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Spatially distributed potential of landfill biogas production and electric power generation in Brazil

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ABSTRACT

Due to the relatively low investment, operation costs, and technical requirements, landfills are still the most widespread alternative for final disposal of municipal solid waste (MSW). The biogas produced in the landfill, a renewable energy source, may be an important alternative for electric power generation. Brazil has a significant number of operating landfills, which receive the most part of the collected MSW. However, the country has only 17 landfill biogas power plants (LBPPs), resulting in about 122 MW of capacity. The United Kingdom, for instance, which is about 3 times smaller than Brazil in population, has 442 LBPPs (corresponding to 1051 MW of capacity). This fact highlights a considerable unexplored potential of landfill biogas in Brazil. It is also important to estimate this potential throughout the country to provide information for the government, researchers and companies in decision making, planning and formulation of public policies regarding this use of landfill biogas. Therefore, this study aims at estimating the spatially distributed potential of landfill biogas production that can be used for electric power generation in Brazil from 2015 to 2045, considering two scenarios: (i) operating sanitary landfills and (ii) hypothetical scenario of Territorial Arrangements (TA) comprising every Brazilian city, considering one landfill per TA. The total installed capacity estimated in 2018 for scenario 1 is about 523 MW and 87% of this number are related to LBPPs bigger than 1 MW. In this same year, the total installed capacity estimated for scenario 2 is 768 MW and 95% of this number are related to LBPPs bigger than 1 MW. These results emphasize that Brazil has a considerable unexplored potential of landfill biogas and the importance of municipal consortiums for MSW management.

1. Introduction

Landfills are still the most widespread alternative for final disposal of municipal solid waste (MSW) because of the relatively low investment, operation costs and technical requirements (Hu et al., 2017). A proper landfill, also known as sanitary landfill, is a planned and controlled site with leachate drainage and treatment systems, preventing ground water contamination, and other systems to collect and burn the generated biogas (Youcai and Ziyang, 2017). In high-income countries, landfilling is the most common method of MSW final disposal, whereas low and lower-middle-income countries still have open dumps as the main alternative. Moreover, several middle-income countries have poorly operated landfills classified as controlled dumping or controlled landfills (Hoornweg and Bhada-Tata, 2012).

In Brazil, there are three main types of municipal solid waste destination sites (MSWDSs): sanitary landfills, controlled landfills and open dumps. Controlled landfills do not have leachate drainage and treatment systems, but only a cover layer using soil. Open dumps are the worst way for final waste disposal, with neither cover layers nor systems for collection and treatment of leachate and biogas (Brazil, 2012b). On the other hand, these systems, including cover layers, are required for sanitary landfills, respecting technical specification of the Brazilian Association of Technical Standards (ABNT, 1992, 2010).

According to the last Brazilian Diagnosis of Municipal Solid Waste Management (SNSA, 2015), in 2015 the country had 60.9%

Abbreviations: LBPP, landfill biogas power plant; MSW, municipal solid waste; MSWDS, municipal solid waste destination site; TA, Territorial Arrangement.

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of the collected waste destined for sanitary landfills, 11.5% for controlled landfills, 10.1% for open dumps, 2.1% for sorting and composting units, and a portion of 15.4% without information. This diagnosis (SNSA, 2015) does not have a census characteristic with the participation of 3520 municipalities, corresponding to 63.2% in number of municipalities and 79.4% of the total population. Although the investment of a landfill is relatively low, the costs of one-year operation are about one third of the initial investment. Due to the limited municipal budget of many Brazilian cities, the public collection of MSW and public cleaning services are prioritized over the final disposal of MSW (MMA, 2009), which contributes to the large amount of MSW that is still destined for open dumps. The Brazilian federal government has goals to regulate this situation based on the Brazilian National Policy on Solid Waste, law 12305/10 (Brazil, 2010). According to this law, 2014 was the deadline to regulate all open dumps in the country, which was postponed to 2018. In addition, every landfill project in Brazil must obtain environmental license, respecting municipal, state or federal regulations (Van Elk, 2007).

MSW has a large amount of biodegradable components, mainly food leftovers and paper. According to Hoornweg and Bhada-Tata (2012), in low-income countries, food leftovers and paper represent 64 and 5% of the amount of generated waste, respectively, whereas in high-income countries these proportions are 28 and 31%. In Brazil, these proportions are 51.4 and 13.1%, respectively (IPEA, 2012). In the lower layers of landfills and open dumps the oxygen concentration is low and the biodegradable organic components are mainly decomposed by anaerobic biologic process, generating a gas containing about 50–60% methane (USEPA, 2016).

The global warming potential of methane is estimated to be 28 times greater than the warming potential of carbon dioxide (Myhre et al., 2013) and landfills are amongst the largest human-related sources of methane emissions (Kormi et al., 2017). In addition, at high concentrations, landfill biogas represents risk of explosion (Silva et al., 2017), besides the unpleasant odours (Lucernoni et al., 2017).

