TECHNICAL AND ECONOMICAL FEASIBILITY ANALYSIS OF ENERGY GENERATION THROUGH THE BIOGAS FROM GARBAGE IN LANDFILL - A NEW ALTERNATIVE OF RENEWABLE ENERGY GENERATION

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Abstract. The power generation through Biogas from wastes in landfill is a way to reduce the dependence 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. The intensification of human and industrial activities in the last few decades has generated one sped up increase in the production of urban solid wastes (USW), becoming a serious problem for public administrations. The disordered rise of the population and the increase without planning of great urban nuclei make actions on residues handling very difficult. 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. In this paper, Gramacho's landfill was chosen as study case. The more important environmental contribution associated to this project is the reduction of greenhouse gases emissions (GHG), by means of the conversion of methane in carbon dioxide, since the methane has a potential of global warming about 21 times higher than carbon dioxide. Comparative studies was 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, Landfill and Biogas.*

1. INTRODUCTION

It is essential for the sustainable development to adequately solve the final disposal of solid wastes in an integrated way, since its origin until final disposal. The ideal approach for this problem must include minimizing the generated amount of residues, their recycling, reutilization and the reintegration of materials. This is the principle of the four "Rs" concept: "to reduce, to recycle, to reuse and to environmentally reintegrate it".

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 amount of garbage generated by the societies are increasing in the whole world, either due to population increase, either due to increment of the per capita production of residues. Additionally, current production and consumption models prioritize the use of disposable materials and products, not taking in account the necessity of maintenance of a sustainable ambient. The characteristics of a consumption model have direct impacts on the environment as much from the way of use of natural resources and energy for the production of goods as for the generation of residues, discarded from human activities.

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).

However, adversely to the increase of population and urban agglomerations, it takes place the reduction and consequently price increasing of the available sites to be destined to the implantation of landfills.

In accordance with the above mentioned, it justifies the present proposal as a new technological alternative, to the appropriated management of the garbage. This aims at energy generation through Biogas from garbage in landfill, beyond finding solutions for a sustainable environment (generating renewable and clean electric energy), collaborating with the energy matrices of the countries, leaving them more heterogeneous and reducing the global impacts caused by the use of fossil fuels. Moreover, the proposal of electric energy generation from biogas search the reduction of landfill greenhouse gases (GHG) escapes and the raising of the methane conversion index, which is counted for emission of carbon credits in the clean development mechanism (CDM).

2. BIOGAS FROM URBAN SOLID WASTES (USW)

The biogas generated in landfills is basically 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.

The biogas generation in a landfill starts little time after the beginning of wastes deposition and continues for about 15 years after the landfill had been closed. For each 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).

Currently 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 as energy source for the evaporation of the leachate, whose hot vapor, one of the final products, passes through a humidity retainer filter and conduce it to a burner, from where it is launched dry and free of impurities in atmosphere. (Monteiro et al., 2001)
- 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 use as fuel in a thermoeletrical facility for electrical energy generation.

The Kyoto Protocol (1997) has established the reduction of the GHG Emission, mainly CO_2 and CH_4, considering a model of relaxation through the Clean Development Mechanism (CDM). This International Agreement propitiates that industrialized countries that are not able or not desire to reduce its emissions, alternatively, can acquire the Certified Emission Reduction (CER) from underdeveloped countries.

The negotiation of carbon credits via CDM induces investments in sustainable projects assuring a model of clean development mechanism for the emergent countries, where the costs of implementation of such projects are greater than inside developed countries.

Brazil, a signatory country of the Kyoto Protocol, is qualified to develop projects of GHG reduction and to emit the carbon credits to the industrialized countries that must reduce its emissions until 2012.

3. OBJECTIVE

This paper aims at presenting a Technical and Economical Feasibility Study (TEFS) of energy generation through biogas from waste in landfills. Gramacho's landfill, located in the city of Duque de Caxias (RJ), was chosen as case study.

