TECHNICAL AND ECONOMICAL FEASIBILITY ANALYSIS OF ENERGY GENERATION THROUGH THE BIOGAS FROM WASTE - GRAMACHO, CAIEIRAS AND SANTO ANDRE LANDFILLS

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Abstract. *The power generation through biogas from wastes in landfill is a way to reduce the consumption of fossil fuels, beyond finding solutions environmentally sustainable to collaborate with the energy matrix of the countries, turning it more diversified and reducing the global impacts provoked by the burning of the same ones. Green house gas emissions are additionally avoided by methane combustion in the electrical energy generation facility. Furthermore, the use of large landfills (and other inadequate ways of urban solid wastes treatment) in great urban centers are still common, which causes sanitary and ambient problems. This study aims at estimating the methane production rate in the Gramacho landfill located in the state of Rio de Janeiro and Santo André and Caieiras landfills located in the state of São Paulo. In the Gramacho landfill the waste disposal occurred between 1993 and 2010. In the Santo André landfill the waste disposal occurred between 1986 and 2009, and in Caieiras landfill, it occurred between 2002 and 2009. Comparative studies are presented demonstrating when gas turbine, internal combustion engines (Otto or Diesel cycles) or other technologies of energy conversion have technical and economical feasibility for implantation of the thermoelectrical plant.*

Keywords*: Renewable energy, Biogas and Landfill*

1. INTRODUCTION

Waste disposal in landfills can generate environmental problems such as water pollution by leachate, unpleasant odors, risks of explosion and combustion, risk of asphyxiation, vegetation damage, and greenhouse gas emissions (Popov, 2005). In underdevelopment countries, these are accomplished by social problems as underemployment, accidental contamination, diseases dissemination and diseases vectors propagation since poor population inhabit landfill neighborhoods and there are poor or no people access control to landfills, who are looking for recycling materials.

Landfill gas is generated under both aerobic and anaerobic conditions. Aerobic conditions occur immediately after waste disposal due to entrapped atmospheric air. The initial aerobic phase is short-lived and produces a gas mostly composed of carbon dioxide. Since oxygen is rapidly depleted, a long-term degradation continues under anaerobic conditions, thus producing a gas with a significant energy value that is typically 55% methane and 45% carbon dioxide with traces of a number of volatile organic compounds (Meraz et al., 2004 and Zamorano et al., 2007) The anaerobic process begins after the waste has been in the landfill for 10–50 days. Although the majority of CH_4 and CO_2 are generated within 20 years of landfill completion, emissions can continue for 50 years or more (Popov, 2005).

According to prediction of the United Nations Organization (United Nations, 2002), the world-wide population must grow until 2050 about 40% in relation to 2002, reaching 8,9 billion people. The Agenda 21 from ECO-92 Conference foresees the duplication of the amount of residues produced in the world until 2010, based on values of 1990 and they will quadruplicate until 2025 (United Nations, 1992).

The production of domiciliary wastes in Brazil varies between 0,5 and 1,2 kg/inhabitants/day. So, the national daily production of domiciliary residues is estimate in 120 thousand tons, which must be added to, between 30 to 40 thousand tons of residues collected in the public areas, to know the total garbage that must be adequately treated and destined each day (Ferreira, 2000).

2. BRAZILIAN ENERGY MATRIX AND BIOGAS FROM MUNICIPAL SOLID WASTE (MSW)

Brazilian Energy Matrix is compound of approximately 48.4% from renewable energy sources and 51.6% from non renewable ones (EPE, 2009).

Nearly 80% of electricity in Brazil is originated from hydro plants, not considering that thermal generation is mainly originated from biomass. World average for renewable generation is 15.6% (EPE, 2009). So, Brazil has one very advantageous position in facing global environmental problems.

In Brazil, 149,199 tons of municipal solid wastes (MSW) have been daily collected (ABRELPE, 2009). The national average daily production is 0.950 kg per capita.

