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Systematic Review of Decision-Making Tools, Alternatives and Criteria in Urban Solid Waste Management

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Abstract

This scientific article provides a comprehensive review of the main tools and criteria employed in Municipal Solid Waste Management (MSWM) for achieving sustainable waste management. The objective of this study was to evaluate the most effective technology or combination of technologies for treating urban solid waste, along with the most used methodology for selecting such technologies. To achieve this, we conducted a systematic review of the literature, carefully selected relevant articles, and compiled data from various criteria studied to facilitate a comprehensive discussion and evaluation of the findings. The article evaluates the main tools and their combinations used in aiding decision-making in MSWM, in accordance with the objectives of the decision. The benefits of integrated waste management are highlighted, along with the challenges associated with its implementation. These challenges are inherent in each situation and must be evaluated individually, based on their characteristics. Optimizing sustainability criteria in MSWM can be achieved by searching for a technology implementation sequence. The article also synthesizes the frequency of each MSWM technology, such as landfill, incineration, anaerobic digestion, composting, gasification, pyrolysis, and recycling, being selected in decision-making in the literature. Furthermore, an analysis of the environmental, economic, social, technical, political, and administrative criteria and their sub-criteria in MSWM is carried out. It has been observed that Analytic Hierarchy Process and Life Cycle Assessment are the primary tools involved in multicriteria decision-making for Municipal Solid Waste Management (MSWM). Moreover, these tools demonstrate ease of integration with other methods, showcasing their flexibility and comprehensiveness. While the combination of MSWM technologies is a common goal in the studies examined, integrating a larger number of technologies poses challenges. Finally, the most frequently studied criteria in MSWM, in descending order of frequency, are environmental, economic, social, technical, and political/legislative/administrative aspects. Therefore, it is crucial to explore the less frequently studied criteria to overcome barriers and establish a more sustainable management approach for urban solid waste. In conclusion, the article suggests future work, including the development of a model that assists in the technology implementation sequence and assessing the feasibility of integrating the largest number of MSWM technologies. Although gaps exist in the literature on MSW issues and potential solutions, this review provides valuable information for decision-makers in MSW planning and in the search for scenarios that demonstrate superior performance.

Keywords: solid waste management, decision-making tools, select criteria, life cycle assessment, integrated management

1. Introduction

1.1 Municipal Solid Waste Management

The rapid increase in municipal solid waste (MSW) production has been a significant concern worldwide due to its potential environmental and social impacts (Batrancea, 2021). The current approach of waste disposal in controlled landfills or dumps has resulted in the depletion and accumulation of resources and residues. It is essential to implement integrated waste management strategies that consider the natural cycles and embrace the circular economy for the sustainable management of waste. The objective of this systematic review is to identify and compare the most popular decision-making aid methods in municipal solid waste management (MSWM) (MCDM and LCA), their criteria, and the alternatives that present the best performance.

The technological evolution of man has resulted in a disconnect between natural processes and human activities.

However, the concept of being part of nature and the need for the integration of human processes with natural processes are gaining momentum. This reintegration is challenging, especially for products derived from human activities that have relatively long processing times by natural processes. The current industrialization, aligned with demographic growth and changes in living and consumption standards, has led to a sharp increase in MSW production and is projected to continue growing.

The final disposal of waste in landfills is the most common approach worldwide, but it has significant environmental and social impacts. The number of MSW treatment technologies has been growing, and there are ongoing efforts to identify the most efficient combination of these technologies and processes to form an integrated management system that presents better environmental, social, and economic performance. However, this integrated management has considerably higher initial costs.

The application of decision-making methods (MCDM) and life cycle assessment (LCA) has proven useful in identifying the best waste treatment scenario, the most suitable place to install treatment plants, and the best collection routes. MCDM and LCA are widely used in various areas such as supplier selection, financial risk assessment, and material selection. However, their application in MSWM is relatively new.

The focus on MSWM needs to be the "Zero Emission" strategy, based on natural cycles and in line with the circular economy, by promoting reverse logistics for MSW (Batrancea, 2021). This approach sees all waste as raw material for another process, directing it to business sectors to avoid the accumulation of waste and promote the circular economy (Batrancea, 2021). Part of the waste is sent for recycling, transforming it for reuse.

This systematic review aims to identify the most popular decision-making aid methods in MSWM, the criteria involved in MSWM, and the alternatives that present the best performance. The current approach to waste disposal in landfills has significant environmental and social impacts, and an integrated waste management strategy is necessary. The application of MCDM and LCA in MSWM is relatively new, but they have been useful in identifying the best waste treatment scenarios. The "Zero Emission" strategy is crucial in promoting the circular economy and reducing waste accumulation.

Municipal Solid Waste Management (MSWM) poses an environmental, economic, social, technical, political, and administrative challenge for municipalities, often resulting in limited and inadequate implementation of waste treatment technologies. Therefore, in order to contribute to the discourse on achieving sustainable management of urban solid waste, this study aimed to evaluate the optimal technology or combination of technologies for treating solid urban waste. Additionally, we sought to determine the most utilized tool for selecting MSMW technologies. The hypothesis tested posits that a combination of technologies would offer greater advantages and be the preferred choice among the studies analyzed. Despite the significance of this discussion within the scientific community, studies exploring the connection between decision-making tools and the objectives of decisions, as well as the identification of technological priorities in Municipal Solid Waste Management (MSWM) and the key criteria involved, are limited. Furthermore, we propose an integrated management model that combines the primary technologies used in MSWM.

1.2 Problem Related to MSWM

The vertiginous growth of the generation of MSW has drawn the attention of specialists, government, entities and the population (Soltani, Sadiq, & Hewage, 2015; Kharat, Raut, Kamble, & Kamble, 2016; Hoornweg & Bhada-Tata, 2012). difficulty in measuring the volumes and characteristics of the MSW, mainly in underdeveloped and developing countries, due to the lack of equipment, organization in the processes and many times, part of these MSW do not get to be collected for a final destination (Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, & Ismailova, et al., 2014; Vučijak, Kurtagić, & Silajdžić, 2015; Su, Hung, & Chao, 2016). All this lack of structure, management, and information collection around the MSWM makes decision-making difficult.

