A Comparative Study for Two Solid Waste Management Scenarios Based on Economic Cost and Sustainability Indicators

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Abstract

This work presents the results of a comparative evaluation of two possible scenarios for Municipal Solid Waste (MSW) Management in Paraíba do Sul city - RJ - Brazil, using economic cost and sustainability indicators. The novelty of this work is in validating by means of cost and sustainability indicators the MSW management proposal that use of the organic fraction of waste in a local composting process. The first scenario, Simulated Scenario 1, which is currently being assessed by municipal management is: sending all MSW collected in the city to the new private landfill. The second scenario, Simulated Scenario 2, is a novel model proposed in this work, which involves the shipment of organic waste to a composting yard. The scenarios are examined on a case study composed of ten neighborhoods from the municipal core. The results obtained reveal a difference of less than R$ 10,000.00 per month between the total estimated costs for each scenario, with the second simulation being the most expensive. For the second scenario, there is the possibility of generating income through the sale of the compost, which could cover the excess cost. Insights from the score of the sustainability indicators show that the second scenario is the best from the environmental point of view. The technological simplicity and the low economic cost of the indicated method for composting are highlighted, as well as the existence of selective collection and the use of organic waste as the main advantages of Simulated Scenario 2.

Introduction

The Brazilian National Policy on Solid Waste (BNPSW) are established based on the Federal Law 12,305/2010 (Maiello et al. 2018), which requires environmentally sound disposal of solid waste in all Brazilian municipalities with more than twenty thousand inhabitants (Deus et al. 2017). One of the biggest challenges for municipalities is to properly collect, recycle, treat and dispose the increasing volume of solid waste (Silva et al. 2018). About 60% of Brazilian municipalities, especially small ones, still dispose their urban solid waste improperly (Jabbour et al. 2014).

The state of Rio de Janeiro has 92 municipalities; 53 dispose their waste to landfills, with soil waterproofing (WL), 20 send it to controlled landfills, without waterproofed soil, and 19 send their MSW to open-air dumps, known as “dumps” (Observatório da PNRS 2017).

It is known that smaller municipalities do not have enough investments for good solid waste management, many of them still having as main final destination the irregular open-air dumps (França 2013). There is thus a need for better solid waste management strategies in small urban regions, and possible policies to encourage reduction, reuse, and recycling, fostering sustainability waste management practices (Deus et al. 2017).

In a natural ecosystem, waste from one species is food to another, so matter and energy can circulate continuously. This same understanding can be observed in the urban environment where the transformation of waste into resources leads to a circular urban metabolism, closing the water, matter and energy cycle, and promoting sustainable communities (Ragossnig and Schneider 2019). As such,
potential future alternatives that need to be explored include the stepwise reduction of landfilling by the introduction of composting (Liikanen et al. 2018), anaerobic digestion and mechanical-biological treatment (Mondal and Banerjee 2015).

Sustainable waste treatment should be capable of recovering the raw material in order to conserve natural resources; this can be achieved through total waste utilization or recycling of all effluents generated in the treatment (El-Haggar 2007). In this sense, a composting of organic waste is one of the most advantageous techniques for the recovery of organic solid waste (OSW), mainly because it generates organic compost that can be made into an excellent organic soil conditioner compound fertilizer (Van Fan et al. 2016).

Composting of organic waste is a controlled process of transforming the organic waste into a conditioning compound (fertilizer), with the aid of microorganisms and temperature monitoring, which can happen aerobically or anaerobically (Cesaro and Belgiorno 2015). In Brazil, the largest share (50% - 51.4%) of MSW is composed of organic matter (MMA 2017; Deus 2017); however, composting is rarely used as a treatment technology, mostly due to issues of lack of public support, institutional vulnerability, political-administrative discontinuities and negative impacts on the neighborhood, such as bad smell and attraction of animals (Siqueira and Assad , 2015). In 2008, only 3.8% of Brazilian municipals had access to composting plants and about 11.6% of municipalities destined the municipal solid waste to recycling plants (Deus 2017).

During agricultural harvests, several nutrients are removed from the soil (Nitrogen, Phosphorus, Potassium, Iron, etc.) that are not replanted by synthetic fertilizers. When the material generated by the composting process is used as fertilizer in the crops, these nutrients are returned to the soil, featuring an organic recycling model, which also promotes soil aeration and drainage, as direct advantages (INÁCIO and MILLER, 2009, p.15-16, 21Zhang, 2012). Massukado (2008), in his experiment, visually compared the difference, in the cultivation of carrots and beets, with and without the use of organic compost vs. synthetic fertilizers, as shown by Figure 1.

There are national researches that deal with the integrated management of solid waste in Brazilian cities, based on environmental and economic analyzes. The term “integrated” means not only disposing the waste in a proper place for its environmentally correct final destination, but also considering treatments and alternatives available to reduce the amount of material that will inevitably go to the landfill. The following are the environmental analyzes. Mersoni eande Reichert (2017) evaluated the environmental performance of five MSW management scenarios for a Brazilian city with 32,000 inhabitants, using the Life Cycle Assessment (LCA) technique. Such scenarios integrated recycling, composting, anaerobic digestion and incineration processes, compared to a base scenario that only considered landfill. All scenarios that included treatments such as composting performed better than the scenario that included only the final disposal in landfill.

The authors concluded, among other aspects, that the return of the material to the environment reduced the potential environmental impacts in the analyzed scenarios. To achieve this objective, an arrangement
of technological alternatives for recycling the different types of MSW should be established on a case-by-case basis. In order to compare the benefits of different management systems, they suggest that stakeholders include economic and social criteria for the location, considering the premises of sustainable development. (Mersoni and Reichert 2017).

Marchi (2015) developed a theoretical model for the Installation and Management of Solid Waste Disposal Equipment, aiming to offer a more comprehensive alternative than the technical-operational models, which are more widespread in the literature. The author stressed the importance of considering environmental and management aspects in studies of this type, and concluded that city halls act in a technically correct way when implementing landfills in cities, but they end up becoming open-air dumps due to poor management, operational, lack of technically qualified personnel to operate the equipment and lack of financial resources. Siqueira and Abreu (2016) discuss the challenges of implementing the composting process in Brazilian cities, mainly due to the difficulty in separating organic waste from inorganic and tailings. The authors inform that the final quality of the compost is directly related to such segregation and that it must be done at the generating source. In addition, selective collection is also fundamental to the success of the system. The research reports that there was a widespread spread of sorting and composting plants throughout the country during the 1980s, which failed due to the lack of appropriate technical planning. Such an unsuccessful experience seems to be the cause of the low acceptance of composting as a solution to MSW among public managers.

The work also analyzes the issue of selective collection in Brazilian cities in the last 20 years, informing that, when it exists, it is focused only on inorganic residues (paper, plastic, metal, etc.), and not on organic ones (food scraps and pruning), as the former are more commercially valued. Given the above, the authors warn of the idea of resuming composting along the same lines of centralization and without selective collection of organics, as an unsustainable model that extends the social and environmental interests of the municipalities. (Siqueira and Abreu 2016).