Table 1 shows MSW disposal in Brazilian geographical regions.

Table 1. MSW disposal in Brazil

Region	Total (tonnes/day)	Open dump	Control Landfill	Landfill	Others
North	11.067	56,7%	28,3%	13,3%	1,7%
Northeast	41.558	48,2%	14,6%	36,2%	1,0%
Southeast	141.617	9,7%	46,5%	37,1%	6,7%
South	19.875	25,7%	24,3%	40,5%	9,5%
Center-west	14.297	21,9%	32,8%	38,8%	6,5%
Brazil	228.413	21,2%	37,0%	36,2%	5,6%

Source: IBGE, 2001

2.1 Biogas from Urban Solid Wastes

The biogas generated in landfills is composed of methane (CH_4 , 55 - 65%), carbon dioxide (CO_2 , 35 - 45%), nitrogen (N_2 , 0 - 1%), hydrogen (H_2 , 0 - 1%) and sulfidric gas (H_2S , 0 - 1%) (Polprasert, 1996).

Taking in account a period of 100 years, the methane contributes 21 times more for global warming than the carbon dioxide (UNFCCC, 2007). Methane complete combustion results in carbon dioxide and water vapor.

Biogas generated in landfill starts after the beginning of wastes deposition and continues for about 15 years after the landfill had been closed. For one ton of residue in a landfill, it is generated about 200 Nm^3 of biogas. In order to the biogas can be explored commercially through its energy recovery, the landfill must be able to receive at least 200 tons/day of wastes, and must have a minimum capacity of reception of about 500,000 tons throughout its useful life combined with a minimum height of loading of 10 meters (World Bank, 2005).

Actually in Brazil the alternatives of handling of biogas from landfill are:

- Capture of biogas and its total burning in flare, aiming at only the reduction of the global warming potential from methane to carbon dioxide in the ratio 21:1;
- Capture of biogas without treatment to distribute it to the community or conduct it already purified for to be added to the natural gas network for domestic supplying, or still, used as fuel for vehicles. (DANESE, 1981 in Duarte and Braga, 2006).
- Capture of biogas for utilized as fuel in a thermoeletrical for electrical energy generation.

3. OBJECTIVE

This paper aims at presenting a Technical and Economical Feasibility Study (TEFS) of energy generation through biogas from waste in landfills. This study aims at estimating the methane production rate in the Gramacho landfill located in the state of Rio de Janeiro and Santo André and Caieiras landfills located in the state of São Paulo. In the Gramacho landfill the waste disposal occurred between 1993 and 2010. In the Santo André landfill the waste disposal occurred between 1986 and 2009, and in Caieiras landfill, it occurred between 2002 and 2009.

4. METHODOLOGY

LandGEM model was proposed and gradually refined latter by the USEPA. It is based on the first-order decay equation. The corresponding model software is widely used because of its clarity and simplicity. The originality of the model comes from the aspect that it considers the kinetic of decomposition of different type of organic waste. The mass of methane generated is assumed to be a function of methane generation potential (L_0) and the mass of degradable waste deposited. In addition, it assumes that the production of methane is not affected by its concentration. For its complete determination, it is further projected the methane capacity to be 50% and 50% carbon dioxide by volume of the total LFG (EPA, 2005).

For accomplishment of the TEFS, it was carried out a survey of technical options of power generation from biogas, as well as determination of the potential of biogas to be produced and the estimated electricity generation. For biogas generation potential calculation, it was used the model recommended by the United States Environment Protection Agency (EPA, 2005).

For biogas generation potential calculation, it has been used the model recommended by the United States Environment Protection Agency, showed in Equation 1 (EPA, 2005).

$$Q_M = \sum_{i=1}^{n} 2\,k\,L_o\,M_i\,(e^{-kti}) \tag{1}$$

where:
QM = methane generation (m³/years);
L_o = potential methane generation capacity (m³/tonnes);
Mi = annual waste disposal in year i (tonnes);
k = methane generation (decay) rate constant (1/years);
t = time elapsed (years);
i = time increment in one year.

