Journal of Cleaner Production xxx (2016) 1–13

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life Cycle Assessment and Multi-criteria Decision Analysis: Selection of a strategy for domestic food waste management in Rio de Janeiro

Ana Carolina Maia Angelo [a,*], Anna Bernstad Saraiva [a], João Carlos Namorado Clímaco [b], Carlos Eduardo Infante [c], Rogerio Valle [a]

[a] Production Engineering Program, Federal University of Rio de Janeiro, COPPE/UFRJ, Rio de Janeiro, Brazil
[b] Universidade de Coimbra, INESC-C, Coimbra, Portugal
[c] Federal University of São João del-Rei, UFSJ, Minas Gerais, Brazil

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form
8 December 2016
Accepted 11 December 2016
Available online xxx

Keywords:
Life Cycle Assessment
Food waste
Multi-criteria analysis
VIP-Analysis

ABSTRACT

Results from Life Cycle Assessment (LCA) of solid waste management are, in many cases, difficult to interpret because there is no entirely satisfying alternative. Therefore, most of the studies focus on a small number of environmental impact categories. While this might facilitate the interpretation of the results, it also creates a risk of excluding relevant aspects from the assessment. For instance, the limited impact-coverage of Carbon footprint calculations where exclusively climate change related greenhouse gas emissions are considered. On the other hand, the inclusion of a larger number of impact categories in the study creates a risk of conflicting results. Multi-criteria Decision Analysis (MCDA) is a powerful approach for decision aiding, where highly diversified indicators can be analysed in the same framework helping to organise the available information and identify pros and cons in the decision process as well as its aggregation. This paper aims at improving decision making in solid waste management by combining LCA and MCDA techniques harmonically, using management of food waste from households in the city of Rio de Janeiro as a case study. Oriented to support decisions in choice problems, the software VIP-Analysis was used to choose the best food waste treatment option among the results of the LCA conducted. The VIP-Analysis is perfectly applicable in aggregating the LCA results due to its ability to handle problems with impreciseinformation, improving the decision making process.

1. Introduction

The Brazilian National Solid Waste Policy (PNRS - *Política Nacional de Resíduos Sólidos*) was implemented in 2010 after 20 years of congress debates. It has established three main goals: eradication of dumps by 2014, preparation and implementation of Municipal Solid Waste Plans at state and municipal level, and implementation of selective collection and composting systems for treating the organic fractions of municipal solid waste (BRASIL, Law No. 12,305, 2010). Nevertheless, few municipalities have really eliminated their dumps – 45.95% of total solid waste generated in Brazil in 2014 was still disposed of in open dump sites and 14.65% in controlled landfills (IPEA, 2014).

Similar to the waste hierarchy suggested by the European Commission (Directive, 2008/98/EC), PNRS considers the following priority on managing solid waste: non-generation, reduction, reutilisation, recycling, solid waste treatment and environmentally adequate disposal. In general, applying this waste hierarchy should deliver the best overall environmental option. However, in cases where specific circumstances and/or specific waste streams lead to deviations from the waste hierarchy, the waste hierarchy can be complemented by Life Cycle Assessment (LCA), a quantitative method to assess the environmental performance throughout the entire life cycle of a product, in order to identify the best environmental option of waste treatment. Moreover, Life Cycle Thinking, as a conceptual approach, is considered a strategic issue to guarantee the sustainable use of natural resources (European Commission, 2005, 2008; Manfredi and Pant, 2011).

A recent review shows LCA to be the principal method used for evaluating solid waste management systems (SWMS) (Allesch and Brunner, 2014) and a corresponding substantial increase in the number of publications over the last decade (Laurent et al., 2014). The same review highlights agreements with ISO standards and

* Corresponding author.
E-mail address: ana.maia@sage.coppe.ufrj.br (A.C.M. Angelo).

http://dx.doi.org/10.1016/j.jclepro.2016.12.049
0959-6526/© 2016 Elsevier Ltd. All rights reserved.

ILCD Handbook recommending the inclusion of all relevant impact categories in performance of LCA (ISO, 2006; European Commission, 2010). However, most SWMS LCAs focus on a small number of environmental impact categories. While this might facilitate the interpretation of the results, it also creates a risk of excluding relevant aspects from the assessment. On the other hand, the inclusion of a larger number of impact categories in the study creates a risk of conflicting results, i.e. one alternative can be preferable in relation to some aspects, while another is preferable in relation to others. Thus, while results from a LCA can facilitate understanding of the pros and cons of each waste management option, determining the *best* alternative might be difficult.

Multi-criteria Decision Analysis (MCDA) is a powerful approach for decision aiding, where highly diversified indicators can be analysed in the same framework helping to organise the available information and identify pros and cons in the decision process as well as its aggregation (Matteson, 2014; Clímaco and Valle, 2016; Valle and Clímaco, 2015; Recchia, 2011). Roughly speaking, MCDA aims to help managers make better decisions. In complex problems, MCDA interactive procedures avoid a final aggregation of the preferences of decision agents based on a unique criterion, in some cases proposing the combination of algorithmic protocols with the experience and intuition of decision agents in the process of preference aggregation.

