

ENERGY GENERATION FROM MUNICIPAL SOLID WASTE AND THE CURRENT SCENARIO OF BIOGAS RECOVERY IN BRAZIL

GERAÇÃO DE ENERGIA A PARTIR DE RESÍDUOS SÓLIDOS URBANOS E O PANORAMA ATUAL DA RECUPERAÇÃO DE BIOGÁS NO BRASIL

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Abstract

The landfill is a method of treatment and final disposal of municipal solid waste (MSW) widely employed all over the world, mainly in developing countries. The biogas released from landfills raises environmental concerns, as it contributes to the greenhouse effect, due to its high content of methane and carbon dioxide, and in relation to the potential damage to health caused to the surrounding populations of these areas. However, biogas has a great energy potential, representing economic and environmental advantages, making the waste disposal in landfills more sustainable in relation to these economic and environmental aspects. In Brazil, few landfills are technically prepared in recovering energy from biogas, which may be encouraged by the new Solid Waste National Policy, which aims to fit the landfills to the technical criteria of engineering, as well as to provide appropriate instructions on the waste management throughout its life cycle. The present review deals with the process of biogas generation based on municipal solid waste and some techniques that provide quantitative data on the biogas emission, and also the current scenario in Brazil related to the energy recovery from such source of bioenergy and its future potentialities.

Keywords: Energy potential; landfill; biogas.

Resumo

O aterro sanitário é um método de tratamento e disposição final para os resíduos sólidos urbanos (RSU), largamente utilizado em todo o mundo, sobretudo nos países em desenvolvimento. O biogás emitido em aterros sanitários desperta grande preocupação ambiental, já que contribui para as emissões intensificadoras do efeito estufa, pelo seu alto conteúdo de metano e dióxido de carbono, e também quanto aos danos potenciais à saúde das populações circunvizinhas aos aterros, além do incômodo olfativo. No entanto, esse gás possui grande potencialidade para uso energético, o que apresenta vantagens econômicas e ambientais, tornando a disposição do lixo em aterros mais sustentável do ponto de vista econômico e ambiental. No Brasil, poucos aterros estão preparados tecnicamente para a recuperação energética do biogás, o que deve ser impulsionado pela nova Política Nacional de Resíduos Sólidos, que visa adequar os aterros quanto aos critérios técnicos de Engenharia, bem como orientar a gestão do lixo em todo o seu ciclo de vida. Este trabalho aborda o processo da geração de biogás a partir de resíduos sólidos urbanos e algumas das técnicas que permitem estimar quantitativamente essas emissões, bem como o atual panorama brasileiro referente à recuperação energética dessa forma de bioenergia e potencialidades futuras.

Palavras-chave: Aproveitamento energético; aterro sanitário; biogás.

1. INTRODUCTION

Growing concerns about climate change, air quality, dependence on energy imports and scarcity of fossil fuel have increased the demand for renewable fuel (Rasi, Läntelä and Rintala, 2011). As a result, landfill gas (LFG) represents a more sustainable alternative source of energy, as it reduces the environmental impact at the pollutant source (Salomon and Lora, 2005). Biogas is a renewable and versatile biofuel that can be used in the production of energy and heat, or even, it can be converted into biomethane and used as vehicular fuel. Biogas can be used either at the place of production or distributed through the gas distribution system (Rasi, Läntelä and Rintala, 2011).

In landfill, the municipal solid waste (MSW) forms a unique ecosystem, where several microbiological communities develop and are responsible for the organic matter degradation. In order to promote degradation, physical, chemical and biological processes occur in the solid waste mass (Warith, Li and Jin, 2005). A large part of the domestic waste consists of biological material, whose disposal in deep landfill cells allows the establishment of suitable conditions for the anaerobic digestion. The production of methane in landfills is known for decades; however, only from the 1970s the idea of using this byproduct gained attention (Imre et al., 2009). Along with gases, the leachate produced can negatively affect the environment, if they are not properly managed.