The USEPA model requires that the site's waste disposal history (or, at a minimum, the amount of waste in place and opening date) be known. The model employs a first-order exponential decay function, which assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation. The USEPA model assumes a one-year time lag between placement of waste and LFG generation. After one year, the model assumes that LFG generation decreases exponentially as the organic fraction of waste is consumed.

5. ESTIMATING THE METHANE PRODUCTION RATE

5.1 Santo André and Caieiras Landfills

Santo Andre's landfill is a complex of treatment and solid waste final destination. This landfill have an area of 217.000², destined to receive the solid wastes produced in Santo Andre's landfill, had the activities initiated since 1986 and has forecast to finish your actives 2016. Currently the complex operates with the capacity of solid waste reception approximately 20,000 tons/month.

The results had been gotten considering the real deposition tax of USW in Santo Andre's landfill. The parameters used of the USEPA for conventional landfill and World Bank had been produce estimated realistic and gas production tax. It has deposition registers of the USW in landfill of form that are known the characteristics, dates and deposition place. The Figure 1 shows the deposition tax of USW in Santo Andre's landfill in function of the time, where all the data had been gotten of registers carried through landfill, except the referring data to the year of 2009 that it was estimated.

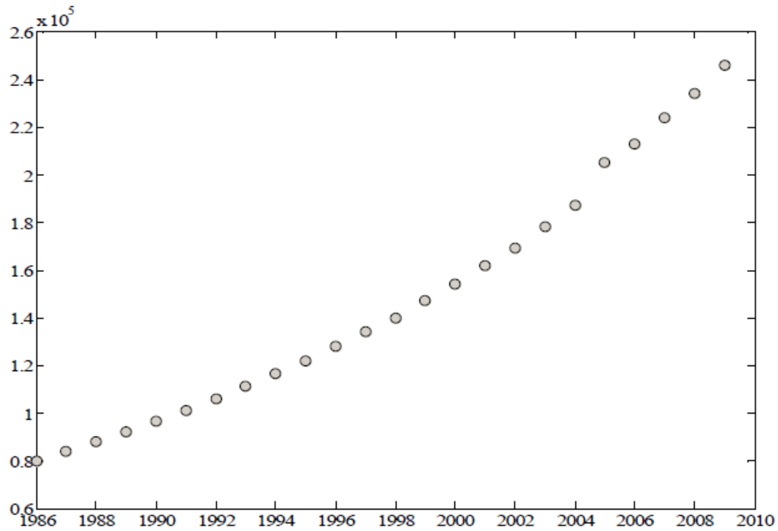

Figure 1. USW deposition tax in Santo Andre's landfill
Source: Semasa, 2010

Figure 2 are presented the methane production estimated in Santo Andre's landfill in accordance with conventional USEPA model, World Bank, for presented values greaters and minors of methane production tax.

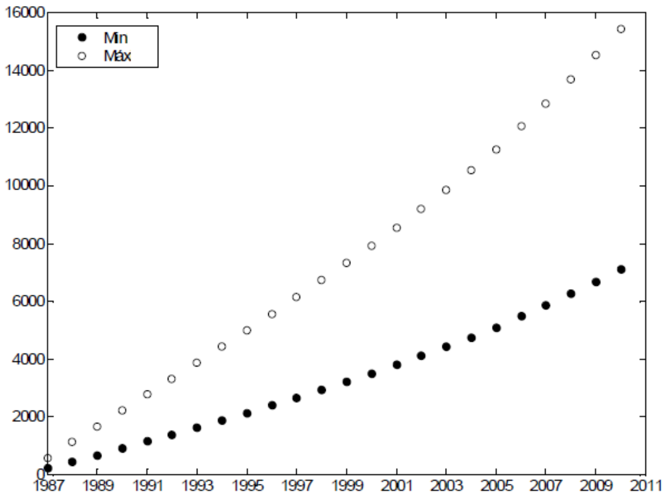

Figure 2. Methane production of Santo Andre's landfill (tons/years)
Source: Silva (2010)