The advantages of this kind of project are:

Incomes obtained with energy production and emission of carbon credits;

Appropriated final destination of USW with leachate treatment, minimizing odors and environmental pollution. Furthermore the useful life of landfill is augmented;

Development of a renewable source of energy, contributing to the diversification of the energy matrix of the countries, enlarging reliance and security of energy supply;

Construct scientific bases solving real problems, to serve of support for ecologically friendly production.

4. METHODOLOGY

Gramacho's landfill was chosen because its importance for the city of Rio of Janeiro and its metropolitan region. This landfill was originally a open dump that since the beginning of the decade of 1990 has started to receive some cares to minimize its environmental impact. Most recent it was the conclusion of the first phase of its Effluent Liquids Treatment Station, that treats daily, according to *Companhia de Limpeza Urbana* (Comlurb), 960 m³ of leachate. The leachate was one of the main concerns of the ambient professionals, because contamination risk of the Guanabara Bay.

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).

The estimate of methane production is expressed by Eq. (1):

$$QM = \sum_{i=1}^{n} 2\, k\, L_o\, Mi\, (e^{-kti})$$

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 annual input amounts of garbage are inserted in Eq. (1) and the parameters of speed of degradation (k) and potential methane generation capacity (L_0) are adopted in accordance with the conditions of the studied region.

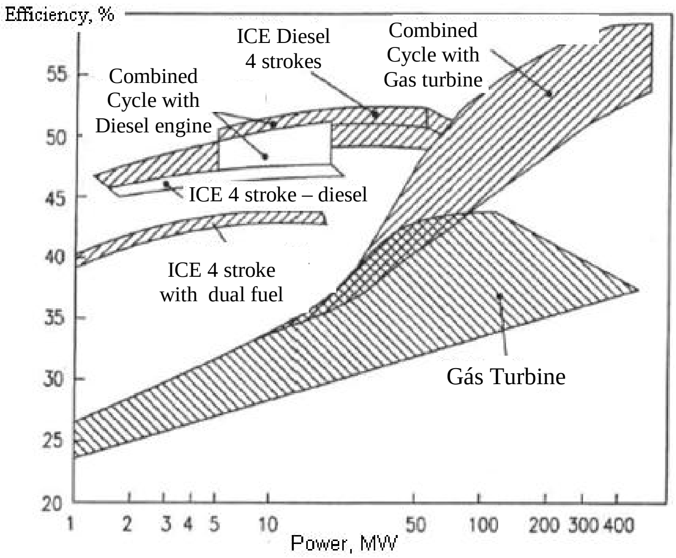
For economical analysis, the chosen parameters are Liquid Present Value (LPV) and Return Internal Tax (RIT)

5. TECHNICAL AND ECONOMICAL FEASIBILITY STUDY (TEFS)

5.1. Technical Analysis

The capital costs for the development of a biogas recovery project and those related to the operation, maintenance and regular expansion of the biogas collection system were estimated, including recurrent costs for capacity expansion of the ventilation and burning station.

Figure 1 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. Since Gramacho's potential power generation has been estimated at 10MW, internal combustion engines present better performance than gas turbines for this application .



Source: Lora and Nascimento, 2004

Figure 1: Efficiency comparison among diverse energy conversion technologies

5.1.1. Initial Cost of the Plant

The initial cost for accomplishment of the 10MW (bulk) TEP has been estimated in US$ 9,624,000 (table 1) using internal combustion engines, fed with biogas, intended to attain all landfill and its own energy consumption and to sell the exceeding energy to the electrical grid

Table 1. Costs of the Thermoelectrial Plant (TEP)

Detail	Estimated total cost ($) (1)
Plant of Energy of 10MW supplied with biogas (2)	$8,025,000
Interconnection of 3km	$500,000
Construction of the Plant/work in the place (including tubing)	$174,000
Measurement of biogas and equipment of register	$50,000
Engineering/contingency (10% of other costs)	$875,000
Total Costs	$9,624,000

Source: SCS Engineers (2005)

(1): The values are in U$ dollar (quotation of 2,6738), and are not adjusted to the inflation.
(2): The costs provide energy generators kept in containers, without necessity of any construction

The costs of the biogas collection and burning system were added (cost of 5,890,880 US$ - table 2). It was assumed that the plant will start to operate in first day of the third year of the project and will continue to operate until 15^{th} year (in this case until 2024). So, the value of investment is US$ 15,514,880.

