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Environment

Quantification of biogas in landfills in Rio de Janeiro: application of the IPCC method

Quantificação do biogás em aterros do Rio de Janeiro: aplicação do método IPCC

Cuantificación del biogás en vertederos de Rio de Janeiro: aplicación del método IPCC

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ABSTRACT

This study was based on the generation of biogas in landfills in Rio de Janeiro and the importance of this activity for the environment. According to the Environment Institute (INEA), the state has 20 landfills and, according to data from the National Solid Waste Management Information System (SINIR), only 5 produce biogas. The aim of this project is to quantify biogas generation using the Intergovernmental Panel on Climate Change (IPCC) method, which calculates the cubic meterage of biogas based on the amount of waste that reaches these landfills. In addition to calculating the generation of biogas, forms were applied through technical visits to two landfills. Using the IPCC method, it was possible to diagnose the difference in biogas generation between the results of the calculation and the data provided by SINIR, the biggest difference being 42,908,263.48 m³.

Keywords: Landfill; Biogas; Generation; Methods; Waste

RESUMO

O presente estudo foi embasado na geração do biogás nos aterros sanitários do Rio de Janeiro e a relevância desta atividade para o meio ambiente. O estado possui, segundo o Instituto do Meio Ambiente (INEA), 20 aterros sanitários e de acordo com dados do Sistema Nacional de Informações sobre a Gestão de Resíduos Sólidos (SINIR) apenas 5 produzem Biogás. O objetivo deste projeto é quantificar a geração do biogás por meio do método do *Intergovernmental Panel on Climate Change* (IPCC), na qual calcula a metragem cúbica de biogás a partir da quantidade de resíduos que chegam até esses aterros. Além do cálculo da geração do Biogás, foram aplicados formulários através de visitas técnicas em dois aterros.

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Utilizando o método do IPCC, foi possível diagnosticar a diferença na geração de biogás entre os resultados do cálculo e os dados fornecidos pelo SINIR, sendo a maior diferença de 42.908.263,48 m³.

Palavras-Chave: Aterro Sanitário; Biogás; Geração; Método; Resíduos

RESUMEN

Este estudio se basó en la generación de biogás en los vertederos de Río de Janeiro y la importancia de esta actividad para el medio ambiente. Según el Instituto de Medio Ambiente (INEA), el estado tiene 20 vertederos y, de acuerdo con los datos del Sistema Nacional de Información de Gestión de Residuos Sólidos (SINIR), sólo cinco producen biogás. El objetivo de este proyecto es cuantificar la generación de biogás utilizando el método del Grupo Intergubernamental de Expertos sobre el Cambio Climático (IPCC), que calcula el metro cúbico de biogás a partir de la cantidad de residuos que llegan a estos vertederos. Además de calcular la generación de biogás, se aplicaron formularios mediante visitas técnicas a dos vertederos. Utilizando el método IPCC, fue posible diagnosticar la diferencia de generación de biogás entre los resultados del cálculo y los datos proporcionados por SINIR, siendo la mayor diferencia de 42.908.263,48 m³.

Palabras clave: Vertedero; Biogás; Generación; Métodos; Residuos

1 INTRODUCTION

The generation of waste can be considered one of the major sources of environmental problems, even though the issue is still neglected by many. Nowadays, it is considered that the inadequate management of solid waste directly generates important impacts, both on the environment and on human health (Gouvieia, 2012).

According to the National Solid Waste Policy (PNRS), Law 12.305/2010, solid waste is any discarded material, substance, object or good resulting from human activities in society, while waste is a solid waste that, after all possibilities of treatment and recovery by technologically and economically viable processes have been exhausted, has no other possibility than environmentally appropriate final disposal.

According to the National Agency for Technical Standards (ABNT, 2004), solid waste can be present in solid and semi-solid states, and comes from industrial, domestic, hospital, commercial, agricultural, service and sweeping activities.

Worldwide, more than 2 billion tons of waste are produced every year. Around 99% of the products purchased are discarded within 6 (six) months. Every day, 145,000 tons of waste are disposed incorrectly, an amount equivalent to what is generated by 27% of the Latin American and Caribbean population, or 170 million people (ONU, 2018).

According to ABELPRE (2017), between 2016 and 2017 there was a 1% increase in the generation of municipal solid waste (MSW) while the population grew by 0.75%. The annual generation of Municipal Solid Waste in Brazil is approximately 78.4 million tons, of which 31.9% is recyclable material, such as metals, paper, plastic and glass, 51.4% organic matter and 16.7% other materials (IPEA, 2012). Out of Brazil's 5,570 municipalities, 3,352 disposed of 40.9% of their waste in inappropriate places in 2017.

Dumps receive solid waste that is deposited in the open, generating numerous social and environmental problems. In a landfill, the waste is deposited in waterproofed soil, preventing substances from contaminating the ground and water table (CTR Essencial, 2021).

