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ORIGINAL PAPER

The multi-criteria analysis (AHP) method use for the environmental problems management: case of the household waste in Morocco

Driss Elhamdouni[1] · Abdelkrim Arioua[1] · Ismail Karaoui[1] · Kamal Ait Ouhamchich[1] · Elhousna Faouzi[1] · Baaddi Aba[2]

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Abstract

Household waste management is currently a major environmental challenge for all local authorities in Morocco. This study aims to evaluate the use of a new decision-making method—the analytical hierarchy process (AHP), which is based on matrix calculations—to select the most suitable waste management system for the Khenifra region of Morocco. A management system appropriate for the context of the region is suggested from a sustainable development perspective. Firstly, several schemes are examined and analyzed by applying the AHP method, which consists of a multi-criteria analysis of parameters and constraints linked to financial, technical, environmental, and socioinstitutional aspects. Secondly, five alternative management systems are compared and classified according to their performance levels and efficiencies. The results obtained using the complete priorities vector show that system 3 is the most appropriate household waste management scenario for this region, because it receives the greatest appreciation in all decisions made by the decision maker. The selected system (waste sorted at source, recycling–composting) follows the 3R principle (recycle, reduce, and reuse) and provides better control of integrated household waste management while respecting the environment and taking into account the conditions in developing countries. The multi-criteria analysis method and the evaluation criteria processing procedure proposed in this study provide decision makers with recommendations for the future of integrated household waste management in the Khenifra region in particular and developing countries in general.

Keywords Multi-criteria analysis (AHP) · Environmental problems · Household waste · Morocco

Introduction

Sustainable solid waste management is one of the major challenges facing humanity at present and in the future. Indeed, this solid waste problem, caused by growing urbanization, improved living standards, increased consumption, and the lack of an adequate waste management policy, is generating enormous risks to the environment and the health of populations (Ben Ayed et al. 2005; Strunk and White 1979; Van der Geer et al. 2000; Mettam and Adams 1999).

Household waste characterization studies performed in certain developing countries such as Tunisia (Zaïri et al. 2004; Ben Ammar 2006), Algeria (Tahraoui et al. 2012), and Morocco (Elhamdouni et al. 2019) have shown that this waste is rich in organic matter, which suggests that biological treatment (composting) would be the most suitable waste management method.

Household wastes produced in the Khenifra region are rich in fermentable matter (67–70% dry weight) and have a high humidity content (67–85% fresh matter). Composting is a possible solution to reduce the quantity of solid waste and to compensate for deficiencies inorganic matter, such as to increase the organic content of soil (Elhamdouni et al. 2019, 2021).

The establishment of a sustainable solid-waste management scheme that integrates the whole chain requires the selection of the most suitable model for regions in developing countries, which calls for decision-making based on multi-criteria analysis of several attributes. Multi-criteria analysis is commonly used for decision support (Malczewski

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✉ Driss Elhamdouni
elhamdounistu@gmail.com

[1] Water Resources Management and Valorization and Remote Sensing Team, Department of Earth Sciences, Faculty of Sciences and Technics, University Sultan Moulay Slimane, Mghila, B.P. 523, Beni Mellal, Morocco

[2] Province of Khenifra, Khenifra, Morocco

2006; Makan 2013), and is even considered the most important method in the field of environmental science (Jiang and Eastman 2000). However, the analytical hierarchy process (AHP) is used much more in the weighting of criteria and in multi-criteria evaluation (Chakhar 2006; Scener et al. 2011; Elhamdouni et al. 2017; Barakat et al. 2017) relating to the criteria hierarchy, pairwise comparison factor weighting (Saaty 1980a, b), of the criteria standardization according to fuzzy logic. To this end, multi-criteria analysis methods play an essential role in decision-making regarding problems related to waste management.

The study reported here provides the platform for a basic approach that should help decision makers to set up the most suitable system for the sustainable management of solid waste in developing countries, taking into account different socioeconomic, technical, and environmental criteria using a multi-criteria analysis method (AHP).

