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ECOSYSTEMS

Decentralized composting: gated communities as ecologically promising environments

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Abstract: The global need to strengthen circular economic chains highlights the importance of composting, since the organic fraction corresponds, on average, to 50% of the municipal solid waste. As centralized composting programs have been showing slow advances, especially in low and middle-income countries, the decentralized scale is a promising tool. Gated communities stand out as potential targets for decentralized composting programs, as they generally have organization, tools, employees, space, and a high density of gardens. This study detected, through online questionnaires sent to residents of gated communities, a high probability of adherence to composting programs in the condominium, predisposition for waste sorting, use of the compost, and participation in meetings to address the issue, in addition to a relevant potential for reducing the disposal of organic waste in landfills. On the other hand, the absence of leaders, lack of knowledge about community projects and fear of unpleasant odors and pests were evidenced. Among 106 respondents, residents of 25 condominiums, no variability was detected between positions of different genders, ages, and education. This diagnosis points out challenges and suggests alternatives to overcome them, based on successful experiences, focused on strengthening leadership, technical training, provision of equipment, improvements in communication and socio-environmental awareness.

Key words: Circular economy, composting, organic waste, recycling, urban solid waste, waste management.

INTRODUCTION

The global production of solid waste has increased significantly in recent decades due to factors such as population, urban and economic growth, globalization, changes in lifestyle, and consumption patterns (Minghua et al. 2009, Quested et al. 2013, Singh et al. 2014, Thyberg & Tonjes 2016). About a third of the food produced in the world becomes waste, totaling approximately 1.3 billion tons of food waste (FW) annually (FAO 2011). The unidirectional movement of biomass and nutrients from fields to cities threatens food security and favors the depletion of natural resources (FAO 2011). Often, especially in areas distant from urban centers, the high volume of municipal solid waste (MSW) generated is not collected, accumulating in inadequate spaces, causing flooding, pollution, and the spread of disease vectors (Li et al. 2011). The most immediate and least efficient way to collect this waste is to dispose of it in open-air areas ("dumpsites") or landfills (sanitary or not). Landfills are responsible for high releases of greenhouse gases (GHG) such as CO_2 and CH_4, the latter several times more potent for the greenhouse effect than the former (Myhre et al. 2013). Globally, landfills account for about 13% of total methane emission (Awasthi et al. 2019). The final disposal of FW in landfills is also harmful to the economy, as it wastes resources used

from production to consumption of products (FAO 2011). Populations close to landfills are often harmed, as these facilities can favor the proliferation of pathogens and emit unpleasant odors (Joshi & Visvanathan 2019). Heavy metal pollution is associated with the incorrect disposal of various products such as batteries, sprays, kitchen utensils, paints, electronic components, and various types of packaging (Koledzi et al. 2011). In addition, landfill capacity is increasingly saturated, especially in low and middle-income countries (LMIC), leading to the search for more distant locations for new landfills, increasing transportation costs and environmental impacts (Anwar et al. 2018, de Kraker et al. 2019).

Currently, several national and international laws, agreements, and guidelines pressure countries to divert FW from landfills and favor the circular economy (CE), such as the Sustainable Development Goals (SDGs) of the 2030 Agenda (UN 2015), the Kyoto Protocol, and the Paris Agreement, whose signatories are more likely to not direct FW to landfills to decrease GHG emissions (Joshi & Visvanathan 2019, Souza & Drumond 2022). Different types of treatment have been adopted alone or in aggregate, in centralized or decentralized scales, including recycling, aerobic and anaerobic digestion, and incineration, providing environmental, social, and economic advantages over the single landfill disposal model. In general, PBMR has also been adapting its public policies to these new trends, as is the case in Brazil, which enacted the Brazilian National Solid Waste Policy (NSWP), determining landfill disposal as the last alternative, to favor reduction, reuse, and recycling of solid waste (BRASIL 2010). However, LMIC commonly present the history of MSW management failure due to a lack of financial, institutional, and technical resources, and political will (Ogwueleka 2009). Recycling inorganics is common in several of these countries, mainly practiced by informal sectors (Rutkowski & Rutkowski 2017), while organics recycling is not widespread, although this fraction of residues corresponds, on average, to 53-56% of total MSW (Kaza et al. 2018). In Brazil, whose MSW growth between 2013 and 2014 was about 2%, generating 1.062 kg/hab. day (ABRELPE 2014) with 51.4% of this amount composed of organics (CEMPRE 2019), only 1.6% of organic waste was composted in 2008 (IPEA 2012).

