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10TH International Conference on Sustainable Energy and Environmental Protection:

Environmental Management and Impact Assessment

(June 27TH - 30TH, 2017, Bled, Slovenia)

(Conference Proceedings)

Editors:
Emeritus Prof. dr. Jurij Krope
Prof. dr. Abdul Ghani Olabi
Prof. dr. Darko Goričanec
Prof. dr. Stanislav Božičnik

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Prof. Abdul Ghani Olabi, Ph.D. (University of the West of Scotland, UK),
Asso. Prof. Darko Goričanec, Ph.D. (University of Maribor, Slovenia),
Asso. Prof. Stanislav Božičnik (University of Maribor, Slovenia).

Review: Prof. Željko Knez, Ph.D. (University of Maribor, Slovenia),
prof. Niko Samec, Ph.D. (University of Maribor, Slovenia).

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Preface

The 10th International Conference on Sustainable Energy and environmental Protection – SEEP 2017 was organised on June 27th – 30th 2017 in Bled, Slovenia, by:

- Faculty of Chemistry and Chemical Engineering, University of Maribor, Slovenia,
- University of the West of Scotland, School of Engineering and

The aim of SEEP2017 is to bring together the researches within the field of sustainable energy and environmental protection from all over the world.

The contributed papers are grouped in 18 sessions in order to provide access to readers out of 300 contributions prepared by authors from 52 countries.

We thank the distinguished plenary and keynote speakers and chairs who have kindly consented to participate at this conference. We are also grateful to all the authors for their papers and to all committee members.

We believe that scientific results and professional debates shall not only be an incentive for development, but also for making new friendships and possible future scientific development projects.

General chair
Emeritus Prof. dr. Jurij Krope

Plenary Talk on The Relation between Renewable Energy and Circular Economy

ABDUL GHANI OLABI - BIBLIOGRAPHY

Prof Olabi is director and founding member of the Institute of Engineering and Energy Technologies (www.uws.ac.uk\ieet) at the University of the West of Scotland. He received his M.Eng and Ph.D. from Dublin City University, since 1984 he worked at SSRC, HIAST, CNR, CRF, DCU and UWS. Prof Olabi has supervised postgraduate research students (10 M.Eng and 30PhD) to successful completion. Prof Olabi has edited 12 proceedings, and has published more than 135 papers in peer-reviewed international journals and about 135 papers in international conferences, in addition to 30 book chapters. In the last 12 months Prof Olabi has patented 2 innovative projects. Prof Olabi is the founder of the International Conference on Sustainable Energy and Environmental Protection SEEP, www.seepconference.co.uk

He is the Subject Editor of the Elsevier Energy Journal https://www.journals.elsevier.com/energy/editorial-board/abdul-ghani-olabi, also Subject editor of the Reference Module in Materials Science and Materials Engineering http://scitechconnect.elsevier.com/reference-module-material-science/ and board member of a few other journals. Prof Olabi has coordinated different National, EU and International Projects. He has produced different reports to the Irish Gov. regarding: Hydrogen and Fuel Cells and Solar Energy.

CORRESPONDENCE ADDRESS: Abdul Ghani Olabi, Ph.D., Professor, University of the West of Scotland, School of Engineering and Computing, D163a, McLachlan Building, Paisley, United Kingdom, e-mail: Abdul.Olabi@uws.ac.uk.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Plenary Talk on Energy Footprints Reduction and Virtual Footprints Interactions

JIŘÍ JAROMÍR KLEMEŠ & PETAR SABEV VARBANOV

Increasing efforts and resources have been devoted to research during environmental studies, including the assessment of various harmful impacts from industrial, civic, business, transportation and other economy activities. Environmental impacts are usually quantified through Life Cycle Assessment (LCA). In recent years, footprints have emerged as efficient and useful indicators to use within LCA. The footprint assessment techniques has provided a set of tools enabling the evaluation of Greenhouse Gas (GHG) – including CO_2, emissions and the corresponding effective flows on the world scale. From all such indicators, the energy footprint represents the area of forest that would be required to absorb the GHG emissions resulting from the energy consumption required for a certain activity, excluding the proportion absorbed by the oceans, and the area occupied by hydroelectric dams and reservoirs for hydropower.

An overview of the virtual GHG flow trends in the international trade, associating the GHG and water footprints with the consumption of goods and services is performed. Several important indications have been obtained: (a) There are significant GHG gaps between producer's and consumer's emissions – US and EU have high absolute net imports GHG budget. (b) China is an exporting country and increasingly carries a load of GHG emission and virtual water export associated with consumption in the relevant importing countries. (c) International trade can reduce global environmental pressure by redirecting import to products produced with lower intensity of GHG emissions and lower water footprints, or producing them domestically.

To develop self-sufficient regions based on more efficient processes by combining neighbouring countries can be a promising development. A future direction should be focused on two main areas: (1) To provide the self-sufficient regions based on more efficient processes by combining production of surrounding countries. (2) To develop the shared mechanism and market share of virtual carbon between trading partners regionally and internationally.

CORRESPONDENCE ADDRESS: Jiří Jaromír Klemeš, DSc, Professor, Brno University of Technology - VUT Brno, Faculty of Mechanical Engineering, NETME Centre, Sustainable Process Integration Laboratory – SPIL, Technická 2896/2, 616 69 Brno, Czech Republic, e-mail: klemes@fme.vutbr.cz. Petar Sabev Varbanov, Ph.D., Associate Professor, Brno University of Technology - VUT Brno, Faculty of Mechanical Engineering, NETME Centre, Sustainable Process Integration Laboratory – SPIL, Technická 2896/2, 616 69 Brno, Czech Republic, e-mail: varbanov@fme.vutbr.cz.

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JIŘÍ JAROMÍR KLEMEŠ - BIBLIOGRAPHY

Head of "Sustainable Process Integration Laboratory – SPIL", NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Czech Republic and Emeritus Professor at "Centre for Process Systems Engineering and Sustainability", Pázmány Péter Catholic University, Budapest, Hungary.

Previously the Project Director, Senior Project Officer and Hon Reader at Department of Process Integration at UMIST, The University of Manchester and University of Edinburgh, UK. Founder and a long term Head of the Centre for Process Integration and Intensification – CPI2, University of Pannonia, Veszprém, Hungary. Awarded by the EC with Marie Curies Chair of Excellence (EXC). Track record of managing and coordinating 91 major EC, NATO and UK Know-How projects. Research funding attracted over 21 M€.

Co-Editor-in-Chief of Journal of Cleaner Production (IF=4.959). The founder and President for 20 y of PRES (Process Integration for Energy Saving and Pollution Reduction) conferences. Chairperson of CAPE Working Party of EFCE, a member of WP on Process Intensification and of the EFCE Sustainability platform.

He authored nearly 400 papers, h-index 40. A number of books published by McGraw-Hill; Woodhead; Elsevier; Ashgate Publishing Cambridge; Springer; WILEY-VCH; Taylor & Francis).

Several times Distinguished Visiting Professor for Universiti Teknologi Malaysia, Xi'an Jiaotong University; South China University of Technology, Guangzhou; Tianjin University in China; University of Maribor, Slovenia; University Technology Petronas, Malaysia; Brno University of Technology and the Russian Mendeleev University of Chemical Technology, Moscow. Doctor Honoris Causa of Kharkiv National University "Kharkiv Polytechnic Institute" in Ukraine, the University of Maribor in Slovenia, University POLITEHNICA Bucharest, Romania. "Honorary Doctor of Engineering Universiti Teknologi Malaysia", "Honorary Membership of Czech Society of Chemical Engineering", "European Federation of Chemical Engineering (EFCE) Life-Time Achievements Award" and "Pro Universitaire Pannonica" Gold Medal.

CORRESPONDENCE ADDRESS: Jiří Jaromír Klemeš, DSc, Professor, Brno University of Technology - VUT Brno, Faculty of Mechanical Engineering, NETME Centre, Sustainable Process Integration Laboratory – SPIL, Technická 2896/2, 616 69 Brno, Czech Republic, e-mail: klemes@fme.vutbr.cz.

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Plenary Talk on
Renewable energy sources for environmental protection

Hakan Serhad Soyhan

Development in energy sector, technological advancements, production and consumption amounts in the countries and environmental awareness give shape to industry of energy. When the dependency is taken into account in terms of natural resources and energy, there are many risks for countries having no fossil energy sources. Renewable and clean sources of energy and optimal use of these resources minimize environmental impacts, produce minimum secondary wastes and are sustainable based on current and future economic and social societal needs. Sun is one of the main energy sources in recent years. Light and heat of sun are used in many ways to renewable energy. Other commonly used are biomass and wind energy. To be able to use these sources efficiently national energy and natural resources policies should be evaluated together with the global developments and they should be compatible with technological improvements. Strategic plans with regard to energy are needed more intensively and they must be in the qualification of a road map, taking into account the developments related to natural resources and energy, its specific needs and defining the sources owned by countries. In this presentation, the role of supply security was evaluated in term of energy policies. In this talk, new technologies in renewable energy production will be shown and the importance of supply security in strategic energy plan will be explained.

Correspondence Address: Hakan Serhad Soyhan, Ph.D., Professor, Sakarya University, Engineering Faculty, Esentepe Campus, M7 Building, 54187 - Esentepe /Sakarya, Turkey, e-mail: hsoyhan@sakarya.edu.tr.

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HAKAN SERHAD SOYHAN - BIBLIOGRAPHY

Professor at Sakarya University, Engineering Faculty. 50 % fot teaching and the rest for reasearch activities.

Teaching, courses taught:

Graduate courses:

- Combustion technology;
- Modelling techniques;

Undergraduate courses:

- Combustion techniques;
- Internal combustion engines;
- Fire safety.

Tehnical skills and competences professional societies:

- 25 jurnal papers in SCI Index. 23 conference papers;
- Editor at FCE journal. Co-editor at J of Sakarya University;
- Head of Local Energy Research Society (YETA);
- Member od American Society of Mechanical engineers (ASME);
- Member of Turkish Society of Mechanical Engineers (TSME).

CORRESPONDENCE ADDRESS: Hakan Serhad Soyhan, Ph.D., Professor, Sakarya University, Engineering Faculty, Esentepe Campus, M7 Building, 54187 - Esentepe /Sakarya, Turkey, e-mail: hsoyhan@sakarya.edu.tr.

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J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Rating the Environmental Quality of Buildings for Different Building Geometries

VESNA ŽEGARAC LESKOVAR, MAJA ŽIGART, REBEKA KOVAČIČ LUKMAN, MAJA LEŠNIK & MIROSLAV PREMROV

Abstract Considering the environmental impact in the new building design stage with the aim of reducing the environmental loads has become a high priority issue of the construction sector. The geometry and the size of the building, two of the multiple factors encompassing mostly a careful selection of building materials, also affect the environmental impact to a certain extent.

The paper discusses the influence of the building geometry on its environmental impact. A basic functional unit is a house model with external dimensions of 6.50 x 6.50 x 3.00 metres constructed in cross-laminated timber (CLT) system. The basic unit undergoes vertical and horizontal parametrical multiplication into larger house models representing the specific building typology such as single-storey, double-storey, detached, semi-detached or terraced house. The numerical analysis is performed with the "baubook eco2soft" tool indicating the environmental quality through the global warming potential, acidification potential and non-renewable primary energy content.

Keywords: • environmental impact • operational energy • building geometry • building typology • cross-laminated timber•

CORRESPONDENCE ADDRESS: Vesna Žegarac Leskovar, Ph.D., Associate Professor, University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: vesna.zegarac@um.si. Maja Žigart, Assistant, University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: maja.zigart@um.si. Rebeka Kovačič Lukman, Ph.D., Assistant Professor, University of Maribor, Faculty of Energy Technology, Slovenia, e-mail: rebeka.lukman@um.si. Maja Lešnik, Assistant, University of Maribor, Faculty of Civil Eng., Transportation Eng. and Architecture, Smetanova ulica 17, 2000 Maribor, Slovenia, email: maja.lesnik6@um.si. Miroslav Premrov, Ph.D., Professor, University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: miroslav.premrov@um.si.

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1 Introduction

In 2014 the European Commission adopted the Climate and Energy package with the three main targets: reduction of greenhouse gas emissions for 40 % in a comparison to the baseline year 1990, increase in the share of renewables to 27 % and 27 % improvements in energy efficiency [1]. The European Commission further identified that the construction and use of buildings in the European Union account for around half of all the extracted materials and energy consumption and generating one third of all the waste which represents an enormous environmental burdens, emerging from the life-cycle phases, encompassing manufacturing of building products, construction, use of buildings, refurbishment, management of buildings waste [2]. In order to assess the overall building sustainability, a life-cycle assessment (LCA) represents an important tool. As argued by Holberg et al. [3] and Flager et al. [4], the LCA is not commonly performed in the architecture and construction projects, not even in an early stage of the building design, although it offers the highest potential for optimisation to achieve lower energy demand and reduce environmental impacts.

Many studies have shown that buildings using timber load-bearing elements, especially CLT, have the lowest global warming potential in comparison to alternative construction materials (also the research presented in SEEP-48 [5]). Along with the selection of construction materials also the design of building geometry represents another important aspect influencing the embodied and operational emissions. The study considering the building geometry in terms of operational energy for heating and cooling [6] indicates the positive influence of the proper building design on the reduction of energy need and consequently also operational emissions. Studies examining the relation of the building geometry to the environmental impacts in terms of the LCA are less frequent and mainly focus on office buildings only [7-9]. These studies indicate the envelope design has a significant environmental influence.

In order to investigate the environmental aspect for different building typologies, the current study examines a relationship between the building geometry and environmental impacts, focusing on global warming (GWP) and acidification potentials (AP) as well as non-renewable primary energy content (PENRT). The study is developed as a systematic upgrade of the research presented in SEEP-48 [5] and SEEP-33 [10] integrating hitherto not thoroughly researched topic concerning the environmental impact of different building typologies.

2 Methodology

The environmental performance of the house models is calculated with the "baubook eco2soft" software. The rating of environmental quality considers several indicators, the primary energy content of all non-renewable resources (PENRT), the global warming potential (GWP100 total), acidification potential (AP). The total energy resources required to produce a product or service are collectively referred to as the primary energy content (PE). The PE is specified in kWh and calculated from the lower calorific value of the energy resources deployed. The "PENRT" specifies the primary energy content of all non-renewable resources (crude oil, coal, etc.) including resources for energy-related as well as material uses. The global warming potential (GWP100 total) describes the contribution of a gas to the greenhouse effect in relation to that of an identical quantity of carbon dioxide. Factors are expressed as global warming potential for time horizon 100 years (GWP100) in relation to year 1994. The indicator "GWP total" includes both the contribution to global warming in terms of greenhouse gas emissions and the quantities of carbon dioxide stored in the biomass. GWP100 total is expressed as kg CO_2/kg emission, in accordance with CML 2001 v3.9 [11]. Acidification is caused mainly by the interaction of nitrogen oxides (NO_x) and sulphur dioxides (SO_2) with other constituents of air, such as the hydroxyl radicals, which can be converted into nitric acid (HNO_3) and sulphuric acid (H_2SO_4) – both substances which are instantaneously soluble in water and can precipitate as acid rain. Unlike the greenhouse effect, acidification is a regional, not a global, phenomenon [12]. Acidification Potential (AP) for emissions to air is calculated in accordance with CML 2001 v3.9 [11], describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents/kg emission. The environmental impacts are considered also in terms of operational energy, whereby the energy need for heating and cooling for the selected house models is additionally analysed.

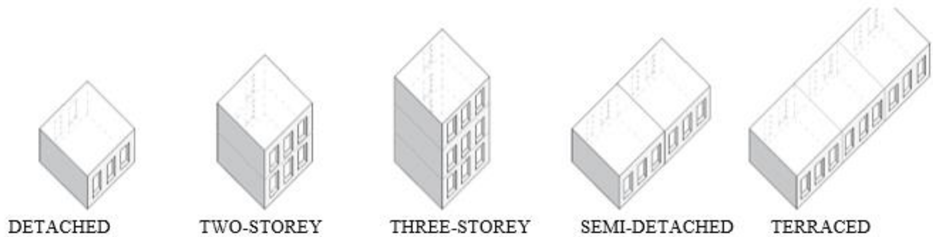

Figure 1. The selected house models

The exterior walls and the roof are considered to be meeting the requirements of the low-energy house standard with $U = 0.10\ W/m^2K$, while the bottom plate thermal transmittance is 0.135 W/m^2K. The window insulating glazing with glass characteristics $U_g = 0.51\ W/m^2K$ and $g = 52\%$ and timber frame thermal transmittance of $U_f = 0.73\ W/m^2K$. The glazing is taking a share of 35 % on the south and 10% on the north façade. The detailed composition of the house model structural elements is presented in Table 1.

Table 1. Composition of the house model thermal envelope elements

BOTTOM PLATE	Solid parquet	1 cm
	Cement and cement flowing screed (2000 kg/m³)	6 cm
	Polyethylene (PE) foil	0.01 cm
	Glass wool (80 kg/m³)	3 cm
	EPS (19.5 kg/m³)	6 cm
	Reinforced concrete with 1% of reinforcement (2300 kg/m³)	20 cm
	Polyethylene (PE) foil	0.04 cm
	XPS (32 kg/m³)	10 cm
	Polymer bitumen sealing sheeting	0.78 cm
	XPS (32 kg/m³)	10 cm
	Lean concrete / cast and compressed concrete	10 cm
	Building paper	0.03 cm
	Fillings made of sand, gravel, grit (1800 kg/m³)	30 cm
	PP fleece	0.02 cm
EXTERIOR WALL	Cross-laminated timber (475 kg/m³ - e.g. spruce)	9.5 cm
	Rock wool (120 kg/m³)	34 cm
	Silicate plaster (without synthetic resin additive)	0.19 cm
ROOF	Fillings made of sand, gravel, grit (1800 kg/m³)	6 cm
	PP fleece	0.02 cm
	XPS (32 kg/m³)	6 cm
	Polymer bitumen sealing sheeting	0.78 cm
	EPS (23 kg/m³)	16 cm
	EPS (23 kg/m³)	6 cm
	Polyethylene (PE) vapour brake	0.18 cm
	Cross-laminated timber (475 kg/m³ - e.g. spruce)	18.2 cm

3 Results

The environmental indicators normed per 1 m^2 of reference area (usable floor area) are presented in Figures 2 to 4. The usable floor area for single-storey house model is 42.25 m^2, for two-storey and semi-detached house 84.5 m^2 and for the three-storey and terraced house 126.75 m^2.

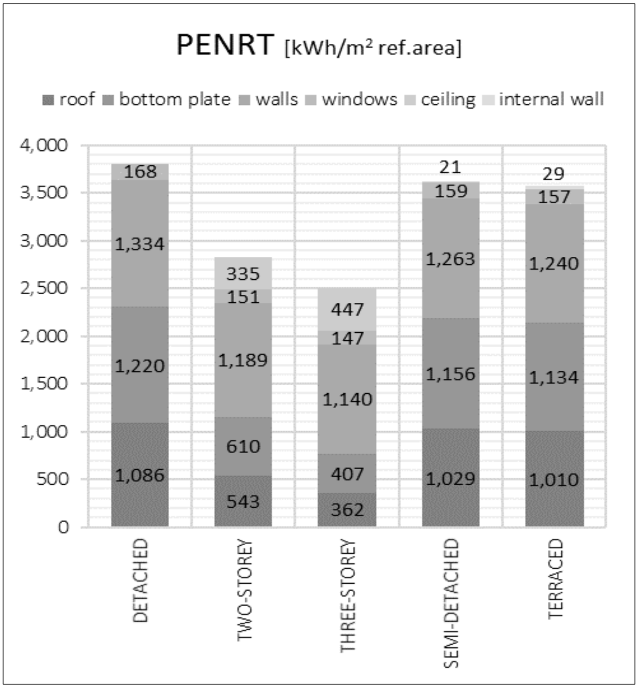

Figure 2. The comparison of PENRT indicator for the considered house models

Figure 2 shows the primary energy content of all non-renewable resources being the lowest for the three-storey and slightly higher for the two-storey house model. All treated single-storey models exhibit much higher PENRT with the highest value of 3.80 kWh/m^2 ref. area for the single-storey detached house. The biggest difference in PENRT between single-storey and two- or three-storey models are caused by the influence of the bottom plate and roof. For both elements the ratio of the element area itself to the usable floor area (hereinafter A_e/A_{uf}) varies highly in terms of building typology. On the other hand the A_e/A_{uf} remains almost constant for walls and windows, therefore the PENRT as a contribution of walls and windows is relatively similar for all treated house models.

Figure 3 presents the global GWP100 total for all analysed house typologies.

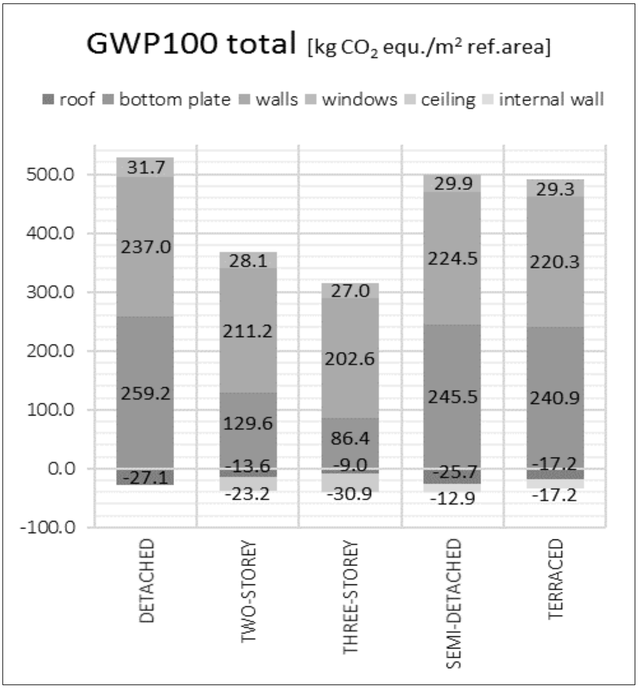

Figure 3. The comparison of GWP100 total indicator for the considered house models

The results are in general similar to those for PENRT. The three-storey model proves once again to have the lowest environmental impact with the *GWP= 276.1 kg* CO_2 *equ./m*^{2} *ref. area* being almost twice lower from the GWP of detached house. Having a deeper insight into the influence of individual building elements we can notice the stronger environmental impact of the bottom plate for one-storey models again. Interesting results are shown for the roof element, where GWP100 total in all treated models is negative. The latter is a consequence of the high amount of stored carbon in a very thick (18.2 cm) roof plate made of cross-laminated timber. Although timber is used also for the load-bearing wall structure, the wall GWP potential being 219 kg CO_2 equ./m^2 in average is much higher if compared to the roof. The latter arises from two reasons. Firstly, the wall load-bearing timber structure with sequestered carbon is only 9.5 cm thick. Secondly, various insulation materials with different environmental impacts were used for the roof (polystyrene) and walls (rock wool) next to the amount of insulation being higher in wall elements.

The environmental indicator representing acidification potential is shown for all treated models in Figure 4.

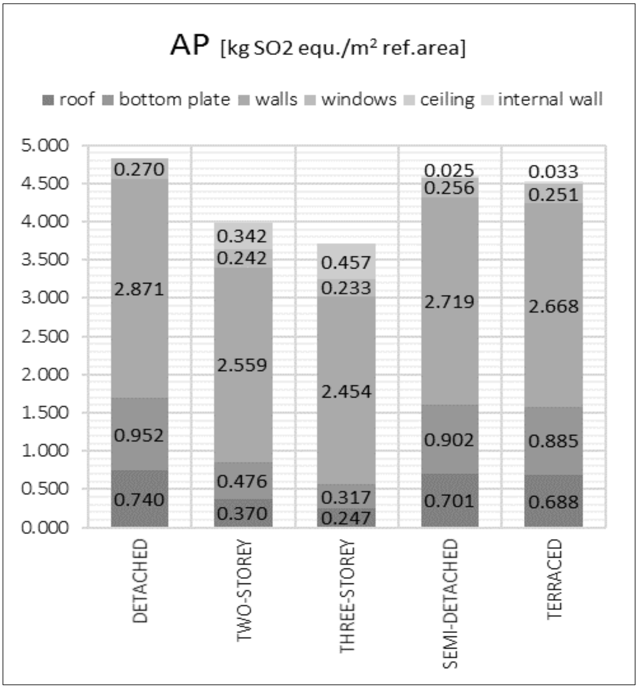

Figure 4. The comparison of AP indicator for the considered house models

The detached house exhibit highest acidification potential if compared to two- and three-storey ones. However, in the case of AP, the walls carry the highest burden among all building elements. The latter arises from the type of insulation material used in wall elements. The rock wool exhibits the highest acidification potential among all insulation materials used in this study. The additional analyses investigating the use of alternative insulation materials would be beneficial, however the latter wouldn't influence the ratio between the impacts of the analysed building typologies.

Since the presented environmental potentials don't consider the operational energy for heating (Q_h) and cooling (Q_c), which both influence are responsible for an evident share of environmental burdens in the phase of building use, the additional analysis is presented in Table 2.

Table 2. Comparison of energy need for heating and cooling

	Q_h kWh/m^{2}a	Q_c kWh/m^{2}a	Q_h+Q_c kWh/m^{2}a
DETACHED	22.87	3.84	26.71
TWO-STOREY	15.67	3.85	19.52
THREE-STOREY	13.35	3.91	17.26
SEMI-DETACHED	17.97	3.58	21.56
TERRACED	16.36	3.51	19.87

It is interesting to compare the results presented in Table 2 with the results for GWP100 total presented in Figure 3 where the operational energy need is not taken into account. It can be seen that the relation between the detached, two-storey and three-storey model (vertical extension of the building) is similar as by GWP indicator. The three-storey model exhibits the lowest values for the energy need for heating. Especially significant is the difference between the two-storey (Q_h*=15.67 kWh/m*^{2}*a*) and the detached single-storey model (Q_h*=22.87 kWh/m*^{2}*a*). The difference between the two- and three-storey model is smaller (15.67 kWh/m^{2}a and 13.35 kWh/m^{2}a respectively). Both comparisons prove a good correlation with the total GWP100 total results from Figure 3, where the ratios of the obtained results are very similar. However, the correlation of the results from Table 2 and Figure 3 for the detached, semi-detached and the terraced models (horizontal extension of the building) is weaker. The results for Q_h in Table 2 exhibit quite important difference, especially between the detached (Q_h*=22.87 kWh/m*^{2}*a*) and the semi-detached house (Q_h*=17.97 kWh/m*^{2}*a*) which proves the difference in approx. of 27%. This is not in a correlation with the results for GWP from Figure 3 where the difference between these two models is only about 5%.

4 Conclusion

The numerical analysis is performed with the aim to indicate the environmental quality of different house models through the global warming potential acidification potential and non-renewable primary energy content. The treated models are linked to the particular building typologies. The worst environmental impacts are shown for the single-storey detached house, while the three-storey building had the best results in all assessment categories. Single-storey buildings are generally less environmental friendly in regard to two- or three-storey buildings.

Only from the perspective of additional information, the operational energy need for heating and cooling for the considered building typologies is presented briefly. The comparison of the operational energy results with the results for GWP100 potential indicates exhibits very similar behaviour for the case of the building vertical extension.

However, the horizontal building extension shows a strong influence on operational energy, while only a weak on the GWP100 total.

The general conclusions for the analysed building typologies indicate the three-storey building typology as the best solution from the energy-efficiency and environmental impact viewpoint. On the contrary, the detached house model exhibits the highest environmental impacts in all assessment categories, as well as the markedly highest energy need for heating, which leads to the conclusion for single-storey detached houses being evaluated as the worst building typology.

For the further study it would be beneficial to integrate the operational energy need into environmental assessment indicators in order to obtain direct correlation between all phases of the building life-cycle. The latter would indicate a more complex comparison of different housing typologies. The conclusions of the study can be useful to architects and building planers in the early design and decision-making process.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

An Analysis of Carbon and the Water Footprint in the White Shrimp Aquaculture Industry in Taiwan

CHING-CHIH CHANG & MING-HSI WU

Abstract This article is based on the ISO/TS 14067 and the ISO 14046 standards to evaluate the carbon footprint and the water scarcity footprint of the ecological white shrimp (Penaeus vannamei) cultivated in Kaohsiung City, Taiwan. The results are based on the scope of two scenarios: from cradle to gate and from cradle to grave. To be specific, the carbon footprint is 8.17 kgCO2e and 8.63 kgCO2e, respectively. For the water scarcity footprint in scenario 1, the blue water footprint of 0.26 m3 is added to the gray water footprint of 1.83 m3 to make a total of 2.09 m3. In scenario 2, the blue water footprint of 0.26 m3 is added to the gray water footprint of 2.43 m3 to make a total of 2.69 m3.

Keywords: • Ecological • cultivated • white shrimp • carbon footprint • water footprint

CORRESPONDENCE ADDRESS: Ching-Chih Chang, National Cheng Kung University, Department of Transportation and Communication Management Science and the Research Center for Energy Technology and Strategy, No. 1, University Road, Tainan 70101, Taiwan, e-mail: chan5305@mail.ncku.edu.tw. Ming-Hsi Wu, National Cheng Kung University, Department of Transportation and Communication Management Science, No. 1, University Road, Tainan 70101, Taiwan, e-mail: sidbears@hotmail.com.

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1 Introduction

According to the Food and Agriculture Organization of the United Nations (2011) disclosed that the food sector (including kitchen refuse) accounted for 22% of total global greenhouse gas emissions. In addition, fish production (including aquaculture) was 2.1%, as illustrated in Figure 1.

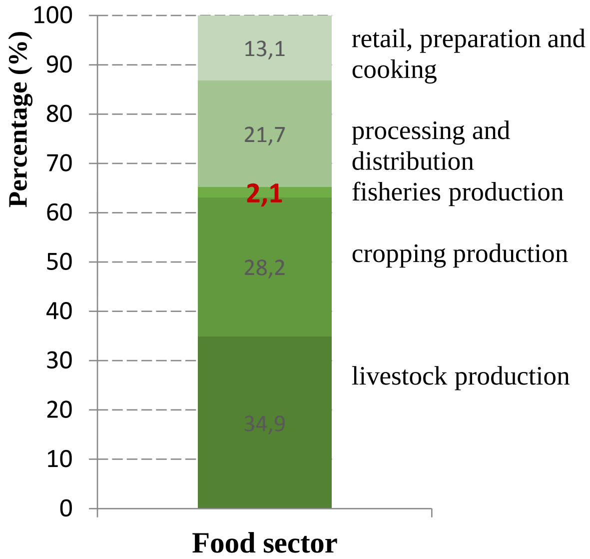

Figure 1. Global greenhouse gas emissions according to food sector.

Although the fishery industry is not the largest greenhouse gas emitter, several approaches could still be applied to reduce emissions. For instance, UNEP et al. (2012) recommended the fishery industry to adopt green technology to reduce fossil fuel consumption. In the area of aquaculture, FAO officer Doris Soto (2011) stressed that the replacement of imported fishmeal and fish oil with local terrestrial crops for emission mitigations.

Meanwhile, white shrimp is one of the dominant aquaculture species in Taiwan. If we introduce the concept of the carbon footprint into the shrimp supply chain, the following advantages would be attained: first, farmers would be able to monitor instantly the stages where there are emission hotspots and then further propose an emission reduction plan. Second, consumers will benefit from the transparency of carbon emissions objectives. The objective of water footprint is similar to that of carbon footprint.

Therefore, this study is an attempt to investigate the impact of the carbon footprint and the water footprint for Taiwan's organic white shrimp (*Penaeus vannamei*) cultivated in Kaohsiung City. The rest of the article is organized as follows: Section 2 contains related literature reviews on the carbon emissions of shrimp. Section 3 describes the cultivation processes, methods and procedures, as well as the framework analysis of the carbon footprint and the water footprint. In addition, we further discuss the inventory results. Section 4 presents the conclusions and policy suggestions.

2 Literature Review

Several kinds of literature have applied the ISO 14040 standard to calculate the carbon emissions of shrimp, which can be further divided into catches and aquaculture. In cases of catches, Farmery et al. (2015) discussed the environmental impacts of the capture white banana prawn (*Penaeus merguiensis*) and the tiger prawn (*Penaeus esculentus*) by the Northern Prawn Fishery of Australia. The carbon footprint for white banana prawn was 7.2 kgCO_2e/kg and for tiger prawn was 32 kgCO_2e/kg. Ziegler et al. (2011) investigated the environmental impacts of the Southern pink shrimp (*Penaeus notialis*) with different approaches of catches in Senegal. The carbon footprint by the automatic method was 38 kgCO_2e/kg, which was much higher than traditional one of 7.8 kgCO_2e/kg.

In the cases of aquaculture, Santos et al. (2015) compare the environmental impacts of the local amazon prawn (*M. amazonicum*) and the exotic giant river prawn with the traditional one and the better effluent management (BEM). Its system boundary was from cradle to farm-gate (Not include the package). The carbon footprint was 3.6~3.8 kgCO_2e/kg for giant river prawn; while the carbon footprint was 6.67~6.86 kgCO_2e/kg. Jonell and Henriksson (2015) explored the environmental impacts of black tiger shrimp, including the traditional intensive aquaculture and the organic aquaculture in the Ca Mau province in Vietnam. The system boundary was from cradle to farm-gate. The carbon footprint with organic aquaculture was 9.6, and that with traditional aquaculture was 20 (ton CO_2e FU-1).

3 Life Cycle Assessment

3.1 The aquaculture procedure

The farmer drains the water and dries the bottom beds with sunlight every February. Afterwards, the farmer cultivates phytoplankton in March and then transfers the post larvae in early April. Initially, the post larvae feed on phytoplankton and aquatic insects, then the farmer steadily adds the self-made amino acid and aqua-feed. After three months, the farmer harvests shrimp for sale.

The farmer adopts ecological farming methods to cultivate shrimp. For example, he uses a machine to remove the weeds instead of the uses of chemicals or antibiotics. In addition,

farmers used tea seed meal instead of trichlorofon to kill smaller fish and other fresh water shrimps (such as *Macrobrachium asperulum*) when cultivating phytoplankton because tea seeds have an abundance of plant saponin.
For aqua-feed, this farmer uses agricultural waste, as suggested by Doris Soto (2011). To be specific, one of the self-made amino acid is made from forage fish, soybean flour, molasses, and a digestive enzyme that will adjust to the needs of different kinds of forage fish. The aqua-feed is made of soybean flour, bean dregs, rice bran, wheat bran, and fish meal, which constitute the most common agricultural waste products in Taiwan.

3.2 The goal and scope

We evaluate the carbon footprint of the cultivated white shrimp in Taiwan based on ISO/TS 14067: 2013 with the impact assessment of the midpoint IPCC 2013. In addition, the emissions coefficient, we first consider the data released by the Environmental Protection Administration (2013) of Taiwan, and the data in the Sima pro 8.0 is used next.

While the water footprint was based on ISO 14046:2014 as the research framework. Nevertheless, ISO 14046 does not provide instructions for quantification, so we adopted the quantifying method proposed by the WFN: the stepwise accumulation approach.

For the blue water, the impact assessment is based on the midpoint analysis of Hoekstra et al. (2012). As illustrated in
Figure 2, we counted the irrigation water and the underground water inputted initially, added up the rainfall and subsidized the evaporation and the storm overflow to be the direct water usage. We refer to rainfall and evaporation data from the weather station located in Xinhua District in Tainan City, and then multiply it by the pond area. Due to rainfall was more than expected, so the farmer pumped out the excess storm overflow from the pond, and the remainder became cultivation water in the aquaculture stage. The measurement of the usage coefficient was based on data released by the Water Resource Agency of Taiwan, and the data collected in the SimaPro 8.0 was used subsequently.

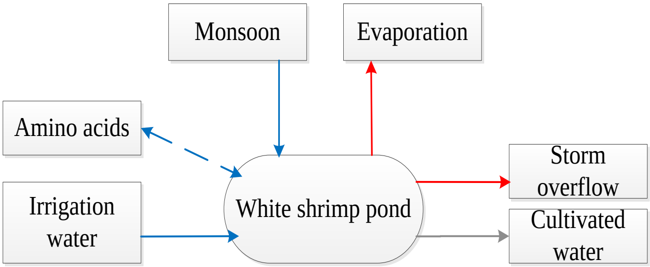

Figure 2. The direct water balance diagram

Then, we refer to the biochemical oxygen demand (B.O.D.) in Sima pro 8.0 and that of Lin et al. (2005) to calculate the gray water. We adapted the settings of Yen et al. (2013)

and assumed the maximum concentration of the water body to be the same as that near the aquaculture farm, and the water quality of the local nearby river was set at zero.

The data is from January through early July of 2016. The functional unit is 1 kilogram of white shrimp. We set up two scenarios: the first one is from cradle to farm-gate (excluding the packaging and classification); the second is from cradle to grave. The consumption stage is assumed to be when water is heated from 20℃ to 100℃ and then the shrimp is cooked for three minutes. We also assume from experience that one needs 3,000 c.c. of water to cook 1 kilogram of shrimp and that the head and shell (which are disposed of) accounts for 40% of the entire shrimp product.

