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Full Length Research Paper

Technical and economical feasibility analysis of energy generation though the biogas from waste in landfill

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Biogas from wastes in landfill can reduce the dependence on fossil fuels, beyond finding solutions that are 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 increase in the production of municipal solid wastes (MSW), becoming a serious problem for the society. Furthermore, the uses 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, had it's importance for the city of Rio of Janeiro and metropolitan region. Moreover, an ambiental concern of the contamination of the Guanabara Bay with the leachate of this 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.

Key words: Biogas, renewable energy, landfill.

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).

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 amounts of wastes generated by the societies are increasing in the whole world, either due to population increase or 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 (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.

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Table 1. MSW disposal in Brazil.

Region	Total (tones/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).

Since oxygen is rapidly depleted, a long-term degradation continues under anaerobic conditions, thus producing a gas with a significant energy value that is 55% methane and 45% carbon dioxide with traces of a number of volatile organic compounds (Meraz et al., 2004; Zamorano et al., 2007). For Polprasert (1996), the biogas generated in landfills is basically composed of methane (CH_4, 55 to 65%), carbon dioxide (CO_2, 35 to 45%), nitrogen (N_2, 0 to 1%), hydrogen (H_2, 0 to 1%) and sulfidric gas (H_2S, 0 to 1%).

The anaerobic process begins after the waste has been in the landfill for 10 to 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).

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.

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 originates from hydroplants, not considering thermal generation. 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 and Jucá, 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

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.

METHODOLOGY

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. In 2009, the first phase of the Effluent Liquids Treatment Station, treated daily, according to *Companhia de Limpeza Urbana* (Comlurb), was completed in 960 m³ of leachate. The leachate was one of the main concerns of the ambient professionals, because of the contamination risk of the Guanabara Bay.

The Gramacho's landfill is located at the following coordinates: 22°44'46" South and 43°15'37" West, as it is showed in Figure 1.

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

Municipality	Unit of treatment	Waste disposal (tones/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	Muribeca Landfill	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).

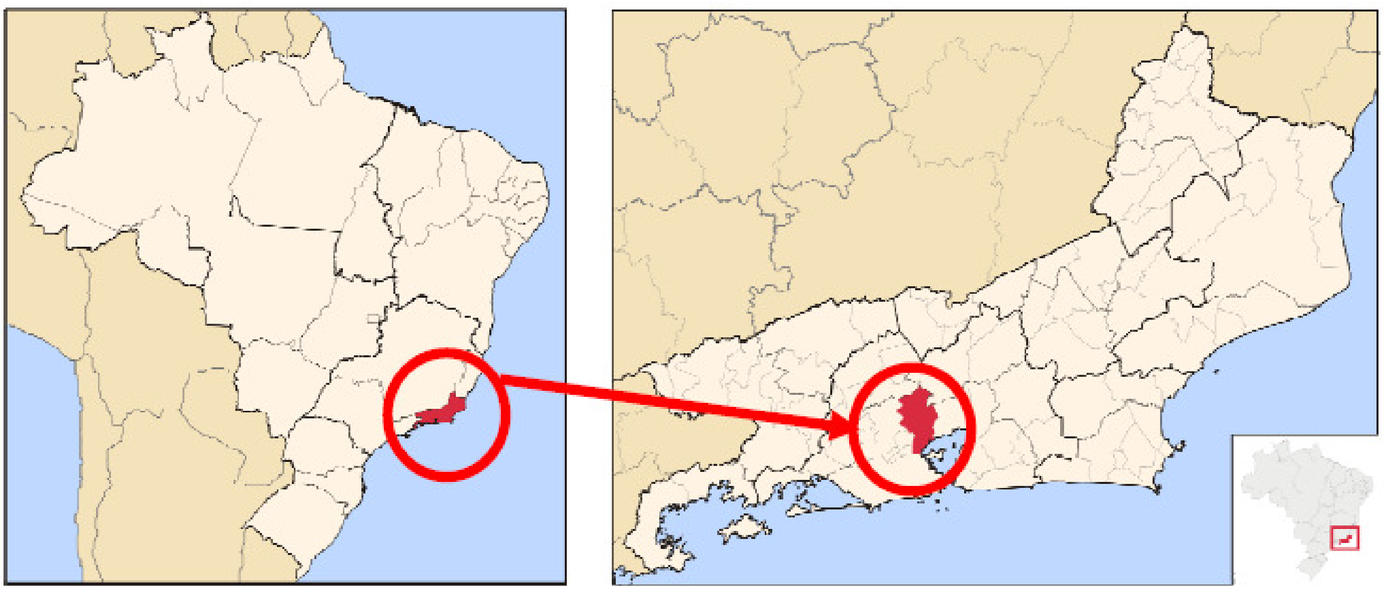

Figure 1. Gramacho's landfill localization.

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. Excluding waste disposed in the open dump, it is estimated that there was more than 40 million tonnes of waste in place at the Landfill as of the end of 2010. The site currently receives approximately 250,000 tonnes per month (3,000,000 tonnes per year). The Landfill is expected to close at the end of 2011, at which time there will be more than 43 million tonnes of waste in place.

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 e for steam

Table 3. Solid waste disposal in Gramacho's landfill.

Year	Waste disposed	Waste in place
	Tonnes	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	34.290.632
2008	2.920.000	37.210.632
2009	3.000.000	40.210.632

Source: Comlurb (2010).

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 (Abreu, 2009).

Economical analysis

The following assumptions have been considered:

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

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

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

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.

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

Table 4. Summarizes TEP schedule, proposed by SCS Engineers (2005).

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 10 MW
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).

