TECHNO-ECONOMIC EVALUATION OF ELECTRICITY GENERATION THROUGH LANDFILL BIOGAS UTILIZATION IN BRAZIL

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Abstract. *This study evaluates the techno-economic feasibility of electricity generation through the use of biogas produced by landfills, based on hypothetical cases. For this purpose a computer simulation tool was developed. It uses a spreadsheet computer program to calculate the economics for a fixed set of inputs. The method calculates the methane generated by the landfill, and estimates the costs and incomes associated with the recovery of biogas and sales of electricity and carbon reductions credits on Clean Development Mechanism (CDM). Base case results are presented for cities ranging from 100 thousand to 2 million inhabitants. The simulation results can help an analyst see the key variables affecting the economics of a project. Results shows that a project in the smallest city landfill would be feasible only with a carbon reduction market, and if the biogas were recovered since the beginning of landfill operation. The biggest city shows better results. In this case the project shows feasibility even without a CDM project. The key factors affecting the economics of a project are the sales price of electricity and carbon reductions.*

Keywords*: Biogas, Landfill, Energy, Economic, Carbon reductions.*

1. INTRODUCTION

By definition the term "waste" suggests a byproduct of a process, which has no functionality or value for a particular population, group or institution. However, the factors that make this a waste at a certain perspective, does not necessarily make this byproduct useless or worthless otherwise, everything depends on the function that the user can expect of this material. The advantage of using waste to produce power lies in the fact that energy is a product widely requested by population. According to Zamorano (2005), the energy recovered from waste may represent about 6-7% of the total energy consumed by the population that generates it.

There are several methods to produce energy through the Municipal Solid Waste (MSW). Worldwide, the most common technology is the direct incineration of waste with subsequent use of the heat generated in a Rankine cycle. When the option is the use of landfills, the biogas rich in methane produced by anaerobic decomposition of organic fraction of MSW, is commonly used in Internal Combustion Engines (ICE) or more rarely in Gas Turbines (GT) to generate electricity and heat (Murphy, 2004).

The waste generated in cities leads to a series of environmental, social and economic issues. Due to the lack of appropriate policies for this sector, 60% of Brazilian cities still dump their waste in non-regulated landfills, the remnants 40%, including the biggest Brazilian cities, dump their trash in regulated landfills (SNIS, 2009). Unregulated landfills do not have drainage systems for gas and leachate, lower sealing, and sometimes even daily soil cover. This situation brought serious environmental and social problems. In recent years, municipalities try to deploy regulated landfills in their territories, which are considered by Brazilian politics as an environmentally sound alternative. Yet, the waste treatment technologies used in the various countries pursue a diversion from landfills. For example, in 1999 European legislation determined the amount of biodegradable waste that can be grounded permanently in landfills, with reduction targets of 75% for 2010 reaching 35% by 2020, compared with 1995 levels (Council Directive, 1999).

Assuming a rate of 50 Nm^3 of methane per ton of MSW (Themelis, 2007) and the total garbage produced by Brazil (73,200 ton/day - SNIS, 2009) that is sent to regulated landfills, may be conclude that Brazil has a potential of 400 MW in its landfills. Today, Brazil produces 65MW of power through the use of biogas from landfills in São Paulo (11.244. 369 hab.), Belo Horizonte (2.375.444 hab.) and Salvador (2.676.606 hab.) (ANNEL, 2011).

Typically in Brazil, these projects are being implemented only in large landfills which have high capacity for generating biogas and energy. Smaller landfills are left aside and the methane produced by them is wasted. This study evaluates the techno-economic feasibility of electricity generation through the use of biogas produced by smaller landfills, based on hypothetical cases. The case studies include cities ranging from 100 thousand to 1 million inhabitants.

To evaluate the feasibility of such projects a computer simulation tool was developed in cooperation with CEMIG company. The program is able to perform techno-economic diagnostics of such initiatives. Its goal is to assist decision making for the construction of projects focused on energy recovery from biogas produced by landfills, based on economic indicators commonly used in investment analysis as the Cash Flow (CF), Net Present Value (NPV) and Internal Rate of Return (IRR).