According to NBR 8,419/92, a sanitary landfill is a technique for disposing of solid urban waste on the ground through a method that uses engineering principles to confine solid waste to the smallest possible area, minimizing environmental impacts without causing damage to public health and safety.

The PNRS, established by Law 12.305 of 2010, outlines the correct management of waste generated in institutions, how it should be packaged and disposed of, as well as the priority order for waste, which is non-generation, reduction, reuse, recycling and environmentally appropriate final disposal, i.e. before the waste is sent to landfill, for example, there are other means of recovering the waste that need to be considered.

According to the Brazilian Association of Public Cleaning and Special Waste Companies (ABELPRE) 2012, in 2011 Brazil generated approximately 180,000 tons of waste per day, totaling 62 million tons for the year. 58% of this waste was sent to sanitary landfills, 24% to controlled landfills and 17% to dumps.

According to the State Solid Waste Plan (PERS) for the state of Rio de Janeiro (2013), data was collected on the apparent consumption of waste appropriate to the gravimetric estimate of waste, generated in relation to the number of residents in the state, as can be seen in Table 1.

Table 1 – Gravimetric Estimation of the State of Rio de Janeiro

Municipalities	Organic matter	Paper/ cardboard	Plastics	Glass	Metals	Others
Small (Population up to 100,000 inhabitants)	52.72%	13.45%	18.63%	2.83%	1.58%	6.79%
Medium-sized (Population 100,001 to 1,000,000 inhabitants)	53.03%	16.57%	19.69%	2.95%	1.49%	6.27%
Large (Population over 1,000,001 inhabitants)	53.28%	15.99%	19.14%	3.28%	1.57%	6.74%

Source: PERS, 2013

According to Carvalho Junior and Mcquay (2007), the difficulty in finding a solution to overconsumption and the environmentally appropriate disposal of solid waste is related to other current problems, such as large-scale deforestation, basic sanitation in homes and the generation of greenhouse gases, for example.

In order for these problems to have less of an impact on society, one of the solutions is to change consumer standards. According to Gutberlet (2012), mitigating the impacts generated by the overconsumption of products can be done by reducing the amount of waste, where one of the premises would be the understanding that waste should be treated as resources, and thus promoting the recovery of these materials.

According to Nogueira and Lora (2003), municipal solid waste is an inexhaustible source of energy and the larger the city, the greater its potential for generation, due to its characteristics and quantity.

According to the Ministry of the Environment and Climate Change MMA (2017), organic waste can be determined as elements that decompose and recycle nutrients from nature. This waste can come from leftover food, animal excrement and vegetable scraps and/or waste related to basic sanitation such as sewage treatment plant (STP) sludge.

The improper disposal of organic waste can generate leachate and methane emissions, encouraging the proliferation of vectors, diseases and air pollution MMA, 2017. Brazil is among the 10 countries that waste the most food in the world, accounting for 35% of all its agricultural production (IPEA, 2009).

The excess of organic matter among the components of household waste, with values above 50%, is a typical characteristic of developing countries, and is added to, among other factors, the lack of prior preparation of fruit and vegetables, the small quantity of other components and the lack of suitable household equipment for reusing food (Monteiro, 2001; Firmo, 2006). According to Monteiro et. al (2001), the characteristics of waste vary according to social, cultural and geographical aspects, as shown in Table 2.

Table 2 – Composition of solid waste

Material	Brazil	Germany	Holanda	EUA
Organic waste	65.0%	61.2%	50.3%	35.6%
Glass	3%	10.4%	14.5%	8.2%
Metal	4%	3.8%	6.7%	8.7%
Plastic	3%	5.8%	6%	6.5%
Papel	25%	18.8%	22.5%	41%

Source: Monteiro et al., 2001

According to the State Solid Waste Policy of the state of Rio de Janeiro (2013), small municipalities (population of up to 100,000 inhabitants) have an estimated 56.72% organic matter in their gravimetry, while medium-sized municipalities (population of 100,001 to 1,000,000 inhabitants) have 53.03% and large municipalities (population of over 1,000,001 inhabitants) have 53.28% organic matter. The anaerobic decomposition of organic matter produces biogas (UFP, 2017).

The process of decomposing organic waste in landfills generates toxic gases that affect and impact the environment. Some of the factors involved in the biodegradation of waste are: Composition of the waste, age of the landfill, humidity, PH of the waste deposited, temperature and availability for microorganisms, according to the United States Environmental Protection Agency (USEPA) 1991.

The limitation of fossil fuels, coupled with the increase in energy consumption, means that clean energy sources need to be varied. As a result, the Brazilian energy matrix has diversified and is increasingly made up of renewable sources (Achão et al., 2016). Out of the biomass sources, 89% come from sugarcane bagasse, 1% from biogas and 10% from other sources (EPE, 2017).

According to the Energy Research Company (EPE) 2015, the main sources of biogas production are landfills (51%), the food and beverage industry (25%), pig farming (14%) and sewage sludge (6%).