Materials and methods

Study area

The Khenifra region is located in the center of Morocco (Fig. 1); it is part of the Béni Mellal-Khénifra region, which is one of the 12 Moroccan regions created by the territorial division performed as part of advanced regionalization. Administratively, Khenifra is split into 22 municipalities, including two in the urban area and 20 in the rural area. According to censuses carried out during 2014, its population is estimated at 371,145 inhabitants (GCPH 2014). The climate of this region is that of continental Mediterranean mountains; it is characterized by a cold and rainy winter with periods of snow in the high mountains and a hot and dry summer with stormy periods (Elhamdouni et al. 2017).

Studies carried out on household waste management in the study area have shown the existence of several problems with and constraints on the current management system (Elhamdouni et al. 2018). They have shown that efficient and sustainable exploitation of the waste deposited requires a combination of three treatment methods: recycling, energy recovery in the form of solid recovered fuels (SRF), and composting (Elhamdouni et al. 2019).

Choice of an appropriate method (AHP)

Several methods are available for multi-criteria decision support (Vincke 1992; Makan 2013). There are no better or worse techniques, but some techniques are better suited to particular decision problems than others. It is essential to develop in detail all the elements related to the situation about which a decision must be made before selecting a method to use to solve the studied problem.

The method used for decision-making should not be decided upon early in the process; it is important to wait until the decision maker understands the problem, the possible alternatives, the different outcomes, and the conflicts between the criteria and the level of uncertainty in the data.

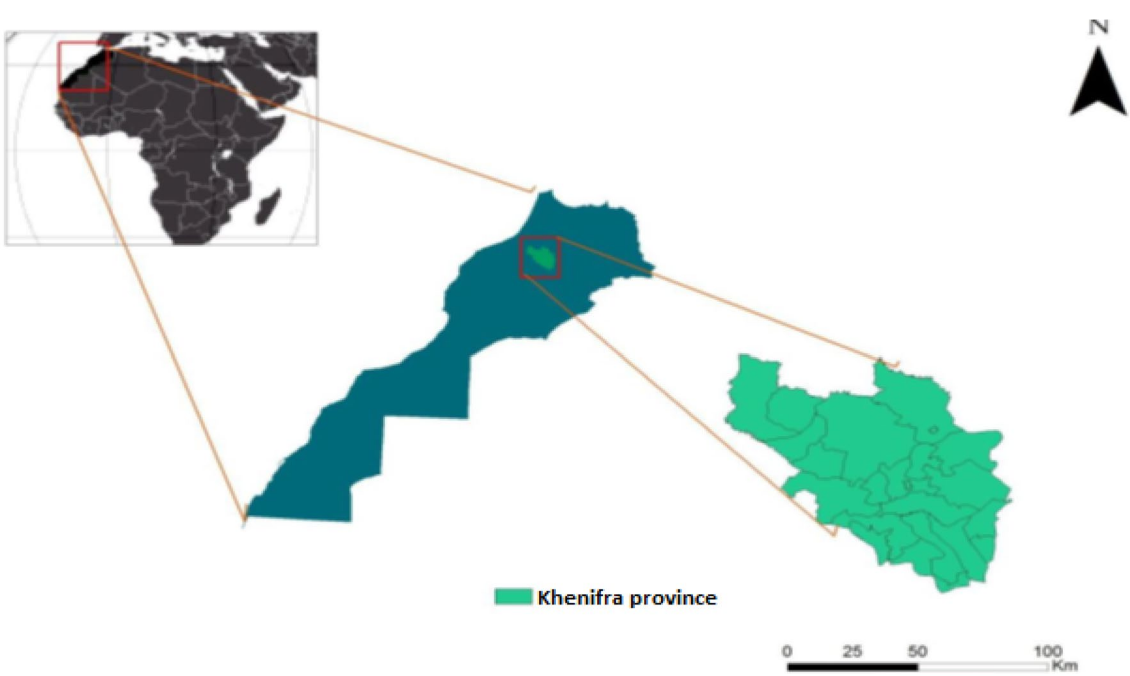

Fig. 1 Map of the study area

In this study, the AHP (analytical hierarchy process) method was chosen because of its efficiency and its ability to reconcile the way the human mind expresses and synthesizes preferences in the face of multiple conflicting decision perspectives (Şcener et al. 2010; Mansour et al. 2014; Elhamdouni et al. 2017). The AHP method is based on complex calculations using matrix algebra and allows a complex problem to be broken down into a hierarchical system in which binary combinations are established at each level of the hierarchy. Ranking the situations encountered by the decision maker hierarchically can allow relative priorities to be deduced.

