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Scientific Paper

Barriers to the implementation of reverse logistics for organic solid waste in the Amazon: A study in a city in the metropolitan region of Belém

Barreiras à implementação da logística reversa de resíduos sólidos orgânicos na Amazônia: um estudo em cidade da região metropolitana de Belém, Pará

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ABSTRACT

The reverse logistics of organic solid waste (OSW) aim to return these to the economy, seeking the recovery of organic matter and reintroduction into other productive cycles, aiming for an ecologically correct outcome. However, to achieve such results, barriers between the involved stakeholders must be overcome. In this context, this study aims to answer the following research question: What is the relative importance of barriers to the implementation of OSW reverse logistics for individual waste generators in a given territory? Therefore, the objective of this research is to verify if the barriers related to the implementation of reverse logistics of OSW for the generator stakeholder (individuals), identified in the literature, are confirmed for the reality of the city of Castanhal, Pará, as well as to rank them according to their determination for the topic using the TOPSIS tool. To do so, a survey of seven barriers in the literature was conducted, followed by a survey to confirm which barriers found in the literature are reinforced for individual waste generators in Castanhal, Pará. The results indicate that for individual waste generators, only the barrier related to the difficulty in waste separation was validated in the context of the city of Castanhal, Pará. In contrast, the affirmation regarding this barrier ranked ninth in the ranking generated from the TOPSIS method. The contributions of this study are practical and theoretical, as it reinforces the existence and importance of the tested barriers empirically, adding to the collection of studies in the area and expanding discussions on the topic. In the practical field, it validates and ranks the barriers to OSW reverse logistics, assisting in identifying difficulties and opportunities for improvement, both for public and private managers.

Keywords: reverse logistics; barriers; stakeholders; organic solid waste; sustainability.

RESUMO

A logística reversa dos resíduos sólidos orgânicos (RSO) objetiva o retorno destes para a economia, visando à recuperação e à reintrodução da matéria orgânica em outros ciclos produtivos, almejando um resultado ecologicamente correto. No entanto, para obter tais resultados, devem-se superar as barreiras entre os atores envolvidos (*stakeholders*). Assim, o objetivo desta pesquisa é comprovar se as barreiras relacionadas à implantação da logística reversa de RSO para o *stakeholder* gerador (pessoa física) levantadas na literatura se confirmam para a realidade da cidade de Castanhal, Pará, bem como ranqueá-las de acordo com sua determinância para o tema utilizando o método TOPSIS. Para tanto, foram realizados um levantamento na literatura de sete barreiras e na sequência uma *survey* para confirmar quais barreiras encontradas na literatura são reforçadas para os geradores pessoa física em Castanhal. Os resultados apontam que para os geradores pessoa física apenas a barreira que trata da dificuldade na separação dos resíduos foi validada para o contexto da cidade de Castanhal. Em contrapartida, a afirmativa referente a essa barreira ficou em nono lugar no *ranking* gerado por meio do método TOPSIS. As contribuições deste estudo são práticas e teóricas, pois para a teoria reforça a existência e importância das barreiras testadas de forma empírica, acrescentando ao acervo de estudos na área e ampliando as discussões sobre o tema. Já no campo prático, valida e ranqueia as barreiras à logística reversa de RSO, auxiliando na identificação de dificuldades e oportunidades de melhoria tanto para gestores públicos quanto privados.

Palavras-chave: logística reversa; barreiras; *stakeholders*; resíduos sólidos orgânicos; sustentabilidade.