Jacobi and Besen (2011) provide a Brazilian overview of the sustainability challenges for the management of MSW, informing that there is a growing investment by the federal government in infrastructure, with the construction of sanitary landfills and sorting and composting plants, among others. However, the national scenario highlights the responsibility and the need to commit local management (city halls) to more sustainable choices: both economically (low cost), and in the sense of technologies compatible with the municipal context in question. The authors reinforce the need to reduce waste in generating sources and to be disposed of in landfills, through a well-designed and agreed waste plan with society. They also highlight, in line with the PNRS, that landfill should not be seen as a final solution, but rather as an alternative to waste that is not subject to other previous treatments; and that incineration is not a good solution, from the point of view of environmental sustainability. Both cases can contribute to the harmful consumption patterns in force. (Jacobi and Besen 2011). Finally, they comment that there is a “vicious circle”, based on economic interests in private contracts, which makes it difficult to abandon grounding systems. They then determine that the major challenge for MSW management is to
reverse this logic, investing in the reduction of excessive waste generation, selective collection and composting - to the detriment of the final destination in landfills. (Jacobi and Besen 2011).

There are works that address the theme of Clean Development Mechanism (CDM) with projects that reduce landfill participation in MSW management. Prioritizing other types of waste treatment would be a smarter guideline for developing countries, which have not yet been able to massively implement WL (Barton et al. 2007). The studies presented point to the need to reduce the volume of MSW to be sent to landfills through alternatives that prioritize the return of matter to the environment, in decentralized models.

Regarding the selection criteria, it should be remembered that in Brazil, around 50% of the MSW is organic (MMA 2017). As WL is a costly device with a short life span (20 years on average), composting appears to be a good strategy for reducing the amount of grounded MSW, especially through the UFSC Composting Method, which proposes the composting using passive aeration static windrows (Van Fan et al. 2016). In addition, several studies present insights into the benefits of organic waste recycling through composting over the landfill, in terms of landfill life extension, compost product, and mitigation of greenhouse gases (Seng et al. 2013, Van Fan et al. 2016, Kumar 2009).

There are also surveys where economic analyzes have been carried out.

Garré et al (2017) carried out a feasibility study for a sorting and composting plant in the municipality of Pelotas, RS (320,000 inhabitants), establishing results that point to the economic viability of the model, in addition to socio-environmental advantages. The study's proposal is a large-scale plant that receives heterogeneous material - differently from the studies directed at environmental analysis, previously presented. Gunaruwan and Gunasekara (2016) carried out a comparative assessment between two composting plants in Sri Lanka, having concluded about the technical and economic feasibility of both. The study indicates that the plants are not attractive to private investors, but they could receive government subsidies or improve their financial performance to become commercially viable. For one of the evaluated models, the authors believe that if the plant were less expensive and generated more compost production, it would enter a financially attractive limit. Specifically on this topic, the study makes it clear that the high capital invested is questionable, as it totally excludes the financial attractiveness of these plants. He also mentions that some local administrations seem to have been successful in the implementation and administration of composting facilities with much smaller investments. Finally, it indicates the possibility of using compost in networks of establishments that generate large amounts of organic waste, such as markets. (Gunaruwan and Gunasekara 2016)

Wartchow et al (2011) carried out a case study in the municipality of Ijuí, Rio Grande do Sul - which has about 83,000 inhabitants - comparing 4 scenarios for the management of household solid waste, using the Net Present Value (NPV) method. The scenarios considered different arrangements between composting and WL, or just WL. For scenarios that included composting, the authors chose the method that uses revolved windrows with air insufflation, and the solutions varied between sorting and composting plants or just composting (without sorting, with the use of segregated material at the
source). The results showed that the scenario that presented the lowest NPV for the costs of MSW management was the one that established the composting of 45% of the waste considering the segregation of organic waste in the generating source (households). In addition to greater global efficiency, the authors highlighted 3 other financial advantages in this scenario: reduced costs of transporting waste to the WL and also with treatment of leachate in the WL (by reducing the amount of material sent there) and savings on cleaning urban public health. (Wartchow et al 2011).

Finally, the study by Pandyaswargo and Premakumara (2014) is presented, which analyzed the cost-benefit of plants at different scales in developing Asian countries. All the plants studied had some type of financial support from governments, universities and donor agencies. To construct the analysis, the authors evaluated 4 scenarios, the worst of which was the absence of any financial support. Throughout the study, relevant information is presented. The authors report, for example, that the chosen composting method directly influences the plant's operating costs: traditional windmills require more labor, while sophisticated technologies require greater electricity consumption - which can mean heavy costs in locations where energy costs more. Also worth noting is the information that all evaluated plants receive financial return through the sale of organic compost, and the smaller the scale of the plant, the greater the control over the final quality of the compost - which increases the market value of the compost. Finally, it was reported that the cost of transportation is highly significant in large-scale plants, which can make them unprofitable (Pandyaswargo and Premakumara 2014). The results of the study showed that the medium and low-large-scale plants (51 and 200 t / day, respectively) obtained the best economic performances, to the detriment of the large and small-scale plants. However, the two small-scale plants evaluated proved to be financially viable, even though they offer low profitability. The authors indicate that in such cases, the government can play the role of provider of investment costs. (Pandyaswargo and Premakumara 2014).

After analyzing the studies presented, it was concluded that composting - associated with a means of final disposal, such as landfill - seems to be a good solution for waste management in small cities in developing countries. With only 2 exceptions (Mersoni and Reichert 2017; Wartchow et al 2011), all the composting cases analyzed by the authors above are on a community scale (educational institutions, condominiums) or in large and medium-sized cities, such as São Paulo, Pelotas and some foreign cities.

Among the exceptions (Mersoni and Reichert 2017; Wartchow et al 2011 - which evaluated cities between 32,000 and 85,000 inhabitants), the authors did not inform the composting method used or it was a method with slightly more improved technology (windrows revolved with air insufflation).

Thus, the literature review identified the following research gap: the possibility of associating the landfill with a low-tech composting method and decentralized implementation, as a way to improve strategies for waste management in Brazilian cities with up to 50,000 population. Approximately 80% of Brazilian municipalities have less than 50,000 inhabitants (Demographic Census, IBGE, 2010), so this is a relevant contingent to be considered as the focus of MSW policies.
Thus, in order to reduce environmental impacts, taking into account the premises of sustainability and the closing of the cycle of materials locally, the following hypothesis was launched: Analyze the probability of the association of Municipal Composting (under the UFSC Method in decentralized implementation) with the Landfill, as a way of improving strategies for waste management in small Brazilian cities.

To test this hypothesis, this work aims to present a practical case study in the city of Paraíba do Sul, in the form of comparative evaluation of two possible scenarios for Municipal Solid Waste (MSW) Management, one of which with the proposed association municipal composting with landfill, using economic cost and sustainability indicators. The novelty of this work is to apply the UFSC Method associated with the Landfill for small cities in Brazil. As landfill is an expensive and short-lived device (20 years on average), composting may be a strategy to reduce the amount of landfill MSW and extend its useful life.

