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ORIGINAL ARTICLE

Characterization of solid waste of restaurant and its energy generation potential: case study of Niterói, RJ, Brazil

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Abstract
The change in the profile of Brazilian society has shown a growing increase in meals out of home, at restaurants. Wastes generated from anthropic activities contribute to the stress in our natural systems through impacts associated with production and disposal, since the food and nutrition units (FNUs) are responsible for their collection, transportation, and disposal, becoming responsible for their entire process. The objective of this study was to characterize the solid wastes generated in a food and nutrition unit, located in the municipality of Niterói – RJ, Brazil, evaluating the potential of using the non-recyclable organic waste produced to generate energy, through biogas. For this, data were collected everyday for a period of 3 months at a restaurant located in the Ingá neighborhood in Niterói, which serves meals for lunch, extrapolating these data for the period of 1 year. As a result, the annual amount generated is 209.35 tons, equivalent to a possible production of 266,492.16 kWh per year, which can meet the demand of a total of 137 medium-sized residences. It is concluded with this study that it is feasible to apply anaerobic decomposition technology for energy production using organic solid wastes from restaurants of Niterói/RJ, and this is an environmentally accepted alternative.

Keywords Organic waste · Energy · Biogas · Decomposition

Statement of novelty
The objective of this work is to outline a profile of food consumption outside the home of the inhabitants of a city in Niteroi, RJ, Brazil through the gravimetric characterization of solid waste from a restaurant and the use of extrapolation methodology, enabling the evaluation of the potential for use of the gases generated by the decomposition of this residue to generate energy for municipal residences. Thus, this study aims to demonstrate the feasibility of using this clean energy through the waste generation technology in medium-sized municipalities in developing countries, such as Brazil.

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1 Introduction

1.1 World food waste

Globally, 1.3 billion tons of food are wasted or are lost along the food production chains, and this amount represents 30% of all the food produced per year on the planet [31, 35]. The United Nations Food and Agriculture Organization (FAO) aims by 2030 to reduce by half the losses in production and supply systems, including in the post-harvest period, which accounts for 46% of the amount of food thrown in the garbage. The losses occurring mainly in the production, storage, and transportation phases correspond to 54% of the total [17]. At the same time, tons of still-edible food are discarded everyday at the end of the food chain, causing problems related to the disposal of these wastes, in addition to financial costs [16].

Another problem related to food waste is the step of product transportation, from the point of production to the final consumption. In general, Brazilian roads do not have adequate driving conditions, and there are also problems related to the use of untrained labor, which ultimately leads to the waste and spoilage of a larger amount of products and to the use of poor-quality packages, which compromise the integrity of the final product [43]. Often the investment in the logistics or packaging process does not pay off due to the low added value of the goods, which ultimately contributes to increasing the waste in general [38].

In Brazil, the number of hungry people has increased, from 4.6 million in 2018 to 5 million in 2019, due to changes in government social policies implemented in the country [34].

1.2 Municipal solid waste

It is known that the composition of municipal solid waste (MSW) is not uniform in the world, as it depends directly on the degree of economic development [12]. In industrialized nations, approximately 70% of waste is inert and 30% is considered biodegradable. In developing nations, such as Brazil, exactly the opposite occurs, which leads to large amounts of biodegradable waste, affecting the useful life of landfills, which are generally used for the disposal of these wastes [11]. The recycling of inert waste and the correct destination for biodegradable waste will bring as direct benefit to landfills the extension of their useful life and generate savings [26].

Cities do not have reverse logistics program for biodegradable wastes, which are simply disposed of in open dumps that have more than 50% of their capacity occupied by remains of organic products. This represents a waste of matter and energy that could have been reincorporated into the system, in the form of a compost, promoting high environmental and financial gains [18].