Among the advantages of composting accompanied by the use of the generated compost opposite to landfills are reduction of waste biomasses (Sadef et al. 2016), waste stabilization, nutrients recovery, generation of jobs and alternative income (Asomani-Boateng 2007), increased environmental awareness, and community participation in waste management (Bruni et al. 2020), reduction of GHG emissions (about ten times) (Inácio et al. 2010) as a result of decreased volume deposited in landfills, carbon sequestration and the consequent mitigation of climate change (Asses et al. 2018, Mohammadi et al. 2017), increased lifetime of landfills, reduced emissions from mineral fertilizer production and peat extraction, increased carbon sequestration, and soil restoration (Anwar et al. 2018, Bong et al. 2016, Chia et al. 2020). In addition, FW compost can go through the pelletizing process, which increases its density, its storage capacity, and facilitates its transport and application by agricultural machines (Chew et al. 2018).

Historical records of centralized composting plants (large-scale, highly mechanized) built in recent decades and closed, discontinued or operating well below their potential accumulate in several countries, including China, India and Brazil, due to a combination of factors such as poor compost quality and its insufficient flow (Dou 2015, Handa et al. 2013), incipient development of the compost market, high transportation, initial and operational costs, and

inappropriate technologies (De Siqueira & Assad 2015, Yeo et al. 2020). It has been estimated that centralized units have a higher risk of bankruptcy than decentralized ones (De Siqueira & Assad 2015), and it has been found, in Brazil, that several municipalities (almost all of them) are financially unfeasible to establish a selective collection route for inorganic recyclables and another for organic ones (UFPE 2014). As a result, decentralized treatments stand out, operating on a small scale (in the home, neighborhood or community), occupying less space, being more adaptable and flexible, diverting waste that would be destined for centralized treatment, reducing public spending, taking place in the vicinity of where the waste is generated and the compost is used, requiring shorter transports (particularly relevant in the case of biomass, composed of about 80% water), with lower rates of expenditures, GHG emissions, road wear, traffic and noise (Arrigoni et al. 2018, Bortolotti et al. 2018, de Kraker et al. 2019, Lombardi et al. 2015, Nhubu et al. 2019). They also contribute to soil improvement through the use of compost, generally of better quality than that produced in centralized plants, due to more efficient separation and lower risk of contamination (Bruni et al. 2020). Decentralized treatments use simpler, cheaper, and more easily trained equipment and tools (Asomani-Boateng 2007) and generally favor manual labor over the use of machines, generating jobs for the low-skilled labor, that is surplus especially in LMIC (Pai et al. 2019). The prevalence of social technology over industrial technology and the proximity of the treatment plant to its users favor their mobilization, as they become aware of their own waste generation and tend to reduce this amount, in addition to paying more attention to the impacts involved (de Kraker et al. 2019, De Siqueira & Assad 2015). Decentralized composting can occur at the institutional, community, or household levels. The first is carried out in public or private institutions that treat their own waste, such as public agencies, hotels, restaurants, markets, associations, hospitals, prisons, and educational institutions. The second usually takes place in neighborhoods, public parks, villages, and condominiums, with local treatment of kitchen and garden waste and delivery of the final compost to the residents. Home composting ("backyard composting") takes place at the generating source and is recommended as an important waste management option by European Union policies due to advantages such as no need for waste transportation, provision of nutrients for home gardens, and encouragement of environmental awareness (Koerner et al. 2008).

Given the above scenario, decentralized composting is the first and most feasible step to improve MSW management in several LMIC cities. However, there are few examples of decentralized composting in these countries, especially at the community level, with the exception of some successful initiatives, such as in Bangladesh (Yedla 2012). In Brazil, reports of community composting were found in the scientific literature only in residential buildings in the municipalities of Sorocaba and Araras, both in São Paulo (De Siqueira & Assad 2015). This research investigates the potential of gated communities for carrying out community composting. Gated communities, also called condominiums of houses or condominiums of lots, are very common in several cities in LMIC. In general, they are surrounded by a fence or wall, and only authorized people are allowed to enter through specific places (entrance gates). In the condominium, common and exclusive parts coexist, with the lot being the exclusive property of the condominium owner. They usually house a significant portion of the middle and upper classes and, consequently, generate

significant amounts of organic waste. Since gated communities already have a collective organization, deliberative meetings, digital communication groups, collective financial management, own tools and employees, available common areas, a large proportional amount of gardens (individual and collective), among other factors, it is expected to find in these places favorable conditions for the implementation of decentralized composting systems of household organic waste and garden waste. Until this research was carried out, no studies were found in the scientific literature about the potential of gated communities to carry out decentralized composting.

