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The electric energy potential of landfill biogas in Brazil

Regina Mambeli Barros*, Geraldo Lúcio Tiago Filho, Tiago Rodrigo da Silva

Natural Resources Institute, Federal University of Itajubá, National Reference Center for Small Hydro Power, (Instituto de Recursos Naturais da Universidade Federal de Itajubá, Centro Nacional de Referência em Pequenas Centrais Hidrelétricas), Av. BPS, 1303, Itajubá-MG, CEP 37500-903, Brazil

HIGHLIGHTS

- Increases in the energy capacity related to the Gross Domestic Product (GDP).
- To increase energy generation from landfills by thermal biogas plants in Brazil.
- Population/landfill size for financially viable enterprise to generate electricity.
- Relationships between projected collection of solid wastes and projected GDP.
- Values related to energy sources from residual fuels by National Energy Balance.

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ABSTRACT

The increases in a country's energy capacity are related to its gross domestic product (GDP). In Brazil, increases in income and the consumption of goods and services have led to an increase in the generation of solid waste (SW), which is sent to landfills as a method of treatment and final disposal. The purpose of this study was to facilitate an increase in energy generation from renewable resources, specifically from landfills via thermal biogas plants, and the research was divided into two phases. The first phase involved the assessment of the potential population size contributing to the landfill, which could result in the installation of a financially viable enterprise to generate electricity in Brazil. Next, an estimate of the costs associated with the generation and collection of solid waste in Brazil was predicted by GDP prognoses, the latter being in accordance with the National Energy Balance (Balanço Energético Nacional – BEN) plan created by the Mines and Energy Ministry of Brazil (Ministério de Minas e Energia do Brasil – MME). The net present value (NPV) and internal rate of return (IRR) of each enterprise scenario was used in the first stage to assess the plan's financial viability. In the second stage, estimation curves such as logistics, decreasing rate of growth, and logarithmic curves were used to establish relationships between the generation scenarios and the projected collection of SW and projected GDP. Thus, a range of possible landfill biogas/methane generation values and installed energy capacities were created, considering the extreme maximum and minimum values. These values were related to the energy sources from residual fuels reported by BEN. The results demonstrated that such values still represented a small percentage (0.00020% in 2010 and 0.44496–0.81042% in 2030) of the projected energy generation from residual fuels. Thus, an urgent need was identified to formulate policies that would encourage landfills as a source of renewable energy, broadening the number of financially viable initiatives for energy generation from landfill biogas for populations of fewer than 200,000 inhabitants.

1. Introduction

An increase in industrial production, population and urbanization increases the consumption of goods and services and results in increased solid waste generation, particularly in urban areas, in which waste includes public and household solid waste and is called municipal solid waste (MSW). The most common method for treating and disposing of MSW in Brazil has been waste disposal on the ground, which can include inappropriate disposal methods, such as in an open-air landfill, or disposal in a controlled, regular landfill. The latter utilizes methods for the treatment and final disposal of MSW according to project and operation guidelines based on engineering criteria.

The organic matter in landfills degrades in a predominantly anaerobic environment, resulting in products such as leachate, a mixture of slurry and rain water percolating through the landfill cell, and biogas, which is composed mainly of methane (CH_4; 50–60%),

* Corresponding author. Tel.: +55 3536291224; fax: +55 3536291265.
E-mail addresses: remambeli@hotmail.com, remambeli2001@yahoo.com.br (R. Mambeli Barros), tiago_unifei@hotmail.com (G.L. Tiago Filho), tirgo@hotmail.com (T.R. da Silva).

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carbon dioxide (40–50%) and small traces of other gases like nitrogen (N_2; 5%), hydrogen sulfide (H_2S; $<1\%$) and non-methane organic compounds (NMOC; 2700 ppmv) (Amini and Reinhart, 2011; Amini et al., 2012; Schneider et al., 2012; Themelis and Ulloa, 2007).

A portion of the methane generated in landfills can be captured and used as a source of renewable energy (Themelis and Ulloa, 2007; Chynoweth et al., 2001). The calorific power of landfill gas (LFG) is sufficiently high to permit its use as a fuel in combustion processes, such as those in internal combustion engines (ICE), and the production of electricity (Gewald et al., 2012; Schneider et al., 2012), In this way, a certain amount of fossil fuel can be saved while still obtaining an equivalent quantity of energy (Schneider et al., 2012).

According to Oliveira and Rosa (2003), the 20 million tons of municipal solid wastes produced annually in Brazil, when used to generate electricity together with certain energy supply options (incineration, LFG, *etc.*), could enhance electricity supplies by 50 TWh. Because landfills are the most widely used disposal technique in Brazil, a study of LFG's electricity generation potential electricity generation would be relevant to improving the country's energy situation. This concept has been supported by data from The Brazilian Association of Public Cleaning Companies and Special Wastes, (2009) stating that of the MSW collected in 2009, 56.8% was destined for landfills, 23.9% went to controlled landfill sites and 19.3% ended up in garbage dumps. A relevant study must account for and correlate data regarding Brazil's energy expansion plan, MSW collection rates, population and GDP grown projection data, but also consider the constraints derived from an analysis LFG power plant ventures' economic viability.