The final disposal of waste, in addition to not being ideal for a wide variety of compounds present in MSW, is becoming unsustainable for the large volume that is destined (Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, & Ismailova, et al., 2014). Another important point is the need to monitor and maintain the landfill throughout its life after its saturation. In addition, it is common to see final disposal sites that do not have the characteristics/standards of a sanitary landfill, being characterized as a controlled landfill or even in open-air dumps (when there is no covering and sealing structure for the MSW underground) causing pollution of bodies of water, soil and atmospheric emissions, health problems, vibrations, fires and explosions (Kharat, Raut, Kamble, & Kamble, 2016;, Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, & Ismailova, et al., 2014; Erses Yay, 2015; Thampi & Rao, 2015; Dong, Chi, Zou, Fu, Huang, & Ni, 2014; Louis, Magpili, & Pinto, 2014).

There is a lack of interest from the governmental parts of the municipalities and the population, who have shared responsibility for the MSWM. In addition, to places where there is no legal/legal incentive for the union of municipalities to resolve this issue by producing a common MSWM center, which ends up making actions difficult (Hung, Ma, & Yang, 2007). The lack of resources, the lack of financial support and the reluctance of users to pay for the service, makes MSWM a burden on the finances of municipalities. Among the main barriers faced by decision makers at MSWM are the lack of knowledge about the problems generated and treatment alternatives, the lack of financial resources, infrastructure, organization and institutional leadership, reliable data, among others (Guerrero, Maas, & Hogland, 2013).

Therefore, there is a need to take measures to end this problem. These measures need to be broad, involving population awareness, developing the knowledge of decision makers, seeking government support and incentive funds, encouraging the search for more accurate data, developing the recycling market, and recovered products. A sustainable MSWM, in addition to solving the various problems described, is an opportunity to obtain economic gains with the sale of secondary products and social gains with, for example, job creation."

1.3 Main Decision-Making Tools

There are several methods available to solve problems related to MSWM. The three main models used in management are multi-criteria decision making (MCDM), life cycle assessment (LCA), and multi-objective programming (MOP) (Su, Hung, & Chao, 2016). Hung et al. also include cost-benefit analysis (CBA), but a multidimensional evaluation that addresses several criteria, often conflicting, is more accurate in decision-making. This type of evaluation provides a comprehensive view from different perspectives.

MCDM is a branch of operational research that is useful for studying complex problems involving several contradictory criteria generating uncertainties. These tools evaluate the advantages and disadvantages of each alternative and result in a ranking of the alternatives that have the best performance in consideration of the various criteria involved. Clear objectives of decision-making need to be defined, possible alternatives identified, and evaluated with different perspectives (criteria) to distinguish acceptable alternatives from unacceptable ones (Jovanovic, Savic, Jovicic, Boskovic, & Djordjevic, 2016). MCDM helps understand and evaluate complex situations, promotes systematic decision-making processes, collects subjective evaluations of experts, evaluates problems in different aspects, and facilitates communication between different stakeholders (Arıkan, Şimşit-Kalender, & Vayvay, 2015).

LCA is commonly used to assess environmental and energy aspects throughout the life cycle. It evaluates inputs and outputs of a given system to measure natural resources needed for operation and outputs of the process, such as atmospheric and liquid emissions, secondary products, and so on (Cherubini, Bargigli, & Ulgiati, 2007). LCC (life cycle costing) evaluates economic balances of processes over the entire life period, considering financial inflows and outflows. Although LCA and LCC account for impacts, MCDM is necessary to aggregate their results (Soltani, Sadiq, & Hewage, 2015).

1.4 Integrated Management of Urban Solid Waste

Although one of the main objectives of MSWM is to discontinue the use of landfills, the road to abandoning them is long. Thus, they can still be useful until the implementation of scenarios that use the entire volume of waste in reduction, reuse, and recycling processes. Sorting is also a decisive process in an integrated scenario, facilitating the division of waste groups. The more technologies are combined, the greater the volume of waste reduced and the greater the recovery of products (Jovanovic, Savic, Jovicic, Boskovic, & Djordjevic, 2016). Must pay attention to the sequence of technology implementation until we build the ideal scenario, diluting the implementation and costs. This implementation sequence needs to be based primarily on the reduction benefits and waste recovery, with low environmental and social impact, and compatible with financial conditions, infrastructure, composition of resource wastes and objectives of the municipalities, in addition to being aligned with stakeholders.

In an integrated scenario with the combination of the main processes and technologies of MSWM (Figure 1), sorting could start in residences, providing lower costs and stimulating awareness of the population, or it could be done in sorting stations. With the separation of the organic fraction from the inorganic fraction of MSW, each will follow a different destination. The organic fraction will go to an anaerobic digester (AD) where fermentation will take place to produce energy, which will be sold or used in the production of electricity. The AD residues will be combined with part of the organic MSW from the source to a composting station that will transform part of these residues into material rich in nutrients that will be commercialized in the form of fertilizer. The residues from these processes would be combined with unused residues of the inorganic fraction in the pyrolysis/gasifier.

The inorganic fraction of MSW goes to a sorting station for recycling, where groups of inorganic materials will be separated for possible commercialization. Of the compounds that do not undergo recycling, those with a high concentration of carbon in their molecules will join the residues of biological processes in the gasifier/pyrolysis (reduction of up to 95%). The gasifier/pyrolysis is preferred over the incinerator as it has greater efficiency in energy recovery and has less environmental impact. Substances that are not reused will follow the path towards the WtE incinerator, if necessary. The gasifier/pyrolysis residues can be used as fertilizers due to their richness in organic matter. The gases (CH4) produced from this process can be sold or used to generate electricity. The ash from the incinerator, if its implementation is necessary, will follow the path to the landfill or can be used in the building materials industries. If any waste is produced from these processes, it will be sent to landfills.

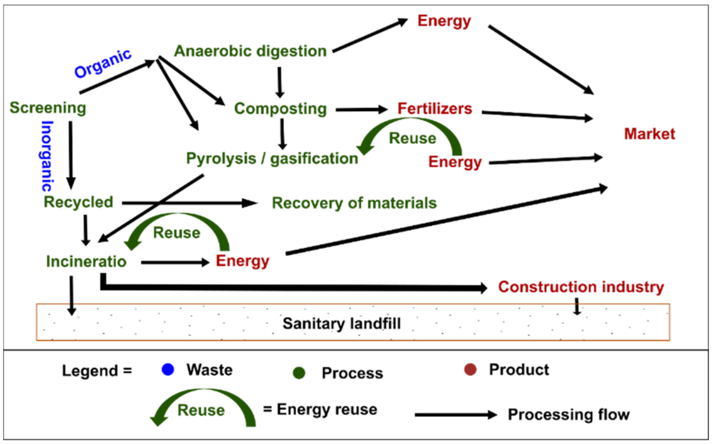

Figure 1. Combinations of solid waste treatment technologies

This scenario aims to combine all the main MSWM alternatives in an integrated scenario. However, it may not be feasible to implement certain technologies, such as the incinerator, due to inadequate volume and composition. Another possibility is to implement only the gasifier to reduce the organic fraction of MSW, saving on the implementation of composting and AD. Therefore, the search for an integrated scenario will depend on regional factors such as financial situation, waste volume, and waste characterization. Further studies on the combination of these technologies are needed.