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INTRODUCTION

The increasing quantity of products with shorter life cycles and the variety of models that have intensified in recent decades require logistic planning for the return of a portion of these products, justified by the interest in their reuse and end-of-life management (Leite, 2017). Solid waste management (SWM) is the most challenging environmental issue in developing countries (Mushtaq; Dar; Ahsan, 2020), where the problems faced are greater due to the disproportionate increase in municipal solid waste (MSW) generation, especially in the context of increased urbanization, population growth, and economic globalization as in BRICS countries (Gonçalves *et al.*, 2018), posing a challenge for sustainable city management. Achieving zero greenhouse gas (GHG) emissions by 2050 requires a shift in resource management, and the use of organic waste is currently an untapped opportunity in Latin America (Ludlow *et al.*, 2021). SWM is a revolutionary issue that requires more informed decision-making by authorities and experts from various perspectives (Behrooznia; Sharifi; Hosseinzadeh-Bandbafha, 2020). Perteghella *et al.* (2020) emphasized that waste management tools are rarely applied in developing countries due to a lack of data and difficulties in interpretation. Huang, Liu and Dhar (2022) pointed out that limited research in a given territory is a barrier to advancing SWM. Additionally, the incorporation of stakeholders in most decision-making tools and processes and the availability of reliable data in developing countries are often limited (Perteghella *et al.*, 2020).

It is estimated that MSW generation will increase worldwide, from 2 billion tons/year in 2016 to 3.4 billion tons in 2050, with the majority of this increase observed in low-income countries, where generation is expected to triple (Abrelpe, 2022). Organic solid waste (OSW) in urban areas represents a significant environmental challenge due to the volume generated and its improper disposal, resulting in methane emissions into the atmosphere and the spread of disease vectors, as well as the generation of odors and leachate (Albuquerque Neto, 2007). From a sustainable perspective, OSW should be efficiently reused in the economic and productive cycle (Bhat; Singh; Vig, 2017), serving as an urban resource that, when combined, can generate revenue for municipalities or private companies, thus improving social well-being and promoting sustainable development (Hartmann, 2018). In this way, it can contribute to the circular economy by allowing waste to be used as resources in other economic activities in the form of a reverse supply chain of waste, involving all entities in the flow of discarded products aiming to recover and/or dispose of them properly (Van Engeland *et al.*, 2020).

Reverse logistics (RL) enables the structuring and functioning of the reverse channel, as it encompasses a set of actions, procedures, and means capable of enabling the collection and return of solid waste to the productive sector or environmentally sound final disposal (Brasil, 2010). The idea is to build a product life cycle that does not end after consumption but undergoes reuse or proper disposal (Silva; Cardoso, 2021). Within a reverse channel, some stakeholders are individuals or organizations that may have some interest in the organization's actions (Freeman, 2010) and who share responsibilities (Brasil, 2010). This shared responsibility covers the holders of public services for SWM and waste generators (Brasil, 2010), who have legal responsibility from the production of a product to its consumption (Machado, 2012). Therefore, effective management of these stakeholders in RL is crucial to ensure the efficiency of the reverse channel. Urban residents, responsible for waste production and consumption, are one of the stakeholders in the OSW reverse channel, referred to as individual generators (Nagata *et al.*, 2022).

In Brazil, for waste such as plastic, metal, glass, and paper, there is minimal awareness of environmental, social, and economic issues (Abrelpe, 2016). On the contrary, millions of tons of OSW are disposed of daily in landfills, where it is estimated that 62.5 million tons of MSW are disposed of and only 1.12 million tons are recovered (Brasil, 2022). For the OSW reverse channel, the process also aims at its recovery, with composting and anaerobic digestion (with or without energy conversion) being the most recommended technologies worldwide for recycling these wastes (ESA, 2014). Composting results in organic fertilizer that can be used to improve soil characteristics without harming the environment and brings advantages such as reducing solid waste disposed of in landfills, utilizing produced organic matter, and recycling soil nutrients (Macêdo, 2006). Anaerobic digestion has the advantage of producing biogas that can be used as a source of renewable energy and in digestate (a nutrient-rich biofertilizer), which can reduce the volume of organic waste as well as soil and water pollution (Carvalho; Chaudon, 2018). Despite the existence of ways to recover OSW, millions of tons are wasted, with no opportunity to return to the productive cycle in low-income territories like Brazil.

