rooted in socially close communities, where interaction is expected to be more easily facilitated.

This short-paper is divided into six parts. After a short introduction, it follows a literature review on the main concepts used. The paper then describes the policy context on which the research was developed, from international to the local level. Sections 4 and 5 present and discuss the main results of the IS analysis and the final section presents the concluding remarks.

2. LITERATURE REVIEW

2.1 Circular Economy, Industrial Ecology and Industrial Symbiosis

Industrial Ecology rejects the concept of waste [5]. It emerges as the study of relationships between society, environment and economy to develop and implement regional resource synergies [3], thus closing material loops. Its tools and systems are drawn from the analogy with ecosystems, which are the best available example of a sustainable system: their functional principles include energy cascade and closed cycles of materials through relationships between organisms [3] from which valuable lessons of efficiency can be drawn [6]. An Industrial Ecosystem [6] is a network of relationships between industrial organizations, in which resources are shared and cycled, minimizing the waste sent to landfill, and it was first uncovered in the Danish city of Kalundborg.

Among the strategies for implementing IE is Industrial Symbiosis: the cooperation between processes within a company and between enterprises, based on the synergy of different productive activities for greater resource efficiency and environmental and economic benefits [7]. It is a business strategy dependent on the collaboration of diverse industries, centered on the use of waste/by-products instead of raw materials [8], thus promoting environmental sustainability with tools that lie at the intersection of engineering, ecology and economy [9].

Industrial Symbiosis is also an important tool in assisting the transition to a more Circular Economy [10]. Until now, the economy has mainly operated on a 'take-make-dispose' model – a linear model where every product reaches its 'end of life'. A transition to a Circular Economy shifts the focus to reusing, repairing, refurbishing and recycling existing materials and products. 'Waste' can be regarded as a resource. This concept takes the inspiration from IE and IS, by which it is best understood by looking into natural, living systems: products are intentionally designed to fit into material cycles, and as a result materials flow in a way that keeps the value added for as long as possible – and residual waste is close to zero [10].

2.2 Industrial Symbiosis and Clusters

The grouping of businesses in Kalundborg started as a cluster of industries focused on increasing groundwater protection. This type of strategy is not confined to localized production and trade of waste byproducts, and it should not be confused with industrial clusters in geographic proximity [11]. But the concepts and theories of IE and of clusters have much to learn from each other, since networks and cooperation are key aspects in both [12]. Competitive advantage can be achieved by looking beyond the company's boundaries and by forming relationships between enterprises where companies combine resources in a unique way, make exchanges that would not be possible alone, thus achieving extra profit [13].

The development of IS becomes easier when there is already a form of cooperation between stakeholders or organizations where there is great similarity between the synergies: anchor industries, recycling networks, industrial associations and industrial clusters [3]. In a cluster, the success of the company is affected by the support businesses and the surrounding infrastructures [14]. Much like IS, a cluster is also a network that can emerge within a geographic location where the proximity of firms and institutions ensures certain commonalities, increases the impact of communication and interaction [15] [16].

The geographic scope of clusters ranges from a region, a state, or even a single city to span nearby or neighboring countries. The geographic scope of a cluster relates to the distance over which informational, transactional, incentive, and other efficiencies occur [15].

3. CONTEXT DESCRIPTION

3.1. European Level

The European Commission adopted the Communication "Towards a circular economy: zero waste programme for Europe" to establish a framework to promote the circular economy through recycling and preventing the loss of valuable materials; the reduction of greenhouse emissions and environmental impacts; the creation of jobs and economic growth; showing how new business models, eco-design and IS can move Europe towards zero-waste. The Commission also aims to increase recycling/re-use of packaging waste recycling/re-use to 80% in 2030 with material-specific targets set to gradually increase between 2020 and 2030 (to reach 90% for paper by 2025 and 60% for plastics, 80% for wood, 90% of ferrous metal, aluminum and glass by the end of 2030); phase out landfilling by 2025 for recyclable (including plastics, paper, metals, glass and bio-waste) waste in nonhazardous waste landfills(maximum landfilling rate of 25%); reduce food waste generation by 30% by 2025; introduce an early warning system for compliance difficulties; ensure full traceability of hazardous waste; increase the cost-effectiveness of Extended Producer Responsibility schemes; simplify the reporting obligations of SMEs; harmonize and streamline the calculation of the targets and improve the reliability of key statistics; and also improve the overall coherence by aligning definitions and removing obsolete legal requirements.

3.2. National level: The Sea Knowledge and Economy Cluster

The fish canning sector is generally seen as the main segment of the fishing manufacturing industry at national level [17]. Several plants in operation are part of the Sea Knowledge and Economy Cluster, a limited number of collective efficiency initiatives which the Portuguese government recognized in 2009, that integrates several entities from different sectors of activity, seeks to promote cooperation among scientific institutions, it presents itself as a potential for innovation in the use and recovery of by-products from waste and it realizes the dynamic position the sector and of opportunity for new markets.

3.3 Regional Level: The Fish Canning Industry Cluster

The fish canning industry is a highly regarded industry in Portugal. In the 1960s, Portugal was the world's leading producer of the fish canning industry. Canned fish was the largest export chain. Today this sector has about 20 enterprises, modernized and internationalized [18] producing 58,500 tons of canned fish and seven of them are located north of Douro River [19]. The fish canning industry is part of the Sea Knowledge and Economy Cluster, previously mentioned, accounts for 7% of the exports of the food industry sector in Portugal and it employs about 2000 people presenting a turnover of 180 million euros [20].

4. ANALYZING THE POTENTIAL FOR IS IN THE FISH CANNING INDUSTRY

The abundance of fish and its quality, the length of coastline and the tradition of fishing, combined with the simplicity of the techniques, have created conditions for the establishment of the fish canning industry in Portugal [18].

Fish canning industry constitutes a fundamental sector for the economy of Portugal, where enterprises have an essential role in its economy, it is important to foster the sustainability through the responsible consumption of raw materials, the prevention and reduction of waste generation and the use of clean and green technologies [21].

