Advances in Internet of Things, 2026, 16(1), 1-10
https://www.scirp.org/journal/ait
ISSN Online: 2161-6825
ISSN Print: 2161-6817

Contextual Selection of Multi-Criteria Decision-Making Methods for Waste Management in Low-Resource Settings: A Conceptual Framework and Comparative Analysis

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How to cite this paper: Tshimpanga, D., Mushage, O.B., Manirabona, A. and Ndikumagenge, J. (2026) Contextual Selection of Multi-Criteria Decision-Making Methods for Waste Management in Low-Resource Settings: A Conceptual Framework and Comparative Analysis. *Advances in Internet of Things*, **16**, 1-10.
https://doi.org/10.4236/ait.2026.161001

Received: October 10, 2025
Accepted: November 23, 2025
Published: November 26, 2025

Abstract

Municipal solid waste management represents one of the major challenges faced by cities in low-resource settings, where data scarcity, technical constraints, and weak institutional capacities limit effective decision-making. In this context, multi-criteria decision-making (MCDA) methods provide a structured framework for evaluating and prioritizing alternatives, although their transferability remains uneven. This paper proposes a conceptual and comparative framework to identify, among five reference methods (AHP, TOPSIS, ELECTRE, PROMETHEE, and Fuzzy MCDA), those most suitable for constrained environments. The evaluation is based on five selection criteria: data availability, ease of use, robustness, cost, and social acceptability. The results highlight the superiority of AHP, whose flexibility and transparency meet the decision-making needs of low-resource cities, while more complex methods show applicability conditioned by the level of institutional development. The discussion emphasizes a gradual methodological progression from simple approaches toward more sophisticated hybrid models. This reproducible and adaptable framework helps fill a methodological gap by providing a decision-support tool for selecting MCDA methods in urban planning and sustainable waste management in low-resource countries.

Keywords

MCDA, AHP, TOPSIS, ELECTRE, PROMETHEE, Fuzzy, Waste

Management, Low-Resource Settings

1. Introduction

Municipal solid waste management represents one of the major environmental, economic, and social challenges of the 21st century [1] [2]. According to the World Bank, the world generated approximately 2.01 billion tons of waste in 2016, with projections reaching 3.4 to 3.8 billion tons by 2050 [3]. This growth, driven by rapid urbanization and demographic dynamics, accentuates disparities between regions. While high-income countries collect more than 96% of their waste, the average drops to 48% in urban areas and 26% in rural areas of low-income countries. In Sub-Saharan Africa, collection rates reach only about 44%, revealing significant structural vulnerabilities [4]. These disparities result in illegal dumping, increased health risks, uncontrolled methane emissions, and persistent pressures on urban sustainability.

These challenges stem from structural causes such as insufficient infrastructure, weak institutional capacity, unreliable data, and limited financial resources. Existing planning and collection systems, often linear and monodimensional, fail to integrate the interactions among technical, social, and economic dimensions that characterize low-resource cities. As a result, decision-making remains largely empirical, dependent on subjective judgments, and difficult to replicate.

Multi-Criteria Decision-Making (MCDA) methods offer a formal framework for ranking complex options by simultaneously integrating economic, technical, environmental, and social criteria [5]. Their use has spread widely across urban planning, energy management, transportation, and waste management. However, most applications concern industrialized contexts with robust datasets and advanced computational tools, which limits their transferability to low-resource environments [6] [7].

Several researchers have also combined different MCDA methods to capitalize on their respective strengths, such as AHP-TOPSIS [8] [9] or ELECTRE-Fuzzy [10] [11]. These hybridizations aim to enhance evaluation accuracy and improve the treatment of uncertainty. Nevertheless, few studies have examined the intrinsic relevance of each method with respect to the contextual constraints of low-resource countries, such as the Democratic Republic of the Congo, where data availability is limited and institutional capacity remains weak. This gap reduces the ability of decision-makers to select approaches that are truly adapted to their technical, human, and organizational realities.

