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Comparative lifecycle assessment of alternatives for waste management in Rio de Janeiro – Investigating the influence of an attributional or consequential approach

A. Bernstad Saraiva [a,*], R.G. Souza [b], R.A.B. Valle [a]

[a] SAGE/COPPE, UFRJ, Rio de Janeiro, Brazil
[b] Institute of Science and Technology, UNESP - Univ Estadual Paulista, São José dos Campos, Brazil

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The environmental impacts from three management alternatives for organic fraction of municipal solid waste were compared using lifecycle assessment methodology. The alternatives (sanitary landfill, selective collection of organic waste for anaerobic digestion and anaerobic digestion after post-separation of organic waste) were modelled applying an attributional as well as consequential approach, in parallel with the aim of identifying if and how these approaches can affect results and conclusions. The marginal processes identified in the consequential modelling were in general associated with higher environmental impacts than average processes modelled with an attributional approach. As all investigated waste management alternatives result in net-substitution of energy and in some cases also materials, the consequential modelling resulted in lower absolute environmental impacts in five of the seven environmental impact categories assessed in the study. In three of these, the chosen modelling approach can alter the hierarchy between compared waste management alternatives. This indicates a risk of underestimating potential benefits from efficient energy recovery from waste when applying attributional modelling in contexts in which electricity provision historically has been dominated by technologies presenting rather low environmental impacts, but where projections point at increasing impacts from electricity provision in coming years. Thus, in the present case study, the chosen approach affects both absolute and relative results from the comparison. However, results were largely related to the processes identified as affected by investigated changes, and not merely the chosen modelling approach. The processes actually affected by future choices between different waste management alternatives are intrinsically uncertain. The study demonstrates the benefits of applying different assumptions regarding the processes affected by investigated choices – both for provision of energy and materials substituted by waste management processes in consequential LCA modelling, in order to present outcomes that are relevant as decision support within the waste management sector.

1. Introduction

Environmentally sound municipal solid waste (MSW) is a worldwide concern, but of particular priority in transition countries with large urban areas, dense populations and challenging geographical conditions. The per capita waste generation in countries like Brazil still is low (1.041 kg/capita and day in 2013) (Abrelpe, 2014), compared to Sweden and the US (1.263 and 1.995 kg/capita and day in 2013 respectively) (Waste Sweden, 2014; EPA, 2015). However, the total generation of MSW in Brazil in 2013 was estimated to almost 210,000 tons per day, an increase by 4.1% compared to the year before, while population increased by 3.7% (Abrelpe, 2014). Although waste management in Brazil is focused primarily on eliminating waste disposal in open dumps, the newly implemented National Solid Waste Policy, (PNRS, 2010) opens the possibilities for technological leapfrogging and introduction of more advanced waste-to-energy and material recovery technologies, not necessary leading to disposal in sanitary landfills. The environmental benefits of such strategies could be investigated through use of lifecycle assessment (LCA) methodology.

According to Laurent et al. (2013), there is an evident confusion of concepts and terminology surrounding different types of Lifecycle Inventory (LCI) modelling frameworks in previous LCAs of solid waste systems. One of the reasons identified behind this is a lack of

* Corresponding author.
E-mail address: anna.bernstad.saraiva@sage.coppe.ufrj.br (A. Bernstad Saraiva).

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adequate goal definition, and subsequently, lacking stringency in the choice of LCI modelling framework. The selected type of LCI modelling framework has a significant influence on the definition of system boundaries (EC, 2010). Attributional lifecycle assessment (ALCA) employs a system-modelling approach in which the inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule (Sonnemann and Vigon, 2011). Consequential LCA (CLCA), on the other hand, is change-oriented and quantifies the effects associated with changes in the life cycle of a system brought about by a decision (Curran et al., 2005). In this way, the consequential approach seeks to take the environmental assessment a step further, in order to analyse how environmental burdens may vary in response to changes when processes are linked via market mechanisms beyond the foreground system (Vázquez-Rowe et al., 2013). Such linkages occur for example when waste is used for energy or material recovery, as waste-based goods are released on the market, with the effect of substituting other product-systems.

