Decision Model for Selecting Advanced Technologies for Municipal Solid Waste Management

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Abstract The National Solid Waste Policy (PNRS) was implemented in 2010; it aims to prevent and reduce waste generation, eliminate the so-called 'landfills' and implement municipal solid waste management plans. Waste selective collection and recycling can reduce the amount of waste destined to landfills, reduce transportation frequencies and minimize overall disposal costs. However, the conventional approach currently adopted in Brazil is inefficient considering economic, social and environmental aspects. There is an urgent need to improve municipal solid waste management (MSWM) by proposing alternatives, which cover product-service systems (PSS) and IoT based smart trash dustbins. This study provides an assessment through multicriteria analysis whether the implementation of scenarios using IoT smart trash cans is to be considered a sustainable operational strategy for the municipal public administration. The criteria used in the study was extracted from a systemic literature review; AHP and TOPSIS Fuzzy Methods were applied to achieve the best solution according to the selected criteria, which is the research main objective.

Keywords Selective waste collection · Procknow-C · AHP · Fuzzy-TOPSIS

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1 Introduction

The Law 12305, which deals with the National Solid Waste Policy (PNRS), was implemented in 2010. It aims to eradicate the so-called 'dumps', prepare and implement municipal solid waste plans. Thinking in terms of the circular economy, Da Silva (2018) argues that investments in public policies of environmental education, sectoral and innovation policies are necessary to reorganize chains, turning a problem into an opportunity for municipalities.

An alternative to selective waste collection is to transform the traditional service (static) approach into a Product-Service-System (PSS). Thus, a service component (waste collection) is improved by a product component, i.e., technological alternatives to monitor waste, allowing the management of variable and dynamic waste streams (Elia et al. 2018). These technical options are part of a new way of thinking productive systems through smart cities. Díaz-Díaz et al. (2017) analyzed and compared business models in Intelligent Cities. Their results indicated that municipal services using smart technologies generally present a value proposition focused on service efficiency, which in consequence reduces environmental impact and lower costs.

Sustainability in operations is a necessity associated with waste management activities due to the complexity and amount of produced waste. Alternative systems and technologies for waste management have been researched as a way to solve or improve conventional systems, using dumpsters with sensors and Internet of Things (IoT), for example (Misra et al. 2018; Wen et al. 2017; Yerraboina et al. 2018).

However, these alternatives are not only technological. Others are related to paying schemes for the produced waste, by either weight or volume (Dahlen et al. 2010). These options can be very efficient when associated with waste bins technologies with RFID sensors tags. These bins can assist in charging through the measurement of weight and volume as well as in the inspection of the collection, transport and final destination (Wen et al. 2017).

Considering this context, the main objective behind the study is to structure a model to evaluate the implementation of sustainable operations and innovative technologies in the MSWM. A systematic review of the literature was carried out. The opinion of experts was used to select criteria and more adequate alternatives adjusted to the setting of a municipality in the Western region of the Brazilian state of Santa Catarina.

2 Theoretical Background

The management of solid waste by municipalities is crucial for public health, environmental protection and avoid visual pollution. It is necessary to properly manage all activities involving solid waste, from collection to final disposal (Al-Khatib et al. 2007). Hlatka et al. (2018) point out that residue separation is significantly influenced by the conditions of households for solid waste sustainable management. Topaloglu et al. (2018) emphasized that waste management must be environmentally sound, economically viable and socially acceptable.

According to Coban et al. (2018), solid waste management depends on the composition of waste produced by the population; it is strongly influenced by socioeconomic factors, seasons and family size. Considering an urban development with inefficient infrastructure and management, waste issues become increasingly complex. Authorities require effective tools to select appropriate technologies that meet the needs of the local infrastructure. Coban et al. (2018) state that multicriteria decision tools (MCDM) stand out as a group of techniques to evaluate MSWM scenarios. The authors also indicates that MCDM methods have gained popularity over the last decade in the area of MSWM, since complex and integrated processes involving distinct dimensions such as environmental, social and economic are very solvable with the use of MCDM. Among the MCDM tools proposed by several authors, TOPSIS has been the most prevalent, because of its ease of use and consistency of results. Additionally, Coban et al. (2018) show that using a single MCDM method to rank alternatives may lead to proposed solutions susceptible to uncertainties.

