Chapter

Suggestion of Life Cycle Impact Assessment Methodology: Selection Criteria for Environmental Impact Categories

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Abstract

In life cycle assessment (LCA), environmental impacts are classified according to the methodology used. Several life cycle impact assessment (LCIA) methods are currently used, and the method selected and the particulars thereof may influence the results obtained. This study characterized the main LCIA methods used and the most relevant categories of environmental impact. In total, 87 articles were initially retrieved using relevant keywords. After screening, 11 articles were shown to address the topic of study and were reviewed. The results showed that CML is the most widely used method. The main environmental impact category was global warming potential followed by acidification. Studies using LCA depend on the confirmation of the efficacy of the methods in the effort to represent and assess impacts in different regions of the world.

Keywords: LCA, LCIA methodologies, environmental impacts, global warming potential, acidification

1. Introduction

Life cycle assessment (LCA) is an essential tool in the characterization of environmental risks in the different stages of a product's life cycle [1]. Research on LCA is a source of important information in management and decision-making strategies designed to improve environmental practices and execute technological adjustments or transformations in organizations [2].

With the use of LCA on the increase, the biofuel sector is the object of considerable research publications, followed by energy generation and agriculture [3]. In addition, LCA is the foundation of studies that assess environmental impacts in several production chains such as the steel industry [4], construction [1, 2], steel recycling processes [4], and urban solid waste management [5, 6].

Standardized by the International Organization for Standardization (ISO) as ISO 14.040, the execution of an LCA is divided into four stages, namely the *definition of goal and scope*, *inventory analysis*, *impact assessment,* and *interpretation of results* [7].

In LCA studies, environmental impact is classified according to the methodology used to assess it. The methods used for life cycle impact assessment (LCIA) establish the relationship between each stage of the life cycle inventory and the corresponding environmental impacts [8]. Several LCIA methods based on software and inventory databases have been developed. Notably, the variety and the specific aspects of these methods may affect the end results of LCA [9]. Moreover, it is important to understand the implications of LCA studies from a broader, more inclusive perspective that considers not only the environment but also human health, since important factors may be overlooked if an all-encompassing, holistic approach to environmental impact is not carried out [10]. For this reason, LCA studies require the evaluation of the LCIA method that best characterizes the potential environmental impacts in a given process considering the scope and hypotheses guiding the conduction of study.

The objective of this study was to identify the key LCIA methods used today and characterize the main categories of environmental impact assessed using these methods.

This chapter is structured so as to initially characterize the obstacles and difficulties faced when classifying the environmental impacts central to the conduction of LCA. Next, we carried out a literature review using specific keywords currently used to define the main criteria and the most important categories of environmental impact. Early research already warned of the implications of not including all relevant categories of environmental impact in LCA when comparing the impacts of recycling paper solid waste and incinerating it [11].

2. Methods

Prior to the literature review carried out, we first discussed cases of environmental impact that indicated the importance of a diagnostic evaluation of the selection of all impact categories used in decision-making.

This study was carried out searching the Journals Portal of University Professor Improvement Bureau (CAPES), which includes more than 250 databases of theses, journals, and books. Some of the databases included are SCIELO, Science Direct (Elsevier), and Scopus (Elsevier). The search was carried out in November 2018, and the keywords used were *industrial solid waste* and LCA. Initially, the keywords retrieved 87 publications issued from 1993 to 2018. Subsequently, the articles were screened so as to include only the publications addressing the study topic, namely the use of LCA to investigate solid waste from industrial processes. Some of the articles included were noteworthy literature reviews on the use of LCA [12, 13]. Waste management assessments carried out using other methodologies were excluded from the present report [14, 15]. Similarly, studies that used advanced environmental tools like material flow analysis (MFA) [16, 17], circular economy [18], and industrial symbiosis [19] but did not employ LCA were also disregarded.