The existence of barriers preventing this reuse and linked to the reverse logistics of these OSW are identified in the literature. The quality separation of OSW at the source is a key factor in its management, as it conditions the subsequent stages of collection and recycling (Thi; Kumar; Lin, 2015). The management of OSW separated at the source is one of the most effective mechanisms to reduce the entry of biodegradable material into landfills (Espanha, 2014; ECN, 2016) and constitutes a barrier for certain territories. Reusing OSW for energy generation is one way to bring this waste back into the production cycle, but there are challenges and prospects for bioenergy production from OSW (Uddin *et al.*, 2021). Therefore, we pose the following research question: What is the relative importance of barriers to implementing OSW RL for the individual generator in a given territory? Thus, the objective of this research is to verify if the barriers related to the implementation of OSW RL for the individual generator stakeholder, identified in the literature, are confirmed for the reality of the city of Castanhal, Pará, as well as to rank them according to their determinacy, using the TOPSIS multicriteria analysis tool.

METHODOLOGICAL PROCEDURES

The present research followed four main stages:

- literature review;
- planning and data collection;
- data treatment and analysis, including the ranking of barriers and the use of TOPSIS;
- discussion of results.

In the first stage, a systematic literature review was developed following the PRISMA method recommendations (Galvão; Pansani; Harrad, 2015). The research steps are described as follows.

Identification

Searches were carried out in the Scopus and WOS databases up to July 2023. These databases were chosen as two of the most important existing databases (Wang; Waltman, 2016). The following search terms were used: "municipal solid waste," "urban solid waste," "barrier," "limitation," "challenge," "wet waste," and "organic waste." The search returned 194 and 180 articles in the WOS and Scopus databases. The following inclusion and exclusion criteria were applied in these results: works must be in English or Portuguese and must have been published until 2023, excluding conference articles and duplicates. As a result, 220 articles were obtained.

Selection

In the second stage, the titles and abstracts of the articles collected in the first stage were read, classifying them as follows: irrelevant, did not meet the research criteria (English works on RL for OSW); low relevance, presented points related to RL but not focused on the OSW research; medium relevance, presented minimal points related to RL of OSW but not related to its implementation barriers; and high relevance, presented both points highlighted for the research focus. Articles of low and no relevance were excluded from the base, leaving those of medium and high relevance, totaling 123 articles.

Eligibility

The 123 articles from the selection stage were read in full. In this step, 55 articles were excluded because they were not accessible or the article did not address the theme of this study, resulting in 68 articles for the next stage.

Inclusion

In this stage, full-text reading of the articles was conducted, and the extracted data were organized in Excel spreadsheets to answer the following questions: what are the bibliographic data?; what is the research objective(s)?; what is the research methodology?; what are the research result(s)?; what barrier(s) were identified in the research?; and what is the method(s) for recovering organic waste?

Next, the barriers found were identified and classified by stakeholder groups involved in the OSW RL. However, for this research, the focus is on the individual waste generator stakeholder. Finally, a literature review was conducted for the barriers to OSW RL identified for individual waste generators, encompassing 21/68 articles contained in the final database, according to Table 1.

For the second stage, planning and data collection were carried out. Google Forms was used to create the data collection instrument, containing statements regarding barriers to OSW RL, specifically applied to the population (waste generator stakeholders) of Castanhal, Pará.

To determine the sample size, the calculation for finite populations (Maravelakis, 2019) was used based on IBGE data (2022), assuming a desired confidence interval of 95% and a tolerable sample error margin of 7%.

The survey consisted of two sections: the first section for respondent characterization, seeking information on the neighborhood, frequency of handling OSW at home, duration of domestic OSW handling, duration of domestic OSW recovery, age, education, and income. The second section presented statements regarding the seven barriers identified in the literature. These were assigned a scale of 0–10, where 1 = not part of my actions in this context and 10 = part of my actions in this context. The electronic form was disseminated through local media coverage, social media, and posters placed on university and school campuses in the municipality.