This study investigated the potential for economically viable electricity generation using energy recovery from landfill biogas in Brazil, considering this concept within the context of an official energy expansion plan created by the Energy Research Company (Empresa de Pesquisa Energética – EPE, 2007). The research established populations of between 80,000 and 500,000 inhabitants served by landfills using official Brazilian census data to verify constraint values for economic investments in this type of venture. Next, the software "Biogas generation and energy use, landfills," version 1.0 (The Company of Technology of Environmental Sanitation, 2006), was used to create a prognosis for theoretical biogas generation and possible projects. A thermoelectric plant powered by LFG was designed to receive a given annual amount of solid waste from a given population size to analyze combinations of power *versus* time. From these, three combinations of power *versus* time for each population were established for economic feasibility studies by considering an IRR of at least 9.5% per year. Based on the establishment of a minimum population to be served by a landfill's electric energy generation that could be considered an economically viable project, it was possible to establish correlations between growths in the generation and collection of solid waste based on predicted value of gross domestic product (GDP) growth. The GDP values used were those found in prognoses given by the official Plan for Energy Expansion (EPE/MME; EPE, 2007). The prognoses for both population and the generation and collection of solid waste growth were made based on theoretical logistic growth, logarithmic growth and declining rate of growth curves. Based on the input values obtained from these curves in the software LandGem®, created by the U.S. Environmental Protection Agency (2005, 2008), predicted values were generated with maximum and minimum values for LFG power generation. Using this potential energy contribution, it was possible to predict the energy generated from landfill biogas in relation to residual fuels in country's final energy consumption, as calculated from projections made by the EPE (2007).

Finally, it should be noted that policy incentives for energy recovery from landfill biogas will require further study because these policies would be highly beneficial for the consolidation of the National Solid Waste Policy (Brazil, 2010a, 2010b) and the National Climate Change Policy (NCCP) (Brazil, 2009). Policies with subsidies or incentive programs would enable the exploitation of the existing potential for electricity generation from landfill biogas, even for landfills that serve small populations. Such a policy could facilitate major environmental and energy gains. The NPCC (Brazil, 2009) is aimed at reducing anthropogenic emissions of greenhouse gases (GHG), including those originating from landfills. In this research context, the policy also aims to stimulate the development of the Brazilian Market for Emissions Reduction (BMER).

2. Municipal solid waste management

The most effective integrated waste management systems for the elimination of municipal solid waste are commonly recognized by the international community (Hao et al., 2008). The steps involved in such solid waste management systems, ranging from collection to environmentally sound disposal, should be planned as interrelated steps, each of which must not affect the performance of the subsequent step, and in the system must consider several dimensions recommended by the premises of sustainable development (Barros, 2013). According to Bove and Lunghi (2006), both the prevention of municipal solid waste (MSW) generation and its integrated management have been recognized by the international scientific community as the only way of reducing environmental loads related to solid waste disposal. Recycling minimizes the amount of waste to be processed and makes possible the preservation of important natural resources. Solid wastes capable of being recycled are processed to produce organic compost that can be used in agricultural processes allowing energy recovery. A portion of the remaining solid waste is then burned or gasified, obtaining additional energy and materials recovery. The final remaining solid waste is placed in landfills (Bove and Lunghi, 2006). It should be emphasized that energy recovery is still possible in landfills by means of landfill biogas utilization. However, as recognized by Hao et al. (2008), most of MSW is directly discarded in landfills without any pre-treatment or processing. In this case, according to Barros (2013), the presence of organic matter is crucial, and research on energy balances must be performed compare the benefits of composting and energy recovery from LFG.

The majority of MSW contains significant amounts of energy that can be exploited through well-established treatment and commercially available technologies. MSW has higher calorific values between 18–20 GJ/ton and lower calorific values between 8–12 GJ/ton (Poulsen and Hansen, 2009; Habib et al., 2013). There has been interest in developing efficient and economic viable technologies to effectively address waste management issues using LFG. Such biogas can be sold as high-Btu pipeline-quality gas to various utility companies, medium-Btu gas or in other forms. The biogas can also be used as a medium-Btu fuel for onsite electricity generation (Shin et al. 2005; Hao et al., 2008) or the evaporation of leachate (Hao et al., 2008). In all, despite the difficulty of recovering energy from municipal waste material, which potentially limits its use, there are still significant economic and environmental benefits in cases where the waste energy can be extracted and used (Poulsen and Hansen, 2009; Habib et al., 2013). Case studies of municipal landfills have been reported in the literature. For instance, a previous study has been created by Penteado et al. (2012) using the IPCC's First-Order Decay (FDO) Model to evaluate the biogas flow rates emitted by a Brazilian landfill. The results have been compared with those extracted to use FDO-validated values for the key parameters and correctly employ the model.