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Using Multi-Criteria Decision Making to optimise solid waste management

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Abstract

Multi-Criteria Decision Making (MCDM) encompasses a broad range of methods to support decision making to reach a compromise solution when there are multiple criteria. One example of a multi-criteria problem is identifying the most sustainable solution to manage solid waste. In this case, different conflicting objectives exist, which can be categorised based on environmental, economic, social and technical metrics. In this article, the most relevant MCDM methodologies and tools are described and discussed, focusing on their applicability to assess solid waste management systems. The most relevant methodologies identified are the Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), Outranking procedures and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). A common weakness of these methodologies is that the evaluation criteria set by decision makers are generally subjective. It is recommended to integrate various methods and tools, or to develop bespoke methodologies to optimise solid waste management.

Keywords

Solid waste management; MCDM; AHP; MAUT; PROMETHEE; ELECTRE; TOPSIS.

1 Introduction

Vast amounts of solid waste are generated at residential, industrial and commercial sites. Adequate management of this waste is paramount to minimise environmental impacts, reduce economic costs and eliminate any social impact to citizens. These operations include the management of the generation, collection, transport, storage, treatment and disposal of the solid waste. A key step in this chain is the selection of the optimal option to treat the solid waste. A number of alternatives are currently used, including recycling, anaerobic digestion, composting, incineration and landfilling. Nevertheless, a number of stakeholders exist around the selection of the optimal treatment solution. They have different criteria and interests, and therefore identifying the option that satisfies them all may be complicated.

Multi-criteria decision-making (MCDM) is a generic methodology to support decision making when there are multiple, usually conflicting, criteria to reach a compromise solution. MCDM can successfully integrate views from various stakeholders or decision makers who have different priorities and goals. MCDM methods usually consists of the steps shown in Figure 1 [1].

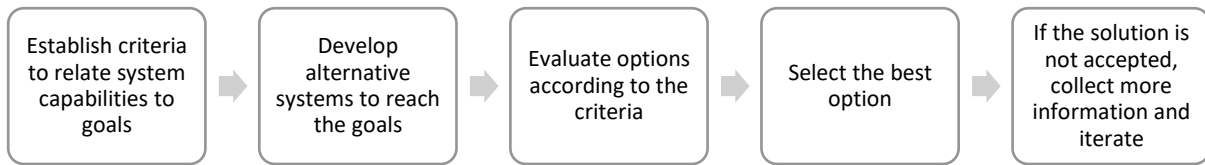


Figure 1. Basic steps in MCDM methods

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MCDM has been widely used to support waste management. There are a number of different MCDM methods, which generally differ in the type of decision criteria, type and number of alternatives, approach to compensation amongst decision criteria and preference ordering [2]. The most relevant MCDM methods used to study solid waste management systems are described and discussed next.

2 Analytic Hierarchy Process

AHP is the most common MCDM method to study most waste management systems, such as waste-to-energy systems [3] and management of waste electrical and electronic equipment [4]. The Analytic Hierarchy Process (AHP) is formed of the steps shown in Figure 2 [5].

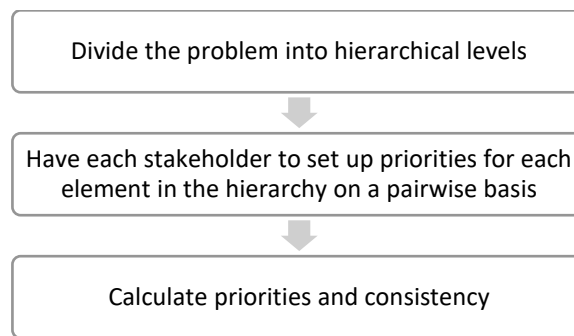


Figure 2. Basic steps in AHP

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AHP has also extensively been used to decide the location of waste treatment plants [6]. For instance, Kamdar et al. (2019) [7] assessed environmental and socio-economic indicators by AHP and Geographic Information System (GIS) to find optimal landfill sites. Mallick (2021) [8] also used AHP and GIS to select the optimal landfill site, based on indicators such as drainage density, land use, slope, elevation, lineament density, normalized difference vegetation index, rainfall, distance from airport, distance from road, and geology.

Khoshand et al. (2019) [9] applied fuzzy AHP to study recycling, exporting and landfilling options to manage electronic waste considering economic, social, environmental and technical indicators. Buyuk and Temur (2021) [10] also applied a fuzzy approach, based on spherical fuzzy sets, with AHP to select the best alternative for food-waste management.