Table 2. Costs of biogas collection and burning system

Detail	Estimated total cost
Mobilization and management of the Project	$50,000
Main tubing of Gas Collection (1)	$2,250,250
Lateral tubing	$173,200
Footbridge	$47,300
Management of the Condensed	$27,300
Wells of Vertical Draining(2)	$323,000
Horizontal collectors(3)	$971,830
Equipment of Ventilation and Burns (Burning)(4)	$1,400,000
Engineering, contingency, and Initial Costs of Transaction of the CDM (5)	$558,000
Total Costs	$5,890,880

Source: SCS Engineers (2005)

(1): The collection tubing includes the isolation valves.
(2): The costs of the draining wells include wells, headstocks of the wells, covers for the covering of the wells, valves of flow control, bomb of leachate and tank of storage, and deposition of the residues of perforation for the 55 wells
(3): The costs of the horizontal collector include the tubing, grit, headstocks of the wells, and valves of control of the flow for 4,530 m of horizontal collector.
(4): These equipment includes the fan and burner: five fans of 2,500 pcm (4,590 m^3/hr) and burners, work of construction, equipment for measurement and register of biogas, costs of start-up of the burner and test of beginning.
(5): The initial costs of transaction of the CDM are estimate in $50,000 and include the preparation of the Document of Conception of the Project, register, legal validation and procedures.

5.1.2. Operation and Maintenance Costs

The annual estimated operation and maintenance costs of the energy plant are approximately 1,8 cents of dollar per kilowatt-hour (kWh) of generated electricity (annually estimated in 73,55 million kWh), i, e., about US$ 1,323,900,00 per year.

5.1.3. Energy Generation

The predicted biogas recovery is graphically shown in figure 2, with three scenarios: 90%, 70% and 50% of recovery of the potential biogas.

Table 3 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 3. Evolution of the Wastes Deposition in Gramacho's landfill

Years	Tonnes	Accumulated residues
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	34,290,632
2008	2,920,000	37,210,632
2009	1,460,000	38,670,632

Source: Comlurb, 2009

[(1)]: In 2009, the value of 1,460,000 is a expectative of wastes deposition only for the first semester.