2. METHODOLOGY

2.1. Methane Production

The energy potential of a landfill depends on the amount of methane produced by it, which is a function of the quantity of degradable organic carbon present in the mass of MSW. Mathematical models were developed to estimate the production of this gas by landfills. These models were formulated from usual techniques witch fit theoretical curves with experimental results. Usually, these curves are described by a first order kinetics equation equal to (Castillos, 2003):

$$Lt = L_0 (1- e^{-kt}),$$

Where,
Lt = the total methane production at time t;
L_0 = methane potential from waste;
t = time in years an;
k = degradation rate of carbon.

With information on the composition and amount of garbage that is send to the landfill, the software is able to estimate the site biogas potential, making statements in accordance with information provided by the user. The results are influenced by many variables, so the program was developed to give the user freedom to establish all the parameters involved in the diagnosis.

The program estimates the landfill methane generation based on the IPCC (2006) methodology. The amount of Certificates Emission Reductions (CERs) achieved by implementation of CDM are calculated based on methodology for landfill gas project activities ACM0001 (2011) and ACM0002 (2011).

The rate of biogas production by a landfill is not constant in time. This occurs because the site is filled gradually over the years, with quantities of MSW being grounded in different time periods. As a result, each cell of waste will have different capacities to produce methane as a function of its residence time inside the landfill. The total biogas produced by a landfill, at a given instant is the sum of individual capacities of each individual cell inside the landfill. The consequence of this system of covering waste is an increased production of biogas until the last year of landfill operation (if equal amounts of waste are deposited annually). In Figure 1 above we can find an example of a landfill biogas production.

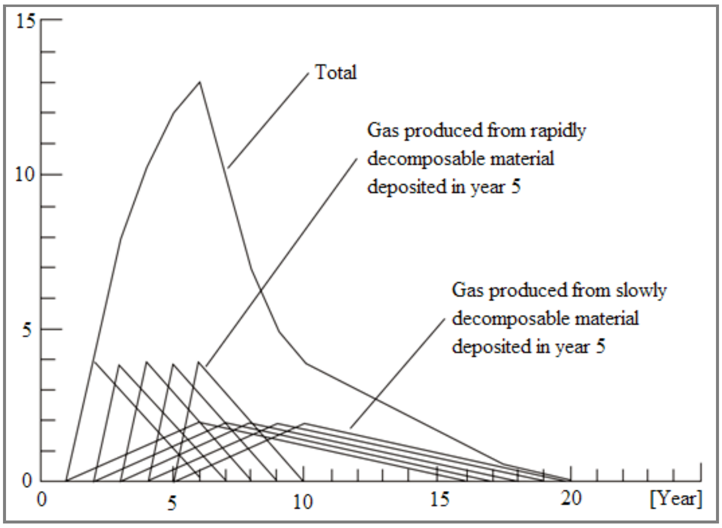


Figure 1. Biogas Generation in Landfills (Tchobanoglous, 1993).

2.2. Energy Balance

With the information about the biogas produced by the site, the type of implemented technology, and the internal landfill electricity consumption, the program realizes an energy balance of the project and determines the amount of energy that will be sent to the national electric system during the years of project operation. In this work is considered that methane has a net calorific value of 50.000 kJ/kg and it is used in internal combustion engines. But the program can be applied to any technology that uses biogas to generate electricity, like gas turbines or even Stirling motors.

The use of landfill biogas to generate electricity can be accomplished with the application of generator modules, which are installed and uninstalled according to the rate of biogas production. The modules are self-contained power stations, requiring fuel gas and electrical connections. Included within the modules are dump heat radiators, control/switchgear panels, ventilation fans, exhaust systems, plus oil and water tanks. In the event of excess gas, the installation can continue to burn the biogas in high temperature flares to ensure the environmental quality of the emitted gases. However, the use of flares is not required by Brazilian law. In Brazil, these devices are used only when the project stakeholders desires to obtain carbon credits from it, since flares reduced methane to carbon dioxide, which has 21 times less global warming potential than CH_4.