4.1. Material Input-Output Analysis

Material input-output analysis was mainly based on literature review of several studies concerning the fish canning industry [17] [18] [21] [22] [23] [24] [25]. Based on that data, it was possible to identify the main environmental problems, and therefore the main flows on which IS should concentrate. The main environmental problems of fish canning industries are high water consumption and high organic matter, oil and grease and salt content in their wastewaters [17]. IS strategies should focus on that output, promoting the sharing of resources from by-products among industrial players to add value, reduce cost and improve the environment [26] through material flow and energy flow [27]. By-products and wastes generated from the fish processing industry are regarded as a source of highly valuable compounds, in some cases even higher in value than the starting material [23] (See Table 1.).

Table 1. Raw materials and by-products in the fish canning industry
Source: Adapted from [22] [23] [24]

Raw Materials	**By-products (example of possible compound)**
Fish, water, energy, chemicals, oils, salt and aluminum	Head, viscera (enzymes), skin, tails, scales and blood; wastewater; salting effluents (free amino acids); oil and grease.

4.2. Industrial Symbiosis Identification

In Portugal, the waste reduction approach provided by IS strategies is still very much underdeveloped, with many opportunities yet to be uncovered and/or promoted. The lack of consistent quantitative and qualitative data on material outputs is a setback that needs to be addressed, at public policy level as well as the local level, with assessment and facilitation teams. This means that the opportunities identified in this research are a first approach and need to the followed through in order to properly assess its economic and environmental impact.

Table 2. Two examples of possible IS within the fish canning industry
Source: Adapted from [3] [22] [23] [24]

By-products (example of possible compound)	**Possible Industrial Symbiosis**	**Explanation**
Head, viscera (enzymes), skin, tails, scales and blood; wastewater; salting effluents (free amino acids); oil and grease.	**By-product synergy**	Extraction of compounds from fish by-products of the fish canning industry can be used as a high valued resource in pharmaceutical applications, for instance. Biodiesel production using oil extracted from fish canning industry wastes.
	Information and knowledge synergy	Knowledge and information exchange between companies and universities allow innovation projects such as "ValorPeixe" and "BioFatRecovery".

Symbiotic relationships although existing had not yet been identified as IS (See Table 2) in the by-product synergies projects of fish canning industries (by-product from one company as input material for another; resources as water used in a closed cycle within the company) [16]. Usually «business as usual» is a synergy among customer and supplier located nearby as it is the case of the fishing fleet and of the fish canning industry in the northern region [18]. Also information and knowledge synergies where identified when there is exchange of information among companies and/or facilitated by universities or public institutions [3] as for instance the projects "ValorPeixe" and "Biofatrecovery" of the fish canning company Poveira fish canning company.

5. DISCUSSION OF RESULTS

A potential Industrial Symbiosis implementation network within the fish canning industry could be established in Portugal by integrating several opportunities. The literature review allowed collecting information that could generate a potential plan of IS, but it still lacks and thorough economic and environmental assessment.

The identification of potential strategies was made using a SWOT Matrix approach [28]. These are short-term proposals, and for them to be long-term it must involve the entire cluster in an in-depth study of materials and waste flows throughout the value chain, account for economic and environmental costs and benefits and preferably it should be sponsored by the cluster itself [16] [29]. In the specific case of the canning industry, solid waste and waste water from canned fish processing can be reduced and recovered through the recovery of compounds added value that can be applied in various industries and technical fields, and it's a process of great economic recovery and practical interest. Reductions in environmental impact and in creating new economy based on value-added compounds markets promote sustainability and competitiveness of canning industries [23]. Several key-elements to develop strategies for the implementation of Industrial Symbiosis within the fish canning industry were identified such as the innovation capacity of this type of industry and its energy and water costs, the diminishing of fish stocks and the circular economy strategy within the European Union.

6. CONCLUDING REMARKS

Moving to a truly circular economy could require a mixture of different business models and product and service innovation, where consumers and policymakers also have a central role. But it is possible to rethink how things are made and used. The companies that are starting now may well define the future of sustainable business, enabling global prosperity on a crowded planet with finite resources.

In Portugal, the Industrial Symbiosis approach could be achieved within the scope of annual projects. These projects could be carried out by entities with the consultancy of universities and municipalities; and financed by the European Union, the governments and companies. The general objective of the projects would be the introduction of Industrial Symbiosis into an area as a mechanism to increase the collaboration and solidarity between companies for the purpose of achieving both environmental and economic improvements in the region, as well as creating a background for a national program that shows waste is not just waste and transforms our current model of production and consumption into a resource efficiency economy.

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SYNERGIES FOR DECENTRALIZED BIOGAS AND FERTILIZER PRODUCTION - RESULTS OF AN INDUSTRIAL SYMBIOSIS PILOT EXPERIMENT IN PORTUGAL

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Keywords Pilot experiment, anaerobic co-digestion, organic wastes synergies, decentralised biogas production, industrial symbiosis.

Abstract *A biogas system in a livestock farm, dedicated to the treatment and valorisation of slurry, from the point of view of industrial ecology can be considered an industrial unit with which synergies can be developed with local use of by-products, energy, or waste. In order to be established, anaerobic co-digestion technology plays a key role once it allows the integration in a biogas production process of a multiplicity of organic streams produced in the region and simultaneously the production of a co-product with agronomic value.*

This study aimed to demonstrate, the effectiveness of anaerobic co- digestion of pig slurry (PS), fruit wastes (FW) and wasted sardine oil (WSO) at farm level. During one year, a biogas mobile pilot plant was operated in real conditions, in a pig farm. Mesophilic (35 - 37˚ C) continuous trials were performed within organic loading rate (OLR) range of 1,6 kg COD/$m^3.d^{-1}$ and 5,2 kg COD/$m^3.d^{-1}$.

FW after a bioconversion pre-treatment (BFW) are an excellent co-substrate. When compared with the mono-substrate digestion of pig slurry (%v/v) PS:BFW of 100:0, a composition (%v/v) PS:BFW of 70:30 and 34:66, increased the productivity of the digester respectively 3 and 3,6 times. Trials with WSO concluded that a composition (% v/v) PS:WSO of 95:5, could increase in a 3,7 fold the digester productivity.

Process stability indicators pH and T-VFA/BA ratio, suggests that a co-digestion process designed with compositions of PS:BFW and PS:WSO can be robust. On the other hand thanks to the bioconversion pretreatment of FW and the complementary seasonality was concluded the possibility to use in farm scale biogas plants FW and WSO throughout the year.

