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A Case Study for Environmental Impact Assessment in the Process Industry: Municipal Solid Waste Incineration (MSWI)

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Life Cycle Assessment (LCA) has been introduced in the evaluation of chemical processes and or products in order to take into account the Supply Chain and its environmental constraints and burdens. Regarding to the environmental assessment of chemical processes and/or products two main variables need to be taken into account: Natural Resources Sustainability (NRS) and Environmental Burdens Sustainability (EBS). NRS includes the use of energy, water and materials whereas EBS is given by the environmental sustainability metrics developed by the Institution of Chemical Engineers (IChemE). The main components of EBS have been classified in 5 environmental impacts to the atmosphere (acidification, global warming, human health effects, stratospheric ozone depletion and photochemical ozone formation), 5 aquatic media impacts (aquatic acidification, aquatic oxygen demand, ecotoxicity (metals), ecotoxicity (others) and eutrophication) and 2 land impacts (hazardous and non-hazardous waste disposal). To reduce the number of variables and thus, the complexity, the development of a normalisation and weighting procedure is required. This work proposes the normalization of EB based on the threshold values of the European Pollutant Release and Transfer Register (E-PRTR) and a similar procedure based on the values given by the BREF document on waste incineration for the NRS normalisation. This procedure will help in the decision making process in the waste management field and in the particular, in Municipal Solid Waste Incineration (MSWI).

1. Introduction

Life cycle Assessment (LCA) is a tool to assess the potential environmental impacts and resources used throughout a product´s life-cycle; i.e., from raw material acquisition, via production and use phases, to waste management (Finnveden et al., 2009). LCA has been introduced in the evaluation of chemical processes and or products in order to take into account the Supply Chain and its environmental constraints and burdens. This methodology should be applied using the ISO 14040 series (ISO, 2006), describing LCA as a four-phase process:

a) Goal and scope definition: The intended application of the study, system boundaries, functional unit and the level of detail to be considered are defined (Cavallet et al., 2012).
b) Life Cycle Inventory (LCI) analysis: It includes the data collection and modelling of the system.
c) Life Cycle Impact Assessment (LCIA): The inputs and outputs data are translated into an impact indicator results related to human health, natural environment, and resource depletion (EC JRC, 2010b). LCIA includes two mandatory steps and two optional stages:
   - Classification: It includes the selection of the impact categories and characterization models (so-called impact assessment methods) (Bare J.C., 2010). Figure 1 shows the classification of the impact categories into midpoints and endpoints (Rack et al., 2013) and Table 1 presents a summary of the main LCIA methods based on the data published by Rack et al. (2013) and IHOBE (2009).

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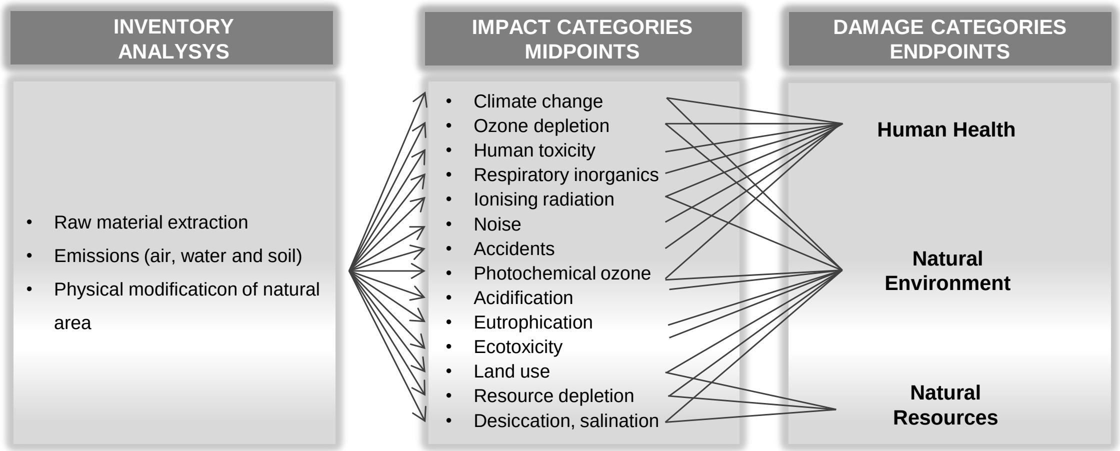

Figure 1: Framework of impact categories at midpoint and endpoint (Adapted from Rack et al., 2013).

