

Sustainable transformation: reusing organic waste as an energy resource for community development

ABSTRACT

The urgent need to address interlinked global challenges such as poverty, inequality and climate change is driving the search for clean and accessible energy sources. The aim of this study was to estimate the theoretical potential of methane production from organic waste generated in the community of Jardim Florida in the city of Francisco Morato (São Paulo, Brazil). Based on a case study, it was found that the estimated production of organic waste per family is 0.019 tons per week and the theoretical methane production would be approximately 8.58 m³ per month. Using this fuel as cooking gas, the savings for the families would amount to R\$57.70 per month, which is equivalent to R\$692.40 per year. The cost of the biodigester would be R\$ 419.50 per household. In conclusion, the use of biodigesters promotes sustainability by enabling waste management and energy production, thus helping to overcome the challenges faced by the community studied.

PALAVRAS-CHAVE: Biodigester. Methane. Sustainability. Biogas.

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INTRODUCTION

According to the definition of the World Commission on Environment and Development, sustainability is the ability to meet present needs without compromising the ability of future generations to meet their own needs (United Nations, 1987). This concept provides for a balance between economic growth, environmental protection and social well-being.

In this context, the circular economy aims to transform production and consumption, minimize waste and promote sustainability through the reuse of resources generated by human consumption. It goes beyond the traditional "3 Rs" - reduce, reuse and recycle - by combining sustainability with the technological and commercial dynamics of today's world.

Programmed obsolescence generates waste that accumulates exponentially, as shown by the extensive Brazilian generation of municipal solid waste (MSW), which amounts to approximately 81 million tons per year, or 382 kg per inhabitant per year (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais, 2024). Organic waste, which consists mainly of food scraps and garden waste, accounts for around half of the country's municipal solid waste (Brasil, 2019; Lana and Proença, 2021).

Organic material decomposes naturally and recycles nutrients through processes such as the carbon and nitrogen cycles. However, the generation of this waste on a large scale can become a serious environmental problem (Bermann, 2008).

Conversion technologies, such as anaerobic digestion, can convert this waste into valuable renewable energy sources such as biogas (Santos, Guimarães, 2023; Schoefs et al., 2024). The main energy component of biogas is methane (CH_4), which usually accounts for between 50 and 75 per cent of the biogas volume and is therefore the primary energy source for this biofuel. However, biogas also contains other gases such as carbon dioxide (CO_2), hydrogen sulfide (H_2S) and traces of ammonia (NH_3), which can be corrosive or harmful to the environment. For various applications, such as use in vehicles or injection into natural gas networks, these undesirable components must be removed or reduced through purification processes to ensure safety, efficiency and compliance with environmental standards (Fernandes Filho, 2018).

In many communities, the limited availability, high cost and/or lack of access to conventional sources of electricity and fuel represent significant barriers to socio-economic development and general well-being (Angelidaki, Sanders, 2004). Considering this reality in different cities in the São Paulo metropolitan area, the objective of this study was to investigate the theoretical potential for CH_4 production from organic waste generated in the municipality of Jardim Florida in Francisco Morato, São Paulo, Brazil.

The study is in line with SDG 7 - Affordable and Clean Energy, which aims to ensure access to reliable, sustainable and modern energy for all, and SDG 11 - Sustainable Cities and Communities, which aims to make cities and human settlements inclusive, safe, resilient and sustainable.

METHODOLOGY

The methodology used included data collection from local authorities. Estimates of the theoretical potential for CH₄ and the feasibility of its utilization were calculated using mathematical models and data from similar previous studies (Rocha, 2016; Ferreira, 2015; Santos et al., 2018; Calloni, 2020).

Study area

The community of Jardim Flórida (Figure 1) in the city of Francisco Morato (São Paulo, Brazil) faces challenges related to basic sanitation, land use and irregular waste collection. The area studied is located on hills and slopes, which leads to flooding and landslides during periods of heavy rainfall. Residents often build their houses irregularly in vulnerable areas, which further complicates the implementation of already limited public policies for this vulnerable population.

Figure 1 - Study area



Source: Google Maps (2023)

For the data collection in this study, interviews were conducted with around 100 families with an average of five members per household. The interviews with the community revealed that each family consumes an average of 13 kg of liquefied petroleum gas (LPG) per month. Regarding the municipal waste generated in the area, there is no separate waste collection.

