COBEM2021-0836
PREDICTION OF BIOGAS GENERATION AND BIOENERGY USING MCI FOR THE MARITUBA-PA LANDFILL

Yan dos Santos Lima[1]
Ana Paula Mattos[2]
[1,2]Federal University of Pará
[1]yanlims11@gmail.com
[2]anapmattos@ufpa.br

Abstract.

Urban solid waste (USW) destined for landfills produces garbage gas from anaerobic decomposition, which is an excellent source of energy with a high lower heating value (LHV). The objective of this article is to quantify the generation of methane in biogas and to estimate the production of electric energy utilizing internal combustion engines (SI) for the landfill in Marituba, in Pará. Utilizing three methodologies of biogas: LandGEM, IPCC, and Cetesb, to obtain greater accuracy in the results. Methane production, from 2015 to 2025, was estimated at 58.4 10^7 m³ using the IPCC methodology, 37.1 10^7 m³ of CH_4 using the LandGEM methodology, and 29.2 10^7 m³ of CH_4 using the Cetesb methodology. For generation bioenergy utilized 60% of CH_4 and the efficiency of SI medium value 28.6%. Through the Cetesb result, approximately 20.93% of the population of the city of Marituba can be served with electricity in 2021, by the LandGEM methodology, approximately 26.37% of the Marituba's population in the year 2021 and by the IPCC methodology, approximately 43.04% of the population of Marituba. Through the results, the present study demonstrates the importance of the use of USW to bioenergy production, in addition to the great energy potential of the landfill.

Keywords: *Biogas, Bioenergy of landfill, Cestesb, LandGEM, IPCC.*

1. INTRODUCTION

Nature is cyclical, all types of organic matter decompose with the action of decomposing microorganisms that transform them into nutrients for the soil and, in the absence of oxygen, produce biogas. In past centuries, the waste generated was reintegrated into natural cycles and served as fertilizer for agriculture. However, in the current scenario, urban solid waste (USW) has become a health issue, contamination of soil, air, and water (MMA, 2017). Due to the large production of garbage in urban centers and the absence of effective waste management systems, landfills have become one of the biggest problems in the world (MMA, 2018). Regarding the final disposal of urban solid waste, in 2020, about 72.7 million tons of USW were produced, with 43 million tons destined for sanitary landfills and 29 million tons went to inadequate disposal units (ABRELPE, 2020).

The growth of policies emphasizing renewable energy is on the agenda in today's Brazilian scenario to mitigate the damage to the environment caused by aging energy matrices. Brazilian electricity generation is mainly composed of water sources, corresponding to 64.9%. In Brazil, the electric matrix comprises hydraulic sources, natural gas, wind, and biomass, as shown in Table 1. However, biogas can generate electricity, which is not widely used in the Brazilian scenario, which can further attenuate non-renewable electricity sources in the national matrix. Biogas is a renewable biofuel with an excellent calorific value and can be used for electricity generation (EPE, 2020a). Biogas is generated by the anaerobic digestion of organic matter of plant or animal origin. Renewable energy sources emphasize worldwide as an alternative energy matrix, as they are a clean and less polluting energy source (Ren21, 2019).

In 2010, with the sanction of Law No. 12,305/2010, the National Solid Waste Policy (PNRS) imposed the urgent need to replace open-air dumps with sanitary landfills to measure environmental protection. As of the enactment of the law in 2010, 29.2% of Brazilian garbage was destined for sanitary landfills, and in 2018, about 59.5% is destined for sanitary landfills (MMA, 2019). According to the report itself, this situation is configured as an admittedly inadequate destination scenario, which requires urgent and structural solutions for the sector (PNUD & MMA, 2010). The priority destination would be landfilled (MMA, 2018). The sanitary landfill is considered the most advanced technology today in terms of environmental safety and the population's health and guarantees the best cost-benefit. They have more efficient and controlled control of the waste storage process. Landfills work similarly to a reactor through chemical and biological reactions, emissions such as landfill biogas, liquid effluents such as leachate, and mineralized waste from the decomposition of organic matter (PNUD & MMA, 2010). According to the NBR 8419/NB843 standard responsible for the technical guidelines of the essential elements for landfill projects, such as waterproofing the base, superior waterproofing, environmental and geotechnical monitoring, leachate and gas drainage system, requirements for special

cells for waste from health services, presentation of the landfill operation manual and definition of what will be the future use of the landfill area after the end of activities (PNUD & MMA, 2010).

Table 1. Brazilian Electric Matrix, referring to the year 2019 (EPE, 2020b).