A sensitivity analysis can be conducted to identify the critical path for implementing processes and technologies for integrated waste management, considering the main barriers and objectives encountered. This analysis can help identify the cheapest sequence of implementation or the sequence with the greatest reduction in organics or inorganics or the greatest energy recovery.

2. Method

For the development of this article, a systematic review of the literature inspired by the work of (de Almeida Biolchini, Mian, Natali, Conte, Travassos, 2006) was applied. Figure 2 shows the steps of the review. Initially, the search bases were defined, with Google Scholar and Scopus being used. selected to obtain a broader search scope. Afterwards, the keywords involved in decision-making and MSWM were chosen to create the following Boolean expressions: ["MCDM and solid waste waste" or "Sustainability and MCDM and Solid Urban Waste"] and the combination of different decision support tools with "treatment of municipal solid waste waste" such as ["AHP and treatment of municipal solid waste waste" or "TOPSIS and treatment of municipal solid waste waste" or "PROMETHEE and treatment of municipal solid waste waste waste" or "LCA and Treatment of municipal solid waste waste"].

Of the 48 works used to compose the data for this review found in Google Scholar, 41 were also found in Scopus. Only studies published in journals were considered for having more reliable data due to peer reviews. Firstly, only articles in English were selected, however, as no articles were found from South America, to fit data from this region in the analyses, two Brazilian works in Portuguese were added. Forty-eight papers identified in the searches were used in this review. These works were selected because they contain useful information to answer the questions of this review. Some of the unselected works dealt with the treatment of specific waste such as organic (Babalola, 2016), electronics (de Souza, Clímaco, Sant'Anna, Rocha, do Valle, & Quelhas, 2016), health

(Liu, Wu, & Li, 2013), selection of the place to install MSWM alternatives (Liu, You, Chen, & Fan, 2014) or that it was not possible to access (Liu, Wu, & Li, 2013).

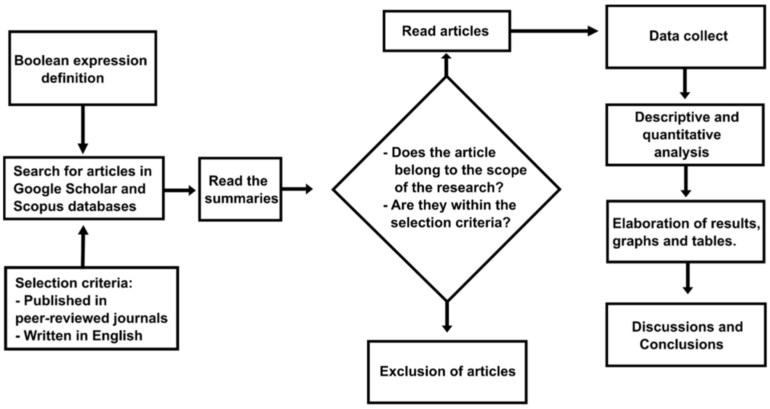

Figure 2. Review work flowchart

This review focused on works that use multi-criteria decision-making (MCDM) and life-cycle assessment (LCA) methods in MSWM. These tools, depending on the configuration of your decision matrix, have the potential to obtain an assessment of the impacts environmental, energy, economic, social, sustainable, etc. Thus, other evaluation methods such as benchmarking (Liu, You, Chen, & Fan, 2014), Cost benefit analysis (CBA) (Mavrotas, Gakis, Skoulaxinou, Katsouros, & Georgopoulou, 2015), were not identified in the searches. Allesch and Brunner (Allesch & Brunner, 2014) demonstrated that the MCDM and LCA tools account for more than 50% of the studies that evaluate MSWM in some way. Details of the tools MCDM, criteria, subcriteria and alternatives for each article are shown in the Supplementary tables (Table S1- S9).

3 Results and Discussion

3.1 Decision-Making Tools at MSWM

In this review, 48 articles were identified that applied management tools to aid in understanding the scenario and decision making. Of these, 23 studies utilized a single tool, 21 studies combined two tools, and 5 studies combined an analysis with three tools. Among the observed tools, AHP was the most frequently used, appearing in 42% of the papers, followed by LCA in 40%, TOPSIS in 20%, and PROMETHEE in 16% (Figure 3).

LCA was applied in 20 out of the 48 articles studied, with a focus on environmental aspects in most cases. In 12 works, it was used alone, and in 8 works, it was combined with MCDM. The application of MCDM with LCA is justified as it expands the perspectives of a complex problem by assigning weights to the criteria and prioritizing the most relevant criteria for a given situation, taking into account important qualitative aspects (Kadafa, Manaf, Sulaiman, & Abdullah, 2014).

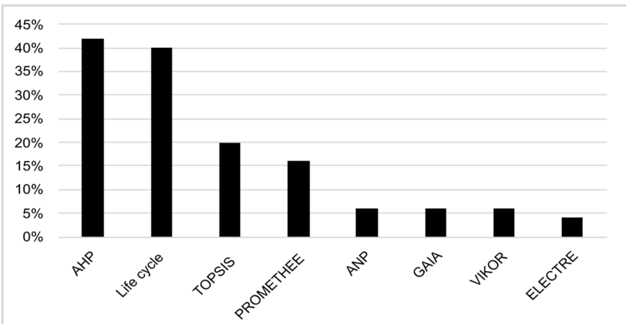

Figure 3. Frequency of use of tools MCDM in MSWM

AHP was observed in 21 of the studies. Its high frequency is explained by its ease of application, and it is the most popular MCDM tool among scientific works in several areas (Arena, 2012). Data collection is done only by interviews, despite the regular problem of inconsistent answers. Of the 21 applications, only 3 were isolated, and 18 were combined with another tool. AHP is typically used to assign weights to criteria and alternatives by experts and stakeholders, capturing their subjective knowledge (Soltani, Hewage, Reza, & Sadiq, 2014). It is crucial that different stakeholders participate in data collection to consider different perspectives and interests.