The software was adapted only to use generator modules however, in real cases the landfill biogas can be applied in other ways, such as transportation fuel or pipeline gas.

2.4. Costs and Revenues

The costs used in this work were obtained through a literature search. The information on investment costs and operation and maintenance (O&M) were drawn mainly from USEPA (2008) but also from Alves (2000) and ICLEI (2009). The selling price of electricity and RECs were obtained from CCEE (2011) and ECX (2011), which are $ 78 MWh and $ 18/ton eq.CO_2 respectively.

Table 1. Average initial investment costs for electricity generation thought landfill biogas usage.

Landfill biogas-fueled power plant	$ 1.200.000/MW
Well field installation	$ 30.000/ha
Engineering, legal and other professional services	$ 200.000
CDM project registry	$ 100.000

Table 2. Average annual costs for electricity generation thought landfill biogas usage.

Well field maintenance	3 % of field cost
Flare station maintenance	2 % station cost
Operating labor / Security / Administration / Instrument maintence / Fees / Engineering	$ 95.000 - $165.000*
Qualifying for emissions reductions credits	$ 30.000
Registration fees on emissions reductions credits	3 % of annual credits
Biogas power plant O&M	$ 17/MWh

*This value can vary according to the size of the landfill

The cost for the flare station which includes the costs of purchasing, delivering, installing, and starting-up equipment is estimated as follow by the software:

$$650000 \times \left(\frac{biogasflow}{1800} \right)^{0,7} \tag{1}$$

The biogas flow on equation (1) must be in Nm³ and the results are in US dollars. That is, a flare station designed for 1,800 Nm³/h is estimated to cost $650,000. The ratio of the actual estimated landfill biogas flow to 1,800 Nm³/h is raised to the power of 0.7 and multiplied by $650,000 to estimate the cost of the flare station (USEPA, 2008).

2.4. Economic Analysis

To generate insight in the project profitability, the CF of the project is calculated by the software jointly with the IRR and NPV. The NPV indicates whether the project is profitable, taking into account the time value of the cash flows, i.e. revenue streams, capital investments and operational costs. The IRR is the discount rate that produces a zero NPV.

In calculating the NPV, was considered an annual interest rate of 11.25% (BCB, 2011). Taxes on annual profits were assumed to be 35%.

3. CASE STUDIES

Three hypothetical cases were evaluated in this work. For all of them it was considered the average composition of the Brazilian waste (Table 3) and the rate of domestic waste production in Brazil: 316.7 kg/hab.year (ALBREPE, 2006).

According to IBGE (2002) 16.23% of the Brazilian residents lives in cities with populations that exceeds 2 million inhabitants, 17.00% lives in cities with populations between 500,000 and 2 million and 27.23% lives in cities with populations between 100 thousand and 500 thousand. In agreement with the demographic situation in Brazil, three cases that illustrate this distribution were selected; the first scenario exemplifies a city with 100 thousand inhabitants, the second scenario a city with 500 thousand hab. and the third a city with 1 million hab.

Table 3. Average composition of MSW in Brazil, wet weight (ABRELPE, 2006).

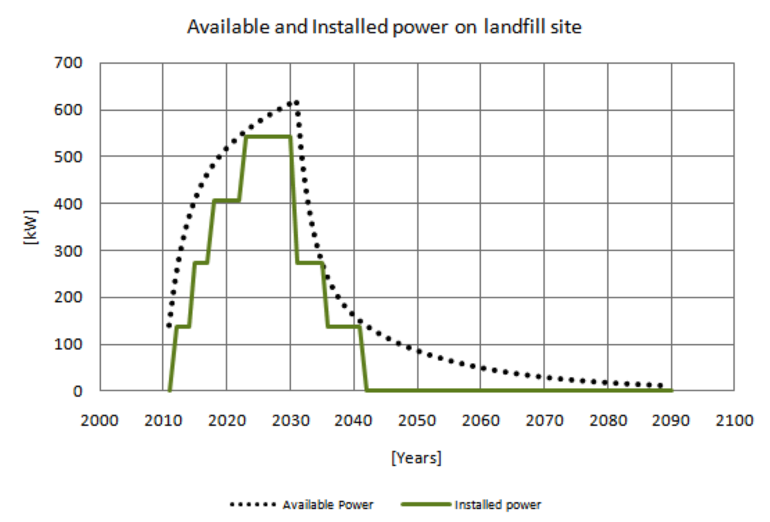
Organic Matter	57,4%
Plastics	16,5%
Paper/Cardboard	13,2%
Glass	2,3%
Metal	2,1%
Other	8,5%