BARRIERS AND OPPORTUNITIES OF WASTE VALORISATION IN RICE AGROINDUSTRY

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Keywords Co-gasification, Co-pyrolysis, Energy recovery, Wastes, Rice

Abstract *Rice is one of the most consumed cereals worldwide. In Portugal, rice is the third most produced cereal and the one with the highest productivity. Rice straw (RS), rice husk (RH) and plastics (PL) are the main residues from rice production and processing. Although these residues are adequate for energy valorisation through thermochemical processes, no valorisation route is performed in Portugal – RS is mostly burnt in rice fields; RH is used as animal feed and bed material; PL are sent for recycling. In this context, the main aim of this work was to determine the technical and economic barriers and opportunities for the recovery of rice residues. The quantities of rice residues produced in Portugal were estimated through surveys on rice producers and processing industries. Based in a bibliographic review, the chemical and physical properties of each residue were analysed, as well as their behaviour when subjected to gasification and pyrolysis. RS is the most abundant (1.21 $t.ha^{-1}.y^{-1}$) waste in rice culture and the one with the lowest valorisation ability. Based on the surveys, RH was quantified as 0.126 $t.t^{-1}$rice produced. RH is the hardest biomass to be gasified and the most suitable gasifier seems to be the fluidized bed reactor. The amount of PL (0.0016 $t.t^{-1}$rice produced) is very low when compared to biomass wastes. PL wastes present the best valorisation conditions in terms of energetic content, but as they are mostly recycled, the energetic valorisation is difficult to implement. The estimated purchase (30 $€.t^{-1}$) and transportation (0.875 $€.t^{-1}.km^{-1}$) costs of RH were the highest costs of all wastes and a significant barrier for its valorisation. RS and RH have the low density as a common barrier, which implies a pre-densification process. One of the biggest opportunities regarding the valorisation of these wastes lies in the fact that their production is centralized in 4 counties located close to each other. Co-gasification and co-pyrolysis of these wastes may increase the yield and quality of products, which is a strong technical opportunity to support their energetic valorisation.*

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the second most produced cereal in the world, being a common food consumed by over 2 billion people (80 $kg.person^{-1}.year^{-1}$ in Asian countries and 10 $kg.person^{-1}.year^{-1}$ in USA and European countries). Its production is mainly located in Asia (611.7 Mt in 2009). It is estimated that rice will be consumed by twice of the current consumers in 2025 [1]. At the European level, Portugal is the fourth largest producer and the highest consumer of rice (18 $kg.person^{-1}.year^{-1}$) [2]. As a sustainable annual crop, rice cultivation, harvesting and processing generate wastes every year [3]. Several solid wastes are produced in different amounts and present different properties [4]; the most important solid wastes are rice straw (RS), rice husk (RH), plastics (PL) from phyto-pharmaceutical packages and rice packages, and cardboard generated in the packaging process of final product. The solid waste produced in rice cultivation, harvesting and processing might be subjected to energy recovery by thermo-chemical technologies as gasification and pyrolysis (for example, [5,6]). This strategy could reduce the waste volume and produce renewable fuels that might be used in rice cultivation, harvesting and processing which should contribute to the reduction of energy costs and GHG emissions. Unfortunately, this strategy is not used in the Portuguese rice agro-sector.

The main aim of this study was to identify the techno-economic opportunities and barriers of the energetic valorisation, through co-gasification and co-pyrolysis, of solid wastes produced in the Portuguese rice agro-sector, in order to promote its economic and environmental sustainability.

2. METHODOLOGY

The present study was based on a systematic bibliographic review and two surveys conducted on rice producers and processing industries. The systematic bibliographic review was performed in English and Portuguese languages, within a time span from 2000 to 2014, without any geographic restriction. Scientific databases were used in the bibliographic search (e.g. Science Direct, Springer Link, B-on), as well as databases from organizations on food issues and statistics, as FAO and the Portuguese Institute on Statistics (INE).

The two surveys on rice Portuguese producers and processing industries were representative of 37.53% (11260 ha) of the rice cultivated area in 2013 (30000 ha). Among the responding entities, three organisations were from Lisboa and Vale do Tejo region, other two were from Alentejo region and another one belonged to the Middle region of Portugal. These are the most important rice producing regions in the country.

3. RESULTS AND DISCUSSION

3.1. Rice production and waste generation

Rice is produced in 112 countries worldwide and is the second most produced cereal, just after corn. Asia is the leading continent in rice production (611.7 Mt in 2009) and rice cultivated area (143.4 Mha in 2009), followed by America and Africa (Table 1).

Table 1. Rice production, cultivation area and rice productivity per continent in 2009 [2]

Continent	Production (*10^6 t)	Cultivation area (*10^6 ha)	Arable land (*10^6 ha)	Yield ($t.ha^{-1}$)
Africa	24.4	10.0	222.80	2.44
America	38.2	7.3	365.43	5.25
Asia	611.7	143.4	470.28	4.36
Europe	4.1	0.7	276.99	6.14
Oceania	0.3	0.04	45.02	8.03

According to a more recent estimate [7], the annual rice production in Europe is of 4.4 $Mt.year^{-1}$, with an average yield of 5.8 $t.ha^{-1}.year^{-1}$. In Portugal, rice is the cereal with the third largest annual production (182 kt in 2011), after maize and wheat, with a cultivated area of about 30000 ha and a productivity yield of 5.8 $t.ha^{-1}$ [7].

The main solid wastes generated during rice cultivation, harvesting and processing are rice straw (RS), rice husk (RH), plastics (PL) from phyto-pharmaceutical packages, from rice packages and from old big-bags used in rice transportation, and cardboard generated in the packaging process of final product. Table 2 shows the relative amounts of RS, RH, and PL obtained from the surveys carried out to rice producers and rice processing industries.

Table 2. Relative amounts of the different solid wastes produced during rice cultivation, harvesting and processing based on the surveys performed

Waste type	Relative amount generated
RS	1.21 $t.ha^{-1}.year^{-1}$ 0.09 $t.t^{-1}_{rice\ produced}$
RH	1.64 $t.ha^{-1}.year^{-1}$ 0.126 $t.t^{-1}_{rice\ produced}$
PL	0.021 $t.ha^{-1}.year^{-1}$ 0.0016 $t.t^{-1}_{rice\ produced}$
Cardboard	0.0076 $t_{card}.ha^{-1}.year^{-1}$ 0.00058 $t.t^{-1}_{rice\ produced}$

3.2. Quantitative and qualitative properties of solid wastes from rice production and thermo-chemical valorisation routes

The solid wastes from rice production present different properties (Table 3). Despite of the high SiO_2 content of RS and RH, the amounts and chemical composition of these wastes are adequate for thermo-chemical valorisation through either pyrolysis or gasification [6,9]. The high LHV of PL and the absence of ashes in this waste make it an interesting co-fuel to be used in blends with RS and RH to be submitted to co-pyrolysis or co-gasification [8].