The inclusion criteria adopted concern the third stage of LCA studies, namely LCIA. Software, the LCIA method, and the categories of environmental impacts used in these publications were considered. If a study presented assessments of more than one category such as midpoint and endpoint categories like global warming potential and climate change, for example, it was still considered one publication only. The impact categories considered had to be addressed in more than one single publication. However, studies that have produced significant findings were mentioned in the assessment. Later, evidence explaining the selection of environmental impact categories assessed in each study was analyzed.

3. Criteria used to select life cycle impact categories

The use of a LCIA is justified considering the effort to generate a priority matrix that may be used to define the most relevant impact categories in LCA studies. This matrix would be helpful in the characterization of the impact categories that should be considered in each LCA based on specific criteria and score systems.

The criteria to be defined should take into account the importance of each impact in each case studied. Therefore, criteria like *type of process* (that is, the environmental impacts that are more important in a given process and the most affected compartments) and *region* (the scarcest or most susceptible natural resources in a determined area, for example) become important factors to be considered in the definition of the priority matrix. Other important requisites include spatial coverage, duration, reversibility, probability of occurrence, harm to human health, harm to ecosystems, exhaustion of resources, and treatment alternatives [20].

Therefore, based on these criteria, the priority matrix may be helpful in the definition of the most appropriate impact categories to be considered in a given LCA study. It is also important to evaluate the metric that most accurately and realistically represents the categories defined.

For example, the contaminants generated by a given industrial activity are a function of the associated production processes [21]. A metalworking company carries out processes like purification, surface treatments, and quenching. For this reason, such a company would generate by-products like

- foundry sand waste
- cured resin waste
- polymer paint bottoms
- boiler ashes and soot
- quenching salt waste
- galvanizing bath dregs
- metal scrap in general

More specifically, metal processing may generate waste items like metal scrap and sand casting scrap that in turn release phenols, cyanides, mineral oil, and heavy metals. In turn, surface treatments and quenching operations are sources of antimony, arsenic, petroleum ether, benzene, lead, cadmium, chromium, cyanides, copper, mineral oil, nickel, mercury, acids, bases, selenium, and zinc. Investigation on these contamination hazards is an important source of data on the major environmental impact categories in LCA of products manufactured using such processes.

Concerning the situation of a given region in order to assess how its environmental compartments behave and how degraded the region is, the Rio Grande harbor, in southern Brazil, provides a good example. According to Fundação Estadual de Proteção Ambiental Henrique Luiz Roessler (FEPAM), the local environmental authority that records incidents with hazardous materials (http://www.fepam.rs.gov.br/emergencia/rel_acidentes.asp), the accident with the cargo ship Bahamas in 1998 was the first major event in Rio Grande harbor. This ship was transporting concentrated sulfuric acid when it was moored to canal in Rio Grande harbor.

Due to operational problems, sea water leaked into the tanks, diluting the acid in a strongly exothermic process in view of the large cargo (approximately 12,000 t) and considerable volume of water that leaked into the ship [22]. The risk of explosion was significant. The alternative found was to control the release of the sulfuric acid into the canal of the Rio Grande harbor. Fortunately, the canal waters were discharging into the ocean, leading the contaminant to flow away from the harbor area. It should be emphasized that if the waters were flowing into the canal, then the acid would have remained in the harbor area, spreading to Patos Lake and triggering a large-scale environmental disaster due to the ecological susceptibility of the region [22]. From the chemical standpoint, the dilution of sulfuric acid releases high levels of hydroxonium (H_3O^+), sulfate (SO_4^{2-}), and bisulfate (HSO_4^-) ions. Considering that the density of sulfuric acid is higher than that of sea water and that the pH varied from 8 to 3 during the incident (returning to 8 subsequently), it may be hypothesized that solubilized metal ions were stabilized in the aqueous medium by conversion to insoluble sulfate or bisulfate species [22]. This induced the sedimentation of these materials on the floor of the canal.

Three minor accidents took place in the Rio Grande harbor in the past 20 years. Two of these events involved fuel oil and one involved bunker fuel, in 2001 and 2004, respectively. However, since these fluids are poorly soluble and less dense than water, the contamination of the canal floor could be ruled out.