Municipal solid waste (MSW) management has become one of the major problems to be solved by the municipalities, being a challenge that includes society in the search for solutions, since the correct segregation of these wastes occurs at the origin of its generation and this is the time to define what will be recycled and what will be disposed of in a landfill [40]. With regard to the generation of solid waste, Brazil has specific legislation, called the national solid waste policy. This legislation defines some guidelines aimed at the principle of non-generation, reduction, reuse, recycling, treatment of the waste generated, and especially its final environmentally correct disposal [2]. It is believed that these guidelines will prolong the useful life of landfills (from 20 to 30 years on average) and end the predatory occupation of urban expansion areas of the cities, including permanent preservation areas [1].

The city of Niterói has a history of disposing of MSW in inappropriate locations and currently seeks solutions for its environmental liabilities, besides taking measures towards the correct management of its waste. One of the main strategies for such adequacy and improvement is the incentive to selective collection of recyclable materials [14]. The municipality has the oldest selective collection initiative in Brazil, but it remained concentrated in the São Francisco neighborhood, where it was created. Another important practice, elaborated by the Urban Cleaning Company of Niterói (CLIN), was a selective collection program that also did not develop much, being limited to a small percentage of waste recycling [23].

The Niterói City Hall, through law n° 2685, of 12/30/2009, published on 12/31/2009, defines that: §1 The CLIN collection service will collect up to 120 (one hundred and twenty) liters of waste per collection per day, and the generating units referred to in Paragraph 1 of Article 8 of this law which produce waste beyond the abovementioned volume shall provide, at their expense, the bagging, collection, transport, treatment, and final destination, considered surplus/extraordinary garbage [14].

The amount of solid waste collected in the municipality of Niteroi has been increasing, mainly due to an increase of about 20% in the number of restaurants, motivated mainly by university students and elderly residents in the municipality [14]. The waste collected in restaurants in the municipality of Niteroi is transported and disposed of in landfills located in the surrounding municipalities, such as São Gonçalo and Marica, both located in the state of Rio de Janeiro, responsible for the storage of about 70% of the collected waste [23].

1.3 Power generation from organic waste

Countries such as China and Germany are the pioneers in the use of anaerobic biodigesters for biogas generation and consequently the possibility of conversion into energy. In China, for example, the use of biogas began in the 1950s, with the construction of the first biogas units by wealthier families. Since the year 1970, the government of China began to encourage the use of biogas, giving greater visibility and lower cost to this technology, favoring the construction of millions of small digesters throughout the country [13].

In India, the development of simplified biogas plants for rural families began around the 1950s. The advance in the number of biogas units occurred in the 1970s through government support [30]. In Germany, the first liquid effluent anaerobic treatment plant was built in 1906. However, only in 1974 did the German government begin to encourage the generation of biogas in biodigesters [42].

Germany is already recognized as a world power in energy production from biogas, which is a source of energy that can be considered clean. One of Germany's targets is that, in 2022, it will be able to deactivate all of its highly polluting and environmentally problematic nuclear power plants, which correspond to an installed power of about 20,000 MW, replacing them with alternative sources that are renewable, such as biogas, which is cleaner and safer than the nuclear source [10].

As for the Brazilian reality, biodigesters are primarily present in rural areas, which had a greater development in the 1980s, through the support of the Ministry of Agriculture and the Ministry of Mines and Energy. Until 1988, about 8000 units, mainly the Chinese and Indian models, had been built in the country [3]. However, this technology still faces problems arising from the low financial resources, relatively high cost of biodigesters, and especially the cultural issue, which associates biodigesters with the idea of an energy source of low-income families [13].

A biodigester is a closed chamber where biomass is fermented, by the action of methanogenic bacteria, without the presence of air.

Anaerobic biodigestion is relatively simple, but the biomass to be used in the process must undergo a pre-treatment, which consists in separating materials that can be recycled, contaminant and non-combustible, and homogenizing organic materials that will be introduced into the digester [25]. There are several types of biodigesters used, and Table 1 exemplifies the three most common and most used types in the world.

The Indian model can be operated as a biodigester with automatic discharge, with no need for the compensation tank. This is the most used model in Brazil, because great results have been obtained with floating fiberglass bells, and these materials are more accessible in the market, with a more viable final cost than other alternatives, such as steel plate.