4. RESULTS

Figures and tables below show the results obtained by the software simulation executed in this work. In all cases the schedule for generator modules was developed to get the most of biogas produced by the landfill. However for some sites more biogas could be used to generate energy due to the framework utilized in each place.

In the graph is shown the installed and available power for each project. The other side of the figure shows the utilization rate of biogas captured by the drainage system and bellow we can see the schedule for the generator modules for the project. All modules are equipped with reciprocating engines from Caterpillar or Fockink.

Figure 2. Available and Installed power for the 100 thousand inhabitant's city.



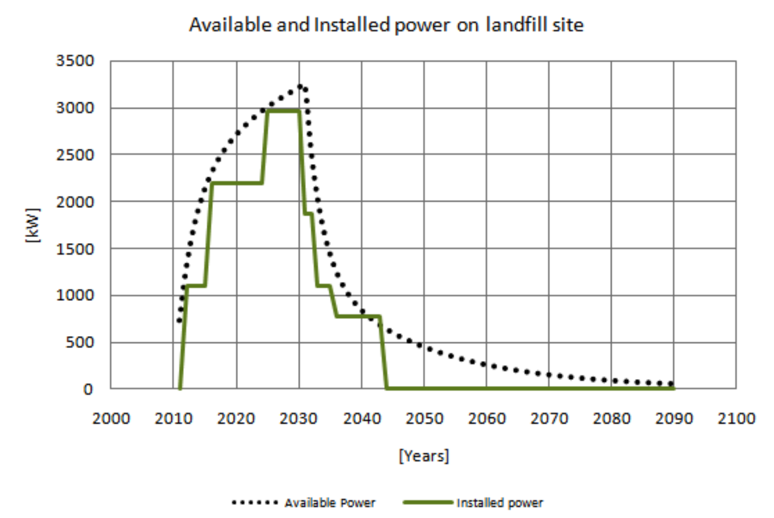
Utilization rate of biogas captured: 64%
Specific project costs [$/MWh]: 44

Generator Modules ICE: Fockink SG170B

Schedule for generator modules

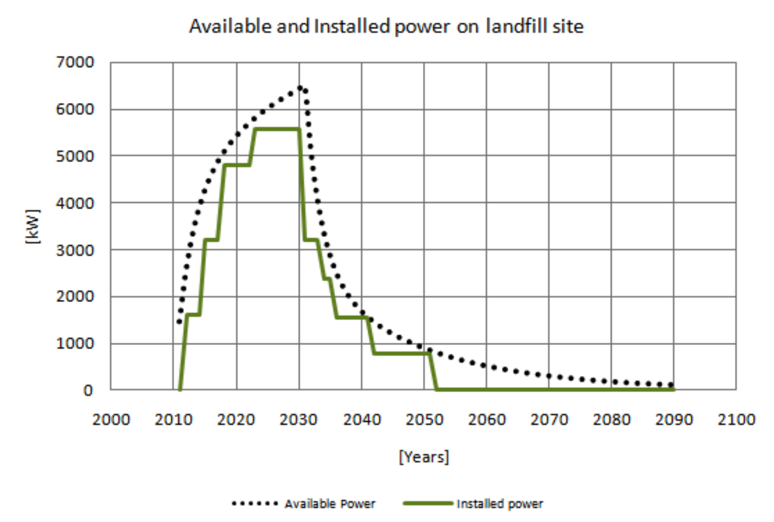
Modules	Power [kW]	Start of operation	End of operation
Module 1	136	2012	2019
Module 2	136	2020	2027
Module 3	136	2028	2035
Module 4	136	2015	2022
Module 5	136	2023	2030
Module 6	136	2018	2025
Module 7	136	2026	2033
Module 8	136	2023	2030
Module 9	136	2034	2041