The approach

In this paper, we will develop the decision-making process necessary to use the AHP method. This process occurs in several stages, and the goal of the analysis must be clearly identified beforehand. The steps are shown in Fig. 2.

Problem definition

The problem posed is the selection of the most appropriate solution for the context of the Khenifra region (Morocco). To facilitate the implementation of the solution that is optimally adapted to the problem, the analysis must take into account environmental, social, economic, and technical aspects.

Description of scenarios/systems

According to the literature, there are various possible waste management systems (Makan 2013). The waste management systems and scenarios studied here were selected based on several factors: the specific characteristics of the country and region of interest, the experience gained from applications at an international scale, and the properties of small territories such as the study area. Systems that offer pyrolysis, ethanol fermentation, and gasification were eliminated because

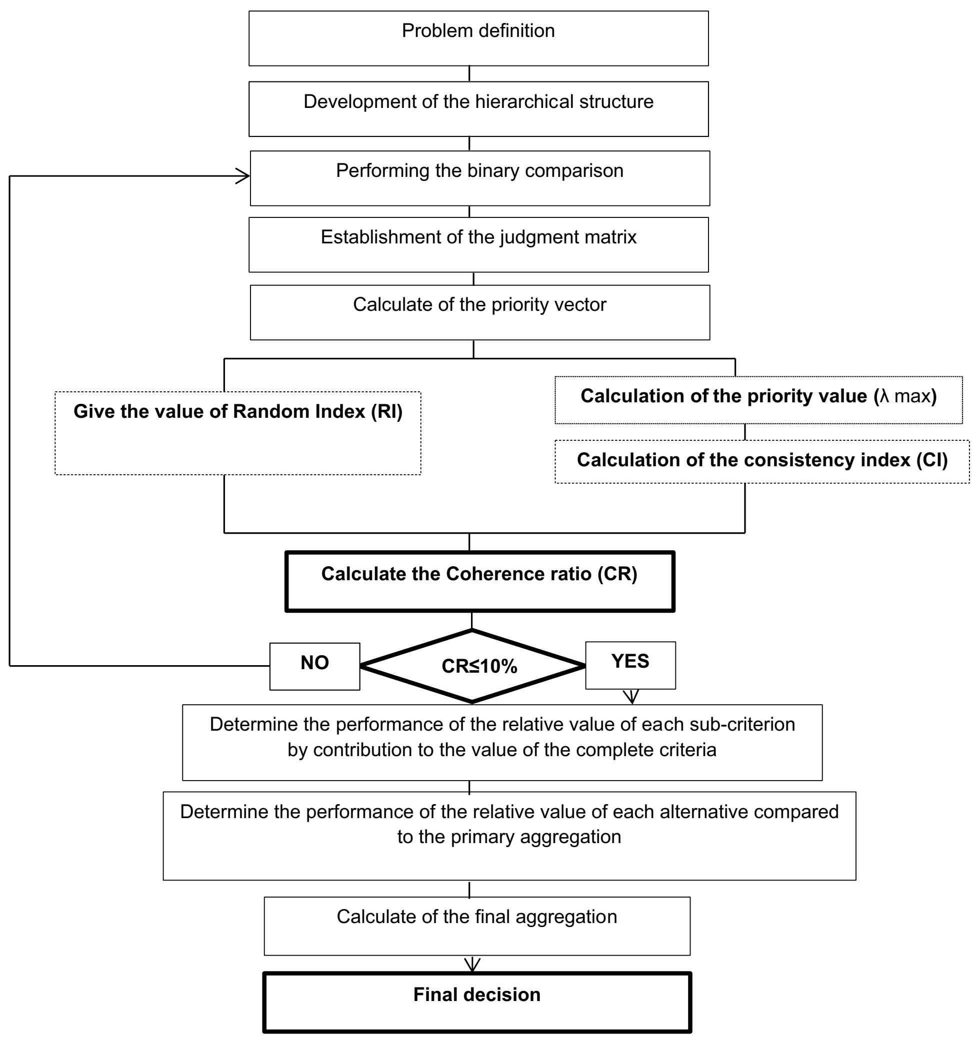

Fig. 2 Steps involved in applying the AHP method

they are highly technical and very expensive. Therefore, the selected scenarios are as follows:

– Scenario/system 1: landfill

This is the baseline scenario for evaluating the performance of every other management scenario because it is used as a management system in many countries. It involves collecting the waste and disposing of it at the landfill.

– Scenario/system 2: mixed collection–mechanical sorting–anaerobic digestion

In this scenario, mixed waste is collected and transferred for mechanical sorting to recover recyclable materials (glass, plastic, cardboard, and metals); the rest of the waste (biodegradable) is subjected to biological treatment by anaerobic digestion.

– Scenario/system 3: sorting at source–composting–landfill

In this system, the waste is separated at source into different bins. Recyclable materials are brought to a treatment station to recover glass, paper, plastic, and ferrous and nonferrous metals. The biodegradable materials are taken to another station to undergo biological treatment by aerobic digestion (composting). The solid waste residues recovered after these treatments are then transferred to the bins in the landfill.

– Scenario/system 4: mixed collection–mechanical sorting–composting

Here, mixed solid waste is collected for mechanical treatment followed by biological treatment. Mechanical processing enables the recovery of glass, ferrous and nonferrous metals, paper, and plastics, which are shipped to users, while biological processing enables the composting of biodegradable organics. The residues are disposed of in a landfill.

– Scenario/system 5: mixed collection–mechanical sorting–incineration

In this case, the collected mixed solid waste is subjected to primary mechanical sorting to recover Fe and non-Fe metals. The remaining combustible materials are subjected to incineration. The residues are transferred to landfill.

Evaluation criteria

In this research, we use four hierarchical levels: level 0 is the objective, level 1 compares the criteria with respect to the objective, level 2 compares the subcriteria with respect to the criteria, and level 3 compares the scenarios (systems) with respect to the subcriteria. The aim of each analysis is to target the best criterion and the best scenario in relation to the higher hierarchical level. The decision tree represents the hierarchy of criteria and subcriteria that we adopt in this study (Fig. 3).

Performing pairwise comparisons

The weights of the criteria, subcriteria, and alternatives are determined from a series of pairwise comparisons, taking into account the relative importance of one element compared to another. The scale used in the pairwise comparisons is that proposed by Saaty (1980a; b), which ranges from 1 to 9 (Table 1).

To test the consistency of the weights obtained, which indicates whether the comparison made is logical, it is necessary to calculate the coherence ratio (CR) by calculating certain indices:

– Random index (RI). This is a value that depends on the number of criteria studied, and is determined using a scale reported in Saaty (1980a, b); see Table 2.
– Maximum eigenvalue (λ_{max}). This is the arithmetic mean obtained after multiplying the elements of the normalized comparison matrix by the elements of the priority vector (weight obtained).
– Consistency index (CI). The consistency of a matrix of order N is evaluated as follows (Saaty 1980a, b):

$$CI = (\lambda_{max} - N) / (N - 1),$$

where λ_{max} is the maximum eigenvalue of the matrix and N is the number of criteria.
– Coherence ratio (CR). This is the ratio of the coherence index to the random index (RI) of a matrix of the same dimension (Saaty 1980a, b):

$$CR = CI / RI.$$

The CR value must be less than 10% (Rakotoarivelo 2015; Elhamdouni et al. 2017).