The composition of gases resulting from the biodegradation varies from one landfill to another. Differences also occur within the same landfill, since these facilities are designed for a minimum useful life of 10 years, it is expected that the biogas generated in the oldest cells to be different than that generated in the newest cells. Also, the composition and amount of biogas generated vary according to the conditions of the biological degradation (Alcântara, 2007).

Studies on the generation potential of biogas produced in landfills from waste in different stages and degradation specific conditions are justified for several reasons. First, it is evident the importance in studying the particularities of biogas generation, once the comparison with studies carried out in other countries may not be appropriate, due to the great variation in biogas composition generated in different landfills, besides the particularities of the MSW gravimetric composition and the technologies employed in the operation of the landfills. It is known, for instance, that the MSW composition is directly related to economic conditions of the general population (Sharholy et al., 2007). Other factors mentioned by Alcântara (2007) include the climate, the seasons of the year, the population habits and the current environmental regulations. Second, the energy recovery of biogas in landfill becomes a viable option that meets the growing demand for renewable fuel and the international concern with sustainability. However, biogas has to be treated in order to remove impurities at trace level before use, which are related to toxicity, corrosion and bad smell. In addition, many gases produced in landfills contribute to the ozone layer depletion (e.g. chlorofluorocarbons) and the tropospheric ozone formation (e.g. volatile organic compounds – VOC) (Saral, Demir and Yildiz, 2009).

Determining the potential for biogas generation and predicting this generation is essential to establish recovery programs for the gas generated in landfills, since these studies provide relevant information for the technical and economic-financial assessment. This information may also support the calculation of the energy generation capacity in the biogas recovery plant, as well as the level of treatment required for its composition, which affects the final cost of energy. All these measures provide better sustainability in the management of MSW biogas emission, in order to represent a viable alternative from the economic and environmental point of view.

In such context, this review aims to present the process of biogas production from municipal solid waste and some techniques in order to estimate the generation potential for this type of bioenergy, as well as the current scenario in recovering the biogas energy produced in the Brazilian landfills and its future potential.

2. SOLID WASTE AND LANDFILLS IN BRAZIL

According to the ABNT NBR 10.004:2004 standard, the Brazilian Technical Standards Association (ABNT, Brazilian abbreviation) defines the solid waste as solid and semi-solid residues originating from the industrial, domestic, hospital, commercial, agricultural, service and sweeping activities. This concept is also extended to the sludge from the water treatment plants, and that generated in the pollution control equipment and liquids whose release in the public sewage system and water bodies is not recommended due to their particular characteristics (ABNT, 2004).

Nowadays, modern landfills are designed and operated with technology that ensures the population health and the environmental protection, whose support should remain ensured even after completion of the activities, through appropriate monitoring. Landfills can be future sources of income, since it is possible to extract some resources from them, such as methane gas, in addition to the future uses set (after the waste disposal), which include the use for leisure, parks, golf courses, among others, in line with the economic viability (Tchobanoglous, Kreith and Williams, 2002).

When studying landfills, the residue is classified as municipal solid waste (MSW). The Solid Waste National Policy (PNRS, Brazilian abbreviation) in Brazil (Federal Law 12.305/2010, instructed by the Federal Decree 7404/2010) defines the municipal solid waste as that included in the following categories: “a) household waste: originating from urban household activities; b) municipal cleaning waste: derived from sweeping, street cleaning and public spaces, and other municipal cleaning services” (Brasil, 2010a). The waste considered as relevant in landfill studies is the waste appropriate to be disposed in a landfill (or MSW); however, many landfills receive hazardous waste or material that must have a different final destination.

Municipal solid waste is today one of the main issues that raise concerns regarding the environmental aspect. Borges and Guedes (2008) pointed out that the growth rate for the waste generation is higher than that for the growth rate of the population. In addition, this generation is directly related to the economic factor, that is, the richer a country, the more waste is generated. In Brazil, the generation rate per capita ranges between 0.5 and 1.0 kg of MSW per day (Borges and Guedes, 2008).