TOPSIS was the third most used tool in MSWM, appearing in 10 papers, and in all studies, it was combined with another tool to assign weights to criteria. A sensitivity analysis, alternating the weights of the criteria, enables a broader understanding of the problem and allows alignment of the decision objective in relation to the criteria weights (Panagiotidou, Stavrakakis, & Diakaki, 2015).

PROMETHEE had the fourth highest frequency of use in MSWM, appearing in 8 articles, and in 5 works, it was combined with another tool. It differs from other decision-making methods by not only considering pairwise comparison of criteria but also the interaction between them (Arıkan, Şimşit-Kalender, & Vayvay, 2015).

Each tool has its positives and negatives. AHP is mainly used to capture the subjective knowledge and preferences of decision-makers. PROMETHEE and TOPSIS, on the other hand, can collect data from interviews and measuring responses through language scales and databases. Finally, LCA has a strongly quantitative approach through field data collection. These qualitative and quantitative variations between the tools allow their combination to assess different aspects (Soltani, Hewage, Reza, & Sadiq, 2014).

As the application of these tools is already well described in the literature, we decided not to include them in this review. For a better understanding of their application, we suggest reading articles that include their use, such as (Soltani, Sadiq, & Hewage, 2015) (LCA), (Pires, Chang, & Martinho, 2011) (AHP-TOPSIS), (Lolli & Ishizaka, 2016) (PROMETHEE), among others.

3.1.1 Relation between the tools MCDM and the objectives of MSWM

The diverse characteristics of decision aid tools make them perform differently depending on the situation and objectives. For instance, the AHP is an easily applicable tool that captures subjective information from decision makers and assists in the interpretation of criteria and alternatives. PROMETHEE, on the other hand, considers the relationship between criteria, a feature that AHP lacks. To establish some correlation, Table 1 aimed to associate the main objective of the reviewed articles with the utilized tool. The main objectives of the analyzed articles were defined based on the objectives outlined in the abstract of each article.

Table 1. Frequency of use of tools MCDM by objectives in MSWM

Goals	AHP	LCA	TOPSIS	PROMETHEE	ANP	DEMATEL	GAIA	ELECTRE	VIKOR
Decision making model	6,2%		4,2%	2,1%	4,2%	2,1%	2,1%		4,2%
Cooperation between municipalities				2,1%			2,1%		
Alternative or suitable scenario	22,9 %	14,6 %	14,6%	8,4%		2,1%			
product recovery	10,4 %	6,2%	2,1%	2,1%				2,1%	
Base on sustainability	17%	10,4 %	12,5%	18,8%	4,2%		4,2%		4,2%
Environmental	2,1%	12,5 %		2,1%			2,1%		
Environmental and Economic	4,2%	6,2%	4,2%		2,1%				2,1%
waste reduction	2,1%	2,1%	2,1%						
Symbiosis with industry		2,1%							

Multicriteria decision making tools: *AHP: Analytic Hierarchy Process; LCA: Life Cycle Assessment; TOPSIS: Technique for Order Performance by Similarity to Ideal Solution; PROMETHEE: Preference Ranking*

Organization Method for Enrichment of Evaluations; ANP: Analytic Network Process; DEMATEL; GAIA; ELECTRE; VIKOR.

In general, decision aid tools perform differently depending on the situation and objectives. The distribution of tools is even among MSWM objectives, with AHP being the most popular tool and appearing in most of the studies. However, PROMETHEE was used more frequently in works related to sustainability due to its ability to measure the interaction between criteria (Arıkan, Şimşit-Kalender, & Vayvay, 2015). These studies evaluated the triple bottom line of sustainability, including environmental, social, and economic aspects.

In contrast, LCA was used more frequently in works focused on environmental aspects, which is its main focus (Soltani, Sadiq, & Hewage, 2015). When it comes to energy recovery and waste reduction, it is recommended to use tools based on more quantitative data as they involve quantitative parameters. The high frequency of AHP use in product recovery reflects a trend toward using subjective approaches to quantitative questions, but this should only be the beginning of the investigation (Soltani, Sadiq, & Hewage, 2015).

3.2. MSWM: Alternatives and Scenarios

Among the MSWM processes, the alternatives for treatment, recovery, and final disposal are the most complex processes. These MSW treatment alternatives can be divided into four categories: final disposition, biological systems, thermal systems, and recovery (Arıkan, Şimşit-Kalender, & Vayvay, 2015). Among them, the most commonly used in the world is the final disposal in landfills due to its low cost and ability to receive varied waste (Yap & Nixon, 2016). However, due to the large demand for land that the landfill requires, potentiated by the increasing trend in MSW production (Dong, Chi, Zou, Fu, Huang, & Ni, 2014; Song, Wang, & Li, 2013), together with the appreciation of land close to cities, the environmental and social impacts, and the low capacity to recover waste, motivated the search for alternatives that contribute to better performance in these aspects, minimizing dependence on landfills. Therefore, these new technologies start to compose a MSWM scenario, along with the landfill, where each technology assumes a group of waste to be processed. The more alternatives employed in MSWM, the greater the volumes reduced for landfill disposal; however, the initial costs also increase (Jovanovic, Savic, Jovicic, Boskovic, & Djordjevic, 2016). Therefore, waste separation becomes a process of great importance in scenarios with more than one alternative to allocate the waste to the appropriate technology.

The sorting of MSW can be applied through selective collection, where the types of waste are collected separately at the source or separated in sorting stations. The best option depends on the local infrastructure conditions (Vučijak, Kurtagić, & Silajdžić, 2015) and even on the culture of the region. According to (Su, Hung, & Chao, 2016), sorting is the most important process to ensure the recovery and reduction of waste in the various alternatives.

3.2.1 Frequency in Ideal Scenarios

Most of the papers on which this review was based aimed to select a sustainable MSW treatment alternative/scenario. Combining the information from these works, it was possible to construct Figure 4. It can see in Figure 4 a that recycling is the alternative that appears most in ideal scenarios, followed by landfill, and tied anaerobic digestion, composting, incineration, and finally gasification. This result demonstrates the worldwide difficulty in abandoning landfills, despite Switzerland proving this possibility (Oliveira, Medeiros, Paes, & Mancini, 2021). We can also observe that most works prioritize scenarios with the integration of technology focusing on the recovery of some type of product, mainly energy.