The uncertainties arise from qualitative parameters, better known as linguistic variables, collected in the study, which are essential for the decision-making. Thus, the fuzzy method proposes the solution by converting linguistic terms into diffuse numbers (Topaloglu et al. 2018). In the present study, two MCDM were used: AHP and fuzzy TOPSIS. The integration of these methods is explained and discussed in the research methodology section.

3 Research Design

This paper presents an evaluation model for the selection of practices and technologies for solid waste management (Fig. 1). The model initially consists of a systemic literature review for the identification and hierarchization of the evaluation criteria. The opinion of experts allows the selection of the most relevant strategy for solid

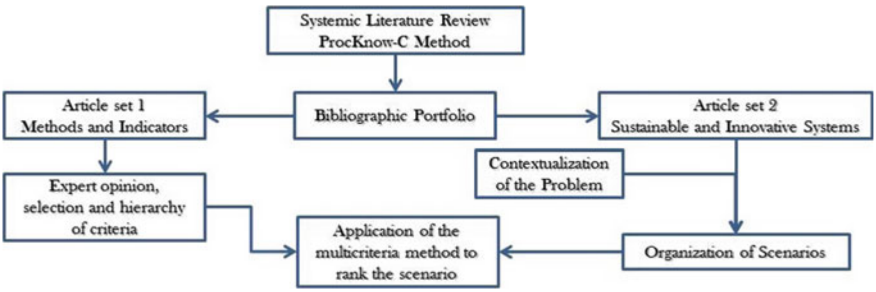

Fig. 1 Selection model of practices and technologies for waste management. *Source* The authors

waste management. Practices of sustainable and innovative operations, which associated with a specific context, may support technological and organizational alternatives for the construction of scenarios were identified through the literature review. Multicriteria decision support methods guide the selection of the best practices and technologies for waste management based on the selected criteria and organization of scenarios.

Using a systemic review of literature based on the method proposed by Ensslin et al. (2010), the Knowledge Development Process-Constructivist (Procknow-C), a 'Paper Set' was organized to analyze the content of the papers. It aimed to identify evaluation criteria and characteristics of innovative and sustainable operations for waste management. A questionnaire based on these results was developed (Table 1) and filled out by experts, selecting criteria relevant to the implementation of waste management sustainable and innovative operating systems.

The Analytic Hierarchy Process (AHP) analyzes the criteria judgments, performed by the experts, through the correlation between the criteria, using the classification shown in Table 2.

The TOPSIS methodology is based on the principle that there are '*n*' criteria and '*m*' alternatives. The selected alternative has a minimum distance from the ideal positive solution and a maximum distance from the ideal negative solution (Gupta and

Table 1 Questionnaire for selection of criteria

	Public acceptance		Quality of collected waste
	Political support		Amount of collected waste
	Infrastructure capacity		Revenue
	Capacity of innovation		Power recovery
	Products lifecycle		Recovery of raw materials
	Public awareness		Reduction of recyclables in landfills
	Creation of new jobs		Income from recyclables sold
	Cost with equipment		Environmental risks/impacts
	Cost with qualified staff		Noise
	Maintenance costs		Safety and hygiene
	Transportation costs		System sustainability
	Investment costs		Size of the population to be served
	Operational costs		Discard rate
	Unemployment		Recycling rate
	Availability of collection points		Collection time
	System efficiency		Type of waste to be collected
	Atmospheric emissions		Vehicle traffic
	Aesthetics		Waste treatment
	Odor		Operational feasibility

Source The authors

Table 2 Numerical classification

Value	Definition	Explanation
1	Equal importance	Identical contribution
3	Low importance	Slightly higher judgment
5	Strong importance	Judgment strongly in favor
7	Very strong importance	Recognized domain
9	Absolute importance	Proven domain
2, 4, 6, 8	Intermediate values	Doubt

Source Adapted from Saaty (2008)