The most recent Basic Sanitation National Research, carried out by the Brazilian Institute of Geography and Statistics – IBGE (Brazilian abbreviation), in 2008, demonstrated that, in Brazil, most cities (50.8%) dispose the municipal solid waste in open-air dumps; 22.5% use controlled landfills and only 27.7% dispose in sanitary landfills (IBGE, 2010). Landfill should be a more viable option, since they have been considered as the most acceptable economic and environmental options for disposal of municipal solid waste all over the world since 20th century (O’Leary and Tchobanoglous, 2002).

3. GENERATION AND COMPOSITION OF GASES IN A LANDFILL

Gas emission in landfills has negative impacts on the environment, due to the presence of methane, carbon dioxide and other gases at trace level. Mitigating measures that have been adopted involve methane recovery with energetic purposes and plans to reduce emissions, associated to the Cleaning Development Mechanism (CDM), which supports the initiatives intended to eliminate the open-air dumps, to promote the social inclusion and to contribute to the sustainability of the MSW management (Maciel and Jucá, 2011).

In Brazil, according to estimates for 2005, published in the Second Brazilian National Communication to the United Nations Framework Convention on Climate Change, methane emissions totaled 1.7 Tg, and from this total, 63% refers to the waste disposal. The same report also informed that the emissions of the Waste Treatment sector represented 9.6% of the total methane released in this country in 2005. Moreover, CH₄ emissions originated from the waste treatment increased 42% in the period between 1990 and 2005 (Brasil, 2010b). This data confirms the relevance and the need for studies to quantify the emissions in landfills and the energetic valuation of waste biogas.

3.1. Landfill biogas generation

Gas generation in landfills is affected by factors including waste composition, moisture content, pH, particle size, temperature, nutrients, buffering capability and oxygenation rate (Castilhos Jr. et al., 2003).

Previous characterization of the waste allows the identification of its degradability conditions and the potential to convert the biodegradable organic matter into methane, in addition to the possibility of determining the biogas production rates (and composition) and the leachate in the landfill (Bidone and Povinelli, 1999). In general, it is relevant to know the following parameters: gravimetric composition, specific mass, field capacity, moisture content, particle size, temperature and compressibility (Alcântara, 2007). The physical or gravimetric composition presents the percentage in weight for the main components of the MSW, among these, it is commonly found paper, cardboard, rag, leather, hard plastic, soft plastic, glass, organic matter, rubber, wood, iron and non-iron metals, and others (Alcântara, 2007; Bidone and Povinelli, 1999).

Waste can vary qualitatively and quantitatively as a function of aspects such as social, economic, cultural, geographical and climatic; or even factors that differ from one community to another (Castilhos Jr. et al., 2003). It is common to predominate organic matter in the MSW of developing countries (Tchobanoglous, Theisen and Vigil, 1993), while in developed countries, most components consists of recyclable waste, such as paper, cardboard, metal and plastic (Alcântara, 2007).

Temperature directly influences the bacterial enzymatic activity. It is known that abrupt changes in temperature cause imbalance for methane-producing bacteria. The production rate of methane is connected to the operating temperature in the landfill. The ideal temperature ranges for the gas generation are between 32°C and 37°C at the mesophilic operational band and from 60 ° C to 65 ° C at the thermophilic phase (Castilhos Jr. et al., 2003).

The ideal pH for methane generation corresponds to the band ranging between 7.0 and 7.2, from neutral to slightly alkaline. During the first years of waste disposal in landfill, most landfills present high acidity, however, the pH value tends to become neutral after some years (USEPA, 1991).