The allocation is based on the bio-mass if necessary. Others that were excluded from the inventory include omission of breeding and capital goods. In addition, for the water footprint, since the first-order supplier does not consume green water, we focus on the blue water footprint and the gray water footprint.

3.3 Inventory analysis

3.4.1 The carbon footprint

Scenario 1

The carbon footprint per kilogram was 8.17 kgCO_2e under scenario 1. In addition, the aqua-feed is the largest emission source (90.18%).

Scenario 2

The greenhouse gas emissions in scenario 2 are depicted in **Napaka! Vira sklicevanja ni bilo mogoče najti.**. The emission of aqua-feed was the highest (85.33%).

3.4.2 The water footprint

Scenario 1

The first consumption volumes of the water usage in the first scenario is aqua-feed in the raw material stage (63.81%), followed by aquaculture water (21.15%) and electricity (13.48%).

Scenario 2

The first three types of water usage in scenario 2 included the aqua-feed (49.56%), the water for blanching the shrimp in the consumption stage (22.34%), and the water in the aquaculture stage (16.42%). What’s more, the gray water footprint accounted for 90.28%.

4 Conclusions

This study was aimed toward assessing the cultivated white shrimp (*Penaeus vannamei*) located in the Hunei District in Kaohsiung City, Taiwan based on the implementation ISO/TS 14067:2013 for the carbon footprint and on the implementation of ISO 14046:2014 for the water footprint. The time period was from January through early July in 2016. We discuss two scenarios: from cradle to farm-gate, and from cradle to grave.

The carbon footprint in scenario 1 was 8.17 $kgCO_2e/kg$; while that in scenario 2 was 8.63 $kgCO_2e/kg$. In both scenarios, the emissions from the aqua-feed emerged was the highest (85.33~90.17%).

The water footprints in scenario 1 were 0.26 m^3 for the blue water footprint and 1.83 m^3 for the gray water footprint, for a total water footprint of 2.09 m^3. In scenario 2, the blue water footprint of 0.26 m^3 is added to the gray water footprint of 2.43 m^3 to make a total of 2.69 m^3. The aqua-feed has the highest water consumption. In addition, the gray water footprint accounts for 90% indicates that most of the water usage for cultivated white shrimp is for eliminating water pollutants

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J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

LCA Analysis for Alternative Materials for Tin Doped Indium Oxide (Ito) Used in Electronics Industry for Sustainable Energy Production

MAGDA HELENA BARECKA, ALEKSANDRA ZIEMIŃSKA-STOLARSKA & IRENEUSZ ZBICIŃSKI

Abstract It is widely accepted that abundant use of natural resources limits the availability of those reserves for future generations and process alternatives leading to more sustainable production must be considered. One of such resources is Indium, which is currently broadly used in electronics industry in doped indium oxide (ITO) for production of transparent conductive films (TCO). Promising candidates for Indium replacement are widely analysed in terms of quality, yet the environmental impact of newly developed layers is unknown. This paper studies the environmental effect of ITO replacement by other materials, such as zinc oxide by life cycle assessment (LCA) technique. Different materials for TCO layer and different deposition techniques were evaluated. Obtained results were benchmarked towards the current industrial standard TCO layer composed from ITO. Effects of process scale-up were studied based on a sensitivity analysis. ZnO was determined to be a promising material for ITO replacement in any case.

Keywords: • LCA • TCO • ITO • zinc oxide • sensitivity analysis •

CORRESPONDENCE ADDRESS: Magda Helena Barecka, MSc. Eng., PhD candidate, Lodz University of Technology, Faculty of Process and Environmental Engineering, Wolczanska 213, 90-924 Lodz, Poland, e-mail: magda.barecka@p.lodz.pl. Aleksandra Ziemińska-Stolarska, PhD, Assistant, Lodz University of Technology, Faculty of Process and Environmental Engineering, Wolczanska 213, 90-924 Lodz, Poland, e-mail: aleksandra.zieminska-stolarska@p.lodz.pl. Ireneusz Zbiciński, Professor, Lodz University of Technology, Faculty of Process and Environmental Engineering, Wolczanska 213, 90-924 Lodz, Poland, e-mail: ireneusz.zbicinski@p.lodz.pl.

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1 Introduction

The global market for electronic components is experiencing fast growth, mostly due to increasing use of smart electronics in key industrial sectors. Transparent conducting films (TCO) are an important component in numerous electronic devices such as photovoltaic cells, touchscreens, LEDs. The TCO layers are composed of an optically transparent and electrically conductive material. Currently, indium tin oxide (ITO) is the most widely used for TCO layers manufacturing [1]. Nevertheless, due to growing demand for electronics containing TCOs and depletion of Indium resources, development of valid and robust alternatives to indium is essential [2]. Such materials and related deposition techniques should not only be characterized by performance and least as good as for the state-of-the-art technology, but should as well prove to have minimised environmental impact over the entire life-cycle of a product (raw materials extraction, manufacturing, usage and product disposal). Life Cycle Assessment (LCA) is a widely applied, holistic approach for rigorous evaluation of the impact of the product on environment. Therefore, the goal of this paper is to calculate LCA of the TCO layer deposition process for a benchmark ITO and a number of materials being currently studied as possible replacement for indium-based layers. Furthermore, different deposition techniques are studied in order to consider process-related impacts.

2 lca analysis

2.1 LCA methodology

For the reported analysis, eco-indicator based method (SimaPro®) was selected due to availability of environmental impact coefficients for majority of compounds considered in the analysis. Furthermore, an eco-indicator based method enabled a deep insight into various impact categories, such as global warming, human toxicity, ecotoxicity, and acidification. Following analysis was performed in accordance to ISO standards and consisted as four interrelated phases: goal definition and scope, inventory analysis, impact assessment and improvement assessment.

2.2 Goal and scope definition

LCA analysis will be carried out to assess which alternative for ITO and in which configuration will produce smaller environmental impact over the entire period of its product's cycle ("from cradle to grave", during manufacturing, operation and waste management). Promising alternative materials for ITO replacement are zinc oxide (ZnO), pure or doped with Aluminium (Al) either boron (B) and tin oxide (SnO_2). Further, such layers can be deposited by different techniques, among which Physical vapour deposition (PVD), Chemical vapour deposition (CVD) and Atomic layer deposition (ALD) are most popular. Within each technology, materials consumption and energy efficiency vary significantly; therefore LCA calculations were performed for different deposition techniques. Overview of performed analysis is given in Table 1.

Table 1. Materials& deposition techniques considered in the LCA analysis.

Materials	Analysed deposition technique
ITO (benchmark technology)	PVD
ZnO	PVD
ZnO:Al	PVD, ALD
ZnO:B	CVD
SnO_2	PVD

The basic unit of analysis is defined as 1 cm^2 of a TCO layer. The focus of the analysis put only on the process of TCO layer deposition. Impacts related to the production of the support (wafer) for the TCO and treatments following the deposition process were not considered. Furthermore, environmental impacts related to the infrastructure needed for the process are not considered. This impact may vary significantly between different production sites due to local restriction on the construction materials, equipment used for the process and most importantly scale of the production. As a result, if all of those impacts would be considered, the actual impact of the deposition process itself could be shadowed by the impacts related to the infrastructure. Therefore, capturing of the actual benefit or loose for the environment resulting from application of new TCO's or/and change of the deposition technique might not be possible. Hence, the scope of analysis was drawn around the deposition process itself and related consumptions and emissions.

2.3 Inventory analysis

The first step of LCA analysis consists of collection of detailed data on the process. Based on this data, additional mass and energy balances can be calculated and subsequently all impacts on environment are quantified. The data was collected for lab-scale devices operated by different project partners [3]. Due to sensitivity of data, only an aggregated data is given here for the benchmark layer composed from ITO and deposited by PVD technique (Table 2).

Table 2. Inventory analysis data for the benchmark layer (ITO, PVD technique)

Inputs/outputs	Unit	Amount
Cooling water	m^3/cm^2	2,80E-05
ITO target	g/cm^2	1,01E-04
Argon gas	m^3/cm^2	1,21E-07
Oxygen gas	m^3/cm^2	9,88E-10
Electricity	kWh/cm^2	7,53E-05
Waste for reuse, recovery, recycling	g/cm^2	6,01E-03
Waste for final disposal	g/cm^2	1,54E-05
Waste water without treatment	m^3/cm^2	1,33E-10

2.4 Impact assessment

Layers deposited by Physical vapour deposition (PVD)

Subsequently, data for all processes was further recalculated and introduced to SimaPro software. For the PVD technique, a solid source of ITO/ ZnO is used, what facilities the exact quantification of materials used for deposition and waste generated by the process. Therefore, only the units of consumption needed to be recalculated. Additionally, the impact of the transport of raw materials was assessed. The raw materials (ITO, ZnO) were assumed to be transported by ferry from China to Europe (Marseille) and further by lorry to the target production place.

What is crucial in LCA analysis is the availability of impact coefficients in the selected database. In case of PVD processes and related source of ITO, ZnO or ZnO doped with Al such data was available, what ensured exact analysis without need for further assumptions. Resulting process trees for ITO and ZnO layers, showing different stages of the deposition process and related impacts is shown in Fig.1-2, (SimaPro®). The individual impact of all parts of the process in expressed in ecopoints, which gives a single score value of environmental impact. However, such a unit may be only used in a comparative analysis identifying which process option is more or less environmentally friendly. Therefore, in this analysis, layers composed of different materials and deposited by different processes are further benchmarked towards the industrial standard ITO layer.

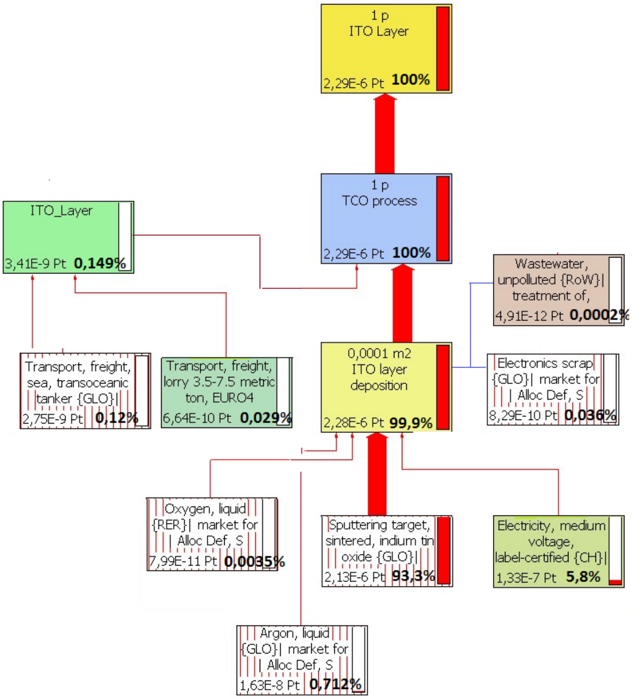

Figure 1. Process tree for ITO layer deposited by PVD technique.

For the ITO layer, majority of environmental impact comes from raw materials usage. Indium doped tin oxide used for the layer accounts for 93,3% of the total impact. Electricity, transport and waste generation are responsible only for 0,01% of impact. Therefore, process optimization should be targeted on material replacement. Based on results of LCA analysis, ZnO seems to be a good alternative for ITO: its total environmental impact is 42% lower (2,29E-6 Ecopoints for ITO vs. 1,32E-6 for ZnO layer). The impact related to the material usage is of minor importance and accounts only for 2,41% of the total LCA score, whereas the majority of impact is related to electricity consumption.

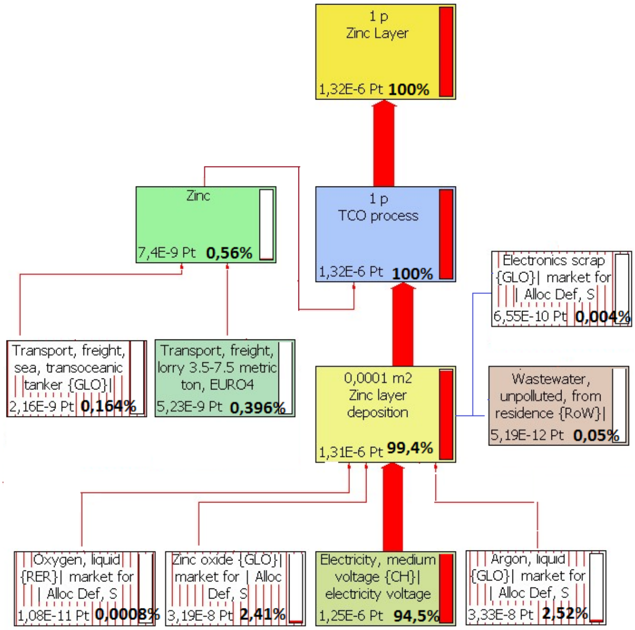

Figure 2. Process tree for ZnO layer deposited by PVD technique.

The results for ZnO layer doped with Aluminium are very similar to the score for ZnO layer, due to minor amount of Al used.

Layers deposited by Atomic layer deposition (ALD)

Subsequently, ALD technique was evaluated. From the environmental point of view, the major difference between the PVD and ALD technique is related to the source of ZnO and Al doping deposited on the layer. In case of ALD liquid precursors are used, such as for e.g. Diethyl zinc, which participate in reactions leading to e.g. ZnO and Al_2O_3 formation. Naturally, a number of volatile by-products is generated and present in the exhaust gases which are further scrubbed before the final gas disposal. In order to provide accurate LCA analysis, we have quantified the amount of waste gases purified in the scrubber and subsequently modelled the environmental impact of waste generated from scrubbing process.

The main challenge of LCA for ALD technique is the use of complex precursors, which are not available in the SimaPro database. In such case, two the following LCA procedures can be applied: the missing compounds can be replaced by the compounds which have a similar environmental impact or, alternatively, the missing compounds can be 'synthesized' using the substrates required for compound production. Such an approach gives a simplified picture of the environmental impact, but still this is the most accurate procedure to be performed in case of lack of data [4]. In order to determine sensitivity and accuracy of applied LCA methodology, we carried out calculations for both methods - compound replacement and compound synthesis.

Subsequently, for the ‘replacement’ approach, Trimethylborate was selected as the most adequate replacement for diethylzinc and trimethylamine for trimethylaluminium. For the ‘synthesis’ based approach, the reactions and efficiencies was obtained from literature [5]. We found that the results obtained with replacement/ synthesis approaches are very close. The process tree for ZnO:Al layer, ALD technique is given in Fig. 3., showing that the main contributions are related to electricity consumption and nitrogen usage. Impact related to the deposited material is of minor importance.

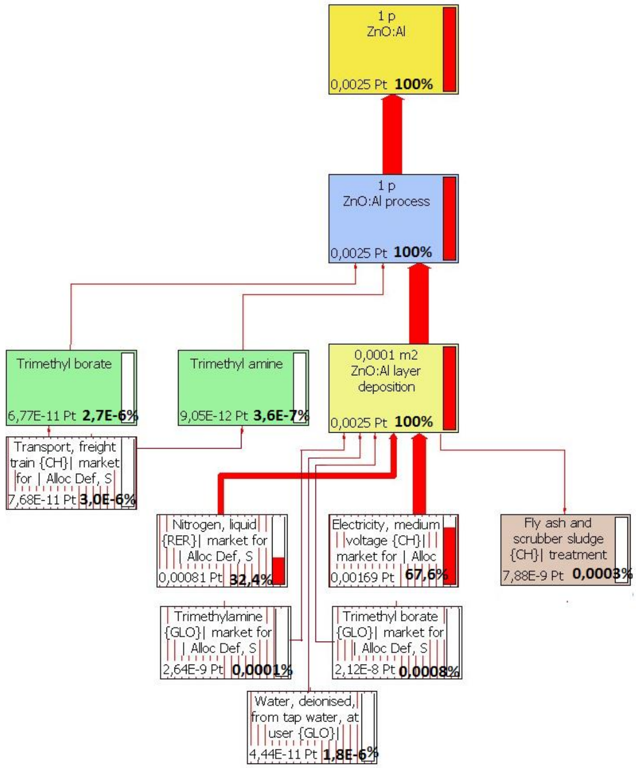

Figure 3. Process tree for ZnO:Al layer deposited by ALD technique.

Layers deposited by Chemical vapour deposition (CVD)

In the next stage of the work, LCA analysis of CVD deposition of ZnO with Boron doping was carried out. For CVD technique of ZnO:B deposition, all the data necessary for LCA calculations, except Diethylzinc (DEZ) were available in the SimaPro databases. Trimethylborate was selected as the most adequate replacement for actually used diethylzinc. Resulting process tree has a similar structure to the ALD process and again key impacts are related to electricity consumption (Fig. 4.)

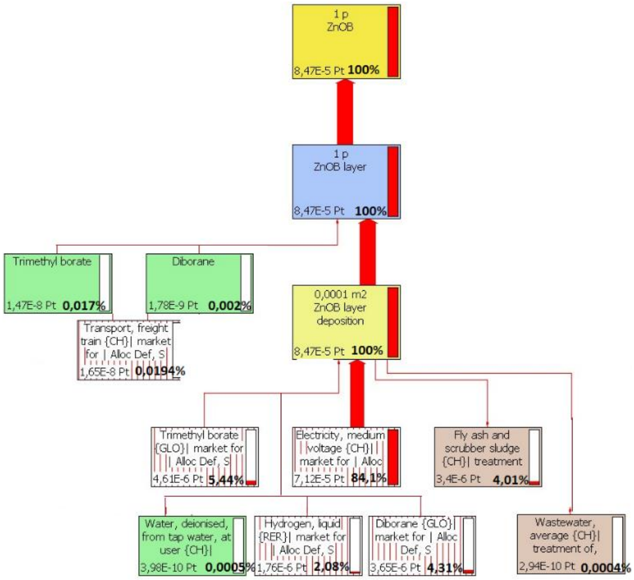

Figure 4. Process tree for ZnO:B layer deposited by CVD technique.

2.5 Improvement assessment

In case of ZnO-based layers, deposited by different techniques, electricity consumption proved to be the key contributor to environmental impact. However, the LCA calculations were based on data gathered from lab-scale devices, which usually are less energy efficient than industrial scale ones. Therefore, it is essential to validate how the results of analysis would change as a function of energy efficiency of the process. LCA analysis was recalculated assuming for each case, assuming that the energy consumption for the deposition process was reduced by 10, 20, 50 and 100%. Resulting plot of LCA single score vs energy consumption reduction is given in Fig. 5. For all analysed energy efficiency of PVD process, ZnO layer showed lower environmental impact that the ITO layer. The CVD and ALD techniques are characterized by higher energy consumption than the PVD process; consequently improvement of energy efficiency for CVD& ALD has a more significant impact on LCA results.

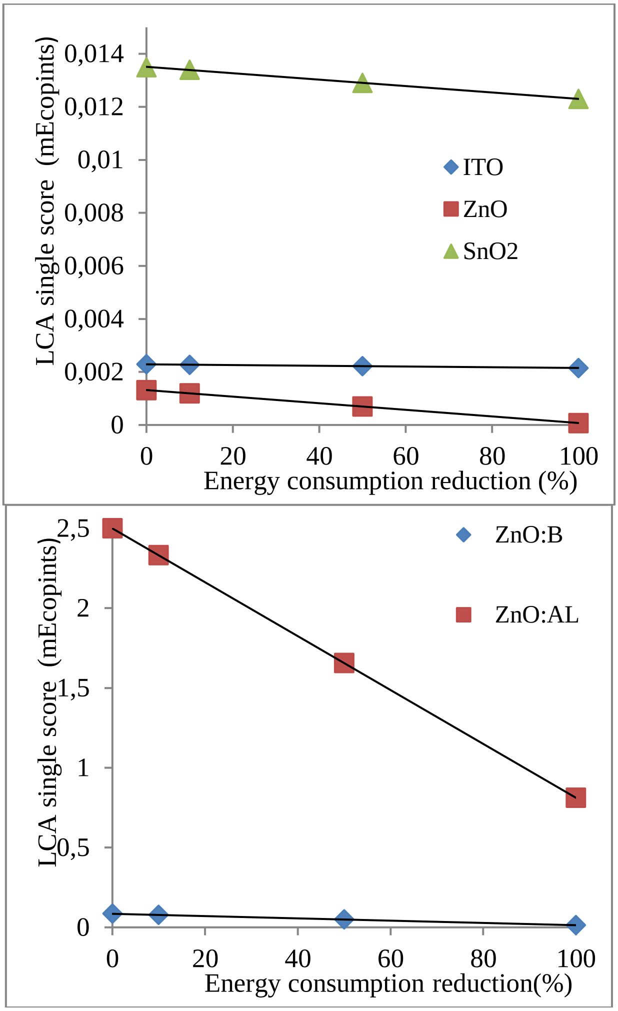

Figure 5. Sensitivity analysis results: LCA results vs. energy consumption reduction for a) PVD processes, b) CVD and ALD processes.

3 Discussion of Results

Results for all analysed cases are summarized in Table 3. For the PVD technique, replacement of ITO by ZnO / ZnO:Al reduces environmental load by ca 40.%. ZnO /

ZnO:Al layer deposited by PVD seems to be the best option for ITO replacement. The results obtained for the ZnO:Al layer deposited by CVD and ALD techniques cannot be directly benchmarked towards the ITO layer deposited by PVD, since differences in deposition technologies result in significant difference in the single score for each technique. However, in case of all layers deposited by CVD and ALD techniques the main impact is related to electricity or nitrogen consumption and the impact produced by the material is of minor significance. Hence, that proves that ZnO has a low environmental impact and is an appropriate replacement for ITO in all cases. This result is further confirmed by results of sensitivity analysis, showing that with higher energy efficiency, ZnO-based layer generates lower environmental impact with respect to ITO.

Table 3. Summary of results of LCA for all considered techniques.

No.	Compound	Dep. Tech.	Single Score [Pt]	Main impact [%]
2	ZnO	PVD	1,32E-6	Electricity 94,5
3	ZnO:Al	PVD	1,33E-6	Electricity 94,2
1	**ITO reference case**	PVD	2,29E-6	Indium tin oxide 93,3
4	SnO_2	PVD	1,35E-5	Tin dioxide 91,4
5	ZnO:B	CVD	8,47E-5	Electricity 84,1
6	ZnO:Al	ALD	2,5E-3	Electricity 67,6

4 Conlcusions

As an outlook for project development, we can conclude, replacement of ITO by ZnO proved to be a successful strategy for minimization of environmental impact for the TCO layer deposition process. Further process improvements for all analysed techniques should be focused on energy efficiency. Among the analysed process, PVD technique has the lowest environmental impact.

The following additional conclusions come from results:

- The PVD and CVD techniques are more environmentally friendly (Ecopoints in the range 1E-6 to 1E-7 than ALD (Ecopoints in the range 1E-3-1E-4).
- Aluminium doping for ZnO layer did not affect environmental impact due to low concertation of the material in the layer.

Acknowledgements

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J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Reducing Environmental Impacts of a Ups System Based on Polymer Membrane Fuel Cell with Circular Economy

Rok Stropnik, Mihael Sekavčnik & Mitja Mori

Abstract In this paper an environmental impact of a 3 kW UPS system with hydrogen technologies (HT-UPS) was evaluated with a life cycle assessment (LCA) method. The analysis was focused on the development of end of life (EOL) scenarios that will help to reduce environmental impacts during manufacturing stage. Numerical model of the HT-UPS was developed using Gabi software. The scope of analysis was cradle-to-grave with functional unit 1 kWh of produced electrical energy. In operating phase hydrogen is produced with electrolysis on site at two geographical locations. Three EOL scenarios were used in the study. With realistic EOL scenario in average a 68% reduction of all environmental impacts in the manufacturing phase was achieved, while a 74% reduction of GW emissions with was achieved with a feasible EOL scenario. EOL phase of HT-UPS represents low environmental impacts compared with other phases of LCA. Finally results show that with recycling and reuse of the materials in HT-UPS a 20% reduction of environmental impacts can be achieved in entire LCA.

Keywords: • Life cycle assessment • hydrogen technologies • end of life assessment • polymer exchange membrane fuel cell • uninterruptible power supply •

Correspondence Address: Rok Stropnik, Young researcher, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: rok.stropnik@fs.uni-lj.si. Mihael Sekavčnik, Ph.D., Professor, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: mihael.sekavčnik@fs.uni-lj.si. Mitja Mori, Ph.D., Assistant Professor, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: mitja.mori@fs.uni-lj.si.

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1 Introduction

Uninterruptible power supply (UPS) system provides clean, conditioned and uninterruptible power to the sensitive loads such as airlines computers, data centres, communication systems, telecommunications grids and medicals support systems in hospitals, [1]. For reliable operation without grid break downs, electrical energy is needed all the time, without interference. Because of the complexity of electrical grid system, the probability of the electricity cut outs is not negligible. In these cases the UPS systems provide reliable constant voltage and constant frequency power in case of mains failure, [2]. Conventional UPS systems consist in most cases from battery stacks as storage source and provide good performance during grid interruption. However batteries cannot provide backup for a very long period of time and have limited charge/discharge cycles. Actually, battery-backed UPS with emergency power generation is based on rapid start diesel engines (ICE-UPS) for longer backup operation [3]. However, these systems have certain negative characteristics, such as low energy density, short life time, strict working temperature range, high maintenance cost and hazardous effect to the environment, [4]. Also batteries contain toxic heavy metals such as cadmium, mercury, and lead which may cause serious environmental problems, [5]. To mitigate those drawbacks, many researchers have been working on alternative power sources to replace the battery based UPS systems. UPS systems with hydrogen technologies use fuel cells for electricity generation and are limited mostly with fuel (hydrogen) availability. HT-UPS is better than traditional ICE-UPS in many aspects, such as higher energy density, higher efficiency and no pollution during operation, [6]. The very important issue is that operation with HT-UPS releases less harmful emissions for environment and for people’s health into earth’s atmosphere, soil and water than operation with ICE-UPS systems that use fossil fuels.

A life cycle assessment (LCA) standardised methodology is used in this study to determine the environmental impacts associated with all phases of a product’s lifetime. HT-UPS have been evaluated in other studies without assessing their environmental performance, [7]–[10].

This paper evaluates environmental impacts in entire life cycle of the HT-UPS system at two different operating locations. The main contribution of this study is to show the importance of end of life assessment (EOLA) for hydrogen technologies and how emissions could be reduces with recycling and dismantling strategies.

2 Description OF HT-UPS

The HT-UPS system has several advantages over conventional UPS systems, such as longer backup time, higher efficiency, higher energy and power density, longer lifespan, lower maintenance cost as well as environmental friendliness, [11]. Up till now, several HT-UPS systems were proposed and studied by other authors, [12]–[14]. If hydrogen is produced from renewable energy sources (RES), such a system emits very small amounts of emissions in its operational phase. However, in other phases of its life cycle: raw materials production, manufacturing, transport and end of life, it is expected to have certain environmental impact. LCA analysis of the 3 kW HT-UPS system (shown in Figure 1), produced by Electro Power Systems from Torino, is the main objective of this study. Main components included in the study are: air blower, external heat exchanger, hydrogen recirculation blower, PEM fuel cell stack, air humidifier, controls and regulation system. Main cabinet and lead batteries are manufactured in different locations across Europe. In the study all components were modelled according to detailed manufacturer's data and numerical models for all balance of plant (BOP) components were set up.

3 LCA OF HT-ups

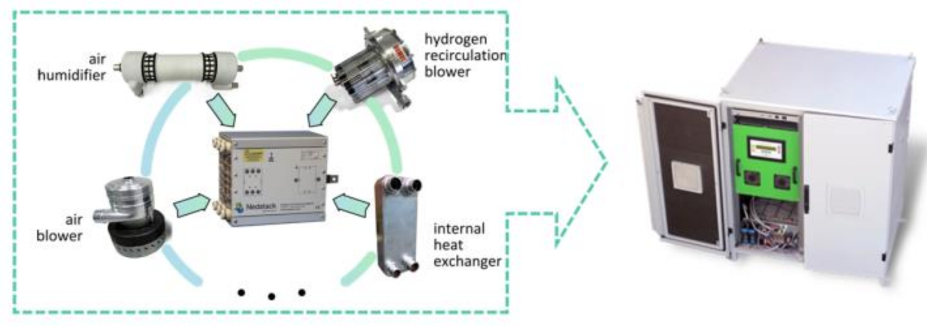

Figure 1. Left: Fuel cell and developed BoP; Right: FluMaBack HT-UPS system [18]

LCA method is the most comprehensive method for evaluating the environmental impact of the product in all its life cycle stages. The LCA method evaluates material and energy inputs, outputs and potential environmental impacts of a product during its lifetime. It consists of four stages: the definition of the goal and scope; the life cycle inventory (LCI) analysis, which is the construction of the product's life cycle model where all relevant mass and energy flows are quantified; the life cycle impact assessment (LCIA) which is the evaluation of the environmental relevance of these flows; and finally the interpretation of results. LCA was made according to FC-HyGuide document [15], and ISO standards 14040/44, [16], [17].

3.1 The goal and the scope of the study

The goal and scope define the exact questions that the analysis will try to answer, and set its spatial, temporal, and technological boundaries. The product's function is defined and quantified by the functional unit and in this study the functional unit is 1 kWh of produced uninterrupted electricity. The goal of the study was to determine environmental impacts of the 3kW HT-UPS and evaluate those impacts at different phases: manufacturing, transportation, operation and EOL. Two different operation sites, one in northern Africa

(Marrakesh, Morocco) and one in northern Europe (Oslo, Norway), were evaluated. The study is physically limited to the HT-UPS system, while the manufacturing of the hydrogen production facility was not included. The system's physical boundaries include the all UPS's subsystems. Transport via railway, cargo ship and truck has been included in the numerical models. Operation phase is considered for 10 000 h which is approximately 10 years' time. In the model the maintenance of the system is excluded. The type of analysis was cradle-to-grave (from production of raw materials to different EOL scenarios).

3.2 Numerical model of HT-UPS system

Numerical model is shown in Figure 2, with all material and energy inputs. A top-to-bottom principle was used to model the system, which contains: materials and energy inputs, seven manufacturing processes (FC, air blower, hydrogen blower, external chiller, humidifier, battery stack and additional components), nine transport processes, two operation processes and three EOL scenarios for each operating site. Model was set up on four layers with plan nesting technique in Gabi software. All parts in manufacturing phase were modelled according to detailed manufacturer's data presented in public document, [18]. In the EOL phase landfill, reuse and recycling strategies were used.

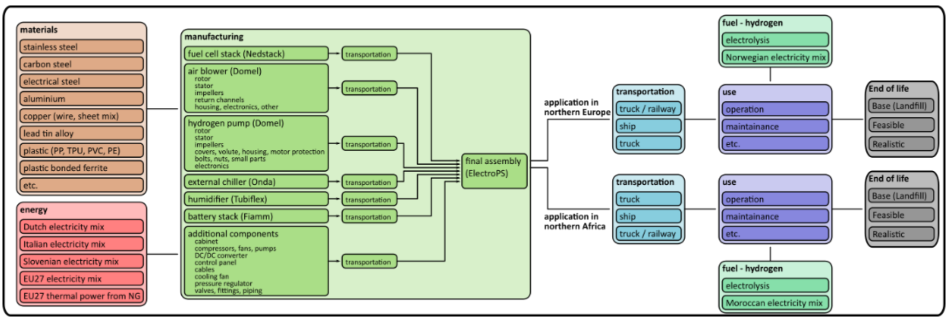

Figure 2. The numerical LCA model of 3 kW HT-UPS system with boundaries

3.3 LCI Analysis of HT-UPS

In LCI analysis all input and output flows are translated into contribution to the chosen environmental impact categories. In the study all virgin material mass flows, used for BoP components manufacturing processes, are included. Also, emissions during the phases of materials extraction, manufacturing, transport, operation and end of life are included. Data consist of primary data gathered on the basis of manufacturers' masses of materials as inputs in manufacturing processes of BoP components. Secondary data, which are generic databases [19], are used in all cases where primary data are not available.

3.4 Manufacturing phase

For manufacturing phase detailed data was provided by manufacturers for all components and parts. All detailed data are presented in public available study from EU funded project FluMaBack, [18].

3.5 Operation and hydrogen production

One of the goals was also comparison of the operation phase of HT-UPS system at two different operation sites with various electrical energy mix for production of hydrogen using on-site electrolysis. Manufacturing of hydrogen production facility was not included in the numerical model. In the case of Morocco, the energy mix consists of electricity produced: 43% from coal, 24% from oil, 23% natural gas, 7% hydro and 2% of wind power. On the contrary, in Norway 95 % of energy mix consist of energy produced in hydro power plants.

3.6 End of life assessment scenarios

For systems with hydrogen technologies different disposal strategies can be considered after its lifetime, like reuse of materials, landfilling or recycling of materials. If no information is available, when the lifetime of the products reaches its end, the worst case scenario of disposal is applied, which is landfilling.

In our LCA analysis the landfill scenario was used as base case scenario. According to the waste management hierarchy, landfilling is the least preferable option and should be limited to the necessary minimum. Landfilling is an unwanted option for the disposal strategies of hydrogen technologies, but it is the most common form of waste disposal.

The second EOL scenario in is feasible scenario, which represents the highest theoretical reuse and recycling possibilities for all materials in the HT-UPS system. Feasible scenario drastically lowering input of new materials in the manufacturing phase. For feasible scenario the 68% of reuse and 32% of recycling for all HT-UPS system materials was used. The feasible scenario is technically difficult to implement in real situations, because of the complexity of recycling of some specific materials and life time of used components. That is why the analysis of third scenario was used.

Third scenario is realistic EOL scenario and is somewhere in between the first two scenarios. Realistic scenario represent the highest practical amount of reuse and recycling of the materials and components used in the HT-UPS system considered in the study. In realistic scenario the reuse of main housing and components with easy dismantling procedure (50% of all mass) and 41% of other materials with easy recycling procedure was used. Other 9% represents landfilling of small electronic devices and components of the fuel cell, because of the missing specific guidelines and legislations of dismantling and recycling of hydrogen technologies. All EOL scenarios mass flows are presented in Table 1.

Table 1. End of life scenarios of HT-UPS

Scenario	*Base*	*Feasible*	*Realistic*
Landfill	283kg (100%)	/	26 kg (9%)
Reuse	/	91kg (32%)	115 kg (41%)
Recycle	/	192kg (68%)	142 kg (50%)

4 Results and Discussion

The results were analysed in terms of chosen environmental indicators, and major contributors to environmental impacts were identified. Global warming (GW), abiotic depletion (AD), ozone depletion (OD), acidification (A), eutrophication (E), photochemical ozone creation (POC), and human toxicity (HT) were calculated as environmental impact indicators [20], according to the CML2001 methodology, [21]. In the first part of discussion the environmental indicators for manufacturing, transportation and operational phase were calculated for base case scenario. The second part of results is focused on comparison of different EOL scenarios of HT-UPS, which are base, feasible and realistic scenario.

4.1 Manufacturing, transport and operational phase of HT-UPS

In manufacturing process the main impacts for GW, POC and A come from manufacturing of fuel cell, battery and the cabinet (Figure 3). For E and HT the main impacts come from auxiliary components and air blower. Environmental impact is high due to the high mass of steel used in the case of cabinet. In the case of fuel cell and battery high energy consumption (electricity energy mix) during the manufacturing process is a very important parameter.

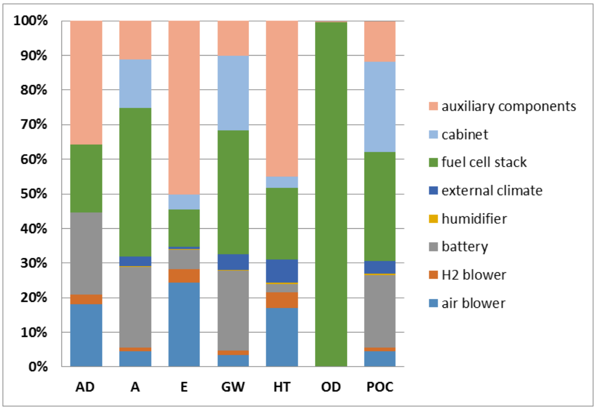

Figure 3. Environmental impact of single BoP components in manufacturing phase

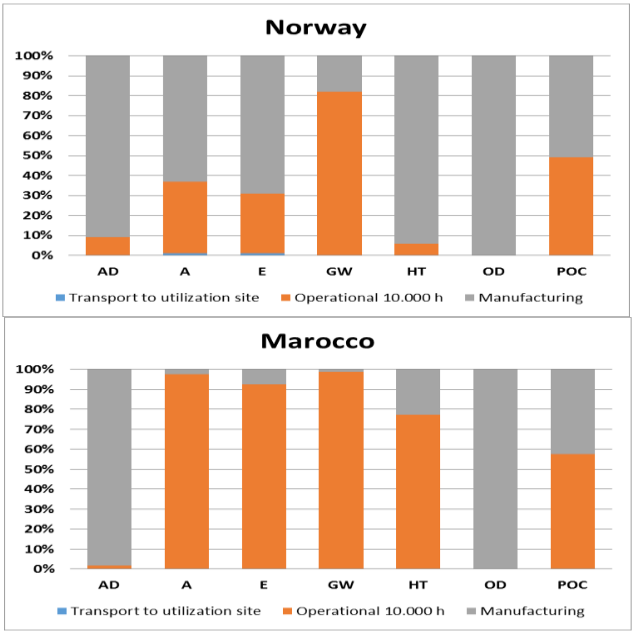

Figure 4. Environmental indicators in different life cycle phases of HT-UPS

From results in Figure 4 and 5 it is also evident that operating phase is very influential according to the GW and A. The electricity grid mix of the country (MA and NO) has a great influence on all environmental indicators during operation of HT-UPS with electrolysis on-site. Transport has negligible influence on environmental impact compared to manufacturing and operation. For manufacturing, transport and operation phase the calculation was done. Results show that the GW emissions were 278 g of CO2 eq. per 1 kWh of produced electricity for Norway and 4390 g for Morocco.