In the third stage, data treatment and analysis were performed, including the ranking of these barriers using the TOPSIS tool. Microsoft Excel spreadsheets were used for data analysis and table generation. The methodological procedure for using the TOPSIS tool, as described below, was based on the considerations of Singh *et al.* (2016).

Step 1: Initially, matrix D was structured with the elements xij, where i represents an alternative, and j represents a criterion for analysis. In the context of the application proposed in this study, the alternatives (i) were characterized by the statements derived from the seven barriers identified in the literature review. Regarding the criterion, the respondents' experience time with OSW RL was considered, as it was deemed relevant for the research results. It was divided into three analysis groups with the following characteristics and weights: 0–5 years of experience with a weight of 20%; between 5 and 10 years of experience with a weight of 30%; and above 10 years of experience with a weight of 50%. For this analysis, a matrix was created from the responses obtained in the questionnaire presented to the respondents, which is the result of the average data in each of the alternatives according to their group.

Step 2: Next, matrix D is normalized, and the coefficients rij are calculated using Equation 1.

Step 3: From the calculated coefficients rij, these were weighted with the pre-established and aforementioned weights.

Thus, the values of Vij (Equation 2) were calculated, which will compose the following matrix, called matrix V (Table 2).

Step 4: From matrix V, the positive ideal solution (vj+) and the negative ideal solution (vj–) were calculated. With such data in hand, the calculation of

Table 1 – Barriers to organic solid waste reverse logistics (OSW RL) regarding the individual stakeholder generator.

Barriers	References
B1—Heterogeneous composition (mixture) of waste that hinders reuse/recovery	(Cerda *et al.*, 2018; Gonçalves *et al.*, 2018; Behrooznia; Sharifi; Hosseinzadeh-Bandbafha, 2020; Xiao *et al.*, 2020; Dell'Orto; Trois, 2022)
B2—Difficulty in separating waste to obtain good quality reuse mass	(Lohri *et al.*, 2017; Wei *et al.*, 2017; Pour; Webley; Cook, 2018; Perteghella *et al.*, 2020; Xiao *et al.*, 2020; Daskal *et al.*, 2022)
B3—Aversion to the recovery of organic waste	(Pan *et al.*, 2015; Pour; Webley; Cook, 2018; Naz *et al.*, 2020; Daskal *et al.*, 2022; Carmen-Niño *et al.*, 2023)
B4—Social acceptance for the recovery of organic waste	(Pan *et al.*, 2015; Uddin *et al.*, 2021)
B5—Understanding of biological processes for waste recovery	(Lohri *et al.*, 2017; Naz *et al.*, 2020)
B6—Limited technical knowledge of waste identification and separation	(Laner *et al.*, 2015; Pan *et al.*, 2015; Shen *et al.*, 2015; Gonçalves *et al.*, 2018; Kazuva; Zhang, 2019; Lunag *et al.*, 2021; Carmen-Niño *et al.*, 2023)
B7—Lack of measures to incentivize waste recovery by stakeholders	(Siqueira; Assad, 2015; Hettiarachchi; Meegoda; Ryu, 2018; Kazuva; Zhang, 2019; Behrooznia; Sharifi; Hosseinzadeh-Bandbafha, 2020; Khamkeo, 2021)

Source: Developed by the authors based on the literature.

the positive and negative Euclidean distance for each of the alternatives that make up the analysis begins. These calculations are made from Equations 3 and 4 (Table 2).

Step 5: With the values of the positive and negative Euclidean distances for each alternative, the indicator Ci* is calculated. The higher the values of Ci*, the better the results. These values range from 0 to 1. Equation 5 (Table 2) shows how this indicator is calculated.

Step 6: Finally, the alternatives of the analysis were ordered according to the values of Ci* that were calculated, creating a ranking of the alternatives according to their degree of importance. Thus, information was obtained on which barriers are most important regarding the difficulty in implementing OSW RL in the city of Castanhal, Pará.

