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Applying life cycle assessment to support environmentally sustainable waste management strategies in Brazil

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ABSTRACT

This paper aims to investigate sustainable waste management solutions for the city of Rio de Janeiro in Brazil, based on a life cycle approach. The Life Cycle Assessment (LCA) was performed by using the LCA-IWM methodology. The model was adapted to the Brazilian solid waste context and to the local characteristics, including waste composition, electricity mix and regulations. The annual amount of waste generated was the functional unit adopted. Eight municipal solid waste management strategies were evaluated. Scenarios including mixed waste collection and source separated collection as well as materials recovery and energy from waste were investigated. Scenarios were ranked based on the LCA results. Sensitivity analysis was carried out by varying the electricity mix. The results indicate that the current situation of municipal solid waste (MSW) in Rio de Janeiro presents the worst performance in terms of aggregated environmental burdens, indicating the urgency for implement new strategies toward a more environmentally friendly and sustainable MSW management system. It is noted that the better LCA performances were obtained in scenarios with high separately collection rates. Among them, the scenario based on recyclables recovery and anaerobic digestion shows to be a promising strategy to improve environmental sustainability. Sensitivity analysis demonstrates that the ranking of scenarios was not affected by changes in the electricity mix. From the results, the investment in source separated waste collection and materials recovery is the most environmentally friendly MSW strategy for Rio de Janeiro. In addition, scenarios with an emphasis in materials recovery presented higher environmental benefits than the alternatives focused on energy generation.

1. Introduction

1.1. Background of the study

Sustainable development encompasses the reduction of polluting emissions and the establishment of sustainable waste management practices (Belboom et al., 2013). Particularly, waste management is a method directing managements and/or institutions to acting for sustainability by displaying their ability to use and protect current resources (Orhan, 2011). For Cucchiella et al. (2014) a sustainable society should not generate wastes exceeding its capacity of manage them. Indeed, as stated by Cherubini et al. (2009), an important factor for sustainable development is an affordable, effective and truly sustainable waste management. Thus, on the one hand solid waste management (SWM) is crucial to achieve sustainability. On the other hand, increases in population, urbanization and economic development have led to the growth of concerns in this field (Tulokhonova and Ulanova, 2013; Levis et al., 2013). As a result, SWM has emerged as one of the most challenging service sectors in the 21st century for municipal authorities (Puig et al., 2013; Zaman, 2014). Particularly, according to Bowdewijn (2015), emerging countries as China, Russia, South Africa, Brazil and India are facing this problem. As stated by Marshall and Farahbakhsh (2013), in developing countries the health and environmental implications related to solid waste management are mounting in urgency. Indeed, municipal solid waste (MSW) becomes an important issue for cities in emerging economies due to the high costs associated and to the lack of understanding over the factors that affect the different stages of SWM (Guerrero et al., 2013).

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Thus, several decision support models have been developed to aid decision makers in the planning of SWM strategies (Karmperis et al., 2013). Life Cycle Assessment (LCA) approaches are one of the most largely used methodologies to assess solid waste systems (Giugliano et al., 2011; Allesch and Brunner, 2014). LCA consists in a method to evaluate environmental effects related to a product or process from raw material acquisition to final disposal, i.e. during its whole life cycle. According to Manfredi et al. (2011) the life cycle thinking concept and quantitative tools such as LCA can provide a science-based support to a more environmentally sustainable decision-making in SWM. In fact, LCA supports a holistic approach to sustainable waste management by enabling a comprehensive view of the impacts involved and providing directions to the development of environmentally sound strategies (Del Borghi et al., 2009; Tulokhonova and Ulanova, 2013). LCA applications in SWM are currently used to the analysis of potential environmental effects of waste management options (Yay, 2015). Indeed, according to Galvez-Martos and Schoenberger (2014) and Leme et al. (2014), LCA has been extensively used to evaluate and compare SWM scenarios. A review of studies related to this theme is provided in Del Borghi et al. (2009) and Laurent et al. (2014a,b). It is important to note that several LCA models with a focus on waste management have been developed since the late 1990s, such as IWM-1 (White et al., 1995), ORWARE (Dalemo et al., 1997), IWM-2 (McDougall et al., 2001), WASTED (Diaz and Warith, 2006), EASEWASTE (Kirkeby et al., 2006), WISARD (Buttol et al., 2007), LCA-IWM (Den Boer et al., 2007) and FENIX (Margallo et al., 2014).