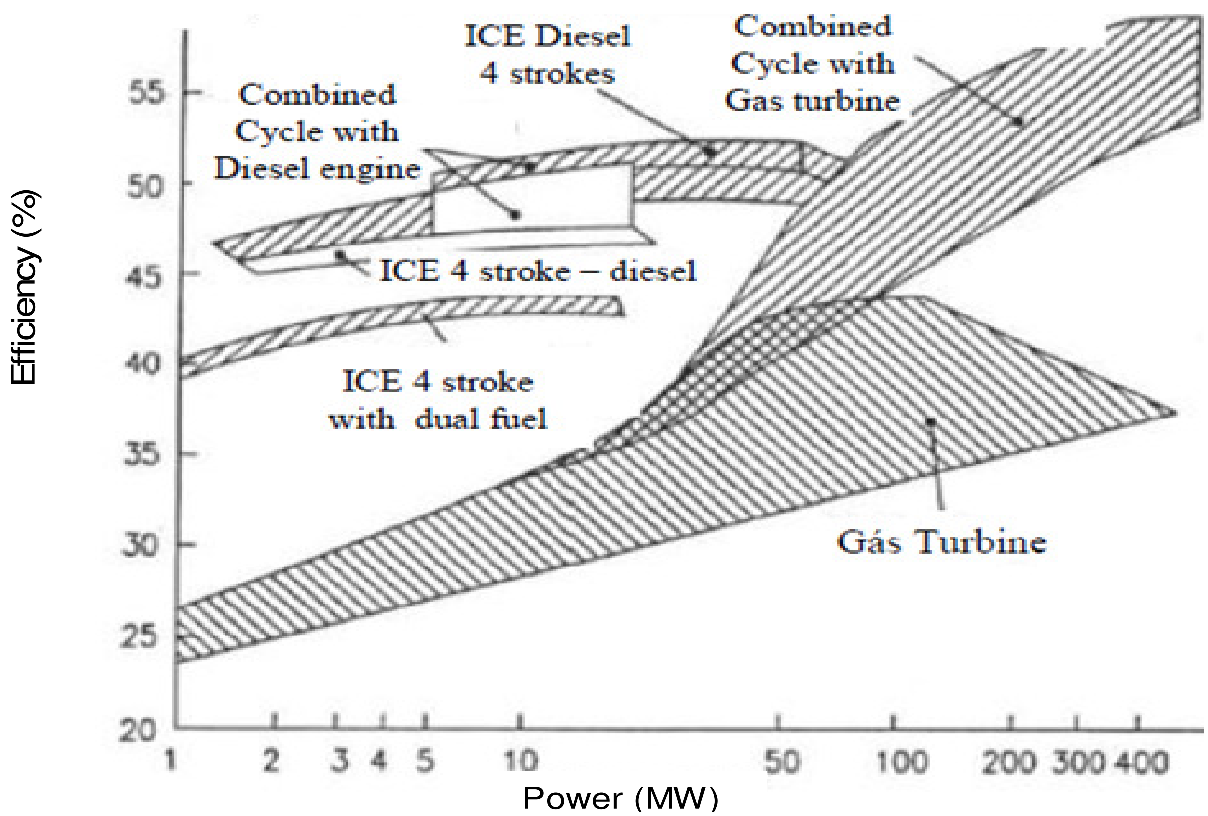

Figure 2. Efficiency comparison among diverse energy conversion technologies (Lora and Nascimento, 2004).

waste at the Landfill. The methane recovery potential for Gramacho Landfill is 84.8 m³/Mg (SCS Engineers, 2005). Table 4 summarizes TEP schedule, proposed by SCS Engineers (2005).

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 2 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 10 MW, internal combustion engines present better performance than gas turbines form this application.

The initial cost for accomplishment of the 10 MW (bulk) TEP has been estimated in US$ 11,885,640 (Table 5) using internal combustion engines, fed with biogas, intended to attain all landfill and its own energy

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 3 km	$617,500
Construction of the Plant/work in the place (including tubing)	$214,890
Measurement of biogas and equipment of register	$61,750
Engineering/contigency (10% of other costs)	$1,080,625
Total costs	$11,885,640

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

consumption and to sell the exceeding energy to the electrical grid.

The costs of the biogas collection and burning system were added (cost of 7,164,086 US$ - Table 6). 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 7 shows the other costs of Thermoelectrical Plant. Table 8 shows the recipes and costs of Thermoelectrical Plant. The typical payback for Thermoelectrical Plant is nine years, in this scenario actual. Then, 2014 is the year of payback of this project. 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 shows sensibility analysis, scenario without carbon credits.

Table 10 shows a summary of the results of the economic evaluation in the scenario of the energy plant with carbon credits, having presented a composition of financing options using the LPV and RIT. 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).

As demonstrated in Table 10, the economic projections of the TEP are presented attractive for financing scenarios. On the other hand, the scenario without carbon credits is not attractive.

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.

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.

Brazilian GHG emissions are mainly originated from hydro power plant reservoirs, forest burning and uncontrolled emissions from landfills. By employing

Table 7. Others costs of thermoelectrical plant.

Year	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. Thermoelectrical plant - recipes and costs.

Year	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	(106,133,088)
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. 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. 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

control improvements followed by energy generation, a great amount of GHG emissions will be avoided.

Energy generation facilities shall be included in future landfill projects. A methodology for evaluation of social and environmental costs shall be added in economical evaluation of WTE.

Energy generation from landfills does not impact Brazilian Energy Matrix, although saves transmission costs since landfills are close to urban concentrations. The main advantage of implementing WTE facility is waste volume reduction, lengthening landfill useful life and technical servicing.

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

(i) Simplification of the environmental licensing procedures for landfills.
(ii) 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).
(iii) Dissemination of technical and economical data on construction and operation of landfill with exploitation of biogas, as well as the achieved benefits.
(iv) 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.

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