Biogas is a gaseous mixture generated by the decomposition of organic materials, composed primarily of methane (CH_4) and carbon dioxide (CO_2) with small amounts of hydrogen sulfide (H_2S) and ammonia (NH_3). Occasionally, low concentrations of hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), saturated or halogenated carbohydrates, and oxygen (O_2) are found in the biogas [25]. Biogas generation occurs when microorganisms decompose carbohydrates, proteins, and fats into methane (CH_4) and carbon dioxide (CO_2). This process has four phases: the first is hydrolysis, where large polymers (proteins, fats, and carbohydrates) are broken into smaller molecules such as amino acids, fatty acids, and simple sugars; the second is acidogenesis through monomers in alcohols, organic acids, CO_2, and H_2 by aerobic digestion of microorganisms; the third is acetogenesis, which is the decomposition of alcohols and organic acids by acetogenic bacteria into acetic acid (CH_3COOH), carbon dioxide (CO_2), and hydrogen (H_2); and the fourth is methanogenesis, which is anaerobic digestion and consists in the generation of methane (CH_4), carbon dioxide (CO_2), and water from the end products of acetogenesis, as well as some of the products of hydrolysis and acidogenesis [5].

1.4 Objective of this work

The general objective of this work was to analyze the generation of organic waste in a food and nutrition unit and subsequently make an extrapolation to the municipality of Niterói, Brazil, evaluating its potential use for energy generation through biogas.

2 Materials and methods

Niterói is a municipality in the state of Rio de Janeiro, in the southeast region of Brazil (Fig. 1), and has an estimated population of 513,584 inhabitants, according to data from the Brazilian Institute of Geography and Statistics of 2019, and an area of 133,757 km^2. It integrates the metropolitan region of Rio de Janeiro and has the highest municipal human development index in the state of Rio de Janeiro and the seventh highest among the municipalities of Brazil in 2010 [14, 24].

A mass balance is an application of the mass conservation principle for the analysis of physical systems. By accounting for material entering and leaving a system, it is possible to identify mass flows, which can be unknown or difficult to know without this technique. Figure 2 shows the mass balance applied to the public policy of solid waste management in Niterói, where this study was conducted.

In order to evaluate the solid waste disposal alternatives, considering the disposal in landfills or incineration, it was necessary to do a survey on which solid wastes were generated in the municipality of Niterói (RJ). The surveyed data indicated that the municipality of Niterói-RJ generated 700 tons of solid wastes per day, of which 55.12% were household waste, 13.69% were civil construction waste, 8.56% were

Table 1 Main types of biodigesters used

Model	Characteristic
Navy or Canadian (balloon)	It is a horizontal model with its enlarged sun exposure area, which provides higher biogas production; its dome is of soft plastic, type PVC17, which inflates with gas production. It can be built buried or not. This model with PVC canvas cover, replacing the bell (metal or fiberglass), has been widely used due to lower costs and ease of implementation [22].
Chinese	It is a vertical fixed-domed biogas production system built below ground and with masonry. In this model, the pressure in the gasometer is not constant, varying according to biogas production [8].
Indian	It is composed of a digestion chamber and a mobile gas tank that floats directly on the digestion or water seal sludge, which makes it possible to maintain constant gas pressure. This type of biodigester can be operated as a self-discharging biodigester without the compensation tank [20].