3.2. Landfill biogas composition

Landfill gas is formed by a variety of gases present in large amounts (main gases) and a number of other gases in very small amounts (trace gases). The main gases come from the MSW organic fraction digestion; the trace gases, even in small amounts can present toxicity, and may represent risk to the population health (Tchobanoglous, Theisen and Vigil, 1993). In the landfill gas composition, methane (60 to 70%) and carbon dioxide (30 to 40%) prevail (Imre et al., 2009), and these are the main byproducts of the anaerobic degradation of the organic matter found in the MSW (O'Leary and Tchobanoglous, 2002).

Biogas production and composition in landfills may vary significantly in time and space, due to different fillings of MSW or different materials at different sites in the landfill. Some landfill cells may have been concluded (totally filled) earlier, from 10 to 20 years, than more recent cells. In addition, some cells may have received other types of waste, such as sludge or industrial waste (Rasi, Läntelä and Rintala, 2011), which, although not allowed and not ideal, may occur in landfills, mainly where the operation is less rigorous or careful.

In general, some factors may influence the landfill gas composition, which are: the type of MSW landfilled; the stage of the decomposition process (Brosseau and Heitz, 1994); the operational conditions, such as the landfill covering system (Brosseau and Heitz, 1994; Rasi, Läntelä and Rintala, 2011); temperature, pH, moisture, the heterogeneity of the MSW, among other aspects. The waste

disposed may also contain high concentration of sulfur in its composition, which results in higher emission of sulfur in the biogas (Rasi, Läntelä and Rintala, 2011).

Cooper et al. (1992) stressed that several studies were carried out aiming to characterize the landfill gas emission. However, large variation in the composition of gases was observed and over 50 types of volatile organic compounds (VOCs) were identified. Some of these compounds are: simple alkanes, olefins, aromatic compounds, and chlorinated compounds, besides other substances that are known as or suspected of being carcinogenic, such as benzene and vinyl chloride (Cooper et al., 1992). Tchobanoglous, Theisen and Vigil (1993) also highlight other substances among the VOC present in the biogas, at trace level: dichloromethane, toluene, acetone, tetrachlorethylene, xylenes, chloroform, chlorobenzene, methylethylketone, among others; and the organic acids and ketones as examples of odorous gases.

Regarding the concentrations of trace compounds, some variation also occurs in different landfills as well as variations in time. This variation depends on the amount and the quality of the waste, as well as on the weather conditions of each place (Rasi, Läntelä and Rintala, 2011).

The concern about the effects of trace gases in the landfill biogas has increased recently. This is because the composition of these gases reflects on the waste properties, and that the trace gases are an indicator of volatile contaminants coming from this waste (Assmuth and Kalevi, 1992). In addition, given recent advances in the use of biogas as source of energy with different applications, more attention has been focused on the biogas specific composition.

Additionally, the landfill gas presents some occupational risk, since the landfill staff are exposed to hazardous gases, dust and risk of explosion (Assmuth and Kalevi, 1992). A study performed by Assmuth and Kalevi (1992) measured the concentrations of around 30 trace gases of organic contaminants, aliphatic and halogenated, from samples collected from landfills with 3 years of age (concluded), and also in an active landfill in Southern Finland. The chloromethane, chloroethene and aromatic compounds reached 100 mg.m^{-3} , which exceeded the acceptable levels (background concentration), for the urban environment, up to 100,000 times. Of the compounds analyzed, among those that represent higher toxicological risk, due to the concentrations and acute toxicity, or carcinogenicity, are carbon tetrachloride, dichloromethane, toluene and benzene (Assmuth and Kalevi, 1992).

Although the landfill workers are exposed on a daily basis to trace gases with toxic and odorous potential, the population around this area also suffers from the odorous effects of the emissions (Saral, Demir and Yildiz, 2009) that requires action towards minimizing these adverse effects.

4. BIOGAS PRODUCTION POTENTIAL IN THE LANDFILL

For the purpose of biogas recovery emitted in the landfill, further studies are necessary, concerning the potential for methane generation in relation to each landfill of relevance, which also allow analyses of the economic-financial viability, fundamental for implementing such a project.