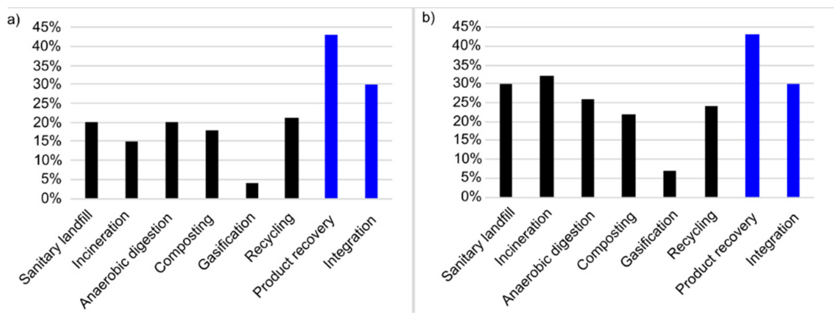

Figure 4. Frequency that the alternatives occupied the a) 1st preference and b) 1st and 2nd preferences together in the works studies

Incineration, despite ranking 5th among the alternatives with first preference, becomes the 1st technology with the highest frequency in ideal scenarios when its second preference frequency is added (Figure 4 b). This result can be explained by the poor environmental performance and high investments associated with incineration (Song, Wang, & Li, 2013) in contrast to its ability to reduce the volume of inorganic waste. Thus, despite its negative points, incineration continues to be preferred, mainly because it, along with recycling, is an alternative for inorganic waste.

Technologies specialized in reducing organic waste generally exhibit good environmental performance. Anaerobic digestion, for its low cost and high recovery capacity, was the best alternative among them (Yap & Nixon, 2015), followed by composting for being the cheapest alternative and with some product recovery capacity (Song, Wang, & Li, 2013). Gasification, despite showing good environmental performance, product recovery, and waste reduction, which can make the operating budget viable, is the most expensive and least known technology among them, which may explain its low performance in studies (Yap & Nixon, 2015).

Thus, the combination of technologies today presents better performance in recovery, reduction, and valorization of residues by exploring the positive points of each technology, generating environmental, economic, and social benefits.

3.3 Analysis of the Criteria Involved in MSWM

MSWM is a complex problem involving different criteria. MCDM is an important tool to help solve problems of this type. To apply MCDM, it is necessary to first define the decision objective, select the criteria involved in the problem, and define the alternatives to achieve the objective. In this way, a problem can be evaluated from various aspects, depending on the criteria chosen according to the objective. Table 2 represents the criteria involved in MSWM found in the literature.

From the 1990s onwards, with stricter public policies regarding waste, studies began considering more factors with deeper analyses, diversifying the criteria and alternatives (Tseng, 2016). The criteria involved in sustainable MSWM can be classified as environmental, economic, social, technical, political, and administrative, as shown in Figure 5. To stratify the criteria, we considered environmental sub-criteria as those that are directly linked to environmental disturbances (biotic and abiotic). The economic sub-criteria were selected based on values, assets, and finances. The social sub-criteria were separated because they deal with social relations between classes, groups, entities, among others, or social indices such as HDI or GDP. Technical criteria represent characteristics of technologies without considering their efficiency. The political criteria involve legislative issues and political relations. Finally, administrative criteria were separated by their characteristic of management and decision-making in MSWM.

Tabela 2. Critérios observados na literature please revise it in English wrods

Scope of waste types	social acceptance	acidification	Adoption of the consortium solution	Habitat change	Environmental
Political Support	Global warming	social welfare	Work conditions	Legal compliance	resource consumption
Air pollution control	budget control	Initial cost	maintenance cost	Operational cost	Pre treatment cost
Total cost	Management demand	Land Demand	market development	ozone depletion	Technological availability
Education	Technical Efficiency	Economic Efficiency for the population	Gross energy used	Community involvement	Depletion of fossil fuels
eutrophication	Flexibility	support funds	job creation	HDI	ecological impact
Independence from other Technologies	Social justice	Location	Net profit	Maintenance	Maturity
Technological Maturity	Odor	operation functionality	photochemical oxidation	GDP	Pollution
Atmospheric pollution	Ground pollution	Pollution of water resources	Noise pollution	Visual pollution	Implementation deadlines
Progress Deadlines	Pre treatment	Prevalence of use	administrative procedure	Continuous process	Radiation
Revenue from secondary products	Waste recovery	waste reduction	infrastructure requirements	political return	qualified HR
Human health	Separation of	social/ cultural	Fee paid by the	Technician	Transport

	waste		population
energy viability	Financial/ Economic viability	Overall Feasibility	

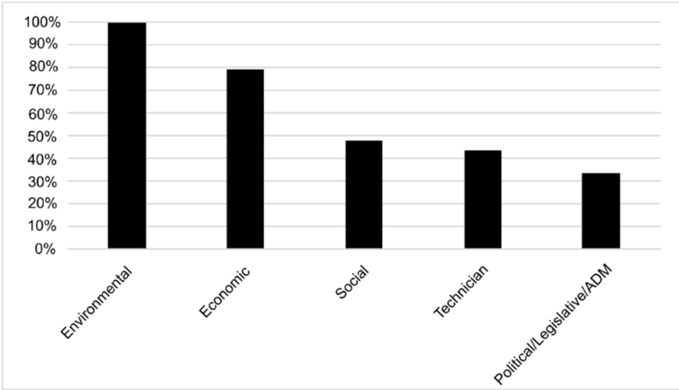

Figure 5. Main criteria involved with the MSWM

According to the stratification proposed, all the surveyed works evaluated the environmental aspects of MSWM. Economic aspects were evaluated in 79% of the works, social aspects in 48%, technical aspects in 44%, and political-administrative aspects in 33%.

In addition to being the most frequent in the literature, environmental criteria are also the ones with the most sub-criteria (Figure 6), which are often not clearly and systematically selected (Manaf, Basri, & Ahmad, 2009). Some of these sub-criteria are strongly related to technical criteria, such as the waste reduction capacity or the energy recovery efficiency of the studied alternatives. Environmental criteria also relate to social aspects such as human health, visual and noise pollution, etc. Economic sub-criteria have also been well explored, but they are not as complex as the environmental ones in terms of sub-criteria. They involve a variety of cost and revenue-based terms and can relate to social aspects such as job generation.