It is recognized that despite the inherent limitations of conducting a case study, the results will serve as a benchmark for Brazil para ser aplicado nas cidades brasileiras com até 50.000 habitantes. A pesquisa que aqui se apresenta teve como motivação a carência de estudos práticos sobre esta área temática.

The waste management in the city of Paraíba do Sul, in the state of Rio de Janeiro is unsatisfactory. The city is located in the central region of the state, 138 km from the state capital, with a total area of 587.68 km², and an estimated population in 2016 of 42,737 people. The municipality has a largely rural area, but it is in its urbanized stretch (about 10 km²) where about 88% of the population concentrates (IBGE Cidades 2017). The daily amount of MSW collected in the municipality is 23.5 tons per day, since it is split into 0.55 kg per inhabitant per day when related to the population of the municipality. The gravimetric composition of the waste in the region where the city is located is 53.63% organic matter, 20.31% plastic, 16.08% paper, 2.84% glass, 1.74% metal and 5.40% of other residues (MCIDADES 2017, SEA 2013, MMA 2009).

Costs for urban sanitation services in the city of Paraíba do Sul are high with the MSW management expenditure can exceed 13% on total annual municipal expenditure amount (SEA 2013). The city is lacking a Municipal Plan for Integrated Solid Waste Management (MPISWM) (BRASIL 2012); The process for the execution of the study is still in the bidding stage through the Paraíba do Sul Middle Committee. The municipality has only completed the Municipal Basic Sanitation Plan (MBSP), but because it has more than 20,000 inhabitants, it must have the MPISWM independent of the MBSP (SEA 2013).

After this brief description of the city of the case study, in the next section, an overview of the method adopted will be presented, followed by results, discussion and conclusion.

### Comparative Evaluation Method

The comparative evaluation method will be applied to two scenarios simulated under quantitative and qualitative parameters. The quantitative parameters refer to the economic dimension and the collection
system, and the qualitative parameters refer to the technological and environmental dimensions. Finally, both scenarios will be compared to evaluate the results and make recommendations for the best scenario, as can be noticed from the framework in Fig. 2.

Thus, the objective of this work is validar a hipótese apresentada, através da avaliação destes two simulated scenarios of Solid Urban Waste Management in the case study's city, Paraíba do Sul - state of Rio de Janeiro, using economic cost indicators (for collection, treatment and final disposal) and sustainability (technological and environmental dimensions). It also aims to propose a complementary strategy to the landfill, given the urban scale of cities up to 50,000 inhabitants, and the possibility of a more sustainable treatment of MSW, using the composting of its organic fraction.

The first scenario evaluated - Simulated Scenario 1 - involves sending of all MSW collected in Paraíba do Sul to the new Três Rios Private Landfill (TRPL).

The second scenario evaluated - Simulated Scenario 2 - involves sending of the segregated organic waste at source to a composting yard, named “Municipal Composting Yard” (MCY) that would be implemented in Paraíba do Sul. Such waste would only be collected from large generators, and would also include municipal pruning waste. The remaining MSW would be sent to TRPL.

It is important to highlight two factors related to the successful application of the composting process at the municipal level, in Scenario 2: the MCY implementation model and the selective collection of organic waste previously segregated at the source of production (which are the major generators of organic waste, such as restaurants and fairs).

MCY will follow the decentralized deployment model, which is a model located close to generating sources and receives waste from a few groups (characterized by urban, institutional / corporate, community and / or domestic composting yards) - Siqueira and Assad 2015 - table p.246), which has been proven to be the most efficient and long-lived in previous studies (Siqueira and Assad 2015, Fehr 2006). Thus, the yard will serve only some neighborhoods of Paraíba do Sul urban core.

The UFSC Composting Method was chosen for use in MCY because it works with previously segregated waste collected from large generators (restaurants, markets, fairs, etc. besides municipal pruning waste, abundant in the municipality). In this method, the windrows have a dry vegetal cover, which allows the passive aeration of the internal material and prevents the access of animals such as flies and rats, as shown in Fig. 3. This means that the process is less expensive because it does not require constant material revolving, and more effective, as it avoids impacts on the neighborhood related to smell and attraction of animals - the responsibility for the closure of most composting units (Siqueira and Assad 2015).

The methodology used to achieve this objective was quantitative and qualitative exploratory research, evaluating aspects of economic costs and strategies related to the sustainable development of the data collected.
The quantitative research is based on the estimate of MSW generation (total and organic of large generators in ton per month), cost estimation for collection (conventional and selective to organic waste); and estimate of costs for final disposal and waste treatment (Landfill and Municipal Composting Courtyard).

The qualitative research uses sustainability indicators, in order to evaluate the proposed scenarios of this research.

The sample used in the research was composed of ten districts of the municipal headquarters of Paraíba do Sul, chosen due to they are located in the central nucleus of the municipality with high population density and because they have a great concentration of organic waste generators. This is a representative sample of the study universe, since most of the inhabitants are present at the municipal headquarters and, therefore, is where the largest portion of MSW is generated (Souza et al. 2020).

Next, the instruments, sources and parameters of the research method for each of the quantitative and qualitative indicators, proposed in the evaluation of the scenarios simulated in this case study, will be presented.

**Quantitative indicators**

**Economic cost indicator - municipal solid waste generation estimates**

Two estimates of waste generation were made: total MSW (heterogeneous) and OSW of large generators. In order to define such quantities, a survey of the area and population of the proposed neighborhood cut was carried out. To define the area and population of this section, data from the Territorial Development Master Plan of Paraíba do Sul were used. The total amount of MSW collected in this universe was estimated, in tons per day, based on the 0.55kg / inhab / day figure, described in the Introduction (IBGE Cidades 2017, MCIDADES 2017, SEA 2013, MMA 2009).

To identify and select the large generators of OSW, a survey was made in the municipal register of companies and the survey of the areas of such establishments, in m² - information that was used to estimate the amount of waste generated. According to MMA (2010), the main generators of OSW are: restaurants, snack bars, juice shops, fruit and vegetables, markets, producers of food for delivery, and hotels.

The amount of OSW generated in the selected establishments was derived from COMLURB (2012), which indicates the following estimates: 0.70 liters / day / m² for stores, hotels and inns and 1.00 liter / day / m² for restaurants, snack bars and the like. The quantities found in liters refer to the heterogeneous residue, and were converted from volume to weight, using the PROSAB index (2003), which defines the average density of 300 kg / m³ for the newly collected MSW. To define the compostable quantities, the heterogeneous quantities were multiplied by 0.50, since the organic fraction is about half of the total waste, by weight (MMA, 2017).
**Economic Cost indicator - collection cost estimates**

Two estimates of collection costs were made: cost of conventional collection and cost of selective collection of organics from large generators. Such estimates are composed of: vehicle fuel consumption and employee salaries. To produce maps with the collection routes (MMA 2010), Google Maps digital system, with its Routes and Markers functionalities, was used to identify the relevant travel routes.