The chemical characteristics of the MSW of the landfill are determining factors in the calculation of the methane potential, since they reveal the portion of waste that can really be converted into gas (Maciel, 2009). The theoretical yield for the operational life of a landfill should lie within the interval of 150 to 300 m^3 of biogas per ton of MSW, with around 50 or 60% methane in volume. In terms of energy, this is equivalent to 5 or 6 GJ per ton of waste. It is relevant to emphasize that the yield should in fact be lower, once the conditions are more diverse in the field than in a biodigester, for instance, with lower temperature and humidity levels, which result in a slower process that extends for years instead of weeks (Imre et al., 2009) compared to bench scale reactors.

Several techniques can be employed to estimate biogas production and its composition in landfills: vent sampling, passive sampling, area-of-influence method and the flux chamber method, which is considered (by the authors) as having the highest accuracy, simplicity and flexibility (Cooper et al., 1992). All these methods refer to field studies.

The assessment of the potential to generate methane can also be achieved through experimental studies. It can be carried out in bench scale reactors (laboratory scale study), lysimeters or in pilot-scale (*in situ*). Field studies present limitations regarding the monitoring period and the fugitive emissions, implying a certain degree of uncertainty in determining the potential to generate biogas. This uncertainty can be reduced by the extrapolation in the curves of gas generation of the landfill (Maciel, 2009).

The potential to generate biogas can also be estimated from theoretical models. The models for estimating the methane production in landfills are useful tools to estimate such emissions over time, from a mass of confined waste in a landfill. These models can be used for dimensioning the biogas collection systems, evaluating and projecting the energetic production. When compared to other methods (eg. field methods), the theoretical models have many advantages, such as the low cost and the results that can be observed in the short term (Vogt and Augenstein, 1997).

A zero-order model indicates that the methane generation rate disregards the amount of remaining substrate or the amount of biogas already produced (Abrelpe, 2013).

First-order models are the most widely used models of gas generation in landfill nowadays (Abrelpe, 2013). This type of model uses the effect of the degradation time of the MSW as a variable, considering that the degradation follows a first-order kinetics (microorganisms remain constant during the decomposition). The main variables are: generation potential (L_0) and CH_4 generation constant (k) (Maciel, 2009).

A first-order decay model can be used to obtain the generation rate of methane over time. This type of approach has been widely used over recent years for modeling the gas generation rate curve in individual landfills and in a set of waste disposal areas, enabling to estimate emission rates for countries or regions (IPCC, 1996). IPCC (1996) presents the equation of a first-order decay model, as follows (Equation 1):

$$Q = L_0 \times R \times (e^{-kc} - e^{-kt}) \quad (1)$$

Where:

Q = methane generated in the current year ($m^3 \cdot year^{-1}$)

L_0 = methane generation potential ($m^3 \cdot Mg_{MSW}^{-1}$)

R = annual average acceptance of waste throughout operational life ($Mg \cdot year^{-1}$)

k = methane generation rate Constant ($1 \cdot year^{-1}$)

c = time since the closure of the MSW disposal cell (year)

t = time since the opening to the MSW disposal cell (year)

Variants of this type of model are widely employed, and even United States Environmental Protection Agency (USEPA) developed a computer version to be applied in a first-order model (Vogt and Augenstein, 1997), the LandGEM. The USEPA LandGEM is considered a standard first-order model in the landfill gas segment, which must be used in landfill biogas emission estimates in the United States, regulated by the USEPA, through the Clean Air Act (CAA) (Abrelpe, 2013).

The traditional first-order models for predicting biogas generation must be used carefully in locations with different climate characteristics since, as pointed out by Maciel and Jucá (2011), the waste degradation in large-scale experimental cells in tropical humid climate was around four or five times as fast as the predicted for such models, when default values are used. The biogas generation was also higher than the reported in the literature for similar cells. This performance can be attributed to the physicochemical characteristics of the waste and the climate conditions in the region under study (Recife, Pernambuco State) (Maciel and Jucá, 2011).