This paper aims to improve decision aiding in solid waste management by combining LCA and MCDA techniques, using management of food waste from households in the city of Rio de Janeiro as a case study. MCDA seems useful for improving aggregation of LCA results. However, the more commonly used aggregation procedure, a simple weighted sum of the normalised values of criteria results, is not acceptable in most situations (Rowley et al., 2012). Therefore, other approaches should be exploited, which take into account that waste management models should combine MCDA and LCA harmonically, in order to maximise their strengths and/or minimise their weaknesses (Karmperis et al., 2013). In this paper we propose an interactive learning oriented multi-criteria tool based on the additive model only requiring partial/imprecise information on the weights.

This paper is organised into six sections, including this introduction. Section 2 describes the SWMS in the city of Rio de Janeiro. Section 3 presents a short overview of the use of MCDA in LCA and SWMS. Section 4 presents the methodology, including the LCA study of the current situation of domestic food waste management. It also shows how the study will integrate the LCA study with the MCDA chosen method, in our case VIP-Analysis (Variable Interdependent Parameters - Analysis). In Section 5 LCA results are used as inputs to the VIP-Analysis software. The aim is to select the preferred environmental option for handling the organic fractions of household waste. Finally, conclusions are presented in Section 6.

2. Household waste management in the city of Rio de Janeiro

The municipality of Rio de Janeiro has more than 2 million homes and 97% of its total population live in urban areas (IBGE, 2010). The SWMS in the city of Rio de Janeiro is carried out by the Municipal Urban Waste/Cleaning Company (COMLURB), which is responsible for collecting household solid waste, street cleaning, transferring and final disposal of waste, and composting, among other services not related to regular waste management system (e.g. vector control). Of the 9666 tons/day of solid waste produced in the city of Rio de Janeiro, 8511 tons/day are collected by COMLURB of which 44.9% is household waste which represents 1,828,754 tons/year. The amount not collected by COMLURB (1155 tons/day) comprises the solid waste generated by large quantity generators (not including waste from civil construction). These large quantity generators produce over 120 L or 60 kg of solid waste each day and, for this reason, in accordance with municipal law 3723/2001 they must use a private waste management company (SMAC, 2012). The household waste composition is presented in Table 1. Data on food waste generation was obtained only as an average for waste of animal and vegetable origin. However, as both the potential biogas generation and the nutrient content differ largely between food waste of animal origin and food waste of vegetable origin (Riber et al., 2009), it is important, in the present study, to establish the relation between them. Due to a lack of data from the case study area in question, the relation was based on a Swedish case, where detailed assessments of food waste composition were performed (Bernstad and Andersson, 2015), stating a relation of 12% and 88% for animal and vegetable origin, respectively, in domestic food waste from urban areas.

There are 160 neighbourhoods in the municipality of Rio de Janeiro, but only 41 of them have access to formal systems for source-segregation of dry materials, such as metals, plastics, glass, paper and cardboard (SMAC, 2012). The source-segregation systems in these 41 neighbourhoods account for only 0.22% of the total solid waste collected by COMLURB each year (COMLURB, 2013a). Post-separation of recyclables is performed on a small amount of waste collected from households in the city. The organic fraction separated in this process is later mixed with organic waste from commercial generators, for later treatment through composting. Produced compost (150 tons/month), cannot be used in agricultural activities due to the high content of inorganic matter (COMLURB, 2013b). Therefore, it is used by the municipality in landscaping projects (SMAC, 2012).

As recommended by the PNRS waste hierarchy, alternatives to landfills should be found for treatment of organic waste. The Municipal Policy of Integrated Management of Solid Waste of Rio de Janeiro (SMAC, 2012) has established guidelines and targets for increased diversion of organic waste from landfills but, as for now, no investigations of the environmental effects of different alternatives for achieving this have been made.

3. Application of MCDA in LCA and SWMS

The use of MCDA methods is no longer uncommon in

Table 1
Household waste composition in the city of Rio de Janeiro, based on data from COMLURB, 2013a,b.

Waste type	%	Waste fractions	%
Paper and cardboard	16.9	Other clean paper	11.7
		Paper and carton containers	3.7
		Milk cartons	1.5
Plastic	19.0	Hard plastics	4.4
		Soft plastics	12.7
		Plastic bottles	1.9
Glass	3.4	Clear glass	1.6
		Brown glass	1.8
Food waste	52.8	Animal food waste	9.9
		Vegetable food waste	42.9
Metal	1.6	Other metals	1.0
		Food cans	0.6
Inert material	1.1	Stones, concrete	0.9
		Ceramics	0.2
Others	5.2	Rubber	0.3
		Yard waste, flowers	1.4
		Wood	0.5
		Textiles	1.9
		Shoes, leather	0.3
		Coconut shells	0.5
		Batteries	0.3
Total	100%	Total	100%

Please cite this article in press as: Angelo, A.C.M., et al., Life Cycle Assessment and Multi-criteria Decision Analysis: Selection of a strategy for domestic food waste management in Rio de Janeiro, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.12.049