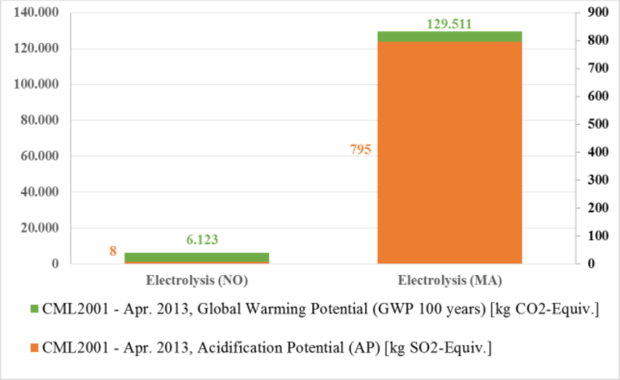

Figure 5. A and GW for operation phase

4.2 Results of EOL scenarios for HT-UPS

With recycling and reuse of materials in the EOL phase the reduction of environmental impacts during manufacturing stage was done with the use of different EOL scenarios. The results in Figure 6 show the reduction of environmental impacts during the manufacture phase for each used EOL scenario: base, feasible and realistic.

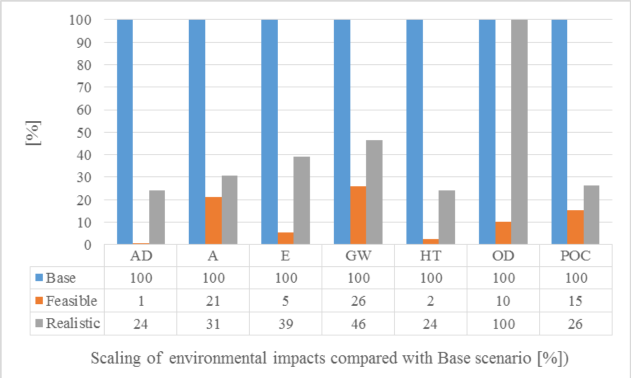

Figure 6. Reduction of environmental indicators according to EOL scenarios

Results of realistic scenario show that in average a 68% reduction of all environmental indicators has been achieved in manufacturing phase. The OD indicator is excluded in realistic scenario because there are not enough data available for Nafion recycling, which has the main contribution to the OD indicator. With feasible scenario a 74% reduction in GW emissions has been achieved, and even higher reductions for other environmental indicators, compared to base case EOL scenario. For manufacturing and EOL phase the comparison for relative contributions to environmental impacts was done (Table 2).

Table 2. Relative contributions in entire LCA

Base	**AD [%]**	**A [%]**	**E [%]**	**GW [%]**	**HT [%]**	**OD [%]**	**POC [%]**
Manufacturing	100,0	99,8	99,8	99,8	100,0	100,0	99,7
Landfill	0,0	0,2	0,2	0,2	0,0	0,0	0,3
Feasible	**AD**	**A**	**E**	**GW**	**HT**	**OD**	**POC**
Manufacturing	78,6	74,7	80,6	94,9	71,6	98,1	74,4
Recycling	21,4	25,3	19,4	5,1	28,4	1,9	25,6
Realistic	**AD**	**A**	**E**	**GW**	**HT**	**OD**	**POC**
Manufacturing	99,5	81,6	97,0	95,4	97,0	99,8	83,4
Landfill	0,0	0,1	0,1	0,1	0,0	0,0	0,1
Recycling	0,5	18,3	2,9	4,5	2,9	0,2	16,4

Results of relative contribution show that recycling has low environmental impact compared with manufacturing phase. From results, it can be concluded that with circular economy a high reduction of environmental impacts in manufacturing phase can be achieved for HT-UPS. With realistic EOL scenario for Norway a 20% reduction of all environmental indicators can be achieved in entire LCA.

5 Conclusions

HT-UPS system environmental impacts were analysed with LCA method. Hydrogen for operational phase was produced on-site with electrolysis in Norway and Morocco. Study shows that the main environmental impacts come from operational and manufacturing phase. One of the key measures for reducing total environmental impacts is the reuse and recycling of the materials in the EOL phase. Nevertheless, compared to the manufacturing phase the EOL phase represents low environmental impacts in entire LCA of the HT-UPS. With realistic scenario we could achieve in average a 68% reduction of all environmental impacts and with feasible EOL scenario a 74% reduction of GW emissions in the manufacturing phase.

Acknowledgements

The work has been accomplished within EU funded project FluMaBack (Grant agreement nº: 301782), [18]. These results will be used for future research about existing, new recycling and dismantling technologies applied to fuel cell and hydrogen technologies in undergoing EU project HYTECHCYCLING - funded by the Fuel Cells and Hydrogen Joint Undertaking (Grant Agreement No. 700190).

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Reducing the Life Cycle Assessment Heterogeneity: A System Design View

GIANLUCA ROSPI, MICHELE DASSISTI, FRANCESCA INTINI, ANTONIO GIOVANNINI, OSIRIS CANCIGLIERI JUNIOR & EDUARDO ROCHA LOURES

Abstract The Life Cycle Assessment (LCA) represents the most used tool to evaluate the sustainable performances of a product, process or activity. The ultimate purpose of a LCA is to have a metric to compare the impacts of life cycles of products, process and activities on the environment, the society and the economy. All existing methods for each LCA stage leave an important role to the subjectivity of the practitioner. This causes heterogeneity of the assessment that reduces the comparability of the LCA results. In this paper, the heterogeneity effects on the LCA for each stage of the assessment are discussed according to a system design perspective. This will permit to transpose the practitioners' subjective decisions into a coherence problem between 1) the choices about the methods for each LCA stage and 2) the comparability of the resulting LCA.

Keywords: • sustainability • sustainable performances • LCA methodology • unresolved problems in LCA • LCA heterogeneity •

CORRESPONDENCE ADDRESS: Gianluca Rospi, Ph.D., adjunct professor, University of Basilicata, Department of European and Mediterranean Cultures, via San Rocco 3, 75100 Matera, Italy, e-mail: gianluca.rospi@unibas.it. Michele Dassisti, Professor, Polytechnic University of Bari, Department of Mechanics, Mathematics & Management, via Japigia 182, 70126 Bari, Italy, e-mail: Michele.dassisti@poliba.it. Francesca Intini, Ph.D., University of Basilicata, Department of European and Mediterranean Cultures, via San Rocco 3, 75100 Matera, Italy, e-mail: francesca.intini@unibas.it. Antonio Giovannini, research, InResLab scarl, Monopoli, Italy, e-mail: ant.giovannini@gmail.com. Osiris Canciglieri Junior, professor, Polytechnic School - Production and System Engineering Graduate Program - PPGEPS, Pontifical Catholic University of Paraná (PUCPR), Brazil, e-mail: osiris.canciglieri@pucpr.br. Eduardo Rocha Loures, professor, Polytechnic School - Production and System Engineering Graduate Program - PPGEPS, Pontifical Catholic University of Paraná (PUCPR), Brazil, e-mail: loures@vtfpr.br.

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1 Introduction

The comparability is a critical issue of the Life Cycle Assessment (LCA). The LCA should guarantee a metric to evaluate the sustainable performances of a product, process or activity. Actually, for each stage of an LCA study, there are issues related to the identification of the ideal method. Choices for each LCA stage are still subject to the subjectivity of the practitioner. In principle, the choice of the method should depend on the features of the life cycle to analyse. Instead, in the most of cases, more than one possible methodological solution is available for each stage and of the analysis. Moreover, different methods lead to different LCA results. As a consequence, two practitioners assessing the same life cycle can achieve different LCA results.

In this paper, an analysis of the causes of the LCA heterogeneity is presented. The heterogeneity is reviewed according the stages of the LCA: 1) goal and scope definition, 2) life cycle inventory, 3) life cycle impact assessment and 4) life cycle interpretation. The main contribution of this paper is the discussion of an ideal scenario in which the LCA heterogeneity is minimized, i.e. the subjective role of the practitioner is strongly reduced.

The LCA issues are interpreted according to a system design perspective. This perspective permit to translate the practitioner's choices into system design choices to meet some stakeholders' requirements. By doing so, the LCA method-logical choices can be reduced to a matter of coherence, similarly the coherence between the design choices and the stakeholders' requirements. The final goal is to provide guidelines related to this point of view. These recommendations should guarantee that if two or more practitioners are analysing the same life cycle, they must produce the same LCA results. In the last part of the paper, the main implementation issues are discussed.

In the following sections, the system design perspective for the LCA is introduced. Then, the LCA issues for each stage of the analysis are reviewed according the system design perspective. Finally, a discussion about the future works on LCA according the system design perspective is provided.

2 A System Design View on LCA

About the stakeholders requirements. The expression of the stakeholders' needs triggers every system design stage. The stakeholders formalise their needs during the definition of a list of requirements. The requirements represent the constraints that the system has to respect. Actually, the requirements define an initial scenario (S(t0) in Fig. 1) (e.g. the initial punching process, the room usage) and a desired change to this scenario (S(tx), with x from 1 to N in Fig. 1) (e.g. reduce the scrap of a punching process, change the temperature of a room). A requirement is measurable and not am-biguous [1]. In order to guarantee the unambiguity 1) each requirement should be linked to measure-ments, 2) each measurement has to be characterized by what, where and when to measure, 3) each one of this proper-ties has to be characterized by a value, a tolerance (i.e. error of the system of measurement) and a unit of measure (UOM) [2]. The measurements definition allows an unambiguous verification of the coherence between the features of a proposed system and the stakeholders' requirements.

Therefore the stakeholders of the LCA process should constrain in an unambiguous and measurable fashion the S(t0) (e.g. technology of silicon photovoltaic panels, amount of newspapers to replace, litres of gasoline use) and S(tx) (e.g. silicon recycling results, performances of tablets that replace the newspapers, quantity of gasoline to replace). These constraints should be characterized by a definition of the UOM, tolerances and values of each properties of each measurement linked to the requirements.
About the system. A system is an aggregation of interacting elements organized to meet the stakeholders' requirements [3]. Therefore the system is the object that introduced in S(t0) allows to perform the transformation from S(t0) to S(tx), e.g. alternative punching strategies, alternative air-conditioning systems.

In the LCA, each life cycle to be assessed can be considered as a transformation (e.g. recycling photovoltaic panels of a country, replacing newspapers with tablet for news reading, replace the use of gasoline with ethanol mixtures) that is subject to a S(t0) and allows to respect the constrained objectives, S(tx).

About the design of a system. Every system that is able to meet the stakeholders' requirements can be considered an alternative solution, e.g. alternative punching strategies, alternative air-conditioning systems. Every alternative system shares a required transformation (from S(t0) to S(tx)) and one or more criterion according to which the alternative sys-tems are assessed, e.g. the deployment cost. This assessment allows to select the best alternative for the stakeholders.

An LCA can be compared to this process of selection. The criteria of selection for the LCA are about the sustainable performances of the analysed life cycles. The LCA study, as the system alternatives comparison, is moved by a request of comparison of one or more alternatives, e.g. different recycling processes. These alternatives can be considered as systems (e.g. silicon recycling process, manufacturing and distribution processes of tablets or ethanol) deployed to per-form a transformation (e.g. recycling photovoltaic panels of a country, replacing newspapers with tablet for news reading, replace the use of gasoline with ethanol mixtures). Every alternative, in order to be comparable, has to perform the same transformation (constrained by the stakeholders' requirements) and is evaluated according the same com-parison criteria, i.e. sustainable performance calculated in the LCA. When two life cycles subject to different S(t0) and S(tx) are compared is like comparing two systems related to different requirements.

About the LCA heterogeneity. The LCA heterogeneity is a matter of subjectivity for the methodological choice during the LCA stages. This subjectivity makes ineffective the comparison between two or more LCAs of the same product, process or activity. By considering an LCA process in a system design perspective, the aim is to project the effect of every methodological choice on the 1) initial scenario (S(t0) in Fig. 1), the 2) transformation objectives (S(tx) in Fig. 1) and the 3) criteria for the selection of the best transformation. These will be considered inputs of the LCA. Doing so, every choice can be evaluated on the basis of the coherence with these three points, i.e. like the coherence of a system feature with the related stakeholder requirements. A life cycle comparison will be possible only if the process, products, or activities to be compared have equivalent initial scenario, transformation objectives and assessment criteria. In summary, the LCA heterogeneity issue is transformed to an issue of coherence between the methodological choices during the LCA stages and defined initial scenario, transformation objectives and assessment criteria.

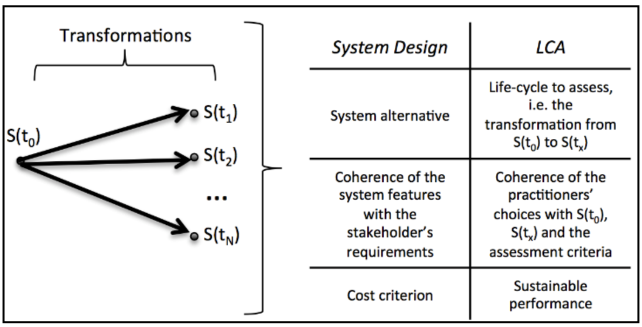

Fig. 1 – LCA and system design perspective

About data quality. Research works identified several issues concerning the data quality and lack of knowledge in the LCA studies, e.g. [4] [5]. Data problems (e.g. confidentiality, lack of coherence) or lack of knowledge (e.g. values of process parameters) are out of the scope of this paper. From a *system design* perspective, LCA with these issues is like performing a design process without the right information about the stakeholders' requirements, the available resources and so on. Concerning *uncertainty* issue, when the uncertainty propagation is possible, the uncertainty should be smaller than the *tolerance* values of the criteria used for the LCA study (defined as input of the analysis), i.e. the tolerated measurement error that is required for an effective impact measurement has to be smaller than the uncertainty of the calculated value.

3 Heterogeneity Issues in LCA Stages: A System Design Perspective

The following sections are organized as the LCA surveyed problems in [5] [6]. Every issue is explained and reviewed according a system design point of view.

3.1 Goal and scope definition

3.1.1 Functional unit

In [7], the *functional unit* is defined as the measure of the performances of the functional outputs of a considered system. In the same standard the importance of the functional unit for the comparability of the LCA results is highlighted. Actually in researches such as [8] [9] is shown how the choice of different functional units leads to different LCA results.

In [10], the authors compare the environmental impact of watching daily news online, on TV or on a newspaper. Considering the news item or the whole daily news as functional units leads to substantially different results of the LCA. This is due to the contribution of the manufacturing processes of the computer, the infrastructure to run the Internet and so on. The impact on the ethanol LCA results of the functional unit is analysed in [9]. The authors perform two assessments. In the first, the *kg* of ethanol is the functional unit. In the second, the functional unit is the *km* that is possible to drive by using ethanol. In the second case, the functional unit choice reflects the unlimited availability of ethanol. This difference of scenario makes the LCA results diverge.

System design perspective. Considering the LCA as a metric to compare *alternative* that respects $S(t_0)$ and $S(t_x)$, the functional unit should be related to these constraints. In other words, the coherence of the choice about the functional unit can be verified with the definition of the initial scenario and the transformation objectives.

Let us consider the above example of the ethanol. The LCA results are used to help the decision of replacing as much as possible the usage of gasoline in USA. Considering the USA scenario (i.e. initial scenario $S(t_0)$), the assumption of unlimited ethanol availability is not credible. Therefore the choice of the *km* as second functional unit leads to LCA results that do not reflect the initial scenario. The attempt to compare these alternatives is like comparing systems that respond to different stakeholders' requirements, i.e. not designed to be comparable.

In the case of ethanol the choice was about the nature of the measurement, i.e. weight or distance. In the case of the newspaper is about the value of the measurement, i.e. an item or the daily news. Concerning the newspaper analysis, two issues can be identified: the first one is related to the allocation of the manufacturing and infrastructure impacts on the news items; the second one is related to the multiple functions of the electronic media that generate an allocation problem on the function *reading*. The second issue is treated in the section 0. In the case of this first issue, the identification of the objectives of the *transformation* (i.e. $S(t_x)$) to be assessed with the LCA helps to discriminate between the functional units. Let us consider that the decision concerns the complete replacement of the newspapers by the electronic media in a particular location. The LCA should consider the impacts of the usage of an electronic media by a certain percentage of readers in the location for a defined period of time (e.g. the lifetime of a tablet or a computer). Instead of referring to the news items, an LCA related to this *transformation* should compare the amount of electronic media and newspapers to fulfil the need of news of the readers. Moreover, considering the transformation and the news items as functional unit, the change of support (i.e. newspaper or electronic media) can determinate a change in the quantity of news items that defines the need of the readers.

In summary, for every LCA comparison, the choice about the functional units should be implicitly included in the definition of the initial scenario, $S(t_0)$, and the objectives, $S(t_x)$. In fact, $S(t_x)$ and $S(t_0)$ determine all the constraints that a life cycle should respect and therefore they include the identification of the functional units. Moreover, when different functional units correspond to different $S(t_x)$ and $S(t_0)$, they should correspond to different analysis, i.e. the resulting LCAs will not be comparable. In other words, $S(t_x)$ and $S(t_0)$ define the *transformation* that is assessed in the LCA. Comparing different transformations is like comparing products related to different requirements.

3.1.2 Reference flow, system boundaries and scenario: definition of the life cycle to assess

Reference flow. A reference flow is the amount and type of energy and materials required by a product, process or activity to produce the performances described by the functional unit [11] [12]. The pur-pose of the reference flow definition is about the specification of functional units into product flows (for each alterna-tive to be compared by means of the LCA) [12].

Usually, research works [13] [11] [6] consider the issues about the reference flow definition strictly related to the functional unit definition. Issues are about the definition of product life-time, performances and dependencies of the product, process or activity considered. The lifetime depends on the cos-tumer habits, the environment in which the product is used, accidents, and so on. The performances depend on the customer habits, additional functions and functions not related to quantitative performances. The dependencies con-cern the impacts of the subsystem features on the performances.

Scenario. In [14], a scenario in LCA is defined as a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future, and (when relevant) also including the presentation of the development from the present to the future. Except for the uncertainty related to the formulation of hypothesis on the future, the critics about the scenario definition are also on the lack of the comparison of the designed scenario with a scenario of inactivity[15], i.e. if the change analysed in the LCA is not realized.

System boundaries. The system boundaries identify the process and activities that are considered in the LCA. The boundaries choice impacts the breath and depth of the assessment and therefore the confidence in the LCA results interpretation [6]. About the boundaries definition, the ISO 14040 [3] recommends to orient the decision on the basis of the LCA goal, scope, application, audience, constraints and clearly described and under-stood cutoff criteria. The cutoffs should be performed on the basis of the results of a sensitivity analysis on the impacts of the process or activity on the LCA results.

Main critics [16] [17] [6] about the ISO recommendation are about: 1) the proportionality between mass and energy contribution and environmental impacts; 2) the overall importance of aggregations of negligible contributions. The other methods for the boundaries definition also present is-sues. There are two groups of methods in literature: process-based and IO (input/output) LCA-based [6]. The former suffers high truncation errors and capital goods exclusion. The latter suffers issues of 1) data reso-lution, 2) neglecting difference between similar production technologies, economic structures, industries and 3) unjusti-fied truncation of recycling industry sectors and of stages of the process life cycle.

System design perspective. Once the S(tx) and S(t0) are identified, the reference flow, the system boundaries and the scenario permit to determine the processes allowing to meet the objectives S(tx) from S(t0). In other words, these three LCA stages define the life cycle to be assessed, i.e. the object of the assessment. This life cycle can be considered a sys-tem alternative. If different processes permit to perform the transformation, then different systems alternatives can be identified.

In fact, different hypothesis about the scenario or the reference flow should determine different life cycles that should be considered in different LCA studies. For instance, in [18], the authors consider the assessment of biodiesel production from microalgae. Here 4 variants for the production process are identified because of 1) the 2 al-ternative solutions for algae culture and 2) the 2 solutions for the oil extraction process. The definition of 4 processes to meet the objectives S(tx) from S(t0) leads to 4 different assessments for the biodiesel production from microalgae. In summary, the variants of scenario and the reference flows are inputs of the LCA and thus their heterogeneity only impacts the number of life cycles to be compared.

Instead, the issue of the system boundaries is about the resolution of the LCA. The definition of the boundary of the system is related to the exclusion (cut-off) of the factors (i.e. features of the process, product or activity to be assessed) that do not influence the system's impacts that have to be considered in the analysis. In the General System Theory [19], Von Bertalanffy defines a system as consisting of interacting parts that cannot be neglected if their interactions with the rest of the system is not linear or not weak. Therefore, a cut-off of a factor should be per-formed only if its influence on the rest of the system has these characteristics. To respect this recommendation, a com-plete knowledge of the interactions between the system's parts should be required. In the LCA case, the interactions to consider are the ones related to the sustainable performances to be assessed. In this vision, if the sustainable perfor-mances that are required to compare different life cycles should be related to a tolerance value, a cutoff (ISO 2006) [3] should be performed when a factor does not represent an impact greater than the defined tolerance for the perfor-mance parameter. In summary, the system boundaries should not be considered as inputs but they should be comput-ed on the basis of the knowledge about the influences of the factors in the system on the sustainable performances to be assessed. This computation is analyst-independent only if the knowledge related to the system behaviour is equiva-lent for each practitioner.

For instance, in [20], the material and energy used for milk production in conventional and organic farm is compared. A cut-off is performed on medicines, detergents and other minor stable supplies. This deci-sion can be univocally made by every practitioner only if: 1) the knowledge, which this cut-off is based on, is shared; 2) the impact of these cut-off is lower than tolerance related to the material and the energy used for the milk production.

3.1.3 Economic and social impacts: coping with measurability issues

LCA is the most common tool to evaluate the sustainable performances. The sustainability of a product, process or activity does not involve only the environmental aspect. Unfortunately, the ISO 14040 [3] fails to include the assessment of economic and social impacts [21] [22] The diffi-culties to integrate economic and social aspects in the LCA are mainly about [6]:

- Social – consensus on indicators, qualitative approaches and dependencies not only on the life cycle but also on the companies behaviour;
- Economic – neither scientific nor procedural agreement on the terminology, methodology and so on; diffi-culties in handling externalities, costs allocations, system boundaries alignment and future cost estimation.

System design perspective. In the case of this LCA aspect, the issue is matter of measurability. Let us consider the agreement on the indicators and on the computation process for them. The choice of the indicators to take into ac-count the sustainable performances should define the criteria of assessment of the considered life cycles, as a cost cri-terion can serve as metric to assess system alternatives. The criteria have to be common for all the life cycles to be compared with the LCA, as the cost has to be calculated following the same computation for all the system alterna-tives. Therefore the choice of assessment criteria should be considered as input of the assessment.

Concerning the qualitative approaches, to increase the comparability of the LCA, the assessment criteria have to be measurable. Although for the economic aspects the measurability is not an issue, for the social indicators, this can be a tricky task. Even if it is hard to think about measuring properties in the social sphere, to reduce the ambiguity of the assessment, the qualitative measurements should be converted in quantitative ones, e.g. in [23] the au-thors propose to set a balanced diet as functional unit to consider the social impact of food products. Moreover, en-couraging works oriented to the quantification of human-related properties have been performed in the domain of the system-human interface [24].

3.2 Life cycle inventory analysis

The life cycle inventory (LCI) analysis represents the quantification of the material and energy flows. Excepts for the data problems and the negligible contribution (see section 2.1.2), the issues at this stage concern the allocation and the local technical uniqueness [6].

3.2.1 Allocation

The allocation refers to technics for allocating the environmental burden of processes with more than one output, i.e. function or product [6]. Let us consider the electronic media example discussed above. Electronic media is product with more than one provided function, i.e. a computer can be used to provide more than the sole *reading news* function. Therefore if the LCA is considering only the *reading news* function, how to allocate the environmental cost of the computer manufacturing process?

The ISO 14040 [3] recommends dividing processes into sub processes or expanding system boundaries in order to avoid the allocation. Obviously, the quality of the process decomposition physical and economical depends on the independence of the sub processes [25]. On the other hand, the system boundary expansion leads to a larger and more complicated model [26]. This appeal of the standard seems to confirm the apparent intractability of the problem [27].

When the allocation is not avoidable, the ISO standard also propose the allocation by causal, physical relationships. This method implies a full knowledge of the causalities because using different causality principle for the allocation can lead to important differences in the LCA results (e.g. example of chlorinated dioxins allocation on the incoming materials of an incinerator [28]). In the case of lack of knowledge, non-casual relationships are recommended, i.e. allocation based on energy or exergy content, mass, volume, etc. This allocation can be not enough accurate [25].

System design perspective. An *allocation* of impacts can be seen as an allocation of manufacturing costs on a product, when, for instance, more than one product is manufactured during the same process. The *allocation* is an issue when an identification of economically and physically independent sub-process is not possible. In this case, the assessment should be extended to the set of outputs (e.g. a product or process family) of the considered manufacturing process.

This approach looks like the boundary expansion. Let us consider the LCA of the solar grade silicon for the manufacturing of the first generation PV cells. If the process considered for the silicon purification is the Siemens process (Heinrich 1962), there is an allocation problem. The Siemens process produces electronic grade silicon (for the semiconductor industry). The solar grade silicon is only the scrap of the process. In place of the allocation, in this case, the impact difference between two scenarios should be considered: 1) the production of a particular amount of solar grade silicon with the Siemens process; 2) the production of the same amount of solar and electronic grade silicon produced by means of other processes. This approach was proposed in [29]. Except for missing data, the same authors identified the lack of alternative production systems as the limit to the deployment of this approach. This means that there exist no alternatives for the considered process. In this case, the comparison should be performed by defining a *zero* scenario, i.e. as if the considered process is not performed, e.g. the production of energy in a particular area without the amount of considered solar grade silicon.

3.2.2 Local technical uniqueness

Difference of location can reflect difference in technologies for extraction, production distribution and end-of-life [6]. These differences between region, firms, facilities, production lines can severely impact the LCA results [25], e.g. type and amounts of required resources, wastes produced by the transformation of these resources.

System design perspective. Neglecting the technical uniqueness is like not considering system features that can impact the system costs. The local uniqueness issues are about the lack of precision in the definition of the features of the transformation to assess. The data for the LCI should have a geographical characterization. An example is in [30]. Here, the authors perform a comparative study on the margarine and the butter production in UK, Ger-many and France. The collected data are from local production sites and suppliers. Data about milk production is from various published studies with a local characterization.

3.3 Life cycle impact assessment

The aim of the life cycle impact assessment (LCIA) is to build the relationship between the right burdens with the right impacts at the correct time and place [5].

3.3.1 Impact category selection

This stage concerns the connection of data collected during the LCI with the right impact category, e.g. global warming, acidification, human toxicity, waste resource consumption, etc. Main difficulties about the impact category selection are the lack of standardisation, the disuse and the mid-/end-point selection.

The lack of standardisation among different proponent organisations of these categories present an important point of heterogeneity in the LCA results [25]. The slightly differences between the proposed categories usually reside in the selected modelling

approach, e.g. midpoint versus endpoint [5]. The disuse of some im-pact categories is imputable 1) to lack of data support, indicators or agreement on indicators for an appropriate as-sessment or the lack of agreement on indicators, 2) the relevancy consideration and 3) the lack of consideration by the methodology of the tool used [5]. The midpoint versus endpoint selection fosters a controversy: the endpoints are less comprehensive and have higher levels of uncertainty [31]; midpoints are harder to interpret because not directly related to an area of protection [32]. Moreover, two further issues are due to the in-experience of the LCA practitioner such as 1) double counting of impacts the same environmental burden on more than one impact category and 2) delegate the category choice to the LCA software.
System design perspective. This issue is about the lack of knowledge of the practitioner and/or about the impacts. We can consider the body of knowledge required for an LCA study like the expert know-how needed to design a system. Starting from the same stakeholders' requirements, different knowledge leads to different system alternatives. There-fore different body of knowledge for the LCA will always lead to not comparable LCA results. An example are the LCA results of photovoltaic panels before the first recycling process were developed [33].

3.3.2 Spatial variation and local environmental uniqueness: space characterisation

Impacts calculation and their effect on the environment can have a heavy dependency on the spatial characterisation. Actually, some impacts consider local, regional and continental scale. In this case, the characterisation of the meteor-ology, topology, hydrology and land use condition affect the calculation of the impacts, e.g. acidification, eutrophica-tion, health effects, water contamination [5]. Moreover, the spatial characterisation issue involves the variability of how different particular environments are affected by the same impact. Actually, the effect of a resource extraction or pollution can change depending on the local environment uniqueness, e.g. soil features, population densi-ty [5].

System design perspective. As for the system boundary definition, here the issue is about the definition of a tolerance value for the transformation to consider and its sustainable performance. Therefore the characterisation of all the fea-tures of the transformation that can affect the sustainable performance (according their tolerance values) to consider in the LCA has to be performed. An example of environmental uniqueness consideration is in [34]: the biomass cultivation for hydrogen production by electrolysis is related to the local features of the Italian territory.

3.3.3 Dynamics of the environment and time horizons: time characterisation

According the ISO 14040, the LCA is a tool that normally excludes the temporal axis. This feature affects 1) the as-sessment of impacts that are time-dependent and 2) the time horizon variability of some analysis. Even the ISO 14042 [35] acknowledges that neglecting the dynamic nature of the industrial and environmental features can reduce the relevance of the LCA results.

The time-dependency of the impacts refer to the time irregularity of emissions [36], impacts that requires years to become evident [32], impact comparisons have results that changes over the considered time horizon [37]. Usually this time-dependency is ignored and the impacts are averaged [5].

The definition of a time horizon allows to integrate the impact over the time and to perform a comparison between different LCA results. Hellweg et al. showed how the choice of two different time horizons can affect the environmen-tal impact profile of the same process, i.e. waste incineration [38] and groundwater contamination [39]. If a choice of infinite limits can appear the most appropriate, this can discount short-term impacts [32].

System design perspective. This issue is about the time characterisation of the transformations and the criteria for the impact assessment. The dynamic aspects and the time horizon of the system behaviour should be included in the in-puts of the LCA. In fact, these aspects influence the system factors that should be considered and the sustainable per-formances that should be assessed. As for the system design, this time characterisation of the transformation should be considered part of the constraints included in the definition of S(t0) and S(tx). Therefore a different time characterisa-tion leads to different transformation features to consider and so to not comparable LCA results.

3.4 Life cycle interpretation

The life cycle interpretation is the process that involves the analysis of the inventory and the impacts to support a product/process selection, an improvement of some product feature of process aspect, etc. Per definition, the interpretation is a process that implies a work of subjectivity that is not only based on the natural science [27]. When a decision must be made, the aggregation of the result and consequent issues of weighting and valuating are is unavoidable [5]. Notice that, according the hypothesis detailed in the introduction, the *uncertainty in the decision process* (as in the classification in [5]) is out of the scope of this paper.

The most common weighting methods are the monetization, the panel method and the distance-to-target method [40]. *Monetization* represents one of the solutions for *weighting*. Monetization methods usually use the expression of a willingness to pay to monetize impacts; *who* is paying, *what* values and *how* that is measured varies between the methods; this can affect the accuracy of the comparison; moreover, the monetization of human health and future impacts remain point of controversy [5]. The *panel method* is based on three different cultural perspectives on nature that depends on the involved stakeholders, e.g. government officials, industry experts, scientific institutes [41]. The

distance-to-target approach is a method based on a comparison between the current performance of a reference country and the standards, laws or goals within the society; the subjectivity in the definition of the target make the method context-dependent [40].
System design perspective. During a system design stage, the unambiguous definition of the stakeholders' requirements allows to move the decision between the *system alternatives* to a matter of production cost [2], i.e. if the performances of the system alternatives equally meet the requirements.

In the case of an LCA, the identification of a unique criterion for the comparison of the alternatives is a more complex deal. The ideal criterion should be able to relate all the impacts calculable during the LCA, in order to give a definition of the most sustainable alternative. Let us consider the definition of *sustainable development* in the Brundtland report [42]: *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. The *restoration work* concept [43] seems to be the most coherent to this definition. Actually, the calculation of the restoration work allows to assess the *minimum work that would be required to restore a degraded non-renewable resource.* Resources that should be used to repair social or environmental impacts are also considered. Obviously, in order to obtain homogeneous calculation of the restoration work, a *common knowledge base* about the restoring process should be available.

4 Discussion About a Scenario with Ideal Lcas Comparability

The recommendation expressed in the previous section can be summarized as follows:

- The functional units should be included in the definition of an initial scenario and the objectives of the prod-uct, process or activity to be assessed; this characterization allows to cope with the multi-functional products (or processes or activities) and the local scenarios; since they are defined as inputs of the LCA, they do not contribute to the heterogeneity increase;
- The reference flows, social and economic criteria and the scenarios should be considered as inputs of the LCA and therefore not involved in the heterogeneity increase;
- Social criteria should be made quantitative;
- The system boundaries should be computed considering the impact of the system factors on the sustainable performances to be assessed; when the impact of a factor impacts is lower than the fixed tolerance for the performance, the factor should be the object of a cut-off;
- Promote the comparison with alternative solution or with zero-scenarios in place of the allocation for LCI;
- LCI should have geographical characterization in order to deal with local technical uniqueness;
- To have a univocal LCIA process, the practitioners' body of knowledge should be common;

- The space and time characterization of the system factors and the sustainable performances to be assessed should be provided as inputs of the LCA (not contributing to the heterogeneity);
- A general criterion should be considered to provide to the object of the LCA a sustainable note considering economic, social and environmental aspects; this criterion could be the restoration work;
- All the LCA inputs have to be unambiguously defined.

In general, these recommendations tend to increase the level of detail of the life cycle specification, e.g. tolerances re-lated to the sustainable performances, geographical, spatial and temporal characterization, etc. This level of detail en-hances the comparability but decreases the reusability of the LCAs, e.g. an accurate geographical characterization re-stricts the reuse only on the considered area.

5 Conclusions

In this paper, an analysis of the LCA heterogeneity issues has been discussed. These issues reduce the comparability of the LCA results. The heterogeneity sources have been analysed from a system design point of view. This view permitted to transform the subjective practitioners' choices into a matter of coherence between the decision at each LCA stage and the LCA inputs (the initial scenario, the objectives of the transformation and the sustainable performances to be assessed).

A list of recommendation has been formulated. Two main obstacles for the LCAs comparability can be highlighted: 1) the definition of the comparison 2) the definition of the life cycles to compare.

The first point is about the attempt to compare things of different nature: two transformations subject to different ini-tial scenarios and/or objectives cannot be considered in the same comparison process. Expressing S(t0), S(tx) and the restoration work is possible to address the methodological heterogeneity about the functional unit definition, the sys-tem boundaries definition, the uniqueness issues, the dynamic aspects, the economical and social aspects and the life cycle interpretation. Actually, as discussed in the previous section, these choices about methods for LCA can be har-monised if related to the definition of S(t0), S(tx) and the restoration work. Moreover, the unambiguous definition of common initial scenario (S(t0)), transformation objectives (S(tx)) and sustainable performances (defined as the calcu-lation of the restoration work) should be the base for a comparison of LCAs. Therefore, the definition of these three constraints allows to motivate the methodological choices and to deploy a significant comparison among the alterna-tives that respect these three constraints. The main effect of this proposal is the increase of the specificity of the LCAs. Actually, each LCA is similar to an assessment of a particular transformation project, e.g. recycling all the silicon in PV panels of France, replacing the newspapers with tablets in the northern Europe, replacing gasoline with ethanol mixture in USA. On one hand, this approach would increase the comparability. On the other hand, this would reduce the reuse of the LCA results. But, if the computation of sustainable performances requires a certain degree of life cycle specifici-ty, is a more generic LCA study really effective?

