TECHNICAL AND ECONOMICAL FEASIBILITY ANALYSIS OF ENERGY GENERATION THOUGH THE BIOGAS FROM WASTE IN LANDFILL

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Abstract. *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. The intensification of human and industrial activities in the last few decades has generated one sped up increase in the production of municipal solid wastes (MSW), becoming a serious problem for society. Furthermore, the use of large landfills in great urban centers are still common, which causes sanitary and ambient problems. Gramacho's landfill was chosen as study case for technical and economical feasibility analysis of energy generation though the biogas from waste in landfill . 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. Studies and comparative analysis 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*: Biogas, Renewable Energy 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.

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 (Abreu, 2009).

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).

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).

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)

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.

Electricity generation in Brazil reached 463.1 TWh in 2008, or 4.2% higher than 2007 total. Main contributors are public utilities, with 89.0% of shares. From those, hydro utility plants remain as main source, even with a reduction of 1.4% in comparison to 2007. Thermal generation increased in 63.2%, specially from natural gas (116.6%) and nuclear (13.1%) (BEN, 2009).

Landfill gas (LFG) recovery and utilization have not been significantly evaluated in Brazil. A number of reasons might have contributed for this scenario, including: public regulation uncertainties, lack of financial incentives, absence of public and private investments, operational conditions of landfills, and low level of technical support. The only full scale LFG power plant started its operation in the beginning of 2004 with an installed capacity of 20 MW (Bandeirantes Landfill/São Paulo) (MACIEL, F.J. and JUCÁ, J.F.T. 2005**)**.

Bandeirantes and Sao Joao landfills were disabled in 2007 and 2009, respectively, and thermoelectric power plants were installed to burn LFG produced by the decaying waste. Eleven million tons of CO_2 eq shall be prevented from being thrown in the atmosphere by 2012, generating tradable Reduced Emissions Certificates (RECs), part of it sold at two public auctions in the Brazilian Stock Exchange (C40 cities 2010).

Table 2 shows potentials of methane recovery and electricity generation in main Brazilian landfills

Table 2 - Potentials of methane recovery and electricity generation in main Brazilian landfills

Municipality	Unit of Treatment	Waste Disposal (tonnes/years)	Methane Recuperation (MM m³/day)	Power Generation (MW average)
Duque de Caxias/RJ	Gramacho Landfill	2.258.429	484	53,8
Rio de Janeiro/RJ	CTR Gericinó	1.081.848	232	25,8
Caucaia/CE	ASMOC Landfill	1.038.670	223	24,8
Jaboatão dos Guararapes/PE	Muribeca Lanfill	955.746	205	22,8
Belo Horizonte/MG	CTRS BR040	909.520	195	21,7
Brasília/DF	Joquei Landfill	846.669	182	20,2
Salvador/BA	Centro Landfill	828.514	178	19,7
São Paulo/SP	Bandeirantes Landfill	743.208	159	17,7
Manaus/AM	KM 19 Landfill	709.696	152	16,9
São Paulo/SP	São João Landfill	701.472	150	16,7
Curitiba/PR	Caximba Landfill	670.790	144	16,0

Source: Zanetti (2009)

This article aims at presenting a technical and economical evaluation of energy generation from MSW at Gramacho's landfill in Brazil.

Waste-to-energy (WTE) technologies, which combust municipal solid waste to produce energy, are often not competitive, when viewed solely from a waste management or energy production perspective. However, more appropriate analysis examines the energy and solid waste management questions simultaneously (Miranda and Hale, 2005). Although their proposed strategy to include social costs is quite reasonable, and it increases the feasibility of the thermo power facility, difficulties in accounting add to lack of precise data do not allow that social costs were included in the present study.

2. METHODOLOGY

2.1. Gramacho's landfill

Gramacho's landfill was chosen as study case because its importance for the city of Rio of Janeiro and its metropolitan region.