According to Sagula (2012), biogas is made up of 60 to 70% methane (CH_4) and 30 to 40% carbon dioxide (CO_2), as well as hydrogen gas (H_2), nitrogen gas (N_2) and hydrogen sulphide gas (H_2S). Methane (CH_4) is considered to be 21 times more polluting than carbon dioxide (CO_2) for global warming purposes (IPCC, 2006).

The treatment of biogas is important before the start of the electricity operation. According to Deublein et al. (2008), the burning process only becomes viable when it is free of corrosive gases, but biogas contains hydrogen sulphide, which increases the likelihood of corrosion in pipes and boilers.

After purification, biogas is referred to as biomethane, typically containing 95 to 97% CH_4 and 1 to 3% CO_2 (Ryckebosch, 2011). According to Oliveira (2009), the use of biogas as a fuel has various utilities and can be added in gas turbines or microturbines (Oliveira, 2009).

According to studies carried out by the Ministry of Mines and Energy (2008), one ton of organic waste from MSW is capable of producing 60 to 75m³ of biogas, depending on the technology used and the organic compound, which can be vegetable or animal. Animal organic matter has the greatest capacity to produce biogas. Considering energy production, it can be said that it is possible to obtain between 120 and 290 KWh per ton of MSW, considering an efficiency of 35% in thermal conversion to electrical energy.

Biogas can be generated continuously, which is different from wind and solar energy. It can be stored at low cost, whether as raw materials or compressed gas. It is important to note that biogas has a “negative carbon footprint”, as it mitigates the pollution that would be caused by the release of the gases that make it up. In other words, the methane that would have gone into nature, polluting the soil and atmosphere, is transformed into a source of energy (BNDES, 2018). According to Santos (2000), 1 m^3 of biogas is equivalent to 6.5 kWh of electricity.

According to Orizon (2023), biogas is a renewable fuel that can be used for thermal, mechanical or electrical energy. They can be used for the following applications: biodigesters as cooking gas for small farms or homes, to power motor generators and, through purification, to generate biomethane as food for motor generators in electricity grids, or even as fuel for cars.

According to Oliveira (2002), Brazil has great potential for generating electricity from solid waste, and the alternative could increase the country’s current supply by 50 million Megawatt hours per year.

This study aimed to compare the data provided by SINIR on the generation of biogas produced by landfills in the state of Rio de Janeiro (RJ) with the data generated by the IPCC method. The state’s landfills that generate biogas were identified, the biogas generation of Rio de Janeiro’s landfills was calculated using the IPCC method and, finally, the results obtained using the IPCC method and data from the National Solid Waste Management Information System (SINIR) on biogas generation were compared.

2 METHODOLOGY

During the research, two visits were made to landfills that produce biogas in the state of Rio de Janeiro: Nova Iguaçu Waste Treatment Center (CTR) and Seropédica CTR. During the visits, a form was applied containing questions such as: The amount of waste the landfill receives daily, in tons, from which municipalities the landfill receives waste, the amount of biogas it produces and whether it produces electricity from the biogas. They were also asked about the electricity produced at the landfill, whether it could be consumed within the plant itself or sold, among other questions relevant to the research.

Landfills that produce biogas in the state are located in five (5) different cities: Seropédica, Nova Iguaçu, São Gonçalo, São Pedro da Aldeia and Barra Mansa (SINIR, 2019).

In 2013, the IPCC presented a methodology for calculating biogas generated from solid waste. This method takes into account the amount of degradable organic carbon in the waste, in order to calculate the amount of methane that can be generated by the waste (Mendes & Sobrinho, 2005).

The method to be used in this project to quantify biogas generation (m^3) in landfills that already have catchment is entitled “Simple method for estimating CH4 generation”. This method is provided by the IPCC (2006) and makes it possible to measure the generation of biogas from MSW disposed in landfills.

The IPCC methodology is based on estimating the organic degradation of the carbon contained in solid waste, as well as the organic carbon accessible for biochemical decomposition, making it possible to calculate the amount of methane that can be generated in the mass of waste (Souza, 2009).

The first calculation to be carried out is the COD (Chemical Oxygen Demand). To calculate the COD, the data must take into account the Rio de Janeiro State Solid Waste Plan, which mentions the gravimetric percentage of the types of waste according to the municipality’s population (IPCC, 2013).

$$COD = (0.4*A) + (0.7*B) + (0.15*C) + (0.3*D) \qquad (1)$$

Being,
A - MSW fraction made up of paper and textiles;
B - MSW fraction made up of garden waste;
C - MSW fraction made up of food waste;
D - MSW fraction composed of wood and straw.

$$L_0 = FCM \times COD \times COD_F \times F \times \frac{16}{12} \quad (2)$$

Where,
FCM - Methane correction factor;
COD - Organic carbon fraction;
COD_F- Fraction of unassimilated COD;
F - Volume fraction of methane.

The IPCC (2013) proposes standard values, depending on the type of landfill, specific to solid waste management. The predefined values are listed in the following table (Table 3).

