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Techno-economic analysis and environmental impact assessment of energy recovery from Municipal Solid Waste (MSW) in Brazil

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ABSTRACT

Due to the lack of appropriate policies in the last decades, 60% of Brazilian cities still dump their waste in non-regulated landfills (the remaining ones dump their trash in regulated landfills), which represent a serious environmental and social problem. The key objective of this study is to compare, from a techno-economic and environmental point of view, different alternatives to the energy recovery from the Municipal Solid Waste (MSW) generated in Brazilian cities. The environmental analysis was carried out using current data collected in Betim, a 450,000 inhabitants city that currently produces 200 tonnes of MSW/day. Four scenarios were designed, whose environmental behaviour were studied applying the Life Cycle Assessment (LCA) methodology, in accordance with the ISO 14040 and ISO 14044 standards. The results show the landfill systems as the worst waste management option and that a significant environmental savings is achieved when a wasted energy recovery is done. The best option, which presented the best performance based on considered indicators, is the direct combustion of waste as fuel for electricity generation. The study also includes a techno-economical evaluation of the options, using a developed computer simulation tool. The economic indicators of an MSW energy recovery project were calculated. The selected methodology allows to calculate the energy content of the MSW and the CH_4 generated by the landfill, the costs and incomes associated with the energy recovery, the sales of electricity and carbon credits from the Clean Development Mechanism (CDM). The studies were based on urban centres of 100,000, 500,000 and 1,000,000 inhabitants, using the MSW characteristics of the metropolitan region of Belo Horizonte. Two alternatives to recovering waste energy were analyzed: a landfill that used landfill biogas to generate electricity through generator modules and a Waste-to-Energy (WtE) facility also with electricity generation. The results show that power generation projects using landfill biogas in Brazil strongly depend on the existence of a market for emissions reduction credits. The WtE plant projects, due to its high installation, Operation and Maintenance (O&M) costs, are highly dependent on MSW treatment fees. And they still rely on an increase of three times the city taxes to become attractive.

1. Introduction

Solid waste has emerged as a significant pressure on the environment, mostly due to the population growth the changes in consumption habits and of the patterns of the communities' developments. The Municipal Solid Waste (MSW) is the largest volume of residues produced worldwide; at the same time, the citizens' demands for an environmentally sound management of MSW have significantly increased during the last decades (Achillas et al., 2011; Cleary, 2009).

The Integrated Solid Waste Management (ISWM) includes several solutions to achieving lower environmental and social impacts. This alternative combines different solutions such as the reduction of waste generation, the materials recovery, the recycling, the energy recovery and as a last option, the landfills. This practice is incorporated to any modern strategy involving the MSW management. The European Union (EU) has, for example, introduced targets aiming to reduce the amount of landfilled biodegradable waste. The Landfill Directive (EC, 1999) prevents the disposal of

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Nomenclature

a	cost scale factor (dimensionless)
C	capacity factor of the equipment ($/MWh)
C_0	capacity factor of the equipment starting from reference values ($/MWh)
Ga	MSW garbage/food content (%)
HHV	higher heating value (kJ/kg)
k	decay rate of landfill waste (1/year)
L_0	methane generation potential from MSW (m^3 CH_4/Mg MSW)
LHV	lower heating value (kJ/kg)
n	economic lifetime of the system (years)
P	freight on board (FOB) price of the equipments ($)
P_0	FOB price of the equipments starting from reference values ($)
P_a	MSW paper content (%)
Pl	MSW plastic content (%)
Q	methane production (m^3/year)
t	time of waste disposal (years)

organics in landfills by 2016; this fraction of MSW must be composted or digested (Murphy and McKeogh, 2006). Furthermore, landfilling of certain types of waste such as combustible waste or untreated organic waste, are now illegal in some EU member states, e.g. Denmark, Sweden and Germany; also in the EU, great effort is being made to identify alternatives to the landfilling biodegradable wastes (Münster and Lund, 2009).

The incineration of MSW with energy recovery is a widespread solution in some countries despite the fact that this alternative aroused harsh criticism in the 80s and 90s, due to the high emissions of air pollutants. For this reason, strict emission limits were applied in this sector, which repressed the installation of new plants. However, new advances in gas treatment technologies for air pollution control make the incineration, with energy recovery, attractive from an environmental point of view and its use is being encouraged in much of the developed world. According to Psomopoulos et al. (2009) incineration appears particularly attractive as a way to produce energy and reduce the MSW volume in so-called Waste-to-Energy (WtE) plants. The WtE emissions have been reduced to a point that in 2003 the United States Environmental Protection Agency (US EPA) considered WtE a cleaner source of energy.