The Gramacho's landfill is located at the following coordinates: 22º44'46" South and 43º15'37" West. Gramacho's landfill operations started as an open dump in a mangrove swamp in 1978. Initial filling was performed by pushing waste into the swamp area to fill it to a point where it was above high sea level. Subsequent fill activities consisted of haphazard dumping, waste burning, and uncontrolled scavenging. Since the beginning of the decade of 1990 it has started to receive some cares to minimize its environmental impact. In the early 1990s, the landfill operator, Companhia de Limpeza Urbana (COMLURB), began converting the open dump into a sanitary landfill. By 1996, most of the attributes of a modern sanitary landfill were in place, including controlled access, a recycling facility, well-maintained access roads, waste compaction by bulldozers, and the application of daily and intermediate cover soils. (SCS Engineers, 2005).

Table 3 shows solid waste disposal evolution in Gramacho's landfill. All waste deposited prior to 1993, during the open dump operations, were not included in the present study. Historical deposition rates between 1993 and 2007 were estimated from waste weight measurements. Estimated data from 2008 and 2009 were obtained from preliminary data from 2009.

Table 3. Solid waste disposal in Gramacho's landfill, from COMLURB (2010)

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).

2.2. 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.

2.3. Economical analysis

The following 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;
- All Brazilian applicable taxes have been taken in accounting.

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).

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

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 employed values for k and L_0 are, respectively, 0.06 and 84.8 m^3/Mg. Table 4 summarizes TEP schedule, proposed by SCS Engineers (2005).

Table 4. TEP schedule

Years	Planning of TEP - 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

Source: SCS Engineers (2005)

3. RESULTS

The costs of capital 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 .

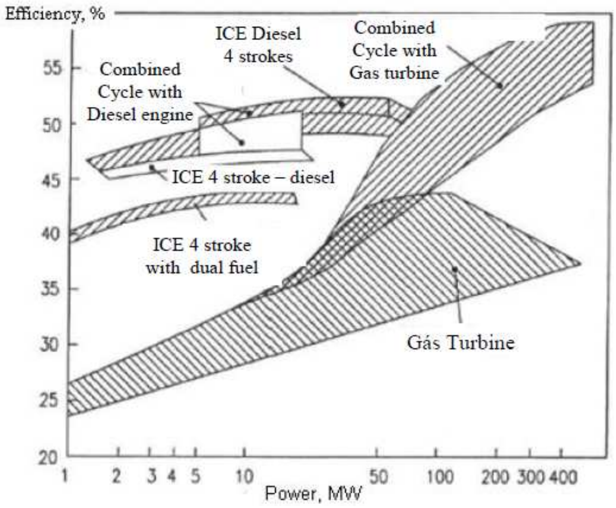

Figure 1: Efficiency comparison among diverse energy conversion technologies

The initial cost for accomplishment of the 10MW (bulk) TEP has been estimated in US$ 11,885,640 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 5 shows the costs of the Thermoelectrial Plant.

Table 5 - Costs of the Thermoelectrial Plant (TEP)

Detail	Estimated Total Cost ($)[1]
Plant of Energy of 10MW supplied with biogas	$9,910,875
Interconnection of 3km	$617,500
Construction of the Plant/work in the place (including tubing)	$214,890
Measurement of biogas and equipament of register	$61,750
Engineering/contigency (10% of other costs)	$1,080,625
Total Costs	$11,885,640

Source: Abreu (2009)

Table 6 shows the costs of the biogas collection and burning system were added (cost of 7,164,086 US$). It was assumed that the plant will start to operate in first day of the third year of the project and will continue to operate until 15th year (in this case until 2024). So, the value of investment is US$ 19,049,726.

Table 6 - Costs of biogas collection and burning system

Detail	Estimated Total Cost ($)
Mobilization and management of the Project	$61,750
Main tubing of Gas Collection	$2,779,058
Lateral tubing	$213,902
Footbridge	$58,415
Management of the Condensed	$33,715
Wells of Vertical Draining	$398,905
Horizontal collectors	$1,200,210
Equipment of Ventilation and Burns (Burning)	$1,729,000
Engineering, contingency, and Initial Costs of Transaction of the MDL	$689,130
Total Costs	$7,164,086

Source: Abreu (2009)

Table 7 shows the other costs of Thermoelectrical Plant.