Table 3 – Defined values for FCM

Types of Landfill	FCM
Landfill	1
Uncontrolled - deep (≥ 5 m of waste)	0.8
Uncontrolled - shallow (< 5 m of waste)	0.4
Solid waste not otherwise specified (not included in the category)	0.6

Source: Cabrera, 2011

The value to be considered for the COD_F, according to the IPCC (2013), will be 0.77. The fraction of CH_4 in the landfill gas (F) to be used will be 0.5, but it can vary between 0.4 and 0.6 depending on various factors, like the composition of the waste. If the material includes large amounts of fat including or oil, this value may increase.

The method considers that in the same year that household solid urban waste is deposited, all possible CH_4 is generated, Eq. 3.

$$CH_4 = [(RSUdom \times L0) –] R] \times (1 – OX) \quad (3)$$

Where,
CH_4 - Amount of methane emitted in the year in tons;
MSWdom - amount of solid urban waste deposited in the landfill (t/year)
L0 - Methane generation potential;
R - Methane recovered during the year in tons, considered zero in the equation;
OX - Oxidation factor

Finally, the final value must be divided by 0.668 since the value is in t/year and will become kg/m³ year, so 1 Nm³

$$CH_4 = 0.668 \text{ kg } CH_4 \quad (4)$$

The product to be developed will be an article produced using information from this project on the potential generation of biogas and energy from waste disposed of in the state's landfills.

3 RESULTS AND DISCUSSION

According to the PNRS, Law 12.305/2010, the environmentally appropriate final disposal of waste must be implemented within deadlines established by law according to the number of inhabitants of the municipalities. Table 4 shows the deadline by which they should have been implemented in the municipalities of Rio de Janeiro. This survey was carried out according to the Brazilian Institute of Geography and Statistics (IBGE) 2022 population survey.

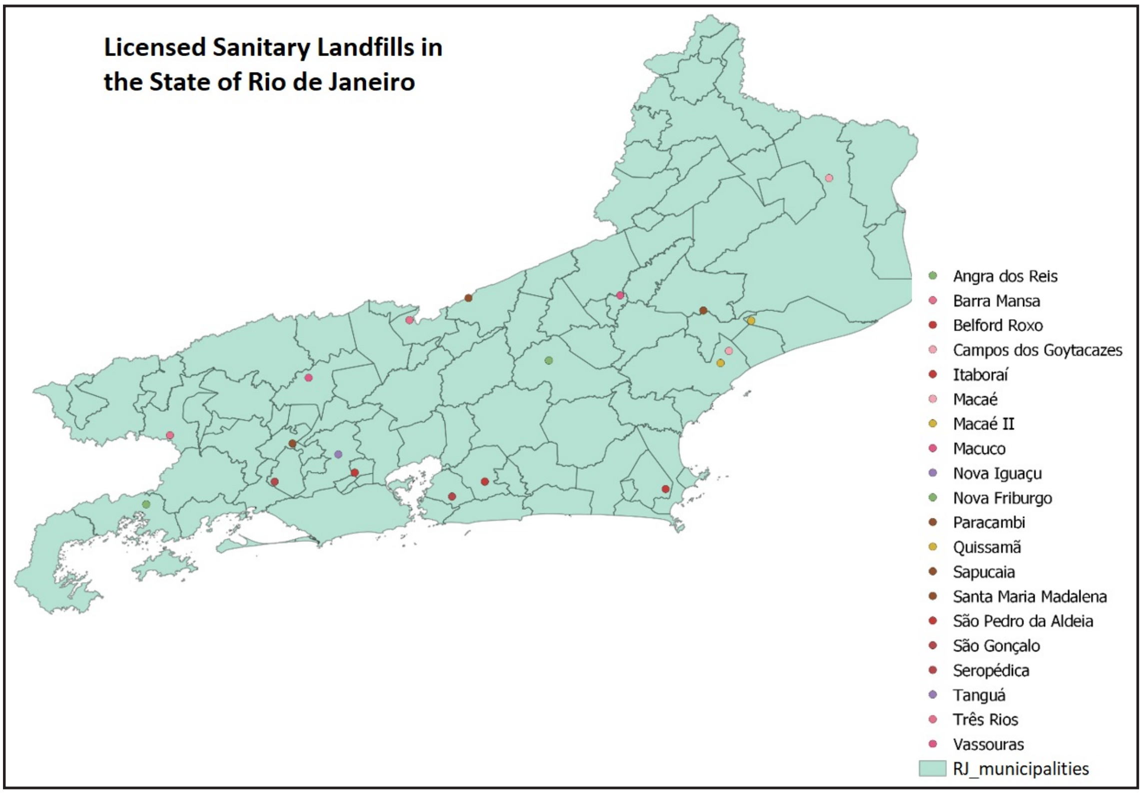
Table 4 – Survey of municipalities in the state of Rio de Janeiro