Electric power source	Percentage in matrix
Water	64.9 %
Natural gas	9.3 %
Aeolic	8.6 %
Biomass	8.4 %
Coal and derivatives	3.3 %
Nuclear	2.5 %
Oil derivates	2.0 %
Solar	1.0 %

To reduce Greenhouse Gases (GHG), the Clean Development Mechanism (CDM) has a tool that enables countries committed to GHG reduction to acquire Certified Emission Reductions (CERs) (Orienta, 2010). CERs can be generated and traded by developing countries with emission reduction projects in addition to those that would occur in the absence of the project registered as CDM. This ensuring real measurable and long-term benefits to the environment for the mitigation of global climate change, in the form of a financial, tradable asset (Alves et al., 2013; Orienta, 2010). The CDM provides opportunities for developing countries to take advantage of actions to reduce greenhouse gas emissions by implementing projects that contribute to sustainability (MCTIC, 2015).

The use of waste for biogas generation becomes an alternative instead of burning the waste to produce thermal, electrical, and mechanical energy. This electrical and thermal energy is generally consumed locally or introduced into the grid in excess electricity. However, with the purification of landfill biogas to a minimum percentage of 94% methane gas, which is called biomethane (ANP, 2020). The options for use are diversified, such as biofuels, injection into the natural gas network, or compression, among other generation processes using biogas (Milanez et al., 2018). These alternatives arise to mitigate GHGs and, at the same time, increase the country's decentralized energy generation capacity. Biogas or landfill gas (LFG) is being used as one of the sustainable development tools involving the CDM with projects to capture and burn methane from landfills, from anaerobic sewage, effluent, and rural waste treatment stations, quantities of solid organic waste are segregated and used as fuel in electric power generation units with steam boilers (Cetesb, 2014).

An energy use project aims to convert the LFG into some form of valuable energy, such as steam (heat), electricity, fuel from internal or external combustion equipment, or even from a vehicle fleet (FEAM, 2012). In general, there are three basic ways of using biogas produced in landfills (EPE, 2008): direct use gas, energy production/cogeneration, and sale of the gas (in gas pipelines or as Natural Gas for Vehicles). Among the main advantages of the energy use of LFG, EPE (2008) highlights the reduction of greenhouse gas emissions since methane is combusted and oxidized into carbon dioxide, whose global warming potential is more than 20 times lower. The generation of complementary revenue for existing landfills, derived from the sale of the energy produced and any carbon credits generated, and the use of material previously classified as useless after its transformation and service for energy production or fuel.

Biogas, produced in landfills, is an excellent option for use due to its energy power and the available amount generated by the tailings grounding system. The destination of landfill biogas for bioenergy generation reduces landfill costs and contributes to the enterprise (Viera et al., 2015). The composition of landfill biogas is basically: methane (CH_4 - from 45 to 60%), carbon dioxide (CO_2 - from 40 to 60%), nitrogen (N - from 2 to 5%), oxygen (O - from 0.1 to 1%), sulfur (S - from 0 to 1%), ammonia (NH_3 - from 0.1 to 1%), hydrogen (H - 0 to 0.2%), carbon monoxide (CO - 0 to 0.2%), gases in lower concentration 0.01 to 0.6% (Macêdo, 2002). The generation of biogas in a landfill starts a few months after the start of waste disposal and continues for 15 years after its closure. A ton of waste disposed of in a landfill generates an average of 200 Nm^3 of biogas (Abreu et al., 2009).

In biogas, the concentrations of methane gas and carbon dioxide vary infinitely due to the dissolution of part of the carbon dioxide in the aqueous fraction of the waste mass (Ensinas, 2003). Typically, a biogas composition contains ammonia ranging from 0.1 to 1% and up to 350 harmful constituents, some shown in Table 2, which vary from 0.01 to 0.6% and may represent up to 1% of the total biogas from landfill or garbage gas (LFG) (Alves et al., 2013). Mostly, these constituents come from organic matter; despite the inorganic components, there are volatile metallic compounds: cadmium, mercury, zinc, and lead (Tchobanoglous, G.; Theisein, H., Vigil, 1993).

Table 2. Toxic constituents in landfill biogas (Alves, 2008).

Compound name	Maximum concentration detected (ppm)	Toxicity degree

Toluene	758.0	Harmful
Hexane	25.0	Harmful
Xylene	664.0	Harmful
Benzene	52.2	Toxic
Vinyl chloride	48.1	Toxic
Methyl furan	40.0	Toxic
Carbon tetrachloride	68.3	Very toxic
Hydrogen sulfide	700.0	Very toxic