This study evaluates the perception, interest, and predisposition of residents of gated communities in relation to the implementation of community composting of their own organic waste within the condominium. The generation and disposal of waste by residents are also investigated, as well as their demand for the use of fertilizer compost, in order to assess the possible benefits and challenges of the initiative. The general objective is to outline, in an unprecedented way, a diagnosis identifying strengths and threats to the implementation of community composting in gated communities to guide public and/or private projects aimed at these audiences, important collaborators for the improvement of MSW management.

MATERIALS AND METHODS

Case study

The study area corresponds to gated communities in the city of Lagoa Santa, Minas Gerais, Brazil, locally known for its high number of these communities. In 2021, a population of 66,744 people was estimated in the municipality (IBGE 2021), and by the time this research was carried out, 47 inhabited gated communities had been identified. There is no official disclosure of the number of residents of these condominiums, but an association formed by 26 of these condominiums discloses on its website that the associated condominiums inhabit more than 10,000 people (ACOLASA 2019).

An anonymous online questionnaire (Supplementary Material - Table SI), with a cover letter, informed consent form (ICF), and contacts of those responsible for the study was sent to residents of condominiums, being considered invalid those answered by non-residents of these places or by people under 18 years of age. The research was authorized by the Research Ethics Council (process number 40555620.1.0000.5149). In this questionnaire, respondents took a position regarding statements such as "If my gated community offered the option of collecting organic household waste for community composting, our family unit would join in and separate our waste", "Composting, when done according to technical guidelines, only generates benefits", "Composting generates bad odors and attracts unwanted animals", "I would exchange the compost that I buy for the compost produced in my community, as long as it is good quality", "Sorting organic waste at home is not worth the trouble", "It would be too expensive to prepare a place in the condominium for composting, collect the organic waste and manage the compost", "Composting would devalue my condominium", "We could get a counterpart from the municipal government, since the amount of waste sent to the landfill would be lower", and "I would participate in meetings to address the issue".

Data analysis

To estimate the per capita generation of organic waste per day in each family unit, respondents were asked how many people live with them and how much organic waste, on average, is

produced in the house, with response options ranging from 0 to 1 liter/day, 1 to 2, 2 to 3, 3 to 4, more than 4, and "I don't know". For each response interval the intermediate value was considered (0.5; 1.5; 2.5; 3.5, respectively), and for the three respondents who claimed to produce more than four liters per day, the value 4.5 was considered. Answers "I don't know" (n=22) were disregarded. The mentioned value was divided by the number of people in the house to estimate the daily per capita generation of organic waste in each family unit. To calculate the overall mean, the sum of the averages obtained for each family unit was divided by the number of family units. To convert the values in liters to kilograms, the density of 600 $kg.m^{-3}$ of organic waste was considered (Melo et al. 2009).

The opinions of the unit owners about the theme were obtained throughout 15 sentences, judged according to a 5-level Likert scale: totally disagree (TD), partially disagree (PD), do not know (NK), partially agree (PA) and totally agree (TA). The internal consistency of the questionnaire was measured by two Cronbach's alpha coefficients, one referring to the sentences favorable to decentralized composting and the other referring to the sentences adverse to decentralized composting, in front of which the respondents took a stand. Sentences that were not related to attitudes favorable or unfavorable to the activity, about which no coherence with the position demonstrated in the other sentences is expected, were disregarded to calculate the alpha coefficient (Table I). To calculate the

Table I. Degree of agreement with each sentence (%).

If my gated community offered the option of collecting organic household waste for community composting, our family unit would join in and separate our waste (Favorable 1)	92%
Composting, when done according to technical guidelines, only generates benefits (Favorable 2)	95%
I would exchange the compost that I buy for the compost produced in my community, as long as it is good quality (Favorable 3)	91%
Even if few neighbors join, it could be worthwhile (Favorable 4)	85%
I would accept the composter near my house if the technical guidelines were constantly followed (Favorable 5)	67%
I'm familiar with household waste composting programs among neighbors (Neutral 1)	47%
We could get a counterpart from the municipal government, since the amount of waste sent to the landfill would be lower (Neutral 2)	87%
I would participate in meeting to address the issue (Neutral 3)	82%
Generally speaking, my condominium neighbors get along well enough to deal with collective projects (Neutral 4)	51%
I consider chemical fertilizers more efficient than organic composts resulting from waste (Adverse 1)	20%
Compost generates bad odors and attracts unwanted animals (Adverse 2)	32%
Sorting organic waste at home is not worth the trouble (Adverse 3)	14%
It would be too expensive to prepare a place in the condo for composting, collect the organic waste and manage the compost (Adverse 4)	22%
I would not accept that in my condominium (Adverse 5)	10%
Composting would devalue my condominium (Adverse 6)	10%

degree of agreement with each sentence, the NK answers were discarded and the number of valid positions each sentence obtained was calculated. Values 0, 1, 2, and 3 were assigned to the types of positioning (TD, PD, PA, and TA, respectively). The maximum possible score for each sentence was the maximum value (3) multiplied by the number of valid positionings in the sentence. The sum of the values obtained in each sentence was divided by the maximum possible value for the sentence, obtaining the degree of agreement, with a minimum value equal to zero and a maximum value equal to one.