Month/Year	RJ Municipalities	Inhabitants
August/2021	22	Metropolitan Region and Integrated Development Region
August/2022	14	More than 100 thousand inhabitants
August/2023	3	Between 50,000 and 100,000 inhabitants
August/2024	53	Less than 50 thousand inhabitants
Total number of municipalities in RJ	92	

Source: Own production, 2024

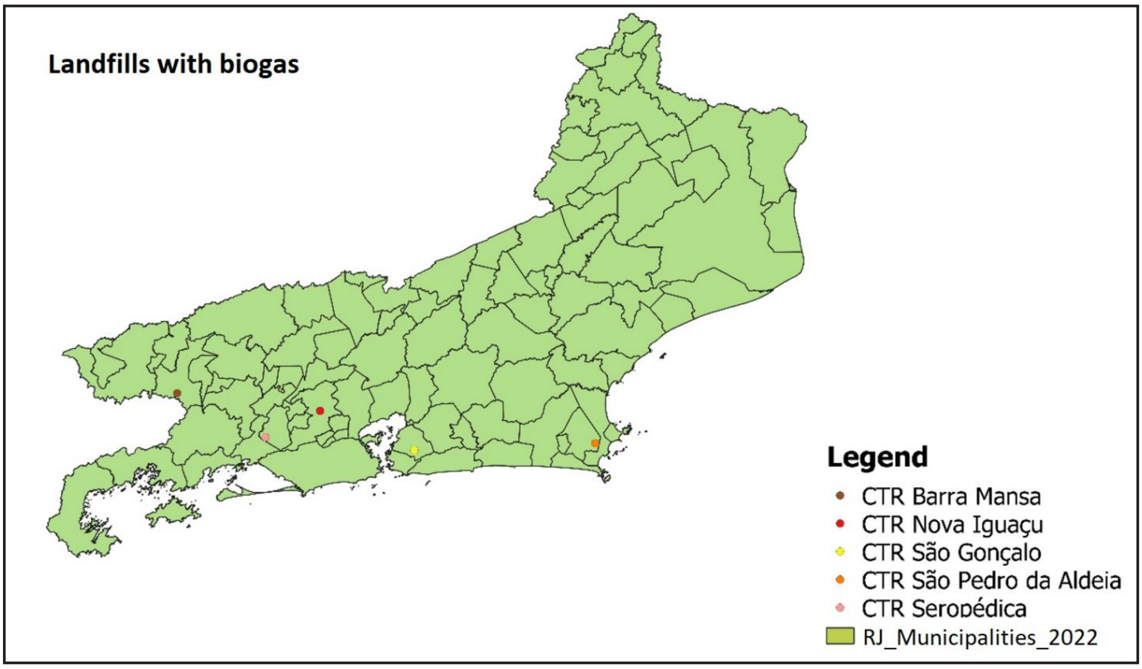
The map in the form of a figure (Figure 1) illustrates the municipalities in which the state's operating landfills are located.