Social sub-criteria were less explored due to the difficulty of definition and measurement. However, as seen in Figure 6, the evaluation of social aspects has a high frequency, proving its importance. Technical sub-criteria have a frequency like the social ones. These criteria are strongly related to environmental aspects related to environmental impacts, economic aspects in relation to the ability to recover value-added products, or social aspects in job generation. Political/Administrative sub-criteria are little explored and applied so far. They relate to environmental criteria in environmental regulation and to social criteria in societal involvement, harmonization with the legislature, or with environmental groups.

Finally, Administrative sub-criteria are related to all criteria because they are directly involved in decision-making, which affects all criteria. Therefore, we realize that all these criteria interact with each other and can be classified in different ways in different studies. These criteria were classified into environmental, economic, social, technical, political, and administrative. Figure 7 represents the sub-criteria variations found in the researched articles according to their classification.

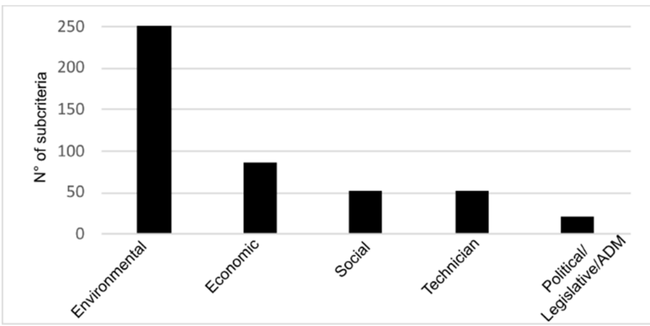

Figure 6. Number of subcriteria

In Figure 7, we observe that the most common environmental sub-criteria are "Human health" (46%), followed by "Resource consumption" (40%), "Waste reduction" and "Global warming" with the same frequency (35%), and "Atmospheric pollution" and "Pollution of water resources" also tied (33%).

The term "Human health" (46%) includes "Human toxicology" (Banar, Cokaygil, & Ozkan, 2009). "Resource consumption" (40%) also involves "Water intake" (33%), as seen in some studies (4,33). "Waste reduction" (35%) and "Waste recovery" (31%) are related, demonstrating the importance of their establishment. A concern related to air pollution is also evident, represented by the sub-criteria "Global warming" (35%), "Atmospheric pollution" (33%), "Air pollution control" (15%), and "Ozone depletion" (10%). This concern can be explained by the emissions of alternatives related to global warming, acid rain, and emissions of toxic substances (Kollikkathara, Feng, & Stern, 2015). The high frequency of the sub-criterion "Pollution of water resources" (33%) may be attributed to one of the main environmental impacts of the dump or landfill through the pollution of groundwater and surface water.

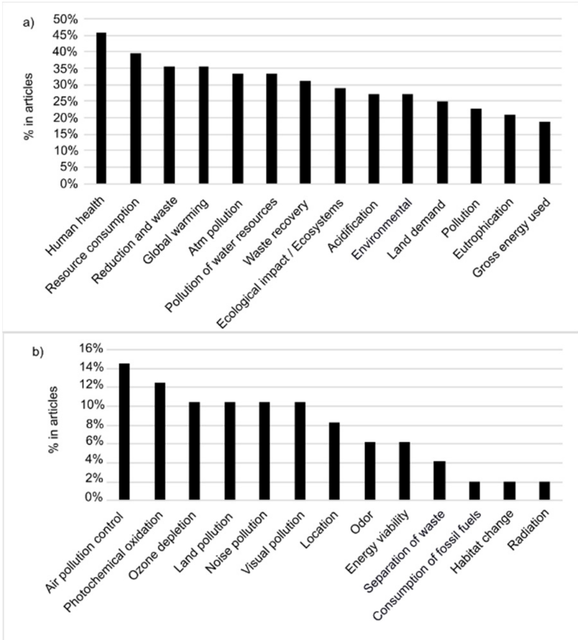

Figure 7. Frequency of the a) most and b) least present subcriteria in the articles

All of these sub-criteria represent some form of environmental impact, which can be summarized as an "ecological impact" sub-criterion (Soltani, Sadiq, & Hewage, 2015; Kharat, Raut, Kamble, Kamble, 2016; Thampi & Rao, 2015; Nixon, Dey, Ghosh, & Davies, 2013; Manaf, Basri, & Ahmad Basri, 2009).

Figure 8 shows that "initial cost" (50%) and "operating cost" (42%) are the most established sub-criteria of the economic criterion for MSWM. "Initial cost" often overlooks the value of the implementation land (Su, Hung, Chao, 2016; Dong, Chi, Zou, Fu, Huang, & Ni, 2013; Antonopoulos, Perkoulidis, Logothetis, 2014), but others consider it (Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, & Ismailova, et al., 2014; Inglezakis, Ambăruş, Ardeleanu, Moustakas, & Loizidou, 2016) or treat it as a separate sub-criterion (Panagiotidou, Stavrakakis, Diakaki, 2015; Makan, Malamis, Assobhei, Loizidou, & Mountadar, 2013). "Operating cost" may also include maintenance costs or not (Vučijak, Kurtagić, & Silajdžić, 2016; Arıkan, Şimşit-Kalender, Vayvay, 2015; Aghajani Mir, Taherei Ghazvinei, Sulaiman, Basri, Saheri, Mahmood, et al., 2015). Another notable sub-criterion is "income from secondary products" (17%). Although this sub-criterion was introduced in 2003 (Makan & Mountadar, 2013), it became more prevalent in research articles from 2011 onwards, reflecting a trend in MSWM to make MSW treatment financially viable. Another issue surrounding the economic sub-criteria is the low frequency of "support funds" (2%) and "market development" (2%). As previously mentioned, the primary issues with MSWM are the lack of financial support (Guerrero, Maas, & Hogland, 2013) and the creation of markets for products recovered from treatment processes (Liu, Wu, Li, 2013; Yap & Nixon, 2016).