Table 7. Others Costs of Thermoelectrical Plant

	Annual Cost O&M - Thermoelectrial Plant	Annual O&M of the Collection System and Gas of Control and Ampliation of Costs	CDM Register and annual verification	Comlurb Recipe	Payment of Garbage's Participation Deep
2005	-	-	-	-	-
2006	-	-	-	-	-
2007	-	-	-	-	-
2008	-	-	-	-	-
2009	-	-	-	-	-
2010	-	-	-	$741,000	$1,482,000
2011	-	$435,023	$58,986	$770,640	$1,541,280
2012	$2,010,809	$448,073	$60,755	$801,465	$1,602,931
2013	$2,071,133	$461,516	$62,578	$833,524	$1,667,048
2014	$2,133,267	$475,361	$64,455	$866,865	$1,733,730
2015	$2,197,265	$489,622	$66,389	$901,539	$1,803,079
2016	$2,263,183	$504,311	$68,381	$937,601	$1,875,202
2017	$2,331,079	$519,440	$70,432	$975,105	$1,950,210
2018	$1,715,031	$535,023	$72,545	$1,014,109	$2,028,219
2019	$1,766,482	$551,074	$74,721	$1,054,674	$2,109,348
2020	$1,819,476	$567,606	$76,963	$1,096,861	$2,193,722
2021	$1,874,061	$584,634	$79,272	$1,140,735	$2,281,470
2022	$1,930,283	$602,173	$81,650	$1,186,364	$2,372,729
2023	$1,988,191	$620,238	$84,100	$1,233,819	$2,467,638
2024	$2,047,837	$638,846	$86,623	$1,283,172	$2,566,344

Table 8 shows the Thermoelectrical Plant payback, with recipes and cost in this project.

Table 8. Thermoelectrical Plant payback

	Recipe	Costs
2005	-	(19.160.877)
2006	-	(20.693.747)
2007	-	(22.349.247)
2008	-	(24.137.186)
2009	-	(26.068.161)
2010	22.043.968	(30.376.614)
2011	42.724.070	(37.225.110)
2012	66.862.995	(46.544.500)
2013	90.663.678	(56.609.719)
2014	114.448.897	(67.507.297)
2015	138.516.482	(79.328.396)
2016	163.144.780	(92.169.497)
2017	188.597.458	(106.133.098)
2018	213.640.347	(120.642.457)
2019	239.855.345	(136.424.834)
2020	267.472.725	(153.598.599)
2021	296.721.613	(172.290.691)
2022	327.832.772	(192.637.454)
2023	361.041.200	(214.785.521)
2024	396.588.563	(238.892.757)

Table 9 shows a summary of the results of the economic evaluation in the scenario without taking account recipes from RECs or carbon credits.

Table 9 - Investment Analysis (scenario without carbon credits)

Value of Initial Investment	Percentual value of the Initial Investment of capital (%)	LPV	RIT*
19.160.877	100	-$36.157.454	-
4.790.219	25	-$37.221.947	-

* RIT – Return Internal Tax

Table 10 shows a summary of the results of the economic evaluation in the scenario of the energy plant, having presented a composition of financing options 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 10 shows sensibility analysis, scenario with carbon credits ($17 tCO_2 eq. – Gramacho’s adopted tax).

Table 10 - Investment Analysis (scenario with carbon credits)

Value of Initial Investment	Percentual value of the Initial Investment of capital (%)	LPV	RIT
19.160.877	100	$33.833.352	24,95%
4.790.219	25	$32.768.859	35,40%

The economic projections of the TEP are presented attractive for financing scenarios. On the other hand, the scenario without carbon credits is not attractive.

4. CONCLUSIONS

Biogas energy is one of the important options which might gradually replace oil, which is facing increasing demand and may be exhausted early in this century. Brazil can depend on the biogas energy to satisfy part of local consumption.

Support for biogas research and exchange of experiences with countries that are advanced in this field is necessary. In the meantime, the biogas energy can help to save exhausting the oil wealth.

Based on results, the landfill biogas energy exploitation of Gramacho's Landfill is viable taking as reference the value of CER in $17 of ton.$CO_2$eq and any of the financing options analyzed.

As demonstrated in this work, the economic projections of the TEP are presented attractive for financing scenarios. On the other hand, the scenario without carbon credits is not attractive.

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.

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5. RESPONSIBILITY NOTICE

The authors (Fábio Viana de Abreu, Mila Rosendal Avelino, Mauro Carlos Lopes Souza and Joao Claudio Motta França Correa) are the only responsible for the printed material included in this paper.