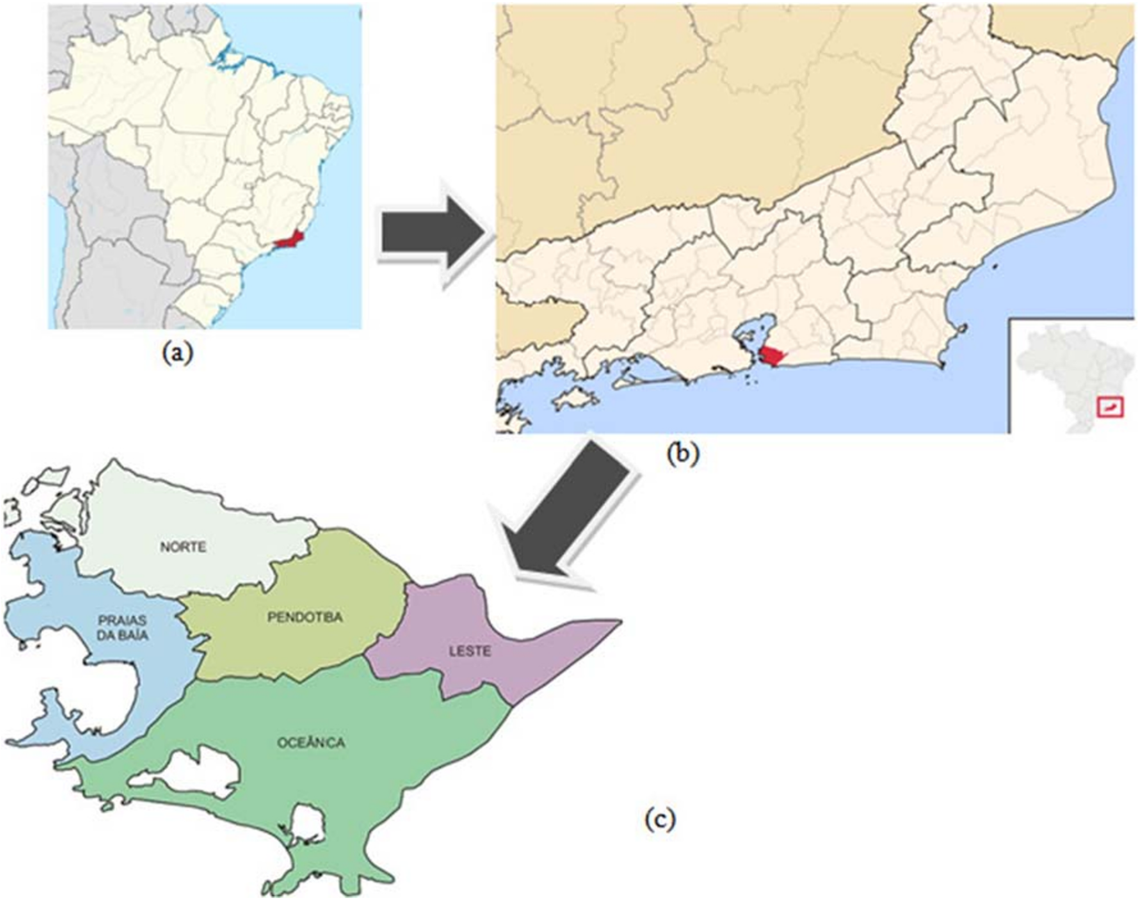
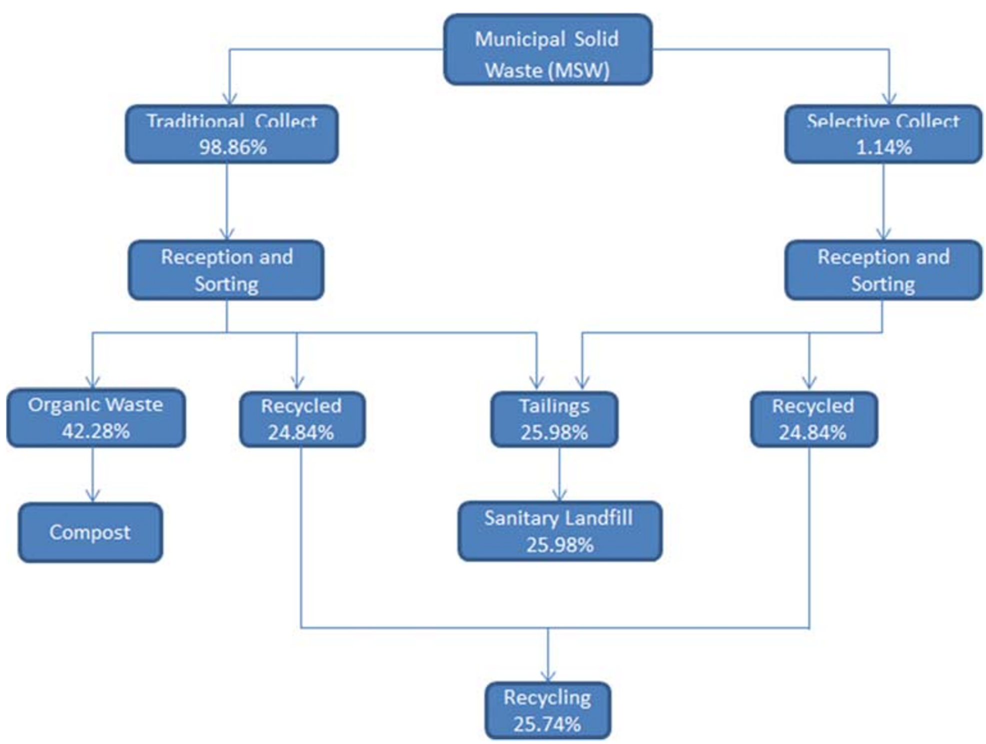