Barua 2018). The ideal positive solution is the solution that maximizes benefit criteria and minimizes cost criteria. The ideal negative solution is the solution that maximizes cost criteria and minimizes benefit criteria (Mesquita 2014). Chen (2000) extended TOPSIS as triangular Fuzzy Numbers (FN). The researcher introduced a vertex method to calculate the distance between two triangular FN. If $\tilde{x} = (\mathrm{a1}, \mathrm{b1}, \mathrm{c1})$, $\tilde{y} = (\mathrm{a2}, \mathrm{b2}, \mathrm{c2})$ are two triangular FN (1).

$$d(\tilde{x}, \tilde{y}) := \sqrt{\frac{1}{3}\left[(a1 - a2)^2 + (b1 - b2)^2 + (c1 - c2)^2\right]} \quad (1)$$

In the study, TOPSIS Fuzzy procedure was applied as per the instructions by Nădăban et al. (2016). Step 1 is the assignment of rating to the criteria and alternatives, assuming there is a decision group with K members. The Fuzzy classification of the decision makers kth about alternatives $\mathrm{A_i}$ w.r.t. criterion $\mathrm{C_j}$ is denoted $\tilde{x}^{\mathrm{k}}_{\mathrm{ij}} = (\mathrm{a}^{\mathrm{k}}_{\mathrm{ij}}, \mathrm{b}^{\mathrm{k}}_{\mathrm{ij}}, \mathrm{c}^{\mathrm{k}}_{\mathrm{ij}})$ and the weight of the criterion $\mathrm{C_j}$ is denoted $\tilde{w}_{kj} = (\mathrm{w_{kj1}}, \mathrm{w_{kj2}}, \mathrm{w_{kj3}})$. In Step 2, the aggregate diffuse classifications for the alternatives (Table 3) and diffuse weights aggregated for the criteria are calculated (Table 2).

The aggregated fuzzy classification $\tilde{x}_{\mathrm{ij}} = (\mathrm{a}_{ij}, \mathrm{b}_{ij}, \mathrm{c}_{ij})$ of ith alternative w.r.t. jth. The criterion is obtained as per Eq. (2).

Table 3 IVIFS linguistic values for linguistic terms

Linguistic term	IVIFS
Low (L)	(0.0; 0.1; 0.3)
Reasonably low (RL)	(0.1; 0.3; 0.5)
Medium (M)	(0.3; 0.5; 0.7)
Reasonably high (RH)	(0.5; 0.7; 0.9)
High (H)	(0.7; 0.9; 1.0)

Source Adapted from Nădăban et al. (2016)

$$\mathrm{a_{ij}} = \frac{\min}{k}\{a_{\mathrm{ij}}^{k}\}, \mathrm{b_{ij}} = \frac{1}{K}\sum_{k=1}^{k} b_{ij}^{k}, \mathrm{c_{ij}} = \frac{\max}{k}\{c_{\mathrm{ij}}^{k}\}. \tag{2}$$

The aggregate weight fuzzy $\tilde{w}_{\mathrm{j}} = (\mathrm{w}_{j1}, \mathrm{w}_{j2}, \mathrm{w}_{j3})$ for the criterion C_j is calculated by the formulas:

$$\mathrm{w_{j1}} = \frac{\min}{k}\{w_{\mathrm{j1}}^{k}\}, \mathrm{w_{j2}} = \frac{1}{k}\sum_{k=1}^{k} w_{kj2}, w_{j3} = \frac{\max}{k}\{w_{\mathrm{j3}}^{k}\}. \tag{3}$$

The normalized fuzzy decision matrix is calculated in Step 3. The normalized fuzzy decision matrix is $\tilde{R} = [\tilde{r}_{ij}]$, (4) and (5).