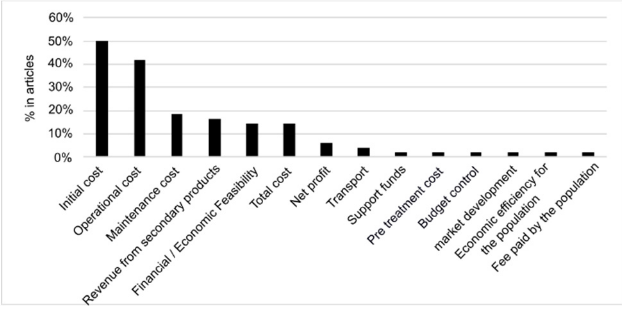

Figure 8. Frequency of economic subcriteria

The sub-criteria that most commonly appear in MSWM and involve social aspects are "Social acceptance" (31%) and "Employment generation" (27%) (Figure 9). These sub-criteria have been studied in various research articles, including those by (Kharat, Raut, Kamble, & Kamble, 2016; Vučijak, Kurtagić, Silajdžić, 2016; Thampi, Rao, 2015; Arıkan, Şimşit-Kalender, & Vayvay, 2015; Panagiotidou, Stavrakakis, Diakaki, 2015; Lolli, Ishizaka, Gamberini, Rimini, Ferrari, Marinelli, et al., 2016; Antonopoulos, Perkoulidis, Logothetis, & Karkanias, 2014; Inglezakis, Ambăruş, Ardeleanu, Moustakas, & Loizidou, 2016; Makan, Malamis, Assobhei, Loizidou, & Mountadar, 2013; Arena, Mastellone, & Perugini, 2013). It is worth noting that these sub-criteria may also represent an economic sub-criterion (Babalola, 2015).

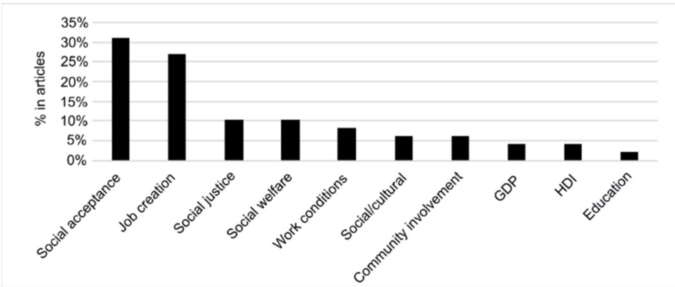

Figure 9. Frequency of social subcriteria

Among the technical sub-criteria (Figure 10), "Qualified HR" (25%) and "Technological Maturity" (21%) stood out. "Qualified HR" is an important sub-criterion for ensuring process efficiency and contributing to the dissemination of knowledge related to MSW problems. The lack of knowledge is also one of the barriers faced by MSWM. "Technological Maturity" is important in attributing confidence in the implementation of technology, given that the investments and risks attributed are high.

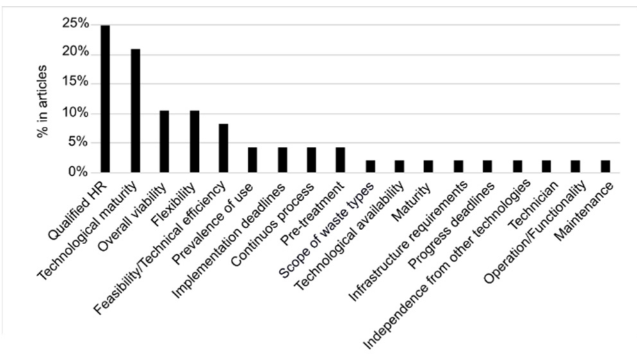

Figure 10. Frequency of technical subcriteria

Legal compliance" (23%) is the most mentioned political sub-criterion (Figure 11), followed by "Political support" (8%). Some authors consider legal compliance as a technical sub-criterion (Vučijak, Kurtagić, Silajdžić, 2015; Makan & Mountadar, 2013) while others consider it as a political sub-criterion (Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, Ismailova et al., 2014; Inglezakis, Ambăruş, Ardeleanu, Moustakas, & Loizidou, 2016).

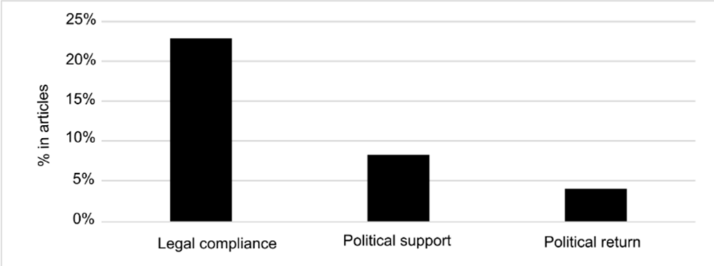

Figure 11. Frequency of political subcriteria

The administrative sub-criteria, as shown in Figure 12, include "Adoption of consortium solutions" (4%), "Administrative procedures" (2%), and "Management demand" (2%).

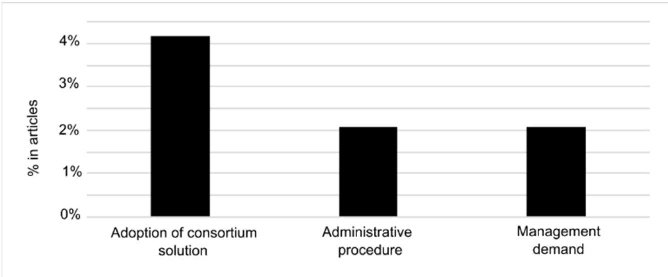

Figure 12. Frequency of administrative subcriteria

The same criterion can represent and be represented in different ways in the literature. For example, "human health", in addition to being normally represented in this way (Kharat, Raut, Kamble, & Kamble, 2016; Vučijak, Kurtagić, & Silajdžić, 2016), has also been represented as “human toxicity” (41), or as “exposure to pathogens” (Babalola, 2016) and even as “cancerous” and “non-cancerous” (Soltani, Sadiq, & Hewage, 2015). In addition, “human health”, which is normally seen as an environmental sub-criteria, was also classified as a social sub-criteria (Inglezakis, Rojas-Solorzano, Kim, Moustakas, Aitbekova, Ismailova, et al., 2014). “Location” can be seen as an environmental sub-criterion. Thampi and Rao (2015) representing the impact of waste transport or as a social sub-criterion (Vego, Kučar-Dragičević, and Koprivanac (2007) representing the impact of installation near populated regions.

Another sub-criterion that has variations in its definition is “atmospheric emissions”, which can represent any type of emission can also be divided into particulate matter and gases or into dust and organic matter and even divided into organic and inorganic. In many works, specific problems of atmospheric emissions are separated from the criterion “atmospheric emissions” such as “global warming” (Pandyaswargo, Onoda, & Nagata, 2012; Tan, Lee, Hashim, Ho, & Lim, 2013; Cherubini, Bargigli, & Ulgiati, 2008; Özeler, Yetiş, & Demirer, 2006) and the “depletion of the ozone layer” (Zaman, 2016).