But a lead acetate spill was recorded in the container park of the harbor in July 2001. Different from the accidents with oil, lead acetate was being transported in the solid state. Due to the high solubility in water and high density compared with sea water, the compound posed a high risk of contamination of the canal floor. Though lead acetate is a low-hydrolysis rate organic salt formed from a weak acid, the compound is toxic and the possibility that hydrolysis takes place indicates that Pb^{2+} ions might have reacted with the ions in solution in the waters of the canal of Rio Grande harbor.

In view of that, the record of incidents in the Rio Grande harbor clearly indicates the categories of environmental impacts that are essential to be considered in LCA studies in the region—or in any other harbor zone. These events signal that the activities carried out in a harbor may have high environmental impact hazard.

Considering the prerequisites discussed in previous research [20] and the criteria defined above, which are represented in detail in the accidents described, the present study indicates the need for a priority matrix that addresses these prerequisites. The objective is to provide a decision-making tool in the definition of the main life cycle impact categories to be considered in an LCA.

4. Life cycle impact assessment (LCIA) methods

Of the 87 studies initially retrieved, 11 met the objectives of this review and were appraised. The studies included in this investigation were about LCA of industrial waste like copper tailings [23], management of hazardous industrial waste [24], steel recycling processes [4], solid urban waste management [5, 6], and cement industry [1, 2, 25, 26]. **Table 1** shows the case studies and the environmental impact categories assessed.

It is possible to observe that the LCIA method called CML was the most applied in research, being used in three articles carried out in Turkey, China, and Arabia [1, 5, 6]. The Eco-Indicator 99 method [23] and the Impact2002+ method [2] were also used. Other studies used the software tool developed by IKE Environmental Technology Co. Ltd., the eBalance package, which defines 16 midpoint categories of LCA [26, 27].

Study	Region	Functional unit	Software	LCIA	Impact categories								
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Chen et al. [4]	China	1 kg steel (raw state)	SIMAPRO 7	IPCC 2007	x								
Morris [28]	USA	Solid waste management	BEES 3.0	—	x	x	x						
Song et al. [23]	China	1 t copper	GaBi 4	Eco-Indicator 99	x	x			x		x		x
Al-maaded et al. [6]	Arabia	10 kg plastic waste	GaBi 4	CML 2001	x	x		x		x			
Banar et al. [29]	Turkey	1 t urban solid waste	SIMAPRO 7	CML 2000	x	x	x	x		x		x	
Song et al. [1]	China	1 t Portland cement	NI	CML 2001	x	x	x	x	x	x	x	x	
Yang et al. [2]	China	1 t cement of different resistance values	NI	IMPACT2002+	x	x	x		x				x
Shen et al. [25]	China	Portland cement	Not used	—	x								
Changzai et al. [26]	China	1 t SAC clinker production	IKE Environmental Technology Co. Ltd	eBalance	x	x	x			x			x
Hong et al. [24]	China	1 t of mixed industrial hazardous waste	NI	ReCiPe and USEtox™	x	x	x				x	x	
Wang et al. [16]	China	1 t of coal and 1 MWh power	IKE Environmental Technology Co. Ltd	eBalance	x	x	x						

1: Global warming potential; 2: acidification potential; 3: eutrophication potential; 4: human toxicity potential; 5: ecotoxicity potential; 6: abiotic depletion potential; 7: ozone depletion potential; 8: photochemical oxidation potential; 9: respiratory toxicity potential (inorganic).

Table 1.
Case studies selected and their relationships with environmental impact categories.

The use of the LCIA method is explained based on how a method is applied in LCA studies [2, 23]. However, some studies provide no explanation about the decision concerning the LCIA method selected. The use of a given method based on technical criteria was not reported in any study reviewed.

In LCA studies, environmental impacts are classified into categories based on the methodology used to assess the impact. The selection of categories of environmental impacts to systematically understand the aspects involved in each process is highly important at this stage, since the paucity of information may affect all decision levels.

The results of this review show that the main categories of environmental impacts taken into account in LCIA studies were *global warming potential* and *acidification potential*, which were used in 11 and 9 studies, respectively. *Ecotoxicity* was a category assessed in three studies.