Table 3. Quantitative and qualitative properties of solid wastes generated in rice production

Waste type	RS	RH	PL	Ref.
Estimated production in Portugal (1)	36300 $t.year^{-1}$	49200 $t.year^{-1}$	630 $t.year^{-1}$	Surveys
Proximate analysis (w/w db)	Cellulose: 32.0-60.3% Ashes: 11.4-15.4% LHV: 13.73 $MJ.kg^{-1}$	Fibres: 45.9% Ashes: 8.5-21.0% LHV:13.65 $MJ.kg^{-1}$	Synthetic polymers No ashes LHV: 41.50 $MJ.kg^{-1}$	[1,3,5,6,8]
Ultimate analysis (w/w db)	C: 33.96-44.82% H: 5.01-6.62% O: 37.2-48.3% SiO_2: 22-28% High mineral content	C: 38.5-46.6% H: 4.61-5.6% O: 36.6-49.3% SiO_2: 20-24% Low mineral content	C: 62.1-90.5% H: 4.8-14.5% O: 22.8% High concentration of certain metals, as Ti	

(1) Assuming an average production area of 30000 ha

4. BARRIERS AND OPPORTUNITIES

Many studies have been published in the last 14 years on the valorisation of RS, RH and PL through pyrolysis and gasification. Due to the limited space, not all of them are referred here. Nevertheless, no one was identified on the co-pyrolysis and co-gasification of blends of these wastes. As stated above, the chemical properties of these wastes point out for the possibility of getting high quality products on the co-pyrolysis and co-gasification of these wastes. However, other opportunities and barriers may appear when these technologies are assessed as energetic valorisation options for blends of RS, RH and PL in Portugal. The most important barriers and opportunities identified in this work are presented in Table 4.

Table 4. Barriers and opportunities of energy recovery by co-pyrolysis and co-gasification of RS, RH and PL in Portugal

Waste type	Barriers	Opportunities
RS	• Seasonal production • Variable production over the years • Low density • Fibrous structure hindering boiler feeding • High costs of collection/densification (20 €.t^{-1}) and transportation (0.175 €.t^{-1}.km^{-1})	• Centralized production in 4 counties located close to each other • There is no route of energy recovery • Can be valued by gasification and pyrolysis
RH	• Intrinsic economic value of acquisition (30 €.t^{-1}) • Low density • High costs of transportation (0.875 €.t^{-1}.km^{-1})	• Centralized production in 4 counties located close to each other • Can be stored by silage • Can be valued by gasification and pyrolysis
PL	• Higher density than for RS and RH • European and national legislation encourage recycling	• High C-content • High LHV • Can be valued by gasification and pyrolysis • Lower transportation costs (0.140 €.t^{-1}.km^{-1}) than for RS and RH

5. CONCLUSIONS

High amounts of RS and RH are produced annually in Portugal in the rice agro-sector. Much lower amounts of PL are produced than those of bio-wastes, but its use in the co-pyrolysis and co-gasification of RS and RH might increase the quality of the final products. Therefore, in the technical point of view, the co-pyrolysis and co-gasification of blends of RS, RH and PL seems to be possible and advantageous for the energetic valorization of these wastes.

Nevertheless, some constraints appear when these technological options are considered as valorization routes for those wastes. The low density of RS requires a densification process, which increases its collection cost. The low density and high intrinsic economic value of RH increase its costs of acquisition and transportation, making this waste very difficult to be considered in either a co-pyrolysis or co-gasification valorization route. Therefore, new assessments are needed on the establishment optimization of the thermo-chemical plant, and also on the evaluation of other available wastes that can be mixed with rice production wastes and subjected to either co-pyrolysis or co-gasification.

ACKNOWLEDGMENT

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INTEGRAL SIMULATION-OPTIMIZATION APPROACH FOR ECODESIGN OF FOOD MANUFACTURING PROCESSES

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Keywords Ecodesign, Food Life Cycle Assessment, Food manufacturing processes, Sustainable food industry

Abstract *Ecodesign of food manufacturing processes aims at optimizing their environmental, technological and socio-economic performance while securing the overall quality of the food. Cumulative legislative, economic and ecological pressure along with a growing demand for food in developing and emerging, and functionalized food in Western countries call for revision of the state-of-the-art food manufacturing. The aforementioned constraints merely reduce the degrees of freedom with respect to both design and process control and prevent the search for a real compromise between the different and often conflicting technological, economic and environmental objectives of a process. The purpose of this paper hence is to propose an integral simulation-optimization ecodesign approach (ISOA), especially designed for food manufacturing processes and to address the research questions in order to promote a sustainable food industry. The ISOA encompasses simulation of both the production of utilities and the food process itself considering the generation of waste, wastewater and by-products in addition to environmental and socio-economic impact assessment, multi-objective optimization and multi-criteria decision-making thus directing at an optimal process control. The ISOA likewise considers the food quality including bacterial safety and the nutritional, techno-functional and gustative properties of the food product. However, implementation of the ISOA proves difficult due to the deficient understanding of the impact of processes on the food properties and the subsequent lack of models. Therefore, as a basis, systematic data acquisition is essential with particular focus on the influence of process parameters on the different food properties. Quantitative indicators representing the food quality need to be established. The development of dynamic models for food manufacturing processes is necessary integrating the inevitable cleaning stages. Ultimately, advancement in environmental and socio-economic impact assessment including standardization of evaluation procedures to provide reliable indicators and results is also required.*

1. INTRODUCTION

Ecodesign aims at reducing the environmental impact of a product, a process or an entire system in due consideration of socio-economic aspects and can thus be regarded as an approach for putting sustainability into practice. Ecodesign of processes can thus be of use to the food industry, which currently meets the challenge to review its state-of-the-art food manufacturing in the face of its increasingly identified environmental impact and a growing population [1-3]. Food manufacturing processes are of paramount importance with regard to both their environmental and socio-economic impact given that more than 70% of the agricultural goods produced in the European Union (EU) are transformed into other industrial products [4]. As an intermediate step in the entire food supply chain, food processing has furthermore the potential to reduce the wastage in the consumption, for example, through extension of the shelf life of food products. Some isolated attempts to improve the environmental and/or the economic performance of food manufacturing processes have already been made. However, a holistic ecodesign approach offering a real compromise between the different and often conflicting technological, socio-economic and environmental objectives of a process has not yet been proposed. The purpose of this paper therefore is to offer an integral simulation-optimization ecodesign approach (ISOA) especially designed for food manufacturing processes and to expose the research questions that still need to be addressed in order to promote a sustainable food industry.