RESULTS AND DISCUSSION

Descriptive analysis of the data

The object of this research refers to the city of Castanhal, Pará, with a territorial area of approximately 1,029.300 km² and a population of 192,256 inhabitants (IBGE, 2022), the most populous municipality in the northeastern region of Pará and the third most populous in the Metropolitan Region of Belém (MRB). In relation to SWM in the municipality, the disposal takes place at the Pantanal landfill, where the total volume in 2019 was 80,000 tons. Selective collection of 50 tons is carried out by cooperatives of waste pickers (Brasil, 2020). The Pantanal landfill is considered a 1/11 environmental liability in the state of Pará, categorized as inadequate final disposal. It has a potential for waste reuse estimated at 235.96 tons per day (Brasil, 2020). The municipal department responsible for household waste collection and public cleaning is the Municipal Works Secretariat (Prefeitura de Castanhal, 2014). This research, as it deals with urban SWM, is related to the Sustainable Development Goals (SDGs) 11—Sustainable Cities and Communities (target 11.6—municipal waste management) and 12—Responsible Consumption and Production (targets 12.2, 12.4, and 12.5—environmentally sound management and waste generation reduction).

From the survey conducted among individual waste generators, 196 valid responses were obtained from October 2–30, 2023. The sample's heterogeneity, when analyzing the neighborhoods where the respondents reside, showed a 100% participation rate, considering the 28 neighborhoods listed on the Castanhal City Hall website.

Regarding the age range of the respondents, there was mainly participation in the age group between 18 and 35 years, with 152 responses. The sample's heterogeneity regarding the participating age groups, when compared to the population data of Castanhal (IBGE, 2022), was very low, only approaching the data for the age groups between 36 and 60 years with 33 responses (16.84%). This result reflects the audience of students and young people who volunteered to participate in the survey, whose chosen locations, for convenience, for application were university campuses and sports courts in Castanhal.

Regarding education level, the result reflects a predominant higher education level (complete and incomplete) among 55.10% of the respondents, which could contribute to their knowledge regarding the research topic.

Ranking analysis of barriers to organic waste recycling: TOPSIS analysis

This section presents the result of the ranking with the application of TOPSIS, the associated discussions, and their implications for theory and practice. To obtain the ranking of barriers according to what respondents consider most determinant for the context in which they are inserted, the data processed through the TOPSIS technique were divided into three groups according to respondents' experience regarding handling, reuse, and final disposal of OSW.

First, the average of the scores assigned by each respondent was calculated, as shown in Table 3; this step was executed for each of the statements presented in this study.

The next step involved calculating and then normalizing using Equation 1, resulting in the matrix represented in Table 4.

Later, weights were assigned to each group of respondents, with the first group, consisting of respondents with over 10 years of experience having a weight of 0.50, the second group consisting of respondents with between 5 and 10 years of experience having a weight of 0.30, and finally, the third group, composed of

Table 2 – Stages of the TOPSIS method.

Matrix 1	$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$	Matrix 3	$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix}$
Equation 1	$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2}$	Equation 3	$s_i^* = \left[\sum_j \left(v_{ij}^* - v_j^+ \right)^2 \right]^{1/2}$
Matrix 2	$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$	Equation 4	$s_i' = \left[\sum_j \left(v_{ij}' - v_j^- \right)^2 \right]^{1/2}$
Equation 2	$v_{ij} = w_j r_{ij}$	Equation 5	$c_i^* = \frac{s_i'}{(s_i^* + s_i')}$

Source: Singh *et al.* (2016).

respondents with up to 5 years of experience having a weight of 0.20. From this, it was possible to obtain Matrix V, as presented in Table 5.

Table 6 presents the result of the calculation of positive and negative ideal solutions.

From Table 6, the calculation of the values in Table 7 was carried out, which correspond to the Euclidean distances from the positive and negative ideal solutions. After this step, and using Equation 5, it is possible to calculate the coefficient Ci*, which is used to generate the ranking of the statements considered in this study.