Table 1: Review of the LCIA methods

Scope of application		Method	Impact assessment level	Creator	Reference
Asia	Japan	LIME	Combined	-Tokyo City University/ Kogakuin University	Itsubo and Inaba, 2012
	Singapore	Singapore IMPact ASSessment (SIMPASS)	Midpoint	-National University of Singapore/Institute of Chemical and Engineering Sciences of Singapore	Chan et al., 2012
Europe	Switzerland	IMPACT 2002+	Combined	-École polytechnique fédérale de Lausanne (EPFL)	Jollie et al., 2003
		Ecological Scarcity	Midpoint	-Swiss Ministry of Environment (BUWAL)	Frischknecht et al., 2006
	The Netherlands	ReCiPe	Combined	-Pré Consultans	Goedkoop et al., 2012
		Eco-Indicator 99	Endpoint	-Pré Consultans	Goedkoop et al., 2000
		CML 2001	Midpoint	-Centre of Environmental Sciences (CML)	Guinée et al., 2001
		LC-IMPACT	Combined	-Radboud University	LC-IMPACT, 2009
	Denmark	EDIP 2003	Midpoint	-Technical University of Denmark (DTU)	Hauschild and Potting, 2005
America	USA	TRACI	Midpoint	-Environmental Protection Agency (EPA)	Bare et al., 2003
	Canada	LUCAS	Midpoint	-CIRAIG	Toffoletto et al., 2007
Global		IMPACT World+	Combined	-CIRAIG/DTU/Quantis International/University of Michigan /EPFL/Cycleco	IMPACT World+, 2012

- Characterisation: The impact of each emission or resource consumption is modelled quantitatively using a characterisation factor. That factor expresses how much that flow contributes to the impact category indicator (EC JCR, 2010b).
- Normalisation (optional): It related the magnitude of impacts in different impact categories to reference values (Bare, 2011). The characterised impact scores are associated with a common

reference, facilitating comparisons across impact categories (EC JCR, 2010a).

- Weighting (optional): The different environmental impact categories are ranked according to their relative importance. Weighting may be necessary when trade-off situations occur in LCAs which are being used for comparing alternative products (EC JCR, 2010a).

d) Interpretation: The LCI and LCIA results are analysed giving the conclusions and recommendations of the study.

Most LCA studies apply impact methods which comprise several impact categories. The study of different processes by means of group of several impact categories makes difficult the process compassion. To reduce the complexity, this work proposes a LCIA methodology based on the Natural Resources Sustainability (NRS) and the Environmental Burdens Sustainability (EBS) (Irabien et al., 2009). Natural Resources (NR) include the use of primary resources energy, water and materials while Environmental Burdens (EB) is given by the environmental sustainability metrics developed by the Institution of Chemical Engineers (IChemE, 2002). However, as NR and EB are rarely normalized a normalization procedure is proposed. The normalization of EB is based on the threshold values of the European Pollutant Release and Transfer Register E-PRTR (E-PRTR Regulation, 2006) and a similar procedure based on the values given by the BREF document on waste incineration (European Commission, 2006) for the NRS normalization. This procedure will help in the decision making process in the waste management field and in the particular, in the waste incineration process.

2. Application of LCA to the waste management sector

LCA of a waste management system is divided in the same stages (from cradle to grave) that the LCA of a product. The main difference resides in what it is meant by cradle and grave. Whilst they share the same grave, they do not share the same cradle (Fullana and Puig, 1997). LCA methodology has been used to evaluate several types of wastes, such as the management of contaminated dredged sediments (Puccini et al., 2013), sewage sludge (Aranda-Usón et al., 2012), or fly ash from a coal burning power industry (Ondova et al., 2013). However, most of LCAs are focused in the study of Municipal Solid Waste (MSW). Evidence of that are the studies conducted to assess solid waste management systems in China (Zhao et al., 2011), compare different waste treatment options such as incineration and landfill (Hong et al., 2010) and evaluate the environmental feasibility of extending the selective collection of MSW in small villages of Spain (Margallo et al., 2010). Regarding to waste treatment, recently the study of the incineration process has taken off. The aim of these works was to assess the environmental performance of waste incinerators (Scipioni et al., 2009), compare different incineration technologies (Chen and Christensen, 2010), flue gas cleaning processes (Moller et al., 2011), management options of waste from incineration processes (Margallo et al., 2013), and different energy recovery strategies (Guigliano et al., 2008). Although all these studies use the LCA methodology, different impact assessment methods, summarized in Table 2, are applied.

3. Methodology

The LCI methodology includes the 4 steps included in the ISO 14040 (ISO, 2006): classification, characterisation, normalization and weighting.