The second issue is about the definition of the transformation to assess, i.e. the definition of the reference flows, the scenarios, the result of the allocation and the impact category selection. These stages should be meant as a design of a system alternative. Therefore each life cycle has to respect the three set of constraints discussed above. However, if the body of knowledge used to design the alternative is not the same, different practitioner can compute different impacts and different restore work for the same life cycle, i.e. more than one LCA result is associated with the same life cycle. For instance, let us consider the development of the same air conditioning unit (i.e. that meets the same requirements) by using two different bodies of knowledge. If the relationships between the vibration and the noise produced by the system are not included in both the bodies of knowledge, then different impacts are computed for the same system. Therefore, a scenario with only one possible LCA result for the same life cycle implies the usage of a common knowledge base. This base should allow to harmonise the data in the LCI databases by formalising the relationships between the different processes and between the processes and the impacts. As discussed above, the boundaries should be fixed according the tolerance values. The limit of this vision is related to the effort for the knowledge acquisition, representation, maintenance and integration with the LCI databases. Future works should involve the definition of the minimum knowledge required to harmonize the LCI databases information, the knowledge about the impact catego-ries and the restore work and so to have the heterogeneity reduction effects here described.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Economic and Environmental Impact Assessment of Microgrid for Rural Areas of Pakistan

ZAIN ZIA & FURQAN ALI SHAIKH

Abstract Microgrid is a small, clean and friendly power network which can provide solution for energy supply to remote areas. This project focuses on the areas of Baluchistan where localities are not able to connect to the distribution network due to physical or economic constraints. The idea is to design microgrid from a limited budget of USD $ 200000. Using HOMER an optimal solution is presented combining solar and wind resources in combination of conventional diesel or gas generator. The optimal solution is obtained by analyzing the net present cost (NPC). The paper also intends to assess environmental and social impact of microgrid..

Keywords: • Microgrid • Rural areas • Pakistan • Environmental assessment • HOMER • Economic assessment •

CORRESPONDENCE ADDRESS: Zain Zia, PhD student, Asian Institute of Technology, School of Environment and Resource Development, Pathumthani, Bangkok, Thailand, e-mail: zainzia8@gmail.com. Furqan Ali Shaikh, Program Officer, Asian Institute of Technology, AIT Extension, Pathumthani, Bangkok, Thailand engrfurqanali@gmail.com.

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1 Introduction

Pakistan has a huge potential of energy resources but it’s a dilemma that the people still have to suffer energy deficiency. Conventionally, Pakistan has been fulfilling its energy needs through fossil fuel. However, the declining production and rising demand have made this country a huge importer of crude oil. In this scenario renewable energy as an alternative is gaining importance which was previously taken as insignificant.

Global warming is becoming a worldwide concern and climate change have led many international forums to consider it as an important factor in wide range of sectors. Pakistan has dominantly an agricultural economy and recently it is also being affected by the change in climate. The only solution to this problem is to reduce the carbon dioxide emissions by encouraging the renewable energy. The most attractive benefit of renewable energy is that its fuel is free. Also the renewable energy technologies can be installed in module fashion. There construction and commission time is relatively small with no carbon dioxide emissions.

Solar energy is the most abundant source of energy. The PV technology has seen an unprecedented growth in the last decade. According to International Energy Agency report, there would be 53% increase in global primary energy consumption up to 2030 and 70% of this value is expected to come from developing nations [1]. Nature has gifted Pakistan with such a location that energy can be harnessed with great efficiency throughout the year.

This paper focuses on the economic and environmental impact of microgrid on rural areas of Pakistan where there is no energy supply from the national grid. These areas include parts of Baluchistan where localities are not able to connect to the distribution network as shown in Fig. 1. In such areas diesel or gas generators are used for electric supply because of low capital cost, sufficient reliability and low operational and maintenance cost. The paper focuses on the economic-technical solution by combining the diesel generator with renewable energy resources and storage system. HOMER PRO (Hybrid Optimization Model for Electric Renewable) is used for simulation and evaluation purposes of microgrid. In this project a monthly rate of Rs.500 for every house is establish. This low value is to encourage the community to participate in project.

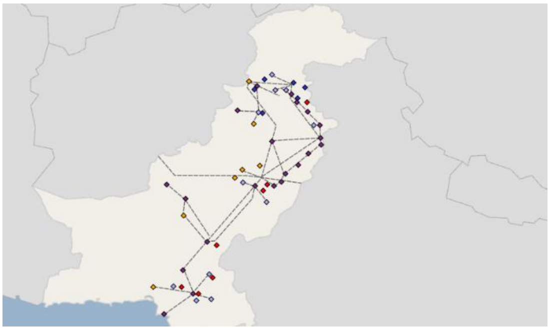

Fig 1. Pakistan map showing location of power plants and transmission lines developed by NREL

2 Electric Load Profiles

In this project the electrical load consists of residential demand and some business stores. The average load of each residence is considered to be 50 KWh/day. The characteristics of the load are estimated according to table I.

Number of residence	18
Peak demand	6.59[KW]
Duration of peak demand	1800-2200
Duration of low demand	0000-0004
Load average	2.07[KW]

The annual daily load profiles of 18 residences are shown in Fig. 2. The horizontal axis represents hours and vertical axis corresponds to KW of consumption.

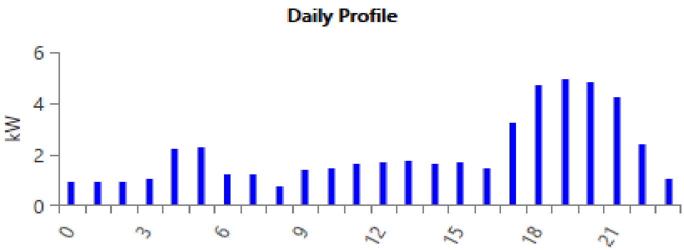

Fig 2. Annual daily load profile of 18 residences

The Fig 3. shows the frequency histogram of annual power consumption of the 18 residences.

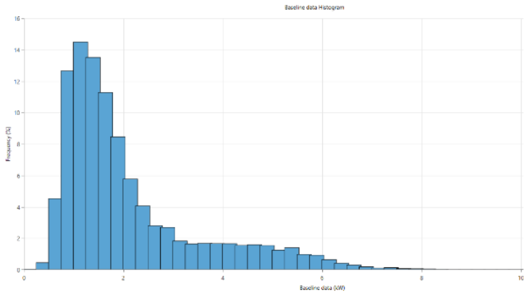

Fig 3. Frequency histogram of annual power consumption of the 18 residences

The annual load profile of the stores is represented by Fig 4.

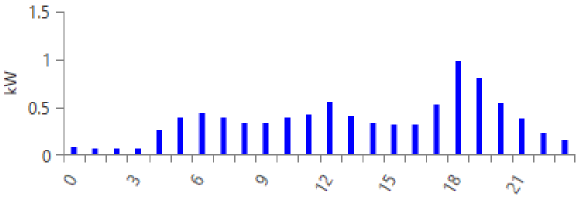

Fig 4. Annual daily load profile of stores

3 Renewable Resources

The annual horizontal level of radiation in area is 5.69432 kWh/m^2/day. Fig 5. shows the monthly horizontal level of solar radiation.

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.631	3.929
February	0.633	4.693
March	0.658	5.890
April	0.621	6.398
May	0.647	7.175
June	0.642	7.293
July	0.600	6.713
August	0.637	6.722
September	0.658	6.170
October	0.693	5.438
November	0.652	4.221
December	0.622	3.635
Average:	0.640	5.694

Fig 5. Monthly horizontal level of solar radiation

The annual average wind speed considered to be 5.189 m/s. It can be seen from Fig 7. that the wind speed remains in the range of 5-6 m/s throughout the year. This range is very appropriate for the implementation of wind power project.

Month	Wind Speed (m/s)
January	4.995
February	5.154
March	5.360
April	5.218
May	5.663
June	5.624
July	5.511
August	5.413
September	4.929
October	4.635
November	4.767
December	4.994
Annual average:	5.189

Fig 6. Monthly average wind speed

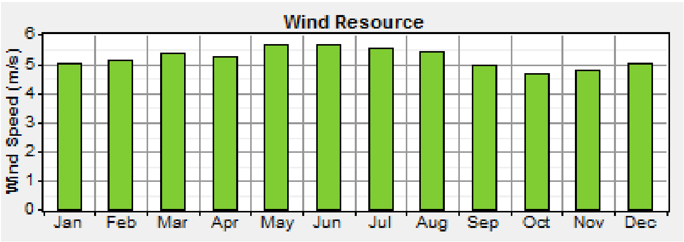

Fig 7. Graphical representation of monthly average wind speed

4 Analysis of Results

The optimal configuration obtained from the simulation is a s follows:

- Solar power project 6 KW
- Wind energy project 1 KW
- Diesel power generator 5 KW

In this project income obtained from electricity consumption of 18 residences gives a monthly amount of Rs.500. Therefore, the system is going to collect Rs.108000 and during 20 years Rs. 2.16 Million. Here the exchange rate is considered to be 1 USD/ Rs.105. This cost is enough to

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	36,000	8,980	384	0	-5,033	40,331
Wind 1kW	4,000	1,335	1,278	0	-249	6,365
Generator	6,000	5,243	4,446	54,087	-128	69,648
Trojan L16P	9,520	18,217	3,579	0	-947	30,370
Converter	3,200	1,202	0	0	-224	4,178
System	58,720	34,977	9,687	54,087	-6,579	150,891

Fig 8. summary of the values of the cost

cover the cost due to maintenance and operation. The summary of the values of the initial capital cost is given by Fig 8. During the 20 years the total cost for the service is USD $ 9687. The NPC of the project is USD $ 150891 which is less that the rural electrification budget USD $ 20000. Hence it is economically feasible. Fig 9. shows the monthly average electric production of different types of resources.

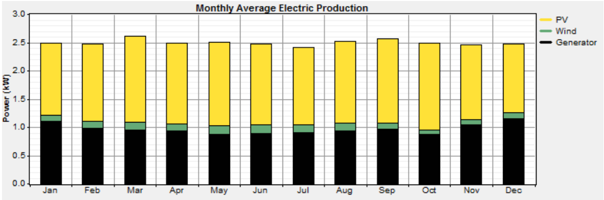

Fig 9. monthly average electric production of different types of resources

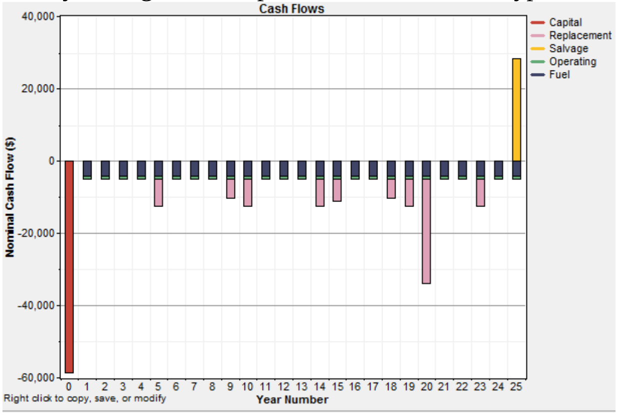

Fig 10. Cash flows for the 25 years

5 Enivironmental Assessment

In this project environmental assessment of microgrid is also discussed. Nowadays Pakistan is also on the list of countries suffering from climate change. This is mainly due to high dependence on fossil fuel. The use of renewable energy will reduce the amount of gaseous pollutants released in the atmosphere.

Diesel fuel contain 2778 gm of pure carbon. A gram of atomic carbon forms 3.666 gm of carbon dioxide when oxidized with O_2. Considering that 99% of fuel is oxidized the amount of carbon dioxide per gallon becomes 10084 gm. Table II shows the amount of carbon dioxide produced by 5 KW generator if operated alone and when integrated with renewable resources.

	Alone	**Integrated**
Gal/hr	225	225
Hrs/yr	4380	2124
CO_2	9937 Mg/yr.	1912 kg/yr.
CO	62 kg/yr	12.05 kg/yr.

From above table it can be seen that the amount of carbon dioxide and carbon monoxide is reduced when the diesel generator is integrated with renewable energy.

6 Social Aspect of Microgrid

When microgrid is installed in rural areas new job opportunities will be produced. Job openings will not only be in design and installation phase but also experts will be required for the operation and maintenance of microgrid. It will also help to develop the livelihood of the local lower middle class families by creating jobs for them.

Reliable and affordable supply of electricity will help to boost up the local economy. Nowadays electric infrastructure is the backbone of the economy. Initially the business at the stores may be finished by the sunset due to lack of supply and not using diesel generator as it is not economical but by installing microgrid the business hours are also increased to some hours.

7 Conclusion

In this study economic, environmental and social of microgrid are discussed for rural and remote areas of Pakistan which are lacking basic electric infrastructure. The result of the simulation obtained from HOMER shows that it feasible to deploy microgrid by integrating conventional diesel generator with the renewable resources. The optimal configuration is solar power project 6 KW, wind energy project 1 KW, diesel power generator 5 KW.

This study also indicates that the introduction of the microgrid in remote rural areas with help to boost local economy and also have positive impact of the environment. The amount of pollutants released in the atmosphere is reduced by encouraging renewable energy resources.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Life Cycle Assessment of Oil Crop Production for a Modern Biorefinery: Impact of Different Functional Units

MICHAŁ KRZYŻANIAK & MARIUSZ J. STOLARSKI

Abstract Crambe (Crambe abyssinica Hochst ex R.E. Fries) and camelina (Camelina sativa L. Crantz) are oleaginous crops which are attractive feedstock for modern biorefineries due to their reasonably high oil content and valuable composition of fatty acids. However, to compete with other commercially available oil crops, which usually give higher yields, their production sustainability should be studied. Therefore, the aim of this research was to compare environmental impact (especially greenhouse gas emission (GHG)) of camelina and crambe production (straw and seeds) in two production technologies, using the life cycle assessment method. The study was carried out according to ISO 14040 and ISO 14044 standards. Impact assessment was determined with the ReCiPe H method. The study showed that the emission of greenhouse gases from the cultivation of camelina and crambe in both production technologies, with 1 ha as functional unit (FU), was similar and amounted to 1,756-1,804 eq. kg ha-1 CO2. Using 1 GJ of energy contained in seeds and straw as FU also did not show large differences in GHG emission (24.2-27.7 eq. kg GJ-1 CO2). When 1 Mg of seeds was chosen as the FU, the emissions were from 1,176 to 1,548 eq. kg Mg-1 CO2, for crambe produced in reduced tillage technology and camelina from traditional tillage, respectively. When the emission of GHG was allocated to 1 Mg of oil, it turned out that this FU has the highest impact (3,438-4,052 eq. kg Mg-1 CO2). In conclusion, depending on which part of the crop is used and for what purpose (e.g. heat, 1st and 2nd gen. biofuels, bioproducts), greenhouse gas emissions varied considerably.

Keywords: • sustainability • energy crop production • bioproducts • energy • camelina • greenhouse gases •

CORRESPONDENCE ADDRESS: Michał Krzyżaniak, Ph.D., Assistant Professor, University of Warmia and Mazury in Olsztyn, Faculty of Environmental Management and Agriculture, Department of Plant Breeding and Seed Production, Centre for Bioeconomy and Renewable Energies, Plac Łódzki 3/421, 10-724 Olsztyn, Poland, e-mail: michal.krzyzaniak@uwm.edu.pl. Mariusz Jerzy Stolarski, Ph.D., Full Professor, University of Warmia and Mazury in Olsztyn, Faculty of Environmental Management and Agriculture, Department of Plant Breeding and Seed Production, Centre for Bioeconomy and Renewable Energies, Plac Łódzki 3/420, 10-724 Olsztyn, Poland, e-mail: mariusz.stolarski@uwm.edu.pl.

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1 Introduction

Crambe (C*rambe abyssinica* Hochst ex R.E. Fries) and camelina (*Camelina sativa* L. Crantz) are oleaginous crops which, due to their reasonably high oil content (and valuable compositions of fatty acids) are an attractive feedstock for modern biorefineries.

The crambe seed yield may range from 1.2 to 3.2 Mg ha^{-1} depending on the climate. The oil content ranges 31-37%, with a high share of erucic acid of more than 54% [1, 2]. Thus, crambe oil can be used as biodiesel, and derivate for lubricants, rubber additives, nylon, hydraulic fluids and other products [3, 4].

The standard camelina yield ranges from1.0-3.0 Mg ha^{-1}. Seed oil content has been reported to range from 30-49% [5, 6]. Camelina oil is rich in oleic, (14–16%), linoleic (15–23%), linolenic (31–40%) and eicosenoic (12–15%) acids. The oil can be used as biodiesel, hydroprocessed renewable jet fuel, polymers and chemical products, e.g. nanocomposite materials, monomers, alkyd resins and adhesives and others [5, 7].

However, to compete with other commercially available oil crops, e.g. rapeseed, which usually give higher yields, their production sustainability should be studied. Therefore, the aim of this study was to compare the environmental impact (especially greenhouse gas emission (GHG)) of camelina and crambe production (straw and seeds), in two production technologies, using the life cycle assessment method. Moreover, the study presents the possible environmental impact of the use of camelina and crambe for a wide variety of purposes (through varied functional units).

2 Materials and Methods

2.1 Goal and scope

In order to determine the environmental impact of the camelina and crambe production in two cultivation variants, the study methodology was based on the following standards: ISO 14040 “Environmental management – Life cycle assessment – Principles and framework” and ISO 14044 “Environmental management – Life cycle assessment – Requirements and guidelines”[8, 9]. LCA was performed with the SimaPro 7.3.2 program.

The aim of the study was to compare the environmental impacts of crambe and camelina cultivation systems with reduced tillage (RT) and traditional tillage (T) technologies. The main purpose of crambe and camelina cultivation is to obtain oil from seeds for the production of, for example, 1st generation biodiesel. To this end, a functional unit of 1 tonne of oil and 1 tonne of seeds (oilcake may be used for other purposes such as animal feed) was assumed. For biorefineries which could utilise entire plants (seeds and straw), the functional unit adopted was 1 GJ of biomass energy. Moreover, a benchmark unit of 1 ha of the plantation was used.

The study involved field experiments carried out in 2015-2016, in north-eastern Poland. Seeds of crambe (Galactica variety) and camelina (Midas variety) were sown by drill; 13 kg ha^{-1} and 6 kg ha^{-1} respectively. The 2015 experiment was established in the location of Samławki over an area of 1.5 ha (0.5 ha crambe + 1 ha camelina). This experiment involved the traditional tillage system. The experiment of 2016 was organised in Kocibórz, where a reduced tillage system was applied over the total area of 2 ha (1 ha crambe + 1 ha camelina). On each field, nitrogen fertilizer was applied each year as ammonium nitrate at a dose of 100 kg ha^{-1} N.

2.2 LCA methods

System description

The crop production process until the biorefinery gate was adopted as the system boundary. The following steps were within the system boundaries: site preparation, fertilisation, sowing, chemical protection, single stage harvesting, straw baling, transport to the farmstead (field transport), transport of straw and seeds to the conversion plant. It is assumed that biomass transport should not exceed approx. 30 km, the same distance after biomass unloading was added.

The study took into account the environmental impact of emissions from the production process of herbicides, mineral fertilisers and emissions resulting from the application of nitrogen fertilisers. The study also took into account the environmental impact of the production of agricultural machines and the use of road transport vehicles.

The production data were based mainly on the author's studies, the EcoInvent database and additional estimation data. The technical and operational parameters of agricultural machines were based on the data contained in the catalogue of agricultural machines [10] and in materials published by manufacturers of tractors and machines.

Nitrous oxide emissions from the use of mineral fertilisers, according to IPCC [11], may range from 0.25% to 2.25% of the N in the fertiliser used. The default recommended value is 1.25%, which was used in this study. The emission of ammonia to the atmosphere from the nitrogen fertiliser was based on the ECETOC report [12], in which the average emission was 2% NH_3 kg^{-1} N. Emission of nitrates caused by the leaching of nitrogen from mineral fertilisers was taken at 14% NO^{3-} kg^{-1} N [13].

3 Results

The study showed that the emission of greenhouse gases from the cultivation of camelina and crambe in both production technologies, with 1 ha as functional unit (FU), was the lowest for the cultivation of camelina in the simplified variant (RT) (1,756 eq. kg ha^{-1} CO_2) (Figure 1). The GHG emission from the other plantations was slightly higher and ranged from 1-3%. In the simplified variant of production, the CO_2 equivalent emission was lower than in the traditional tillage, however, only by slightly below 2%. These differences were caused by slightly higher fuel consumption in the reduced tillage cultivation. The highest share in the GHG emission was recorded for the production and use of nitrogen fertilisers, which was approximately 70% for both species and cultivation variants.

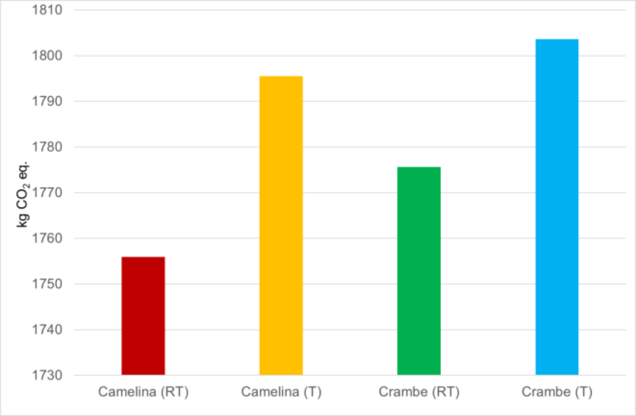

Figure 1. Greenhouse gases emission (eq. kg ha^{-1} CO_2) from crambe and camelina plantations, for two cultivation variants.

If all the plant parts (seeds, seed oil and oilcake as well as straw) could be used as energy feedstock (FU 1 GJ), the GHG emission would be the lowest for crambe cultivated in a reduced tillage variant (24,27 eq. kg GJ^{-1} CO_2), and the highest for crambe cultivated in a traditional variant (Figure 2).

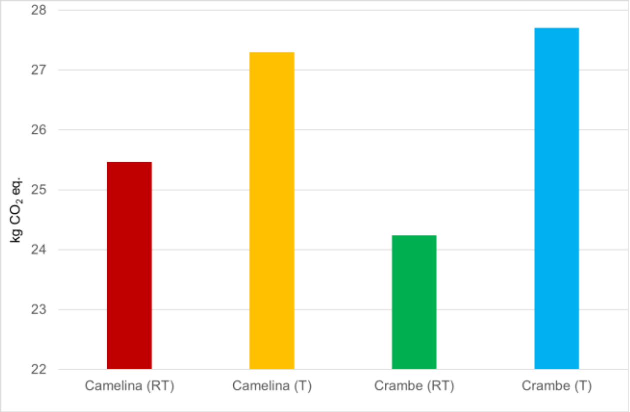

Figure 2. The greenhouse gases emission (eq. kg GJ^{-1} CO_2) for crambe and camelina plantations, for two cultivation variants.

If only 1 Mg of crambe and camelina seeds was used as a FU, emissions of GHG would be from 1,176 to 1,548 eq. Mg^{-1} CO_2, for crambe produced in reduced tillage technology and camelina from traditional tillage, respectively (Figure 3).

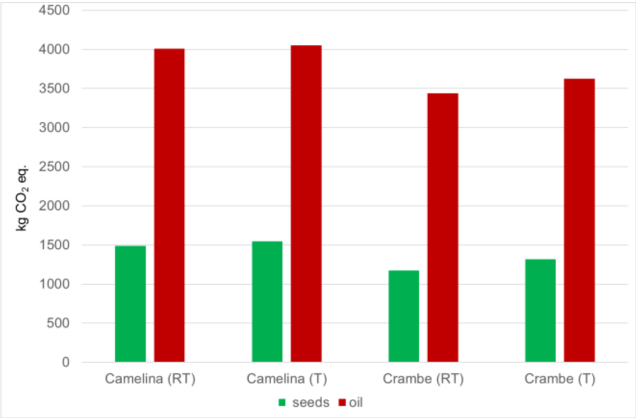

Figure 3. The greenhouse gases emission eq. to 1 tonne of seeds and 1 tonne of oil (eq. kg Mg^{1} CO_2) from crambe and camelina plantations, for two cultivation variants.

On the other hand, if only 1 Mg of oil of the examined plants was used as a product, the emission eq. CO_2 would be the highest from all the adopted functional units (Figure 3). The lowest values of this index were recorded for the cultivation of crambe in reduced tillage variant (3,438 kg Mg^{-1} eq. CO_2), while the highest were for the camelina in traditional cultivation. Lower load on the environment per 1 Mg of oil and seeds for crambe resulted from a higher yield of seeds and oil and for the simplified cultivation as well as from lower fuel consumption.

In conclusion, depending on a part of a plant to be used for biorefinery purposes, greenhouse gases emission vary considerably. To achieve the maximum reduction of greenhouse gases, each part of the plant should be utilised, i.e. straw (for heat, in CHP or for 2nd generation biofuel), oil (for chemicals or 1st generation biofuels) and oilcake (for feed or energy).

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Assessment of Critical Materials and Components in Fch Technologies to Improve Lcia in end of Life Strategy

ANDREJ LOTRIČ, ROK STROPNIK, BOŠTJAN DROBNIČ, BOŠTJAN JURJEVČIČ, MIHAEL SEKAVČNIK, MITJA MORI & ANA MARÍA FÉRRIZ QUÍLEZ

Abstract Fuel cell and hydrogen (FCH) technologies are expected to add to decarbonisation of energy and transport sector. One thing among others that prevents commercialization of FCH is the recycling and dismantling stage. There are no uniform lists of critical materials, no established pathways for recycling processes, incomplete legislation and lack of uniform guidelines. One of the goals of EU funded project HYTECHCYCLING is to assess the criticality of materials used in core components of the FCH technologies taken under consideration. The result of this assessment is the list with relevant materials (LCIA table) that will serve as an input for further work - Life Cycle Assessment (LCA). The main goal of the study is to produce the LCA numerical model, where an appropriate methodology needs to be selected in order to properly cover the whole scope of the LCA study, which has an emphasis on the end of life (EoL) phase.

Keywords: • Critical materials • Hydrogen technologies • End of life • Fuel cells • Electrolyser •

CORRESPONDENCE ADDRESS: Andrej Lotrič, Ph.D. Student, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: andrej.lotric@fs.uni-lj.si. Rok Stropnik, Ph.D. Student, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: rok.stropnik@fs.uni-lj.si. Boštjan Drobnič, Assistant Professor, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: bostjan.drobnic@fs.uni-lj.si. Boštjan Jurjevčič, Ph.D. Student, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: bostjan.jurjevcic@fs.uni-lj.si. Mihael Sekavčnik, Ph.D., Professor, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: mihael.sekavcnik@fs.uni-lj.si. Mitja Mori, Assistant Professor, University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia, e-mail: bostjan.drobnic@fs.uni-lj.si. Ana María Férriz Quílez, MSc., Aragon Hydrogen Foundation, Parque tecnológico Walqa, Ctra. N-330a, Km. 566, 22197 Huesca, Spain, e-mail: aferriz@hidrogenoaragon.org.

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1 Introduction

To follow its low carbon energy supply agenda the EU will need to intensify the deployment of fuel cells and hydrogen (FCH) technologies in energy and transport sectors in the near future. However, the expected, most widely commercialised FCH technologies are not prepared for full deployment when considering the recycling and dismantling stage. Specifically, these devices still comprise significant amounts of harmful, expensive and scarce materials (e.g. PGM in PEM fuel cells), therefore some novel dedicated recycling processes for these FCH technologies could be applied.

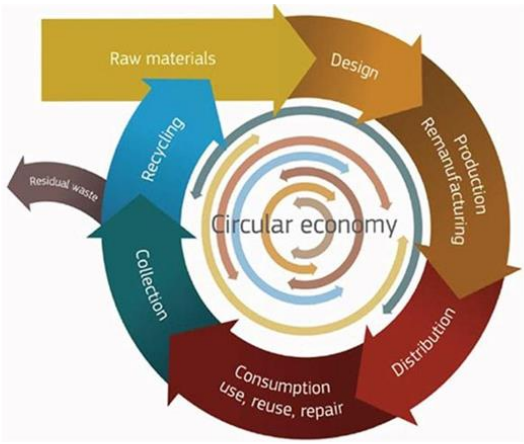

Figure 1. Circular economy envisioned by the European Commission

2 Technologies Under Consideration

While there are several types of FCH technologies the project is focused on those that are most widely commercialised and hence most commonly used. The FCH technologies considered in this project are polymer electrolyte membrane fuel cell (PEMFC), solid oxide fuel cell (SOFC), alkaline water electrolyser (AWE) and PEM water electrolyser (PEMWE).

SOFCs represent environmentally clean and versatile means of converting chemical energy to electrical energy while providing many advantages over traditional energy conversion systems due to high efficiency, reliability, modularity, fuel adaptability, and very low levels of NO_x and SO_x emissions. Furthermore, because of their high temperature of operation (750 - 1000 °C), natural or synthetic gas can be reformed within the fuel cell stack eliminating the need of an expensive, external reformer. The most recent efforts are focused in the development of a so called intermediate temperature (IT) SOFC which operates at temperatures between 600 - 800 °C.

PEMFCs normally operate at atmospheric pressure, temperatures between 60 - 80 °C, and require extremely pure hydrogen. Higher pressures and the use of various composite membrane materials allow the water-based PEMFCs to operate at temperatures up to 130 °C. A variant which operates at elevated temperatures is known as the high temperature (HT) PEMFC. By changing the polymer electrolyte from being water-based to a mineral acid-based system, using phosphoric acid (H_3PO_4), the HT PEMFCs can operate at temperatures of up to 200 °C. High temperatures alleviate the problem of catalyst CO poisoning and simplify the water management in the system. However, there are problems with H_3PO_4 leaching.

PEMWEs can operate at much higher current densities than the AWE. This reduces the operational costs and potentially the overall cost of electrolysis. The low gas crossover rate of the PEM (yielding hydrogen with high purity), allows for the PEMWE to work almost under a full nominal power density range (10 - 100%). This is due to the fact that the proton transport across the membrane responds quickly to the power input, not delayed by inertia as in liquid electrolytes. Normal operating temperatures vary between 50 - 80 °C, and pressures up to 30 bar are used.

AWEs operating pressure could be higher than atmospheric pressure, depending on the end use of the hydrogen. The elevated pressure cells (i.e. operating at 3.5 MPa) reduce the bubble sizes, minimizing ohmic loss due to bubbles, but increase the proportions of dissolved gas and require a more endurable diaphragm. Normal operating temperatures vary between 70 - 90 °C. However, the higher the operating temperature, the more stringent demands for the structural integrity of diaphragm and gaskets materials are required.

To identify the critical materials the FCH technologies in question are broken down to their core components. Materials, constituting the components, are compared according to function (or location) in the core components, environmental aspects, costs, criticality/scarcity, and currently used recycling technologies.

3 Assemssment of Materials

In this section three criteria are defined which are later used for material classification. These criteria include ***hazardousness***, ***scarcity*** or criticality, and ***price*** or value of the materials.

3.1 Hazardousness

Hazardous waste is a waste with properties that make it dangerous, or capable of having a harmful effect, to human health or the environment. Hazardous waste is generated from many sources, ranging from industrial manufacturing process wastes to batteries, and may come in many forms, including liquids, solids, gases, and sludge's.

To analyse and determine the hazardousness of the most commonly used materials in the considered FCH technologies, different sources were used: The Priority List of Hazardous Substances and report from Robert A. Goyer and Thomas W. Clarkson about toxic effects of metals, [1], [2].

3.2 Scarce or critical materials

Resources or materials are considered ‘scarce’ or ‘critical’ when there is a high demand from industry combined with a risk of their supply. A more straightforward manner to plot the different elements is shown in Figure 2, in which the probability of a supply disturbance is plotted against the period of availability. In this graph we can distinguish three groups: critical elements, frugal elements and elements of hope, [3].

Elements of hope: These are the most abundant elements available to mankind and can be extracted from the earth’s crust, from the oceans and from the atmosphere. They constitute both metal and non-metal elements.

Critical elements: There are over 30 elements that have reached the status of “critical”. Many of these (Zn, Li) are also likely to score high on the impact axis in Figure 2 as they are used in societal critical applications like automotive and battery technologies. For these elements it would be advisable to develop some sort of mechanism that ensures that they are used sparsely and only for those applications, where they cannot be substituted by other elements.

Frugal elements: These types of elements are still less scarce than critical elements but they should be used in a frugal (restrained, austere) manner. As with the critical elements, they should only be applied in mass for applications in which their unique properties are essential. In this way their remaining reserves will last longer (most notably copper and manganese).

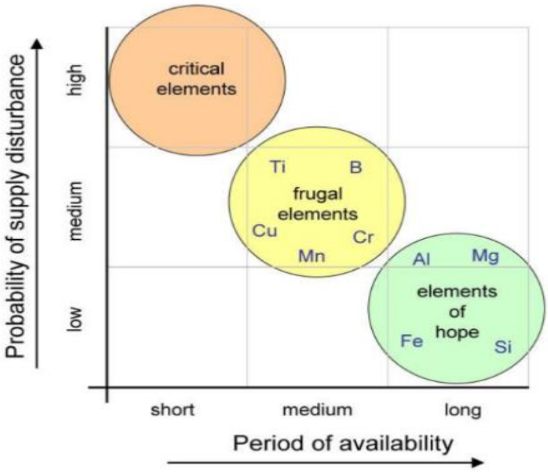

Figure 2. Groups of critical materials

The EU methodology used to assess criticality has a combination of two assessment components: economic importance or expected (negative) impact of shortage and supply risk or poor governance, [4]. The result is a relative ranking of the materials across the two assessment components, with a material defined as critical if it exceeds both the threshold for economic importance and the supply risk, as shown in Figure 3. Due to Europe's high dependence on imports, there is growing concern about the supply of particular materials. In 2010 the EU published a list of 14 critical raw materials, the so called EU-14, materials on which the European economy depends but which might be at risk of supply disruptions.

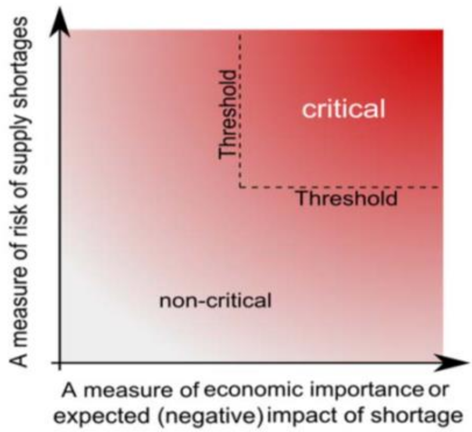

Figure 3. EU methodology used to assess material criticality

The European Commission have since presented a revised list of Critical Raw Materials. The 2014 list includes 13 of the 14 materials identified in the previous list, with only tantalum moving out of the list (due to a lower supply risk) while six new materials appear on the list. When the EU criticality methodology is applied to the list of fifty four candidate raw materials, these twenty materials, classified as critical, are obtained and are shown in Figure 4.

Antimony	**Beryllium**	**Borates**	**Chromium**	**Cobalt**	**Coking coal**	**Fluorspar**
Gallium	**Germanium**	**Indium**	**Magnesite**	**Magnesiu m**	**Natural Graphite**	**Niobium**
PGMs	**Phosphate Rock**	**REEs (Heavy)**	**REEs (Light)**	**Silicon Metal**	**Tungsten**	

Figure 4. EU-20 critical raw materials, [4]

The scarcity or criticality of materials is highly connected with material value or price, therefore, prices of elements and their compounds list was estimate from actual price at the market.

4 Materials Lists

Based on the characteristics of the considered FCH technologies and their core components, the critical materials were identified. The most commonly used materials were listed in separated tables for each individual FCH technology. The most critical components (materials) of all FCH technologies are summarised in
Table 1. Materials are classified according to five different criteria: their function (location) in a component, material hazardousness, material value, scarcity as a material criticality and current recycling and dismantling technologies. From the lists of materials, for each considered technology, some conclusions can be drawn:

- SOFCs materials mainly consist from REE, which makes this FCH technology critical from the perspective of the EU states. Also, these materials are classified as rather costly and hazardous.
- PEMFCs materials are mainly low-to-medium in cost with the exception of Pt or Pt-alloy catalysts. Pt and graphite, which is typically used for bipolar plates and represents a significant proportion in weight and volume of the stack, are classified as critical and semi-critical for the EU states. Majority of the materials used in this FCH technology are classified as non-hazardous.
- PEMWEs materials are more expensive compared to those used in the PEMFCs. The OER catalysts are based on REE while the HER catalysts are based on Pt. These materials are also classified as critical and high in costs. The materials are mainly non-hazardous with the exception of the REE used for OER catalysts.

- AWEs materials are mainly low in costs with the exception of both the anode and the cathode catalysts, which are also classified as critical for the EU states. This FCH technology is also classified as rather hazardous since the alkaline electrolyte in liquid form is used. Also, Ni-based catalyst and asbestos diaphragms, used in older types of AWEs, are classified as carcinogen.