For the average fuel consumption of the vehicles, the collection vehicles and the distances to be covered in both types of collection were defined: for conventional collection, the compacting truck with a capacity of 19m³ - corresponding to 5.7 t of waste (PROSAB 2003) was adopted, while for selective collection, a truck with an open body model Ford F-4000 was simulated (Inácio and Miller 2009). Two types of distances (km / month) were defined for each type of collection: distance D1, referring to the logistics of waste already collected up to its final destination; and distance D2 - referring to home-to-home collection. In conventional collection, D1 is the distance between the urban centre of Paraíba do Sul and the TRPL; in selective collection, D1 is the distance between the urban centre and the MCY. The distance D2 was the same in both collections: to define it, 3 regions of the proposed neighborhood cut were mapped, and the mileage of its streets was measured using the AutoCAD software.

Regions with different street patterns were chosen to reach an average representative of the spatial profile. Each region has 0.25 km², and the average of the 3 regions is 2.9 km of streets - so, by means of a rule of 3, 1 km² is equivalent to 11.6 km of streets (Fig. 4). From the 3 regions, the others were estimated by the total area of each neighborhood, as shown in table 1. Thus, there is an estimated D2 of 113 km of streets to be traveled by conventional and selective collection trucks.

To calculate fuel consumption, Lino's (2009) estimate was used: 0.433 L / km. Diesel oil used in trucks cost about R $ 3.254 / L in November 2017, in the Paraíba do Sul region - a value defined from the average between the values of the cities: Rio de Janeiro, Sapucaia and Teresópolis, available on the National Petroleum Agency (ANP 2017).

Collectors 'and drivers' salaries were estimated through Borges and Ferreira (2008): R $ 478.73 and R $ 500.00, respectively - and adjusted according to the National Consumer Price Index (INPC). The current minimum wage in 2017 (R $ 937.00) was used for adjusted values below this.

In Scenario 1, conventional collection is simulated once a day, except for Sundays (average of 28 days/month), performed by four employees in each truck.

In Scenario 2, in addition to conventional collection (in the same way as described for Scenario 1), selective organic collection is simulated, also under an average of 28 days / month, but by two employees in each truck. In this scenario, the use of 50 L plastic drums to simulate OSW in generating sources is simulated. Full bombs will be offered for collection and emptied at the MCY. At the time of collection, empty canisters will be delivered to the generators, configuring a cycle of containers that are
not disposable and will be purchased by the generators - not comprising costs for the management of municipal MSW.

It is noteworthy that the model proposed for Scenario 2 contemplates the segregation of organic waste from the others, to be carried out by the large generators before offering them for collection - thus not composing any cost for the administration of the system (city hall).

**Economic Cost indicator - final disposal and waste treatment cost estimates**

Final disposal and treatment costs were estimated based on three definitions: Costs for final disposal at TRPL; Costs for MCY implementation and monthly operation; Monthly revenue from marketing the compost.

To determine the costs of the final disposal at TRPL, the amount of R $ 54.25 / t, as described in the National Solid Waste Plan (BRASIL 2012), was corrected, according to the Broad Consumer Price Index (IPCA), in November 2017. For Scenario 1, all generated MSW was considered. For Scenario 2, in the monthly calculation of the generation of heterogeneous waste, the generation of organics from the large generators was subtracted.

To determine the costs of implementing the MCY, the UFSC Method was first defined under the Decentralized Implementation / Management Model, according to its suitability for the proposed case study. The costs of implementing the MCY were estimated globally, in reais (R $), through manuals and similar case studies (MMA 2010, Funasa 2013), and corrected according to the Broad Consumer Price Index “IPCA” - November 2017.

MCY’s monthly operating costs were estimated in a unitary manner, taking into account employee salaries and fixed operating costs. MMA (2010) indicates the need for only one professional - Revirador de Leira -, according to the demographic parameter closest to this study. Such reference was used, considering the need for two more employees: Administrative Assistant and Yard Assistant. The employees’ salaries described in the document - R $ 1,041.01, R $ 1,163.71, and R $ 612.00, respectively (MMA 2010) - were adjusted according to the National Consumer Price Index (INPC) - November 2017 for fixed operating costs, the water and energy consumption values of the MCY were estimated, according to CAOPMA (2012) - namely: R $ 150.00 per month, referring to the sum of both. For inflation adjustment, the General Market Price Index “IGPM” was used in November 2017.

Determining the revenue from the commercialization of the compost, the quantity generated was first estimated. According to MMA (2010), “for each kilo of waste delivered to the unit, [produces] half a kilo of compost”. Thus, the calculated estimate of OSW received at the MCY was multiplied by 0.5. According to a survey in the local market, the average price of 1 kg of compost is R$ 15.00. It was decided to simulate a price below the market value, to promote the local closing of the OSW cycle, selling to small farmers in the region.

**Qualitative indicators**
This paper presents a qualitative analysis of the proposed scenarios applied to sustainability indicators, mainly related to the circularity of materials, the generation of employment and income, the increase of the landfill life, and the prioritization of local solutions based on the previous research of Santiago et al. (2012).

Traditionally, six dimensions of sustainability are often assessed, namely: politics; technological; economic and financial; environmental and ecological; knowledge dimension (environmental education and social mobilization); and the dimension of social inclusion (Santiago et al. 2012).

The applicability of indicators of the Political and Economic dimensions would be difficult to be applied as the evaluation of two simulated scenarios for waste management were developed in the municipality and not for the country.

Also the indicators proposed in the Knowledge and Social Inclusion dimensions do not apply to this research, as they relate to specificities within the MSW theme that are not being addressed in this study such as aspects related to environmental education and inclusion of recyclable waste pickers.

Thus, the present research adopts specific indicators of the Technological and Environmental / Ecological dimensions, as shown in Table 1 and Table 2; in the technological dimension all indicators are used as I2a, I2b, I2c, and I2d. In the environmental and ecological dimension, only the indicators related with solid waste and described below will be employed: I4d, I4e, I4f, I4g, I4h, and I4j.

Table 1. Matrix Pattern of sustainability indicators to MSW—Technological Dimension (Rametsteiner et al. 2011, Souza et al. 2020, Santiago et al. 2012)
| Dimension       | Key question                                                                 | Indicator                                                                 | Description                                                                 | Score |
|-----------------|------------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|-------|
| Technological   | Does this observe the principles of appropriate technology?                  | (I2a) Employs local manpower                                              | All phases of solid waste management                                         | 5     |
|                 |                                                                              |                                                                           | Collection and administration                                                | 3     |
|                 |                                                                              |                                                                           | Only collection                                                              | 1     |
|                 | (I2b) Maintenance of the equipment made locally                              |                                                                           | All phases of solid waste management                                         | 5     |
|                 |                                                                              |                                                                           | Only transport                                                               | 2     |
|                 |                                                                              |                                                                           | External maintenance                                                         | 1     |
|                 | (I2c) Reuse technology with low energy consumption, non-trailer patents, and |                                                                           | Comprises all items                                                          | 5     |
|                 | royalties; easy handling; employs local manpower                             |                                                                           | Only low energy consumption and non-trailer royalties and patents            | 3     |
|                 |                                                                              |                                                                           | Non-attendance                                                              | 0     |
|                 | (I2d) Specific collector vehicle appropriate in terms of capacity, size for  |                                                                           | Yes (only for this function)                                                 | 5     |
|                 | local generation needs                                                       |                                                                           | Yes (also used in other municipal functions)                                 | 2     |
|                 |                                                                              |                                                                           | Non-attendance                                                              | 0     |
| **MAXIMUM SUBTOTAL** |                                                                                |                                                                           |                                                                              | 20    |