RESULTS

One hundred and six residents (69.8% female and 30.2% male) from 25 condominiums answered the questionnaire validly. Respondents were distributed among the age groups from 19 to 24 (13.2%), 25 to 34 (10.4%), 35 to 44 (25.5%), 45 to 54 (19.8%), 55 to 64 (26.4%) and 65 to 72 (4.7%), with high school (13.9%), undergraduate (68.4%) and graduate (17.7%) levels.

Of the 59 respondents (56%) who claimed to separate organic waste from others in their homes, 23 stated that the only destination for the organic waste they generate is the same as common waste, i.e., the landfill in the municipality of Sabará (Minas Gerais), to which solid waste of Lagoa Santa is destined. Although the majority (63%) destines their organic waste or part of it, to the landfill, about 34% destines at least part of it to some type of composting (Fig. 1). The average per capita of organic waste generated daily in family units whose organic waste is not exclusively destined to the landfill is very close to the average of family units whose organic waste is exclusively destined to the landfill (0.4429 and 0.4792 liters/person.day, respectively). The only respondent who stopped separating organic waste, whose practice was done, justified the interruption: "I lived in Switzerland and in the condominium, there was a composting system, I'm always in favor of reuse, I moved to Chile and my condominium does not offer it, I don't like to do it at home and when the condominium has the facility, it gets better!".

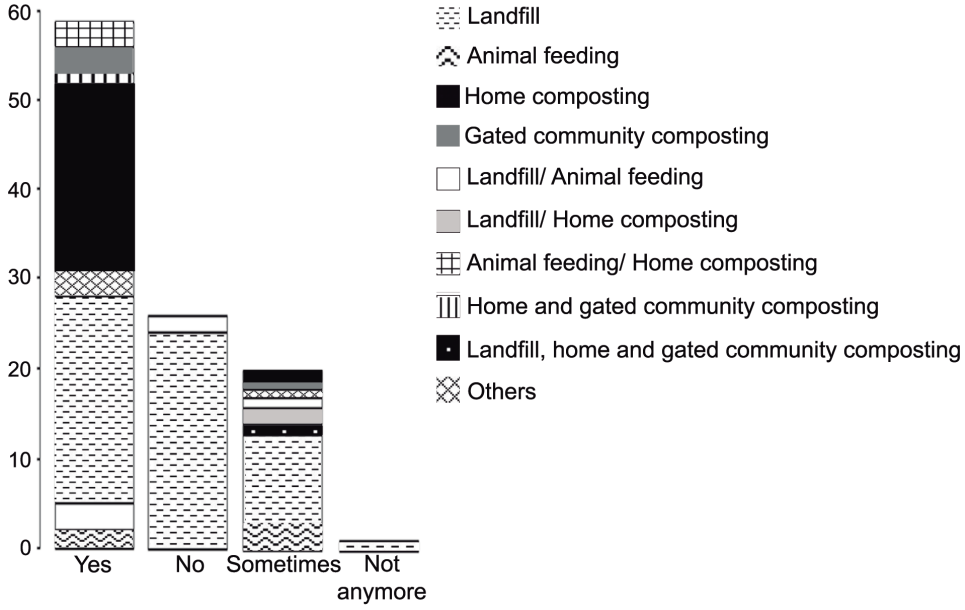

Figure 1. Answers to the questions: "Is the organic waste separated in your house?" (bars) and "What is the destination of the organic waste generated in your home?" (subdivisions of bars).

The answers regarding the presence or absence of organic reuse service within the condominium did not provide clear results, since either the number of respondents from the condominium was insufficient to give consistency to the answer or the answers referring to the same condominium were contradictory to each other, reaching up to 6 different answers within the same condominium. Sixty-three (59%) respondents stated that they buy compost, substrate, fertilizer and/or similar every year for their house. No consistent information was obtained in this regard concerning the condominium (87% of the people could not inform if and how much the condominium buys per year).