More specifically, the four LCA studies that addressed cement as the only product were carried out in China using different methods. Only one category was assessed in the four studies, namely *global warming potential*. The categories *acidification potential*, *eutrophication potential*, and *ecotoxicity* were evaluated in two studies [1, 2]. The fact that these categories were evaluated does not mean that they were relevant in the respective studies. In the studies that assessed industrial waste and processes, the main categories used were *global warming potential* followed by *acidification potential* and *eutrophication potential.*

Previous research carried out an environmental evaluation of a typical Portland cement production line in China and compared the environmental impacts observed with the best available technologies with effects of the replacement of raw materials and of calcination fuels [1]. The functional unit defined was the production of 1 ton of Portland cement. The data were collected in a company operating in northern China and compiled as a database. The environmental impact categories were assessed using the CML 2001 method. The environmental impacts assessed were normalized. It was possible to observe that the category *global warming potential* is more severe compared with the other categories, followed by *acidification potential* and *photochemical oxidation*. The authors observed that the most efficient way to reduce greenhouse gas emissions in Portland cement production in China includes the study of alternative raw materials and fuels, especially due to the effects of calcination and coal consumption. These results were similar to the findings published in previous research [2], which found that the use of alternative materials like industrial waste and by-products is an efficient way to reduce environmental and economic impact generated in cement production.

The environmental performance of cements produced to yield various resistance levels has been compared [2]. The functional unit chosen was the production of 1 ton of cement. Mean annual production data of cement types were obtained from a research carried out by the China United Cement Corporation. Energy, coal, and shipping data were obtained from the literature. The LCIA method used was Impact 2002+. The environmental impacts were calculated based on midpoint and endpoint categories and were normalized. Based on an LCA, the authors concluded that the cement produced to yield high resistance caused the highest environmental impacts compared with lower resistance cements. The results showed that the categories that most contributed to global environmental impacts are *global warming potential*, *respiratory toxicity potential*, *non-renewable energy consumption*, and *terrestrial acidification/eutrophication*. Therefore, two categories were significant in these studies, namely *global warming potential* and *acidification potential.*

Also, CO_2 emissions by the cement industry in China were quantified using an LCA [25]. Although these authors did not use a specific software, the calculations were carried out based on the necessary equations.

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In another study, environmental impacts of the production of sulfoaluminate clinker using industrial solid waste were compared to the results obtained with the conventional method [26]. The results showed that industrial solid waste may significantly reduce the environmental load of the process due to the lower consumption of natural resources and greenhouse gas emissions. The production of sulfoaluminate clinker using industrial waste may reduce the total environmental impact by 38.62% compared with the conventional process.

It has been maintained that most studies about cement production considered only CO_2 emissions and ignored the other environmental impacts [2]. It is observed that this is the case of several LCA studies not only about cement production, but also about other processes. The category *global warming potential* was considered in all studies, which explains the concern of industrial sectors to reduce greenhouse gas emissions.

Another study assessed the generation of energy from coal in China considering the steps of the mining life cycle and the washing and shipping of coal [27]. The authors observed that the main environmental impact category was *smoke and dust*, which is associated with the emission of total suspended particles.

However, it is important to consider all environmental impacts associated with LCA, in view of the relevance of the results of assessments to all decision-making levels. Therefore, it is essential to consider the specific aspects of the regions where a LCA is conducted and identify the relevance of the likely environmental impacts and aspects involved locally.

In addition, decision-makers have to consider a full LCIA, taking into account the associated economic and environmental impacts [4].

The lack of a holistic assessment of environmental impacts was observed in LCA carried out today based on a critical evaluation of LCA studies about concrete [10]. The author reports that LCA studies about concrete published in the literature are based on the use of energy and greenhouse gas emissions, despite the importance of questions like volatile organic compounds, heavy metals, and other toxic emissions involved in the production of concrete components.