An official letter was sent to the Municipal Administration of Francisco Morato to find out the amount of MSW collected weekly in the municipality and the costs associated with the collection and treatment of this waste. Based on this data, the weekly per capita waste generation was estimated, assuming a population of 165,139 inhabitants (Instituto Brasileiro de Geografia e Estatística, 2022).

To estimate the amount of household waste generated by each family, the value for the weekly per capita generation in the municipality was multiplied by five, assuming an average of five people per household. For the estimation of organic waste, it was assumed that 65% of the total MSW generated in the municipality consists of the organic fraction, as reported by the Municipal Waste Cooperative of Francisco Morato.

Theoretical potential for methane production in the study community

To determine the theoretical potential of CH₄, it is important to consider that the production is from the volatile solid fraction in organic waste, the amount (kg/day) was estimated using Equation 1 (adapted from Calloni, 2020).

$$Q_{vs} = Q_{ow} \times f_{sv} \quad \text{Equation 1}$$

where:

Q_{vs} is the amount (Kg/week) of volatile solids.

Q_{ow} is the total amount of organic waste generated in the household (kg/week).

f_{sv} is the proportion of volatile solids in the total mass of organic solids. For this study, a value of 25.1% (0.251) was assumed on the basis of a literature search, which represents an average of the values found by Ferreira (2015).

The theoretical amount of CH₄ (Nm³/day) was calculated using Equation 2 (adapted from Calloni, 2020), assuming that 1 ton of volatile solids produces an average of 400 Nm³ of CH₄ (Ferreira, 2015):

$$V_{CH_4} = \frac{400 \text{ m}^3 \times Q_{vs}}{1000} \quad \text{Equation 2}$$

where:

V_{CH_4} is the theoretical volume (Nm³/week) of CH₄.

Q_{vs} is the amount (Kg/week) of volatile solids.

Proposal for the energy use of methane

CH₄ can be an excellent alternative for use as cooking gas. Once produced, this gas can be distributed via an infrastructure for domestic use. Gas appliances used in the kitchen can be adapted to run on methane, generally requiring minimal adjustments to burners and valves to ensure efficient combustion.

The equivalence between the energy delivered by the CH₄ produced and the energy (kcal) delivered by a 13kg cylinder of LPG has been calculated using Equation 3.

$$E = \frac{E_{CH_4}}{E_{LPG}} \quad \text{Equation 3}$$

where:

E : energy equivalence

E_{CH_4} : energy provided by the CH₄ (kcal)

E_{LPG} : energy supplied by a 13 kg cylinder of liquefied petroleum gas (kcal)

RESULTS AND DISCUSSIONS

Estimating the production of organic waste by families

The weekly production of municipal solid waste in the municipality is around 970 tons, according to the municipal administration of Francisco Morato, based on data from the first quarter of 2024.

An average per capita production was calculated, which resulted in a value of 0.0059 tons. As previously mentioned, 65% of the MSW collected in this city consists of organic waste. Therefore, the weekly per capita production of organic waste in the municipality was calculated to be 0.0038 tons.

The results indicate that each household (five members) can produce 0.019 tons or 19 kg of organic waste per week, which could be used in a biodigester.

Estimation of theoretical CH₄ production

The amount of volatile solids in waste generated by each household in the study population was 4.769 kg per week (Equation 1).

$$\begin{aligned} Q_{vs} &= Q_{ow} \times f_{sv} \\ Q_{vs} &= 19 \times 0.251 \\ Q_{vs} &= 4.769 \end{aligned} \quad \text{Equation 1}$$

where:

Q_{vs} is the amount (kg/week) of volatile solids produced by each household.

Q_{ow} is the total amount of organic waste (kg/week) produced by each household.

f_{sv} is the proportion of volatile solids in the total mass of organic solids. For this study, a value of 25.1% (0.251) was assumed based on a literature search, which represents an average of the values found by Ferreira (2015).

To estimate the monthly production of volatile solids, this value was multiplied by 4.5 weeks, resulting in a total production of 21.4605 kg, which was then substituted into equation 2, giving a theoretical CH₄ production of 8.5842 m³ per month per household.

$$\begin{aligned} V_{CH_4} &= \frac{400 \text{ m}^3 \times Q_{vsm}}{1000} \\ V_{CH_4} &= \frac{400 \text{ m}^3 \times 21.4605}{1000} \\ V_{CH_4} &= 8.5842 \end{aligned} \quad \text{Equation 2}$$

where:

V_{CH_4} is the theoretical volume (Nm³/month) of CH₄ production of each household.