Table 2. Matrix Pattern of sustainability indicators to MSW – Environmental/Ecological Dimension (Souza et al. 2020, Santiago et al. 2012)
| Dimension          | Key question                                               | Indicator                                                   | Description                                           | Score |
|--------------------|------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------|-------|
| Environmental      | Minimal environmental impact?                              | (I4a) Collection efficiency                                 | 91 to 100%                                           | 5     |
|                    |                                                             |                                                             | 31 to 90%                                            | 2     |
|                    |                                                             |                                                             | < 30%                                                | 1     |
|                    |                                                             | (I4b) Population satisfaction with public collection (periodicity/frequency/schedule) | > 70%                                                | 5     |
|                    |                                                             |                                                             | 30 to 70%                                            | 3     |
|                    |                                                             |                                                             | < 30%                                                | 1     |
|                    |                                                             | (I4c) Existence of public cans                               | In the whole urban area, in places where people move  | 5     |
|                    |                                                             |                                                             | Only in the downtown of the municipal core            | 2     |
|                    |                                                             |                                                             | Does not have cans                                   | 0     |
|                    |                                                             | (I4d) Existence of selective collection in the city          | Yes                                                  | 5     |
|                    |                                                             |                                                             | In the deployment phase                               | 3     |
|                    |                                                             |                                                             | Does not exist                                       | 0     |
|                    |                                                             | (I4e) Coverage of selective collection in the city           | The whole city                                        | 5     |
|                    |                                                             |                                                             | The whole urban area of the city                      | 4     |
|                    |                                                             |                                                             | Exclusively in some neighborhoods of the urban area   | 1     |
|                    |                                                             | (I4f) Existence of places for the voluntary offer of segregated waste | Serves more than 50% of the population               | 5     |
|                    |                                                             |                                                             | Serves less than 50% of the population                | 3     |
|                    |                                                             |                                                             | Does not have                                        | 0     |
|                    |                                                             | (I4g) Rate of recovery of the recyclable materials Recovery rate of recyclable materials | Above 10,1%                                          | 5     |
|                    |                                                             |                                                             | Between 5,1 and 10%                                  | 3     |
### Results

After exposing the method applied in the case study city, the results will be presented to test the hypothesis of this work.

#### Scenarios presentation

Scenario 1 contemplates sending all MSW to TRPL. Fig. 5, demonstrates the flowchart for this scenario.
Scenario 2 is a model in which the organic fraction of large generators would be sent to a municipal compost yard, and the other MSW would continue to be sent to TRPL, as shown in Fig 6. Inorganic MSW and hazards would be sent to the Três Rios landfill, as there is neither the technical capacity nor the financial resources to treat locally or give an environmentally appropriate final destination for these types of waste.

**Economic Cost indicator - municipal solid waste generation estimates**

The ten neighborhoods contemplated in the proposed spatial cutout make up the continuous urban fabric of the municipality. They are: “Bela Vista”, “Brocotó”, “Centro”, “Cerâmica D’Angelo”, “Grama”, “Jatobá”, “Lavapés”, “Niagara”, “Palhas” and “Parque Morone”, as presented in Fig. 7. The neighborhoods “Limoeiro”, “Liberdade”, “Santo Antônio” and ‘Fernandó”, despite being in the same urban spot of the map, have morphological characteristics or boundaries that make them stand out from the others, such as the presence of a highway or the accentuated relief (PMPS 2014).

As described in the Territorial Development Master Plan of Paraíba do Sul, 88% of the municipal population of Paraíba do Sul is concentrated in densely populated urban areas (IBGE Cidades 2017, MCIDADES 2017, SEA 2013, MMA 2009). Being the total population (100%) of the municipality of 42,737 inhabitants, the percentage of 88% results in 37,608 inhabitants. From this demographic data, and from the sum of all areas, 37,608 people live in 9.68 km².

For the cut-off neighborhoods, the sum of occupied areas is 4.61 km². From this and the previous data (37,608 people live in 9.68 km²), a rule of three was used to define the population of the cutout neighborhoods, obtaining the population of 17,910 inhabitants in the cutout neighborhoods. Thus, the area studied in this case study has 4.61 km², and its respective population is 17,910 inhabitants (Souza et al. 2020).

From the data of 0.55 kg / inhab / day, and the total population of the spatial area (17,910 inhab.). There is a production of 9.85 t / day of MSW in the analyzed neighborhoods, which becomes 305, 4 t / month (IBGE Cities 2017, MCIDADES 2017, SEA 2013, MMA 2009). It is important to remember that, in Scenario 1, all this production will be displayed in TRPL. In Scenario 2, this value will be lower, when subtracting the organic fraction of the large generators.

The document obtained from the Municipal Register of Companies, in March 2017, organizes companies by activity categories and makes their addresses available. 12 categories / activities were selected as major generators in this case study. From the sum of establishments, we have that the total of large organic SR generators contemplated in this research is 95 establishments.

Estimating the production of organic waste to be sent to the MCY, the procedure described in Method was carried out, which relates the generation of waste to the areas and functions of the establishments - according to COMLURB (2004). Table 3 shows the sum of the areas of establishments by category,
followed by the total production of waste in the category, and finally the total generation of MSW in all categories.

Table 3. Areas and total production of heterogeneous waste from large generating establishments in Paraíba do Sul

| Property category                                      | Area (m²) | MSW production (liters / day) |
|--------------------------------------------------------|-----------|------------------------------|
| Com. Retail. Of horticultural products                 | 734       | 513,80                       |
| Com. Retail. Vegetables                                | 86        | 60,20                        |
| Com. Retail. Merc. In general, with predominance. Food | 668       | 467,60                       |
| Prov. Prepared food for companies                      | 72        | 72                           |
| Hotel                                                  | 4166      | 2916,20                      |
| Snack bar                                              | 1686      | 1686                         |
| Snack bars, tea houses, juices and similar             | 2323      | 2323                         |
| Mini Market                                            | 342       | 239,4                        |
| Alimony                                                | 262       | 262                          |
| Pizzeria                                               | 401       | 401                          |
| Restaurants and similar                                | 2346      | 2346                         |
| Supermarket                                            | 1947      | 1362                         |
| **Total heterogeneous MSW of all categories (liters/day)** |           | **12650,10**                |

Cubic meters to kilograms (density MSW = 300 kg / m³) 3.795 kg

The organic fraction was calculated according the procedure described in Method, reaching an estimated production of 1.9 t / day of OSW in the large generators, which converts to 58.9 t / month - amount of OSW that will be sent to the MCY, in Scenario 2.