5. Final considerations

Based on the rationale presented to determine the selection criteria and the survey carried out about LCA studies on industrial solid waste, it is observed that there is a long way ahead in the definition of a methodology to establish the life cycle environmental impacts that best fit each study in particular. Therefore, it is important to evaluate the methods that include the set of priorities established for the definition of the categories of impact that are of relevance in LCA studies. The priority matrix should include items such as type of activity and overall regional characteristics [20].

6. Conclusions

The objective of this chapter was to evaluate the use of different methods to define the most representative categories of environmental impact in LCA of industrial solid waste. Although initially 87 studies were selected, no study on LCA was carried out using a method that actually helped identify these categories. However, the categories *global warming* prevailed in research, followed by *acidification potential* and *eutrophication potential*.

This chapter also aimed at demonstrating the importance of assessing processes and respective downcycling and upcycling by-products as well as the most frequent pollutants, as in the example of the metalworking organization discussed. The importance of considering the physicochemical characteristics and behavior of compartments like water, air, and soil in the region where an impact occurs is highlighted. It is essential to evaluate the region considering its record of environmental accidents that affect its vulnerability to a given impact category. As opposed to what was observed in this literature review, these peculiarities should not be overlooked, meaning that specific aspects have to be considered in the search for critical points in LCA studies.

In view of that, the present literature review warns of the need to use appropriate LCA methods that consider the factor cited and address spatial area, duration of impact, reversibility, probability of occurring, human health hazards, harm to ecosystems, resource exhaustion, and treatment alternatives. Therefore, research on LCA requires a clearly developed approach to select impact categories that are more relevant in the establishment of environmental critical points, which is one of the objectives of LCA. These considerations form the foundation for a modernized production chain based on sustainable development under research, where LCA is the main tool in decision-making.

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References

[1] Song D, Yang J, Chen B, Hayat T, Alsaedi A. Life cycle environmental impact analysis of a typical cement production chain. Applied Energy. 2016;**164**:916-923

[2] Yang D, Fan L, Shi F, Qian L, Wang Y. Comparative study of cement manufacturing with different strength grades using the coupled LCA and partial LCC methods—A case study in China. Resources Conservation and Recycling. 2017;**119**:60-68

[3] Zanghelini GM, Souza HRA Jr, Cherubini E, Kulay L, Soares SR. Análise da evolução dos temas de pesquisa da ACV no Brasil baseada na relação de co-words. Revista Latino-Americana em Avaliação do Ciclo de Vida. 2016. pp. 34-47

[4] Chen B, Yang J, Ouyang Z. Life cycle assessment of internal recycling options of steel slag in Chinese iron and steel industry. Journal of Iron and Steel Research. 2011;**18**(7):33-40

[5] Banar M, Cokaygil Z, Ozkan A. Life cycle assessment of solid waste management options for Eskisehir Turkey. Waste Management. 2009;**20**:54-62

[6] Al-Maaded M, Madi NK, Kahraman R, Hodzic A, Ozerkan NG. An overview of solid waste management and plastic recycling in Qatar. Journal of Polymers and the Environment. 2012;**20**:186-194

[7] Associação Brasileira de Normas Técnicas (ABNT). NBR ISO 14040: Gestão Ambiental: Avaliação do ciclo de vida: Princípios e estrutura. Rio de Janeiro: ABNT; 2009

[8] Jolliet O, Margni M, Charles R, Rosenbaum RK. IMPACT 2002+ A new life cycle assessment methodology. The International Journal of Life Cycle Assessment. 2003;**8**(6):324-330

[9] Mendes NC. Métodos e modelos de caracterização para a Avaliação de Impacto do Ciclo de Vida: análise e subsídios para a aplicação no Brasil. Dissertation. São Paulo: Universidade de São Paulo; ano

[10] Gursel AP, Maryman H, Ostertag C. A life-cycle approach to environmental mechanical and durability properties of "green" concrete mixes with rice husk ash. Journal of Cleaner Production. 2016;**112**:823-836

[11] Finnveden G, Ekvall T. Life-cycle assessment as a decision-support tool—The case of recycling versus incineration of paper. Resources Conservation and Recycling. 1998;**24**:235-256