Q_{vsm} is the amount (kg/month) of volatile solids produced by each household.

Theoretical energy supplied

The calorific value of LPG is 11,750 kcal/kg (Empresa de Pesquisa Energética, 2017). If a family uses a 13 kg cylinder for a month, the energy supplied by a cooking cylinder is 152,750 kcal. The calorific value of CH₄ is 35,800 kJ/m³ (Lira, 2021). The methane production per household is estimated at 8.5842 m³, the

amount of energy provided by the CH₄ produced in the household in one month is 307,314.36 kJ, which corresponds to 73,449.89 kcal.

Equation 3 was used to compare the equivalence of the energy provided by methane with the use of LPG.

$$E = \frac{E_{CH_4}}{E_{LPG}} \quad \text{Equation 3}$$

$$E = \frac{73,449.89}{152,750}$$

$$E = 0.4808$$

where:

E : energy equivalence

E_{CH_4} : energy supplied by the CH₄ (kcal)

E_{LPG} : energy supplied by a 13 kg cylinder of LPG (kcal)

The result shows that the energy provided by methane per month is equivalent to the energy provided by 0.4808 cooking cylinders per month (approximately half a cylinder). Taking into account the cost of the gas cylinder (R\$ 120.00), the savings for the families would be R\$ 57.70 per month (Equation 4) and R\$692.40 per year.

$$MS = E \times c \quad \text{Equation 4}$$

$$MS = 0.4808 \times 120$$

$$MS = 57.70$$

where:

MS : monthly savings (R\$)

E : energy equivalence

c : cylinders cost (R\$)

Proposal for the Construction of Biodigesters

A 1000 L biodigester would be sufficient to cover the needs of every household. In order to determine the production costs for each family, the necessary materials and their prices were determined (Table 1). The prices for each item were researched in local shops.

Table 1. Materials for the construction of the biodigester

Quantity	Material	Total Cost
1 unit	1000 L Drum	R\$ 200,00
1 unit	Car Tire Inner Tube 17"	R\$ 37,90
1.5 m	150 mm Pipe	R\$ 47,50
1 unit	20 mm Flange	R\$ 17,90
2 units	75 mm 45-Degree Elbow	R\$ 14,00
0.2 m	75 mm Pipe	R\$ 10,00
1 unit	Plastic Garden Faucet	R\$ 5,00
1 unit	Glue and Thread Adapter	R\$ 12,00
1 unit	50 mm Glue Cap	R\$ 12,00

Quantity	Material	Total Cost
1 unit	50 mm Threaded Cap	R\$ 19,00
1 unit	75g Pipe Glue	R\$ 8,00
1 unit	PU Gutter Sealant	R\$ 23,00
0.5 m	50 mm Pipe	R\$ 6,50
1 m	Garden Hose	R\$ 6,70
Total		R\$ 419,50

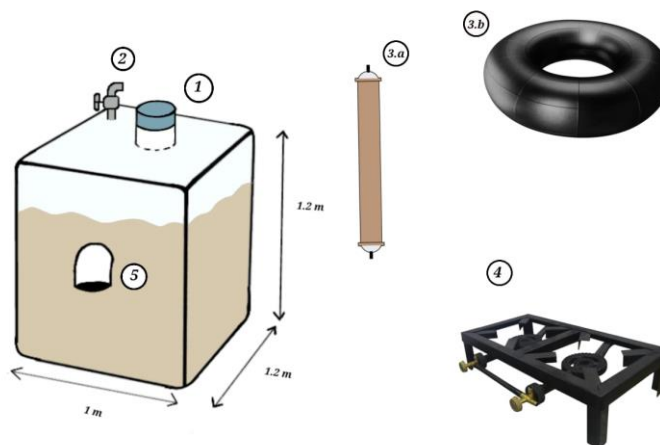
Source: Authors (2024)

The construction of the biodigester should be built on a solid foundation that ensures stability with materials such as concrete or wooden pallets and forms a hermetic container.

In addition, due to the size of the barrel, an efficient organic waste feed system is required. An outlet valve must also be designed for the treated waste water, which can be used as a nutrient-rich fertilizers. Plastic containers can be used to facilitate the transport of these waste materials.