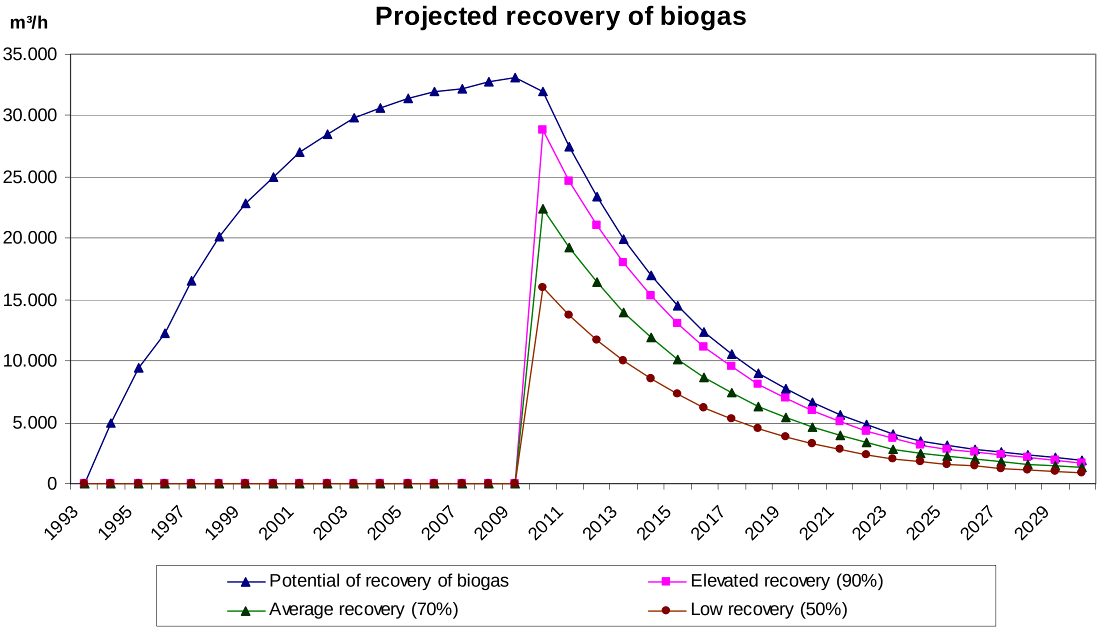


Figure 2. Predicted recovery of biogas in the Gramacho landfill

Table 4 summarizes expected recovery taxes of biogas and its associated power generation. These information are essential to planning the project (that it is demonstrated in Table 5) and to determine the bulk capacity of the TEP.

Table 4. Summary of the Recovery Taxes of Biogas and Capacity of the thermoelectrical plant

Year	Forecast of recovery of biogas (m³/hr)	Maximum capacity of the energy plant (MW)
2012	16,383	27,1
2013	13,981	23,1
2014	11,931	19,7
2015	10,182	16,8
2016	8,690	14,4
2017	7,416	12,3
2018	6,329	10,5
2019	5,401	8,9
2020	4,609	7,6
2021	3,934	6,5
2022	3,357	5,6
2023	2,865	4,7
2024	2,445	4,0

* Capacity of the plant based on the tax of entrance of heat of 10,800 Btu/kW/h (1MW = 604 m³/hr)

Table 5. Summary of estimated secular of the systems of collection and the operation and capacity (MW) of the project

Years	Planning of UTE - Biogás
1	System of collection of gas and burning in construction
2	Beginning of the collection system and burns. Plant in construction
3	Beginning of the functioning of the energy plant; System to operate the capacity of 10MW
4 to the 8	System with capacity of 10 MW
9 and 10	System with capacity of 7,2 MW
11 to the 15	System with capacity of 4,3 MW

5.2. Economical analysis

The economic issues have been evaluated using 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.

5.2.1. Basic assumptions

The following assumptions has been adopted in this analysis:
• It is a common practice to adopt a period of 15 years for this kind of business;
• Two financing options has been considered: one option without financing of capital expenditures (a 100% initial application of the capital expenditures) and another with a 75% financing of the initial capital expenditures (25% of initial investment of capital);
• The scenario for the evaluation of Reduced Emissions Certificates (RECs) has been considered, with the selling price of US$ 10 per ton of CO_2 equivalent;
• The same 8% interests' tax has been used for the liquid present value (LPV) analysis and for the financing of the loan;
• The loan's period payment for the initial investment (for example, 75% of the value = $11,636,160, 00) was of 15 years;
• For this analysis, the payment of approximately 20 percent of REC recipes to the landfill proprietor for the biogas use (represented for a tax of $0,35/MMBtu) has been considered. It had as based on international experience that the payment to the landfill proprietor for biogas can vary from 10 to 30 percent of REC recipes. If the landfill proprietor decided to develop the project alone (what it is unusual) this value would be equal to zero;
• The value of biogas has a 3% annual readjustment;
• Future expenses with operation and maintenance and the improvement of the system have a 3% annual readjustment;
Beyond those estimated basics, for the accomplishment of the TEP, the following estimated technician and economics are applied:

The TEP will starts with seven internal combustion engines of 1,433 MW each, that are bought in the first year and that they will work from 3rd until 8th year. After 8th year, the biogas flow will be reduced and will be enough to operate five internal combustion engines from 9th until 11th year and only three internal combustion engines from 12th until 15th year.

The value of the internal combustion engines (that are removed of service as the production of biogas is reduced) was not enclosed in the financial analysis, although these have a considerable value for resale. This decision was motivated by the conservative countable principle, since the sales of these internal combustion engines are uncertain.