The Caieira's Waste Treatment Center (CTR- Caieiras) has been situated it the northwest of the Metropolitan Region of São Paulo. The landfill area is of 3,5 million m^2 and the activities of landfill had been initiated in 2002. Caieira's landfill operates approximately with the reception capacity of 240,000 tons/month of urban solid wastes.

The methane production estimates in Caieiras landfill had been carried through considering real deposition tax. The parameters of the USEPA for landfill conventional, World Bank and of the Project of the Essencis had been used. The Figure 3 shows the USW deposition tax in Caieiras landfill in function of the time.

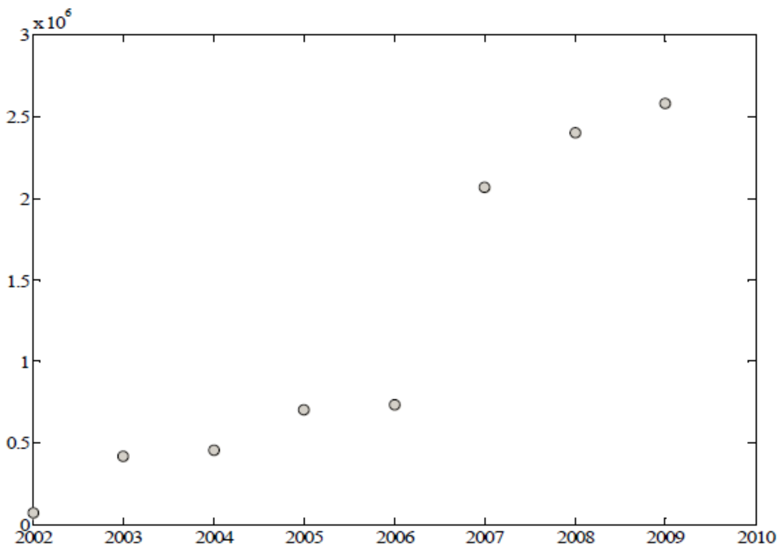

Figure 3. USW Deposition tax in Caieiras landfill (tons/year)
Source: Essencis (2010)

Figure 4 is presented the methane production estimates in Caieiras landfill in accordance with the models of the conventional USEPA, World Bank and the estimated of Essencis Project (Proj). The results in this biogas production estimated mention it waste depositions realized 2002 to 2006, and presented in Figure 3.

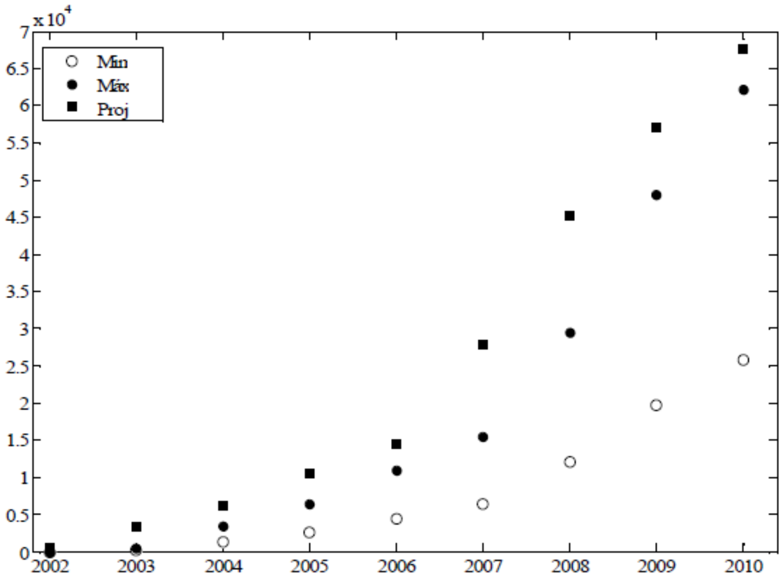

Figure 4. Estimated Methane production tax with estimated deposition in Caeiras landfill (tons/year)
Source: Silva (2010)