The comparison of biogas formation in landfills and dumps in Figure 1 shows that the emission varies in production speed and quantity produced over time. Even with the relatively constant chemical composition, this difference occurs due to climatic factors, forms of disposal, among other factors (Batchelor D., Eeraerts D., 2002; EPE, 2018). According to EPE (2008), food residues deposited in landfills emit more than twice as much methane gas as open dumps. Thus, even though landfills are currently the best way to dispose of them, greenhouse gas emissions are high, especially in the first years of operation, showing the need to use LFG (Jauregui et al., 2017).
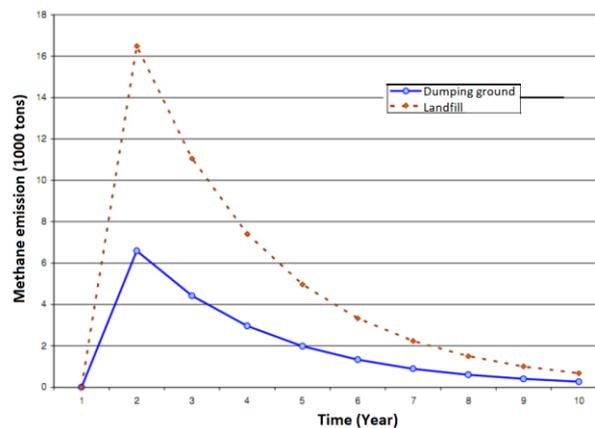

Figure 1. Methane emissions by type of USW disposal. Adapted (PESQUISA e EPE, 2018).

Typically a landfill is built to meet the demand for USW of a municipality or a range of surrounding cities for at least 20 years (MMA, 2018). The length of each stage of the service life of a landfill is determined by the roof material, design profile, weather conditions, and gravimetric composition. Figure 2 presents the final disposal of USW in Brazil and the North region, noting that the North region sends the most significant part to the garbage dump and inadequate landfills concerning the average of Brazil (ABRELPE 2019, ABRELPE 2020).
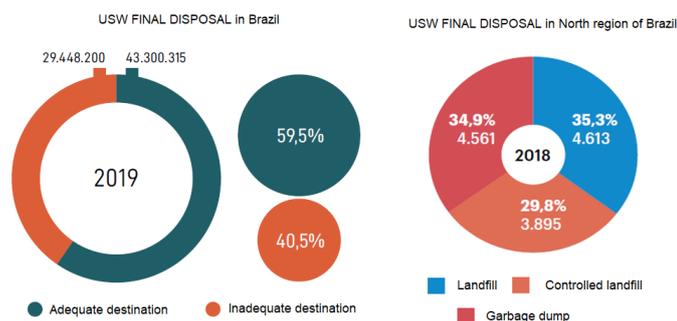

Figure 2. USW final disposal in Brazil and North. (ABRELPE 2019, ABRELPE 2020)

The landfill has increased production from the beginning of its life until the depletion of the landfill, in which this waste deposition ceases, leading to a characteristic, progressive decay curve, according to Figure 3 (Palermo, 2016).

The landfill is considered an appropriate place for the disposal of solid urban waste, to treat the final decomposition of urban waste to reduce environmental pollution (VGRESIDUOS, 2018). When solid waste decomposes in the landfill, exemplified in Figure 4 (a), the LFG and leachate are released, which are pollutants to the environment, which, in order not to come into contact with the soil, need a waterproofing layer, implemeted in the systems drainage (Lima, 2001).

The LFG produced during biodegradation can travel through different pathways inside cells (Alcântara P. B, 2007). During this movement, the methane gas can transform into carbon dioxide due to the action of methanotrophic bacteria, through the oxidation that occurs in the upper layer of the landfill, due to the presence of atmospheric oxygen. CH_4 can

also migrate to the surrounding soil by molecular diffusion or be emitted into the atmosphere by gas drains in the cover layer as shown in Figure 4 (b) (Alves, 2008).
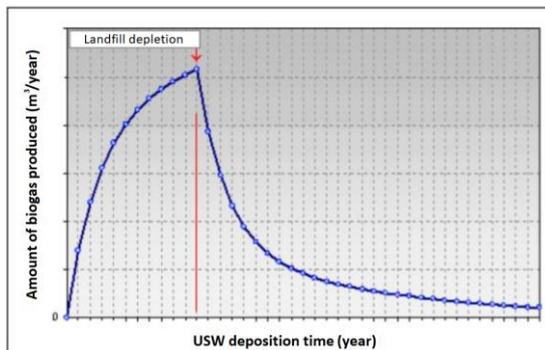

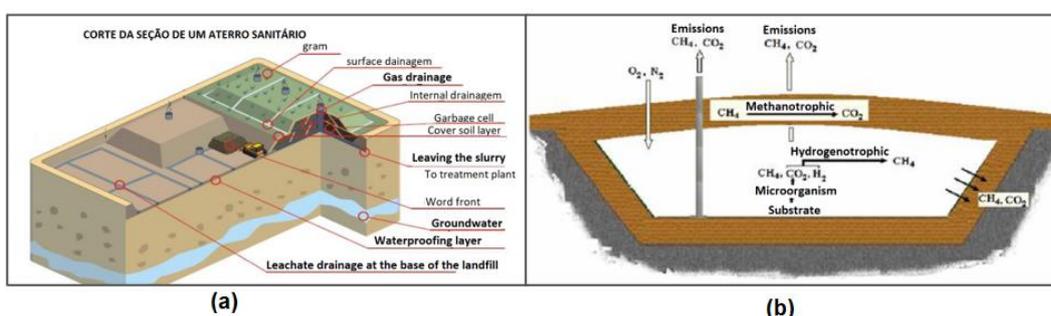Figure 3. Typical curve of landfill biogas production (PALERMO, 2016).