This study addresses this gap by proposing a conceptual and comparative framework to assess the transferability of five reference methods: AHP, TOPSIS, ELECTRE, PROMETHEE, and Fuzzy MCDA. The analysis focuses on waste management in low-resource settings, with particular emphasis on the Democratic Republic of the Congo. The objective is to identify, based on the literature and a comparative matrix structured around five criteria (data availability, ease of use, robustness, cost, and social acceptability) the method that best supports rational and reproducible decision-making in constrained urban environments.

2. Methodology

2.1. Literature Review

The methodology is based on a critical and structured review of the literature concerning multi-criteria decision-making (MCDA) methods applied to waste management and constrained environments. The literature search was conducted using the Scopus and Web of Science databases, covering the period 2000-2025. The following keywords were used: "multi-criteria decision analysis," "MCDA," "AHP," "TOPSIS," "ELECTRE," "PROMETHEE," and "fuzzy MCDA," combined with "solid waste," "municipal solid waste," "developing countries," "low resource," and "Africa". In this study, the term Fuzzy MCDA refers to a general approach that integrates fuzzy logic into multi-criteria decision-making rather than a single method. It mainly encompasses fuzzy extensions of classical approaches (such as Fuzzy AHP or Fuzzy TOPSIS) designed to handle uncertainty and imprecise judgments in data-scarce environments.

In total, approximately 150 publications were identified, of which 40 were examined in full text and 25 were retained for comparative analysis. The inclusion criteria focused on peer-reviewed studies presenting applications or methodological analyses of MCDA in urban contexts. The exclusion criteria removed non-academic documents, purely theoretical works, and studies conducted in high-income countries.

The review reveals a large body of literature on the use of MCDA methods, but very few concrete applications in low-resource countries. Five methods were selected (AHP, TOPSIS, ELECTRE, PROMETHEE, and Fuzzy MCDA) due to their frequent use in the literature and their representativeness of the main MCDA families, allowing a balanced comparison between simple and advanced approaches suited to low-resource contexts. This scarcity justifies a conceptual and comparative approach based on a critical analysis of existing studies and on the structural characteristics of each method, in order to assess their transferability to constrained environments.

2.2. Conceptual Framework

The conceptual framework developed in this study is structured around three interdependent dimensions:

1) Decision-making context, defined by the nature of the problem (for example, prioritizing collection sites or optimizing collection routes), the stakeholders involved (local authorities, private operators, communities), and the specific constraints of low-resource cities (incomplete data, limited funding, and insufficient infrastructure).

2) Characteristics of multi-criteria methods, including data requirements, com-

putational complexity, robustness to uncertainty, and accessibility for decision-makers.

3) Method-context alignment, which assesses the capacity of a method to be realistically implemented in fragile institutional, social, and economic environments.

These three components interact to guide the selection of the most appropriate method, in line with recent approaches emphasizing the contextualization of MCDA [6] [10]. **Figure 1** illustrates this conceptual framework, showing the relationships between the decision-making context, the characteristics of the methods, and their alignment with local conditions.

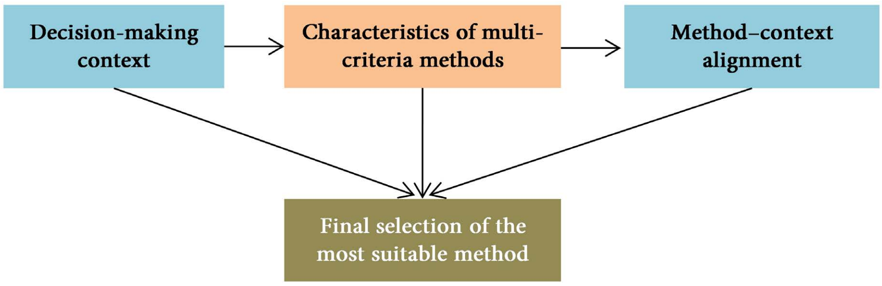

Figure 1. Conceptual framework for selecting an MCDA method in low-resource contexts.