Results and discussion

A weight can be defined as a value assigned to an endpoint that indicates that it is important relative to other criteria in the study. There are several techniques for assigning weight: classification, evaluation, and pairwise comparison. In this work, we focus on pairwise comparison. The criteria weights are calculated using a comparison matrix that contains scale values from 1 to 9 (Table 1). The comparison matrix indicates the relative importance of each criterion in a column

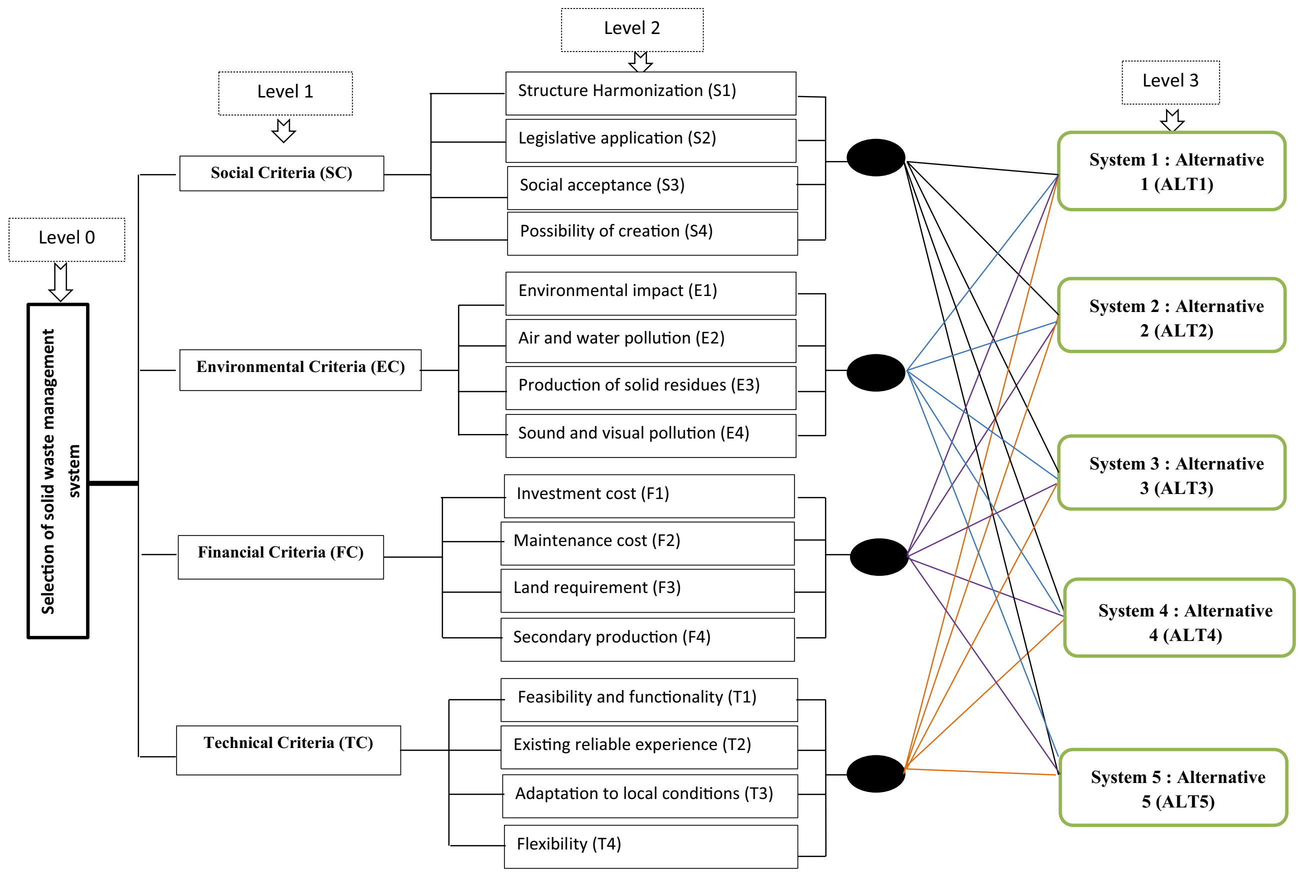

Fig. 3 Complete graphical representation of the studied levels

Table 1 Scale used for the pairwise comparisons (Saaty 1980a, b)

Value	Importance
1	Same importance
2	Equal to moderately important
3	Moderately more important
4	Moderate to high importance
5	Much more important
6	High to very high importance
7	Very important
8	Very to extremely high importance
9	Extremely high importance

compared to each criterion in a row. For each comparison, the more important of the two criteria is decided upon, and then a score is assigned to show how much more important it is. After applying the methodology presented previously for the proposed criteria, subcriteria, and scenarios, we obtain the weights presented in Tables 3 and 4.