A 7% reduction in the electricity production of the plant was presumed to cover the parasitic load, as well as a 90% factor of plant capacity considering the routine and not-routine periods of inactivity. Biogas collected during plant maintenance periods will be directed for burning.

One assumes that all the electricity generated for the project is selling outside of landfill. (The generated electricity will go to supply the energy necessities landfill, and this has been considered a recipe increase, because the bought electricity out of the landfill is more expensive than the electricity generated and sold by the project). On the electricity commercialized in the energy captive market, they have any taxes, main ICMS (from 18% to 25%) and PIS/COFINS (9,25%). With this, it is notable that the energy generated for proper consumption will not have these expenditure taxes, what it brings an additional economy and raises the viability for the project.

5.2.2. Project expenditures

For the economical evaluation, it has been considered the following expenditures for the accomplishment of the TEP:

• Initial investment of capital: Biogas collection and burner systems and TEP;
• Purchase of biogas from landfill's proprietor;
• Annual cost for the operation and maintenance of the biogas collection system, burner and TEP, and for the annual register of REC, checking and verification.

5.2.3. Project Incomes

From authors knowledge, there are three projects of energy generation through biogas from landfill in commercial scale currently in Brazil. In São Paulo and Rio de Janeiro, they exist respectively the projects of Landfill Bandeirantes and Adrianópolis, and another project in Bahia. The sales price of electricity received for the project in Landfill Bandeirantes has a unique structure that is no more available in Brazil. The projection for the energy sales price has beeb based on the following real scenarios:

1. In São Paulo State, they exist electricity independent producers (EIPs) from sugar cane berry that sell electricity to a local installation through an energy sales agreement (ESA) at a price of 80R$/MWh (approximately $ 0,029/kWh).

2. If a project can be eligible for the PROINFA (a federal government program for incentivating renewable energies, through which the ELETROBRAS purchase the energy under a ESA of 20 years), since March $1^{st,}$ 2004, it could be received R$169,08/MWh (approximately $ 0,062/kWh).

3. The third scenario is the Landfill of Bandeirantes project in which a bank is the EIP that produces energy from biogas and supply itself first and export the exceeding to the grid. As a compensation all the branches of the bank receive electricity gratuitously. Then they are selling the electricity for the same price that they are buying from the grid, that is above of R$200,00/MWh (approximately $0,074/kWh)..

The second scenario is not supposedly available because its period of 20 years. To be conservative in the financial analysis, it was used the lowest electricity selling price ($0,029/kWh). The following project assumptions has been considered:

• From 3^{rd} year to 8^{th} year, the energy plant produces a total of 54,504 MW/year, that is sold for the concessionaire to a tax. U.S $0,029/kWh, based on the estimated average rates of purchasing power wholesale.

• CER are sold at a tax of U.S $10 per ton of CO_2eq based on the potential gamma prices of purchase considered by the World Bank for those projects.

5.2.4. Economic evaluations

Table 6 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 6. 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 6, 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

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.

It is necessary that the cities are warned for this potential of profits and they must have the initiative to establish enterprises, preferring partnership with the private initiative for the development of the landfills implantation or improvement.

Analyzing from economical and environmental points of view, 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 (with reduction of CH_4 emissions, reduction of odors and vectors in the landfill due to good management practices, among others).

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 electricity sale price, can positively modify the results of this analysis.

Finally, the implantation of a TEP through biogas from wastes, 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 garbage:

• Simplification of the environmental licensing procedures for landfills, that currently are complex and slow;
• Adoption of fiscal favorable instruments as, for example, “ICMS green”. The cities will have these fiscal privileges case if they fit in criteria of ambient preservation and/or carry through investments in sustainable projects (as it is the case of the implantation of landfill with energy exploitation).
• Dissemination of technical and economical data on construction and operation of landfill with exploitation of biogas, as well as the achieved benefits.
• Establishment of special credit lines by development banks (as BNDES) 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.
• Establishment of penalties to the city halls that keeps on open dumps or other inappropriate ways of the treatment and/or final destination of the garbage, under the concept of “polluting agent-payer”.

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8. RESPONSIBILITY NOTICE

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