Table 1. The most critical components of FCH technologies

Type	Component	Material	Material classification	Material value	Material Criticality
SOFC	Electrolyte	Yttria-stabilised zirconia	Non-hazardous	Medium	High
	Anode	Nickel-based oxide doped with YSZ	Hazardous (Cat. 1 carcinogen)	Medium	High
		Nickel	Hazardous (Cat. 1 carcinogen)	Medium	High
	Cathode	Strontium-doped lanthanum manganite	Hazardous (Irritant)	Medium	High
	Interconnect	Doped lanthanum chromate	Hazardous (Irritant, harmful)	Medium	Medium-High
		Inert metals/alloys	Non-hazardous	High	Medium-High
	Sealant	Precious metals	Non-hazardous	High	High
AWE	Electrolyte	Potassium Hydroxide	Hazardous (corrosive)	Medium	Low
	Anode	Precious metals	Non-hazardous	High	High
	Cathode	Raney-Nickel	Hazardous (carcinogen)	Medium	High
PEMWE	Catalyst layer - Cathode	Pt or Pt-alloys	Non-hazardous	High	High
	Catalyst layer-Anode	Iridium and Ir-alloys	Hazardous (irritant, harmful)	High	High
		Ruthenium and Ru-alloys	Hazardous (toxic, carcinogen)	Medium	High
PEMFC	Catalyst layer	Platinum or Pt-alloys	Non-hazardous	High	High
	Interconnect	Graphite or graphite composites	Non-hazardous	Low	High

5 EoL technologies

The success of products is highly conditioned by their design, which must also take into account the EoL strategies according to the principles of eco-design or design for recycling, [5]. The components and materials identified in FCH products are classified into hazardous materials and high- and low-value ones. The recovery of high-value and hazardous materials is a priority for the EoL strategies. EoL strategies for the FCH products can be similar to (or based on) those used for waste electrical and electronic equipment (WEEE). Common steps used in these strategies are shown in Figure 5.

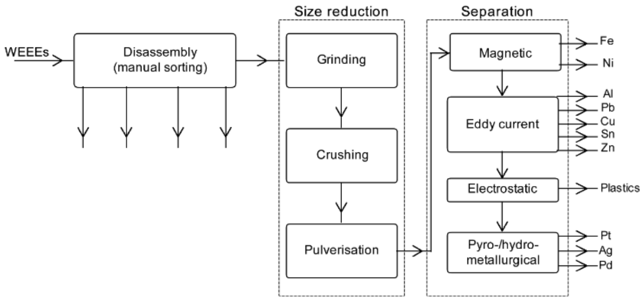

Figure 5. Common steps in EoL strategies

In the potential EoL strategies are listed, which are based on the guidelines by Society of Automotive Engineers, [6].

On the basis of created materials lists and possible EoL strategies the main treatment procedures are identified: treatment of common metals, common plastics, precious metals (Pt, Ni, Ag, etc.) and specific treatments of SOFC systems. As an example, the EoL scheme of the PEM system is presented in Figure 6, using the hydrometallurgical route.
The hydrometallurgical pathway involves the dissolution of interesting elements from solid matrices through acid or caustic attacks followed by separation via solvent extraction, precipitation, cementation, ion exchange, filtration or distillation.

Table 2. Potential EoL strategies for BoP components, [6]

BoP components	**Main Materials**	**EoL strategy**
Blower or compressor	Metals, plastics	Reuse/material recycling
Humidification membrane	Metals, plastics, polymers	Reuse
Pumps	Metals, Teflon®, rubbers, plastics	Reuse
Regulators	Metals, plastics, rubbers	Reuse/alternative use
PCBs	Metals, plastics, semiconductors, precious metals	Material recycling
Power conditioning system	Metals, plastics, semiconductors, precious metals	Material recycling
Deionising filter	Metals, plastics, resins	Reuse
Pipes	Metals, plastics, rubbers	Reuse/material recycling
Valves	Metals, plastics, nylon, Teflon®	Reuse/material recycling
Gaskets (piping system)	Paper, plastics, rubbers	Material recycling/energy recovery
Thermal insulation system	Mineral wool, fibreglass	Energy recovery
Heat exchangers	Metals	Reuse/material recycling
Sensors	Plastics, precious metals, semiconductors, glass	Material recycling
Water condensers	Stainless steel	Reuse/material recycling

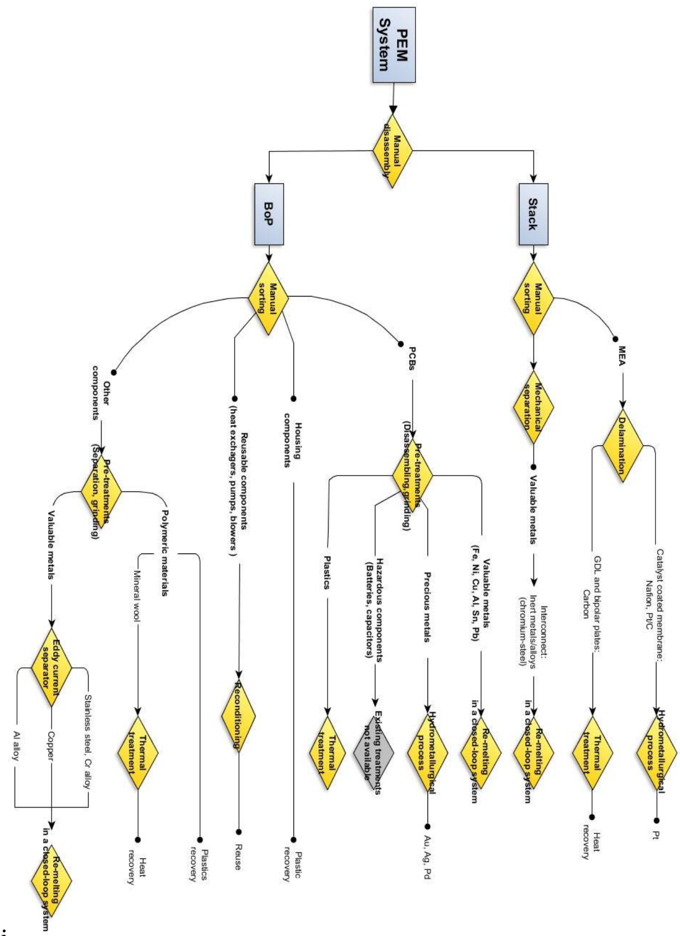

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Figure 6. EoL scheme of PEM systems: hydrometallurgical route

6 Lca Approach

After assessing all the materials data from the perspective of hazardousness, scarcity and value the next step is to define the LCA approach, boundaries of the system, functional unit and set up the LCIA table that will serve as a base for the LCA numerical model.
The scope of the study will be cradle-to-grave, with core technologies modelled in detail and BoP components with some reference average models. Functional unit in manufacturing and EoL phase will be 1 kW of installed power and in operational phase 1 kWh of exergy (electricity or/and heat). CML 2001 methodology will be used with local, regional and global impact criteria used, [7].

In the first stage all critical materials will be assessed with LCA methodology to get a first impression of their environmental impact. In the second stage a reference model will be set up. In the third stage all scenario analyses in the EoL stage will be done to evaluate the influence of reuse, recycle and other possible EoL scenarios (landfill as the worst case), [8].

7 Conclusions

All relevant materials used in core components of the considered FCH technologies were listed. The focus was set to core components of the FCH technologies while the BoP components were not included as they are treated as conventional technology. The study was done on the basis of the current state of the art FCH materials dismantling and recycling processes. The list includes the location of the material used in FCH technologies, its function, contribution to environmental aspect (contribution to LCA), value (contribution to LCC), material classification (hazardousness), criticality of material and currently used (if it exists) recycling technology.

Currently, EoL strategies for PEMFCs, PEMWEs, AWEs and SOFCs are focused mainly on recovery methods (hydrometallurgical and pyrometallurgical) for precious metals used as catalysts for the conversion processes. The possibility of further valuable materials recovery from the BoP components, such as metals and polymers for which mature recycling technologies are available, will also be addressed.

To face effectively the challenge of cost-competitiveness, in order to facilitate the establishment of hydrogen economy, a full EoL strategy to reduce the costs of FCH devices is needed. Currently, there is a lack of complete eco-design and EoL strategies that address the valuable materials recycling and reuse (or alternative use) options. The LCA approach which will be implemented in next step will give some answers regarding the EoL strategies and their influence to environmental impacts

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Internet of Things Innovation on Efficient Control of Water Consumption: (Idrop W)

SALIM AL-HABSI, ZAINAB AL-KINDI, ZUHOOR AL-KHANJARI & RAHMA AL-HABSI

Abstract Our Earth sounds to be inimitable among the other known celestial bodies. It has water, which covers three-fourth of its surface and comprises around 60-70 percentage of the living world. Water is facing numerous risks e.g. pollution, depletion and salinization, which necessitates the need for attention and rational consumption. Moreover, the proliferation of relying on the hands of expatriates to control our farms as well as the traditional methods of irrigation drains a lot of water and electricity. Thus, to solve such issues there is a rational need to use modern innovation to control water usage efficiently while reducing resources costs. Our innovation uses the concept of the Internet of Things (IOT) which allows integration and communication between several technologies in an intelligent way. In this paper, we introduce (IDrop W) innovation tool and its impact on controlling the efficiency of water consumption. This intelligent system allows the owner of the farm / home to manage irrigation tasks via controlling the water tank and daily water consumption using remote operations. Finally, this innovation tool could help to manage the consumption of water around the world.

Keywords: • IoT • IDrop W • WSN • Water Consumption • Irrigation •

CORRESPONDENCE ADDRESS: Salim Alhabsi, Student, Sultan Qaboos University, Department of Computer Science, Sultanate of Oman, e-mail: Salim.ah.alhabsi@gmail.com. Zainab Alkindi, MSc, Sultan Qaboos University, Department of Computer Science, Sultanate of Oman, e-mail:omalkindi@yahoo.com. Zuhoor Al-Khanjari, PhD, Associate Professor, Sultan Qaboos University, Department of Computer Science, Sultanate of Oman, e-mail: zuhoor@squ.edu.om. Rahma Alhabsi, Student, Sultan Qaboos University, Department of Information Systems, Economics and Political Science, Sultanate of Oman, habsi.rahma@gmail.com.

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1 Introduction

Water production and consumption have been under pressure. Due to the traditional methods used in irrigation, a lot of water and electricity has been drained. Moreover, farmers seem to commonly lack satisfaction and incentives to learn about the appropriate water use for each crop type, the amount of water needed and the actual irrigation approaches. Thus, various innovative practices should take place to avoid these burdens and enhance the usage of water. Innovative technologies can improve the economic capability and environmental sustainability of irrigated agriculture while also reducing environmental issues such as water abstraction, energy use and pollutants [1]. Furthermore, providing farmers and home managers with such tools e.g. hardware and software components, can assist them in managing the soil and water usage, reducing agrochemical inputs and providing them with details about each action that should be taken in their farms or homes. Our idea consists of the embedded technology to communicate and sense the usage of water, control the amount of water needed and generate reports on how much water is spent during a certain period of time. (IDrop W) stands for Intelligent Drop which means how we could monitor and manage water use during our day chores at home or even in our farms. In this paper, we introduce (IDrop W) as an innovation tool that can impact water consumption efficiently. Moreover, using traditional methods of irrigation can lead to several side effects. For instance, a farmer manually connects the water tank to the farms and waits for each crop to be irrigated. However, with the use of (IDrop W) the irrigation process is enhanced and the farmer is able to control the water container as well as specify the time needed for crops to be irrigated. The paper includes four sections, section one provides an introduction, section two reviews the previous related studies, section three gives a description of the IoT and our innovation, the last section concludes the paper.

2 Related Work

With the lack of water production, the relationship between crop yield and water should be manged efficiently. This constraint has been the focus of many agricultural researchers in different regions. Due to inaccurate use of modern technologies and rely upon simple timers in irrigation systems, water scarcity has become an immense concern for farmers, home owners and others. Nowadays, most of the traditional techniques are being replaced with smart developments and automated techniques. Advanced technologies e.g. IoT, were developed to offer an operative solution to various irrigation problems. Farmers irrigate the farmland in an efficient manner with automated and informative irrigation system. Many research was investigated in this area to come up with innovation ideas using IoT. It is worth to reviewing previous studies to find out the main concepts behind the IoT and the innovative system in the irrigation field.

In 2016, Parameswaran & Sivaprasath came up with an irrigation idea which was based on soil humidity. The idea was created on the concept of arduino and IoT. The authors described the smart drip irrigation system as a tool that used humidity sensor to monitor the soil humidity. In addition, they described the tool as it can provide the farmers with information that is related to the fertilizers required for the crops, soil PH level and temperature level of the field area [2]. In 2016, Hemalatha and colleagues discussed the needs of replacing traditional irrigation system with automatic techniques especially in India. Due to the high demand of agricultural productivity, poor performance and non-availability of water in India, the authors introduced an irrigation innovation using the perception of IoT. The tool reduces the effort of farmers by allowing them to specify the proper quantity of water at the proper time. Thus, overwatered saturated soils will be reduced, which in turns will improve crop performance, saves energy and resources [3]. In 2016, Sukhadeve and his classmate found a solution for problems in agriculture that framers face e.g. improper irrigation, selection of crops, non-availability of weather information per their region, pest and wild animals. They introduced a platform to transfer and analyse data using IoT technology including the data that is related to water level, crops and pests that destroy the crops [4]. In 2016, Gondchawar and Kawitkar published a research paper which highlighted their innovative idea that describes a smart GPS based on a remote controlled robot to perform tasks like weeding, spraying, moisture sensing, bird and animal scaring, keeping vigilance, smart warehouse management and measurement of temperature, humidity and theft detection [5]. In 2014, Gutiérrez and colleagues developed automated irrigation. The authors modernized their innovation in a distributed wireless network of soil-moisture and temperature sensors which are placed in the root zone of the plants [6]. Moreover, Tyagi and colleagues presented their developed innovation which monitors the temperature and soil moisture sensor that can be placed in appropriate locations on fields for monitoring the temperature degree and moisture of soil [7]. Besides, many studies mentioned the problem of non-use of the automatic system in irrigation area. Pino and colleagues (2017) mentioned that farmers consumed high scale of water during their irrigation activity and this may represent around 90% of a nation's water consumption [8]. Consequently, farmers represent a serious target of water saving and productivity enhancement policies. Therefore, they should adopt innovations that use modern technologies [8]. In 2007, Blanke and colleagues discussed the status of water saving technology in northern China and how the country enhances the awareness of people in the agricultural sector. The paper explained the different technologies followed by the farmers as well as the farm-level perceptions of the water saving properties [9]. Moreover, Nandurkar and colleagues (2014) discussed the reasons behind the need of using smart irrigation tools especially in India, due to climatic conditions and huge number of farmlands. The authors proposed IoT solution with low cost and efficient sensor network. The tool monitors the soil moisture and temperature from numerous locations of the farm along with crop controller which help to take the decision to make irrigation automatically [10]. According to Gubbi and colleagues (2013), IoT is the method of interconnection and sensing devices which provide the ability to share information across different platforms [11]. In addition, Gondchawar and his classmate defined the concept of IoT as a tool that is used in irrigation system as a remote sensing and control of data e.g. water consumption using distributed wireless sensor network [5]. In order to optimize water resources for agricultural production, smart controlling of the resources and effective low cost of tools, the automated irrigation tools have been implemented in many ways as found in the literature. So, we have our own enhanced innovation to advance the previous tools as well as maintain more controlling mechanism using the concept of IoT. Next section discusses the main reasons behind this innovation and introduces the tool in details.

3 Internet of Things (IOT) and our Innovation (IDrop W)

In the studies related to IoT, the researchers discussed the perception behind these smart innovations and the use of wireless sensor network technology. In those studies, the researchers evaluated the soil related parameters such as temperature, humidity, water usage and crops' pest and wild animals via the controlling of remote access applications. For instance, sensors and effective wireless components were placed below the soil and provided monitoring schema details. The current innovation aims to develop a wireless sensor network based on low cost monitoring tool that can track the usage of water tank during the irrigation time. Moreover, it aims to provide remote control for water needed for each crop, allow to schedule the irrigation time and notifies users with water leakage. The complete system is implemented for smart irrigation application using RF and it provides a detailed description e.g. the amount of water used on daily and monthly basis, and allows the user to manage the accessories e.g. temperature, humidity and wind. Also, our innovation contains special database to control the farms in a scientific way as well as provides electronic payment that is required by the water organization. One more unique feature is booking water car. The next section highlights the main components that generate our tool.

3.1 IDrop W innovation

IDrop system is smart, economic and flexible. The system supports the farmers and home owners to manage the process of irrigation using a smart mobile application with connected network. Thus, it will reduce the wrong irrigation system, decrease the attrition and lower the cost of resources. Furthermore, our tool consists of software and hardware components which communicate via wireless sensor network to provide a full control over the system. Figure 1 illustrates the main parts of our innovation.

Figure 7. IDrop W components

The first part of the whole system is the hardware elements. The irrigation process needs to have hardware components which consist of two main parts:

1. Central unit

The central unit is a small device computer-size used to do small computing and networking operations. This is the core portion in the field of Internet of things. It offers access to the Internet and thus the connection of automation structure with remote location controlling device becomes possible. In this element, the process of exchanging data between the software and the hardware and controlling the taps using RF technology takes place. Many functions are performed by this unit e.g. calculate capacity of the tank and the amount of water that can be stored. Also, the unit receives the data from the application and sends the appropriate action to be performed. Figure 2demonstrates the main functions performed by the central unit.

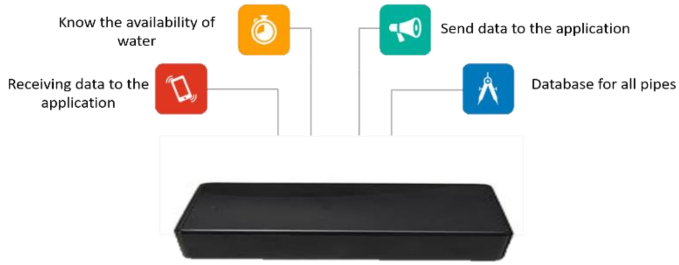

Figure 8 : Central Unit

2. Subunit

Figure 3 shows the Subunit which takes the instructions from the control unit. Then, it keeps updating the central unit with the operations' information to notify the user about them. Moreover, the users of this tool can manage the functions using the real-time software app. The software picks up the signal transmitted by the central unit and analyses the data in the application. In addition, the application will provide the users with several features such as:

1. Controlling the process of opening/ closing the taps remotely and provides a description about water consumption, its cost and its quantity.
2. Responding to a timer to manage the irrigation automatically.
3. Notifies users with water consumption above normal, level of water less than 20 %, irrigation scheduling and water leakage.
4. Includes a special database to control the farm in a scientific way.
5. The app includes a unique function for electronic payment and booking water car.
6. Manging the accessories such as temperatures, humidity, wind and water level.

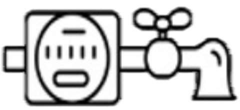

Figure 9.Subunit

Figure 4 introduces the main interface of the app which allows the users to register in the software.

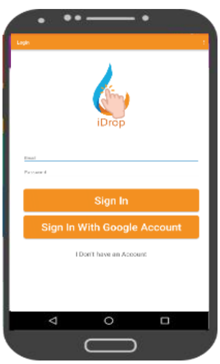

Figure 10. App interface to control the hardware parts

There are many challenges that were faced with this innovation as shown in table 1.

Table 3. IDrop W innovations' challenges.

N	Challenges	Issues	The solution
1	Internal challenge	Water leakage	When the system has water leakage, then the line which have leakage will close automatically and the system will work normally.
2	external challenge	Power outage	If the power outages, then the system will get the power from three suppliers which are the solar system, dynamic power and battery, so that the system does not use the normal electricity only
3	Network	network disconnection	If network connection is lost between the hardware and the software, the system will work normally as if it takes the instructions from the software and will save it in the local database with the hardware.

Finally, innovators develop a smart irrigation tool using the concept of IoT. Such innovation can help in using water for irrigation to enhance crop production compared to the usual procedure carried out by farmers.

4 Conclusion

Water is the most important contribution for growing crops and the management of water consumption can be utilized for other crops too. The current work aims to innovate a smart irrigation system using IoT. IDrop W innovation tool has an impact to control the efficiency of water consumption. Besides, the intelligent system allows users to control the water tank, set out the irrigation timer, check out the status of water, crops issues and tank problems. With the established tool, farmers can increase the quality of the yield and save resources. This innovation is very valuable for farmer as the initial cost is very cheap

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Renewable Energy in the Wine Sector and its Socioeconomic and Environmental Effects

PILAR GARGALLO, NIEVES GARCÍA-CASAREJOS & JAVIER CARROQUINO

Abstract The aim of this work is to identify the socioeconomic and environmental effects of the substitution of non-renewable energies by clean energies in a winery, within the framework of a partnership LIFE project. To carry out this goal, we propose a multi-level approach based on the building of a multi-result value chain together with a multi-stakeholder analysis. This study shows that the installation of alternative energies impacts on three levels of stakeholders: firm, project partnership and community. In turn, the community is divided into three major groups: individuals, companies and institutions. The multi-result value chain permits to classify the effects depending of the length of the term in which they take place: immediate (outputs), intermediate (outcomes) and long-term (impacts). From this information, an impacts map could be built, which would help decision-makers to gather information in order to see if the expected positive impacts have been achieved and being able to replicate the project in other agri-food industries by transferring knowledge.

Keywords: • Renewable energy • wine sector • multi-stakeholder analysis • multi-result value chain • multi-dimensional impact map •

CORRESPONDENCE ADDRESS: Nieves García-Casarejos, Ph.D., Lecturer, University of Zaragoza, Faculty of Economics and Business, Doctor Cerrada 1-3, 50005 Zaragoza, Spain, e-mail: ngarcia@unizar.es. Pilar Gargallo, Ph.D., Lecturer, University of Zaragoza, Faculty of Economics and Business, Doctor Cerrada 1-3, 50005 Zaragoza, Spain, e-mail: pigarga@unizar.es. Javier Carroquino, Ph.D. Candidate, LIFE REWIND project manager, University of Zaragoza, Department of Electrical Engineering, María de Luna, 3, 50018 Zaragoza, Spain, e-mail: javier.carroquino@unizar.es.

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1 Introduction

The European Union has promoted the use of renewable energy sources by several directives, establishing a common framework for the production and promotion of renewable energy sources in order to limit greenhouse gas emissions. In this sense, the EU aims to increase the use of renewable energy by 20% by the year 2020 and shifts this task to its member states.

Renewable energy sources are not only benefical for the environment.

The use of fossil fuels, either in mobility or at fixed locations, produces pollutant emissions such as carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SOx), oxides of nitrogen (NOx), volatile hydrocarbons (HC) and solid particles (C+). Also, by accident or by mismanagement, discharges of own fuel, of lubricants and other substances and polluting residues (filters of air and fuel, etc.) occur. At the same time, the engines are a source of noise pollution. These are currently the only viable alternatives to the use of fossil fuels in agricultural machinery or in mobility. Even first-generation biofuels are to some extent questioned.

Extension of the electricity grid in rural areas has a strong impact (landscape, deterioration of the environment, etc.) both in the place of use of energy and in the entire layout of the extension. The impact occurs during construction and the time of existence (due to its presence and maintenance work). Even at the end of its life cycle, it is very difficult to fully restore the initial situation. Since energy is essential to undertake economic activities, it is necessary to provide environmental sustainability to the energy supplies that these activities need.

The agri-food industry is a growth sector, concerned with product innovation, process and with a clear awareness of what climate change may mean for it. This sector is supposed to have a high receptivity to the implementation of clean energy, as this awareness favours not only the environment but also the essence of its business. Within the agri-food industry, the wineries and their vineyards, due to peculiar characteristics, are more innovative than the rest of the sector and can serve as a model of how the use of renewable energy on a small scale can be profitable.

The aim of this work is to identify the socioeconomic and environmental impact of the implementation of a series of prototypes to carry out the substitution of non-renewable energies by clean energies in the wine sector. This application is framed within a broader LIFE project that addresses climate change in the rural environment, both for mitigation and adaptation. As mitigation, it reduces CO_2 emissions related to energy consumption in agricultural activities and industries. As adaptation to climate variations, it allows the production of clean energy for irrigation in remote or isolated locations. Furthermore, noise, spills and other environmental impacts of diesel are avoided, as well as the impact of the electricity grid in natural areas.

The demonstration of the project takes place in the wine sector. A prototype has been installed in a vineyard, which produces renewable energy by photovoltaic generation. The photovoltaic panels are on three different types of support, including a floating set on the surface of an irrigation pond. The system is stand-alone (not connected to the grid) and is managed by an advanced hardware and software system. The energy produced feeds the water treatment plant of the cellar and drip irrigation in the vineyard. The wastewater of the cellar is purified and used for irrigation. The surplus energy produces hydrogen by electrolysis of water, which is used on the vineyard itself, in an agricultural off-road vehicle with a fuel cell.

The partners of this LIFE Project are the University of Zaragoza, CSIC–LIFTEC[1], *Viñas del Vero* and *Intergia Energía Sostenible*.

All these actions generate different types of results at a company level. The substitution of fossil energies for renewables is made in three directions:

i) In the field, the substitution of diesel by renewable hybrid will drastically reduce the consumption of diesel in irrigation and the corresponding emissions[2].

ii) In the fleet of vehicles and agricultural machinery, the substitution of part of the consumption of gas oil by the use of hydrogen of renewable origin will avoid polluting emissions.

iii) In the cellar, the substitution of electric consumptions, for example, for the purification of water, by the renewable generation will avoid the power consumption of the electricity network and the associated emissions.

But not only are there economic, social and environmental positive effects of alternative renewables at firm level, but also at local and global level. In order to identify them, it is necessary to carry out a multi-stakeholder analysis that shows which are the interest groups linked to the investment made and thus determine the multi-dimensional impacts map. This map is the starting point for the design of questionnaires that allows for an approach to the process of collecting the information about the expected impacts by the different interest groups. Therefore, this information can help the decision-makers to see if the expected positive impacts have been achieved and to replicate them in other agri-food industries by transfering knowledge.

The rest of the paper is organised as follows. Section 2 presents the methodology with the multi-stakeholder analysis, the multi-result value chain and the multi-dimensional impacts map. Finally, Section 3 includes the most relevant conclusion of the paper and the future lines of research.

2 Methodology

In this section the methodology used in the paper is presented. It is based on a multi-level approach (see [2]) that includes a multi-stakeholder analysis together with the building of a multi-result value chain (outputs, outcomes and impacts), which permits us to determine the multi-dimensional impacts map.

2.1 Multi-stakeholder analysis

This multi-stakeholder analysis aims to detect the interest groups, on which the substitution of fossil fuels for renewables by the analyzed winery positively impacts. The identified stakeholders can be classified into three levels: firm, project partnership and community. In turn, the community is divided into three major groups: individuals, companies and institutions. Table 1 further details the composition of each of these groups.

Thus, within the group of individuals, four types of stakeholders would be included: inhabitants, visitors, workers and consumers of the products from the project tractor company. In each of these groups, the project has different effects. For example, the group of workers would expect an increase in the number of new jobs with higher qualifications and the stabilization of existing ones. For the inhabitants, the reduction of the CO_2 emissions due to the activity of the company would improve their environment of life. On the other hand, a major sustainable image of the company would attract a greater number of visitors, which would invigorate the region both economically and culturally. Finally, the communication of environmental improvements by the company (eg. information on the labels on reduction of emissions per bottle ...) has a positive impact on the consumers of its products, favouring its loyalty.

With regard to companies, this project has as a tractor company the cellar *Viñas del Vero* whose expected project results are the improvement of its image and the reduction of its medium and long term costs and, therefore, an increase of its profitability. The immediate expected impact would provoke an imitation effect on other companies of the region (other wineries, as well as other sectors and crops) to implement irrigation systems and transport of people autonomously through renewable energy. The greater imitation effects greater dynamism, which benefits companies that provide accommodation, catering and distribution services through local businesses. In addition, the supplier companies of renewable energy will see an increase in their demand.

Table 1. Classification of the stakeholders

<table>
<tr><th>Tipology</th><th colspan="2">Stakeholder</th></tr>
<tr><td>Firms</td><td colspan="2">Unizar, CSIC – LIFTEC, Intergia, Viñas del Vero</td></tr>
<tr><td>Partnership</td><td colspan="2">Life Rewind Project</td></tr>
<tr><td colspan="3">Community</td></tr>
<tr><td rowspan="4">Individuals</td><td colspan="2">Inhabitants of the region</td></tr>
<tr><td colspan="2">Visitors</td></tr>
<tr><td colspan="2">Company workers</td></tr>
<tr><td colspan="2">Consumers of the company products</td></tr>
<tr><td rowspan="4">Companies</td><td rowspan="2">Clients</td><td>Wine cellars in the area</td></tr>
<tr><td>Other companies / sectors likely to install renewable energy</td></tr>
<tr><td rowspan="2">Suppliers</td><td>Service companies: accommodations, trade, catering,...</td></tr>
<tr><td>Materials and supplies companies for renewable energy system</td></tr>
<tr><td rowspan="4">Institutions</td><td>Public</td><td>County council, county, city councils</td></tr>
<tr><td>Private</td><td>Business and consumers associations</td></tr>
<tr><td rowspan="2">Scientific Community</td><td>Training centers</td></tr>
<tr><td>Research centers</td></tr>
</table>

Public institutions, in their role of support to disseminate, invigorate and promote the use of renewable energy in agro-industrial facilities, there are able to improve environmental quality in their sphere of influence, regenerate employment in the area and find new tourism niches (wine tourism, ecological tourism ...).

Private institutions, insofar as they are aware of the need to implement new, more environmentally friendly energy systems, they can facilitate the training and sensitization of their partners and establish agreements to achieve better conditions to enable the consumers and/or companies to consider the renewable energies as a real alternative to the traditional sources of energy, this allows them to be more in line with social demands.

The scientific community makes it possible to work on an innovative project in the hands of a pioneering company, opening new lines of research that allow the advance of knowledge that can subsequently be replicated in other companies of the agricultural and agro-industrial sector.

Another aspect to highlight is the training and technological dissemination of renewable energy implementation. Regarding the first, training courses for the unemployed in the region could be carried out to improve their employability. With regard to dissemination and technological awareness, guided visits of various groups (schools, businessmen, etc.) could be organised, as well as courses in the region in order to show and present the results obtained in terms of environmental improvement.

2.2 Multi-result value chain

The multi-result value chain proposed in this paper takes as a starting point the impact value chain provided by [3]. This frame contains two dimensions: (1) a traditional linear impact value chain; (2) the efficiency and effectiveness assessment approach between the different parts of the chain, in order to know the created value added. Figure 1 shows the most relevant elements of these two dimensions in an integrated model.

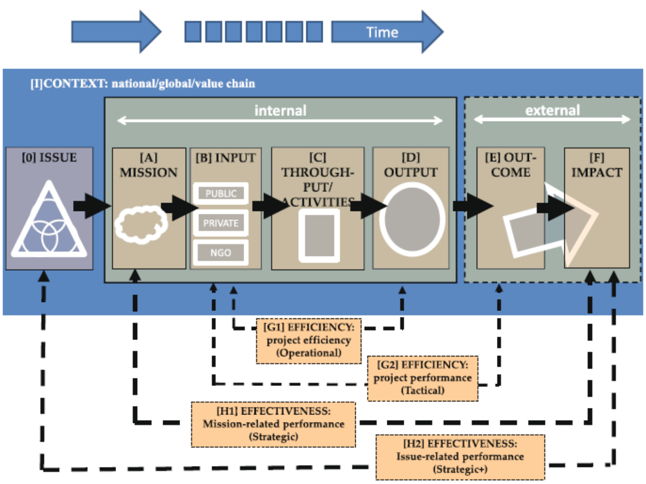

Figure 1. Multi-result value chain (*Source* [3])

According to [4], Figure 1 presents a traditional chain in which organizational inputs and activities lead to a series of outputs, outcomes, and ultimately to societal impacts (see [5]). In contrast to activities and outputs, impacts really capture the effects on society as a result of organizational efforts, instead of measuring intentions or activities undertaken by organizations (see [6]). Therefore, outputs are connected with providers of the product, activity or service, while outcomes and impacts are associated with beneficiaries (see [7]) and other stakeholders. Outcomes and impacts include both intended and unintended effects, negative and positive effects, and mid-term and long-term effects (see [8]).

Traditional linear impact value chain

The traditional linear impact value chain for our case study is materialized in the following elements:

- *Mission* acts as a link between the issue and the input. In our case, the mission consists of demonstrating whether the use of renewable isolate energy system prototypes for field (vine), manufactures (winery) and vehicles and agricultural machinery (field) in the wine industry (demonstrative example) is profitable from an economic, social and environmental point of view.

- *Inputs* are the resources and capabilities provided to achieve the partnership mission. In our case study, the inputs provided by the partners are: money, qualified staff, staff time, capital assets, I+D and commitment.

- *Throughput* is the actual dynamism, execution and implementation process of the partnership, sometimes referred to in evaluation studies as ‘‘activities’’. The concrete activities carried out by the project partnership are the following:

▪ Develop software tools for general and business use to assess the viability of renewable generation
▪ Retrofit a work vehicles to use hydrogen by incorporating a fuel cell (prototype)
▪ Project, install and test a renewable hybrid energy system for pumping water for drip irrigation (in the field)
▪ Project, install and test a renewable hybrid energy system with auto consumption (in the winery)
▪ Monitor the prototypes for an entire year
▪ Disseminate and communicate through traditional and digital media and event participation
▪ Organise summer courses
▪ Manage the project and the partnership
▪ Networking

- *Outputs* are results that a participating organization or project manager can measure or assess directly. This analysis should be done for each of the project firms, as well as for the project itself. For illustrative purposes and without claiming to be exhaustive, the results for the project demonstrative company *Viñas del Vero* could include the following:

▪ Reduction of emissions

- Increase of the number of visitors to the winery
- Increase of the number of appearances in press, radio, television, conferences and congress...
- Personnel trained in renewable energies
- Renewable assets in its facilities
- Reduction of energy bills

Multi-result Impact map

In order to determine the created added value of the extended value chain, three new elements are introduced: issue, outcomes and impacts (see Figure 2). Keeping on with the case study, these three elements are the following:

- *Issue* refers to the definition of the societal topic being addressed by the partnership. Therefore, in our case, the objective is to show the viability, from a technical, environmental and economic perspective, of the use of renewable energy in the agri-food industry. In addition, the project aims to promote the regular use of these sustainable practices.

- *Outcomes* are the benefits or changes for individuals, communities, or society at large after participating in, or being influenced by, the activities of the organizations and the partnership. In our case study, mid-term changes can occur at company level, the partnership, the stakeholder community and the potential beneficiaries, which would include other companies willing to replicate the project. For example, some of them could be the following:

- Image improvement of the project firms
- Profitability improvement of the project companies
- For the demostrative firm, an increase of the use of renewable energies within its energy mix
- Replicability of project in other agricultural and agro-industrial facilities
- Improving and adapting employment to new technologies
- Endowment of energy-efficient equipment and friendly with the environment
- New employment and tourism niches
- Major training in renewable energies
- Increased research in project areas
- Make customers aware of the use more environtmentally respectful products
- Population sensitization

- *Impacts* are the ultimate changes that one effects through the partnership. In our case study, some of the most relevant impacts in the long term of the adoption of renewable energy for the companies are the following:

- Sustainability of the territory

- Improvement of the quality of life
- Control and reduction of environmental impact
- Economic dynamization of the region
- Reputation of clean region
- Settlement of the population
- Accumulation of scientific findings

3 Conclusions

This paper has permitted us to determine the socioeconomic and environmental impacts of the implementation of a series of prototypes to carry out the substitution of non-renewable energies by clean through a LIFE project whose partners are the University of Zaragoza; CSIC – LIFTEC; *Viñas del Vero* and *Intergia Energía Sostenible*. To this aim, a multi-level approach based on the formation of a multi-result value chain (outputs, outcomes and impacts) together with a multi-stakeholder analysis, has been used, which has permitted us to determine the multi-dimensional impacts map. This methodology has been illustrated with the demonstrative cellar (*Viñas del Vero*) located in a region with designation of origin, denominated Somontano Barbastro (Spain).

The multi-dimensional impacts map has enabled the identificationthe most relevant positive effects for the stakeholder community associated to this LIFE project which is, summing up: sustainability of the territory, improvement of the quality of life, control and reduction of environmental impact, economic dynamization of the region, reputation of clean region, settlement of the population and accumulation of scientific findings.

This long-term impacts map will be the starting point for the design of questionnaires that allow the approach towards the process of collecting the information about the expected impacts by the different stakeholders.

In our future research agenda we contemplate the realization of surveys in order to know the stakeholders' opinions on these socio-economics and environmental impacts. The questionnaries will allow the characterization of the stakeholders in terms of their socio-demographic and organizationals typologies, their perception of environmental issues, the motivation for introducing the renewable energies and the degree of implication with environmentally respectful measure (recycling, consumption and energy saving ...).

The obtained results will be able to help the decision-makers to see if the expected positive impacts have been achieved and to replicate them in other agri-food industries by transferring knowledge.

A limitation of this work is the non-consideration of the possible negative impacts associated with the project, and so, they will be incorporated in our future research lines.

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Notes

[1] Consejo Superior de Investigaciones Científicas – Laboratorio de Investigación en Fluidodinámica y Tecnologías de la Combustión
[2] Carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SOx), oxides of nitrogen (NOx), volatile hydrocarbons (HC) and solid particles (C+) emissions

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Management of Desalination Brine in Qatar and the Gcc Countries

NURETTIN SEZER, ZAFER EVIS & MUAMMER KOC

Abstract Reliance on desalinated water has been ever-increasing due to increase in population and over-exploitation of natural fresh water resources. Desalination process produces fresh water at the expense of natural environment. Desalination waste, known as brine, is the major pollutant of seawater. However, there has not been a unique brine management technology that could work effectively everywhere. Therefore, effective processes are required to treat and manage the brine specific to the desalination plants. In Qatar, 99.9% of the potable water is supplied by desalination. In the GCC, for every 1 m3 fresh water produced, 2 m3 brine is generated and discharged into the Arabian Gulf (sea). As a consequence, intensive desalination processes constantly decrease the quality of seawater for desalination and continuously impact the marine life. This paper critically reviews and discusses the available treatment and management methods of brine and recommends suitable methods to Qatar and the other GCC countries.