Figure 3. Available and Installed power for the 500 thousand inhabitant's city



Utilization rate of biogas captured: 69% Specific project costs [$/MWh]: 32			
Generator Modules ICE: Caterpillar G3516A / G3512			
Schedule for generator modules			
Modules	Power [kW]	Start of operation	End of operation
Module 1	1100	2012	2019
Module 2	1100	2020	2027
Module 3	1100	2028	2035
Module 4	1100	2016	2023
Module 5	1100	2024	2030
Module 6	770	2025	2032
Module 7	770	2036	2043

Figure 4. Available and Installed power for the 1 million inhabitant's city



Utilization rate of biogas captured: 72% Specific project costs [$/MWh]: 29			
Generator Modules ICE: Caterpillar G3520C / G3512			
Schedule for generator modules			
Modules	Power [kW]	Start of operation	End of operation
Module 1	1600	2012	2019
Module 2	1600	2020	2027
Module 3	1600	2028	2035
Module 4	1600	2015	2022
Module 5	1600	2023	2030
Module 6	1600	2018	2025
Module 7	1600	2026	2033
Module 8	770	2023	2030
Module 9	770	2034	2041
Module 10	770	2036	2043
Module 11	770	2044	2051

The tables below shown the results of economic evaluations for the three cases analyzed. The existence of a market for GHG emissions reductions is uncertain in the future so for each landfill were considered two different scenarios, one with and other without the CDM project.

Table 3. Results for the 100 thousand inhabitants city.

Investment Results - Without emissions reductions project				Investment Results - With emissions reductions project			
Annual Interest Rate:	5,00%	10,25%	15,00%	Annual Interest Rate:	5,00%	10,25%	15,00%
NPV:	-$569.055	-$570.848	-$556.013	NPV:	$1.499.905	$633.710	$252.965
IRR:		-9%		IRR:		21%	
Total Costs (NPV)				Total Costs (NPV)			
Initial Investment:	$1.375.153	$1.052.902	$883.726	Initial Investment:	$1.470.391	$1.143.605	$970.683
O&M Costs:	$2.140.495	$1.196.785	$778.553	O&M Costs:	$3.598.814	$2.050.572	$1.360.837
Total Revenues (NPV)				Total Revenues (NPV)			
Energy Sales:	$2.946.593	$1.678.839	$1.106.266	Energy Sales:	$2.946.593	$1.678.839	$1.106.266
Carbon Credits Sales:	$0	$0	$0	Carbon Credits Sales:	$3.622.517	$2.149.049	$1.478.219

The economic evaluation performed in the 100 thousand inhabitant's city shows that there is no economic viability in the scenario without the CDM project. The CDM project significantly improved the results making the investment attractive. In order to achieve an IRR above 15% in the case without the CDM would be necessary that electricity were sold at prices above $ 130.00/MWh. In the other scenario (with CDM), to ensure an IRR above 15% the electricity can't be sold at prices below 55 $/MWh or the carbon reductions cannot be sold at prices below $ 14/ton CO_2. Table 4 shows the results for the 500 thousand inhabitants city.

Table 4. Results for the 500 thousand inhabitants city.