The sub-criteria “waste reduction” and “resource recovery” are strongly related to environmental, economic, and technical criteria. The “waste reduction”, which refers to the reduction of waste volume, was classified as an environmental sub-criterion or as a technical sub-criterion (Herva & Roca, 2013). The “resource recovery” that refers to the recovery of energy and materials in many works represents only the recovery of energy. In addition, “recovery of resources” can be classified as an Environmental criterion, technical and economic represented as “product revenue” or “product sales” (Tarmudi, Abdullah, & Tap, 2015; Samah, Manaf, Aris, & Sulaiman, 2011).

We can see that there are different ways of organizing and interpreting the criteria involved in MSWM due to their relationships and influences. This organization is related to the objectives of the decision. Thus, in an illustrative way, we produced Figure 13, which represents a decision matrix of the most frequent criteria in the MSWM of the studies studied.

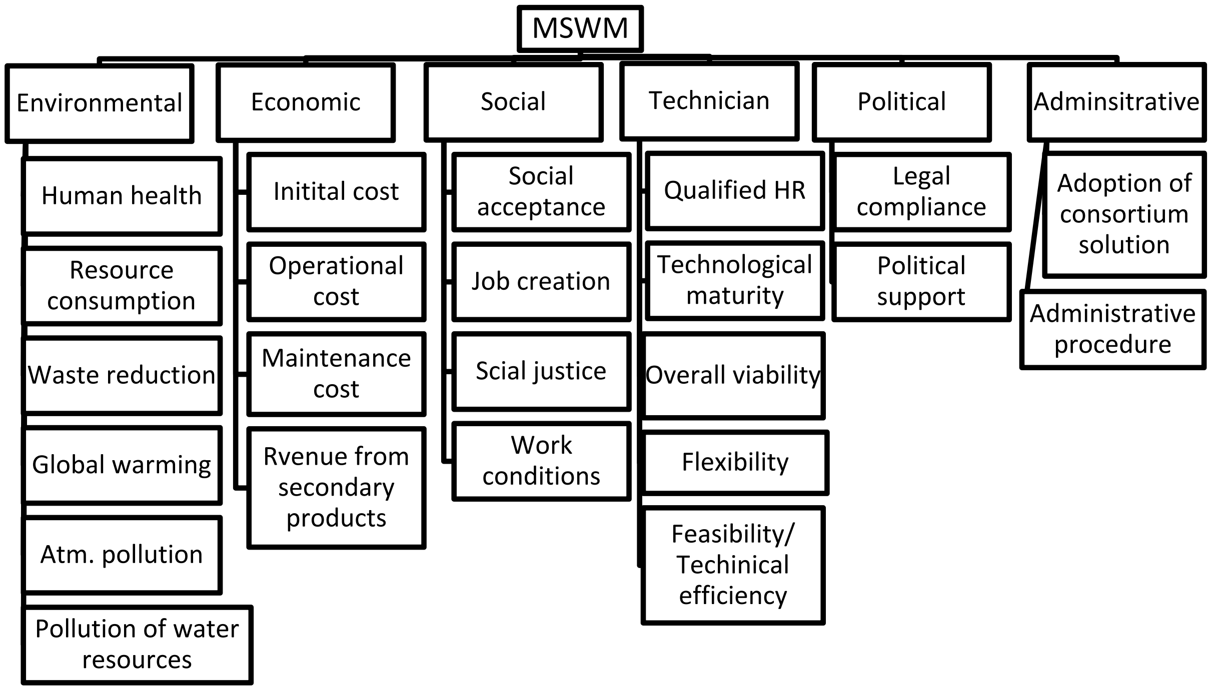

Figure 13. Illustrative matrix of the most frequent criteria in MSWM these review

4. Conclusions

MSWM aims to address various issues associated with the growth of MSW production and yield environmental, economic, and social benefits. Municipalities can use MSWM to plan their actions consistently and combat specific problems to achieve their objectives. LCA, AHP, TOPSIS, and PROMETHEE are the main tools employed to assist in MSWM, and combining two or more of these tools is beneficial for leveraging their distinct advantages.

The criteria involved in MSWM vary according to the objectives of the studies, primarily aimed at achieving sustainable waste management. The main sub-criteria involved include "atmospheric emissions," "waste reduction," "human health," "resource consumption," "emissions," "initial cost," "operating cost," "revenue from secondary products," "social acceptance," "employment generation," "land demand," "product recovery," "qualified human resources," "harmonization with the legislative framework," and "political support." These sub-criteria can fit within different environmental, economic, social, technical, and administrative political criteria, depending on the interpretation and objectives of the decision-maker. There is an important lack of political and administrative criteria that can contribute to a broader view of the difficulties in implementing integrated management.

Based on this review, it is evident that integrated waste management is a promising approach to achieve significant waste reduction, greater recovery of materials and secondary products, and bring MSWM closer to the zero-emission strategy based on natural cycles. However, implementation difficulties arise due to the complexity of the problem, lack of technical knowledge by decision-makers, limited population awareness, inadequate government support, lack of market for secondary products, insufficient financial resources, and inadequate infrastructure. Therefore, in addition to defining a sequence for the implementation of technologies aimed at integrated management, government officials need to take measures to overcome the primary barriers, such as investment funds, the market for secondary products, and public awareness campaigns.

This review provides a better understanding of the main tools used in MSWM, the criteria that influence decision-making, and technology alternatives. Despite numerous works proposing decision models in MSWM, most focus solely on identifying a scenario or alternative without considering the form of implementation. Therefore, this review also suggests the construction of models that aid in the search for an integrated scenario according to the region, given the knowledge gap surrounding MSWM. This information also contributes to the practical identification of important implementation points related to regional aspects and technology performance, thereby assisting decision-makers of city halls or concessionaire companies in planning MSWM and seeking scenarios that demonstrate superior performance.

Despite the contributions of this review, several gaps still exist in the literature regarding MSW problems and potential solutions. Thus, the following suggestions for future work emerge from this study:

• Developing a model that aids in the technology implementation sequence, seeking an integrated scenario.

• Assessing the feasibility of integrating the largest number of MSWM technologies, as it may be that configurations with a smaller number of technologies may be more feasible.

A limitation of this review was that the search was based only on Google Scholar and Scopus databases, and the use of expressions only sought papers that applied some tool in decision-making.

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Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal and publisher adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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