Keywords: • Brine • Brine Management • Desalination • Qatar • Gulf Cooperation Council •

CORRESPONDENCE ADDRESS: Nurettin Sezer, Ph.D. Candidate, Hamad Bin Khalifa University, College of Science and Engineering, Sustainable Development Division, Qatar Foundation, Education City, 5825, Doha, Qatar, e-mail: NurSEZER@hbku.edu.qa. Zafer Evis, Ph.D., Professor, Middle East Technical University, Faculty of Engineering, Department of Engineering Sciences, 06800, Ankara, Turkey, e-mail: evis@metu.edu.tr. Muammer Koc, Ph.D., Professor, Hamad Bin Khalifa University, College of Science and Engineering, Sustainable Development Division, Qatar Foundation, Education City, 5825, Doha, Qatar, e-mail: mkoc@hbku.edu.qa.

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1 Introduction

The world's reliance on desalinated water is ever-increasing due to the increase in water consumption of individuals, growth of global population and exploitation of natural fresh water resources. Knowing that seawater accounts for 97% of water on the earth, it is the most reliable source of fresh water production, especially for water-stressed countries on the coasts. The Middle East is an example for that, since it has arid climate and heavily relies on desalination to meet fresh water demand. Inputs of desalination are seawater and energy whereas the outputs are fresh water and certain environmental pollutants such as brine.

Brine continuously increases the salinity and temperature of seawater. It also contaminates seawater with chemicals used in the process causing further compounding damages to the sea life. Marine environment can tolerate short term changes in temperature and salinity conditions, but the living species are vulnerable to long term changes [1]. Since it is the oftentimes preferred option to discharge brine into the nearby surface water body, immediate corrective and/or preventive actions are required to manage the desalination brine in order to prevent its impacts on the environment. This study aims to describe the existing brine management approaches, and to identify the effective methods for Qatar and the GCC countries in order to prevent the environmental impact of brine. It also aims to develop a possible approach to convert brine into a useful product. The following chapter describes brine management methods, including conventional and new technologies. It also discusses the benefits and constraints of each method. In the final section, a discussion is presented about treatment, management and beneficial use of brine instead of discharging directly into the sea.

2 Brine Management Technologies

In any type of desalination processes, at least half of the feed seawater is discharged as brine. However, brine has detrimental effects on marine life and on the quality of seawater available for future desalination in that area. Brine disposal also accounts for a significant proportion on the total cost of operation, depending on the method selected, ranging from 5% to 33% [2]. Thus, selection of an effective management method would contribute to the desalination plants both economically and environmentally.

Conventional methods for brine management are surface discharge, deep well injection, and evaporation ponds. On the other hand, the newer technologies include irrigation of plants tolerant to high salinity, valuable mineral recovery, zero liquid discharge (ZLD), and production of sodium bicarbonate from brine.

2.1 Surface discharge

The most common practice in treatment of brine is its discharge into the sea. This method does not require conveyance of brine over a long distance, and the sea is the most compatible and easily accessible environment for brine. It is the cheapest and easiest way of disposal. However, this conventional method has detrimental effects on the marine environment. It constantly increases the salinity and temperature of seawater. The chemicals used in the process contaminate the seawater and reduce the amount of dissolved oxygen in the sea. In addition, in the long run, it can decrease the quality of seawater available for desalination. Since it is a small and rather closed water body, the Arabian Gulf, where the majority of desalination operation in the world takes place, is a good example of this case [1].

2.2 Deep Well Injection

In this method, brine is injected by means of disposal wells into a confined deep underground aquifer which is below freshwater aquifers. The method includes an additional set of monitoring wells to ensure that brine is not propagating to the adjacent aquifers [3].

Deep well injection is applied for disposal of brine, especially at inland desalination plants that process brackish water. However, this method requires a detailed geological assessment prior to drilling since any faults in geological structure can cause leakage of brine into water aquifers. Although, in certain cases, this method may be feasible for brine disposal, it has several downsides such as the need to find an available well site, the risk of leakage in well casings, and its vulnerability to inevitable seismic activities and consequent contamination of groundwater [2].

2.3 Evaporation ponds

Evaporation has been considered as the most effective and economic method of brine disposal since it requires a dry climate, and most of the countries that need water from desalination typically have a dry climate such as the GCC countries. However, this method requires construction of multiple evaporation ponds which are relatively shallow ranging from 25 to 45 cm. Therefore, there is a need for a large area of available land. The bottom of the ponds should be carefully lined to prevent brine leakages which may result in subsequent underground water contamination and soil degradation. The success of the operation depends on the evaporation rate in the region. Changes in weather conditions affect the evaporation rate and the efficiency of the method.

Gilron et al. studied Wind Aided Intensified eVaporation (WAIV) to improve the efficiency of evaporation ponds. The WAIV process increased the brine evaporation surface by dispersing the brine over vertical tissues, thus reducing the evaporation land requirements. The study demonstrated that this method can increase the evaporation rate by 50% and decrease the land requirements of ponds [4], but it is still vulnerable to changes in weather conditions [5].

Advantages of the evaporation method are the prevention of seawater contamination and possible production of commercial salt from brine. The drawbacks are its reliance on weather conditions, land requirement, and risk of contamination of soil and underground water in case of leakage.

2.4 Irrigation of plants tolerant to high salinity

Several studies have been carried out to investigate the use of brine for the irrigation of different plant species [6], [7]. Although most of the plants have low salt tolerance, the studies found that brine can be used for irrigation of certain types of species. Sánchez et al. evaluated the use of brine for irrigation. They concluded that the halophytes are the most convenient species for brine irrigation [7]. Halophytes usually have higher salt tolerance and they can yield biofuels, forages, and oilseeds, as product [6].
The main drawbacks of this method are the availability of limited number of species that can be grown on high salinity water, inevitable increase in the salinity of soil, subsequent lower yield potential of the plants, large land requirement for crop planting and its applicability of only on a small-scale.

2.5 Valuable mineral recovery

Recovery of valuable minerals such as magnesium, calcium and sodium chlorides as well as bromine from brine would be a good way to reduce fresh water production costs as well as to avoid land disturbance and waste production caused by mining operations. Recent research have shown that it is possible to precipitate and recover metals and salts from concentrate through chemical processes. The recovery of minerals can provide a substantial increase in revenue, offsetting the cost of desalination [8].

Mutaz and Wagialia studied production of magnesium from desalination reject brine in Saudi Arabia. They concluded that extraction of magnesium from the Arabian Gulf desalination brine can be economically viable. Further studies were suggested to identify its techno-economic feasibility [9].

Cipollina et al. studied the extraction of magnesium salts from the saturated exhausted brine of evaporation pond discharge. The study aimed to recover table salt and magnesium salt from desalination brine. They concluded the reactive precipitation process was a viable solution for the high-purity magnesium hydroxide recovery with high precipitation efficiency [10].

Kovacheva et al. studied precipitation of $MgCO_3 \cdot 3H_2O$ from brine. They designed and experimentally confirmed a method for precipitation of purified $MgCO_3 \cdot 3H_2O$ from desalination brine [11].

Ravizky and Nadav presented a successful commercial salt production from brine of a desalination plant in Eilat (Israel) through evaporation. They suggested the Arabian Gulf

region as a potential global zone for the application of this concept according to its prevailing site-specific conditions [12].
Brum et al. examined the technical and economic feasibility of commercial salt production in Qatar from the country's desalination brine waste. Knowing that Qatar imported 24.5M USD of salt in 2010 and the country has 12.580.7 km^2 of available, arable and undeveloped land that could be used for evaporation ponds; they suggested that salt production from brine waste through natural evaporation method is economically feasible for Qatar and it can turn a $24.5 million (USD) import cost into a surplus [13]

2.6 Zero liquid discharge (ZLD)

Seawater has many valuable constituents, but their value can only be realized if their separation is economically and technically feasible. Zero-liquid discharge technologies including brine concentrators, crystallizers and dryers can convert brine to highly purified water and solid products suitable for landfill disposal or for recovery of valuable salts.
Concentrators (thermal evaporators) can be used to evaporate 90% to 98% of the water in the brine and produce fresh water. Concentrated salt products can be designated for commercial applications.

Crystallizers extract highly soluble salts from concentrate. Concentrate is first fed to a crystallizer vessel and then it passes through a shell-and-tube heat exchanger where it is heated by vapor introduced by a vacuum compressor. The low-salinity water separated from the concentrate is collected as distillate at the end of the condenser. The heated concentrate then enters the crystallizer where it is rotated in a vortex. Concentrate crystals are formed in the vessel and the crystalline mineral mass is then dewatered in a centrifuge or a filter press. The mineral cake removed from the concentrate contains 85 percent solids and is the only waste stream produced by the crystallizer [3].

The aim of the ZLD is the production of freshwater, and solid products such as saleable sodium chloride (NaCl), magnesium hydroxide ($Mg(OH)_2$), and bromine (Br_2) from the brine. After that, the residual solutions can be evaporated to dryness to produce road salt, but minor constituents might be recovered from that residue.

Recovery of salt, through ZLD desalination, is increasingly seen as the most environmentally friendly option to handle brine. It has been demonstrated that the SOL-BRINE system can achieve high quality freshwater (TDS $<$ 100 ppm) with a water recovery of more than 90% and production of saleable dry salts [14].

SOL-Brine technology uses evaporation, crystallization and drying on desalination brine. The required energy for the system is obtained from solar energy. It aims to eliminate environmental impacts of desalination brine by zero liquid discharge and production of commercial salt. The system has been studied on a small scale [14]. However, further studies are required to investigate the effective treatment of large volume of brine.

There are several salt manufacturing plants in Japan that utilize electrodialysis technology to produce a 20% solution of NaCl brine. Brine is then evaporated to dryness with heat from the same power plant that supplies electricity for the electrodialysis [5].
The cost of energy for concentrate evaporation and crystallization is high (100 to 250 kWh/1,000 gallons (3.78 m^3)), and the equipment costs are usually several times larger than the capital investment needed for the other concentrate disposal alternatives. Evaporators and crystallizers are relatively complex to operate and energy intensive [15]. In addition, because of the high capital, operation and maintenance costs, the zero-discharge technologies are not practical unless no other concentrate management alternatives are available [3].

2.7 Sodium bicarbonate production

Production of sodium bicarbonate from desalination brine was achieved by a chemical reaction of reject brine with carbon dioxide in the presence of ammonia. The reaction is based on a modified Solvay process [16].

The Solvay process was first developed by Ernst Solvay in 1881. In this process, ammonia and carbon dioxide are passed into a saturated sodium chloride solution to form soluble ammonium bicarbonate. Ammonium bicarbonate is then reacted with sodium chloride to form soluble ammonium chloride and a sodium bicarbonate precipitate according to the following reactions:

$$NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl \quad (1)$$

$$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O \quad (2)$$

$$2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O \quad (3)$$

The resulting ammonium chloride can be reacted with calcium hydroxide according to Reaction (3) to recover ammonia for further use [17].

Jibril and İbrahim experimentally studied the production of sodium bicarbonate from brine. This preliminary study involved using synthetic sodium chloride solution with pure NaCl and deionized water [18]. The study achieved success in conversion of NaCl. El-Naas et al. studied production of sodium bicarbonate from actual desalination reject brine in different experimental conditions. Brine samples were reacted with carbon dioxide and ammonia in a bubble column reactor at different operating conditions. The research concluded that a dual-purpose large scale process can be designed to reduce the salinity of reject brine and CO_2 emissions with a production of commercial sodium bicarbonate.

The advantages of this method are the reduced salt content of brine, removal of CO_2 from flue gases and production of commercial sodium bicarbonate. Low-salt content brine can be used for irrigation or fed back to the desalination process. However, this process is currently only on bench scale and requires techno-economic feasibility studies. Further studies are also needed to develop a continuous process, including an ammonia recovery unit, on a larger scale.

The majority of the brine management technologies, mentioned thus far, are in the development stage. In addition, most of them are tested only with brackish waters and membrane process concentrates. Therefore, further research and development are required for:

- Testing and validating the methods in continuous industrial scale,
- Investigating the methods separately with brine from membrane processes and from thermal processes,
- Investigating the methods separately with brine from brackish water and seawater desalination plants,
- Investigating the feasibility of the methods with brine from different desalination plants in different regions.

Brine management technologies are gaining importance as the number of desalination plants increases. Discharge of brine into the sea, the current common method for brine disposal rather than management, adversely affects the marine environment by increasing salinity and temperature. However, alternative technologies still require further research to prove their techno-economic feasibility on a large scale. Conventional and modern brine management technologies are summarized in Table 1.

Table 1. Characteristics of brine management methods

Method	Benefits	Constraints
Surface discharge	-Capable of handling large volumes	-Impacts on the marine environment -Often requires discharge permit
Deep well injection	-Eliminates impacts on the marine environment -No land occupation	-Risk of groundwater pollution -No beneficial use of brine -Applicable only on small scale desalination plant
Evaporation ponds	-Potential for commercial salt production -No technologic requirements	-Requires arid climate -Risk of soil and groundwater contamination -Applicable only in small scale desalination plants
Irrigation of plants tolerant to high salinity	-Irrigation of salt tolerant plant species	-Applicable only in small scale desalination plant brine -Risk of increasing salinity of groundwater and/or soil
Zero liquid discharge	-Commercial metal and salt production	-Energy intensive and complex process
Mineral Recovery	-Eliminates impacts of mining and other extraction technologies on environment -Commercial mineral production	-Energy intensive and complex process
Sodium Bicarbonate Production	-Dual purpose; also eliminates CO_2 emission -Commercial sodium bicarbonate production	-Energy intensive and complex process

3 Discussion

Half of the world's desalination plants are located in Middle Eastern countries. The region has the arid climate required for evaporation method. Salt production can be considered as a promising brine management method in the GCC. Applied thermal process is an additional advantage since the temperature of processed brine is already high. This residual heat can be further utilized for evaporation. However, its applicability to the brine from large scale desalination plants of the GCC, and its further subsequent effects on the environment (e.g. bird species), should also be considered. Further improvements are required to make the evaporation method feasible for large scale operations.

Overexploitation of underground water brings the risk of seawater intrusion in Qatar. Applying the plant irrigation method can cause further soil degradation and underground water contamination. In addition, the availability of only a small number of salt tolerant species and large land requirements makes the method infeasible to apply in the GCC.

Magnesium content of typical brine taken from the thermal desalination plants in Qatar is 0.76%, which is comparatively high [1]. Knowing also that Arabian Gulf seawater has high salt content, production of commercial sodium chloride and magnesium salts from brine could be practiced in the GCC countries. Beside environmental advantages, mineral recovery and further processing and manufacturing into final products can also help diversification of local economies.

Although ZLD is conceptually well-defined and available on an industrial scale, the complexity and high cost of its components requires further improvements and feasibility studies.

One of the new technologies, sodium bicarbonate production, can be used for dual purpose in Qatar. The method aims to manage both brine and CO_2. Thermal desalination in the GCC causes air pollution due to energy intensive process, and discharges vast amount of brine which pollute the marine environment. Qatar has the highest per capita CO_2 emission in the world. Production of commercial minerals by eliminating discharge of brine and emission of CO_2 in Qatar would be the best brine management method; however, the method still needs further development to be delivered in practice on a large scale.

Apart from the discussed methods, at present, there are other technologies utilizing membrane processes in brine management. However, high salt content of the reject brine makes this method infeasible in the GCC.

4 Conclusion

This paper critically reviews and discusses the available treatment and management methods of brine and suggests suitable alternative methods to Qatar and the other GCC countries. Most of the brine management technologies are currently in experimental stages. The emerging technologies promise economic and environmentally friendly solutions. However, most of them have just been developed in laboratories and their applicability on an industrial scale are still undefined.

Mineral recovery, zero liquid discharge, and sodium bicarbonate production technologies are suggested for management of desalination brine in Qatar and the GCC. However, further studies including techno-economic feasibility studies are recommended to test these methods on a larger scale with brine from desalination plants around the GCC.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Researching Extreme Weather and Sea Level Events to Support Nuclear Power Plant Safety in Finland

KIRSTI JYLHÄ, MILLA JOHANSSON, MATTI KÄMÄRÄINEN, HAVU PELLIKKA, ULPU LEIJALA, CARL FORTELIUS, HILPPA GREGOW & ARI VENÄLÄINEN

Abstract Overall safety management over the life cycle of a nuclear power plant requires, among others, evaluation of external events triggered by exceptional weather, climate and sea-level events. In order to support nuclear power safety, we have examined the occurrence and intensity of various extreme weather, climate and sea level phenomena since 2007. Because there is a need for estimates on the probabilities of such extremely rare events that have not occurred during the era of instrumental records, a variety of approaches are used. We present our findings for freezing rain, enthalpy, sea level variations and trends at various time scales, as a few examples of the research topics covered. Besides the power companies designing and running nuclear power plants, and the nuclear safety authorities defining the safety regulations for power plant constructions and operations, the results of this research can be utilized by more widely in the energy sector.

Keywords: • nuclear power safety • weather • climate • sea-level • coastal meteorology •

CORRESPONDENCE ADDRESS: Kirsti Jylhä, Ph.D., Senior research scientist, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: kirsti.jylha@fmi.fi. Milla Johansson, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: milla.johansson@fmi.fi. Matti Kämäräinen, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: matti.kämäräinen@fmi.fi. Havu Pellikka, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: havu.pellikka@fmi.fi. Ulpu Leijala, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: ulpu.leijala@fmi.fi. Carl Fortelius, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: carl.fortelius@fmi.fi. Hilppa Gregow, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: hilppa.gregow@fmi.fi. Ari Venäläinen, Finnish Meteorological Institute (FMI), Climate Service Centre, P.O. Box 503, 00101 Helsinki, Finland, e-mail: ari.venäläinen@fmi.fi.

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1 Introduction

About one third of the electricity production in Finland is based on nuclear energy. In 2017, there are four operating nuclear reactors in two power plants in Finland, all on the coasts of the Baltic Sea: two reactors at Loviisa, on the shore of the Gulf of Finland, and two at Olkiluoto, on the shore of the Gulf of Bothnia. In addition, for the Olkiluoto plant, there is a further reactor under construction. A third nuclear power plant (NPP) in Finland is expected to be established at Pyhäjoki on the northern coast of the Gulf of Bothnia.

Overall safety management over the life cycle of a NPP requires, among others, evaluation of external events triggered by exceptional weather and sea level conditions [1]. Probability estimates of weather-related hazards are used as the design basis for new power plant units and in the Probabilistic Risk Assessment of new and existing NPPs [2]. Typically, there are two levels for the design basis; one applied for phenomena leading to administrative power reductions or reactor automatic reactor shutdown, and one relating to phenomena that would endanger the safety of the plant. Adverse and extreme weather events can also indirectly impact the safety of nuclear power plants, e.g. by hampering the transport of personnel and goods to and from the power plant site.

In the existing Finnish NPP units, preparedness against extreme natural phenomena is continuously being improved. For example, actions have been taken to reduce the risk of heavy rainfall-induced flash floods within a NPP yard area; to avoid blockage of the air intake of emergency diesel generators as a consequence of simultaneous snowfall and wind; to prevent problems due to frazil ice formation; and to implement a supplementary cooling system for NPP reactors [3], [4]. Despite these already-taken measures, further research work needs to be conducted. This is because there are considerable uncertainties in estimates of frequencies of very rare weather-related and sea-level-related hazards. Furthermore, since the spread of radioactive releases into the atmosphere from a shore-located NPP is affected by specific coastal atmospheric conditions, improvements in dispersion modelling are beneficial.

The Finnish Meteorological Institute has examined extreme weather, climate and sea level events potentially posing risks to NPPs since 2007 within the Extreme Weather and Nuclear Power Plants (EXWE) project of the Finnish Research Programme on Nuclear Power Plant Safety 2015–2018 (SAFIR2018) and its precursors [5]. EXWE aims to enhance scientific understanding of the environmental conditions at the NPP locations. Occurrences and probabilities of a wide range of weather phenomena and parameters have been estimated, such as freezing rain and extreme enthalpy values, which we consider in more detail. Sea level variations and trends across various time-scales are likewise discussed. The final topic is high-resolution meteorological modelling in support of dispersion modelling.

2 Motivation

The main challenge in evaluating the frequency of extreme weather and sea-level oscillation events arises from the fact that the safety assessments for NPPs require not only observation-based frequencies for the extreme events, but also estimates for the probabilities of extremely rare events that may not have occurred during the past 100 years or so within the observation period. Phenomena that can be considered as beyond the scope of the NPP design basis levels need to have a very low probability, corresponding to return periods of thousands or millions of years. On the other hand, examining moderately rare phenomena, having a return period of tens or hundreds of years, is part of a continuous effort to improve the understanding of extreme weather events, and how to model them accurately.

The probability of occurrence of exceptional external conditions around NPP sites are also subject to changes in climate, whereby the patterns of extreme weather events – both in frequency, extremity, and magnitude – are likely to alter over the course of time. A hazard curve evaluated from a time series of historical measurements must be regularly updated with new measurements.

In addition, for NPPs located on a coast, the different properties of the atmospheric boundary layer over land and over sea strongly influences the atmospheric dispersion of any radioactive pollutants that may be released.

Because of these challenges, a wide range of study material and methods have been applied in EXWE, including instrumental records, eyewitness observations, meteorological reanalysis data, high-resolution atmospheric modelling, climate model output, and extreme value distributions. Some current approaches and their results are outlined below.

3 Extreme Weather

The following weather phenomena have been examined in EXWE: extremely warm, cold or dry episodes, torrential or freezing rain, excess snowfall, extreme enthalpy, storm tracks, very strong winds, and small-scale convective phenomena such as thunderstorms, lightning, large hail and tornadoes (see e.g. [6], [7] and [8]). Here we focus on freezing rain and events with high enthalpy values.

3.1 Freezing rain

Freezing rain (FZRA) is supercooled liquid precipitation which freezes on contact with solid objects, forming a coating of ice. Some severe FZRA events have taken place in Europe during the last few years, e.g. in Slovenia in 2014 [9]. The occurrence of FZRA depends on the vertical profiles of relative humidity and temperature in the lower atmosphere. Climatological occurrence of FZRA can be produced by applying a precipitation typing algorithm partially developed within EXWE [10]. The threshold values used in the algorithm were defined based on reports of FRZA from human observers at European weather stations for the period 1979-2014. The method was first applied to a 4-dimensional (space and time) atmospheric reanalysis data set (ERA-Interim) providing a best estimate of the evolution of meteorological conditions since 1979. It was found that, unlike most coastal and marine areas of Europe, the northern Baltic Sea has relatively frequent FZRA cases [10].

The identification algorithm has also been used together with output from climate model simulations in order to assess future changes in FZRA occurrence based on climate model simulations. Preliminary results indicate that the probability of FZRA occurrence is projected to increase in northern and decrease in southern Europe in the future [11].

3.2 Enthalpy

Atmospheric enthalpy is usually considered when designing ventilation and cooling systems. Enthalpy increases with air temperature and humidity, and also depends on air pressure [12]. We first estimated the annual probabilities of high values of enthalpy in the current climate based on 3-hourly weather data at ten locations in Finland over 1961-2012. Extrapolations from the 52-year observation period out to recurrence periods of up to 1000 years were conducted by using the "peaks over threshold" (POT) method [13]. These results indicate that there is an annual probability of 1% in current climate conditions that the enthalpy transiently exceeds 70 kJ kg^{-1}. It is equally likely that enthalpy continuously exceeds 44 kJ kg^{-1} over a seven-day period.

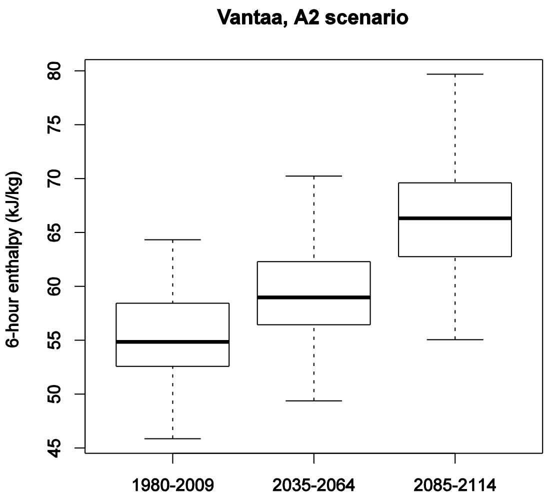

Figure 1. Box-and-whisker plots of annual maximum 6-hour enthalpy at Vantaa, southern Finland, based on observations in 1980-2009 (left), and based on model projections under the A2 scenario for 30-year periods centred on 2050 (centre) and 2100 (right). Shown are the lowest maximum, the 25th, 50th and 75th percentiles, and the highest maximum.

We then assessed the influence of human-induced climate change on enthalpy at four weather stations in Finland during the 21st century. The estimates were based on synthetic future weather data sets with hourly resolution [14] produced using multi-model mean responses of temperature and humidity to global increases in greenhouse gas concentrations in the atmosphere. The results indicate that the enthalpy indices are likely to rise in the future, demonstrated by the box-and-whisker plots of the observed and model-derived annual maximum in 6-hour enthalpy at Vantaa, southern Finland, for selected 30-year periods (Figure 1). Considerable changes in the percentiles of the annual maxima can already be expected by 2050.

4 Extreme Sea Levels

Extreme sea levels are crucial for the safety of the Finnish NPPs which are all located on coastal areas. The processes impacting sea level on the Finnish coast range from the centennial-scale mean sea level changes to rapid oscillations that occur in less than an hour. Sea level has been studied in EXWE since 2008, first focusing on scenarios for the long-term mean sea level, and lately shifting the focus into shorter-period phenomena and their effect on flooding risks [15], [7], [8].

4.1 Mean sea level changes on the finnish coast

The long-term change in the mean sea level with regards to the Finnish coastline depends on three factors: global sea level rise, which the Baltic Sea responds too; local postglacial land uplift in Scandinavia; and long-term changes in the Baltic Sea water balance [16], [17]. The postglacial land uplift is relatively well known, ranging from about 40 to 100 cm per century for the Finnish coastal areas [16]. When developing sea level scenarios for Finland, the most critical question is how much the global sea level will rise in the future.

Based on a literature review conducted within EXWE, the range of global sea level rise projections, including uncertainty, extends from 20 to 200 cm by 2100. The largest uncertainty in sea level rise predictions, especially in the northern latitudes, is the possible instability of the marine sectors of the Antarctic ice sheet causing a worst-case scenario of a sea level rise of more than 1 m on its own [18]. This is greater than earlier estimates and could mean a worst-case global mean sea level rise exceeding 2 m. The effect on mean sea levels at the Finnish coast would be smaller, however, due to the uneven distribution of the global sea level rise and the counteracting effect of land uplift.

4.2 Combined effect of sea level and waves on flooding risk

The height to which water can rise to flood the shoreline is a result of both the sea level elevation and wave height. Local wave height conditions vary greatly depending on the shape of the shoreline, bathymetry, and archipelago shielding of the coastline.
The flooding risk estimates for the Finnish coast have traditionally been based on the probability distribution of sea level extremes, on top of which a location-specific constant value for wave action has been added (e.g. [17]). Within EXWE, however, a new method is being developed, which takes into account three factors: i) the extent of short-term sea level variability; ii) wind-generated wave heights; and iii) future scenarios for the regional mean sea level [19]. The first two are obtained from local observations, with future scenarios for sea level constructed using the methodology developed in EXWE [16]. Probability distributions of these three variables are combined to yield return periods for the height to which the continuous water mass ("the green water") rises.
Currently, the three variables are treated as independent random variables to yield the probability distribution of their sum. However, it is likely that sea level extremes and waves are not independent, and studying this dependency is a topic for further improvement of the method.

4.3 Short-period sea level oscillations

Traditionally, sea level studies and flooding risk estimates have been based on hourly or even less frequent sea level observations. These do not reveal rapid, sub-hourly

oscillations, such as the several meteotsunamis observed on the Finnish coast in 2010 and 2011 [20].
Meteotsunamis are tsunami-like waves caused by air pressure disturbances, such as thunderstorms, moving over the sea. When the speed of the disturbance coincides with the speed of the generated tsunami wave, the resonance between the atmosphere and the ocean leads to the amplification of the wave. In Finland, typical meteotsunami heights recorded by tide gauges are 10–30 cm (Figure 2), but eyewitnesses have reported oscillations of 50–100 cm. The eyewitness observations represent events in which the wave is locally amplified through resonance mechanisms related to the local coastal bathymetry.

Crest heights of meteotsunamis recorded by a tide gauge at Hanko, on the southern coast of Finland, during 1922–1989 were compared with air pressure recordings, and, for 60% of the cases, air pressure disturbances were confirmed as being responsible. Extrapolation of the data suggested that the meteotsunami height (above the prevailing sea level) exceeds 50 cm with a very small annual probability, of the order of 10^{-6}. However, depending on the coastal bathymetry, the probability can be several magnitudes higher in vulnerable locations, as suggested by refraction modelling and eyewitness observations.

Analyses of sea level recordings at 1-minute time resolution, available from Finnish tide gauges from 2004 onwards, have recently been combined with meteorological analyses of cold fronts and mesoscale convective systems [21]. Based on these preliminary results, the strongest events of rapid sea level oscillations in summer were likely formed by resonance effects. Winter events, on the other hand, were due to small storm surges rather than meteotsunamis.

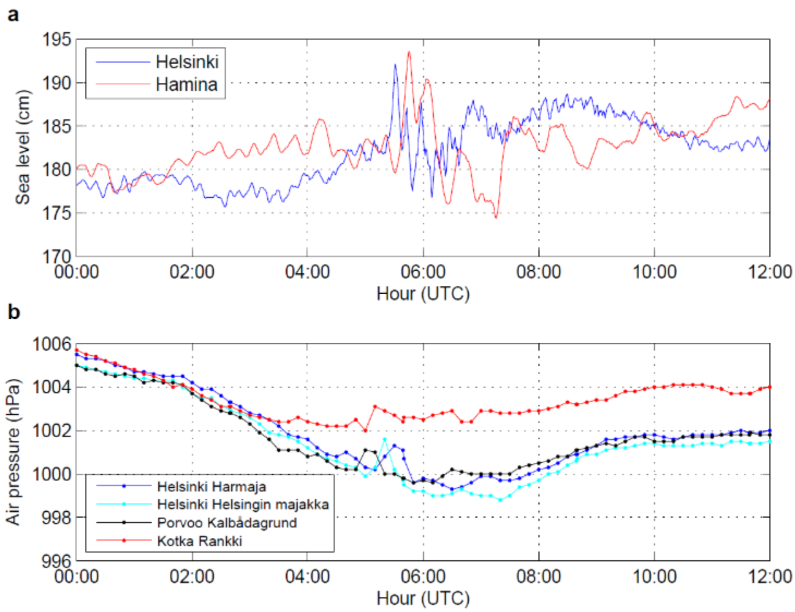

Figure 2. Meteotsunami event in the Gulf of Finland on 29 July 2010. a) Sea level records at Helsinki and Hamina tide gauges show oscillations with a height of 10–15 cm, while eyewitnesses reported wave heights of up to 1 m at other locations on the coast. b) Air pressure at nearby coastal stations. Sea level oscillations are accompanied by a sudden jump in air pressure, indicating the passage of the gust front that created the meteotsunami waves. [20]

5 High-Resolution Meteorological Modelling

Near a coastline, the lowest region of the atmosphere is directly influenced by the contrasting thermal inertia and aerodynamic roughness of land and sea surfaces. This contrast can induce local wind circulations such as sea-breezes where the wind direction is onshore at the surface and off-shore aloft during the day. Depending on the season, the diurnal variation in the strength and vertical extent of atmospheric turbulence can be quite different over land and over sea, which, together with the coastal wind circulation, can induce a marked internal atmospheric boundary layer along the coastline.

State-of-the art meteorological modelling has progressed to a stage where a proper assessment of coastal meteorological conditions can be fed into a modern dispersion modelling system. Within EXWE, an operational weather prediction system (HARMONIE-AROME) was modified to enable very-high resolution simulations. In a domain of about 300 km x 300 km covering southern Finland, model calculations were performed on a grid having a horizontal resolution of only 500 m, and a total of 65 levels in the vertical, 20 of which were situated in the lowest kilometre.

In a springtime case study, the modelling system was able to realistically simulate the temporal and spatial variations of the winds associated with a sea-breeze circulation, corroborated with remote-sensing measurements and in situ data from a tower. The transition from a marine boundary layer structure to a land boundary layer structure was also well simulated. These first results suggest that forecasts generated by the system can become a valuable data source for dispersion modelling and dispersion forecasting.

6 Concluding remarks

The weather and sea-level phenomena being studied in EXWE since 2007 have been selected based on feedback and enquires from the power companies designing and running the Finnish nuclear power plants, and from the nuclear safety authorities defining the safety regulations for the construction and operation of power plants. Besides these stakeholders, the results from this research may be utilized more widely in various sectors, such as energy, infrastructure, insurance, and health.

Acknowledgements

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Remodeling Lubricant Maintenance Strategy with Aid of Lubricant Condition Monitoring

VITO TIČ & DARKO LOVREC

Abstract Majority of industrial lubricants used today are still based on mineral oil, which consists of mixtures of hydrocarbons obtained from petroleum by distillation. While seeking for long-term environmental protection and sustainable use of earth resources, special attention should be paid to optimal use and maintenance of lubricants in industrial applications.

On the other hand, companies are constantly seeking for savings potentials in their production lines. While seeking for extra savings, many companies commit a huge mistake when trying to reduce their maintenance costs by simply reducing the amount of money spent for maintenance work. Sadly, this also applies to proper machine lubrication and correct lubricant use.

In order to cut down the expenses, companies should do just the opposite: invest additional resources and take advantage of modern lubricant maintenance strategies, which can produce significant benefits, not only in production reliability and equipment availability, but also in minimisation of environmental impacts across the whole range of manufacturing, transport, and used lubricant disposal.

Keywords: • lubricant • maintenance • condition monitoring • reliability • productivity •

CORRESPONDENCE ADDRESS: Vito Tič, Ph.D., Assistant, University of Maribor, Faculty of Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: vito.tic@um.si. Darko Lovrec, Ph.D., Professor, University of Maribor, Faculty of Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: darko.lovrec@um.si.

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1 Introduction

The potential bottom-line benefits of proper lubrication are often overlooked. If no effective Complete Lubricant Care (CLC) program is in place, the company and its production is likely to experience significant unplanned downtime at a substantial cost. On the other hand, the right lubrication process can provide opportunities to improve profitability by reducing costs and boosting reliability, increasing the overall life cycle of equipment, and, ultimately, turning out products at a more competitive rate [1].

To develop best practice CLC program it is best to use a phased approach. The first phase is the process of benchmarking and assessment of current condition of fluid management and lubrication program. This helps identify deviations from best practices in the core areas of the program. At the end of this phase we should have a clear understanding of the steps necessary to transform our maintenance and lubrication program together with priority levels of each of the changes to be made [2].

The second phase is to design and develop CLC program considering each individual lubrication point. This includes developing procedures and job plans that consist of equipment hardware modifications, inspections, oil analysis, preventive maintenance and on-condition-based tasks that all relate to improving the equipment maintainability and reliability [2].

The third phase is the implementation of the developed CLC program, which includes program deployment, performing equipment modifications, establishment of project management tasks and work schedules, etc.

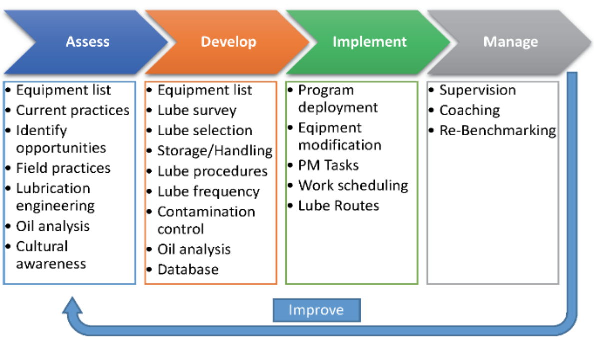

Figure 1. Four phases of Complete Lubricant Care Program [3]

Managing, supervising, re-benchmarking and continuously improving your CLC program is the fourth and last phase. Continuous improvement is an important element of a comprehensive CLC program that is often overlooked.

2 Asses and Benchmark Current Conditions

The assessment and benchmark of current lubricating practices and conditions in the company is a critical step in developing and implementing CLC program [4]. Since employed maintenance personnel usually have insufficient knowledge for performing such assessment, a team of out-sourced experts can help you gather data on critical equipment, maintenance practices, procedures, and technologies currently deployed at the facility. This is done through personnel interviews, record and document reviews and a detailed plant-wide walk-through. With this information, an assessment can be made and a report can be created to compare the findings to the industry's best practices standards [4]. This helps to identify the strengths and weaknesses of the existing fluid care and lubrication program.