In conclusion, by ordering the values of the coefficient Ci*, a comparative ranking of the statements related to the barriers to the implementation of reverse logistics for OSW in the city of Castanhal, Pará, is obtained. Table 8 presents the results of the ranking of the statements and correlates them with their respective barriers, with barriers B03, B04, and B05 being the three most recognized barriers by the respondents.

The result identifies barriers 3 and 4 as the most determinants concerning the recovery of organic waste (OW). The most significant barrier for respondents refers to barrier 3, which deals with aversion to OW recovery. Therefore, measures should be created to educate generators on waste management and to raise awareness among them, ensuring proper waste management until its final disposal (Hettiarachchi; Meegoda; Ryu, 2018). Considering that the current waste collection method in the city of Castanhal does not require prior waste separation, it is evident that a change in waste treatment culture is crucial to reverse the current scenario. According to Abrelpe (2022), Brazil produces approximately 82 million tons of solid waste annually, with the state of Pará, where Castanhal is located, being the largest generator of MSW in the northern region, generating approximately 2.6 million tons/year (Abrelpe, 2022). The Northern Region has the highest percentage of inadequate disposal, with 63.4% of MSW being sent to controlled landfills or open dumps (Abrelpe, 2022). Only 0.41% of collected MSW comes from reused organic waste, with composting facilities representing 1.5% of MSW processing units in operation in Brazil, while branch and pruning management units represent only 0.9% (Brasil, 2020).

Occupying the second position in the ranking is barrier 4. This barrier deals with respondents' acceptance of OW recovery, as public involvement is the key element for adopting methods of organic waste utilization, increasing compliance efficiency, reducing generation, waste segregation at the source, recycling, composting, and reducing landfill volume (Gonçalves *et al.*, 2018; Lunag *et al.*, 2021). Waste recovery is a solution that would effectively address the problems of improper disposal occurring in the city, open dumps, inefficient collection systems, rodent infestation, and so on. Public acceptance of OW recovery and conscientious consumption helps reduce food losses and decreases waste, directly impacting SDG 12.3.1, as well as goals 12.5 and 12.5.1, aiming to reduce waste generation through prevention, reduction, recycling, and reuse by 2030.

Table 3 – Averages assigned to the statements.

Affirmatives	Above 10 years old	Between 5 and 10 years old	Up to 5 years old
AF01	4.625	3.282	3.688
AF02	7.313	2.538	3.785
AF03	6.563	3.795	3.925
AF04	6.313	3.564	4.871
AF05	6.688	6.231	6.086
AF06	8.438	7.641	7.194
AF07	8.188	7.795	6.871
AF08	5.313	8.026	7.409
AF09	4.688	7.641	7.086

Table 4 – Matrix R with normalized values.

Affirmatives	rij +10 years	rij between 5 and 10 years	rij up to5 years
AF01	0.23	0.18	0.21
AF02	0.37	0.14	0.22
AF03	0.33	0.21	0.22
AF04	0.32	0.20	0.28
AF05	0.34	0.35	0.35
AF06	0.43	0.42	0.41
AF07	0.41	0.43	0.39
AF08	0.27	0.45	0.42
AF09	0.24	0.42	0.40

Table 5 – Weighted values of matrix V.

Affirmatives	rij +10 years *0.50	rij between 5 and 10 years *0.30	rij up to5 years *0.20
AF01	0.12	0.05	0.04
AF02	0.18	0.04	0.04
AF03	0.17	0.06	0.04
AF04	0.16	0.06	0.06
AF05	0.17	0.10	0.07
AF06	0.21	0.13	0.08
AF07	0.21	0.13	0.08
AF08	0.13	0.13	0.08
AF09	0.12	0.13	0.08

Table 6 – Positive and negative ideal solutions.

Solution criteria	Over 10 years	Between 5 and 10 years	Up to 5 years
Ideal solution A+	0.213	0.134	0.084
Negative solution A+	0.117	0.042	0.042

Table 7 – Distance from the positive and negative ideal solutions and Ci coefficient.