Figure 1 – Landfills in the state of Rio de Janeiro



Source: Own production, 2023

Figure 2 – Landfills with Biogas Production

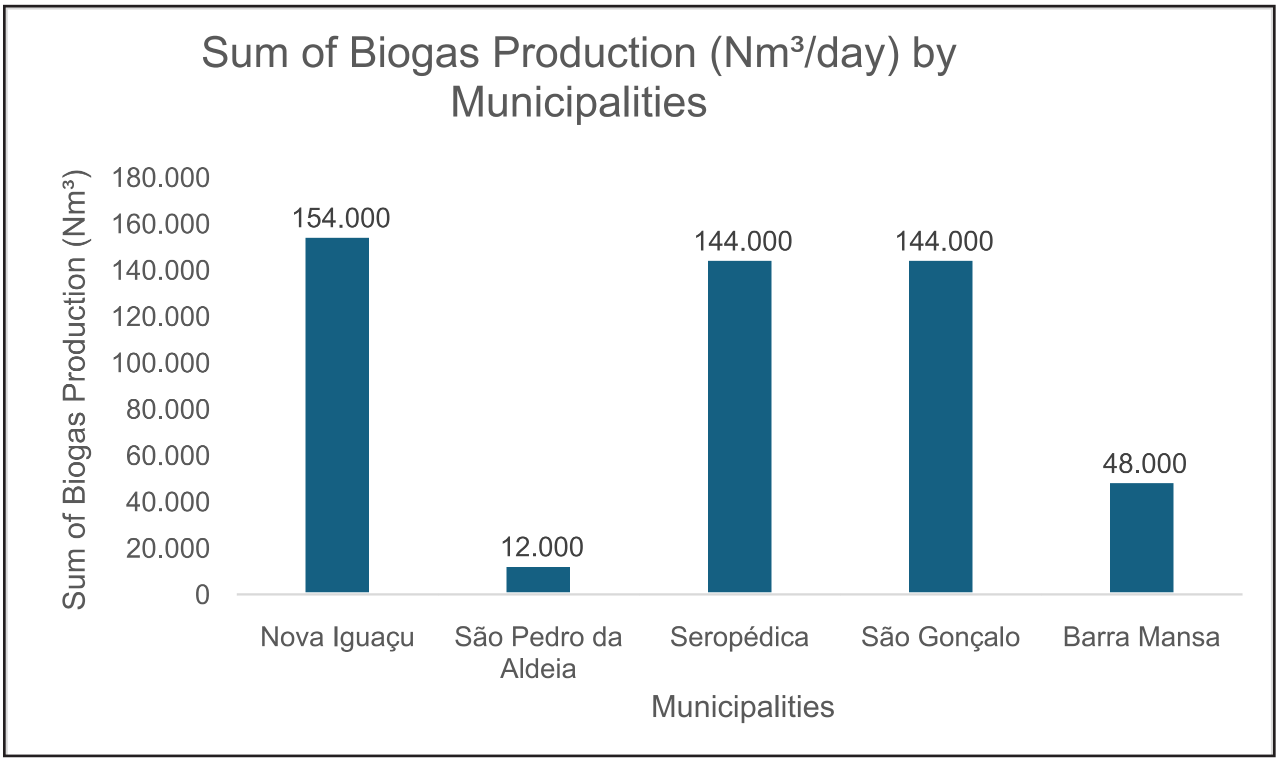


Source: Own production, 2024

According to data from the National Solid Waste Management Information System (SINIR) 2019, only five landfills out of twenty in the state produce biogas from solid waste, as it can be seen in Figure 2.

Figure 3 shows the amount of biogas generated in these landfills, according to data from SINIR.

Figure 3 – Biogas production in landfills



Source: Own production, 2024

According to the president of the Brazilian Waste and Environment Association (ABREMA) 2024), Brazil has around 700 (seven hundred) landfills and according to data from SINIR (2019), 31 (thirty-one) landfills with biogas recovery, of which 19 (nineteen) are in the Southeast, 1 (one) in the North, 7 (seven) in the Northeast and 4 (four) in the South of the country. Representing only 12 (twelve) states out of 26 (twenty-six) in the country. The following table (Table 5) shows the sum of biogas generation in m³ in each state in the country, according to the data provided by SINIR.

Table 5 – Sum of biogas generation by state

States	Sum (M³) of Biogas
Amazonas	156,000
Maranhão	13,559
Ceará	90,000
Pernambuco	260,359
Paraíba	144,000
Espírito Santo	33,900
Minas Gerais	248,813
São Paulo	1,644,115.7
Rio de Janeiro	501,280
Paraná	135,551.4
Santa Catarina	12,480
Rio Grande do Sul	144,000
Total	3,384,058.1

Source: Own elaboration, 2024

Other data provided by SINIR shows the generation of energy in mega watts (MW) in each state from biogas generation, as shown in the following table (Table 6).

Table 6 – Sum of electricity generation by state

States	Sum (MW) of energy/day
Amazonas	10
Maranhão	2
Ceará	0
Pernambuco	16,204
Paraíba	8.2
Espírito Santo	3
Minas Gerais	13.73
São Paulo	67.3
Rio de Janeiro	41.75
Paraná	10.65
Santa Catarina	1
Rio Grande do Sul	8.5
Total	182.33

Source: Own elaboration, 2024

The calculation of the Simple IPCC should take into account PERS Table 1, which shows the weight of solid waste in the state of Rio de Janeiro according to the number of inhabitants.

3.1 Seropédica

The Seropédica landfill receives waste from the following municipalities: Rio de Janeiro, Mangaratiba, Seropédica, Itaguaí, Piraí e Miguel Pereira. According to the IBGE (2022), the sum of these municipalities' populations exceeds 6 million inhabitants, which is why the data relating to the Large Size, a population of over 1 million people, will be used to calculate the COD (Table 1). In addition, it is important to consider that the Seropédica landfill receives 10,000 tons/day, which is equivalent to 3,650,000 tons/year. So:

$$\text{COD} = (0.4 \times A) + (0.7 \times B) + (1.5 \times C) + (0.3 \times D)$$

$$\text{COD} = (0.4 \times 15.99) + (0.7 \times 0) + (0.15 \times 53.28) + (0.3 \times 0)$$

$$\text{COD} = 14.38 \quad (5)$$

$$\text{L0} = \text{FCM} \times \text{COD} \times \text{CODf} \times \text{F} \times \frac{16}{12}$$

$$\text{L0} = 7.36 \quad (6)$$

$$CH_4 = [(RSUdom \times \text{L0}) - R] \times (1 - OX)$$

$$CH_4 = [(3{,}650{,}000 \times 7.36) - 0] \times (1 - 0)$$

$$CH_4 = 26{,}864{,}000 \text{ t/ano} \quad (7)$$

$$26{,}864{,}000/0.668 = 40{,}215{,}568.86\ CH_4\text{m}^3\text{/year} \quad (8)$$