Figure 4. (a) Illustration of a landfill (SOUZA, 2015), (b) Landfill gas balance (ALVES, 2008).

In this context, the present work aims to quantify biogas production, also called waste gases (LFG), from the Marituba landfill from 2015 to 2025 through three methodologies: LandGem, IPCC, and Cetesb. Bioenergy generation was also estimated using internal combustion engines, as a form of decentralized and clean energy generation, following the guidelines of the clean development mechanism. Therefore, the results of bioenergy generation between the three biogas generation methodologies were evaluated, compared with the number of people who could be served with electricity in Marituba.

2. METODOLOGIA
2.1 Generation of biogas or waste gas

The quantification of biogas production in landfills is done through mathematical equation models. Each methodology uses specific criteria of gravimetric composition, landfill, climate, and population to assess the parameters of waste gas generation (LFG). In this study, three biogas prediction models were used in the Marituba landfill in the Pará. To obtain greater accuracy in the quantification of bioenergy generated by spark-ignition internal combustion engines (MCI-ICE), the technology is more utilized because of the investment cost. Also, estimate the number and number of people who could be served with clean and decentralized energy.

LandGEM generation model consists of determining the volumetric flow of methane in one year. The formulation has to assess the rate of biogas generation, the mass of waste up to the nth year, the age of the mass, and the capacity of the potential generation of methane Equation 1. Being available for free with Software and interactive Excel® worksheet. Table 5 presents the values used to estimate methane generation.

$$Q_{CH_4} = \sum_{I=1}^{N} \sum_{J=0,1}^{N} kL_0 \frac{M_t}{10} e^{-kt_{i,j}} \tag{1}$$

Being: Q_{CH4} = Annual methane generation in the year of calculation (m³/year); i = Time increment (year); n = Difference between a year of calculation and initial year of calculation (year); J = Time increment (year); k = Methane Generation rate (1/year); L_0 = Potential methane generation (m³/kg or m³/Mg); M_t = Accepted mass of waste of the umpteenth year (year); $t_{i,j}$ = Age of the J ith mass section (year).

The biogas generation model CETESB, 2006, made available by the Environmental Company of the State of São Paulo, via Excel® spreadsheet free of charge. It is indicated to estimate biogas emissions and the amounts of energy available for its recovery, use in landfills and anaerobic treatment stations for domestic sewage or industrial or residual

effluents (CETESB, 2014). The way to calculate is described in Equations 2 to 2.2. Table 5 presents the data used in the CESTEB model based on the IPCC (2020). The L_0 value and the waste flow were used data according to Solvi (2012).

$$\sum Q_{CH4} = kL_0 \sum R_x e^{-k(x-T)} \tag{2}$$

$$\int \frac{dQ}{dt} = kR_x L_0 \tag{2.1}$$

$$Q_x = kR_x L_0 e^{-k(x-T)} \tag{2.2}$$

Being: Rx = USW flow (Tons/year); x = Current year (year); T = Year waste disposal (year); Q_x = Annual methane generation in the year of calculation (m^3/year).

The IPCC (Intergovernmental Panel on Climate Change) model consists of comprehensive reports to gather, evaluate and interpret research, both technical and socioeconomic, on climate change, its impacts and future risks. The method can be calculated as described in Equation 3 (Schirmer et al., 2018). The IPCC is also available in Excel® spreadsheet free of charge. Table 3 presents the gravimetric composition to estimate methane gas using the IPCC 2006 methodology and other values.

$$Q_{CH_4} = \sum x\{[(A.k.USW_x.USWF_x.L_{0(t)}).e^{-k.(t-x)}] - R_x\}.(1 - OX) \tag{3}$$

$$L_{0(t)} = FCM.COD.COD_f.F_{CH_4} \tag{3.1}$$

Being, USW_x = MSW generation rate per inhabitant per year (%); $USWF_x$ = Fraction of urban solid waste that is deposited in solid waste sites (%); FCM = Methane correction factor (%); F_{CH4} = Fraction of methane in landfill gas (%); Rx = Amount of methane recovered (GgCH$_4$/year); OX = Oxidation factor (dimensionless); COD = gravimetric composition; COD_f = Fraction of COD that decomposes (dimensionless).

In the IPCC methodology, the gravimetric composition of the garbage is of utmost importance to determine organic chemical demand (COD) and COD_f. Thus, we adopted that the trash from Marituba, a city neighbouring Belém, has the same components described in the work of Table 3. The equation 4 and 5 show the how obtain COD and COD$_F$.

$$COD = \%COD_i Componet_i \quad [t\ COD/t\ USW] \tag{4}$$

$$COD_f = 0,014T_m + 0,28 \tag{5}$$

Where T_m is the average temperature of operation the landfill.