Fig. 1 Location of the municipality of Niterói-RJ. **a** Brazil. **b** Rio de Janeiro state. **c** Regions of the municipality

Fig. 2 Mass balance of the municipality of Niterói. Source: Author himself based on CLIN data



commercial waste, 21.43% were public waste, and 0.06% were healthcare waste [6].

This work was carried out at a restaurant located in the municipality of Niterói-RJ, located at the coordinates 22° 54′ 13.74″ S latitude, 43° 7′ 48.67″ W longitude, and average altitude of 19.96 m, using also tabulations in spreadsheets, field visits, and analysis of waste generation, evaluating different methods of waste production and treatment, in addition to bibliographic research related to data of waste collection.

This restaurant serves 350 daily meals, such as lunch and dinner. The process involves the collection of organic material in the sectors of bar, butchery, pre-preparation of legumes, and production, besides food scraps. The recycled materials of the bar, production, and storage were separated from the others.

The data were continuously compiled, once a day, always at the same time, during the months of June, July, and August 2019. The months of collection of the research are representative for an annual sampling because there is a constancy of data in the municipality, observed by the authors in follow-up and according to another study of the literature [14]. The device used for weighing was a TCS scale with capacity of up to 150 kg (Fig. 3a). Waste separation was performed in the sectors, following the principle of organic waste (Fig. 3b) and recyclable waste (Fig. 3c).

After the determination and gravimetric quantification of the wastes generated in the restaurant, the values were extrapolated to the other commercial establishments of the city of Niterói, according to the data researched in the literature and obtained in the field surveys conducted by the authors, enabling the estimation of the total mass of waste generated in all FNUs of the municipality of Niterói over the course of 1 month.

The process of extrapolating the data was necessary because the study was aimed at evaluating a restaurant, but the evaluation of the energy potential was carried out for the entire amount of organic waste produced in the municipality. The existing restaurants in the municipality, as well as the profile of consumers, are very similar because the consumer population is composed of students and elderly people, which contributes to the validation of extrapolation [14].

Thus, according to estimates of conversion of volatile solids (VS) of the organic wastes from the restaurants into biogas, it is possible to estimate the generation potential of the municipality, evaluating its feasibility of conversion into electricity and the potential of use for this purpose [36]. These data can be observed in Table 2 and, according to the literature, there is a variation from 27.6 to 17.1% [27, 37, 39, 41, 45].

According to the data shown in Table 2, based on the studies consulted, the average VS value was 22.94%, which was the value used in the present study. Fernandes and Dos Santos [19] showed the possibility of using average values in these correspondences.

At the end of the whole process, measures were proposed aimed at reducing waste in the establishments, promoting improvements in the processes, and balancing between production, disposal, and energy generation.

3 Results and discussion

3.1 Characterization of the waste generated by the study restaurant

Figure 4 shows the compiled results of the collections at the restaurant of this study along with the observation period.