Several studies have been performed in recent years, using a consequential framework for LCI modelling of waste management systems. Boesch et al. (2014) compared an attributional and a consequential modelling of a Swiss MSW management scenario, considering substitution of both fossil and renewable energy to improve consequential LCI (CLCI) modelling, referring to recommendations by Mathiesen et al. (2009). No considerations were taken to affected suppliers in the modelling of material recovery, and average data was used for these processes in the study. Sevigné-Itoiz et al. (2015) present a CLCA of different alternatives for end-of-life treatment of plastic waste. The identification of marginal electricity was based on projections from national governments and the IEA. Assumptions of substituted heat were not justified and average data was used for modelling of production of virgin plastic substituted through material recycling. Comparing ALCA and CLCA modelling of end-of-life treatment of construction materials, Sandin et al. (2014) refer to literature data in identifying marginal heat provision processes, while data representing current average technologies is used for modelling of substituted materials. The influence of technology development was evaluated through 'explorative' scenarios, investigating the possible range of future outcomes by assuming a single technology to be representative for average future technology. Tonini and Astrup (2012) chose to investigate both short- and long-term changes related to the introduction of a waste refinery system, using CLCI modelling. Average processes were used in the modelling of virgin production of metals, plastics and glass as well as inorganic fertilizers substituted by recycled waste materials and organic fertilizers respectively. Cimpan et al. (2015) consider substitution of both energy and virgin material in a CLCA of a Danish waste management system. While the affected suppliers of virgin metals, plastics and glass not could be identified, marginal nitrogen, phosphorus and potassium fertilizers were identified as calcium ammonium nitrate, diammonium phosphate and potassium chloride, based on Hamelin (2013). In a review of Danish and Swedish consequential LCAs of waste management systems, Mathiesen et al. (2009) demonstrated the wide application of the methodology suggested by Ekvall and Weidema (2004) for identification of affected electricity provision. However, the same authors also stated that reviewed studies did not apply the suggested methodology consistently, and that the current practice should be improved by 1) using combined affected technologies, i.e. a complex set of marginal technologies; 2) using long-term perspectives by identifying affected technologies in several possible future scenarios, and 3) identifying the affected technologies based on energy system analysis with realistic geographical distributions and distribution in time.

The aim of the present paper was to investigate different waste management alternatives under two different LCI-modelling approaches. The objective to discussed if and why different treatment alternatives come across as more beneficial than others, depending on the chosen approach, and how this can affect input given to decision makers. In the present study, the environmental performances of three different scenarios for future development of the municipal solid waste management (MSWM) system in the city of Rio de Janeiro are assessed with an attributional as well as a consequential LCI-modelling approach. The functional unit is set to the collection and treatment of 1 ton of domestic waste, as collected by the municipal waste collection agent.

Energy provision is the background system of principal relevance to the system studied in the present study. MSW management is also increasingly integrated with material provision systems through material recovery and recycling, where environmental benefits can arise through avoidance of virgin material provision. Once a process avoided by waste-to-energy and material recycling or recovery is identified, the affected technology, also referred as marginal (Weidema et al., 2009), should be identified. This is commonly a key issue in consequential LCA modelling. A specific objective is therefore also to compare two different approaches for identification of the processes and technologies affected by the changes investigated in the consequential assessment of environmental impacts.

2. Methodology

Two different approaches were applied for identification of processes and technologies affected by the changes investigated in the present study. Firstly, the methodology suggested by Weidema et al. (2009) is used in a consistent manner for identification of single marginal technologies for production of electricity. This analysis is compared with the official national energy balance plan. Affected technologies and processes related to the handling of biofertilizers from waste management were identified through the approach presented by Weidema et al. (2009), using two different approaches for market delimitation. In the attributional modelling, average data was used for modelling of electricity and fertilizer production. As system enlargement was applied also in the attributional modelling, and factors such as rebound effects were not addressed in the consequential modelling, the largest difference between the two approaches lies within the identification of the unit processes linked to each system.

2.1. Scenario description

The selected functional unit is 1000 kg of mixed municipal solid waste, with the composition presented by the local government (COMLURB, 2014). The fraction of organics in domestic waste in the city of Rio de Janeiro has decreased from 60.7 to 52.8% over the period 2005–2013. However, over the same period, the amount of domestic waste increased by 25%, resulting in an overall increase of domestic organic waste by 8.5% (COMLURB, 2014). Thus, handling of this fraction is of large importance, and was also selected to be the focus of the present study. The scenarios investigated in the study are presented in Table 1.

2.2. LCA study methodology

Exclusively covering the MSW end-of-life phase, this LCA study was conducted following the international standards ISO 14040 and 14044 (ISO, 2006a and b). All scenarios were modelled in the EASETECH software, developed by DTU. This software is based on material flow modelling and enables generation of input- and