Figure 5 is presented the estimates of methane production in Caieiras landfill in accordance with the models of the conventional USEPA (inferior limit), World Bank (superior limit) and the measured in Caieira landfill. For such, had been used real deposition taxes that are presented in the Fig. (3). The results show that the measured values are between the estimates upper and lower of this work, however must be noticed that nor all gas is collected by the system of suction of the installation. Part of the gas escapes for the atmosphere and a part is oxidated into of landfill.

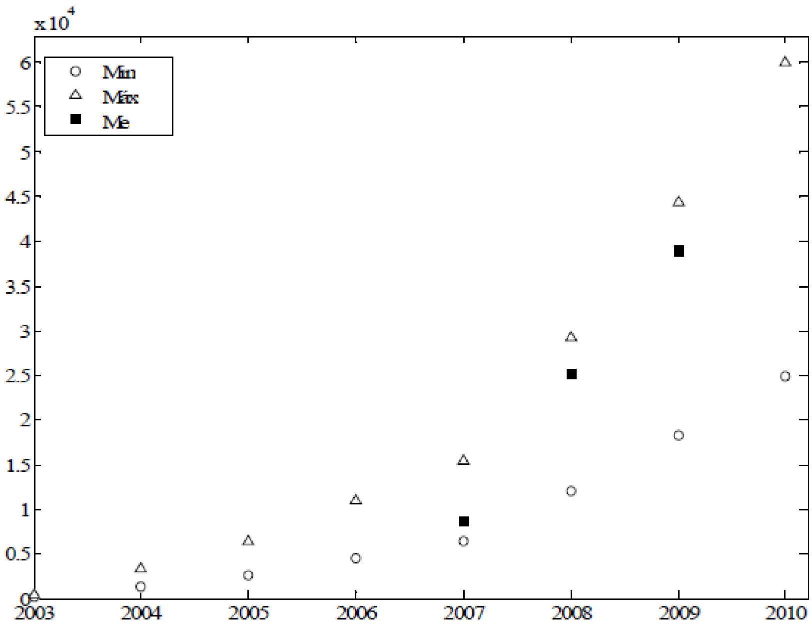

Figure 5. Estimated Methane production tax and measured value in Caeiras landfill (tons/year)
Source: Silva, 2010.

5.2 Gramacho Landfill

Table 2 exhibits annual and accumulated garbage deposition in Gramacho's landfill. The adopted values for the parameters speed of degradation (k) and potential methane generation capacity (L_0) are respectively 0,060 and 84,8 m³/Mg (SCS Engineers, 2005).

Table 2. Solid waste disposal in Gramacho's landfill

Year	Waste Disposed (tonnes)	Waste in Place (tonnes)
1993	1.646.374	1.646.374
1994	1.669.443	3.315.817
1995	1.800.209	5.116.026
1996	2.325.161	7.441.187
1997	2.414.508	9.855.695
1998	2.390.021	12.245.716
1999	2.403.311	14.649.027
2000	2.454.563	17.103.590
2001	2.417.409	19.520.999
2002	2.473.918	21.994.917
2003	2.359.715	24.354.632
2004	2.400.000	26.754.632
2005	2.400.000	29.154.632
2006	2.568.000	31.722.632
2007	2.747.760	34.470.392
2008	2.920.000	37.390.392
2009	3.000.000	40.390.392

Source: Comlurb, 2010.

The Methane decay rate constant (k) is a function of refuse nutrient availability, pH, temperature and, in particular moisture content. For the Gramacho Landfill evaluation, k is 0.06 based on the degradability of the waste components (SCS Engineers, 2005).