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{bc_i}{c_j^*}, \frac{cc_i}{c_j^*}\right) \mathrm{e}\; \mathrm{c_j^*} = \frac{\max}{i}\{\mathrm{c_{ij}}\}(\text{benefit criterion}) \tag{4}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \mathrm{e}\; \mathrm{c_j^-} = \frac{\min}{i}\{a_{ij}\}(\text{cost criterion}) \tag{5}$$

The weighted normalized fuzzy decision matrix is calculated in Step 4. The weighted normalized fuzzy decision matrix is $\tilde{V} = (\tilde{v}_{ij})$, where $\tilde{v}_{ij} = \tilde{r}_{ij} \times \mathrm{w}_j$. In Step 5, the Ideal Positive Diffuse Solution (FPIS) (6) and the Ideal Fuzzy Negative Solution (FNIS) (7) are determined. FPIS and FNIS are calculated as per Eqs. (6) and (7):

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*), \text{ where } \tilde{v}_j^* = \frac{\max}{i}\{v_{ij3}\}; \tag{6}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-), \text{ where } \tilde{v}_j^- = \frac{\min}{i}\{v_{ij1}\}; \tag{7}$$

The distance from each alternative to FPIS and FNIS is determined (Step 6). Compute the distance from each alternative Ai to FPIS and FNIS, respectively (Eq. 8).

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), d_j^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \tag{8}$$

In Step 7, the closeness coefficient $\mathrm{CC_i}$ for each alternative is determined. For each alternative $\mathrm{A_i}$, the closeness coefficient $\mathrm{CC_i}$ is calculated as per Eq. (9).

$$\mathrm{CC_i} = \frac{d_i^-}{d_i^- + d_I^*} \tag{9}$$

Finally, in Step 8, the alternatives are classified. The alternative with the highest closeness coefficient represents the best alternative. The TOPSIS Fuzzy method was applied using a spreadsheet program.

4 Results

The results are described in four subsections. The first subsection was a systematic review of the literature with content analysis on the methods, evaluation criteria and characteristics related to the topic 'waste management'. The second involved interviews with experts for the criteria selection and hierarchization. The third subsection presents the contextualization of a real problem and organization of alternatives for a possible solution. The fourth subsection describes the application of the multicriteria method to select the best alternative.

5 Systemic Literature Review

The application of the Procknow-C methodology starts with the definition of keywords. A list of 23 research terms was divided into three research axes (Table 4).

The collection of papers was performed in the Web of Science™ and Scopus® databases through combinations of the search terms and axes. The search was limited to the last 10 years (only papers). Resulting references were inserted in the Mendeley® software; duplicated papers were excluded. A total of 21,040 papers was obtained. The process continued with the analysis of the titles, which resulted in 503 papers aligned with the research theme.

In the scientific recognition analysis, 228 papers with more than five citations passed through the analysis of abstracts and 88 were regarded as aligned with the

Table 4 Axes and terms used in the research

Axes	Diagnosis	Sustainable operations	Waste management
Search terms	Diagn* Audit* Evaluat* Analy* Perform* Assess* Manag* Means*	Sustainab* "Triple bottom line" "Value creation" "Business model" "Smart Cit*" IOT "Internet of things" Recy* Upcyc* Reduc* Reus*	"waste management" "Solid waste*" "Municipal waste*" "Zero waste*"

Source The authors

research theme. The authors of these papers composed a data set of 254 authors. A list of 275 papers with less than five citations went to the reanalysis process; other 22 were selected. The sum of the selected references resulted in 110 items, after being thoroughly read, the set of papers was organized and composed. Then, the paper set was divided into two other sets. The first aim was to identify waste management methodologies and evaluation criteria in different contexts. The second aim was to identify sustainable and innovative waste management systems. The references and evaluation methodologies of the first set can be verified in Table 5.

Table 5 shows that the TOPSIS evaluation method was the most used as seen in Arıkan et al. (2017), Coban et al. (2018), Hlatka et al. (2018), Jovanovic et al. (2016), Mir et al. (2016), Pires et al. (2011) and Topaloglu et al. (2018). The criteria were identified (Frame 1). Nevertheless, due to different contexts for different indicators, it was decided to group similar criteria. For instance, Jovanovic et al. (2016) uses particulate matter, emission of gases (CH_4, CO_2 and N_2O); Stefanović et al. (2016) used and classified emissions of greenhouse gases (CO_2) and emissions of acid gases (NO_x and SO_2) as environmental indicators. In the current study, all of those are considered in the atmospheric emissions criterion. The second set of papers encompassed 13 references (Table 6). Content analysis aimed to identify solid waste management sustainable and innovative systems.