2.3. Selection Criteria

Five criteria were selected to compare the multi-criteria decision-making (MCDA) methods. These criteria were identified from the literature [3] [5] [12] [13] and adapted to the operational realities of low-resource urban environments. They reflect the typical constraints of developing-country cities, where decisions must often be made despite incomplete data, limited institutional capacity, and restricted technical resources. These criteria make it possible to assess the relevance and transferability of MCDA approaches according to the conditions prevailing in low-resource settings.

Table 1 presents the operational definition of each criterion, accompanied by examples of application and key references. This framework serves as the basis for the comparative matrix developed in **Section 3**, where the five MCDA methods are evaluated according to these dimensions.

Table 1. Selection criteria and operational definitions.

Selection Criterion	Operational Definition	References
Data availability and reliability	Measures the ability of a method to operate with partial, qualitative, or uncertain datasets.	[5] [12] [13]
Simplicity and ease of use	Assesses the level of methodological complexity and the skills required for implementation.	[3] [14]
Robustness and reliability of results	Evaluates the stability of results when data or weightings vary.	[5] [10]

Continued

Cost and required resources	Considers the time, software, and technical expertise needed to apply the method.	[6] [11]
Social and institutional acceptability	Measures the degree of stakeholder participation, transparency, and support in the decision-making process.	[12] [13]

2.4. Selection Procedure

Figure 2 illustrates the six steps of the sequential procedure developed to guide the selection of a multi-criteria method suitable for low-resource contexts. The process begins with the definition of the decision problem and the identification of relevant criteria, followed by an analysis of local constraints and a comparison of methods according to the selected criteria. It concludes with the justified choice of the most appropriate method and a sensitivity test designed to verify the stability of the results. This graphical representation provides a comprehensive view of the overall logic of the process and facilitates its implementation by decision-makers.

This procedure aims to make the selection process more transparent and reproducible while offering a simple framework for adapting MCDA methods to limited technical and institutional capacities. It represents a preliminary step toward the empirical validation of the framework through real case studies, particularly in cities such as Kinshasa.

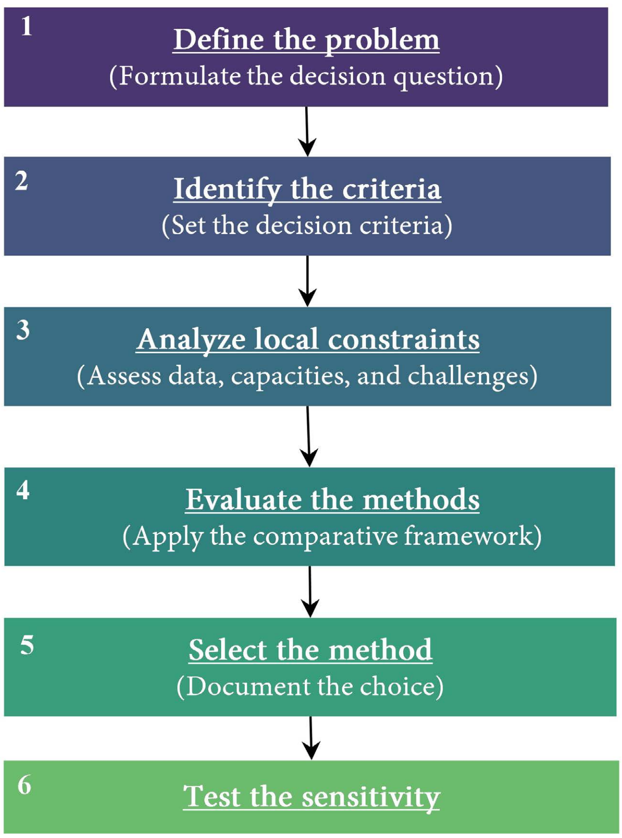

Figure 2. Sequential procedure for selecting an MCDA method in low-resource contexts.