The consistency of the questionnaire concerning the opinion sentences was interpreted as substantial, considering the alpha coefficient values obtained (0.6718 for the group of sentences favorable to composting in the condominium and 0.6377 for the group of adverse sentences), the low number of favorable sentences (n=5) and the low number of adverse sentences (n=6). The positioning of the respondents (Fig. 2) revealed a high probability of adherence to the organic waste composting program in the condominium itself, as well as the observation of the degree of agreement with the favorable and adverse sentences regarding the activity (Table I). The data obtained, when compared between different genders, age groups, education levels, and the number of residents in the family unit, revealed the absence of any substantial variability that would require the application of a formal statistical test. The space available after the questions, in which respondents could leave additional comments if they wish to, was used by 37 people (35%), whose comments were grouped into the categories "Need for rapid implementation of the activity" (4), "High agreement (expressed in the sentence or opinions in the questionnaire) accompanied by reservations regarding collective acceptance" (9), "High agreement (expressed in the opinions in the questionnaire) accompanied by reservations about the functionality of the activity" (4), "High agreement accompanied by

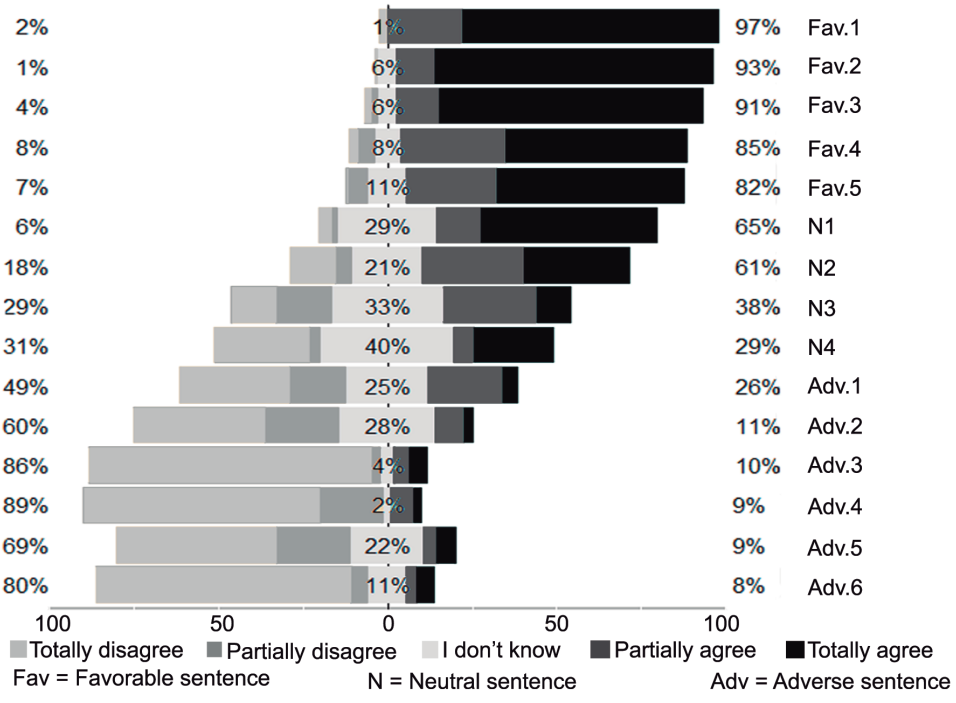

Figure 2. Positions before the 15 opinion sentences (5 sentences favorable to composting in the condominium, 4 neutral and 6 adverse).

the provision of help" (1), "Exclusively favorable notes" (11), "Appointment simultaneously favorable and unfavorable" (1), and "Others" (7) (Table SII).

DISCUSSION

The results obtained point to the high potential of gated communities to carry out community composting programs of organic waste generated within their private (food waste and yard waste generated by residents) and public (generally yard waste) areas. Given the characteristics commonly observed in this type of condominiums, such as collective organization, deliberative meetings, digital communication groups, collective financial management, own tools and employees, common areas available, and proportionally large amount of gardens (individuals and collective), it was already expected to find, among the unit owners, high potential for adherence and prevalence of favorable attitudes in face of the activity. The main findings that supported the hypothesis were the high agreement rate with the favorable sentences regarding community composting in the condominium (average greater than 85%) and the low agreement rates regarding adverse sentences (average below 20%). The high proportion of unit owners that already dispose of some part of their organic waste to some type of composting (34%) is in line with the perception that this is a public inclined to welcome decentralized composting, probably due to the structural factors that life in a gated community provides, such as availability of space for gardening, raising small animals and the possibility of maintaining a composting system away from the house.