As shown in Table 6, the IoT information technologies are the most prevalent features due to the number of papers that address them within the set. They have been studied by Díaz-Díaz et al. (2017), Elia et al. (2015, 2018), Misra et al. (2018), Wen et al. (2017) and Yerraboina et al. (2018).

6 Selection and Hierarchization of Criteria

Three experts were selected. All of them graduated in Environmental Engineering; one has a master's degree in Building Engineering and is a lecturer in the subject of solid waste management. The other two have master's degrees in Environmental Engineering, with experience in municipal waste management. The experts were requested to indicate relevant criteria for the implementation and operations of sustainable and innovative waste management systems, using a questionnaire with closed questions. Each of the experts received a questionnaire to evaluate the criteria, individually and without any consultation with the other interviewees. The 11 selected criteria (Table 7) are observed in the literature and considered relevant by the experts. For the application of multicriteria methods, the selected criteria were divided into three categories (environmental, economic and social).

The experts, according to the AHP methodology and Saaty's classification (Table 2), performed peer comparison. Table 8 shows the results of the weights for each criterion after the judgement by the experts through the AHP method.

Table 5 Methods identified in the first set of papers

Authors	Methods												
	AHP	ASPID	TOPSIS	ELECTRE	VIKOR	ANP	MCDA-C	DEA	PROMETHEE	GAIA	WARM	FUZZY	SAW	Authorial
Arıkan et al. (2017)			X						X			X		
Banar et al. (2010)				X		X								
Coban et al. (2018)			X						X					
Deus et al. (2016)											X			
Herva and Roca (2013)	X								X	X				
Hlatka et al. (2018)			X											
Huang et al. (2011)								X						
Jovanovic et al. (2016)			X										X	
Khalili and Duecker (2013)				X										
Lolli et al. (2016)									X			X		
Makan et al. (2013)									X					
Milutinović et al. (2014)	X													
Milutinovic et al. (2016)	X													

(continued)

Table 5 (continued)

Authors	Methods													
	AHP	ASPID	TOPSIS	ELECTRE	VIKOR	ANP	MCDA-C	DEA	PROMETHEE	GAIA	WARM	FUZZY	SAW	Authorial
Mir et al. (2016)			X		X									
Pires et al. (2011)	X		X											
Rigamonti et al. (2016)														X
Rodrigues et al. (2018)							X							
Sarra et al. (2017)								X						
Simões et al. (2012)								X						
Stefanović et al. (2016)	X	X												
Topaloglu et al. (2018)			X									X		
Vucijak and Silajd (2015)	X				X			X						

Source The authors

Table 6 Sustainable and innovative features identified in the second set of papers

References	Features
Da Silva (2018)	The Circular Economy as a new way of thinking about current issues of urban planning and management, creating opportunities
Dahlen et al. (2010)	Scheme of payments as per waste collection rate *Pay as you throw* based on weight and volume
Díaz-Díaz et al. (2017)	Intelligent city business models based on the benchmarking of eight urban services rendered in the city of Santander; waste management was highlighted due to a 20% reduction in the cost of providing the service yearly
Elia et al. (2015)	It proposes a holistic framework for designing and managing PAYT systems applied to MSWM services through intelligent technology solutions
Elia et al. (2018)	Dynamic collection schemes for Electrical and Electronic Equipment Waste through IoT technology
Gelbmann and Hammerl (2015)	Appropriate business model for the establishment of new (sustainable) systems of products and services (SPSS) for reuse in social enterprises with labor integration ecologically oriented practices (ECO-WISEs)
Manni and Runhaar (2014)	Scheme for the payment of a waste collection rate *Pay as you throw* as an incentive to reduce waste
Misra et al. (2018)	It features an intelligent waste collection system based on an IoT trash can, which measures the level of materials and presence of gases; it sends this information to a cloud server for storage and processing over the Internet
Rada et al. (2013)	Optimization of the selective collection with the implementation of a system based on Geographic Information Systems (Web-GIS)
Rebehy et al. (2017)	Social innovation proposed through a sustainable and inclusive business model, with intensive use of information technology and logistics
Tseng and Bui (2017)	Business management through eco-innovation, and industrial symbiosis to achieve win-win status in supply chain networks
Wen et al. (2017)	Studies the implementation and evaluation of a sensor-based IoT network technology to improve waste management of restaurant food in the city of Suzhou, China
Yerraboina et al. (2018)	Prototype of an IoT trash can called "*Smart Garbage Bin*"