Affirmatives	Positive ideal distance calculation (Si+)	Negative ideal distance calculation (Si-)	Coefficients (Ci)
AF01	0.13	0.01	0.08593
AF02	0.10	0.07	0.39488
AF03	0.09	0.05	0.36276
AF04	0.10	0.05	0.33262
AF05	0.06	0.09	0.60536
AF06	0.01	0.13	0.95153
AF07	0.01	0.13	0.93155
AF08	0.08	0.10	0.56382
AF09	0.10	0.09	0.49524

Table 8 – Ranking of statements and correspondence with barriers.

Position	Ci	Affirmatives		Barriers	
1st	0.952	**AF06**	I have a good level of acceptance regarding the idea of recovering organic waste.	**BO3**	Aversion to organic waste recovery
2nd	0.932	**AF07**	I am willing to separate organic waste for recovery.		
3rd	0.605	**AF05**	I am interested in using organic waste to produce compost through composting.	**BO4**	Social acceptance for organic waste recovery
4th	0.564	**AF08**	I know the biological processes that occur in the recovery of organic waste for compost production through composting.	**BO5**	Understanding of biological processes for waste recovery
5th	0.495	**AF09**	Some incentives make it possible to separate, collect, transport, and perform other necessary processes to recover organic waste.	**BO7**	Lack of measures to incentivize waste recovery by stakeholders
6th	0.395	**AF02**	Sometimes it can be complicated to separate the waste that can be turned into compost from the rest of the waste.	**BO1**	Heterogeneous composition (mixture) of wastes that hinder reuse/recovery
7th	0.363	**AF03**	Sometimes it can be difficult to reuse the waste that can be turned into compost.	**BO4**	Social acceptance for organic waste recovery
8th	0.333	**AF04**	It is necessary to have the technical knowledge to turn organic waste into compost through composting.	**BO6**	Limited technical knowledge of waste identification and separation
9th	0.086	**AF01**	I separate the waste that can be turned into compost from the rest of the garbage.	**BO2**	Difficulty in separating waste to obtain good quality reuse mass

Barrier 5 occupies the third position in terms of determinacy in the ranking, dealing with respondents' understanding of the biological processes involved in OW recovery. Generator involvement in the initial phase is the key element for adopting segregation methods, increasing waste management efficiency to ensure proper final disposal (Lunag *et al.*, 2021). However, there are either insufficient or no measures in Castanhal to encourage learning about practices and their processes among the population. The portion of the population that claims to understand and perform the necessary processes for transforming OW does so based on empirical information about the process. Thus, there is an urgent need for public policies aimed at generators with educational measures to encourage the handling, source separation, and correct disposal of organic waste (Siqueira; Assad, 2015).

Occupying the fourth position is barrier 7, which deals with the lack of incentives to stimulate OW recovery by involved stakeholders. This governmental deficiency hinders separation, collection, transportation, and other processes necessary for organic waste recovery. In addition to creating measures that support recovery incentives and are seen as extra benefits by stakeholders, such as recycling programs and tax discounts, it is also necessary to adopt management that favors OW recovery, avoiding the premature depletion of landfills (Siqueira; Assad, 2015). The public authority in Castanhal indiscriminately collects waste, without prior separation. The establishment of these incentives would contribute to achieving SDGs 11 and 12, specifically targets 12.3 and 11.6, which aim to halve per capita food waste, reduce food losses throughout production and supply chains, and reduce the per capita negative environmental impact of cities, including paying special attention to municipal waste management by 2030.

In the fifth position, barrier 1 is related to difficulties in waste separation. According to Xiao *et al.* (2020), this barrier relates to poorly designed OW screening processes, excessively detailed waste classification standards, and inefficient waste collection and disposal flows, mixing wet and dry waste. Stakeholders' level of knowledge directly influences waste separation, leading to the sixth position occupied by barrier 6, which deals with the technical knowledge involved in waste identification and separation. Limited knowledge about OW recovery or reliance on common sense complicates separation and prevents recovery, with the greatest obstacle being the lack of information among those involved (Pan *et al.*, 2015; Lohri *et al.*, 2017; Pour; Webley; Cook, 2018; Perteghella *et al.*, 2020; Xiao *et al.*, 2020).