Although a significant portion of residents already carry out some type of composting, 44% of residents do not even separate organic from non-organic waste, even though the municipality performs an efficient service for collecting and sending dry waste for recycling. Regarding this lack of waste separation, pointing out limited environmental awareness as the cause is a very generalist approach, which may not lead to concrete results, since each segment of the population has its own demands, questions and views. Successful interventions aimed at improving citizen participation in MSW management commonly segment their audience and seek to understand, in a particular case, what leads to the maintenance or abandonment of certain habits (Sewak et al. 2021). In the case in question, a series of possible causes to be investigated and attacked in MSW management improvement programs can be pointed out. Perhaps a large portion of residents do not separate their types of waste due to lack of knowledge about the quality of the public service offered, as demonstrated in a previous study in which it was observed that the population, especially those with higher incomes, are more prone to segregate when they trust that the waste will not be mixed afterwards (Kala & Bolia 2020). In this case, it is necessary not only for the public service to be efficient, but also for its results to be communicated to citizens. It is also possible that residents are unaware of the socioeconomic importance of the inclusive popular recycling chain, which includes the service in question, carried out through a partnership between the municipal public authorities and the association of recyclable waste pickers in the city, generating jobs and income for citizens of less favored classes (ANCAT 2022). In addition, the attitude of these residents may reflect a limited view that MSW management is the exclusive responsibility of the public authorities, as observed in a study carried out by Kala & Bolia (2020), thus indicating

the need for efforts to train and sensitize citizens to participate in MSW management.

The rate of adherence to voluntary separation of organic waste (92%) and the recognition of the benefits of composting (95%) are close to data obtained in similar studies, such as a survey carried out among residents of a (non-gated) neighborhood of Diadema (São Paulo, Brazil), in which the rates obtained in these items were 84.4% and 88.9, respectively (Yates & Gutberlet 2011), and another carried out in Dakha (Bangladesh), which observed more than 80% of respondents interested in contributing to community composting (Yedla 2012). One of the factors, perhaps the main one, to which it is possible to attribute responsibility for the discrepancy between the high potential for adherence and the absence of such a program in place is the lack of leadership that drives the initiative, identified as a key factor for the success of several programs (Asomani-Boateng 2007, Yedla 2012). This hypothesis is endorsed by the result obtained, which reveals that there is no consensus, among residents of the same condominium, regarding the presence or absence of organic reuse service within the condominium. Even if one or a few residents lead the initiative, if they are not recognized as leaders by the collective and do not broadly communicate their actions, the project will hardly reach greater scope and duration. The results lead to the perception that it is necessary to strengthen potential leaders with technical support and training in the management of community projects, in addition to investing in communicating project actions among current and potential participants. Successful initiatives aimed at encouraging the separation and composting of domestic waste, analyzed by Sewak et al. (2021), used communication strategies such as public meetings, door-stepping, print and digital media. Another known effective way to encourage participation in community composting projects is to make utensils available for each family unit, such as waste-sorting equipment (Sewak et al. 2021). These strategies should be implemented along with environmental awareness campaigns aimed at improving MSW management and effective practice of composting. The fact that 23 respondents, out of 59 who claimed to separate their organic waste, state that all the organic waste they generate is sent to the same destination as the non-biodegradables, is an indication that it is not clear what is meant by "sorting waste at source", because if, after separation, the different residues go together to the same destination, there is no actual separation, at least not the separation to optimize reuse. The separation of waste at source is a basic requirement for the success of composting and the quality of the compost produced, so that confusion about this concept intensifies the need to promote environmental education.

In general, it is expected that family units that somehow reuse the organic waste they generate will show lower per capita generation, as a result of the reduction in wastefulness, promoted by the environmental awareness that usually accompanies the reuse action. However, the averages of waste generation per individual were similar between families that practice some reuse and families that do not. It is possible that the reuse performed is not accompanied by greater awareness or that a large part of the volume of organic waste generated by these residents is composed of gardening waste and, therefore, does not mean wastefulness.

The results indicate that community composting in gated communities would not face difficulties that facilities with the same purpose face in other contexts. The high agreement on sorting organic waste at source (92%) and

replacing purchased fertilizer (or similar) with compost produced in the condominium (91%), as well as the high proportion of unit owners who buy fertilizer every year (59%), demonstrate that common problems such as lack of sorting at source and low demand for the generated compost (Ng et al. 2017, Weidner et al. 2020) would not exist or be easily circumvented. Approximately 100 kg of organic waste generates 30 to 40 kg of compost (WWF-Brazil 2015), whose quality is closely associated with its maturity and stability (Chia et al. 2020). The replacement of purchased fertilizer with generated compost is in line with environmental benefits, as composting also generates GHGs, albeit in a smaller volume than landfills, and this substitution is important for the environmentally favorable final balance (Bernstad & Jansen 2011). Furthermore, the use of compost improves composting performance due to its ability to qualify soil physicochemical properties, increase its aeration, biodiversity, water retention, and carbon storage (Bortolotti et al. 2018).