Source The authors

Table 7 Indicators observed in the literature and selected by the experts

Category	Criteria
Social	C1—Public acceptance
	C2—Awareness
	C3—Safety and hygiene
Environmental	C4—Amount of waste collected
	C5—Environmental risks and impacts
	C6—Reduction of recyclables in landfills
Economic	C7—Equipment costs
	C8—Investment costs
	C9—Operational costs
	C10—Income of recyclables
	C11—System efficiency

Source The authors

Table 8 Weights of the criteria

	Criteria	Weights			Average
		Spec. 1	Spec. 2	Spec. 3	
Social	C1	0.106	0.283	0.106	0.165
	C2	0.633	0.643	0.633	0.637
	C3	0.260	0.074	0.260	0.198
Environmental	C4	0.455	0.748	0.633	0.612
	C5	0.091	0.071	0.106	0.089
	C6	0.455	0.180	0.260	0.298
Economic	C7	0.053	0.370	0.056	0.160
	C8	0.057	0.370	0.084	0.171
	C9	0.362	0.151	0.216	0.243
	C10	0.143	0.073	0.154	0.124
	C11	0.385	0.035	0.490	0.303

Source The authors

7 Contextualization of the Solid Waste Management in a Municipality in the Western Region of the Brazilian State of Santa Catarina to Build Possible Scenarios

According to the Environmental Department of a municipality located in the Western region of the Santa Catarina state, the city does not have landfills or its own machinery for garbage collection. This service is the responsibility of a private company. The municipality pays a fixed amount for the collection of recyclable waste and a variable

Table 9 Description of scenarios

Scenario	Description of the recycling collection scenarios
A1	Current scenario without any changes, door-to-door collection without a recyclable waste identification system and without financial incentives or fines
A2	Door-to-door collection, with the use of identification systems by colored packs/bags without any use of technology or other financial incentives
A3	Door-to-door collection, using identification systems by colored packs/bags without using technology, with the application of fines for those who fail to separate waste
A4	Door-to-door collection with the use of GIS tools, route classification and priority locations, identification of recyclable materials and application of fines for those who fail to perform the separation
A5	Recyclable waste collection points in the municipality and neighborhoods centers placed at strategic points without using technology or financial incentives or fines
A6	Collection points for recyclable waste using IoT trash cans in the center of the municipality, in the center of the neighborhoods, in strategic locations, without a discount in the property taxes or other similar financial incentives
A7	Collection points for recyclable waste using IoT trash cans in the center of the municipality, in the center of the neighborhoods, in strategic locations, with a discount in the property taxes or other similar financial incentives

Source The authors

rate, according to the amount of residue. Decreasing the amount of recyclable organic matter mixed with residue decreases the value of the variable rate to be paid. Thus, the issue can be summarized in the following question: What are the systems alternatives for the optimization of solid waste management?

Considering the results observed in the second set of papers in the portfolio (Table 6), the selected indicators and context, seven possible scenarios were developed. They are used to compare and apply the multicriteria methodology and select a possible ideal scenario. These scenarios are described in Table 9.

8 Analysis Using the TOPSIS Fuzzy Methodology

Through the analysis of the three experts, seven scenarios or alternatives for the collection of recyclable solid waste were evaluated. The context of the city was studied, considering the 11 selected criteria and their respective weights. It should be indicated that the classifications, environmental, economic and social, have equal weights in the study. Hence, the sum of the environmental criteria has the same weight as the sum of the social criteria, which in turn is equal to the sum of the economic criteria.

For the application of the TOPSIS Fuzzy methodology, the experts filled out a spreadsheet with linguistic variables (Table 3), relating the scenarios to the criteria. Tables 10, 11 and 12 show the linguistic judgments regarding the performance of the alternatives.