The last position in the ranking is barrier 2, which deals with difficulties in waste separation and reuse. Wei *et al.* (2017) advocate that this difficulty arises due to the lack of an efficient and comprehensive selective collection system in terms of service coverage, so the absence of this system generates a high demand for waste, and mixed collection of this MSW may contain significant moisture concentrations in the organic composition, affecting composting processing and commercialization. The implementation of mixed collection results in improper waste disposal, and Castanhal lacks a collection system that considers prior waste separation, using open dumps as the final disposal. This method depletes capacity prematurely and causes contamination hotspots in the soil and water.

The result of this study indicates a gap in achieving SDGs (11 and 12), which encompass the scope of this study and address sustainable cities; efficient consumption, management, and production of natural resources, as the city consumes and disposes of waste inadequately and inefficiently. The SDGs and their targets consider waste management, food waste, recycling, and access to services that optimize and dispose of this waste effectively. Therefore, Castanhal does not meet SDG 11.6.1, which aims to measure the proportion of urban solid waste collected and managed in controlled facilities by the total urban waste generated.

CONCLUSION

This study aimed to identify the barriers related to the implementation of OSW reverse logistics for the generating stakeholder (individual), as found in the literature, and to assess the importance of these barriers using the TOPSIS method based on the perception of individual waste generators in the city of Castanhal. Additionally, the barriers were linked to SDGs 11 and 12 and their related targets.

The contribution of this study lies in both the theoretical and practical realms. Theoretically, it contributes knowledge about barriers in a geographical space, as there are few studies and research addressing waste management difficulties in a given territory. By identifying and ranking the barriers to OSW reverse logistics for the studied municipality, this study broadens the debate on the subject, providing a basis for future discussions.

It also contributes practically. First, no empirical survey of these barriers has been conducted for the studied geographical region, thus enabling public policies and private initiatives to be adopted to overcome these barriers for individual waste generators in the OSW reverse channel, providing a guide to the challenges of implementing OSW reverse logistics. Second, because no studies are addressing the difficulties of the OSW management scenario in the study region, those difficulties are related to the actions of government agencies to promote OSW reverse logistics in the territory and the motivation of individual waste generators for the recovery of such waste.

Therefore, government agencies should pay closer attention to the management of urban solid waste and the problems caused by the poor management of these wastes, such as GHG emissions and climate change. Thus, proper waste management and a reverse logistics policy for these materials are of utmost importance, as they are aligned with the themes and principles of SDGs 11 and 12.

There are limitations to this research. The first concerns the obtained results, which cannot be extrapolated to other contexts. The second limitation concerns the 0–10 scale used in the data collection instrument, which may have hindered the response process, as it is somewhat confusing, tiresome, and lengthy for respondents. Additionally, the research sample corresponds to about 0.10% of the population of IBGE (2022), bringing a 7% error to the research results at a 95% confidence level. This low adherence indicates that despite the relevance of the topic and its impact on the daily lives of the population, there is still a lack of engagement with the issue. Lastly, despite the use of digital means for the survey, where a larger reach of respondents was expected, it was observed that respondents needed to be stimulated, with more "face-to-face" contact, to participate in the survey, thus limiting the number of people for this action/stimulus.

In conclusion, future work should be done to expand surveys with stakeholders related to OSW reverse logistics in the other six municipalities belonging to the Belém Metropolitan Region and conduct quantitative and statistical surveys to validate the barriers. Additionally, it is suggested for future research to improve the data collection instrument and the scale used, so that the obtained responses directly reflect the reality of the respondent.

AUTHORS' CONTRIBUTIONS

Teixeira, V.E.G.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Cruz, W.S.C.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Fernandes, R.M.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Nunes, D.R.L.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Martins, V.W.B.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. Nagata, V.M.N.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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