Obtaining carbon-rich material to be added to food waste, which is a common limitation in several community composting facilities (de Kraker et al. 2019), would not be a problem in gated communities, due to the high proportion of green areas in these condominiums. The need for supervision and availability of employees for the activity, essential for its perpetuation (De Siqueira & Assad 2015), can be easily met by mobilized unit owners and employees already providing services to the condominium, since the activity does not require much time of dedication. The demand for land and space, a limiting factor in several community composting experiences, would also not be a problem for condominiums, which, in general, have a high proportion of collective spaces and gardens. Consciously or not, residents of gated communities realize that these challenges commonly faced in community composting initiatives would not become obstacles for them, since in none of the questionnaires were any of these factors mentioned as possible difficulties.

The lower population density of gated communities, compared to other urban areas, configures another advantage for community composting in these condominiums, especially in the extensive model, which requires more space, less technology, lower costs, and greater simplification of labor. Such suitability is due not only to the availability of space for the practice of extensive techniques, but also to the smaller number of people to share the costs. A similar suggestion was already made in a study carried out in Porto (Portugal), which advocated the implementation of anaerobic digestion in densely populated urban areas and composting in more remote and less dense neighborhoods (Weidner et al. 2020). In addition to the advantages presented, in tropical countries, composting is facilitated by the absence of very low temperatures.

Fear of emission of unpleasant odors and attraction of unwanted animals was identified as the main reason for resistance and distrust in relation to composting. Awareness-raising efforts should be directed towards these aspects, which can be circumvented with proper technical care, such as monitoring moisture, pH, temperature, oxygenation, residue size, and carbon to nitrogen ratio (Weidner et al. 2020, Wu et al. 2014). Moisture and oxygenation can be controlled by adding easily obtainable bulking agents such as dried leaves, sawdust, and wood shavings (Waqas et al. 2018). The addition of microbial inoculum can also significantly reduce unpleasant odor, as well as reduce the composting duration, reach higher temperatures, and even improve the compost (Rudnik 2019). The choice of method should be made with expert assistance and consideration of each

condominium's characteristics, such as number of adherents, amount of compostable waste, availability of space, tools, staff, and investment. Previous studies (Sewak et al. 2021) point out that there is a greater tendency for success in the initiative when decisions are made in a participatory way, and not just by a technician and/or a representative of the group. The results obtained point to a probable significant participation of residents in decision-making (82% agreement with the statement "I would participate in meetings to address the issue"), endorsing the hypothesis of a high potential for success in the implementation of community composting in gated communities.

As a parameter, it is possible to mention some methods to be considered for gated communities: manually turned windrows, with protection against rain and medium and large animals, static windrows with a semi-permeable cover that protects against rain, animals, and odor emission, static or rotating composting drums, and extensive vermicomposting (Ng et al. 2017), whose decomposition based on the activity of earthworms, such as *Eisenia fetida* and *Eisenia andrei*, emits even fewer GHGs than composting (Bortolotti et al. 2018). More details and possibilities of decentralized composting methods can be found in Souza & Drumond (2022).

There are systems of community composting in which separated biodegradables are collected from each household, systems in which a person from the family unit takes the waste to the composting site, and intermediate systems, in which residents take their waste to a deposit from where it will later be taken by responsible staff to the composter. In general, the former system provides greater adherence and the latter, implemented in several countries such as Austria, Switzerland, Germany, the United Kingdom, Belgium, and the Netherlands (Sakarika et al. 2019), requires that the deposit be very well managed, otherwise it can create health and environmental risks (Asomani-Boateng 2007). There are examples of success both when the management is done by the generators themselves (Lehec 2020), and when done by employees. In all cases, sorting of waste at source and complete maturation of the compost is essential for success. It is ideal for each gated community to choose, in a participatory manner, the collection model that seems most appropriate to the reality of its residents.

Although the average organic waste generation obtained (0.2774 kg/inhab.day) is lower than the national average in 2014 (0.5458 kg/inhab.day), the value is still high, considering the total annual generation, the harmful consequences of the disposal of this waste to landfills and the depletion of mineral fertilizer sources (De Siqueira & Assad 2015). Moreover, people are not expected to observe precisely how much waste they generate, especially when a waste treatment process is not closely monitored, so that the average value obtained is prone to error. On the one hand, people tend to reduce waste when they become aware of the amount of waste they generate, and on the other hand, they tend to increase their waste, especially food waste, when products are characterized by low price and high accessibility (Shahnoushi et al. 2013) and consumers, due to lack of awareness, over-prepare and lack information about packaging and shelf life (Schanes et al. 2018).