The gravimetric composition of garbage is one of the main factors that influence the generation of LFG and mainly the amount of methane, which is essential gas to generate energy. The Figure 5 shows the gravimetric composition of Brazil, and it can be observed that the Belem produced mor organic matter (food waste+organic matther) and paper than Brazil.

Table 3. Data for estimate methane for IPCC methodology.

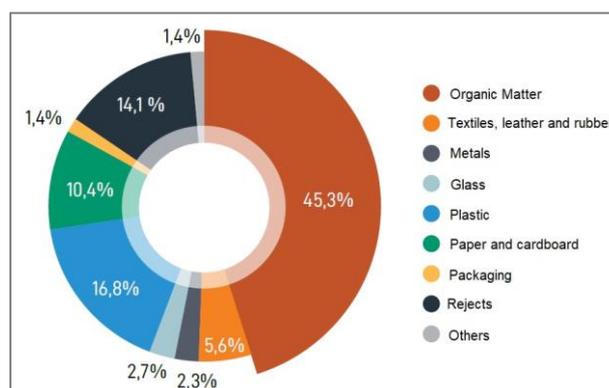| Component	% in mass of COD (IPCC)	Composition (%) of USW of Belém (Pinheiro, 2010).
Paper	40	14
Organic Matter	17	1
Food waste	15	58
Tissue	40	4
Wood	30	1

Figure 5. Gravimetric composition of garbage in Brazil (ABRELPE, 2020)

2.2 Generation Bioenergy

By predicting biogas, as shown, it is possible to estimate the volume of methane with the average efficiency of spark-ignition internal combustion engines, Table 5, through the literature, and thus quantify the production of bioenergy and to analyze the number of people who could be served with electricity in the city of Marituba, Pará. It was decided to carry out a study on the estimation of bioenergy generation using MCI-ICE because it is easy-to-purchase equipment, with expressive yield, and for presenting lower investment and maintenance costs than microturbines, or gas turbines (Mattos et al., 2013).

Equations (6) and (7) present the formulation used to estimate the generated bioenergy.

$$Pot._{ger} = V_{CH_4} * \eta_{MCI} * PCI_{CH_4} \tag{6}$$

$$Bioenenergy = Pot_{ger} * \Delta t \tag{7}$$

Being: η_{MCI} = Average efficiency for SI (%); PCI_{CH4} = Lower heating value (kJ/kg); Δt = Landfill operating hours (hours);

Bioenergy generation can be compared with the population of the city of Marituba, Pará. According to Rede CELPA (2009), residential consumption in 2009 corresponds to 25,019,189 kWh of the 23,880 households in the city, and according to the Brazilian Institute of Geography and Statistics (IBGE), in 2017, the population of the municipality was estimated at 127,858 inhabitants.

Table 4. The efficiency of internal combustion engines.

Parameter	Value	Reference
MCI yield	0.27%	(Salomon; Lora, 2006)
	0.26%	(Szymanski, 2010)
	0.27%	(Moraes; Zaiat; Bonomi, 2015)
	0.30%	(Salomon, 2021)
	0.33%	(Bernal, 2019)
Average income	0.28%	-

Table 5. Parameters utilized for the estimate methane in landfill for three methodologies.

Parameter	Value	Reference
Population	2168873	(IBGE, 2010)
USW rate [tonsUSW/pop.year]	0.32	(ABRELPE, 2018)
Collecte [%]	35.30	(ABRELPE, 2018)
L_0 [tons$_{CH4}$/t$_{ltrash}$]	0.10	Calculate by IPCC (2006)
L_0 [m^3$_{CH4}$/t$_{trash}$]	0.14	Calculate by IPCC (2006)
Rx [tons$_{CH4}$/year]	1.00	(Wander et al., 2016)
OX [%]	0.10	(Wander et al., 2016)
FCM [%]	1.00	(Wander et al., 2016)
COD [t$_{COD}$/t$_{trash}$]	0.16	Calculate by IPCC (2006)
COD$_f$	0.77	Calculate by (IPCC, 2006)
F$_{CH4}$ [%]	60.00	(Wander 2016, Ensinas 2003, USEPA 1991).
T$_m$ [°C]	35.00	(CLIMATE, 2020)
NMOC concentration [ppmv]	600.00	(Epa, 2005)
K [year^{-1}]	0.08	(Cetesb, 2014)
Δt [hour/year]	2763.57	(Solvi, 2012)