Gathered comprehensive information should be presented in a detailed written report, best along with a visual scorecard, where opportunities for improvement in key areas versus current efforts and conditions are summarized. Each assessment should conclude with an summary that specifies the target areas for most rapid return of investment and provides the personnel with a roadmap to address the company status, and provide direction where to focus resources to ensure improvements in equipment reliability and reduction in overall maintenance costs [4].

Designing and Developing CLC Program

An effective CLC program should produce significant benefits in production reliability and equipment availability. Conducting an internal or external assessment of your existing lubrication practices and comparing it to industry "Best Practices" will identify both strengths and weaknesses. Once identified, a recommendation for improvements can be made that ensure optimal performance from your CLC program. The areas that CLC program should address are [5]:

- logistics and supply chain,
- lubricant storage, handling and disposal,
- lubricant selection,
- contamination and condition control,
- sampling methods and collection,
- lubricant analysis,
- lubrication task planning and scheduling,
- safety practices,
- program goals and program management,
- training of maintenance personnel.

Assessment should be made objectively as possible and special attention should be paid to define appropriate weighting system for creating benchmarking spider diagrams, which provide a dynamic overview of the company's strengths and weakness in its existing lubrication practices. The spider diagrams can clearly indicate the primary areas of CLC program implementation.

4 Implementing the Program

With the CLC program designed and developed it is time to start implementing the program according to the plan. There are usually many phases of implementation and, for some companies, it can take several years to fully implement the program. Typically, this applies to cases when significant investments are required to transform lubricant storage areas.

One of the great features of a proper CLC program is that there are also measures to be taken which need significantly less investment. For instance, consistent labelling of lubricants, application equipment, storage sites and containers (Figure 3) can substantially increase production reliability. The risk of using a wrong lubricant for a particular lubrication point is virtually eliminated.

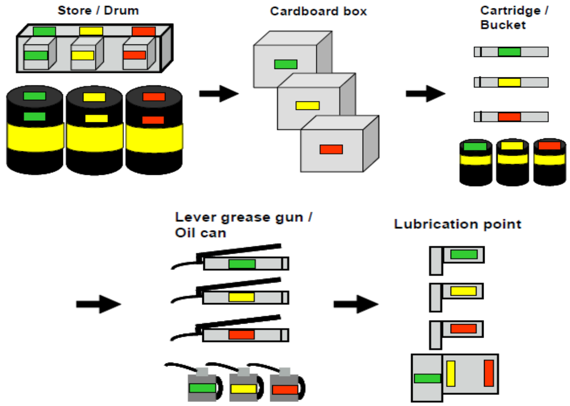

Figure 2. Consistent labelling of lubricants and lubricating points [8]

5 On-Line Condition Monitoring

The above list of key areas that CLC program should address clearly emphasizes that correct lubricant selection and later its continuous condition monitoring and analysis is extremely important in successfully implementing the program.

Monitoring of lubricants can nowadays be done in several ways: from periodic oil sampling and analysis in laboratory, to more frequent periodic on-site analysis, and most reliable option – 24/7 on-line OCM.

Figure 3. Industrial on-line oil condition monitoring systems

These on-line OCM methods are based on the applications of special sensors that are installed within a hydraulic system for measuring the physical properties of hydraulic fluid, e.g. temperature, viscosity, dielectric constant, electrical conductivity, relative humidity and the cleanliness level, as presented in Figure 3.

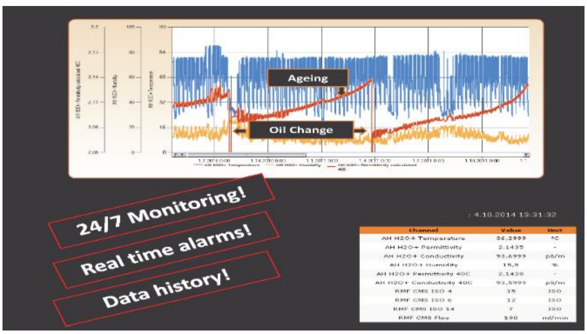

Figure 4. On-line user interface for OCM

A distinct advantage of on-line methods is the continuous monitoring of individual fluids' parameters, thus knowing the oil condition at any time. In addition, any sudden changes are also detected (even an automatic SMS or E-mail alert can be triggered), whilst with off-line methods it cannot be. Figure 4 shows an example of on-line user interface of such on-line OCM system.

6 Controlling and Supervising the Program

The last but not least phase is managing the new CLC program. It is most important to realise that development and implementation of the program is continuously on-going project, which demands repeated steps of re-assessment, re-development and implementation of new strategies and actions. Even if the program was perfectly designed and implemented, it would still require changes from time to time. Changing conditions such as production demands, new equipment and new technologies require some aspects of the program to undergo continuous improvement.

The establishment of goals and metrics is key to improving a CLC program. The selection of specific program goals and the development of key performance indicators by which to measure the progress towards these goals are largely dependent on the maturity of the program.

7 Conclusion

Numerous case studies report about the benefits of implementing an effective Complete Lubricant Care program that involve improvements in equipment reliability, reduction in production down-times and reduction in operating costs.

The development and implementation of Complete Lubricant Care Program will vary based on the company size, company organisation and scope of the project. However, the design and implementation should always be done comprehensively by an integrated approach, which can be divided into phases, as described in the paper. During all of these phases (program assessment, development, implementation and program management) entire company production process and personnel will be affected by the change, including company's top management.

If such program is implemented successfully, the company will gain significant benefits, not only in production reliability and equipment availability, but also in minimisation of environmental impacts across the whole range of manufacturing, transport, and used lubricant disposal.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Carbon Footprint Calculation as a Tool for Energy Efficiency Support in Telecommunications Company

SASA TOMPA & GREGOR RADONJIČ

Abstract Energy efficiency measures and climate policies are closely related to strategic concerns of companies. This paper discusses the application of organizational carbon footprint (CF) according to the GHG Protocol standard in order to quantify direct and indirect greenhouse gas (GHG) emissions of a telecommunications company (telecom operator). The results showed that the largest contributor of GHG emissions is purchased electricity consumption. The employees' commute to and from work, the use of company-owned vehicles and heating represent the next major emitters of GHG emissions. Although the calculated CF is influenced by the assumptions and limitations in the model, its determination can improve management's understanding of company's emissions profile and serve as useful parameter within company's wider energy efficiency measures. In this context, the study could be used as the base for reconsidering the energy efficiency plans for a telecom operator company.

Keywords: • energy efficiency • carbon footprint • GHG emissions • ICT sector • telecommunications •

CORRESPONDENCE ADDRESS: Sasa Tompa, Telekom Slovenije, d.d., Controlling , Strategic Controlling, Cigaletova 15, 1000 Ljubljana, Slovenija, email: sasa.tompa@telekom.si. Gregor Radonjič, University of Maribor, Faculty of Economics and Business, Institute of technology and entrepreneurial environment protection, Razlagova ulica 14, 2000 Maribor, Slovenija, email: gregor.radonjic@um.si.

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1 Introduction

Energy efficiency plays a fundamental role in the transition towards a more competitive, secure and sustainable energy system. The fact is that an efficient use of energy is closely connected to many environmental pollution problems, particularly to those connected with climate change. The reduction of greenhouse gas (GHG) emissions has become an important indicator of energy efficiency measures. Not surprisingly, an increasing number of authors report on mutual interrelations between energy efficiency and energy consumption on one hand and GHG emissions on the other [1,2]. Due to these reasons, the European Commission launched in 2007 the '2020 Climate and Energy Package' where, for the first time, energy efficiency and climate targets and policies became linked at the EU level.

Companies around the world are increasingly faced with the need to integrate environmental protection issue into their business decisions due to many different reasons. In such context, energy efficiency engagements are seen as a top priority in reducing GHG emissions in many companies. Within reporting and communicating approaches, an increasing attention is given to the climate data, including GHG emissions reduction measures. Consequently, many sectors are considering their energy policies as strategically important in order to reduce their environmental impacts. One of them is information-communications technologies (ICTs) sector.

It is a fact that ICTs will face serious demands on further network energy efficiency because the energy consumption of ICTs is continuing to increase [3]. Telecommunications networks provide a fundamental support to all modern communications due to the rapid growth in the use of the Internet, data processing and transfers, mobile communications, etc. This is leading to significant increases in energy use and the resulting GHG emissions. Telecom companies are already ranked among the top three electricity consumers nationally in most EU countries [4]. However, the energy demand of the telecommunications network can create serious environmental burden and this trend is expected to continue as a result of a rapid diffusion of mobile applications and the Internet of things. But on the other hand, ICTs can generate economic and socio-economic value through improved energy efficiency.

In establishing climate policy, the organizations need concrete numerical data as a basis for their decisions. In spite of the fact that a great potential for reducing carbon emissions regarding ICT sector exists, the question how companies get the relevant information on their GHG emissions to start proper actions arises. Carbon footprint (CF) is a term used to quantify the total amount of GHG emissions caused by an individual, product, event, activity, organization or country [5,6]. It allows businesses to focus on achieving the most meaningful reductions not only within their direct-controlled operations but across the entire value chain(s). The information obtained by the CF determination can further serve as useful parameter within company's wider energy efficiency measures. The objective of the study was to examine the application of the CF concept to the telecom operator by taking into consideration direct and indirect GHG emissions in order to understand the role of CF as a tool for company's energy and sustainable policy.

2 Research Methodology

The study is based on the data of Telekom Slovenije, d.d., a comprehensive communications service provider in the Republic of Slovenia and one of the most comprehensive communication service providers in South-Eastern Europe.

Organizational CF determination was based on the requirements and guidelines of the Greenhouse Gas Protocol standard [7, 8]. The operational control approach was selected for setting organizational boundaries of the study, and operational boundaries covering three scopes of GHG emissions sources were included: scope 1 (direct emissions that result from activities within the organization's control, such as on-site fuel combustion, refrigerant losses, company vehicles use), scope 2 (indirect emissions from electricity from the grid, heat or steam the company purchases and uses), and scope 3 (indirect emissions from sources outside the company's direct control, such as employees commuting, business travel, outsourced transportation).

In Figure 1, sources of GHG emissions for a telecommunications company under the study are shown. In Table 1, all three scopes of GHG emissions with related activities and processes, including the type of energy sources are given. The study covered the data related to the operations and activities of the company's facilities located in the Republic of Slovenia only for the time period 2012 – 2014. Due to the paper’s length limitations, a detailed description of data gathering in accordance with GHG Protocol guidelines and requirements is not presented here but can be found in [9].

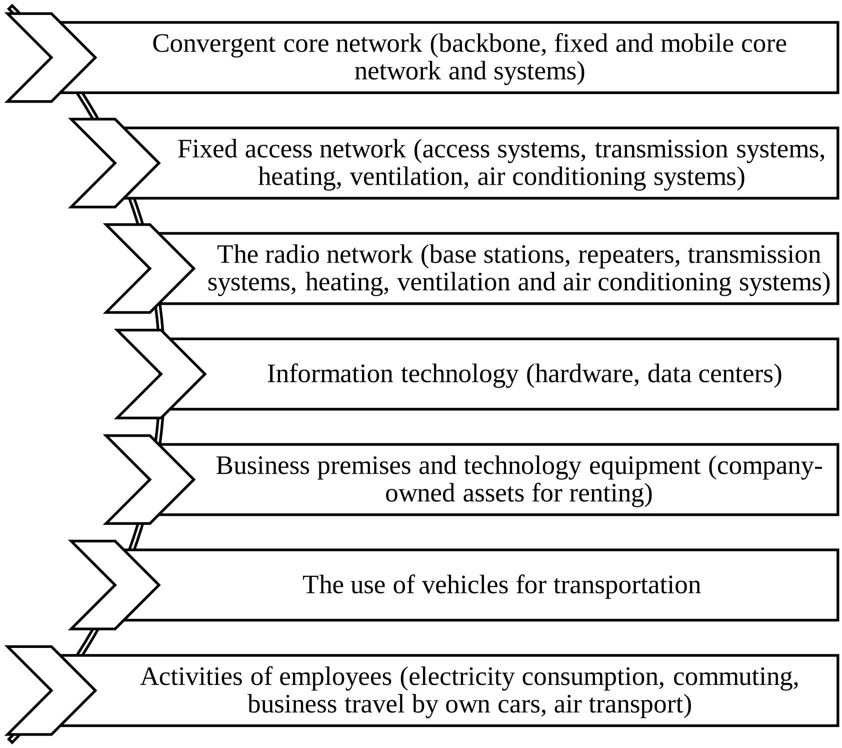

Figure 1. Sources of GHG emissions for a telecommunications company

Table 1. Scopes of GHG emissions with related activities and processes of a telecommunications company together with type of energy sources

Scope	Activities and processes	Type of energy source
Scope 1	Use of cars for transportation	Fuel (gasoline, diesel)
	Use of diesel aggregates for electricity production	Fuel (diesel)
	Air conditioning	HFC gases
	Heating	Fuel oil
		Natural gas
		Liquefied petroleum gas (LPG)
Scope 2	Purchased electricity consumption	Electricity
	District heating	Heat energy
Scope 3	Employees commuting	Fuel (gasoline, diesel)
	Air travel of employees	Fuel
	Use of employees-owned car for business travel	Fuel (gasoline, diesel)
	Electricity consumption of premises rented to business partners	Electricity
	Heating of premises rented to others	Fuel oil
		Natural gas
		Liquefied petroleum gas (LPG)
		Heat energy (district heating)
	Renting cars to business partners	Fuel (gasoline, diesel)

The six GHGs identified in the Kyoto Protocol were taken into consideration [7]. In order to calculate GHG emissions, the values of activity data collected have been multiplied by the corresponding emission factor for each activity within operational boundaries (Table 2) [10,11]. Emission factor for electricity production represents the average value calculated from data of seven national electrical energy distributors for years 2013 and 2014 [9]. Emission factors for activity data in scope 3 group (transport of employees to and from work, air travel) were taken from GHG Protocol tables. Carbon footprint, expressed in CO_2 equivalents (CO_2e), was calculated by multiplying the mass of a given GHG by its global warming potential (GWP) (for 100-year time horizon) [7].

Table 2. Emission factor values (averages for the period 2012 – 2014)

Energy source	**Unit**	**Greenhouse gases**		
		CO_2	**CH_4**	**N_2O**
Fuel oil	t/TJ	74.000	0.0100	0.0006
Liquefied petroleum gas	t/TJ	63.067	0.0037	0.0001
Natural gas	t/TJ	55.291	0.0037	0.0001
Gasoline	t/TJ	70.100	0.0500	0.0020
Gas oil	t/TJ	74.067	0.0027	0.0006
Diesel fuel	t/TJ	74.067	0.0041	0.0291
District heating	kg/kWh	0.3134	-	-
Electrical energy	kg/kWh	0.5720	-	-

3 Results and Discussion

In Figure 2, we can see that the majority of GHG emissions of a telecommunications company is a result of purchased electricity which is used for different operations of telecommunications network and equipment as well as for supporting activities and infrastructure within company-owned buildings. The company has nine electricity suppliers, which opens up various possibilities for the inclusion of sustainability criteria into its purchasing activities. Secondly, using energy efficient technical equipment is also one of the most important parts of energy management for reducing CF. This is followed by electricity consumption in leased assets. Employees’ commute to and from work contributes about six percent what is higher share compared to the contribution of company-owned cars use for business travels. This share is comparable with GHG emissions caused by heating purposes. Air transportation is responsible for less than one percent of all emissions.

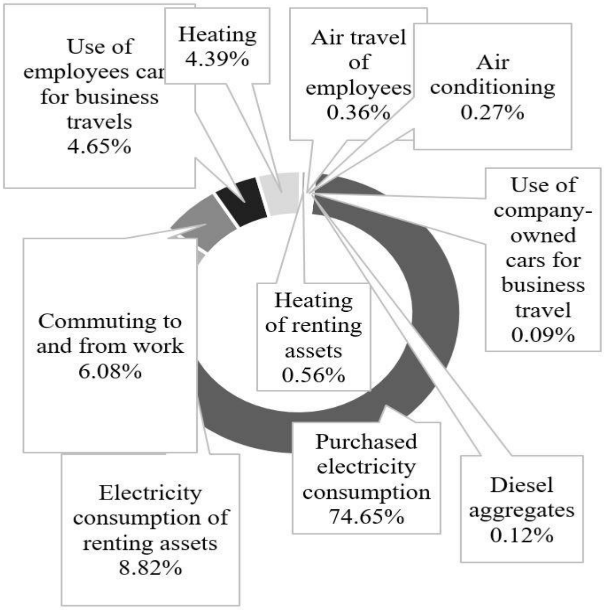

Figure 2. Percentages of GHG emissions by activity or processes of telecommunications company

Organizational CF of a telecommunications company (telecom operator) according to scopes of emissions is presented in Table 3 where both direct and direct emissions are included. It can be seen that organizational overall CF decreased within the examined period. Moreover, the reduction of CF is evident for all three scopes of emission sources, including indirect emissions (scopes 2 and 3). The biggest reduction in the examined period was achieved for scope 2 emissions (almost 10 percent), followed by scope 3 emissions (4.3 percent reduction). According to the overall emissions balance, the focus on the reductions is especially important regarding scope 2 GHG emissions. A further analysis of CF results for the groups of GHG emission sources (scopes) confirmed significant contribution of indirect emissions to the carbon balance of the company (Figure 3). What is interesting is that indirect emissions classified in scope 3 group contribute a higher share to overall carbon footprint balance than the emissions under direct control of the company (scope 1).

Table 3. Carbon footprint values for different scopes of GHG emission sources for a period 2012 - 2014 (in t CO_2e)

	tCO_2e (2012)	**tCO_2e (2013)**	**tCO_2e (2014)**	**tCO_2e (in total)**
Scope 1	3,532.77	3,642.06	3,498.30	10,673.14
Scope 2	46,782.67	45,914.01	45,193.47	137,890.15
Scope 3	9,836.57	9,419.17	8,871.28	28,127.03
Total	60,152.01	58,975.25	57,563.06	176,690.31

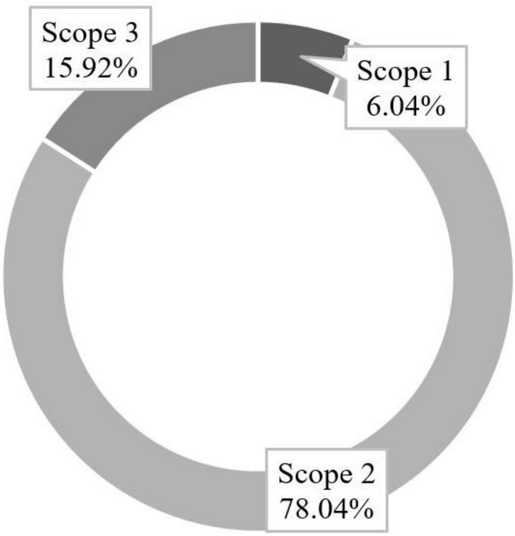

Figure 3. Carbon footprint distribution according to the scopes of GHG emission sources

4 Conclusions

Energy efficiency measures and climate policies have become closely related to strategic concerns of companies, countries and the international community. The goal of the study was to provide a better understanding of the overall (direct and indirect) GHGs impact of a telecom operator. The analysis can help to understand important questions concerning what and who contributes to CF at different company levels and how to integrate the information on carbon footprint calculation into energy efficiency policy. It can help to understand what the key emission sources are and, consequently, to identify which parts of the energy system are particularly suitable for using renewable energy. On the basis of CF analysis, the telecommunications company can help to set priorities for the future improvement of their energy performance and policy and reduce operational costs. In this context, the study could be used as the base for reconsidering the energy efficiency plans for the telecom operator.

The ICT companies have a variety of options for managing power consumption more efficiently. A mobile telecommunications operator has direct control over some of the areas of its environmental impact. In other areas, it can only influence outcomes through a discussion and agreements with suppliers, the education of customers and through its purchasing decisions. An operator's direct control is often concentrated in the operation of networks, but the operator also has a strong influence over the manufacturing and the use/selling of phones. In addition, telecom operators are in direct control of some end-of-life activities, such as recycling of network equipment and co-operating in the establishment of the collection scheme for the returned phones. A move to more flexible working and/or an increased use of teleconferencing can significantly reduce emissions by lessening the burden of commuting and travel to other business locations. Special attention should be given to the energy efficiency of data centres because their emissions are expected to increase most rapidly.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Composite Monetary-Based Criteria of Sustainability and Their Application to Supply Network Synthesis Problems

ŽAN ZORE, LIDIJA ČUČEK, ZORKA NOVAK PINTARIČ & ZDRAVKO KRAVANJA

Abstract Sustainable development is gaining more and more attention as a result of various environmental and social concerns. In recent decades, several economic, environmental, social and composite criteria have been developed based on different concepts and indicators. To overcome some of the limitations of sustainability assessments, a new composite criterion was recently proposed by the authors. Such a metric is termed Sustainability Profit, and is a monetary-based composite criterion based on three sus-tainability factors, economic, environmental and social, expressed as monetary values. Thus, they can be easily merged and can be directly incorporated into the composite sustainability measure. This study presents an extension of the Sustainability Profit metric by analyzing various weights between the monetary-based objectives and sustainability factors. It also introduces monetary-based sub-metrics of sustainability, such as monetary-based bearability, equitability and viability metrics. Various metrics are applied in a large-scale demonstration example of renewable energy and food supply network synthesis.

Keywords: • sustainability profit • sustainability criteria • supply network synthesis • renewable energy • composite criteria •

CORRESPONDENCE ADDRESS: Žan Zore, Junior Researcher and Assistant, University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: zan.zore@um.si. Lidija Čuček, Ph. D:, Assistant Professor, University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: lidija.cucek@um.si. Zorka Novak Pintarič, Ph.D., Full Professor, University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: zorka.novak@um.si. Zdravko Kravanja, Ph.D., Full Professor, University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: zdravko.kravanja@um.si.

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1 Introduction

Governments, industry and society have all recently expressing increased interest and awareness in sustainable development because of problems such as environmental degradation and societal inequity [1].

Besides environmental issues, of which mitigation of climate change is currently the central worrying threat, solving the unemployment problems present in many societies, especially those affecting youth [2], economic growth and security of energy supplies [3] are important issues and objectives. Sustainable development, therefore, requires consideration of three sustainability dimensions - environmental, economic and social [3].

Several economic and environmental, social and composite indicators and metrics have been developed in recent decades to evaluate current problems and to guide us to more sustainable solutions [4]. These indicators are based on concepts such as damage-based assessment, the benefit-based approach, the distance-to-target approach and the prevention-based approach. They differ in terms of qualitative and (semi)quantitative assessments, in handling of subjectivity, dimensionality, weighting, aggregation, normalization, uncertainty, and in a selection of system boundaries and levels of details. However, a small number of indicators and metrics can integrate all three aspects of sustainability [4].

Different economic-based methods have been recently proposed that overcome some of the limitations of sustainability assessments, such as weighting, normalization, multi-objective nature and multi-dimensionality of problems [5]. Such metrics are named Viability Profit (originally termed "Total Profit" [6]) and Sustainability Profit [5] and can be extended to Sustainability Net Present Value [7]. All sub-metrics are expressed as monetary values and can thus be easily merged and be directly incorporated into the composite sustainability measure. Sustainability Profit and Sustainability Net Present Value are monetary based criteria of sustainability that include equally weighed economic, environmental and social factors.

This paper presents an extension of the Sustainability Profit metric by analyzing various weightings of monetary-based objectives. It also introduces monetary-based sub-metrics of sustainability, such as monetary-based bearability, equitability and viability metrics. Various metrics are applied to a large-scale demonstration example of renewable energy and food supply network synthesis. The detailed application of its sub-metrics to objective value and solutions obtained when solving large-scale supply network synthesis problems is studied and demonstrated.

2 Sustainability profit

Sustainability profit (SP) is a composite measurement of economic, environmental and social efficiency expressed in monetary terms and defined as the sum of Economic ($P^{Economic}$), Eco- (P^{Eco}) and Social Profit (P^{Social}) [5]. The monetary value of sustainability is intuitive and easily understandable by the wider public. A higher value of Sustainability Profit or individual criteria (Economic, Eco- and Social Profit) means that the solution is more sustainable (higher SP), viable (higher $P^{Economic}$ and P^{Eco}), equitable (higher $P^{Economic}$ and P^{Social}) or bearable (higher P^{Eco} and P^{Social}). Figure 1 shows different individual profits and their combinations obtained.

Eq. (1) shows general and detailed representations for calculating Sustainability Profit, where weights w^a, w^b and w^c could take any value between 0 and 1. If all coefficients have values of 1, the "truly" sustainable solutions with the highest Sustainability Profit can be obtained. It should be noted that apart from composite profits, such as Bearability, Viability, Equitability and Sustainability Profits, the values of coefficients lower than 1 and greater than 0 can also be applied.

$$
\begin{aligned}
SP &= w^a \cdot P^{\mathrm{Economic}} + w^b \cdot P^{\mathrm{Eco}} + w^c \cdot P^{\mathrm{Social}} \\
&= w^a \cdot \left(R - E - D\right) && \mathrm{P^{Economic}} \\
&+ w^b \cdot \left(\begin{aligned} &\left(\sum_{t\in T} \sum_{i\in R_{\mathrm{UNB}}} q_{m_i}^{\mathrm{R_{UNB}}} \cdot c_{i,t}^{\mathrm{R_{UNB}}} + \sum_{t\in T} \sum_{j\in P_{\mathrm{UNB}}} q_{m_j}^{\mathrm{P_{UNB}}} \cdot f_j^{\mathrm{S/P_{UNB}}} \cdot c_{j,t}^{\mathrm{S}} \right) \\ &- \left(\sum_{t\in T} \sum_{i\in R_{\mathrm{B}}} q_{m_i}^{\mathrm{R_B}} \cdot c_{i,t}^{\mathrm{R_B}} + \sum_{t\in T} \sum_{j\in P_{\mathrm{B}}} q_{m_j}^{\mathrm{P_B}} \cdot c_{j,t}^{\mathrm{P_B}} \right) \end{aligned} \right) && \mathrm{P^{Eco}} \\
&+ w^c \cdot \left(\sum_{t\in T} N_t^{\mathrm{Jobs}} \left(s_t^{\mathrm{Gross}} - s_t^{\mathrm{Net}} \right) + \sum_{t\in T} N_t^{\mathrm{Jobs}} \cdot c_s^{\mathrm{UNE,\,State}} - \sum_{t\in T} N_t^{\mathrm{Jobs}} \cdot \left(c_s^{\mathrm{EMP,\,State}} + c_s^{\mathrm{Company}}\right) \right) && \mathrm{P^{Social}}
\end{aligned}
\qquad (1)
$$

In Eq. (1) the economic part is represented by R as revenue, E as expenditures and D as depreciation. In P^{Eco} q_{m} represents mass flow rate, c eco-cost coefficients for raw materials ($c_{i,t}$) and products ($c_{j,t}$) taking into account burdening and unburdening effects for raw materials (R_{B} and R_{UNB}) and products (P_{B} and P_{UNB}) and technology t, and f substitution ratio between amounts of previously used products (S) and currently substituted products (P_{UNB})[8].

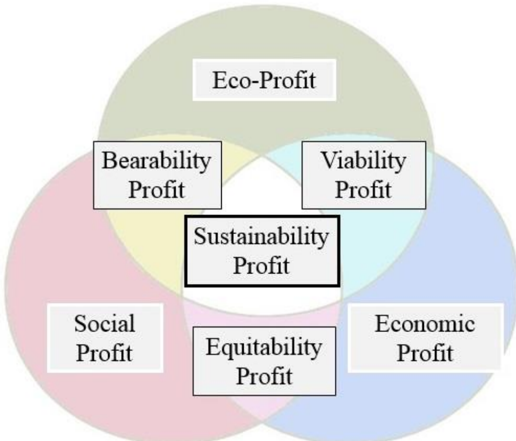

Figure 1: Different profits obtained with regard to considering Economic, Eco- and Social Profits and their combinations (modified from [9]).

P^{Social} is calculated regarding number of jobs created N_t^{Jobs}, average gross s_t^{Gross} and net salaries s_t^{Net} in a production sector, with technology t, average state social transfer $c_s^{UNE, State}$ for unemployed people and average state social transfer $c_s^{EMP, State}$ and an average company's social charge $c_s^{Company}$ per employee employed in an investigated supply chain [5]. It should be noted that the Sustainability "Profit" originating from the new alternative compared to a previous alternative can also be negative if the cost is higher than the benefit (economic, environment-

al and/or social). Because typically the intention is to maximize gain and not to minimize loss, the term profit is thus used. However, sustainability cost and all the sub-metrics, such as economic, environmental, social, bearability, viability and equitability cost can be minimized, and the term "Sustainability Cost" (and similarly for all the sub-metrics - bearability, viability and equitability) can be used.

3 Case study

The case study presents an upgraded multi-period mixed-integer linear programming (MILP) optimization model [10] of a larger-scale renewable-based energy supply network at the EU level [11] with the addition of electricity production. To incorporate electricity production from renewable sources, the usable land in the EU is enlarged for the production of food, biofuels and electricity from 10% to 11%.

Electricity can be produced from three different technologies and sources, photovoltaics for solar power, wind turbines for wind power and binary cycle geothermal plants for geothermal energy. Even though thermal energy could also be produced, only the production of electricity is considered based on estimated data for investment, fixed maintenance and operating cost [12].

In the model there are some restrictions: all food demand should be satisfied, at least 10% of fuel demand should be satisfied, while production of electricity is free of choice. The model considers monthly time periods for less-intermittent sources and products (biomass, food and biofuels), and hourly time periods (because of the size of the model, 6 periods per month and 4 periods per day are considered) for more intermittent sources and products (solar, wind, geothermal and electricity) [13]. The results of different metrics are presented in Table 1.

Table 1: Results of maximizing different profits for a continental-scale biorefinery and alternative sourced electricity supply network

Maximization criteria (in M€/y):	$P^{Economic}$	P^{Eco}	P^{Social}	$P^{Viability}$	$P^{Equitability}$	$P^{Bearability}$	SP
$P^{Economic}$	**99,719**	-49,723,400	-417,041,000	-11,054	99,568	-111,578,000	-11,282
P^{Eco}	-25,071	**546,992**	321,381	202,554	-25,136	546,936	202,727
P^{Social}	1,458	89,694	**142,547**	2,447	1,642	140,078	2,511
$P^{Viability}$	74,648	-49,176,408	-416,719,619	**191,500**	74,432	-111,031,064	191,445
$P^{Equitability}$	101,177	-49,633,706	-416,898,453	-8,607	**101,210**	-111,437,922	-8,771
$P^{Bearability}$	-23,614	636,685	463,928	205,001	-23,494	**687,014**	205,238
SP	76,105	-49,086,715	-416,577,072	193,947	76,074	-110,890,986	**193,956**

All profit figures presented depend on the type of profit that is maximized - Economic, Eco, Social, Viability, Equitability, Bearability and Sustainability. The objective values in the corresponding columns are shown in bold.

Further, Table 2 shows some details regarding results when maximizing these different profits.

From Table 1, it can be seen that economic profit is positive when $P^{Economic}$ and $P^{Equitability}$ are maximized as a result of the small absolute size of P^{Social} compared to $P^{Economic}$. $P^{Economic}$ is significantly negative when it is not taken into account as a maximization criterion. $P^{Economic}$ favours higher production of gasoline substitutes and lower production of diesel substitutes and no renewable electricity because it represents an additional cost in the supply chain. Diesel substitutes are extracted from waste cooking or algal oil with methanol as a catalyst. Also, higher usage of miscanthus, algae, cooking oil and wheat with less wheat straw is preferred.

From an environmental perspective, the demand of gasoline and diesel substitutes are lower when P^{Eco} has a significant influence on maximization criteria, but on the other hand, more generation of renewable electricity, especially from wind turbines, is preferred. The results show that almost 5% of the EU's area out of 11% should be afforested to gain the best environmental results. When additional afforestation is achieved, it is assumed that this brings eco-benefit. For fuel substitutes, less miscanthus and corn stover should be used and diesel extraction from algae and cooking oil should be done with ethanol instead of methanol.

P^{Social} stimulates greater production of biofuels and a higher number of employees regardless of economic cost. Note that similar solutions are given when the absolute sizes of Economic, Eco- and Social Profit are obtained, despite the different usage of weighting factors. Similar pairs are $P^{Economic}$ and $P^{Equitability}$, $P^{Viability}$ and SP because of the small size of P^{Social} compared to $P^{Economic}$ and P^{Eco}. $P^{Bearability}$ does not have such a pair solution but it is clear that it is a combination of P^{Eco} and P^{Social}.

Figure 2 shows in more detail how weighting of sub-profits affects the configuration of Pareto solutions between w^b (P^{Eco} weighting factor) and SP. It shows the material use in correlation with environmental aspects, taking into account different weights in composite criteria SP. It can be seen that with the fraction of P^{Eco} increasing, the amounts of forest residue and waste cooking oil increase and the quantities of miscanthus decrease. The consumption of miscanthus is reduced by a factor of ten in Figure 2. For the same reason, the consumption of cooking oil and forest residues is increased by a factor of ten.

Table 2: Main results from optimization of different profits for a continental-scale biorefinery and renewable electricity supply network

Maximization criteria:	$P^{Economic}$	P^{Eco}	P^{Social}	$P^{Viability}$	$P^{Equitability}$	$P^{Bearability}$	SP
Area used (%)	11.00	10.86	11.53	10.86	11.00	10.83	10.86
- afforested (%)	0	4.89	0	3.38	0	4.86	3.36
Demand for fuel (%)							
- gasoline	62.75	10.28	73.57	36.55	62.84	10.23	36.79
- diesel	28.92	18.50	26.87	23.92	28.92	18.71	23.90
Demand for electricity (%)	0	100.00	100.00	30.12	0	100.00	30.21
- wind	0	36.73	99.90	30.12	0	36.64	30.21
- solar PV	0	63.24	0.10	0	0	63.32	0
- geothermal	0	0.04	0	0	0	0.03	0
Raw materials (Mt/y)							
- corn grain	85,933	85,041	85,041	85,937	85,933	85,041	85,937
- corn stover	50,089	6,160	51,025	51,562	50,089	6,314	51,562
- wheat	131,748	127,808	127,808	131,758	131,748	127,808	131,758
- wheat straw	116,090	130,365	120,400	134,393	116,214	130,365	134,393
- miscanthus	321,961	1,158	348,934	111,239	322,505	1,158	112,394
- forest residue	0	2,447		1,511	0	2,447	1,504
- algae	34,478	29,165	33,885	34,293	34,478	29,165	34,318
- cooking oil	4,089	3,405	4,867	4,012	4,089	3,796	4,012
Technologies*:							
- hydrogen[1]	•		•		•		•
- dry-grind process[2]							
- syngas fermentation[3]	•	•	•	•	•	•	•
- catalytic synthesis[4]	•				•		
- FT synthesis[5]	•	•	•	•	•	•	•
- cooking oil methanol[6]	•		•	•	•		•
- coking oil ethanol[7]		•	•			•	
- algae methanol[8]	•		•	•	•		•
- algae ethanol[9]		•	•			•	
Biofuels (Mt/y)							
- ethanol	74,464	5,836	92,059	40,559	74,592	5,737	40,926
- green gasoline	10,435	5,702	9,248	7,840	10,437	5,724	7,831
- et-diesel**	0	17,267	11,543	0	0	17,643	0
- me-diesel***	20,475	0	9,394	20,312	20,475	0	20,324
- FT diesel	39,257	21,449	34,791	29,494	39,265	21,532	29,459
- hydrogen	5,157	619	4,954	3,960	5,172	608	3,968
Number of employees	235,414	15,167,630	21,491,000	405,387	235,652	21,491,000	407,283

*technologies: [1]gasification and hydrogen production from lignocellulosic biomass [14], [2]dry-grind process using corn and wheat, [3]gasification and syngas fermentation of lignocellulosic biomass, [4]gasification and catalytic synthesis of lignocellulosic biomass [15], [5]gasification, Fischer Tropsch (FT) synthesis and hydrocracking [16], [6] biodiesel production from waste cooking oil with methanol, [7]biodiesel production from waste cooking oil with ethanol, [8] biodiesel production from algal oil with methanol, [9]biodiesel production from algal oil with ethanol [17, 18]

**biodiesel produced using ethanol
***biodiesel produced using methanol

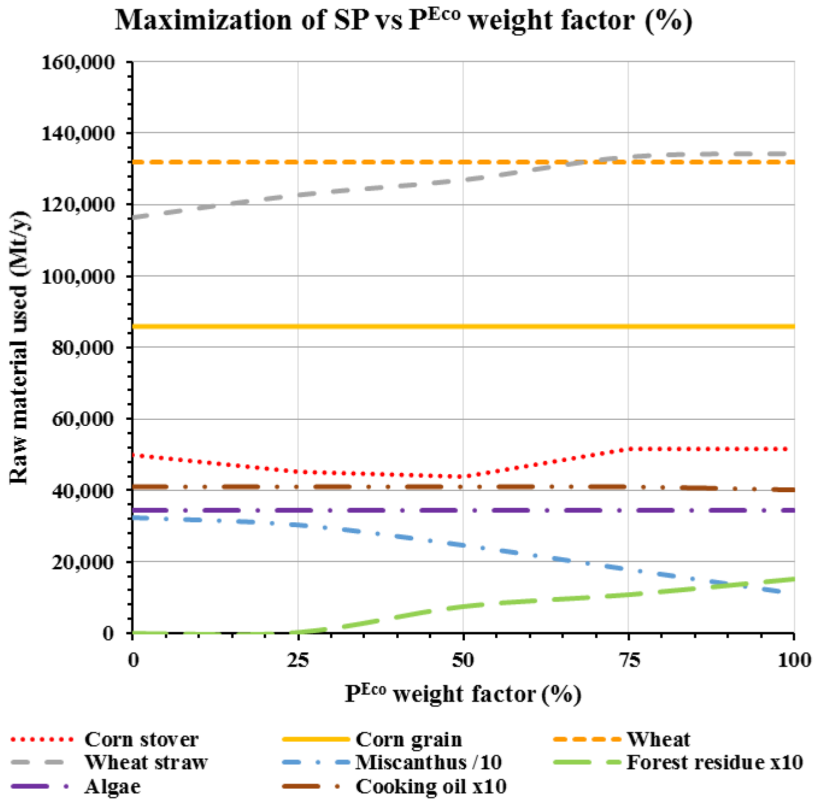

Figure 2: Raw materials used vs. the share of P^{Eco} in SP considered when maximizing SP

Figure 3 shows the demand satisfaction considering the range of solutions, from a solution that considers only economic and social aspects of SP to a solution that considers all three aspects of SP with the same weight.