3.2 Nova Iguaçu

The Nova Iguaçu landfill receives waste from the following municipalities: Nova Iguaçu, Mesquita and São João de Meriti. The sum of the population of these municipalities exceeds 1.3 million inhabitants, so the data relating to large municipalities, with a population of over 1 million people, will be used to calculate the COD (Table 1). Every day 5,000 tons of waste arrive, which represents 1,825,000 tons/year.

$$COD = (0.4 \times A) + (0.7 \times B) + (0.15 \times C) + (0.3 \times D)$$

$$COD = (0.4 \times 15.99) + (0.7 \times 0) + (0.15 \times 53.28) + (0.3 \times 0)$$

$$COD = 14.38 \tag{9}$$

$$L0 = FCM \times COD \times CODf \times \frac{16}{12}$$

$$L0 = 1 \times 14.38 \times 0.77 \times 0.5 \times 1.33$$

$$L0 = 7.36 \tag{10}$$

$$CH_4 = [(RSUdom \times L0) - R] \times (1 - OX)$$

$$CH_4 = [(1{,}825{,}000 \times 7{,}36) - 0] \times (1 - 0)$$

$$CH_4 = 13{,}432{,}000 \tag{11}$$

$$13{,}432{,}000/0.668 = 20{,}107{,}784.43\ CH_4 m^3/year \tag{12}$$

3.3 São Gonçalo

The São Gonçalo CTR is located in the metropolitan region of Rio de Janeiro and receives waste from Niterói, Maricá, Guapimirim and São Gonçalo. The sum of the population of these municipalities exceeds 1.6 million inhabitants, so the data relating to large municipalities, with a population of over 1 million people, will be used to calculate the COD (Table 1). Every day, 2,400 thousand tons of waste arrive, which represents 876,000 tons/year.

$$COD = (0.4 \times A) + (0.7 \times B) + (0.15 \times C) + (0.3 \times D)$$

$$COD = (0.4 \times 15.99) + (0.7 \times 0) + (0.15 \times 53.28) + (0.3 \times 0)$$

$$COD = 14.38 \tag{13}$$

$L0 = FCM \times COD \times CODf \times \frac{16}{12}$

$L0 = 1 \times 14.38 \times 0.77 \times 0.5 \times 1.33$

$L0 = 7.36$ (14)

$CH_4 = [(RSUdom \times L0) - R] \times (1 - OX)$

$CH_4 = [(876{,}000 \times 7{,}36) - 0] \times (1 - 0)$

$CH_4 = 6{,}447{,}360$ (15)

$6{,}447{,}360/0.668 = 9{,}651{,}736.52\ CH_4 m^3/year$ (16)

3.4 São Pedro da Aldeia

The São Pedro da Aldeia landfill receives waste from the following cities: São Pedro da Aldeia, Arraial, Cabo Frio, Búzios, Araruama, Iguaba Grande, Silva Jardim and Casimiro de Abreu. The sum of the population of these municipalities exceeds 600,000 inhabitants, so the data relating to medium-sized municipalities, with a population of between 100,001 and 1 million people, will be used to calculate the COD (Table 1). Every day 600 tons of waste arrive, which represents 219,000 tons/year.

$COD = (0.4 \times A) + (0.7 \times B) + (0.15 \times C) + (0.3 \times D)$

$COD = (0.4 \times 15.99) + (0.7 \times 0) + (0.15 \times 53.03) + (0.3 \times 0)$

$COD = 14.35$ (17)

$L0 = FCM \times COD \times CODf \times \frac{16}{12}$

$L0 = 1 \times 14.35 \times 0.77 \times 0.5 \times 1.33$

$L0 = 7.34$ (18)

$CH_4 = [(RSUdom \times L0) - R] \times (1 - OX)$

$CH_4 = [(219{,}000 \times 7{,}34) - 0] \times (1 - 0)$

$CH_4 = 1{,}607{,}460$ (19)

1,607,460/0.668 = 2,406,377.24 $CH_4 m^3$/year (20)

3.5 Barra Mansa

The Barra Mansa CTR receives waste from the cities of Quatis, Rio Claro, Pinheiral, Volta Redonda, Porto Real and two cities in São Paulo: Bananal and Arapei. The sum of the population of these municipalities exceeds 300,000 inhabitants, so the data relating to medium-sized municipalities, with a population of between 100,001 and 1 million people, will be used to calculate the COD (Table 1). Every day 750 tons of waste arrive, which represents 273,750 tons/year.

$$COD = (0.4 \times A) + (0.7 \times B) + (0.15 \times C) + (0.3 \times D)$$
$$COD = (0.4 \times 15.99) + (0.7 \times 0) + (0.15 \times 53.03) + (0.3 \times 0)$$
$$COD = 14.35 \quad (21)$$

$$L0 = FCM \times COD \times CODf \times \frac{16}{12}$$
$$L0 = 1 \times 14.35 \times 0.77 \times 0.5 \times 1.33$$
$$L0 = 7.34 \quad (22)$$

$$CH_4 = [(RSUdom \times L0) - R] \times (1 - OX)$$
$$CH_4 = [(273{,}750 \times 7{,}34) - 0] \times (1 - 0)$$
$$CH_4 = 2{,}009{,}325 \quad (23)$$

2,009,325/0.668 = 3,007,971.55 $CH_4 m^3$/year (24)

According to the calculations of the IPCC method and the values reported in SINIR (2020) (Figure 3), there is a difference between what is produced and the generation potential of each landfill (Table 7). Below, there is a table with the data obtained using the IPCC method and the information provided by SINIR. To display the data provided by SINIR, this data has been multiplied by the number of days in the year, as Figure 3 illustrates in Nm^3/day.