3. Results and Comparative Analysis

The methodological procedure described in **Section 2** made it possible to evaluate five multi-criteria decision-making (MCDA) methods according to the selected criteria. The evaluation is based on a 1-to-5 scale, where 1 indicates very low performance and 5 indicates excellent performance. The scores obtained, presented in Table 2, highlight the variability of performances among the methods with respect to the selected criteria, particularly those related to data requirements, simplicity, robustness, cost, and social acceptability.

The results show that the AHP method achieves the highest scores, confirming its suitability for low-resource environments. More complex methods, such as ELECTRE, PROMETHEE, and Fuzzy MCDA, display contrasting performances. Figure 3 provides a visual illustration of the relative performance of each method according to the five criteria. AHP stands out for its balanced profile, while advanced approaches demonstrate high robustness but lower simplicity and accessibility.

Overall, the comparison reveals a tension between accessibility and sophistication. AHP appears to be the most transferable method, followed by PROMETHEE and ELECTRE, while TOPSIS and Fuzzy MCDA remain more demanding in terms of data and technical expertise. These trends will be further discussed in the following section.

Table 2. Evaluation matrix of the five MCDA methods according to the selection criteria (1 - 5 scale).

Method	Data	Simplicity	Robustness	Cost	Acceptability	Average Score
AHP	4	5	4	5	5	**4.6**
TOPSIS	2	3	4	3	3	**3.0**
ELECTRE	3	3	5	2	3	**3.2**
PROMETHEE	3	3	5	2	3	**3.2**
Fuzzy MCDA	3	2	5	2	2	**2.8**

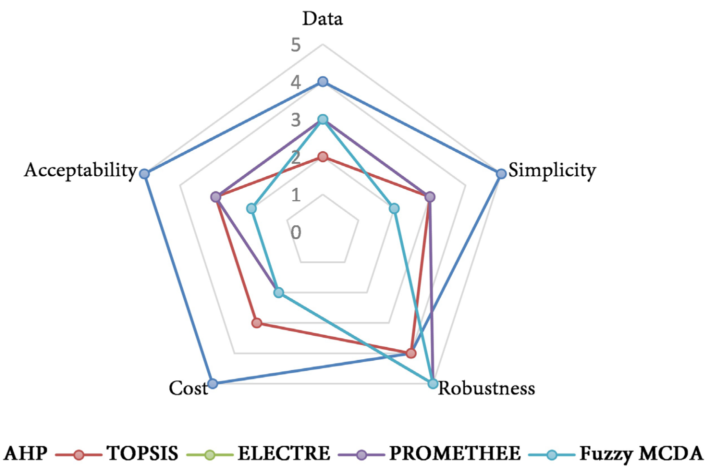

Figure 3. Radar representation of the relative performance of the methods according to the selection criteria.

4. Discussion

4.1. Interpretation of the Results

The results confirm the strong suitability of AHP for low-resource contexts due to its simplicity, transparency, and ability to incorporate expert judgments in the absence of comprehensive quantitative data [13] [14]. Its participatory approach encourages the involvement of local stakeholders and enhances the legitimacy of decisions. Social acceptability differs according to the type of MCDA method. The AHP, through its pairwise comparison structure, is generally more intuitive and participatory, fostering community stakeholder involvement and transparency. In contrast, outranking methods such as ELECTRE and PROMETHEE rely on more abstract preference functions, which may be less accessible to non-experts and thus harder to adopt in low-capacity institutional settings.

The outranking methods, such as ELECTRE and PROMETHEE, demonstrate higher robustness but require technical expertise and specialized computational tools [15] [16]. Their adoption remains limited in environments where institutional and technical capacities are weak. The TOPSIS method performs well in contexts with structured databases [17], while Fuzzy MCDA approaches, although improving the treatment of uncertainty, remain difficult to implement where computational and human resources are constrained [11].