2. ECODESIGN OF FOOD MANUFACTURING PROCESSES

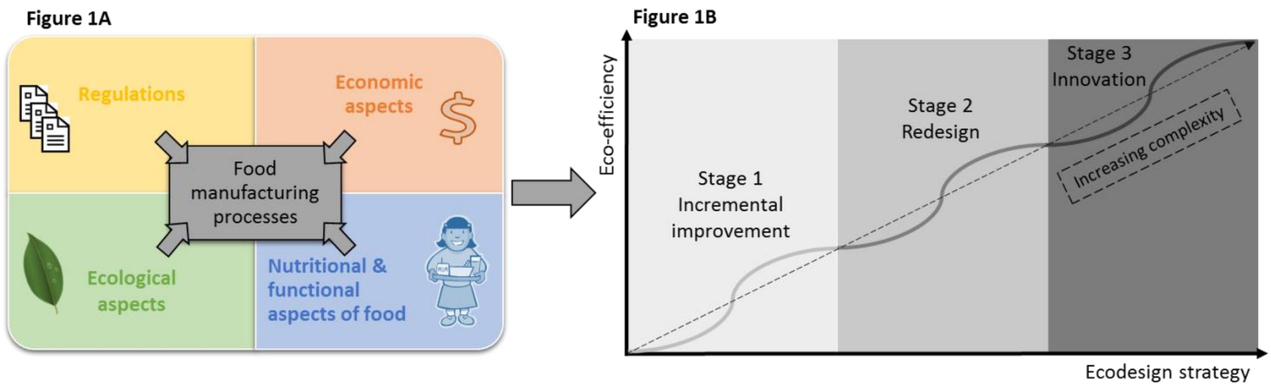

Figure 1. **A**: The food manufacturing industry is facing numerous constraints;
B: The three stages of ecodesign [3]

The food manufacturing industry must simultaneously address different legislative, economic and ecological requirements in addition to nutritional and functional objectives for food products (Figure 1A). These constraints typically reduce the degrees of freedom thus leading to a highly restricted process control and design. Ecodesign allows respecting the different constraints while proposing a feasible process control. Its implementation can be quantified in terms of eco-efficiency, which, in turn, can be regarded as a direct measure of both the environmental and economic performance of a system [5]. Eco-efficiency can basically be achieved through minor adjustments, redesign or major modifications of the entire system corresponding to the 3 stages concept repeatedly found in literature (Figure 1B, [6]). Figure 1B displays the different ecodesign stages and their effects on the eco-efficiency of the process. The sigmoid run of the curve illustrates that at a certain stage, application of an approach will no longer increase the eco-efficiency of the process thus demanding a more advanced one. Incremental improvements (stage 1) cover minor adjustments that help reducing the consumption of both water and energy and the generation of waste. Such measures include process control, good housekeeping, maintenance, efficient equipment in addition to reuse of water, recycle of waste and valorisation of accruing by-products and they do not affect the properties of the food product. Redesign (stage 2) includes emission reducing end-of-pipe technologies, optimization of the sequence of operational units and alternative, at best more efficient technologies. If a process is to be redesigned, it is generally advisable to avoid both non-isothermal mixing and thermodynamically irreversible processes as far as possible. Redesign strategies can, however, modify the properties of the product thus requiring a thorough assessment to avoid compromising the quality of the food product. Innovation (stage 3) will have the highest impact on the eco-efficiency of a process. The innovation can affect the manufacturing process (for example implementation of the concept of a "dry factory" for production of powders based on dry ingredients) but it can also imply changes in the function of a food product (for example health altering foods). Several ecodesign strategies can be attempted each having a different impact on the improvement of the eco-efficiency [3]. Three main approaches can basically be considered: comparative assessment, flow minimization and the integral simulation-optimization approach (ISOA), which can basically be utilized at all ecodesign stages. In this paper we discuss the ISOA, which is intended to stimulate innovation of food manufacturing processes.

3. THE INTEGRAL SIMULATION-OPTIMIZATION ECODESIGN APPROACH

To achieve maximal improvement of the eco-efficiency of food manufacturing processes it is crucial to apply a far-reaching ecodesign approach including a systematic analysis of the manufacturing process and consideration of the generation of utilities, the environmental, and socio-economic performance of the process as well as potential effects on the product. This is offered by the ISOA illustrated in Figure 2, which allows a reasonable compromise between the different objectives.

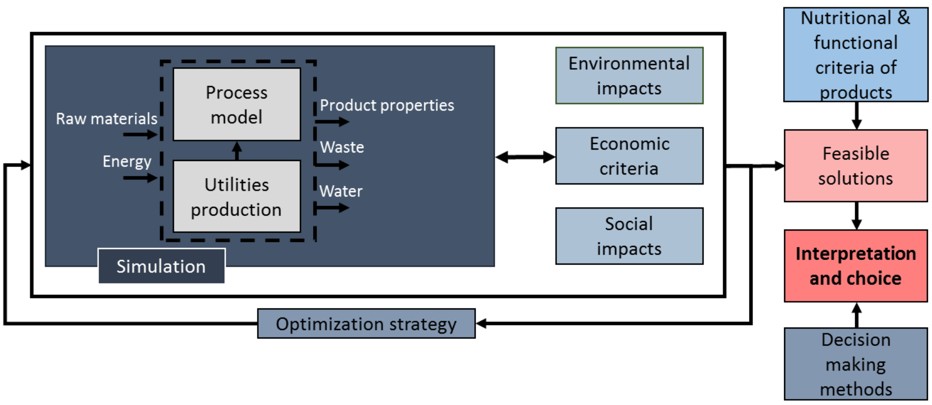

Figure 2. The integral simulation-optimization approach (ISOA) adapted from [7]