Investment Results - Without emissions reductions project				Investment Results - With emissions reductions project			
Annual Interest Rate:	5,00%	10,25%	15,00%	Annual Interest Rate:	5,00%	10,25%	15,00%
NPV:	$2.271.655	$518.541	-$212.228	NPV:	$14.027.822	$7.506.773	$4.614.905
IRR:		13%		IRR:		57%	
Total Costs (NPV)				Total Costs (NPV)			
Initial Investment:	$6.313.442	$4.595.570	$3.730.369	Initial Investment:	$6.408.680	$4.686.273	$3.817.326
O&M Costs:	$8.187.009	$4.704.027	$3.150.415	O&M Costs:	$14.714.693	$8.484.555	$5.701.538
Total Revenues (NPV)				Total Revenues (NPV)			
Energy Sales:	$16.772.105	$9.818.138	$6.668.557	Energy Sales:	$16.772.105	$9.818.138	$6.668.557
Carbon Credits Sales:	$0	$0	$0	Carbon Credits Sales:	$18.379.089	$10.859.462	$7.465.212

It can be observed in the results, as well as the first landfill, that the CDM project is vital for this project to become economically attractive. The results for this option (without the CDM) are negative for interest rates above 15%. The scenario with CDM will shown IRR below 15% only if the price of energy is negotiated at prices below 1$/MWh or if carbon reductions shows prices below 2 $/ ton CO_2, which makes the investment highly attractive because such low values are unlikely to arise. Table 5 forward shows the results for the 1 million inhabitants city.

Table 5. Results for the 1 million inhabitants city.

Investment Results - Without emissions reductions project				Investment Results - With emissions reductions project			
Annual Interest Rate:	5,00%	10,25%	15,00%	Annual Interest Rate:	5,00%	10,25%	15,00%
NPV:	$6.017.460	$1.912.756	$229.117	NPV:	$29.954.180	$15.998.848	$9.961.440
IRR:		16%		IRR:		75%	
Total Costs (NPV)				Total Costs (NPV)			
Initial Investment:	$11.670.697	$8.377.811	$6.698.003	Initial Investment:	$11.765.935	$8.468.514	$6.784.960
O&M Costs:	$15.683.695	$8.752.441	$5.731.567	O&M Costs:	$29.107.652	$16.383.601	$10.831.029
Total Revenues (NPV)				Total Revenues (NPV)			
Energy Sales:	$33.371.853	$19.043.008	$12.658.688	Energy Sales:	$33.371.853	$19.043.008	$12.658.688
Carbon Credits Sales:	$0	$0	$0	Carbon Credits Sales:	$37.455.914	$21.807.954	$14.918.741

In this case the results show that the project has a positive economic viability in the two scenarios analyzed. The CDM project significantly improved the results making the project greatly attractive. This occurs because the application costs of a CDM project are relatively cheap but greatly increases the revenue which is close to the gains acquired by selling electricity.

In the scenario without CDM, for the project does not get an IRR below 15% the energy should be marketed at values above $ 76/MWh. In the option with the CDM project even though the energy was sold for free, carbon credits prices up to $16/ton CO_2 can keep the IRR above 15%. Conversely, with the price per ton of carbon to zero, the energy would be sold at least $ 78 per MWh in order to maintain the IRR above 15%.

3. CONCLUSION

The software developed in this project has a good potential to perform economic analysis of projects aimed to recovery energy from biogas produced by landfills. With it was possible to quickly evaluate different landfills and different economic scenarios which ensure the software user to define the key factors involved in the assessment.

The landfills analyzed in this work differ mainly due to the potential for generating biogas, which make possible to conclude that the economic viability of these projects depends heavily on the energy potential of the site.

The smallest city showed positive results only with the inclusion of a CDM project however the viability can be easily be reversed by pessimistic scenarios with low prices of electricity and carbon credits prices. The project in the city with 500 thousand inhabitants proved to be attractive, but the results showed again that the CDM is essential for the landifills with similar sizes, thought this time the results were more vigorous and possible negative changes in prices and rates should hardly make the investment unattractive.

The landfill in the biggest city showed very good results, especially with the inclusion of a CDM project. The results show that the project is viable with or without the carbon credits and the analysis showed that very low prices of energy and carbon are needed for the project become economic unviable.

With the results, it was possible to conclude that the size of the landfill is a key factor in these projects. Another issue is the great importance of CDM for these projects especially for small's landfills that serves population around 100.000 inhabitants. For this kind of renewable energy continues to growth in Brazil is essential that a world market of greenhouse gases continues to exist.