Public opinion is a most crucial factor in the selection of a suitable final option for any ISWM scheme as well as during the operational phase of a plant, especially for incineration of MSW in a WtE facility; it is clear that incineration presents advantages such as volume reduction, energy recovery and elimination of pathogen agents in comparison with other waste treatments. However, the public opinion in most countries is frequently concerned about the installation of MSW incinerators because dioxins are generally produced in many combustion processes. Traditionally the incinerators have been pointed out as one of the most important sources of toxic emissions of not only dioxins, but also furans, acid gases and heavy metals. The WtE facilities need to be built close to urban conurbations, therefore, public objections to the construction of an MSW incineration facility becomes often much greater. What is revealed is that concerns are mainly focused on the interrelated issues of public health and environmental protection (Keramitsoglou and Tsagarakis, 2013; Achillas et al., 2011; Jamasb and Nepal, 2010).

Specifically in Brazil, in relation to ISWM, approximately 60% of Brazilian cities still dump their solid waste in non-regulated landfills. Unregulated landfills do not have drainage systems for gases and leaches have lower sealing and sometimes even lack daily soil cover. However, the biggest Brazilian cities use regulated landfills as an alternative, meaning that 74.9% of Brazilian MSW mass are dumped in regulated landfills which is considered by the Brazilian environmental regulations an environmentally sound alternative (SNIS, 2012). Only recently Brazil has implemented its first policy to manage the MSW; the Law N° 12.305/2010, establishes the "National Policy on Solid Waste" (NPSW), which provides the principles, objectives and instruments for the management of solid waste, including the responsibilities of producers and the local governments, the guide to the management of hazardous waste and the economic instruments to be applied.

The NPSW was the basis to fixing the steps to route the planning by the federal government to reduce the Greenhouse Gases (GHG) emission in Brazil; however, this policy does not specify mandatory actions, with targets and timetables, neither for the management of solid waste nor for the recovery of energy or the gases generated by the waste sector. The lack of such adequate management policy for MSW will have serious nationwide negative consequences (Loureiro et al., 2013; Cândido et al., 2011).

Brazil still recovers only a small fraction of the energy that is produced from the biogas emitted by the landfills. Assuming a rate of 50 Nm^3 of CH_4/tonne of MSW (Themelis and Ulloa, 2007) and considering a production of 141,700 tonne/day of MSW (SNIS, 2012), sent to regulated landfills, it is possible to estimate that Brazil has a potential of about 660 MW of electric power from landfills (considering 30% of efficiency in the energy conversion) (Salomon and Lora, 2009).

Today, Brazil produces 69 MW of power through the use of the biogas from landfills in São Paulo (11,244,369 inhabitants), Belo Horizonte (2,375,444 inhabitants), Salvador (2,676,606 inhabitants) and Uberlândia (619,536 inhabitants) (ANEEL, 2012). This potential will be greater if we consider the incineration of said waste in a WtE process, with a calculated potential of 1750 MW, considering 18% of energy conversion efficiency (Assamoi and Lawryshyn, 2012) and a LHV of 7.10 MJ/kg; because, first, only the biodegradable part of the MSW is converted into biogas and also only part of the biogas from the landfills can be captured and supplied to engines or turbines. Additionally, burning the waste makes it possible to recover the energy content of other materials present in the waste (plastics and rubber).

Recently, some Brazilian cities have started searching for other alternatives to dispose their wastes other than landfills, because of the lack of space in the surroundings of big cities and also the high land prices, the high cost of long distance waste transportation, depreciation associated to the refusal of people to having landfills near their homes. All of those are clear reasons for the burning of waste to be constantly evaluated by city authorities as a solution to those problems (Fehr et al., 2009).

The Life Cycle Assessment (LCA) is a methodology that considers the entire life cycle of products and services from cradle to grave, in other words, from acquisition of raw material, going through production and use until the disposal of the residues (Ning et al., 2013; Lora et al., 2011; Rocha et al., 2008, 2010). It's possible to state that the LCA is a holistic methodology applicable to the analysis of products and services, proven to be a systematic tool to measure and compare the environmental impacts of human activities, being able to provide an overview of the environmental profile of different strategies, giving additionally a comparison of the environmental impacts of all the options.

LCA has been used extensively by different authors to evaluate and compare various scenarios for ISWM systems (Assamoi and Lawryshyn, 2012; Ning et al., 2013; Cleary, 2009; Khoo, 2009; Cherubini et al., 2008; Emery et al., 2007; Aye and Widjaya, 2006; Bergsdal et al., 2005), the use of LCA in decision making is also well-established, having been used successfully for the comparative assessment of MSW systems. The key point, in an LCA, is that