The amount of heterogeneous waste to be sent to TRPL in Scenario 2 is 7.95 t / day, which converts to 246.5 t / month.

**Cost indicator - collection cost estimates**

Table 4 shows the number of compactor trucks to meet the estimate of total MSW generation in the cutout for collection in the chosen neighborhoods. It also presents the distances D1 and D2, fuel costs and costs of employee salaries.

The number of employees for conventional MSW collection was defined in this way: 3 collectors and 1 driver per truck, totaling 6 collectors and 2 drivers.
**Table 4.** Estimated costs of conventional MSW collection

|                        |       |
|------------------------|-------|
| Total MSW              | 9,85t/day |
| Compactor truck capacity | 19m³  |
|                        | (5,7t)   |
| Number of compacting trucks | 2      |
| D1 (km / month)        | 17.8 km per trip x 4 |
|                        | 71.2 km / day in total x 28 days |
|                        | 1,994 km / month |
| D2 (km / month)        | 113 km / day for 28 days |
|                        | D2 = 3,164 km / month |
| D1 + D2                | 5,158 km / month |
| Monthly fuel cost      | *average consumption of 2,233 L/month* |
|                        | value of diesel per liter (R$ 3.254) |
|                        | approximate amount R $ 7,500.00 / month |
| Monthly salary cost (8 employees) | R $ 7,532.46 / month |
| Total cost             | R $ 15,032.46 / month |

Table 5 shows the number of trucks needed for the selective collection of organics in the 95 large establishments. It also shows the distances D1 and D2, fuel costs and costs of employee salaries.

The location chosen for the installation of the MCY is on a road at an appropriate distance for the urban core. The distance from the MCY to the cutout neighborhoods (D1) is about 3 km.

The number of employees for conventional MSW collection was defined in this way: 1 collector and 1 driver per truck, totaling 2 collectors and 2 drivers.

**Table 5.** Estimated costs of selective collection of MSW
MSW | 1.9t / day
---|---
Capacity of the Ford F-4000 model truck with open body measures 6.5m x 2.5m | 96 50L drums per trip
| 1.44t capacity of waste per trip
Number of compacting trucks | 2
D1 (km / month) | 3 km per trip x 4
| 12 km / day in total x 28 days
| 336 km / month
D2 (km / month) | 113 km / day for 28 days
| D2 = 3,164 km / month
D1 + D2 | 3,500 km / month
Monthly fuel cost | average consumption of 1,515 L / month
| value of diesel per liter (R $ 3.254)
| approximate amount R $ 5,000.00 / month
Monthly salary cost (4 employees) | R $ 3,784.46 / month
Total cost | 8,784.46 / month

**Cost indicator - final disposal and waste treatment cost estimates**

Table 6 presents the costs for the final disposal of waste at the landfill, in Scenario 1 and Scenario 2. The corrected value in November 2017 was R $ 92.15 / t.

**Table 6. Final disposal cost in TRPL - Scenario 1 & Scenario 2**

| Scenario 1 cost | Scenario 2 cost |
|---|---|
| Total amount of MSW | 305.4 t / month |
| Value of MSW / t | 92,15/t |
| Approximate total amount | R $ 28,500.00 / month |
| Total amount of MSW | 246.5 t / month |
| Value of MSW / t | 92,15/t |
| Approximate total amount | R $ 23,000.00 / month |

For the present case study, the value of Jardim (1995), corrected in November 2017: R $ 85,340.00, was used, approximating to the value of R $ 90,000.00. Table 7 shows the operating costs of the MCY - reference values and corrected in November 2017.
Table 7. Estimated costs for operating the MCY. Adapted from MMA (2010) and CAOPMA (2012), 2017

| Items                        | Reference value (R$) | Corrected amount (R$) |
|------------------------------|----------------------|-----------------------|
| Water and energy bills       | 150,00               | 222,53                |
| FUNC. Windmill turner        | 1.041,01             | 1.619,68              |
| Administrative assistant     | 1.163,71             | 1.810,59              |
| Yard assistant               | 612,00               | 952,20                |
| Total corrected (approximated) |                      | 4.605,00 (R$ 5.000,00) |

Based on the estimated amount of OSW received at the MCY (58.9 t / month), multiplying by 0.5, there is an estimated production of 29.4 t / month of compost. The value of R $ 2.00 was stipulated for the commercialization of the 1 kg bag of compost produced at MCY - a value well below that raised in the local market (R $ 15.00 / kg). Then, there is an estimated monthly revenue of R $ 58,800.00, which can be rounded up to R $ 55,000.00 / month. Finally, Table 8 presents a summary of all cost indicators.

Table 8. Summary of cost indicators

| Summary of cost indicators |
|----------------------------|
| description                | Quant. / Order of Greatness | unit |
| 1                          | Estimated total MSW quantity | 305,4 | t/month |
|                             | GG organic fraction quantity estimate | 58,9 | t/month |
|                             | Estimated quantity RSU (-) organic fraction GG | 246,5 | t/month |
| 2                          | Conventional collection cost | 15.032,46 (15.500,00) | R$/month |
|                             | Large organic selective collection cost ger. | 8.784,46 (9.000,00) | R$/month |
| 3                          | Final disposal cost AS for Scenario 21 (all MSW) | 28.142,61 (28.500,00) | R$/month |
|                             | Final disposal cost AS for Scenario 2 (MSW except organic GG) | 22.714,97 (23.000,00) | R$/month |
|                             | MCY deployment cost | 85.340,00 (90.000,00) | R$ |
|                             | Monthly MCY operation cost | 4.605 (5.000,00) | R$/month |
|                             | Estimated revenue from marketing the compost | 58.800,00 (55.000,00) | R$/month |

Qualitative indicators – matrix technology
For indicator I2a, “Uses local labor”, both scenarios scored 3 points, referring to the collection and administration phases. As the other phases of MSW management may require specialized labor - which is not always found in the city - it was decided to mark only these two. For MCY technical management, for example, it is important to have a professional or consultant who specializes in soil and composting techniques. Also the shipment of waste to a WL outside the municipality, by itself, already characterizes external agents. It is noteworthy that waste collection management is currently performed by an outsourced company, but in both scenarios, it is simulated that the city assumes this service.

The second indicator, I2b, “Equipment maintenance performed locally”, scored 5 for both SS, referring to all management phases, since the equipment used is simple and its maintenance is easily found in the city.

Indicator I2c, “Energy-efficient reuse technology, not linked to payment of patents and royalties; easy handling; employs local labor”, did not score any points for Scenario 1 as it does not foresee any reuse technology. For Scenario 2, it scored 5 points, because the utilization model proposed in the simulation (UFSC Composting Method) includes all the described items.

Finally, indicator I2d, “Capacity-specific and size-appropriate collection vehicle for local generation needs”, scored 5 points for Scenario 1 as the conventional collection truck (compactor) is for single use only. MSW management. For the Scenario 2 the indicator scored 2 points, as the organic pickup truck (open body) could be used for other municipal functions. Thus, the total score of the Technology Matrix was 13 and 15, respectively for Scenario 1 and Scenario 2.