According to the data presented in Fig. 4, the collected mass of waste, which includes several subcategories, showed a 37.65% variation between June and July due to the period of final tests in universities close to the restaurant, as the students, who are its main audience, take the meals to eat outside, which interferes with the total volume of waste generated. In the following month, the variation was 2.0%, much lower than the previous one, which represents a consistency throughout this evaluation period. This implies the possibility of working with average values, since periods of lower demand are com-

(a) (b) (c)

Fig. 3 **a** Model of scale used—TCS. **b** Bin with organic waste. **c** Bin with recyclable waste. Source: The authors

Table 2 Characteristic VS composition of food wastes

Author	(Zhang et al., 2011) [45]	(Li et al., 2012) [27]	(Sri Shalini et al., 2010) [41]	(Rasi, 2009) [37]	(Sadef et al., 2016) [39]
VS %	26.4	22.6	17.1	27.6	21.0

pensated with those of higher demand, according to other literature papers that also did the same [29, 39].

After all wastes were collected, they were subjected to gravimetric characterization, followed by screening for their type and control of the number of diners, people who consumed in the restaurant, as can be observed in Table 3.

According to Table 3, the number of diners, and consequently the amount of food sold in June, is higher than in the others, corroborating the idea that in this period, the consumption of meals out of home is higher, due to the period of tests and end of term, which causes the target audience of this restaurant to be maintained. This situation can be extrapolated, in average terms, to the city of Niterói, because it is considered an important university center and most restaurants are located nearby, so the oscillations found over a period are supported by the averages [7].

Although the number of people and quantity of food sold is higher in June, the total amount of waste generated over the month is lower overall, as observed in Fig. 4, due to the consumption of food outside the restaurant. However, the amount of organic waste in this period is larger, as it is directly dependent on the amount of diners [4]. For an average comparison of the amount of waste generated in the city of Niterói, and its possible potential for power generation, some data can be observed in Table 4.

Considering now the possibilities of extrapolating the values found, the average population of Niterói estimated for 2019 is 513,584 inhabitants, according to IBGE data. Other data show that the average population that eats away from home is about 34%, consuming an average of 25% of their monthly income [4, 24].

There are other studies already working with the statistical analysis of food consumption away from home. One of these, through a pre-tested questionnaire, tested a probabilistic sample of 250 consumers, 125 males and 125 females, adults, all living in the municipality of Campinas, SP, Brazil. As a result, it was shown that about 38.8% and 30.4%, respectively, reported lunching out four to seven times a week and dining out one to three times a week. A share of 35.2% of consumers said they lunch out frequently and very frequently at self-service restaurants, so the number of 34% according to IBGE can be extrapolated [29].

Thus, the average population of Niterói who eats during the days of the week away from home is about 174,619 people (34% of the total population), which represents a total waste production (TWP) per year of (Eq. 1):

$$\text{TWP} = [\text{number of people}] \times [\text{average of organic waste per diner in one month}] \times 12$$
$$\text{TWP} = 174,619 \times 0.14 \times 12 = 293,359.18 \text{ kg} = 293.35 \text{ ton}$$

On average, over the course of 1 year, the restaurants produce 293.35 tons of organic wastes, which must be properly collected, transported, and disposed of by each owner. These values do not take into account the quantities produced by the