After determining the weights, the next step is to determine the relative performance value of each scenario by considering the criteria at the highest hierarchical level; this is termed primary aggregation. The numerical performance values of the four criteria (Social, Environmental, Financial, and Technical) and their subcriteria are the result of the criterion and sub-criteria product (Table 5). This aggregation will be used in the treatment of the relative performance values of the alternatives.

$$CR = CI/ RI.$$

The final aggregation step in our analysis of possible waste management systems for the Khenifra region is to calculate the relative performance value of each system by considering the subcriteria. Table 6 shows the technique

Table 2 Random index (Saaty 1980a, b)

Number of criteria	2	3	4	5	6	7	8	9	10	11
Random index (RI)	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table 3 Resulting weights

Criterion	Weight	Subcriterion	Weight	Consistency ratio (%)	Consistency index (CI)
Social	0.151	S1	0.351	0.42	0.003
		S2	0.371		
		S3	0.371		
		S4	0.107		
Environmental	0.371	E1	0.423	0.53	0.004
		E2	0.227		
		E3	0.227		
		E4	0.123		
Financial	0.371	F1	0.58	1.5	0.009
		F2	0.164		
		F3	0.164		
		F4	0.093		
Technical	0.107	T1	0.239	2.3	0.02
		T2	0.394		
		T3	0.197		
		T4	0.169		

Table 4 Criteria and subcriteria weights

Criteria	Social	Environmental	Financial	Technical
	0.151	0.371	0.371	0.107
S1	0.351	0	0	0
S2	0.351	0	0	0
S3	0.189	0	0	0
S4	0.109	0	0	0
E1	0	0.423	0	0
E2	0	0.227	0	0
E3	0	0.227	0	0
E4	0	0.123	0	0
F1	0	0	0.58	0
F2	0	0	0.164	0
F3	0	0	0.164	0
F4	0	0	0.092	0
T1	0	0	0	0.239
T2	0	0	0	0.395
T3	0	0	0	0.197
T4	0	0	0	0.169

for integrating the weights of the scenarios relating to this calculation. The previously obtained results of the criteria and subcriteria aggregation calculations (Table 5) are assigned to the subcriteria. The new weights of the subcriteria replace the criteria weights (Social, Environmental, Financial, and Technical), and the weights of the alternative scenarios (ALT1, ALT2, ALT3, ALT4, and ALT5) replace the subcriteria. Subsequently, we introduce the

Table 5 Relative performance values

Criteria	Social	Environmental	Financial	Technical
	0.151	0.371	0.371	0.107
S1	0.053	0	0	0
S2	0.053	0	0	0
S3	0.029	0	0	0
S4	0.016	0	0	0
E1	0	0.157	0	0
E2	0	0.084	0	0
E3	0	0.084	0	0
E4	0	0.046	0	0
F1	0	0	0.215	0
F2	0	0	0.061	0
F3	0	0	0.061	0
F4	0	0	0.034	0
T1	0	0	0	0.026
T2	0	0	0	0.042
T3	0	0	0	0.021
T4	0	0	0	0.018

scenario weights (ALT1–ALT5) into each corresponding row. The value in each cell is obtained as the product of the subcriterion weight for the column and the scenario weight for the row (Table 6). It can be seen that some cells contain a value of zero (Table 6), which means that choosing the best management system is impractical.

In Table 6, the values are divided into two groups:

– Group 1 (white cells): the value in each cell is zero
– Group 2 (black cells): the value in each cell is greater than zero.

Table 7 summarizes the treatment results and the classification of the proposed alternatives. The obtained results show that the two alternatives ALT3 and ALT4 are the best based on social criteria. Likewise, these two scenarios are considered the most suitable based on environmental criteria, followed by alternatives ALT2 and ALT5. The same results were obtained for the financial criteria, i.e., ALT3 and ALT4 are the best alternatives based on those criteria. The two alternatives ALT3 and ALT4 have equal values for the technical criteria; they are both reasonably acceptable.