These findings are consistent with those of Greco and Govindan, who emphasize that the performance of an MCDA method depends less on its sophistication than on its alignment with the decision-making and organizational constraints of the context under study [5] [10].

4.2. Methodological Implications

The analysis highlights the need for contextual adaptation of MCDA methods. In low-resource countries, the objective is not technical complexity but rather the reproducibility and coherence of decisions based on limited data. The selection of a method should therefore follow a gradual methodological progression inspired by the evolutionary approaches proposed by Greening and Bernow and consolidated by Govindan [10] [18].

This trajectory unfolds across three levels:

1) Simple and participatory approaches (AHP), promoting collective decision-making and transparency.

2) Intermediate methods (ELECTRE, PROMETHEE), applicable as technical and institutional capacities improve.

3) Advanced approaches (Fuzzy and hybrid models), appropriate when data reliability and local expertise reach a sufficient level.

This progressive model provides a realistic roadmap for strengthening decision-making capacities in constrained urban environments [12] [13].

4.3. Practical Implications for Waste Management

At the operational level, the results suggest several directions for improving urban governance in low-resource countries, particularly in the Democratic Republic of the Congo. The adoption of a method such as AHP could enhance the traceability and justification of decisions related to waste collection and planning by making selection criteria explicit. It also encourages the participation of local stakeholders, a key element for the legitimacy and sustainability of public policies [3] [4]. As an illustration, the proposed framework could be applied in Kinshasa to select a new controlled landfill site. In a context characterized by land scarcity, incomplete data, and high urban density, the use of AHP would allow prioritization of potential areas by integrating technical criteria (distance from residential zones, accessibility, topography) and social ones (community acceptability, perceived impact), while enhancing the transparency of the decision-making process. In the longer term, the introduction of more complex methods could be envisaged as technical capacities and data quality improve [6].

This methodological hierarchy thus provides a practical tool for planning a gradual transition toward more robust decision-making systems that are adapted to local economic and institutional constraints.

4.4. Limitations and Research Perspectives

Although this study proposes a solid comparative framework, it remains conceptual and based on qualitative analysis. Empirical validation through a real case study, for instance in Kinshasa, would make it possible to test the consistency of the framework and refine the weighting of the criteria. Future research could explore hybrid approaches, such as AHP-TOPSIS or ELECTRE-Fuzzy, which have already been identified in the literature as promising ways to enhance analytical robustness [8] [9]. Hybrid approaches such as AHP-TOPSIS or ELECTRE-Fuzzy offer the advantage of combining the strengths of different methods. They merge the robust weighting structure of AHP with the efficient ranking of TOPSIS or the uncertainty-handling capability of fuzzy techniques, thus providing more stable and nuanced results in complex decision contexts.

Moreover, the development of simplified digital tools, including participatory interfaces or local applications, represents an interesting avenue for democratizing the use of MCDA methods in municipalities with limited resources.

5. Conclusions

This study proposes a conceptual and comparative framework to guide the selection of multi-criteria decision-making (MCDA) methods in low-resource contexts. By evaluating five reference approaches against five locally relevant criteria, it demonstrates the suitability of AHP as an entry-level method due to its simplicity, transparency, and compatibility with limited data. The developed framework provides a reproducible tool to enhance coherence, traceability, and social acceptability in waste management decisions, while paving the way for a gradual shift toward more robust hybrid approaches as local capacities strengthen.

From a practical perspective, the developed framework constitutes a decision-support tool for local authorities facing data scarcity and complex environmental trade-offs. By making selection criteria explicit, it contributes to improving transparency and the social acceptability of decisions. Empirical validation, particularly in the Democratic Republic of the Congo, will make it possible to refine the weightings and adapt the framework to other urban management sectors, confirming the relevance of a contextualized decision-making approach for strengthening environmental governance.

Ultimately, this study contributes to filling a major methodological gap by proposing a reproducible and adaptable framework for selecting MCDA methods in constrained urban environments.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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