The methane recovery potential (Lo) is the total amount of methane that a unit mass of refuse will produce given enough time, and is a function of the organic content of the waste. For the Gramacho Landfill, started with a default Lo value based on 1,140 mm of annual precipitation, and then adjusted this value based on the ratios of organic and moisture contained in U.S. waste and waste at the Landfill. The methane recovery potential for Gramacho Landfill is 84,8 m³/Mg (SCS Engineers, 2005).

5.3 Technical solutions for energy generation in landfills

Most suitable conventional technologies for direct electric energy conversion from biogas are gas turbines and internal combustion engines, since steam turbines require a furnace for steam generation. From small to medium power generation capacities, internal combustion engines are more appropriated because of its lower cost and greater efficiency in this range. Only for higher capacities, gas turbines are competitive, and their yielding is improved when they are used in combined cycles.

Internal combustion engines are more efficient within the operation range of this project. Diesel cycle engines work on higher compression rates, requiring that biogas is fed mixed with diesel or biodiesel, which would represent an additional input to the energy facility. Moreover, in the Brazilian internal market, Otto cycle engines can be more easily adapted to operate with biogas.

Figure 6 shows the energy efficiency in function of the Thermoelectric Plant (TEP) capacity, for gas turbines, internal combustion engines (Otto and Diesel cycles) and combined cycles. Gramacho's potential power generation has been estimated at 10MW, internal combustion engines present better performance than gas turbines for this application.

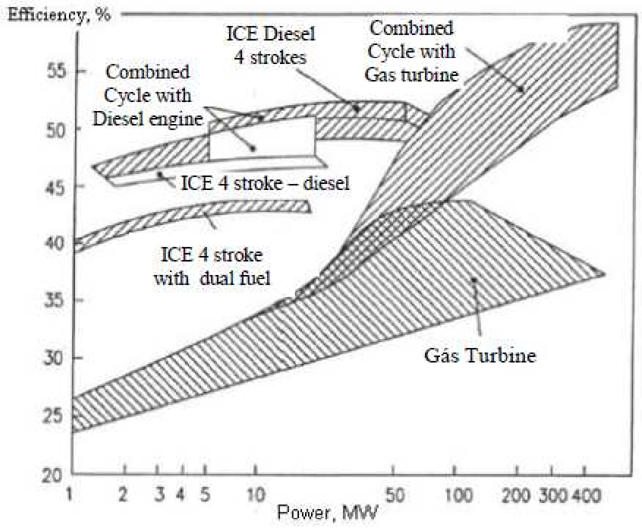

Figure 6: Efficiency analysis among diverse energy conversion technologies
Source: Lora and Nascimento, 2004

5.4. Economical analysis

The economic issues have been evaluated utilizing the projection of the capital and annual costs described in this item, as well as expected incomes presented below. In this evaluation, they have been presumed that the income flows include the generated electricity sale and the economy of avoiding purchasing it to attain energy needs of the landfill. They also include incomes associated with reduced emissions of GHG.

The following basics assumptions have been considered:

• The economical analysis is carried out through a 15-years period;
• Two financing options have been evaluated: one without financing of capital expenditures and another with a 75% financing of the initial capital expenditures;
• Recipes from RECs have been included, with the selling price of US$ 17 per ton of CO_2 equivalent;
• The same 8% interest tax has been adopted for the Liquid Present Value (LPV) determination and for the financing of the loan;
• The loan's payment period for the initial investment is 15 years;
• The payment of approximately 20 percent of REC recipes to the landfill proprietor for the biogas use has been considered, representing a tax of $0.43/MMBtu;
• The value of biogas has a 3% annual readjustment;

Table 3 shows a summary of the results of the economic evaluation in the scenario of the energy plant, having presented a composition of financing options, sale price of the Reduced Emissions Certificates and duration of the project using the LPV and RIT. These values include as many incomes of the certified sales how much incomes from the biogas use. The results do not include calculations of taxes.