In spite of the large number of LCA studies in SWM, Laurent et al. (2014a) found that there is no decisive agreement about a generalized optimum waste treatment strategy because LCA results are very dependent on context and local specificities. The same author reported that the most part of LCA studies in SWM are focused on developed countries. In fact, studies related to LCA applications in SWM in developing countries are scarce and the most part of them focuses on case studies related to Asian countries, such as: China (Chen and Christensen, 2010; Chen et al., 2011a,b; Chi et al., 2015; Dong et al., 2013a,b; Hong et al., 2010; Hong and Li, 2011, 2012; Song et al., 2013; Woon and Lo, 2016; Xie et al., 2013; Zhao et al., 2009, 2012), Malaysia (Hassan et al., 1999; Saheri et al., 2012), South Korea (Kim et al., 2009; Lee et al., 2007; Yi et al., 2011) and Thailand (Chaya and Gheewala, 2007; Kiatkittipong et al., 2009; Liamsanguan and Gheewala, 2007, 2008; Menikpura et al., 2012).

Regarding the BRICS, with the exception of China, LCA is not a largely used approach in SWM in these countries. Indeed, Laurent et al. (2014a) investigated 222 papers related to this topic, but no study was found for South Africa, India, Russia, and only two studies (Mendes et al., 2003, 2004) were recorded for Brazil. The following papers not included in Laurent et al. (2014a) review present the results of LCA studies for BRICS in SWM context: India (Pandyaswargo et al., 2012), Russia (Kaazke et al., 2013; Starostina et al., 2014; Tulokhonova and Ulanova, 2013) and South Africa (Vossberg et al., 2014). So, the number of papers compiled for the aforementioned countries is still too limited, indicating the necessity to develop studies addressed to this theme.

Concerning Brazil, it presents some context specificities that can highly influence the results of LCA in SWM. First of all, differently of other BRICS where fossil fuels are predominant in the electricity mix, in Brazil power generation is based on renewable energy from hydropower, which could influence LCA results in strategies involving energy generation from waste. In addition, according to Veloso (2013), waste generation in Brazil, as well as, in China and in India will probably to double by 2025, which increases the urgency for the implementation of sustainable strategies in SWM in these countries. Moreover, recently it was established the Brazilian National Policy on Solid Waste (NPSW), which presents several goals to the SWM sector whose accomplishment represents an important challenge to the municipal authorities in the next years.

Table 1
Municipal solid waste generated in Rio de Janeiro in 2013 (MSERJ, 2015).

Waste Fraction	Waste generation (ton/year)	Portion of total waste (%)
Glass	110221	3.18%
Metal	58236	1.68%
Paper	668431	19.29%
Plastic	583492	16.84%
Organics	1825460	52.68%
Others	219346	6.33%

So, considering the benefits of LCA to support SWM, the scarcity of these studies in BRICs context and the difficulty of emerging economies in handle MSW (Guerrero et al., 2013), this paper aims to investigate sustainable waste management solutions for a Brazilian city based on a LCA approach.

1.2. Brazilian waste management context

In Brazil it was generated 78,583,405 t of municipal solid waste in 2014 (Brazilian Association of Urban Cleaning Companies – ABRELPE, 2015). In comparison with 2013, this amount of waste represents an increase of 2.9% in waste generation while the population growth in this country was inferior to 1% for the same period. This increase in waste generation greater than population growth is probably related to the rise of the average income of Brazilians that presented an increase of 2,4% from 2013 to 2014 (Brazilian Institute of Geography and Statistics – BIGS, 2015). Similar patterns are observed in the previous years (ABRELPE, 2012, 2013, 2014), indicating a continuous growth of the waste generation per capita. Concerning waste destination, 58.6% of wastes generated in Brazil are disposed in landfills whereas the rest of them are sent to uncontrolled dumps (ABRELPE, 2015). This is a common scenario in emerging economies and, as stated by Bowdewijn (2015), a crucial point to reduce environmental impacts of MSW management in these countries is to move away from landfilling to other waste treatment technologies. Regarding the waste management policy, as already mentioned, in Brazil this sector is regulated by the Law 12,305/2010 which establishes the Brazilian National Policy on Solid Waste (NPSW).

2. Material and methods

2.1. Description of the area in study

Rio de Janeiro, the city studied, is located in the southeast of Brazil. This city presents an area of 1255 km^2 and a population of 6,429,923 inhabitants (MSERJ, 2013, 2015). The climate is humid coastal, the average temperature ranges throughout the year from 21 to 27 °C and the average rainfall rate is 1070 mm/year (National Institute of Meteorology – INMET, 2015). Concerning the waste management context of this city, 3,465,187 t of MSW was generated in Rio de Janeiro in 2013 (Municipal Secretary of environment of Rio de Janeiro – MSERJ, 2015). The waste composition of Rio de Janeiro is presented in Table 1 (MSERJ, 2015).

It is noted that organic fraction represents the most part of the total waste mass, which is a common characteristic of MSW in emerging economies. Indeed, according to Nuss et al. (2012) organic fraction is often between 50% and 70% of MSW mass in developing countries. Papers and plastics also represent an important percentage of waste. Regarding the collection of source separated waste, the amount of waste separately collected by fraction and sub-fractions in 2013 are presented in Table 2 (MSERJ, 2015).

Disposal of MSW in landfills is the predominant solution in Rio de Janeiro, 98% of the municipal solid wastes in this city are