According to Coelho and Lange (2016), MSW management strategies focusing on selective collection and materials recovery are more sustainable than directly landfilling mixed waste. For a region in São Paulo State, Brazil, Deus et al. (2017) estimated that a MSW management program including recycling and composting could save 490.9% in energy and reduce 788% of carbon dioxide emissions comparing to the current situation of the studied region. Using life cycle assessment, Coelho & Lange (2016) showed that the MSW management in Rio de Janeiro, which reflects the Brazilian general condition, presented the worst performance in terms of environmental burdens when compared to scenarios considering recovery materials and waste treatment technologies. This indicates the urgency for implementing new strategies toward a more environmentally friendly and sustainable MSW management system (Coelho and Lange, 2016). However, it is still necessary to consider alternatives for minimizing the impacts of waste landfilling in Brazil, once this is the main technique used for final disposal of MSW in the country.

This way, part of the methane generated in landfills can be collected and used as a renewable power source (Lino and Ismail, 2011; Nadaleti et al., 2017; Ouda et al., 2016). According to the IEA (2016), among the members of the International Energy Agency (IEA), Germany dominates the biogas production with more than 10,000 biogas plants. However, most of them are related to agricultural activities and only 400 are related to landfills. In the second position, the United Kingdom has 913 biogas plants, out of which 442 are landfill plants, corresponding to 1051 MW of capacity. According to the same author, countries as the United Kingdom, Brazil and South Korea have landfills as their largest source of biogas, indicating the higher degree of landfilling of organic waste material in these countries. On the other hand, despite tax incentives related to infrastructure development, including power generation (Brazil, 2007) and incentives towards renewable energy, such as tax reduction for solar, wind or biomass power plants smaller than 30 MW (ANEEL, 2004), Brazil still has a small number of LBPPs. According to ANEEL (2017), the country has only 17 operating power plants using MSW biogas, resulting in 122 MW of total installed capacity, besides four approved projects representing more 52 MW.

According to EPE (2016), the Brazilian potential of electric generation out of MSW biogas has been estimated to rise from 8.8 TWh in 2015 to 9.1 TWh in 2030, corresponding to about 1255 and 1299 MW of total capacity, respectively, using a capacity factor of 0.8. However, this study considered the use of anaerobic reactors for the organic portion of the whole amount of MSW collected in Brazil, which produces 2–4 times as much methane as when compared to landfills (Souza et al., 2014). Therefore, these results cannot be representative, given that according to SNSA (2015) Brazil still has landfills as the main alternative for MSW destination.

Salomon and Lora (2009), estimated 414 MW as the Brazilian potential of electric energy generation out of landfills. The potential was estimated considering that 85% of the total amount of waste generated in Brazil is disposed in landfills. The spatial distribution of the landfills was not considered, as well as the temporal dynamic of biogas generation in landfills.

Souza et al. (2014) estimated 289 MW as the technical potential of electric power generation out of landfill gas for the 16 biggest cities in Brazil (which are responsible for 34% of the waste collected in urban centers). These results were attained within a scenario where the total amount of collected MSW in the 16 assessed cities is deposited in landfills, and the biogas generated is used to produce electricity in an internal combustion engine/alternator. Despite the oriented approach of the aforementioned study, of which estimations were made for landfills as a whole, it presents results only about the year of 2011 and for a restricted number of cities.

Barros et al. (2014), in a more comprehensive study, estimated 452,746 tep as the Brazilian potential of electric power generation out of landfill biogas in 2030, which represents a total capacity ranging from 420 to 750 MW, considering a capacity factor of 0.8. The authors of this study considered only cities bigger than 200,000 inhabitants, given the economic and financial attractiveness of such cities. These cities represent about 44% of the Brazilian population and about 2.5% of the total number of cities. According to Barros et al. (2014), it is important to formulate policies to encourage the use of landfill biogas as a source of renewable energy for cities with a population lower than 200,000 inhabitants. Moreover, there are Brazilian cities that adopt group strategies for final MSW-disposal, which can increase the number of feasible LBPPs. Therefore, municipal consortiums may generate greater results for the potential of power generation out of landfill biogas, once small cities can contribute to this potential as members of consortiums. In Brazil, municipal consortiums are regulated by federal laws, and those signed for MSW destination purposes have priority in obtaining tax incentives (Brazil, 2010).

Most of the studies found in the literature about electric power generation out of landfill biogas in Brazil have a general approach, presenting results for the whole country without considering spatial distribution of landfills and specific characteristics of waste management. Moreover, none of them assess the impact of joint strategies regarding MSW final destination in the potential of biogas generation. Thus, this study aims at better assessing the characteristics of the problem at hand, considering the complexities and important aspects that have not been previously incorporated. It allowed generating better and more comprehensive estimates at local and regional levels, which can be useful for planning and decision-making regarding landfill biogas.

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