The ISOA (Figure 2) is adapted from the chemical sector [7]. It represents an ambitious and systemic approach that is also very data demanding. Models of food processes are at the core of the ISOA. On the one hand, the models enable prediction of both the quantitative and qualitative characteristics of flows under different process conditions while avoiding time-consuming and costly experiments. On the other, they are also expected to forecast the quality of the food product, particularly with respect to bacterial safety but also regarding the nutritional, functional, technological and gustative features of the final product. Food processes generate environmental and socio-economic impacts that are assessed by use of consistent evaluation methods [3]. Two different basic approaches have already been presented to couple process modelling with environmental impact assessment tools either through integration of the evaluation model into process simulation [8] or vice versa [9]. The latter approach, however, jeopardises the detailedness of the process model thus being of limited use for complex food products such as milk, which contains more than 2,000 different molecules. A number of possibly conflicting variables and parameters characterizing the manufacturing process is obtained and, subsequently, a reasonable compromise between these needs to be found through use of specific optimization methodologies. A high number of indicators can render the optimization process very time-consuming due to limited computing power or it can even impede the optimization leading to no feasible solution. In that case, single indicators need to be removed from the optimization process and eventually considered at the stage of decision-making. One particular process control will typically not be able to meet all the different constraints thus leaving the choice between various process designs and operating conditions to the decision-maker. The decision-maker can put more weight on certain aspects and, supported by different decision-making tools he can select a particular process among the optimal ones. Implementation of the ISOA remains challenging, particularly due to a high deficiency of dynamic models for food processes [10]. The poor understanding of the impact of manufacturing processes on the properties of complex foods and the subsequent development of models for food processes is furthermore complicated by a lack of data at industrial scale. Hence, it is paramount to increase efforts in order to understand the impact of processes on the different food characteristics and to acquire data on the consumption of energy, water and other materials in food processing plants [11], even if in some cases missing data can be estimated [12]. Additionally, knowledge integration (KI) can be used to integrate and quantify the relationships between the different operational and state variables of the process and the objectives to be optimized including properties of the end product [13]. In this context, establishment of nutritional and functional indicators for food products needs to be emphasized. Apart from that, there is also a need for research on different methodological problems in connection with various assessment methods. Lastly, the challenge remains to couple the individual steps of the ISOA in order to create a single, user-friendly ecodesign model.

4. CONCLUSIONS

The need for improvement of the eco-efficiency, respective sustainability of food manufacturing processes as a result of accumulating legislative, economic and ecologic pressures justifies the use of ecodesign. For this purpose the integral simulation-optimization ecodesign approach (ISOA) is proposed. It consists of modelling the production of utilities and the food process itself to predict the performances of the system, assessing both the environmental and socio-economic impacts, applying optimization strategies in addition to decision-making methods to find an optimal process design while considering the nutritional and functional properties of the food product. Application of the ISOA is currently impeded by a lack of models for many food processes and deficiently accessible data. Therefore, it is recommended to stimulate data collection on industrial scale in addition to a better understanding of food process, predominantly the effects of process parameters on the food properties, which is also of particular importance for the development of dynamic models. Furthermore, methodological challenges with respect to evaluation procedures must be overcome before a single, holistic and user-friendly ISOA model can be created.

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END-OF-LIFE MANAGEMENT STRATEGIES FOR NATURAL CORK STOPPERS THROUGH LIFE CYCLE ASSESSMENT

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Keywords Environmental impact, Incineration, Landfilling, Life cycle assessment, Natural cork stoppers, Recycling

Abstract *Currently, there are no LCA studies analysing in detail the end-of-life stage of natural cork stoppers. Cork is usually treated as wood in the available literature and only one end-of-life destination, namely, landfilling is considered. The present study focuses on a Life Cycle Assessment (LCA) approach of various waste management strategies for used natural cork stoppers quantifying both their environmental impact and avoided burdens.*

The alternatives studied include various scenarios, as follows:

- *Incineration in a municipal solid waste incinerator with electricity generation (Scenario 1) and electricity and heat generation (Scenario 2) considering as avoided burdens the avoided energy generation by natural gas.*
- *Combustion in a biomass combustion installation with electricity generation (Scenario 3) and electricity and heat generation (Scenario 4) considering as avoided burdens the avoided energy generation by natural gas.*
- *Landfilling in a sanitary landfill without landfill gas recovery (Scenario 5), with landfill gas recovery for flaring (Scenario 6) and for electricity generation (Scenario 7), for the latter considering as avoided burdens the avoided electricity generation by natural gas.*
- *Recycling for the production of agglomerated cork considering the avoided burdens of substitution of both virgin cork (Scenario 8) and industrial waste (Scenario 9).*

The impact categories evaluated are: Climate Change (CC), Ozone Depletion (OD), Photochemical Ozone Formation (POF), Acidification (A) and Mineral and Fossil Resource Depletion (MFRD), as recommended by the International Reference Life Cycle Data System (ILCD). The results show that for the categories of CC and OD, the combustion of the used natural cork stoppers in a biomass installation with electricity and heat generation is the most environmentally efficient management scenario. Nevertheless, the respective scenario of incineration (Scenario 2) presented similar results. For the rest of the categories, the recycling of the stoppers for the production of agglomerated cork substituting the use of raw cork had the best performance.

A COMBINED LIFE CYCLE AND SENSITIVITY ANALYSIS APPROACH FOR DECISION AIDING

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Keywords Sensitivity Analysis, Morris, Sobol, action levers, decision

Abstract *Life Cycle Assessment (LCA) is a methodological frame that is difficult to use for Industrial Ecology Projects (IEP) for several reasons: IEP are localised projects whereas LCA ambition to provide a global overview, IEP account for multiple economic actors and products, whereas LCA do not consider economic actors and is generally focused on a reduced number of products. However, a life cycle approach should be a relevant approach to assess environmental performances of IEP by integrating global and life cycle perspectives. To reach this goal, LCA frame must be adapted to be able to conciliate a double scale approach (local and global), and to integrate economic actors as decision-makers within a life cycle.*

In a first step, the system of a product's life cycle is analysed in terms of interactions between economic actors, leading to a partition into separate sub-systems related to each other by variable functional units. Each sub-system corresponds to the decision perimeter of a given economic actor and is examined as a foreground system. In a second step, physicochemical analytical models providing inventory flows of the chosen foreground system, are combined to decision models where technological and methodological choices are represented by discrete variables and logical tests. The foreground system is also articulated with background system and surrounding contextual constraints. In a third step, all input variables are characterized with their distribution probabilities and are grouped in several categories corresponding to the actor's action possibilities: variables with a direct control are defined as technological ones, variables with a possible indirect control or no control (constraints) are defined as contextual ones, and modelling variables are defined as methodological ones. The fourth step consists in conducting successively Morris and Sobol sensitivity analysis methods, bringing complementary information about system behaviour. Finally, the fifth step is the interpretation of results by identifying action levers for each single actor and by quantifying environmental impacts associated to its choices.