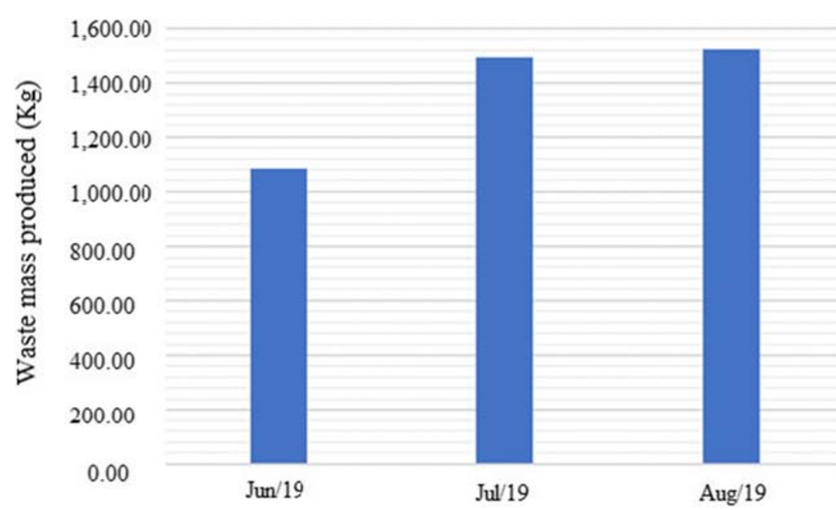


Fig. 4 Total mass of waste produced in the observation months, in kg

Table 3 Gravimetric characterization of wastes collected in the period

Characteristics	Studied restaurant of Niterói		
Month	June	July	August
Number of diners	10,231.00	9877.00	9354.00
Kg food sold	6448.00	5418.00	5308.00
Organic waste in the production step (kg)	1403.00	1112.00	1224.00
Organic waste of food scraps (kg)	90.00	80.40	99.00
Recycled (kg)	206.80	198.32	178.00
Quantity of organic waste generated (production + scraps) (kg)	1493.00	1192.40	1323.00
Organic waste per diner (kg/person)	0.15	0.12	0.14
Average of organic wastes per diner/month (kg)	0.14		
Average of organic wastes/month (kg)	1336.13		

residences, because these values are mixed with those of other municipal solid wastes and are subordinate to CLIN, which is the public company responsible for the collection in Niterói.

3.2 Gas generation potential from organic waste and its energy potential

After knowing the average amount of organic waste produced by the restaurants and other establishments that serve meals in the municipality of Niterói, it is possible to estimate the amount of methane gas produced from anaerobic biodigestion. This gas production process is directly correlated with energy potential, which is one of the objectives of this work. Considering that the average value of volatile solids in the constitution of food solid waste (organic) is 22.94%, according to the literature (Table 2), the total volatile solids (TVS) are:

$$TVS = 293,359.18 \times 0.2294 = 67,296.59 \text{ kg}$$
$$= 67.296 \text{ ton}$$

According to FIEP [21] and Maciel [28], one ton of volatile solids produces on average a volume of 400 m^3 of methane (CH_4). Therefore, the annual production of methane (APM) would be:

$$APM = 67.296 \times 400 = 26,918.40 \text{ m}^3 \text{ of } CH_4 \text{ a year}$$

According to COLDEBELLA [9], under normal temperature and pressure (NTP) conditions, methane has a lower calorific value (LCV) of 9.9 kWh/m^3. Thus, the energy production (EP) is:

$$EP = 26,918.40 \times 9.9 = 266,492.16 \text{ kWh}$$

Considering an annual energy production of 266,592.16 Kwh, the value per month is 22,207.68 kWh/month. In addition to organic waste from restaurants, other wastes have the potential to generate energy through the biodigestion process, as can be observed in Table 5.

There are many wastes in the world that are applied for the production of energy through the anaerobic digestion process, as shown in Table 5. The generation potential is dependent on the physical and chemical characteristics of the waste. Agroindustrial waste, which is produced on a large scale, has a high concentration of lignin and hemicellulose, present in natural fibers, which contributes to energy potential, but still lower than that presented in organic waste [44]. Poultry production waste has a high percentage of fat, which reduces the potential for energy generation [33]. Sewage sludge is rich in organic matter, showing greater adherence to energy production, which is why it presents values closer to that of food waste [32].

According to the monthly review of the electricity market released by the Energy Research Company, in January 2016, the average monthly residential consumption of energy per consumer unit from December 2014 to December 2015 was 161.8 kWh [15]. With the estimated production of 5551.92 kWh per month, it would be possible to meet the demand of 137.25 residences, meeting an average demand of 550 people. It should be pointed out here that this value is

Table 4 Energy generation with wastes produced between 2015 and 2018. Data sources: waste generation—CLIN, population—IBGE, and energy equivalence—CEGAS