3.1 Classification and Characterisation

The methodology consider the impact in the environment due to the use (depletion/exhaustion) of natural resources (NR) and the release of pollutants to the environmental compartments, air, water and soil (EB). In this way, NR includes the consumption of resources such as energy, materials and water for the considered process and/or product, so it can be describe by a NR index X_1. On the other side, EB includes

Table 2: Impact methods applied in waste management LCAs

LCIA method	Waste management studies
CML 2001	• Margallo et al., 2013 • Guigliano et al., 2008
EDIP 1997	• Moller et al., 2011 • Zhao et al, 2011 • Chen and Christensen 2010
ReCiPe	• Puccini et al., 2013 • Aranda-Usón et al., 2012
IMPACT 2002+	• Hong et al., 2010
Eco-Indicator 99	• Scipioni et al., 2009

Table 3: Natural Resources variables (X_1)

NR	Variable	Units	Description
Energy	$X_{1,1}$	MJ/t product	Total primary energy involved in the process (imports and exports)
Materials	$X_{1,2}$	kg/t product	The total raw materials involved in the production. Fuel and water are excluded from this variable
Water	$X_{1,3}$	m^2/t product	the modified and occupied land for the process

Table 4: Environmental Burdens variables (X_2)

EB	Variable	Environmental Impact	Units
Air EB ($X_{2,1}$)	$X_{2,1,1}$	Atmospheric Acidification (AA)	kg SO_2 eq.
	$X_{2,1,2}$	Global Warming (GW)	kg CO_2 eq.
	$X_{2,1,3}$	Human Health (HHE)	kg benzene eq.
	$X_{2,1,4}$	Photochemical Ozone Formation (POF)	kg ethylene eq.
	$X_{2,1,5}$	Stratospheric Ozone Depletion (SOF)	kg CFC-11 eq.
Water ($X_{2,2}$)	$X_{2,2,1}$	Aquatic Oxygen Demand (AOD)	kg O_2 eq.
	$X_{2,2,2}$	Aquatic Acidification (Aq. A)	kg H^+ eq.
	$X_{2,2,3,1}$	Ecotoxicity to Aquatic Life (metals) (MEco)	kg Cu eq.
	$X_{2,2,3,2}$	Ecotoxicity to Aquatic Life (others) (NMEco)	kg formaldehyde eq.
	$X_{2,2,4}$	Eutrophication (Eutroph)	kg phosphate eq.
Soil ($X_{2,3}$)	$X_{2,3,1}$	Hazardous waste (HWD)	t/y
	$X_{2,3,2}$	Non-hazardous (NHW)	t/y

the main impacts to the air, water and soil. According to the suggested procedure four variables can describe NRS (Table 3) (Dominguez-Ramos et al., 2013). On the other hand, as displays Table 4 the EB (X_2) considers a total of twelve variables grouped into the release to each environmental compartment. The EBS is based on the based on the sustainability metrics developed by the Institution of Chemical Engineers (ICheme, 2002) that give a balanced view of the environmental impacts of inputs and outputs (Garcia et al., 2013).

3.2 Normalization and Weighting procedure

Table 5 displays the EB normalization procedure that was developed taking into account the threshold values of the European Pollutants Release and Transfer-Register (EPRT-R) (EPRTR Regulation, 2006).
The E-PRTR Regulation includes specific information on releases of pollutants to air, water and land and off-site transfers of waste and of pollutants in wastewater. Those data have to be reported by operators of facilities carrying out specific activities. Annex II of the E-PRTR Regulation lists the 91 pollutants that are relevant for reporting and specifies an annual threshold value of each pollutant for releases to each relevant medium (air, water, land). On the other hand, the normalization of variables for NRS ($X_{2,i}$) is carry

Table 5: Normalisation procedure (Irabien et al., 2009)

EB	Environmental Impact	Threshold value (kg/year)	Nº substances
Air EB ($X_{1,1}$)	AA ($X_{2,1,1}$)	150,000	6
	GW ($X_{2,1,2}$)	100,000,000	23
	HHE ($X_{2,1,3}$)	1,000	52
	POF ($X_{2,1,4}$)	1,000	60
	SOD ($X_{2,1,5}$)	1	100
Water EB ($X_{1,2}$)	AOD ($X_{2,2,1}$)	50,000	4
	Aq. A ($X_{2,2,2}$)	100	14
	MEco ($X_{2,2,3}$),$_1$	50	11
	NMEco ($X_{2,2,3,2}$)	50	18
	Eutroph ($X_{2,2,4}$)	5,000	8
Soil EB ($X_{1,3}$)	HW ($X_{2,3,1}$)	2,000	H1…H14
	NHW ($X_{2,3,2}$)	2,000,000	

out using the references available from BREF document on waste incineration (European Commission, 2006). Consequently, the two functions, NR and EB, are converted into variables that can be compared. Finally, to reduce the complexity and to help in the decision making process, the 10 environmental impacts to air and water are reduced by means of weighting factors to two variables: EB to air and EB to water (Dominguez-Ramos et al., 2013).

4. Conclusions

The results of a LCA study are a group of environmental impacts that gives a balanced view of the environmental performance of the process or product under study. However, in some cases, the interpretation of these results is harder, requiring a complexity reduction by means of normalization and weighting methods. This paper aims to help in the decision making process in the waste incineration field proposing a normalization and weighting procedure. In particular, the methodology is based on the use of the threshold values of the E-PRTR and BREF document on waste incineration.

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