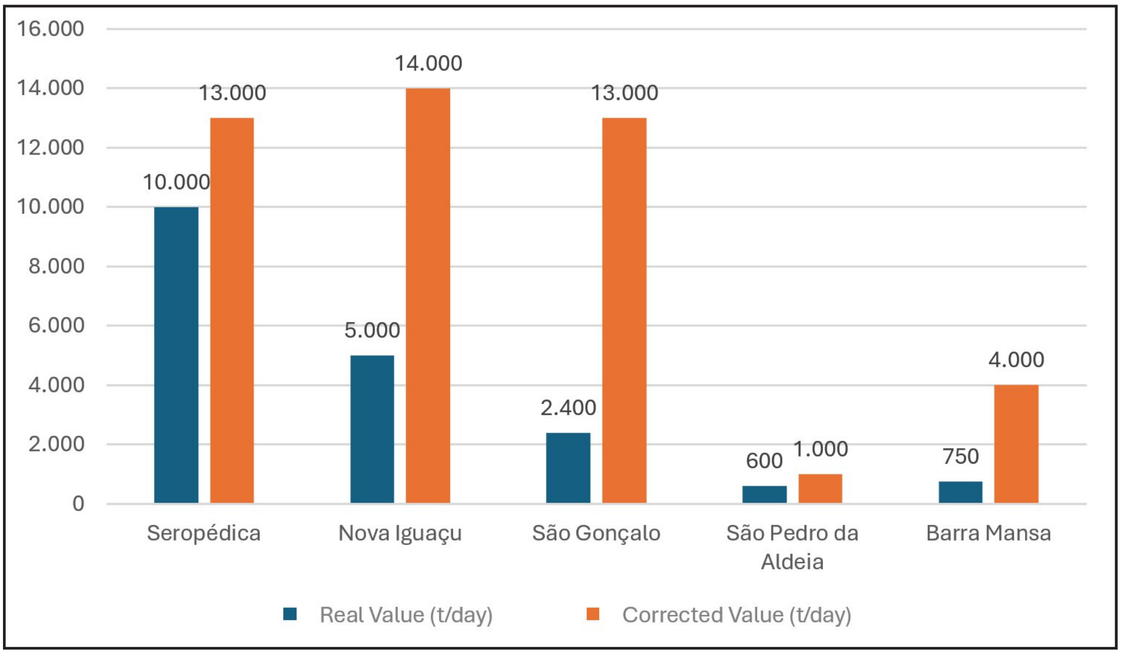
Table 7 – Comparison of SINIR and IPCC data

Landfill name	N/m³ year (SINIR)	N/m³ year (IPCC)
Seropédica	52,560,000	40,215,568.86
Nova Iguaçu	56,210,000	20,107,784.43
São Gonçalo	52,560,000	9,651,736.52
São Pedro da Aldeia	4,380,000	2,406,377.24
Barra Mansa	17,520,000	3,007,971.55

Source: Own elaboration, 2024

Given the discrepancy in the data as shown in Table 6, the corrected values of solid waste, in tons, that should arrive daily at landfills, were analyzed so that the Nm³/year values would be equivalent to those provided by SINIR, as shown in Figure 4.

Figure 4 – Waste (ton/day) in Landfills



Source: Own elaboration, 2024

4 CONCLUSIONS

Based on data provided by SINIR (2020) and data generated using the IPCC method, there is a large variation between these two sets of data. The variation ranges from 1,973,622.76 m³ in São Pedro da Aldeia, which is the smallest difference, to 42,908,263.48 m³ in São Gonçalo, which is the largest. One of the reasons for these differences is the values used to calculate COD. The data used for organic load analysis is provided by PERS (2013), which is outdated and may contribute to the difference in the values obtained, since there is no current data and not all the data requested in the formula is provided. Furthermore, the data is from the state's gravimetry and not from the municipalities, which means that it is comprehensive data and not actual data from the cities.

Another factor that may contribute to the difference between the IPCC and SINIR values is the amount of waste that reaches the landfill, which may have already been updated but not passed on to the population. In addition, these figures are static, so they don't take into account high season periods, such as vacations and festivities, which contribute greatly to the amount of waste generated in a municipality.

Therefore, for landfills that receive waste from more than one municipality and other generators, the IPCC Simple Method calculation does not come close to the reality that is generated in the landfill.

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