3. RESULTS
3.1 Biogas generation
3.1.1 IPCC

The Marituba landfill serves the municipalities of Belém, Ananindeua and Marituba, which, according to IBGE (2020), together total a population of 2,168,873. Taking into account the data in Table 5, it is possible to estimate the methane generated, shown in Figure 6, it can be seen that during constant garbage deposition, the curve tends to have continuous growth in the volume of methane until it reaches its peak, in the year 2024, with the amount of 1.07 E8 Nm3/year. The total amount of biogas generated by the Marituba landfill, taking into account that USW will be deposited constantly from 2015 to 2025, was 5.84 E8 Nm^3 of CH_4. In the calculation, only the collection rate related to sanitary landfills was taken into account, around 35.4%, however if the garbage destined for controlled and sanitary landfills were deposited in the same place, the collection rate would change to 70.2%, thus, the production of biogas in the year 2021 would be 1.28 E8 Nm^3/year, which represents approximately 97.79% more in the production of biogas.
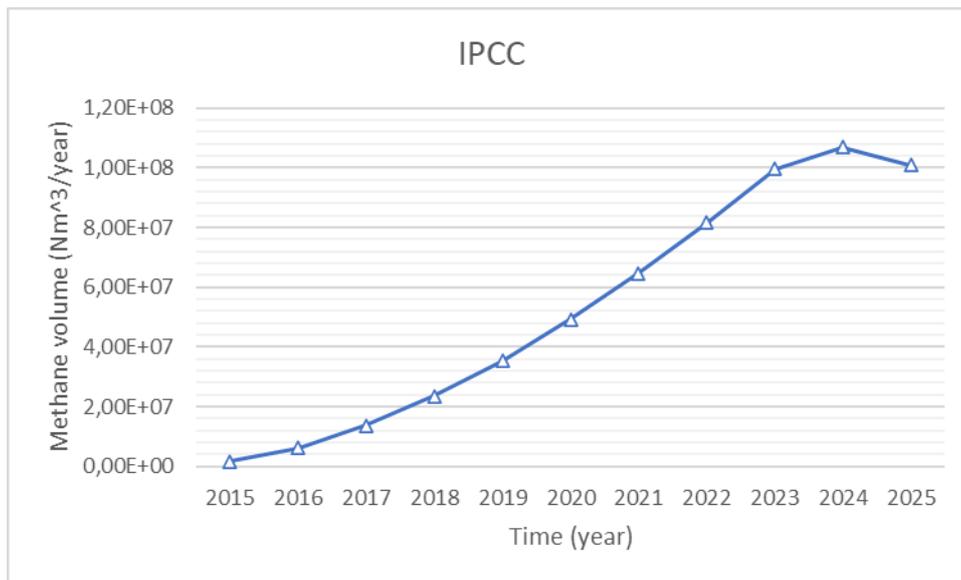

Figure 6. Methane production by IPCC methodology for landfill Marituba.

3.1.2 LandGEM

The initial date of operation of the Marituba landfill is in 2015 and adopting a 10-year disposition, there is a total gas production of 92,450,000 m^3 in the year 2025, Figure 7, and with the generation of methane arriving in peak production of a total of 54,700,00 m^3 of CH_4 in the year 2024. Carbon dioxide represents 34,600,000 m^3. To obtain these results, it is necessary to add the populations of the cities of Belém, Ananindeua, and Marituba, cities which the Marituba landfill serves, the population data according to (IBGE, 2020) the total in 2020 the population is 2,168,873.
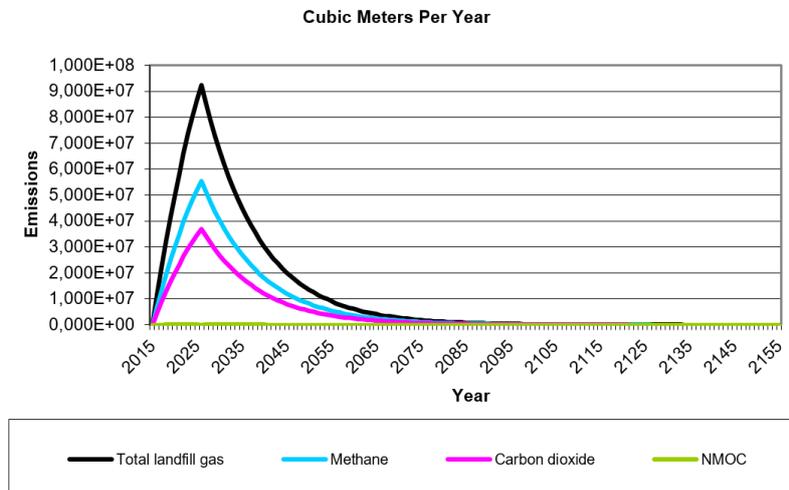

Figure 7. Waste gas production in m^3/year, estimated by LandGEM software.