The dimensions and components that make up this biodigester proposal are shown in Figure 2: 1: inlet port for the organic matter that feeds the biodigester; 2: valve through which the generated gas exits; 3a: philter to purify the gas, with the interior made of steel sponge, lime or caustic soda (to filter out the hydrogen sulfide gas and remove the foul odour); 3b: hoop chamber to store the biogas. 4: stove for utilizing and burning the gas. 5: Disposal pipe for digestate (biofertilizer), which also remains sealed and is only opened to remove excess sludge.

Figure 2 - Biodigester scheme designer



Source: Authors (2024).

Anaerobic digestion of organic waste poses technical and economic challenges that may limit its adoption in municipalities. According to Xu et al. (2017), factors such as the accumulation of volatile fatty acids, process instability, foaming and low buffering capacity can affect the efficiency of converting waste into CH₄. However, strategies such as co-digestion with other substrates, the addition of micronutrients and an improved biodigester design can optimize methane production and make this technology economically viable. Integrating these advances into the model proposed for the Jardim Florida community could

contribute to greater system stability and increased biogas production, maximizing the environmental and economic benefits of the project.

Anaerobic co-digestion of organic wastes, such as food waste and straw, has shown a significant increase in biogas production compared to digestion of each substrate individually. Yong et al. (2015) found that the ideal ratio of food waste to straw is 5:1, resulting in a maximum methane yield of 0.392 m³/kg-VS, an increase of 39.5 per cent and 149.7 per cent compared to the isolated digestion of food waste and straw, respectively. This synergy between the substrates favors a better nutrient balance and optimizes the anaerobic digestion process, making it a viable alternative for recycling organic waste and sustainable energy.

Although the focus of this work is to discuss the potential for energy recovery from the waste generated in the Jardim Florida community, access to information on the costs incurred by Municipal Administration of Francisco Morato for the collection and treatment of MSW (R\$340,751.30/week) raises an important discussion. If the municipality were to set up a programme of public policies to promote CH₄ production and educate the population, the expenses for collection and treatment could be reduced by up to 65%. By adopting sustainable practices to process a significant proportion of the waste generated by the population, the municipality would not only reduce costs but also minimize the negative impact on the environment by reducing the load destined for landfill.

CONCLUSION

The estimated production of organic waste per family in the community studied is 0.019 tons/week, and the theoretical production of methane would be approximately 8.58 m³/month. Using this fuel as cooking gas would save families R\$57.70/month or R\$692.40/year. This study suggests that the conversion of organic waste into energy resources not only helps to reduce the impact on the environment, but also brings significant benefits to the people in the communities, such as the generation of clean and affordable energy.

Finally, this work emphasizes that the continuity and expansion of these initiatives can make a significant contribution to building a more sustainable and inclusive future for all.

Limitations of the study include the use of theoretical estimates and secondary data, without consideration of operational variables such as variations in waste composition, digestion efficiency and maintenance challenges, and the lack of analysis of socio-economic factors that could influence community uptake. Future research should focus on conducting a pilot project in the Jardim Florida to empirically validate the estimates and assess the technical, economic, and social feasibility of biodigester systems, providing insights that support the scalability of the model to similar urban areas.

Transformação Sustentável: Reaproveitamento de resíduos orgânicos como recurso energético para o desenvolvimento comunitário

RESUMO

A necessidade urgente de enfrentar desafios globais interligados, como pobreza, desigualdade e mudanças climáticas, tem impulsionado a busca por fontes de energia limpas e acessíveis. O objetivo deste estudo foi estimar o potencial teórico de produção de metano a partir de resíduos orgânicos gerados na comunidade do Jardim Flórida, na cidade de Francisco Morato (São Paulo, Brasil). Com base em um estudo de caso, constatou-se que a produção estimada de resíduos orgânicos por família é de 0,019 toneladas por semana e que a produção teórica de metano seria de aproximadamente 8,58 m³ por mês. Utilizando esse combustível como gás de cozinha, a economia para as famílias seria de R\$ 57,70 por mês, o que equivale a R\$ 692,40 por ano. O custo do biodigestor seria de R\$ 419,50 por domicílio. Conclui-se que o uso de biodigestores promove a sustentabilidade ao viabilizar o manejo de resíduos e a produção de energia, contribuindo assim para superar os desafios enfrentados pela comunidade estudada.

KEYWORDS: Biodigestor. Metano. Sustentabilidade. Biogás.

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