Machado et al. (2009) used first-order decay models to fit the field data to the laboratory data, regarding the methane generation from municipal solid waste. The field data was obtained in the Metropolitan Landfill, in Salvador, Brazil. The laboratory data was obtained from analyses of waste

with different ages. The values obtained for k and L_0 were very similar to those measured in the field, indicating that the method employed is interesting for a first approximation (Machado et al., 2009).

Aguilar-Virgen et al. (2014) carried out an estimation of biogas production from MSW in the city of Ensenada, northwestern Mexico. For this purpose, the variables k and L_0 were adjusted to local conditions, in which the value obtained for k was 0.0482 year^{-1} and for L_0 was $94,457 \text{ m}^3 \cdot \text{t}^{-1}$. The local variables were inserted in the model *2.0 Mexico Landfill Gas Model*, as proposed by *Stearns, Conrad and Schmidt Consulting Engineers, Inc. (SCS Engineers)*. The results revealed a 26% increase in the generation estimate in relation to predictions employing default values (Aguilar-Virgen et al., 2014). This evidences that the default values can lead to estimation errors, since they are approximations and depending on the purpose of the results, this variation may hinder the application of the landfill biogas recovery program.

5. BIOGAS RECOVERY WITH ENERGETIC PURPOSES IN BRAZIL

Brazil is still highly dependent on hydroelectric power. In 2001, due to the lack of this type of energy and the need to prevent future energy crisis, Brazil released incentive programs for thermal and renewable energy, for instance, the PROINFA (Brazilian abbreviation for Incentive Program for Alternative Sources of Electrical Energy) (Anselmo Filho and Badr, 2004). Anselmo Filho and Badr (2004) identified a great potential to biomass energy in Northeastern Brazil, in which only from the municipal solid waste it was estimated a potential of 16.7 TWh.

The recovery of landfill biogas with energy purposes and reduction in the methane emissions combined with the commercialization of carbon credits and the social insertion, emerge as a more sustainable solution for the biogas problem. Nevertheless, even with incentives provided by governmental entities in Brazil and all over the world, such as the resources coming from the Clean Development Mechanism (CDM), proposed by the Kyoto Protocol, there are few Brazilian experiences with the use of biogas in a commercial scale (Maciel, 2009). Nowadays, there are 46 CDM projects in Brazil comprising solid waste and landfills. From this total, 23 include the use of biogas energy, and 22 are destined to electric power generation (with 254 MW installed capacity of generation) and only one project was intended to purify biogas to be included in the natural gas distribution net, and only this single project was withdrawn by the proponents. The installed capacity to generate electric power, declared in the Project Conception Documents, is about 254 MW. Regarding the distribution by regions, the projects were distributed as follows: 16 in the Southeast, 4 in the Northeast and 1 in the North region (Abrelpe, 2013).

According to information provided by the Brazilian Association of Special Waste and Public Cleaning Companies (ABRELPE – Brazilian abbreviation), based on the data from the year 2012, there are 2 CDM projects in Brazil on the electricity generation, which are: Bandeirantes Landfill, generating 755,700 MWh, and the São João landfill with 476,900 MWh, totaling approximately 1.2 million MWh. The same research carried out by ABRELPE identified another landfill gas energy generation project, in the Salvador Landfill (Bahia) but, in this case, there are no data available on the commencement date for the operations or even for generation.