3.1.3 Cetesb

In Figure 6, the estimated methane generation from the Marituba landfill can be seen using the Cetesb method, the methane peak value estimated by the Cetesb methodology was 43,871,000 m^3 of CH$_4$ in 2025. Based on the results presented, the estimate of biogas and methane gas generation for each methodology is quite different, due to the input parameters of each, such as population density, landfill waste disposal, and gravimetric composition to estimate the
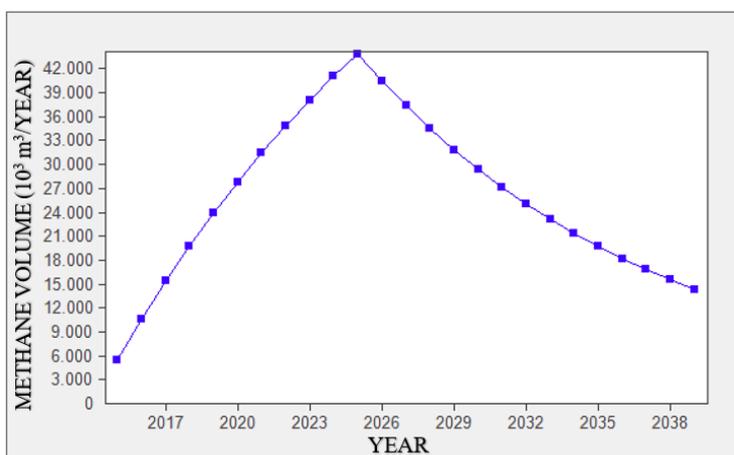

Figure 8. Estimate of methane gas by the Cestesb-SP methodology

generated gas in a landfill. Comparing the results of LandGEM and CETESB there is a difference of 30% and LandGEM with IPCC, 64%.

3.2 Bioenergy generation

Figure 9 shows the results of bioenergy produced with the methane generated using each methodology. Energy production is estimated using spark-ignition internal combustion engines (ICE-SI), bioenergy production is predominant with the IPCC methodology. However, bioenergy production utilizing the volume of methane estimated by CETESB and LandGEM methodologies has similar results. Compared to the year 2021, the IPCC can serve approximately 43.04% of the population of Marituba, LandGEM 23.37%, and CETESB 20.93%.

During ten years of energy production and comparing the electricity consumption by the population of Marituba in 2009, around 25.14% of the population can be supplied with residential electricity, with the average value estimated by the three methodologies in 2015 to 2025. These results show that the amount of bioenergy generated tends to increase from the first year of operation to the last year of garbage disposal in the landfill, as observed in Table 6.
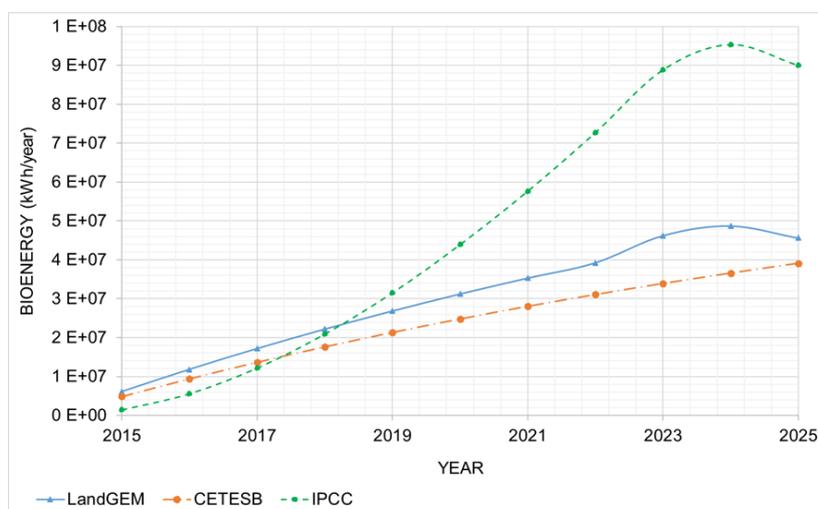

Figure 9. Estimate of bioenergy production with waste gas in 10 years, for each methane generation methodology used.

Table 6. Percentage of the Marituba population that can be served with electricity from the Marituba-Pa landfill over the years.

Year	Bioenergy		
	IPCC	LandGEM	Cetesb
2015	1.1%	4.6%	3.7%
2016	4.2%	8.9%	7.1%
2017	9.1%	12.8%	10.2%
2018	15.6%	16.6%	13.2%
2019	23.6%	20.1%	15.9%
2020	32.8%	23.3%	18.5%
2021	43.0%	26.4%	20.9%
2022	54.3%	29.3%	23.2%
2023	66.3%	34.5%	25.3%
2024	71.2%	36.4%	27.3%
2025	67.2%	34.1%	29.2%
Average	**35.3%**	**22.5%**	**19.8%**

4. CONCLUSION

The present study used data from the literature and public information about the Marituba landfill for the estimation LFG, emphasizing methane gas by LandGEM, Cetesb, and IPCC methodologies and bioenergy production.