**Environmental and ecological matrix**

The indicators I4a, I4b, I4c, I4i, I4l, I4m, and I4n do not apply to the scenarios simulated in this paper, namely: “Collection efficiency”; “Satisfaction of the population regarding collection”; “Existence of public dumps”; “MSW generation per capita”; “Existence of landfill for inert waste”; “Number of clandestine waste points”; and “There is recovery of areas degraded by waste”, respectively.

For indicator I4d, “Existence of selective collection in the municipality”, Scenario 1 did not score points, as this scenario does not provide for this solution. Scenario 2 scored 5 points, referring to the full existence of selective collection.

Indicator I4e, “Scope of the selective collection in the municipality”, also did not score for Scenario 1, as it does not apply. Regarding Scenario 2, it scored 1 point, since the collection of organics serves only some neighborhoods of the urban area.

For indicators I4f, “Existence of points for voluntary disposal of segregated waste”, and I4g, “Recovery index of recyclable materials”, neither scenario scored, as these solutions were not foreseen in either simulation.
In indicator I4h, “Organic waste recovery”, there was no score for Scenario 1. For Scenario 2 there were 3 points, referring to the alternative “Between 5.1% and 30%” of recovery. It is estimated that the total organic waste generated in the municipality is 11.7 t / day since the overall total (heterogeneous MSW) is 23.5 t / day (SEA 2013) and the organic fraction represents on average 50% of the total (MMA, 2017). Thus, the amount of organic waste defined in the case study to be sent to MCY composting (1.9 t / day - referring to the large generators of the cut-off neighborhoods) represents 16.2% of the total 11.7 t / day.

Finally, indicator I4j, “Licensed sanitary and controlled landfill”, scored 5 points in both scenarios, as both simulations predict the use of the TRPL.

Thus, the total score of the Environmental / Ecological Matrix was 5 and 14, respectively for Scenario 1 and Scenario 2. Table 9 below summarizes the sustainability indicators for each scenario.

Table 9. Summary of Sustainability Indicators

| SUMMARY OF SUSTAINABILITY INDICATORS |
|--------------------------------------|
| DIM. | Item | Description | Score Scenario 1 | Score Scenario 2 |
| TECHNOLOGICAL DIMENSION | I2a | Local Manpower | 3 | 3 |
| | I2b | Maintenance of equipment made locally | 5 | 5 |
| | I2c | Reuse technology with low energy consumption, non-trailer royalties; easy handling; employs local manpower | 0 | 5 |
| | I2d | Specific and appropriate collector vehicle | 5 | 2 |
| ENVIRONMENTAL / ECOLOGICAL DIMENSION | I4d | Existence of selective collection in the city | 0 | 5 |
| | I4e | Coverage of selective collection in the city | - | 1 |
| | I4f | Existence of places for voluntary offer | 0 | 0 |
| | I4g | Index of the recovery rate of recyclable materials | - | - |
| | I4h | Index of the recovery rate of organic waste | - | 3 |
| | I4j | Licensed Landfill / Licensed Controlled Dump | 5 | 5 |
| | TOTALS | | 18 | 29 |

Discussion

From the data obtained, the monthly cost of PMPS for the collection and final disposal of its waste is approximately R $ 44,000.00 for Scenario 1; and approximately R $ 52,500.00 for Scenario 2. Table 10
below shows a comparison in real and percentage values for the simulated scenarios 1 and 2.

**Table 10.** Comparison in absolute and percentage values, between the economic cost indicators for Scenario 1 and Scenario 2

| Economic Cost Indicators                  | Scenario 1 Values (R $) | Scenario 2 Values (R $) | Percentage observations                      |
|-----------------------------------------|-------------------------|-------------------------|---------------------------------------------|
| Collection (s)                          | 15.500,00               | 24.500,00               | *Scenario 2 58% more expensive than Scenario 1* |
| Final Disposal at the Landfill - RS heterogeneous | 28.500,00               | 23.000,00               | *Scenario 2 19% cheaper than Scenario 1*    |
| MCY Treatment - RS Organic GG           | --                      | 5.000,00                | *Scenario 2 only*                           |
| **TOTALS**                              | 44.000,00               | 52.500,00               | *Scenario 2 19% more expensive than Scenario 1* |

The difference between the monthly costs between Scenario 1 and Scenario 2 was only R$ 8,500.00, or about 19%, with Scenario 2 being the most expensive. This value is considered low in the scope of the municipal management of MSW, however Paraíba do Sul is a small municipality, which has few resources. Thus, such investment could be required in a program to promote sustainable development initiatives, or in CDM projects - since Scenario 2 includes the composting system.

It is noteworthy that the MCY proposed in this case study would cost approximately R $ 90,000.00 to be implemented in Paraíba do Sul. Such cost is only about one fifth of the estimated value for annual relocation of Green ICMS in the city: R $ 449,522.91 (SEA, 2013). This resource could be required by PMPS in the first year of destination of the city’s waste to TRPL.

Thus, the MCY could be implemented and start operating the following year, generating savings of approximately R $ 5,500.00 / month in the disposal of waste in the TRPL - a value that could be used to finance the monthly operation of the MCY itself (estimated at R $ 5,000.00 monthly).

In Scenario 2, the sale of compost could generate an average monthly revenue of R $ 55,000.00, an amount that fully covers the costs of waste management in Scenario 2 (R $ 52,500.00). Recalling that this total of R $ 52,500.00 does not consider significant costs, related to the depreciation of equipment, taxes, charges etc. It is believed that a feasibility study would establish a final value around 30 to 40% higher. Even so, the sale of the compost would bring a relevant revenue to be considered in the financing of the system.

In this sense, it is believed that the local market would be able to absorb the amount of compost produced in the MCY, since there is great agricultural demand in the region and much of the soil is eroded due to the monoculture of coffee in the 19th century.
Regarding the sustainable indicators applied in this study, the difference of 11 points more for Scenario 2 leaves no doubt what is the best scenario in the environmental context. We highlight the technological simplicity and the low cost of the method indicated for composting, as well as the existence of selective collection and the utilization of organic waste, as the biggest advantages of Scenario 2 in this sense.

It is also worth mentioning the carbon savings contemplated by the local practice of composting - especially if the compost is commercialized also locally. The use of the compost in local agriculture, to the detriment of synthetic fertilizers, may encourage the cultivation of organic foods in the region, closing the cycle of organic materials. Finally, it is highlighted that the costs not included in the calculations of this case study - namely: depreciation of equipment and trucks, fees, taxes, charges and employee benefits - would not make a significant difference in the comparison between the scenarios. This is because, if included, they would only be added to both scenarios, so that the final difference would remain virtually unchanged. As this work is not a feasibility study, it was not considered appropriate to detail such costs.

The case study presented in this article corroborates the authors of the researched bibliography, in the sense of considering other MSW treatments before the final disposal, as a sustainable strategy for municipal management, aiming at lower environmental impacts (Mersoni and Reichert 2017; Marchi 2015; Jacobi and Besen 2011; Wartchow et al 2011; Pandyaswargo and Premakumara 2014)."