The approach has been developed on the case study of a hemp based insulation material for building. It has not yet been applied to IEP systems, but it is in the future research perspective, with a territorial approach of construction waste management.

ENERGY POTENTIAL AND LIFE CYCLE IMPACTS OF MACAÚBA BIODIESEL AND BIOKEROSENE

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Keywords Bioenergy, energy potential, Macaúba, biodiesel, biokerosene

Abstract *Considering the Brazilian scenario of biodiesel production and the increasing of biodiesel proportion added in diesel oil sold by regulatory agency (Agência Nacional do Petróleo), it is timely the study about macauba's potentiality like an oilseed, which may supply part of this demand. Thus, this paper aims to assess the energy potential of macauba (Acrocomia aculeata (lacq) Lood. ex Mart in Brazil, in biodiesel and biokerosene production, comparing physical and chemical characteristics and the greenhouse gases potential with regard to fossil fuels. As goals, we propose to compare macauba's biodiesel and biokerosene with conventional diesel fuel and aviation kerosene, respectively. We performed data survey by: (a) reviewing scientific articles in journals and conferences, (b) researching in organizational websites about the main supply chain drivers and (c) performing semi structured interviews. We identified the main organizational drivers, drew the productive chain and elementary flows, regarding the processes of harvesting, oil extraction and biodiesel production, in extractivistic scheme, because commercial macanauba plantations are not widespread and are not in production stage. As results, we have obtained a mapping of published papers in journals and conferences, and series of technical reports published by research institutes. We identified natural palm tree populations for seed harvesting in extractivistic scheme, as well as active banks of germplasm, crops, intermediate goods industries, and the drivers of main, supplier, and supporting chains. The elementary flow of harvesting, oil extraction, biodiesel and biokerosene production was elaborated. The results of greenhouse emission were obtained with emissions calculator provided by Roundtable on Sustainable Biofuels. The macauba presented physical and chemical parameters, such as acid and kinematic viscosity index, and flash and freezing point, which meet requirements of ANP regulations considering the quality related to fossil fuels and the lower greenhouse gas emission rate.*

FUNCTIONAL UNIT IN CONSTRUCTION LCA: CONSIDERING THERMAL PERFORMANCE REQUIREMENTS OF EXTERNAL WALLS

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Keywords functional unit definition, external wall construction, life-cycle assessment, *performance requirements*

Abstract *In life cycle assessment methodology, the definition of functional units is an important step to benchmark different products with the same function. The purpose of this article is to show how thermal performance requirements of external walls can be used to define functional unit in Brazil, following similar work previously completed in the UK. These steps are followed: (a) survey of thermal performance requirements (TPR) in Brazil; and (b) selection of external walls that meet established requirements. The results show that an external wall built with clay blocks meets TPR in all Brazilian bioclimatic zones. This external wall has to be built with gypsum plaster or cement mortar and painted with light colours on both sides. However, the same external wall with uncoated clay blocks does not meet with the minimum TPR of any bioclimatic zone in Brazil. We conclude that the utilization of external wall performance requirements allows more precision in functional unit definition. Thus, wall typology contains secondary information and the performance information presented expands the focus to beyond just the materials used in the wall construction.*

1. INTRODUCTION

The results from a life cycle assessment (LCA) study provide data on the environmental impacts of a product or service. However, using LCA to compare different products performing the same function requires these results to be based on a suitably defined functional unit of assessment [1], [2]. In a survey about the state of the art of LCA application in the construction sector in Brazil, we observed that the most LCA define functional units without considering the performance requirements of the products assessed [3].

This paper focuses on an external wall as a building system that limits vertically the building and its rooms [4]. In the Brazilian context this system must meet the demands of safety, habitability, and sustainability according to performance requirements of ABNT NBR 15.575 [2], and in the UK context the UK Building Regulations [5].

2. METHODOLOGY

Three steps constitute the methodology: (a) bibliographic research about thermal performance requirements (TPR) in the UK and how LCA professionals use this information; (b) survey of Brazilian TPR; and (c) selection of external wall that meets TPR.

2.1. Thermal performance requirements in United Kingdom and in Brazil

The UK Building Regulations are divided into 14 parts covering whole building and containing general recommendations about expected materials performance. In terms of TPR for external walls, the "Part L: Conservation of fuel and power" defines a minimum Heat Transfer Coefficient (also known as Thermal Transmittance, U-value) of 0.30W/m^2.K [5].

This TPR is then used by LCA experts in the Building Research Establishment (BRE) in the UK to define the functional unit for external wall elements (systems) while carrying out comparative LCA studies [6], [7]. The results of these studies are presented in ISO type III environmental labels and in BRE's Green Guide to Specification according to a benchmark rating scale.

In Brazil, we observed that there is little literature about external walls and their TPR data. We compiled data in an infographic that simplifies the presentation of external wall TPR (Figure 1).

3. RESULTS

3.1. External wall typologies that meet Thermal Performance Requirements

The TPR of buildings are influenced by various external factors such as openings for ventilation, bioclimatic zoning, bioclimatic strategies, external wall, cover characteristics, etc. The focus of the research presented in this article is on external wall characteristics that meet TPR considering the Brazilian bioclimatic zoning.

The Annex D of NBR 15.220-3 standard [8] and Selo Azul da Caixa [10] provides a list of walls and their corresponding Thermal Transmittance (U) and Thermal Capacity (TC) data. Based on this list, we elaborated the Table 2 that associates wall typologies and their corresponding TPR data.