[12] Othman SN, Noor ZZ, Abba AH, Yusuf RO. Review on life cycle assessment of integrated solid waste management in some Asian countries. Journal of Cleaner Production. 2013;**41**:251-262. DOI: 10.1016/j.jclepro.2012.09.043

[13] Cleary J. Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. Environment International. 2009;**35**:1256-1266. DOI: 10.1016/j.envint.2009.07.009

[14] Usapein P, Chavalparit O. Development of sustainable waste management toward zero landfill waste for the petrochemical industry in Thailand using a comprehensive 3R methodology: A case study. Waste Management & Research. 2014;**32**:509-518. DOI: 10.1177/0734242X14533604

[15] Coelho LMG, Lange LC, Coleho HMG. Multi-criteria decision making to support waste management: A critical review of current practices and methods. Waste Management

& Research. 2017;**35**:3-28. DOI: 10.1177/0734242X16664024

[16] Wang W, Jiang D, Chen D, Chen Z, Zhou W, Zhu B. A material flow analysis (MFA)-based potential analysis of ecoefficiency indicators of China's cement and cement-based materials Industry. Journal of Cleaner Production. 2016;**112**:787-796. DOI: 10.1016/j.jclepro.2015.06.103

[17] Vahidi H, Hoveidi H, Khoie JK, Nematollahi H, Heydari R. Analyzing material flow in Alborz industrial estate Ghazvin Iran. Journal of Material Cycles Waste Management. 2018;**20**:450-460. DOI: 10.1007/s10163-017-0601-9

[18] Veleva V, Bodkin G. Corporate-entrepreneur collaborations to advance a circular economy. Journal of Cleaner Production. 2018;**188**:20-37. DOI: 10.1016/j.jclepro.2018.03.196

[19] Sun L, Li H, Dong L, Fang K, Ren JH, Geng Y, et al. Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city China. Resources Conservation and Recycling. 2017;**119**:78-88. DOI: 10.1016/j.resconrec.2016.06.007

[20] Zanghelini GM. Ponderação de categorias de impacto ambiental através de análise de decisão multicritério [thesis]. Florianópolis: Universidade Federal de Santa Catarina; 2018

[21] Schianetz B. Passivos Ambientais–Levantamento Histórico Avaliação da Periculosidade e Ações de Recuperação. SENAI: Curitiba; 1999. 200p

[22] Pereira RS, Niencheski LFH, Vitola MA, Pinto WT. Simulação computacional do acidente com o navio tanque Bahamas no porto de Rio Grande. In: Seminário e Workshop em Engenharia Oceânica. 2004; Rio Grande. Ed. da FURG 2004. p. 17

[23] Song X, Yan J, Lu B, Li B. Exploring the life cycle management of industrial solid waste in the case of copper slag. Waste Management & Research. 2013;**31**(6):625-633

[24] Hong J, Han X, Chen Y, Wang M, Ye K, Qi Cm Ki X. Life cycle environmental assessment of industrial hazardous waste incineration and landfilling in China. Journal of Life Cycle Assessment. 2017;**22**:1054-1064

[25] Shen W, Cao L, Li Q, Zhang W. Quantifying CO_2 emissions from China's cement industry. Renewable and Sustainable Energy. 2015;**50**:1004-1012

[26] Changzai R. Comparative life cycle assessment of sulfoaluminate clinker production derived from industrial solid wastes and conventional raw materials. Journal of Cleaner Production. 2017;**167**:1314-1324

[27] Wang J, Wang R, Zhu Y, Li J. Life cycle assessment and environmental cost accounting of coal-fired power generation in China. Energy Policy. 2018;**115**:374-384

[28] Morris J. Comparative LCAs form curbside recycling versus either landfill or incineration with energy recovey. InLCA case Studies. 2005:**10**:273-284

[29] Banar M, Cokaygil Z, Ozkan A. Life cycle assessment of solid waste management options for Eskisehir, Turkey. ScienceDirect. 2008;**29**:54-62. DOI: 10.1016/j.wasman.2007.12.006