4. REFERENCES

ACM0002: Consolidated baseline methodology for grid-connected electricity generation from renewable sources --- Version 12.1.0. Disponível em: http://cdm.unfccc.int/methodologies/DB/C505BVV9P8VSNN_V3LTK1BP3OR24Y5L/view.html (Acesso em 29/08/10)

ACM0002: Consolidated baseline methodology for grid-connected electricity generation from renewable sources --- Version 12.1.0. Disponível em: http://cdm.unfccc.int/methodologies/DB/C505BV V9P8VSNNV3LTK1BP3OR24Y5L/view.html (Acesso em 29/08/10)

ALBREPE, Associação Brasileira De Empresas De Limpeza Pública E Resíduos Especiais. Panorama dos resíduos sólidos no Brasil. São Paulo. 2006, 160p.

ANNEL – Agência Nacional de Energia Elétrica. Banco nacional de informações sobre geração (BIG). Dsiponível em: www.aneel.com.br (Aceso em 20/03/2011)

BCB – Banco Central do Brasil. Taxa Selic (ano). Disponível em: <http://www.bcb.gov.br> (acesso em 18/02/2011).

Castilhos, J. A.B., Medeiros, P.A., Firta, i. N., Lupatini, G., Silva, J.D., Principais Processos de Degradação de Resíduos Sólidos Urbanos. In: Alternativa de Disposição de Resíduos Sólidos Urbanos para Pequenas Comunidades, Santa Catarina, PROSABE, 2003.

CCEE - Câmara de Comercialização de Energia Elétrica. Site: <http://www.ccee.org.br> (Acesso em 06/03/2011)

ECX - European Climate Exchange. Emissions Prices. Disponível em: <www.ecx.eu> (acesso em 20/03/2011)

IBGE, Instituto Brasileiro de Geografia e Estatísitica. Pesquisa Nacional por Amostra de Domicílios: síntese de Indicadores 2001/ IBGE, Departamento de Empregos e Rendimento, - Rio de Janeiro : IBGE, 2002.

ICLEI – Governos Locais pela Sustentabilidade. Manual para aproveitamento do biogás: volume um, aterros sanitários. ICLEI - Governos Locais pela Sustentabilidade, Secretariado para América Latina e Caribe. Escritório de projetos no Brasil, São Paulo, 2009.

Inter – Governmental Panel on Climate Change, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. In: IPCC National Greenhouse Gas Inventories Programme, Eggleston, S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe (Eds.). IGES, Japan, pp: 3.1-3.4.

Murphy, M. L. Waste-to-Energy Technology. Encyclopedia of Energy, Volume 6. r 2004 Elsevier Inc. All rights reserved.

Sistema Nacional de Informações sobre Saneamento, SNIS. Diagnóstico do manejo de resíduos sólidos urbanos – 2007. Secretaria Nacional de Informações sobre Saneamento – Brasília: MCIDADES.SNSA, 2009.

Tchobanoglous G.; Theisen, H.; Vinil, S. Integrated solids waste management. Engineering principles and management issues. Irwin Macgraw Hill, 978 p., 1993.

Themelis N. J., Ulloa, P. A.. Methane generation in landfills. Earth Engineering Center and Department of Earth and Environmental Engineering, Columbia University. Renewable Energy 32 (2007) 1243–1257

USEPA - U.S. Environmental Protection Agency, Landfill Methane Outreach Program. Landfill Biogas Recovery and Utilization at the Solid Waste Treatment Center BR-040 Belo Horizonte, Brazil: Final Assessment Report. Methane to Markets Contract: EP-W-06-22 TO 008 and 021. 2008.

Waste Framework Directive. Council of the EU, 2008, Council Directive, 2008/98/EC.

Zamorano M., Pérez J. I. P., Pavés I. A., Ridao A. R. Study of the energy potential of the biogas produced by an urban waste landfill in Southern Spain. Renewable and Sustainable Energy Reviews Volume 11, Issue 5, June 2007, Pages 909-922