From the variation in the percentage of methane gas production from the landfill, it was observed that the most accurate value of the percentage of methane generated in the Marituba landfill is essential to manipulate the methodologies and achieve more consistent data, thus it is remarkable that the use of experimental methodologies such as the flow plate is essential to complement this study.

The results obtained demonstrate a significant variation in the estimation of LFG between landfill biogas prediction methodologies, which has a substantial impact on bioenergy production. According to Wander (2018), the method that best represented the landfill analyzed in his study was the IPCC and it is essential to emphasize that the IPCC methodology takes into account a greater number of variables than the Landgem and Cetesb methodologies, which leads to greater reliability in its results even with a bienergy generation on average 67.5% higher than the other methodologies presented in the study.

The values found by the empirical methodologies were approximate. They showed that the landfill is an excellent source of methane gas, which can be used to generate bioenergy with internal combustion engines, thus bringing clean, decentralized electricity.

5. REFERENCE

ABRELPE. (2019). Overview of solid waste in Brazil: 2017. Brazilian Association of Public Cleaning Companies and Special Waste. 73.

ABRELPE. (2020). Panorama dos Resíduos Sólidos no Brasil 2020. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais - ABRELPE, 51. https://abrelpe.org.br/panorama-2020/

ALCÂNTARA P. B. (2007). Avaliação da influência da composição de resíduos sólidos urbanos no comportamento de aterros simulados. In Tese de Doutorado – Centro de Tecnologia e Geociências, Universidade Federal de Pernambuco (p. 366).

Alves. (2008). ANÁLISE EXPERIMENTAL DO POTENCIAL DE GERAÇÃO DE BIOGÁS EM RESÍDUOS SÓLIDOS URBANOS. Programa de Pós-Graduação Em Engenharia Civil - Mestrado Em Engenharia Civil, 1, 134.

Cetesb. (2014). Projetos de biogás no MDL. Mdl, 2020.

CLIMATE. (2020). BELÉM CLIMA (BRASIL).

Epa. (2005). Landfill Gas Emissions Model (3.02).

EPE. (2020a). Balanço Energético Nacional 2020. Rio de Janeiro : EPE, 7–295.

EPE. (2020b). Relatório Síntese BEN 2020-ab 2019_Final.pdf. In Balanço Energético Nacional (p. 73).

IBGE. (2020). Cidades e Estados. https://www.ibge.gov.br/cidades-e-estados. Acessed Jan 2021.

IPCC. (2006). Guidelines for National Greenhouse Gas Inventories.

LIMA, J. D. (2001). Gestão de resíduos sólidos urbanos no Brasil. In ABES (p. 135).

Mattos, A. P., Gotelip, T., Veloso, C., Sotomonte, C., Lopes, A. D. O., & Coronado, C. R. (2013). Electricity Generation From Biogas Produced in. Cobem, 4578–4589.

MMA. (2017). **Lixo Um grave problema no mundo moderno**. , 2017, p. 113–134.

MMA. (2018). Diferença entre lixão e aterro sanitário. Diferença Entre Lixão e Aterro Sanitário.

MMA, S. de Q. A. (2019). Plano nacional de resíduos sólidos. 187.

Palermo, G. C. (2016). Potential of energy recovery from Municipal Solid Waste – A case study for the city of Rio de. October. https://doi.org/10.13140/RG.2.2.19265.97124

Pinheiro, J. F. (2010). III-005 - AVALIAÇÃO DO FECHAMENTO DO LIXÃO DO AURÁ DO MUNICÍPIO DE BELÉM / PA. 1, 1–14.

PNUD, & MMA. (2010). Produto 6 – Resumo Executivo Estudo sobre o Potencial de Geração de Energia a partir de Resíduos de Saneamento (lixo, esgoto), visando incrementar o uso de biogás como fonte alternativa de energia renovável. 56.

Ren21. (2019). Renewables 2019 global status report. 1, 336.

Schirmer, W. N., Bianek, J., Cabral, A. R., Mayer, C. L. D., Eurich, P. H. M., & Martins, E. H. (2018). Comparação Entre Metodologias Usepa E Ipcc De Produção De Biogás Em Aterro Municipal. BIOFIX Scientific Journal, 3(1), 34–40.

VGRESIDUOS. (2018). Como funciona o aterro sanitário? 22/01/2018, 1, 11.

Wander, P., Medeiros, R., Miranda, L., & Teixeira, G. (2016). ANALYSIS OF THE DIFFERENCES BETWEEN ACTUAL DATA AND USEPA, UNFCCC AND IPCC METHODOLOGIES FOR ESTIMATING LANDFILL CH4 GENERATION POTENTIAL. UNISINOS - Universidade Do Vale Do Rio Dos Sinos, 9.

6. LIABILITY NOTICE

Authors Yan dos Santos Lima and Ana Paula Mattos are solely responsible for the printed material included in this article.