Garbage generation × population × M^3 × Kwh					
Year	Waste generation (ton)	Population	Average per capita (kg)	m^3	kWh
2015	283,000	499,494	566.570	588,358	6208
2016	237,000	503,623	470.590	492,723	5199
2017	241,000	507,786	474.600	501,040	5290
2018	226,000	511,786	441.590	469,854	4957

Table 5 Potential for energy generation from various wastes through the biodigestion process

Type of waste	Solid organic waste (this research)	Waste from poultry production Orrico Júnior et al., 2010 [33]	Agricultural wastes (Zhang, et al., 2019) [44]	Yard waste and sewage sludge (Mu et al., 2020) [32]
Energy production per month (kWh/ton)	75.70	66.43	67.81	68.20
Places of use	Brazil	Brazil	China	China

unique and exclusive to food waste from restaurants, so the municipality may have a much higher potential if the organic waste collected from homes is considered. Regarding the cost of the process, the companies should pay in any way (treating or not) for the collection and transport of this material, but instead of having landfills, they should send it to biodigesters. The cost of the separation process can be reduced if it is shared and performed by the restaurants themselves, as in a selective collection [10].

According to the company responsible for the electricity in Niterói, the cost of energy for the residential B1 group is U$ 0.0649275/kWh, without considering fluctuations of tariff flags, public lighting fees, and some taxes, so in 1 year, the saving in terms of electricity consumption (SEC) would be:

$$SEC = 0.0649275 \times 266,492.16 = U\ 17,302.66$$

The overall cost of implementing a biodigester is low and will probably be paid with the saving of energy generated over the one-year period, which is significant and may be an excellent alternative for the lower-income population or even in a more distant community [25]. Some studies have already demonstrated that the implementation of biodigesters represents a cost that is directly paid to reduce the consumption of energy in a certain place, which in itself already justifies the implementation in energy supply systems.

Considering the possible disposal of this waste in landfills, which is the most widely used solution, the average cost of disposal in Brazil is U$ 15.00/ton, so the saving with waste disposal (SWD) would be:

$$SWD = 15.00 \times 293.35 = U\ 4,400.25$$

Other authors obtained values of savings that were proportionally similar to that found in the present study, demonstrating the feasibility and potentiality of using these wastes as an energy source, which can be used for the other organic wastes to be collected in the residences [5, 25, 28]. The cost of disposal in landfills varies considerably in other countries of the world, but in general, these are related to high prices, which ultimately burden the population with respect to the disposal, so means aimed at reducing the volume of waste to be deposited in landfills are extremely advantageous for the economy and environment [1].

One of the major problems of the Brazilian cities is due to the costs related to the disposal of solid waste. Some studies have already shown that about 12% of the budget of the municipalities in Brazil are destined for the collection and disposal of their waste; in the case of Niterói, this percentage is 11.10%, considering direct and indirect values [6, 14]. The savings generated with the implementation of biodigesters may be able to improve the efficiency of municipalities, leaving more resources for application in other areas, such as education and health; this has already been proven in some places in the world, such as China and India [13].

4 Conclusions

It can be concluded with this study that:

- The organic fraction prevails in the gravimetric composition, and instead of final destination in landfills, these wastes have potential for energy generation, through the development of policies to encourage the use of organic wastes in the generation of energy according to their types.
- The characterization of the organic waste from the restaurant under study showed the wide variety of wastes generated and what are the characteristics for their use, so it was possible to verify that very little is done in the municipality of Niterói to use these organic wastes in the generation of energy or any other use that is effectively performed, being directed to landfills for disposal, which will adversely impact their useful life.
- The study pointed to the use of the biomethanization unit, which transforms organic matter from municipal solid waste (MSW) into biogas, used for the generation of energy and biofuel, non-polluting. The material can also be transformed into organic compost to be used as soil conditioner, in agriculture and reforestation.
- Finally, it can be concluded that there is economic viability in using biogas for power generation, which would lead to savings in electricity consumption and with the disposal process, making it possible to meet the demand of 137 houses, so it can be adopted in small neighborhoods of the city of Niterói, with feasibility in the use of this form of energy generation from the solid wastes collected in the restaurants of the city.

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