In relation to the capacity of the biogas from landfills to generate electricity, considering the energy potential, biogas presents from 22,500 to 25,000 kJ m^{-3} of heating value, while methane presents around 35,800 kJ m^{-3} . When treated, the biogas heating value can reach up to 60% of that value showed by the natural gas (Salomon and Lora, 2005). In order to produce electricity and heat from biogas, there are several technologies available, such as boiler, internal combustion engine, gas turbine and fuel cell (Rasi, Lantela and Rintala, 2011). The landfill gas (LFG) can also be employed as a low yield fuel; however, this requires a minimum processing of the gas, such as a condensate removing chamber, in order to reduce the humidity present in the gas. After that, gas can be transported to the consumer, usually through a pipeline, extracting from the own landfill or externally to it, for use in the heating of environments and processes, as fuel in boilers for steam production, for heating or electrical energy through steam turbines, besides the use to heat greenhouses and ovens,

among others (Abrelpe, 2013). It is attractive to use landfill gas for heating, mainly due to the low cost and the efficiency in energy conversion, which is higher in the use for heating than when used to be converted into electrical energy. Since there is a regular demand and the consumer is located near the landfill (preferably within 10 km), the low yield fuel can be a profitable alternative. Another relevant aspect is that, due to the low heating value of the raw LFG, it is necessary that the equipment is designed to receive this type of fuel and can bear the presence of trace gases, which may be corrosive.

The use of methane produced from the treatment of the MSW in the landfill, besides helping to reduce the operational costs, can also be a profitable process. While the sources of fossil fuel tend to exhaust, the methane production from renewable resources will become relevant in the strategies of energy management (Imre et al., 2009).

Thus, besides being interesting from an environmental perspective, the recovery of landfill biogas with energy purposes can be a viable alternative considering the economic-financial aspect, which should be considered in the planning and management of landfills and in the energy policies, remarkably in developing countries, such as Brazil, where the energetic use expected for the landfill gas is still low.

6. FINAL REMARKS

In Brazil, as the income increases along with the consumption of goods and services, a growing volume of waste generated has also been noticed. The most common treatment of waste and final disposal is the disposal in the ground, which includes the confinement in regular landfills, within engineering criteria, or inappropriate methods such as the open-air landfill (Barros, Tiago Filho and Silva, 2014).

The enactment of the Federal Law 12305/2010, regulated by the Federal Decree 7404/2010 started the new Solid Waste National Policy (PNRS, in the Brazilian abbreviation) in Brazil, bringing a new challenge for solid waste management in the country. The main changes regard the concept of shared responsibility, being implemented through the reverse logistics. Thus, the responsibility for the waste is shared among governments, private institutions and population (Brasil, 2010a). The first objective of the new PNRS is to reduce the amount of waste and to ensure appropriate final disposal of the materials that cannot be recycled or reused, promoting improvement of the population health and preservation of the environment. With this new regulation, municipal administrations, which are responsible for waste collection and proper destination in the cities, must terminate the open-air dumps operation by the end of 2014, and to implement selective collection and to license landfills in line with the legal and environmental requirements (Brasil, 2010a).

Since the Brazilian municipalities are committed to not dispose waste in open-air dumps, the number of landfills shall increase significantly, promoting a potential increase for biogas generation with energetic purposes. Then, Brazil presents a scenario of great potential for future gains, whether environmental, economic-financial or social, with the recovery of biogas generated in landfills, mainly after 2014.

There is a need to stimulate the use of landfills as source of renewable energy, expanding viable initiatives, from the economic-financial overview, in order to recover the landfill biogas energy, mainly for populations fewer than 200,000 inhabitants, which are below the number considered financially attractive. Also, considering the environmental relevance of the landfill biogas and the need to decentralize the energy generation, these policies enhance the generation and use of waste energy, making the landfill the most sustainable option for waste management in Brazil (Barros, Tiago Filho and Silva, 2014).

Therefore, a favorable scenario is presented for implementing Brazilian plants for landfill biogas recovery. Additionally, the bioenergy from the MSW contributes not only to reduce the dependence on the fossil fuel sources but also to reduce the emission of greenhouse gases, and also to allow the commercialization of carbon credits through the Kyoto Protocol Mechanisms. This type of biogas can also be an important alternative source of energy, reducing the risk of power failures and

helping to create a self-sufficient energy source in landfills, or even becoming a source of financial gain, by selling the surplus energy through local distribution nets.

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