Table 10 Expert assessment matrix 1 on the performance of alternatives

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	H	L	L	H	H	L	L	L	L	L	L
A2	RH	RL	RL	RH	RH	L	L	L	L	L	L
A3	RL	RL	RL	M	M	M	L	L	L	L	RL
A4	RL	M	M	RL	M	M	RL	RL	RL	M	RH
A5	M	M	M	RL	M	RH	M	M	M	M	RH
A6	RL	M	RH	L	RL	H	RH	RH	M	H	H
A7	M	M	RH	L	RL	H	RH	RH	M	H	H

Source The authors

Table 11 Expert assessment matrix 2 on the performance of alternatives

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	M	RL	L	RL	RH	L	L	L	RL	RL	RL
A2	M	M	RL	M	M	RL	RL	RL	RL	RL	M
A3	L	RH	M	M	RL	RL	RL	RL	M	M	M
A4	RL	H	H	RH	L	M	M	RH	M	RH	RH
A5	M	RH	RH	RH	RL	RH	RH	RH	RH	RH	RH
A6	RH	RH	RH	H	L	H	H	H	H	H	H
A6	H	H	H	H	L	H	H	H	H	H	H

Source The authors

Table 12 Expert assessment matrix 3 on the performance of alternatives

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C8	C10	C11
A1	H	L	L	H	H	L	M	M	RH	L	RL
A2	M	RL	RL	H	RH	RL	RH	RH	H	RL	RL
A3	RL	RH	M	H	RL	RH	RH	RH	H	RH	RH
A4	RL	RH	M	H	RL	RH	RH	RH	H	RH	RH
A5	L	M	RH	L	M	M	M	M	RL	M	M
A6	L	M	RH	M	M	M	M	H	M	RH	M
A7	M	RH	H	RH	L	RH	M	H	M	H	RH

Source The authors

Table 13 Result with the ranking of alternatives

Alternatives	Ranking expert 1	OP	Ranking expert 2	OP	Ranking expert 3	OP	Final ranking	DG average
A1	7	0.509	7	0.513	7	0.476	7	0.488
A2	5	0.526	6	0.528	6	0.478	6	0.494
A3	2	0.531	4	0.534	3	0.522	4	0.526
A4	1	0.533	1	0.552	3	0.522	2	0.532
A5	4	0.527	5	0.534	2	0.526	3	0.528
A6	6	0.525	3	0.534	5	0.514	5	0.521
A7	3	0.528	2	0.552	1	0.548	1	0.549

Source The authors

The values presented in the tables were converted into fuzzy numbers, and the normalized results were then multiplied by the respective weight of each criterion. The ideal positive and negative solutions were calculated according to (4) and (5). Using the method according to (6), (7), and (8), the distances between the values and the ideal positive solutions (FPIS) and the negative (FNIS) were determined. Using (9), the closeness coefficient (CCi) was calculated. Table 13 lists the rankings of the alternatives and their respective Overall Performance (OP) according to the judgment of each expert. Table 13 shows a final ranking, that is, the result of a weighted average of the results.

It is possible to see that the Alternative A7, that is, recyclable garbage collection points using IoT trash cans in the center of the municipality, the center of the neighborhoods, in strategic locations, with a discount in property taxes or other similar financial incentives, has the highest ranking positions. This means that the collection of recyclable solid waste comes closest to the ideal positive solution; it is also the furthest from the ideal negative solution.

9 Conclusion

The study achieved its main goal, i.e., structuring a model to evaluate the implementation of MSWM sustainable operations and technologies. Based on these results, it is not yet possible to ensure that technological and innovative systems are a final solution. However, it is clear, considering the alternatives selected by experts, current waste management methods are not the more adequate. The interpretation of the indicators by experts is regarded as a limitation related to this investigation. The experts selected the criteria based on their experiences. As a future agenda is possible to move beyond the replication of the search, choosing other criteria. In organizing scenarios and selecting possible alternatives, the MCDM approach should also consider the managers' opinions in the criteria selection and hierarchy.

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