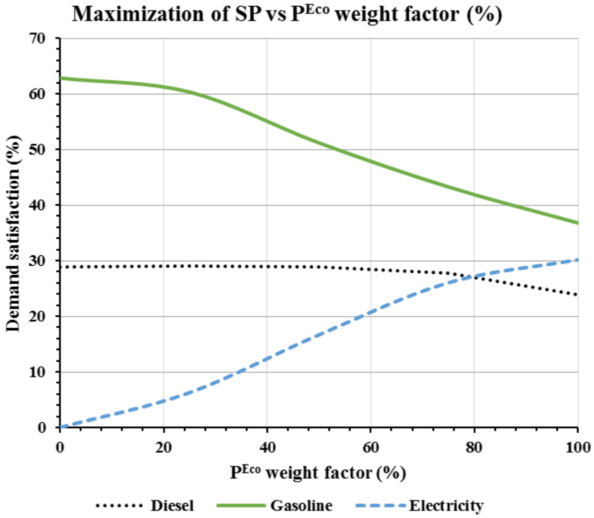

Figure 3: Demand satisfaction vs. share of P^{Eco} when maximizing SP

Increased electricity production could be obtained by increasing the P^{Eco} weight. On the other hand, a significant decrease in gasoline production and a slight decrease in diesel substitutes can be seen. When environmental aspects are taken into account, the use of miscanthus is reduced significantly, while the use of cooking oil and forest residue increases (see Figure 2); however, their capacities are too small to reverse the trend. It can also be seen that production of gasoline substitutes decrease faster compared to diesel ones.

4 Conclusions

This study presents an extension of the metric Sustainability Profit approach by analyzing various weights between monetary-based sub-metrics. Monetary-based sub-metrics of Sustainability Profit introduced are:

- Bearability (Economic and Eco-Profit)
- Equitability (Economic and Social Profit)
- Viability (Eco- and Social Profit)

Our study demonstrates that a continental-scale renewable supply network producing biofuels, electricity and food is sustainable. It was shown that combining various sub-metrics is straightforward, and they can be directly incorporated into a composite criterion when they are monetary-based. The effects of each sub-metric on the composite metric and on the final solution depend not only on its weight, but also on the absolute size of the sub-metric. Even when all the sub-metrics are equally weighted, certain sub-metrics might not interfere enough to be noticeable because of their different orders of magnitude. In our study this was shown with the occurrence of pairs of similar solutions, for instance when $P^{Viability}$ or SP are maximized (see Table 1).

Besides production of food, our study showed that a significant amount of fuels could be produced (more than 36% of gasoline and more than 23% diesel are replaced by biofuels), a significant percentage of the land area could be afforested (from 3.36% to even 4.89% in the case when considering only environmental effects) and more than 30% of renewable electricity could be produced from all of the sustainability aspects, without subsidies.

However, it should be noted that when biofuel and electricity supply networks are optimized, the expected efficiencies may not be attained in practice. Furthermore, there are several variations and consequently uncertainties in yields, prices, and availability of areas in certain locations. In future studies, therefore, such variations in monetary values and uncertainties should be accounted for.

The weighting of sub-metrics could further be upgraded from composite criteria on an annual basis to composite criteria considering the entire lifetime of a network, such as Sustainability Net Present Value and other composite sustainability metrics expressed in monetary values. Furthermore, the work could be extended to more detailed and region- and company-specific economic, environmental and social projects.

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10TH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENTAL PROTECTION (JUNE 27TH – 30TH, 2017, BLED, SLOVENIA), ENVIRONMENTAL MANAGEMENT AND IMPACT ASSESSMENT
J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

A Methodology to Assess Environmental Impacts of Thermal Performance Improvements in Chilean Residential Buildings

WALDO BUSTAMANTE, HÉCTOR JORQUERA, MANUEL BRAHM, VICTOR BUNSTER, FELIPE ENCINAS & SERGIO VERA

Abstract In Chile, about 20% of the energy is consumed by the residential sector. There is consensus in the country that the thermal performance standards for housing are extremely low, explaining the high amount of energy that is currently used for space heating. Nowadays, firewood accounts for close to 50% of this consumption. The high share of this fuel can be explained by its low costs when compared to other alternatives such as kerosene, liquefied petroleum gas (LPG), electricity and natural gas (NG). A direct consequence of this intensive use of firewood are the high levels of air pollution present in urban areas throughout Chile. In Santiago and other cities of the south, particulate matter (PM) 2.5 concentrations exceed the recommended levels (greater than 20 μg/m3 annual average). These environmental pollutants, together with severe levels indoor air pollution, are currently affecting close to 10 million people in the country while generating high rates of heart and chronic respiratory disease as well as premature deaths of thousands. This paper presents a methodology intended to provide critical information in regards to the environmental impacts of improving the thermal performance of new and existing buildings. In order to illustrate its capabilities, the methodology was implemented in representative three Chilean cities (i.e., Santiago, Concepción and Temuco) focusing on the reduction of CO2 and PM2.5 emissions. Overall, this paper demonstrates that the proposed methodology enables empirical assessment of the potential benefits behind the introduction of different thermal performance measures that may be used to inform environmental policies and energy-efficiency measures

Keywords: • environmental impact assessment • urban pollution • housing • energy efficiency • Chile •

CORRESPONDENCE ADDRESS: Waldo Bustamante, Ph.D., Professor, Pontificia Universidad Católica de Chile, School of Architecture, El Comendador 1916, Providencia. Santiago 7520245. Chile. Centre for Sustainable Urban Development (CEDEUS), wbustamante@uc.cl. Héctor Jorquera, PhD, Professor, Pontificia Universidad Católica de Chile, Department of Chemical & Bioprocess Engineering, Av. Vicuña Mackenna 4860, Santiago 7820436, Chile, Centre for Sustainable Urban Development (CEDEUS), Chile, jorquera@ing.puc.cl. Manuel Brahm, M.A., Senior Research Staff Assistant, Columbia University, International Research Institute for Climate and Society (IRI), 116th St & Broadway, New York, NY, USA, 10027, mbc@iri.columbia.edu. Victor Bunster, Ph.D., Postdoctoral Research Fellow, Pontificia Universidad Católica de Chile, School of Architecture, El Comendador 1916, Providencia. Santiago 7520245. Chile. Centre for Sustainable Urban Development (CEDEUS), Chile, v.bunster@uc.cl. Felipe Encinas, Ph.D., Associate Professor, Pontificia Universidad Católica de Chile, School of Architecture, El Comendador 1916, Providencia. Santiago 7520245. Chile. Centre for Sustainable Urban Development (CEDEUS), Chile, felipe.encinas@uc.cl. Sergio Vera, Ph.D., Associate Professor, Pontificia Universidad Católica de Chile, Department of Construction Engineering and Management, School of Engineering, Av. Vicuña Mackenna 4860, Santiago 7820436, Chile. Center for Sustainable Urban Development (CEDEUS) Chile, svera@ing.puc.cl.

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1 Introduction

In Chile, as in many other developing countries, economic affluence has come with substantial social and environmental challenges [1]. According to estimations of the Chilean Environment Ministry, over 10 million people are currently exposed to particulate matter over the PM2,5 norm, while according to the World Health Organization, this pollution may account for close to 4,000 premature deaths per year across the country [2, 3]. Significantly, these hazardous environmental conditions have been estimated to cost close to US 8 million per year, entailing the potential for significant savings to the country's health system [1, 2].

In this context, Chilean authorities have responded with the introduction of a number of policies and decontamination plans that include the definition of maximum concentration levels for different pollutants, monitoring of particulate matter levels, industrial and vehicle restriction programs for days above the norm, and banning or renovation of space heating artefacts such as open firewood heaters among others [2, 4].

Significantly, firewood has been shown to be the main source of pollution for central-southern Chile, concentrating the country's worst environmental quality conditions, while close to 75% of the residential buildings in the area use this type of fuel for space-heating (45% throughout the country) [5, 6]. Accordingly, Chilean authorities have set forth a number of policies and programs to control firewood usage and reduce residential energy consumption [7].

The Chilean thermal regulation (Art. N° 4.1.10 in [8]), introduced in two stages between the years 2000 and 2007, defines the maximum thermal conductivity levels allowed for the envelope (i.e., roofs, walls and ventilated floors) of new residential buildings as well as the maximum percentages for windowed areas according to the building's climatic conditions [see 9]. Although the definition of these minimum thermal performance standards was a substantial step towards the social, economic and environmental sustainability of the building sector, there is consensus across the country that there is still plenty of work to be done.

The introduction of further thermal standards to official regulations is currently under debate [10]. This paper presents a methodology that was developed as a means to support the process of defining evidence-based policy.

2 Methods

In order to assess the potential impacts of the introduction of different thermal performance improvements to residential buildings, a four-point methodological approach was proposed: (a) sampling of representative housing types, (b) simulation of energy demand, (c) assessment of energy consumption, (d) quantification of CO_2 and

PM2.5 emissions. These methodological steps and information sources used to illustrate its capabilities are described in the following sections.

2.1 Housing types

The first step of the proposed methodology consists in the identification and selection of housing types that are representative of the urban area under evaluation. In specific, this was done by accessing official governmental statistics on housing deliveries [11] from 2007, date of introduction of the last stage of the thermal regulation [9], and 2011, date of the latest available information. In this case, the evaluation focused on the cities of Santiago, Concepción, and Temuco-Padre las Casas, three of the largest and most polluted urban areas of central-southern Chile [2]. This first step enabled identification of the most prevalent housing types for each city, which were then categorised under three main criteria, i.e., type (house or apartment), grouping (detached, semi-detached or terraced), and location (municipal district). This categorization is intended to identify the most representative cases that, under these combined criteria, are currently available in the housing market (Table 1).

Table 1. Representativeness of different housing types per city [11]

City	Type	Representativeness †	
		%	N
Santiago	1	13.8%	6,973
	2	16.4%	8,291
	3	2.8%	1,443
	4	20.7%	10,477
	5	14.9%	7,557
	6	13.5%	6,824
	total	**82.0%**	**41,565**
Concepción	1	25.9%	1,745
	2	23.7%	1,599
	3	18.3%	1,237
	total	**67.9%**	**4,581**
Temuco - Padre las Casas	1	21.2%	3,711
	2	29.3%	5,136
	3	8.2%	1,444
	4	12.4%	2,167
	5	3.7%	644
	total	**74.8%**	**13,102**

Note (†): Results for the selected housing types were extended in order to achieve 100% of the dwellings built per city in an average year.

2.2 Energy demand

A second step of the proposed methodology consists in simulating the heating and cooling demand (kWh) of the selected housing types in order to assess the potential impacts of different improvements in their thermal performance requirements. In specific, this was done by defining a base-case scenario for each city, over which different improvement alternatives were evaluated. For estimating heating and cooling demand, the considered minimum and maximum temperatures were 20°C and 26 °C respectively, during the complete day. Simulations were performed with TAS of Environmental Design Solutions Limited.

Location, Climate and Pollution

As mentioned above, the evaluation focused on three of the largest and most polluted metropolitan areas of Chile. Santiago (33°27'S 70°40'W), the country's capital and largest city, has an estimated population of 6,158,080 with a density of 8,470/km^2. In this city, the coldest month of the year is July with a mean minimum temperature of 3.9°C and a mean maximum of 14.9°C. The annual an average of humidity is 71%. Concepción (36°49'S 73°03'W), in central-southern Chile, has an estimated population of 292,589 and a density of 1,318/km2. In this city, for the month of July, the mean recorded temperatures ranges between 6.2°C and 13.4°C, and the annual average humidity levels is 82%. Lastly, Temuco (38°44'S 72°40'W), located in southern Chile, has an estimated population of 262,530 for a density of 570/km^2 with mean recorded temperatures ranging between 4.5°C and 11.7°C (for month of July), and average humidity of 82%. All three cities have dry-summer subtropical (Csb) climate, while their number of days above the PM2,5 norm (50 μg/m^3 per 24 hrs) can reach 65, 61, and 41 in Santiago, Concepción and Temuco respectively [2].

Base-case Scenario

As mentioned before, the maximum thermal transmittance (U) levels allowed by the Chilean regulation were used to define a base-case scenario and to estimate the monthly energy demand for an average year (Table 2).

Table 2. Thermal characteristics of base-case scenarios per city and climatic zone

Zone	City	U values * [W/m2K]		Glazing types
		Walls	Roofs	
3	Santiago	1.90	0.47	Single
4	Concepción	1.70	0.38	Single
5	Temuco - P. las Casas	1.60	0.33	Single

Note (*): Thermal transmittance and glazing types based on Art. N° 4.1.10 in [8].

This starting point enabled grounding further analyses on current housing conditions, towards the evaluation of the potential effectiveness of introducing changes to current thermal conductivity levels.

Improvement Scenarios

After evaluation of energy demand for the different base-case scenarios, the second round of simulations focused on a number of modifications to the thermal performance capabilities of envelope materials (see Table 3).

Table 3. Housing improvement scenarios included in the evaluation

Scenarios	**Improvement *†**		
	U Roof [W/m²K]	**Window [glazing]**	**Infiltration [Ach]**
1	Base case	Single	3.0
2	Base case	Double	3.0
3	1.1	Single	3.0
4	1.1	Double	3.0
5	0.6	Single	3.0
6	0.6	Double	3.0
7	0.4	Single	3.0
8	0.4	Double	3.0
9	Base case	Single	1.0
10	Base case	Double	1.0
11	1.1	Single	1.0
12	1.1	Double	1.0
13	0.6	Single	1.0
14	0.6	Double	1.0
15	0.4	Single	1.0
16	0.4	Double	1.0

Note (*†): All the proposed improvements incorporate changes to the base-case scenario whose thermal performance conditions are defined by Art. N° 4.1.10 in [8].

2.3 Energy consumption

After evaluation of annual energy demand, the third step of the proposed strategy consists in the quantification of the consumption associated with different fuels according to their prevalence in the selected locations. This was done using official governmental datasets

[12] to identify the extent to which different heating artefacts are currently used across Chile (Table 4).

In parallel, the efficiency of different artefacts was defined using the following factors: LPG = 95%, NG = 95%, Kerosene = 95%, Electricity = 100%, Firewood = 40%, and Carbon = 95%.

2.4 CO_2 and PM2.5 emissions

Lastly, the fourth step of the proposed methodology consists in quantifying the potential reduction in greenhouse gases and particulate matter emissions associated with the housing improvements under evaluation. In this case, this was done using the conversion factors for caloric power, CO_2, and PM2.5 emissions summarised in Table 5.

Table 4. Usage of different fuels per city

City	Fuel **	Representativeness	
		%	N
Santiago	LPG	40.55%	191
	NG	1.49%	7
	Kerosene	29.94%	141
	Electricity	13.38%	63
	Firewood	12.31%	58
	Carbon	2.34%	11
Concepción	LPG	23.75%	38
	NG	4.38%	7
	Kerosene	16.25%	26
	Electricity	15.00%	24
	Firewood	40.00%	64
	Carbon	0.63%	1
Temuco – Padre las Casas	LPG	21.17%	47
	Kerosene	9.91%	22
	Electricity	5.41%	12
	Firewood	61.71%	137
	Carbon	1.80%	4

Note (**): Usage estimations based on [12].

Table 5. Caloric power, and CO_2 plus PM2.5 conversion factors

Fuel ††	**Caloric Power [KJ/kg]**	**Conversion Factor**	
		CO_2 [kg/kg]	**PM2.5**
LPG	50,628	3.19	0.00017 [kg/kg]
NG	39,084	2.89	121.6 [kg/10^6m3]
Kerosene	46,444	3.34	0.032 [kg/m3]
Firewood	12,490	1.64	8.27 [kg/ton]
Carbon	29,288	2.88	0.00112 [kg/kg]
Electricity	-	0.397 tCO2eq/MWh	

Note (††): All conversion factors for caloric power and CO_2 extracted from [13] and PM2.5 from [14], excepting Electricity [15].

3 Results and Discussion

Total CO_2 and PM2.5 estimations obtained after implementation of the proposed methodology are summarised in Figure 1. While in Santiago the base-case scenario (i.e., C01) was estimated to contribute an annual share of 159,174 and 304 tonnes of CO_2 and PM2.5 respectively, the best improvement alternative (their combination, i.e., C16) resulted in a potential emissions reduction above 34.8% of this total. In the case of Concepción, estimated emissions of the base-case scenario were substantially lower with 34,957 tonnes of CO_2 and 135 tonnes of PM2.5 whereas the combination of all improvements resulted in a reduction of close to 50.0% of the total.

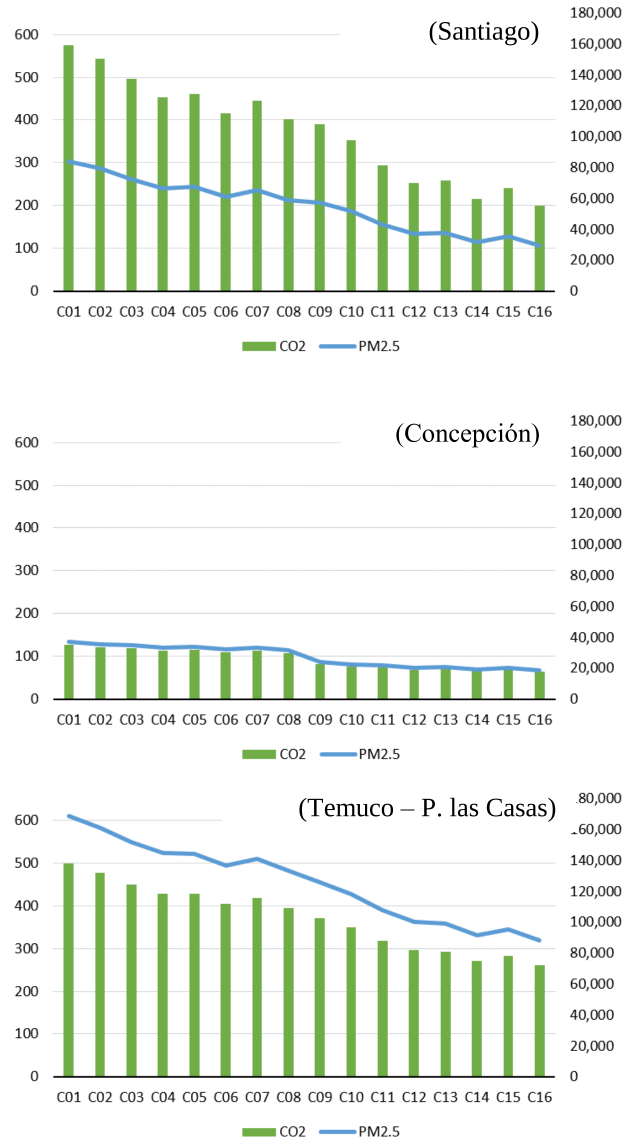

Figure 1. Estimations of CO_2 (right axis) and PM2.5 (left axis) emissions (tonnes) for different improvement alternatives in the cities under evaluation

Closer to the totals of Santiago, in Temuco – Padre las Casas the base-case scenario was estimated to result in 138,074 tonnes of CO2 while PM2.5 were substantially higher with

609 tonnes. The combination of all improvements resulted reduced above 52.3% of these pollutants.

These differences are a direct consequence of the amount of firewood used in southern Chile, suggesting that the introduction public policy focused on the reduction space heating may result in significant health benefits for this region [1, 2].

Other steps in the methodology are: a) determination of costs of improvements in the proposed construction systems, b) benefits due to social impacts on people's health and premature deaths, and c) economic and social evaluation in the life cycle of the building [10].

In previous studies considering this same methodology, for a 20-year horizon, the economic and social benefit for new homes built in a given year, reached the amount of US $ 1,140 million dollars. In this case, heating considered only 7 hours per day. In the case of Temuco, but for a heating period of 20 hours per day, this benefit reached US $ 88 million dollars [10].

4 Conclusions and Further Research

This paper presents a methodology to inform the definition of new thermal performance standards for Chilean residential buildings and illustrates its capabilities through its implementation in three major cities.

The proposed methodology consists of four main steps, i.e.:

(a) identification of representative housing types according to local conditions,
(b) simulation of their monthly energy demand before and after the introduction of thermal performance improvements,
(c) assessment of energy consumption in all cases based on local share of heating artefacts, and
(d) quantification of total CO_2 and PM2.5 emissions for each city.

This methodology was implemented in Santiago, Concepción and Temuco, three of the largest and most polluted cities of the central-southern area of Chile. The results of this implementation evidence significant differences among improvement alternatives and local conditions hence demonstrates the capabilities of this approach as a means to inform decision-makers in the development of evidence-based policy.
Further work is currently focused on the analysis of other highly polluted Chilean cities and on the incorporation of other energy-efficiency strategies, as well as on the socio-economic impacts of introducing measures to control hazardous emissions on the health of urban dwellers.

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J. Krope, A.Ghani Olabi, D. Goričanec & S. Božičnik

Carbon Footprint of Final Food Products

VIKTOR JEJCIC, FOUAD AL-MANSOUR & TOMAZ POJE

Abstract For successful control of energy use in agriculture and related GHG emissions, it is important to determine most important parts of food production chains with the biggest potential for lowering GHG emissions. For this reason, the carbon footprint of agricultural crops production by farm size and farm production methods (conventional, integrated and organic) has been determined. Carbon footprint of agricultural crops production and its processing present also the basics for the estimation of the carbon footprint of final food products (bakery products, vegetable oils, animal food, etc.). Carbon footprint of final food products includes emissions of GHG from the crop production (emissions from primary energy consumption, fertilizer use, etc.), internal and external transport, drying, storage and crops processing. Total emissions of final food products are presented as a sum of all emissions from crops production (with included internal transport, drying and storage) and a sum of emissions of crops processing in final products. Total emissions of final food products depend on the method of farm production (conventional, integrated, organic). Total emissions of final food products from the agricultural production of wheat and processing of it into bakery products are the lowest in conventional, followed by integrated and the highest in organic production.

Keywords: • carbon footprint • energy use • agricultural crops • final food products • GHG •

CORRESPONDENCE ADDRESS: Viktor Jejcic, Ph.D., Agricultural institute of Slovenia, Hacquetova ulica 17. 1000 Ljubljana, Slovenia; email: viktor.jejcic@kis.si. Fouad Al-Mansour, Ph.D., Jozef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia, e-mail: fouad.al-mansour@ijs.si. Tomaz Poje, Agricultural institute of Slovenia, Hacquetova ulica 17. 1000 Ljubljana, Slovenia; email: tomaz.poje@kis.si.

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1 Introduction

Using of large amounts of energy in agriculture has contributed to a typical increase in food production since the sixties of the last century in our country and abroad. Modern agriculture has become increasingly dependent on fossil fuels and causes large emissions of greenhouse gases. It is noted that since the beginning of the industrial revolution at the end of the 18th century, the concentration of CO_2 in the atmosphere varied from 280 ppm up to a higher value, in the year 2015 it has already reached 400 ppm and is currently the highest in the last 800.000 years. The increase in concentration was caused by human activities, primarily the burning of fossil fuels and deforestation. It is of concern that the concentration of CO_2 in the atmosphere is increasing 2 ppm/year. From the pollutants discharged into the atmosphere in the combustion of mineral fossil fuels, the most environmentally harmful are: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), PM, and so on. The combustion of mineral diesel fuel in engines of tractors or other farm machines in various working operations of mechanized agricultural production emits greenhouse gases expressed in the unit kilogram of carbon dioxide - equivalent (kg CO_2 eq.). In the agricultural production in mechanized working operations, the use of mineral diesel fuel is predominant, for this reason greenhouse gases emissions from this source are the highest.

1.1 Energy use for agricultural product

The dominant share of direct energy use on U.S. farms is fuel (including diesel and gasoline) to run machinery for field operations such as planting, tilling and harvesting; to dry crops; for livestock use; and to transport goods, Beckman, J. et al [1]. Direct energy uses on farms with crops production in EU is dominantly depending on fossil fuels, Al Mansour et al [2]. The use of energy is defined as fossil energy measured in MJ. Energy use is defined as the net energy used in the production of agricultural products until they are sold and leave the farm or used as feed in livestock, Dalgaard et al [3]. The use of energy can be divided in direct energy and indirect energy used in the production of agricultural products. Direct energy (EU_{direct}) represents the energy input in agricultural production, which can be directly converted into energy units (mineral diesel fuel, lubricants, energy from LPG or CNG for additional drying, electricity for postharvest processing, etc.). Indirect energy ($EU_{indirect}$) is the energy that is consumed in the production of inputs used in the production of agricultural products, but these entries cannot be directly converted to energy units (machinery, fertilizers, pesticides, etc.). Total energy for the production of agricultural products can be represented by the equation (1).

$$EU_{crops} = EU_{direct} + EU_{indirect}$$

$$EU_{crops} = (EU_{diesel} + EU_{other}) + EU_{indirect} \qquad (1)$$

In the case of mechanized production, mineral diesel fuel is used for tractors with connected farm implements and self-propelled agricultural machinery, which means that EU_{direct} is combustion of the mentioned fuel in engines of farm machines.For calculation of total GHG emission generated in the combustion process of internal combustion engines, the CO_2 emissions and emissions from other GHG have to be determined, which cause the effect of greenhouse gases. This quantity is expressed in unit kilogram of carbon dioxide - equivalent (kg CO_2 eq.). Emissions of GHG from combustion of mineral diesel fuel are estimated at 3.18 kg CO_2 eq./kg or 2.67 CO_2 eq./l (Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting [4]. Different studies have reported, that the use of mineral diesel fuel for various agricultural operations require to consider the average values as measured values for fuel consumption (l/ha or kg/ha), it can be very variable due to different conditions in agricultural production (soil characteristics, machine type and settings, working speeds, harvest amount, plot size and form, etc.), Handler 2011 [5]; Dalgaard 2001 [3]; Jejčič et al. [6]. The most useful unit for fuel consumption in most of the farming field operations is consumption of fuel per hectare, since it enables the comparison between different farms and years (Jokiniemi, T. et al 2012) [7]. The aim of organic agriculture is to augment ecological processes that foster plant nutrition yet conserve soil and water resources. Organic systems eliminate agrochemicals and reduce other external inputs to improve the environment and farm economics (Pimentel, D. et al 2005) [8].

2 Method

2.1 Energy consumption in the production

Analysis of energy consumption in agricultural production was made for: grain maize, wheat, rapeseed and sunflower (in the paper the case of wheat is presented). In the energy analysis all intakes (direct energy) are broken, which is fully consumed in the production period. Inputs of energy over a longer period of production time (more than crops season) or indirect energy (for production of tractors and farm machines as well as energy for the production of mineral fertilizers, pesticides, etc.), were not taken into account. The energy consumption in a mechanized agricultural production is defined as the energy from mineral diesel fuel, to be used in the implementation of various mechanized working operations. The total energy consumed to produce a crop yield per area of one hectare was determined by adding the energy consumption of each energy input.

$$E_{prod} = E_{st} + E_f + E_p + E_h + E_{it} + E_d \qquad (2)$$

E_{prod} = total energy used for crop production (MJ)
E_{st} = energy for primary and secondary soil tillage
E_f = energy consumption for fertilizing
E_p = energy consumption for plant protection
E_h = energy consumption for harvesting
E_{it} = energy consumption for internal transportation of yield
E_d = energy consumption for additional drying crop

For production of crops, an analysis for conventional, integrated and organic production has been made. All three mentioned types of production typically have primary and secondary tillage, seeding, fertilization, care and crops protection, harvesting, internal transportation and additional drying of the crops. Energy consumption in the aforementioned production is determined in the course of working operations with the tractor implements (aggregate tractor + connected machine) for primary and secondary tillage, seeding, fertilization, care, plant protection, etc. Consumption of mineral diesel fuel in the working operations with the tractors aggregated with different implements and self-propelled farm machines at work (eg. harvesters) was measured.

Model calculations are made based on the average fuel consumptions of primary and secondary tillage, sowing, fertilising, plant protection, harvesting and transportation. In addition, energy consumption for harvesting and internal transport crops on the farm itself (transportation by tractors) was covered. Energy consumption in the conventional soil tillage is determined for the soil tillage with a plough. As an alternative to conventional soil tillage is direct sowing without soil treatment - no tillage or zero tillage. For the secondary soil tillage disc harrows or cultivators are used, in the second case, the use of PTO powered tractor implements (rotary harrows or rotary tillers). For sowing conventional seeding machines are used and for direct seeding, seeding machines which allow sowing in the stubble in the fields.

The use of mineral fertilizers is provided in conventional production. In the integrated production the use of mineral fertilizers and organic manure in a ratio of 80% of mineral and 20% of organic fertilizers is provided. For organic farming the use of organic fertilizers (manure or slurry) is provided. For fertilizer spreading, use of spreaders for mineral fertilizers and manure spreaders (integrated and organic farming) is provided. For organic farming the use spreaders for organic fertilizers (manure or slurry) is provided. For crops protection, pesticides that are used in conventional and integrated production (in the paper is valued only direct energy or energy for powering tractors with implements - sprayers for applying pesticides) are provided. In organic production, only plant protection products, which are permitted in the mentioned production, are provided. Replacement of herbicides is done with the usage of mechanical methods for weed control (tractor implements - special harrows for removing weeds). The quantities of fertilizers are calculated on the yields of particular crops. For crops yields SURS data (average for the last ten years) are used. In the organic farming lower crops yields are provided in comparison with conventional and integrated farm production of crops. In conventional, integrated and organic farming mainly the same working operations with mechanization are used, the difference is in the use of machinery for fertilizing and plant protection. The fuel consumption in organic production is slightly higher because the use of the machines for spreading of manure and slurry application is intended (both type of machines have greater energy consumption, compared to the machines for spreading of mineral fertilizers).

For the protection of crops in conventional and integrated production, the use of tractor field sprayers for the application of pesticides is intended. In the integrated production, pesticides in lower quantities are used in comparison with conventional production (also smaller number of passes tractors aggregated with field sprayers in comparison with conventional production). Moreover, use of pesticides is combined with mechanical weed control. In organic farming method, exclusively mechanical weed control with the tractor aggregated with special harrows for removing weeds is provided. For harvesting of wheat, maize, rapeseed and sunflower, combine harvesters are used. For transportation of the crops production the use of tractors with trailers is intended and for transportation after processing trucks are used. Crops that are harvested need processing with dryers (in order to prevent its failure and prolonged storage). The power consumption of dryers is provided for drying the crop on the farm itself or in larger dryers of companies that perform acquisition of agricultural products for processing. For additional drying of crops on the farm, the use of the tractor transport grain dryers is intended. In addition to additional drying on a farm in the small transport dryers for grains an analysis of the additional drying of the crops in large stationary dryers was also made, which are located in companies that are engaged in the purchase and processing of agricultural products. Agricultural crops in this case are stored over a longer period of time for the sale to end consumers or for additional processing into various end products (like mill processing industry, etc.).

2.2 Energy consumption in processing

Before further processing of stored crops in final products, cleaning of crops to remove impurities that have occurred in the process of harvesting, must be carried out, during internal and external transport and intermediate storage. Removing impurities ensures the quality of the final product by reducing the impurities content and other factors that affect the smell and taste. Systems for treatment of cereal kernels and oil seeds, separating the impurities from the grain, are based on various physical properties of the grain, such as size, density, length, shape, colour and so on. In processing of wheat grains into flour for bakery products after grain cleaning, grinding process follows. The process used for the production of flour in mills is via gradual reduction of the particle sizes of the grains of wheat, maize, etc. Milling is followed by cleaning of flour on the different sizes of sieves to separate the small and light particles from the flour. From cleaned grain it can be produced a variety of other products such as flakes and grains for porridges. In all these stages electrically driven machines are used. The similar processes are also used for decentralized processing of grain cereals on farms. The difference is that farms are using a small capacity and simple machines, some stages are also not present on the farms, for example, enrichment of flour and by-products, more challenging packaging, etc.

2.3 Total energy for production and processing

The case of crops production and processing in final products is presented, wheat and oilseed production and processing in final products - bakery and vegetable oils (rapeseed and sunflower oils).

Total energy used in the production of wheat is added to the total energy used for processing wheat into final products. The sum of the two energies is the total energy used for the final product.

$$E_{finprod} = E_{cpro}d + E_{proc}\ (MJ) \tag{3}$$

$E_{finprod}$ = total energy of the final product - food
E_{cprod} = total energy used in wheat production
E_{proc} = total energy consumed in processing wheat into final product

$$E_{proc} = E_{cle} + E_{mf} + E_{fc} + E_{it} + E_{bp} \tag{4}$$

E_{proc}= total energy used in processing wheat grain into final products (MJ)
E_{cle} = energy for cleaning the wheat grain
E_{mf} = energy for milling wheat in flour
E_{fc} = energy for flour cleaning
E_{it} = energy for internal transport
E_{bp} = energy for baking bread or other bakery products

After completion of milling wheat grain into flour, temporary storage and transport flour to bakery for processing it into final bakery products follows.

3 Results

The calculation of the carbon footprint for agricultural final product is based on a calculation of the total greenhouse gas emissions – GHG, resulting from the production of crops (in our case wheat) on a defined field area, since the start of production until harvest, storage and submission to the final consumer or producer of final products. As the basic unit for calculating GHG emissions from production area of 1 ha of arable land was selected. The direct energy used (fossil fuel, electricity and other energy) for 1 ha of arable land is determined and the amount of the annual crops yield on it for production of crops and processing it in final products.

In the paper a method for calculation of carbon footprint of bakery products (bread and other bakery products) for different farm sizes (small, medium, large) for the production of wheat and for three production types (conventional, integrated and organic) is presented. Carbon footprint includes all greenhouse gases in the production of wheat and its processing into finished products (bread and bakery products).

Emissions of GHG are expressed in kg CO_2 eq./kg of the final product (emissions from the production of wheat are added to emissions from processing wheat in the milling and bakery products) and presented in table 1.

Table 1: Carbon footprint of final wheat products (bread and bakery products) for conventional, integrated and organic wheat production, for three sizes of farms (small, medium, large) and two types of seeding

Type of production	Emission [kg $CO_{2,eq.}$/kg final product]								
	Seeding in soil tilled in secondary tillage with rotary tillers			Seeding in soil tilled in secondary tillage with cultivators			Direct seeding in soil		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Conventional	1,307	1,301	1,295	1,303	1,298	1,293	1,283	1,279	1,275
Integrated	1,341	1,333	1,327	1,339	1,331	1,324	1,317	1,311	1,307
Organic	1,447	1,434	1,422	1,441	1,429	1,417	1,403	1,395	1,387

We estimated that emissions are lowering with the size of the farm, the method of the secondary soil tillage and type of sowing. The lowest emissions are in conventional production, followed by integrated and organic production.

4 Conclusions

Carbon footprint of final food products includes emissions of GHG from the crop production (emissions from primary energy consumption, fertilizer use, etc.), internal and external transport, drying, storage and crops processing. Total emissions of CO_2 eq./kg of final food products are presented as a sum of all emissions from crops production (with included internal transport, drying and storage) and a sum of emissions of crops processing in final products. We found that total emissions of CO_2 eq./kg of final food products depend on the type of production (conventional, integrated, organic). Total emissions CO_2 eq./kg of final food products from the agricultural production of wheat and processing of it into bakery products are the lowest in conventional production, followed by integrated and highest in organic production (emissions from wheat production are added emissions from processing wheat in flour and bakery products). Results showed that total emissions CO_2 eq./kg of final food product for wheat production and its processing in bakery products are declining also with the farm size.

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