The present work reinforces the recommendations of Mersoni and Reichert (2017) and Marchi (2015), by suggesting that managers take into account environmental and social factors when making decisions about the MSW management model to be implemented in the municipalities, and highlighting that the problem of waste does not seem to be solved by just disposing of it inexpensive landfills.

In this sense, it is emphasized that the technological simplicity of the proposed composting model for the case study in Paraíba do Sul (UFSC Method) contributes to success in the local context - which can be replicated in several small Brazilian cities. This idea was worked on both by Marchi (2015) when commenting on the abandonment of landfills due to lack of technical capacity and financial resources, and by Jacobi and Besen (2011), who highlight the need for commitment by city halls and the technological adequacy of management solutions of MSW.

Also in terms of the operating costs of the composting units, it is interesting to keep it simple, as in the proposed case study. Thus, Pandyaswargo and Premakumara (2014) and Wartchow et al (2011) reported, and the second study showed savings of 50% in the implementation and operation of simpler plants - which receive segregated material at the source (only compost) - to the detriment of the most complex - that receive heterogeneous waste (sorting and composting).

Regarding the selective collection of organic waste, it is interesting to note that every city has large generators, such as fairs and restaurants - establishments that can easily separate the materials for disposal, offering only organic to the selective collection. The case study presented contributes in this sense, offering a quantitative overview of the generation of OSW in a section of a small Brazilian
The work meets the studies of Gunaruwan and Gunasekara (2016), Wartchow et al (2011), Pandyaswargo and Premakumara (2014), and Siqueira and Abreu (2016) that indicate the receipt of segregated waste at the generating source, for efficiency and success of composting units.

Regarding the quantitative assessment (costs), it is recommended to carry out feasibility studies for the implementation and operation of yards or small composting plants, such as the MCY simulated in the case study. The success of similar alternatives seems to point to a favorable path (Gunaruwan and Gunasekara 2016; Pandyaswargo and Premakumara 2014), but this article did not aim to detail the costs, requiring a more complete and cautious study, which also includes the demand for organic compost in the region - to find out if the model is viable and profitable.

Despite this, it is worth mentioning two factors presented by Pandyaswargo and Premakumara (2014) that contribute to the possible success of the strategy adopted in the present case study (the MCY that serves only some neighborhoods in Paraíba do Sul). They are the scale of the unit and the transport. The authors concluded that the smaller the scale, the greater the control over the final quality of the compost - which increases its market value; in addition, they reported that transportation costs are very significant at larger plants.

**Conclusion**

This paper sought to offer subsidies to a complementary alternative to landfills, which was validated by sustainability indicators, with huge environmental gains: the composting of the MSW organic fraction. It was intended to highlight the importance of considering other solutions before the disposal of waste in landfills by the municipality.

The novelty of this work is in including the UFSC Method in a decentralized municipal compost yard for a city with less than 50,000 inhabitants, as well as validating the MSW management proposal by using part of the organic fraction by means of sustainability indicators. As landfill is an expensive and short-lived device (20 years on average), in these terms, composting may be a strategy to reduce the amount of landfill MSW. The use of this tool can be adopted as a sustainable development strategy for small municipalities, empowering the decision-making process.

It is noteworthy that this project was the first place in the third edition of the Good Environmental Practices Project Competition held by the Paraíba do Sul Middle Committee, in 2018. The contest was intended to disseminate and reward good ideas and successful initiatives. This action is part of the project bank of the CBH-MPS Project Office for possible replication in the municipalities of the Middle Paraíba do Sul basin. It is expected that alternatives such as this may be considered by municipal managers in the future.

This research also collaborated to demonstrate that the sustainable gains of the simulated scenario that contemplated composting were undeniable. Moreover, their costs were not as high as those of the scenario that disregarded such a solution, as common sense might suppose. This result underlies the
rationale for considering sustainable alternatives in MSW projects, even though there are few financial resources available.

It is understood that market adaptation to sustainable solid waste practices is still necessary in order to acquire the technical capacity to respond to new challenges in the sector. However, this factor cannot prevent the application of such practices in the municipalities - especially the small ones, which have much to gain by adopting sustainable development strategies.

There is a challenge to encourage municipalities to invest more and more in the selective collection and composting, thus reducing the amount of material to be sent to landfills and this work certainly sought to offer a new point of view in this regard.

Also, the relevance of composting for society at large is noteworthy in order to foster local and organic agriculture and to close the cycle of organic materials. Such materials would otherwise be sent to a landfill or dump where they would impact on the environment rather than benefit it. In addition to being valued through composting, they can also generate revenue from the sale of compost.

There is an urgent need for a more systemic understanding of the management of MSW in Brazilian cities. As highlighted by Pandyaswargo and Premakumara (2014), managers believe that they can be convinced they can change their strategies based on information about the socioenvironmental benefits of composting.

Thus, as an innovation, the proposal to use a low cost composting method, which uses passive aeration static windrows in a decentralized deployment model, being supplied only with waste previously segregated in large generating sources, is a means of achieving efficiency in the context of Brazilian cities up to 50,000 inhabitants who do not have an effective MSW management model.

However, this work has some difficulties in obtaining data on the subject of composting organic waste and on MSW. These data are not publicly disclosed and a special request and a delay in obtaining them are required.

Hence, more detailed evaluations on the management of composting yards are indicated as a future recommendation by comparing private models against the municipal management of this portion of MSW. Another indication for new works would be the investigation of the existence of demand for organic compost in the central region of Rio de Janeiro state, to evaluate the real possibility of local closure of the organic waste cycle.

**Abbreviations**

*BNPSW* - Brazilian National Policy on Solid Waste;

*MBSP* - Municipal Basic Sanitation Plan;
**Declarations**

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**Conflicts of interest/Competing interests**

The authors have no conflict of interest to declare.

**Availability of data and material**

The data used is available if requested when applicable.

**Code availability**

Not applicable

**Authors’ contributions**

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Alice Souza and Elaine Garrido Vazquez. The first draft of the manuscript was written by Alice Souza and Elaine Garrido Vazquez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Data availability:** Data will available upon reasonable request.

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Figures

Figure 1
Visual test to evaluate the performance of carrot and beet growth in an area without compost with synthetic fertilizer (on the left) and an area with the addition of organic compost (on the right). Source: Massukado, 2008, p.72.

**Figure 2**

Framework of comparative evaluation method

**Figure 3**

Composting windrows by UFSC Method, in Alto Paraíso city, Goiás state, Brazil (MMA2017)

**Figure 4**
Maps of the 3 regions chosen in the proposed neighborhood section, to define the mileage of the collection routes. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

**Figure 5**

Scenario 1 flowchart (Souza et al. 2020)

**Figure 6**

Scenario 2 flow chart (Souza et al. 2020)
Figure 7

Urban areas map of Paraíba do Sul, indicating the denser neighborhoods (Souza et al. 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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