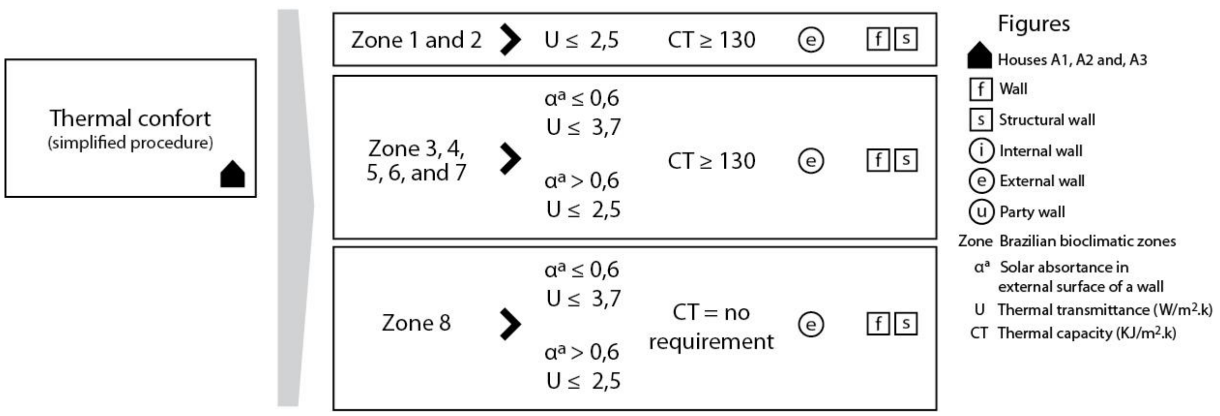

Figure 1. Minimum TPR according simplified thermal assessment procedures [8], [4], [9]

Table 2. Masonry wall typologies and thermal performance data

Wall description	U-value W/m².K	TC kJ/m².K	Thermal performance
Brick 6 holes (9,0 x 14,0 x 19,0 cm) Internal and external mortar: 2,5 cm	2,48	159	Any Brazilian bioclimatic zone
Brick 8 holes (9,0 x 19,0 x 19,0 cm) Internal and external mortar: 2,5 cm	2,49	158	Any Brazilian bioclimatic zone
Brick 6 holes (9,0 x14,0 x19,0 cm) Internal and external mortar: 2,5 cm	2,02	192	Any Brazilian bioclimatic zone
Brick 8 holes (9,0 x 19,0 x 19,0 cm) Internal and external mortar: 2,5 cm	1,80	231	Any Brazilian bioclimatic zone
Concrete brick (9,0 x 19,0 x 39,0 cm) Internal and external mortar: 2,5cm	2,86	203	Meets TPR for zones 3, 4, 5, 6, 7, and 8 with $a^{a} \leq 0,6$
Concrete brick (9,0 x 19,0 x 39,0 cm) Internal mortar: 0 cm; external: 2,5cm	3,09	157	Meets TPR for zones 3, 4, 5, 6, 7, and 8 with $a^{a} \leq 0,6$
Concrete brick (14,0 x 19,0 x 39,0 cm) Internal and external mortar: 2,5cm	2,76	265	Meets TPR for zones 3, 4, 5, 6, 7, and 8 with $a^{a} \leq 0,6$
Concrete brick (14,0 x 19,0 x 39,0 cm) Internal mortar: 0 cm; external: 2,5 cm	2,95	214	Meets TPR for zones 3, 4, 5, 6, 7, and 8 with $a^{a} \leq 0,6$
Ceramic brick (9,0 x 14,0 x 24,0 cm) Internal and external mortar: 2,5 cm	2,59	145	Meets TPR for zones 3, 4, 5, 6, 7, and 8 with $a^{a} \leq 0,6$
Ceramic brick (9,0 x 9,0 x 24,0 cm) Internal mortar: 0 cm; external: 2,5 cm	2,86	100	Meets TPR for zone 8 with $a^{a} \leq 0,6$
Ceramic brick (14,0 x 19,0 x 29,0 cm) Uncoated	3,12	41	Meets TPR for zone 8 with $a^{a} \leq 0,6$
Ceramic brick (14,0 x 19,0 x 29,0 cm) Internal and external mortar: 2,5 cm	1,98	156	Any Brazilian bioclimatic zone

Legend	
	Typology that partially meets acoustical performance requirements;
	Typology that meets acoustical performance requirements;
	Typology that does not meet acoustical performance requirements.

Based on the survey of external wall typologies and TPR, we can use this information to define the functional unit of LCA in the Brazilian Construction sector. If we consider as a functional unit 1m² of external wall with a TPR adequate to Brazilian bioclimatic Zone 8, we can use the following typologies:

- Clay bricks (14,0 x 19,0 x 29,0cm) uncoated, amounting to 14,0cm of thickness;

- Concrete bricks (14,0 x 19,0 x 39,0cm), 0,5cm of rough cast mortar, and 2,0cm of mortar on the external side, amounting to 16,5cm of thickness; or
- Concrete bricks (14,0 x 19,0 x 29,0cm), 0,5cm of rough cast mortar on both sides, and 2,0cm of mortar on both sides, amounting to 19,0cm of thickness.

These typologies cannot be used in Porto Alegre for example, where they do not meet the TPR as this Brazilian city is located in Zone 2 of the Brazilian bioclimatic zoning where external wall typologies with superior thermal performance requirements are needed. This demonstrates that this functional unit is not applicable to that city.

This approach allows a fair and robust comparison of external wall typologies with the same TPR and applicable to the same locations, regardless of the individual component materials.

4. CONCLUSIONS

The use of external wall performance requirements provides a more precise functional assessment basis in the application of LCA methodology in which the wall typology contains secondary information and the performance information presented expands the focus to beyond just the materials used in the wall construction.

We collected information about walls, and their respective building performance, supporting the functional unit definition in such a way that is possible to compare environmental performance between systems with different composition, but the same function.

Finally, we concluded that to improve the functional unit definition it is necessary to incorporate other performance categories, such as acoustic performance, structural performance, water resistance, durability, and fire resistance. However, to accomplish this task it is necessary to amplify technical scientific research about this theme and perform laboratory tests, which will characterise wall typologies according to performance requirements defined by ABNT NBR 15.575. The scope of this scientific research has to be expanded to include other wall typologies such as prefabricated concrete or ceramic panels; gypsum boards; wall partitions, etc., so that it is possible to develop comparative LCA studies covering a range of wall typologies.

Moreover, it is possible to apply this approach of functional unit definition to other building systems which also have performance requirements defined by standards.

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