Successful decentralized units, acting alone or in networks, are often initiated by citizens or NGOs, some supported by international donations (Bhave & Kulkarni 2019), and are dependent on the persistence of a person or group directing efforts for their continuation (Yedla 2012). Community composting initiatives

in LMIC can be inspired by experiences such as those reported in buildings in Mumbai (India) through vermicomposting systems and perforated drums (Iyer 2016) and the non-mechanized windrow community composting in Dakha (Bangladesh) driven by the NGO Waste Concern (Yedla 2012).

Public support, scarce in LMIC, can be decisive for the success of several initiatives, whether financial (particularly relevant in more vulnerable communities), technical, or educational (Asomani-Boateng 2007, Bruni et al. 2020). Considering that the degree of agreement with the statement "It would be too expensive to prepare a place in the condo for composting, collect the organic waste and manage the compost" was only 22%, it is clear that the last two types of support (technical and educational) are more necessary for the implementation of community composting among residents of gated communities, who generally belong to the middle and upper classes. Different public policies have proven to be effective and can serve as models: the municipal composting program in Paris provides equipment (composters, collection buckets, and mixers) and technical support, which includes feasibility study, training, monitoring, and visits (Lehec 2020); New York City provides technical assistance to stakeholders and promotes community composting groups; the City of Washington provides subsidized backyard composting units; the City of Urbana provides training workshops on home composting (Pai et al. 2019).

Community composting simultaneously promotes environmental awareness, social cohesion, shared responsibility for waste management, and environmental benefits over landfill disposal. This social-ecological sustainability mitigates local problems and favors the fulfillment of international commitments and goals. Specifically, in LMIC, the activity is well suited, among the organic treatment options alternatives to landfill, to the context in which they operate: a high proportion of organic waste and poverty, strong presence of the informal sector in the economy, a surplus of non-specialized labor, and low capital and political will for greater investments in waste treatment.

This work faces limitations regarding the representativeness of the population of residents of gated communities in Lagoa Santa since the sample is restricted to unit owners who, by some virtual means, received the questionnaire, were predisposed to answer it and presented some previous informatics knowledge that enabled their participation. For further research and the implementation of a community composting program in a specific gated community, it is necessary to evaluate the local characteristics. It is also necessary to investigate the subject among residents of other types of condominiums, such as buildings, since responses were received (and disregarded in this research) from residents of these other types of condominiums, who were interested and even made their contact available for future conversations.

Notwithstanding these limitations, it is noteworthy that until the moment this study was carried out, no research specifically on the performance of community composting in gated communities was found in the scientific literature, and that several observations obtained are important for carrying out future research and project development. It is concluded that gated communities present factors favorable to the implementation of community composting, such as predisposition and interest of residents, availability to participate in meetings to address the issue, demand for organic compost, ease of obtaining material rich in carbon to be mixed

with organic waste, ease of obtaining labor for the system maintenance and space availability. On the other hand, the success of the project depends on the mitigation of complicating factors:

- most condominium members are in favor of the practice, but do not take the initiative to carry it out;
- almost half of the residents do not even separate dry waste, whose selective collection and recycling service is provided by the public authorities;
- there is a notable lack of knowledge, on the part of the residents themselves, about the services offered within the condominium;
- about a third of residents are afraid of the emission of unpleasant odors and attraction of undesirable animals resulting from the practice of composting;
- there is a lack of residents with the technical capacity and collective recognition to lead the initiative.

Faced with the observed challenges, it is suggested to those interested in the implementation of decentralized composting in gated communities:

- carrying out a diagnosis for each condominium, in order to elucidate local strengths and challenges for the practice, in addition to quantifying the amount to be composted and identifying the appropriate methods;
- use of participatory methodologies that involve residents in decision-making processes;
- strengthening of potential leaders with technical support and training in the management of community projects;
- supply of equipment, technical support and monitoring throughout the entire process;
- strengthening of internal communication of existing projects and elaboration of a communication plan in future projects, for sharing information between current and potential participants;
- improvement of communication between public authorities and citizens regarding MSW management, so that individuals understand the destination of their waste, what their responsibilities are in this management, and, in case the selective collection and recycling service is carried out by organizations of recyclable waste pickers, what is the socioeconomic importance of home separation of waste;
- carrying out environmental education programs and information on the practice of composting, through partnerships between organized civil society and public bodies linked to the environment, education, health and social development;
- utilization of public spaces such as squares, gardens, parks, and schools for the practice of decentralized composting, managed directly or indirectly by the public authorities, so that besides the benefit of composting itself in these places, they would serve as examples, incentives, and guidance to stakeholders.

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SUPPLEMENTARY MATERIAL

Tables SI, SII.

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