On the one hand, the analysis of the results expressed as the vector of the complete priorities of the alternatives presented above (Table 7) indicates that ALT3 is the best scenario for waste management in the Khenifra region, followed by ALT4 and finally ALT2 and ALT5. On the other hand, subcriteria S1, T1, T3, and T4 have no influence on the choice of model in this study, which means that they are not important. In this study, the result of the analysis suggests, without ambiguity, that the scenario of alternative ALT3

Table 6 Integration of the weights of the alternatives by row

Scenario	Sub-criteria	S1	S2	S3	S4	E1	E2	E3	E4	F1	F2	F3	F4	T1	T2	T3	T4
	Weights	0.053	0.053	0.029	0.016	0.157	0.084	0.084	0.046	0.215	0.061	0.061	0.034	0.026	0.042	0.021	0.021
ALT 1	0,061	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	**0.01**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALT 2	0,160	0.00	0.00	0.00	0.00	**0.03**	0.01	0.01	0.00	**0.03**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALT 3	0,382	**0.02**	**0.02**	**0.01**	0.00	**0.06**	**0.03**	**0.03**	**0.02**	**0.08**	**0.02**	**0.02**	**0.01**	0.00	**0.01**	0.00	0.00
ALT 4	0,276	**0.01**	**0.01**	0.00	0.00	**0.04**	**0.02**	**0.02**	**0.01**	0.05	0.02	**0.01**	0.00	0.00	**0.01**	0.00	0.00
ALT 5	0,121	0.00	0.00	0.00	0.00	**0.02**	**0.01**	**0.01**	0.00	**0.02**	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7 Comprehensive ranking of alternative waste management systems

Criterion	Social				Environmental				Financial				Technical				Score
Subcriterion	S1	S2	S3	S4	E1	E2	E3	E4	F1	F2	F3	F4	T1	T2	T3	T4	
Scenario																	
ALT 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
ALT 2	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
ALT 3	0.02	0.02	0.01	0.00	0.06	0.03	0.03	0.02	0.08	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.33
ALT 4	0.01	0.01	0.00	0.00	0.04	0.02	0.02	0.01	0.05	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.20
ALT 5	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06

(waste separated at source, recycling–composting) should be chosen, as this yielded the highest rating.

In this system, the population places household waste into two bins: one for recyclable materials (paper, glass, plastics, and metals) and the other for the rest of the biodegradable organic waste. This organic fraction then undergoes an aerobic biological treatment (composting). During the composting process, the waste is activated to achieve the degradation of organic matter by aerobic bacteria, giving the end product: compost.

The scenario adopted based on the results of this study took the social aspect as a priority, and any sustainable management of household waste requires the involvement of citizens in a participatory approach.

Conclusion

This work focused on the development and application of a multi-criteria decision analysis (AHP) approach for choosing the most appropriate waste management scheme for a developing country (Morocco). The selection of the management system was based on a performance comparison of the alternatives with regard to social, environmental, financial, and technical criteria. The results obtained show that the ALT3 system is the most favorable solution in the case of Morocco. In this system, the waste is separated at source into different containers; recyclable materials are sent to a treatment station for recovery, biodegradable materials are sent to another station to undergo biological treatment by composting, and the collected solid waste residues are subsequently transferred to the landfill.

The power of this decision support method for selecting the optimal solution does not need to be demonstrated since it has been confirmed in several fields and for several sectors. The application of this method, which accounts for local conditions, will allow the development of strategic planning, allowing better waste management for the benefit of urban communities in Morocco, and it should contribute to the promotion of biotechnological processes for the recovery of solid domestic waste. Indeed, according to this method, it is necessary to:

- Carry out pilot sorting actions at source
- Organize and develop the sorting–recycling–composting sector.

Finally, the results obtained are of practical importance, and the proposed algorithm in this study can be used to improve territorial waste-management schemes, regardless of the region.

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Declarations

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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