Table 3. Sumary of Economic evaluation (Plant of Energy)

Value of the Initial Investment	Percentual value of the Initial Investment of capital (%)	LPV	RIT
R$ 15,514,880	100	$ 11,659,887	17,44%
R$ 15,514,880	25	$ 10,797,949	24,22%

As demonstrated in Table 3, the economic projections of the TEP are presented attractive (positive values for LPV and RIT) for both financing scenarios. The main point between (RIT and LPV) for analysis of investment analysis is the LPV. Therefore, the project to be chosen between the two options above will be those with the greatest LPV.

6. CONCLUSIONS

In this article, some methodologies of methane production estimate had been evaluated in many landfills (Santo Andre-SP, Caieiras-SP and Gramacho-RJ) and could be established that the methodology of the conventional USEPA supplies an inferior limit of value of gas production and the methodology of the World Bank supplies a superior limit. Given the great involved uncertainties in these estimates, these results can be used as limits inferior and superior of methane production tax In landfill.

The production of energy from wastes generates great opportunities for the landfill construction and operation market that starts to have a net recipe. So, the landfill operator will have financial resources for applying in pollution control equipment and initiatives, reducing landfill environment impact.

Analyzing from technical, economical and environmental points, the energy production through biogas from landfill represent profits for:

- the society (generation jobs and reduction of under employment);
- the city halls (represent an extra source of income with the commercialization of the biogas generated energy); and
- the environment (reduction of CH_4 emissions, reduction of odors in the landfill due to good management practices).

Based on results of the TEFS, the landfill biogas energy exploitation of Gramacho's Landfill is viable taking as reference the value of REC in $10 of ton.$CO_2$eq and any of the financing options analyzed.

The results are based on limited factors of contingency enclosed in the estimates of capital and the operation and maintenance costs. Improvements to be added in some of the used estimates in the economic evaluation, mainly the electrical sale price, can positively modify the results of this analysis. However, the implantation of a TEP through biogas from waste, generates diverse contributions for the country (mainly locally), amongst which we have the main ones:

- Contribution for the local ambient support:

A project of this port will contribute for the improvement of life quality of the surrounding population, since the project includes the treatment of the landfill generated biogas, that for containing other composites beyond the methane in its constitution, they provoke distasteful smell in neighborhood. Moreover, the project will also contribute for the reduction of explosion risks in the case of occurrence of high gas concentrations in landfill interior.

- Contribution for the development of better working conditions:

The project will be important for jobs generation. Beyond all the implantation phases, that will demand considerable amount of laborers (direct job), it exist the demand for workers in its operation phase.

- Contribution for the income distribution:

Great part of the work will be carry out by operators with low qualification who will be trained especially to understand basic mechanisms of functioning of the project, either in the biogas capture or its treatment, or in the generation of energy. Contribution for the regional development can be measured from the integration of the project with other partner-economic activities in the region of its implantation. It is important to stand out that construction services and later maintenance of the plant also are necessary, putting into motion sectors as transportation, construction and technical servicing.

The following measures are being suggested to promote the growing of energy production through biogas from the waste:

• Adoption of fiscal favorable instruments as, for example, "ICMS green".
• Dissemination of technical and economical data on construction and operation of landfill with exploitation of biogas, as well as the achieved benefits.
• Simplification of the environmental licensing procedures for landfills, that currently are complex and slow;
• Establishment of special credit lines by development banks (as BNDES and World Bank) with favored taxes and dedicated calls in official researching support agencies to promote the scientific initiation and technological innovation for energy exploitation from biogas in landfill.

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7. RESPONSIBILITY NOTICE

The authors (Fábio Viana de Abreu, Manoel Antonio Fonseca da Costa Filho) are the only responsible for the printed material included in this paper.