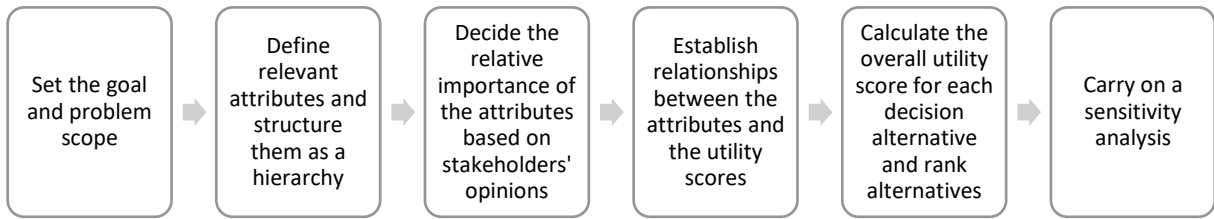
Vučijak et al. (2015) [11] used AHP to evaluate criteria weights along with another MCDM method (VIKOR), to rank alternatives for municipal solid waste (MSW) management based on environmental, economic, social and technical indicators. Sarkkinen et al. (2019) [12] studied the disposal of tailings by analysing economic, technical and social-ecological indicators. They used AHP to choose the best alternative among a discrete set of scenarios and Life-Cycle Assessment (LCA) to evaluate the impacts associated to the emissions, energy demand and the impact to human health.

3 Multi-Attribute Utility Theory

The Multi-Attribute Utility Theory (MAUT) represents the preferences (namely utilities) of multi-attribute outcomes as a function of the utilities of each attribute [13]. MAUT has a similar procedure

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69 than that of AHP, as shown in Figure 3 [14]. After AHP, the most used MCDM methods to assess
70 environmental issues of waste management have traditionally been MAUT and PROMETHEE [11].



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Figure 3. Basic steps in MAUT

73 There is a lack of recent examples of the use of MAUT to study waste management problems. Older
74 examples include work by Kijak & Moy (2004) [15], who proposed a framework for MSW management
75 that includes streamlined LCA, consideration of economic and social implications, data integration,
76 valuation and interpretation. They used MAUT to assist with the integration of qualitative and
77 quantitative information for valuation and interpretation. Binder et al. (2008) [16] used MAUT to
78 assess environmental, social and economic aspects of the use of radio frequency identification devices
79 for waste and resource management. Chadderton et al. (2016) [17] used a modified swing-weighting
80 technique that allows the decision maker to identify the objective that is the most important to them
81 and weigh the other objective relative to that one. MAUT was used to determine the overall utility of
82 each alternative for food-waste management.

83 A simplified, related method to MAUT is Multiple-Attribute Value Theory (MAVT). Deshpande et al.
84 (2020) [18] used MAVT to assess the sustainability of end-of-life alternatives for waste plastics.
85 Specifically, they assessed the environmental, economic, and social impacts of landfilling, incinerating,
86 and recycling of waste fishing gears in Norway.

87 4 Outranking

88 Outranking procedures involves comparing alternatives in a pairwise fashion, which are characterised
89 by the limited degree to which a disadvantage on a particular viewpoint may be compensated by
90 advantages on other viewpoints [19]. Preference Ranking Organization METHod for Enrichment
91 Evaluations (PROMETHEE) and ELimination and Choice Expressing REality (ELECTRE) are the most
92 widely used outranking models.

93 PROMETHEE involves the steps shown in Figure 4 [20]. Makan and Fadili (2020) [21] studied the
94 environmental, economic, social and technical performance of six composting systems to manage
95 organic waste. Ten experts assigned rankings for the criteria selected, and then the PROMETHEE
96 method was applied to calculate the outranking flows for each alternative taking into account the
97 performance for each criterion. In a subsequent study, these authors [22] applied the same method
98 to assess a similar set of criteria of ten treatment systems, including land disposal, incineration and
99 disinfection, with the support of fifteen experts to assign rankings for the criteria. AlHumid et al. (2019)
100 [23] used fuzzy AHP to establish criteria weights and PROMETHEE to aggregate scores in order to select
101 performance indicators for MSW management systems in Saudi Arabia. The indicators were classified
102 into public service and participation, personnel, physical assets, operational, environmental,
103 sustainability, and financial categories. Liang et al. (2020) [24] combined several MCDM methods to
104 select suitable hazardous waste disposal enterprises: hesitant fuzzy linguistic term sets to increase the
105 accuracy of the evaluation process, AHP to determine the objective indicator weights, and
106 PROMETHEE to determine the final order for the selected enterprises.

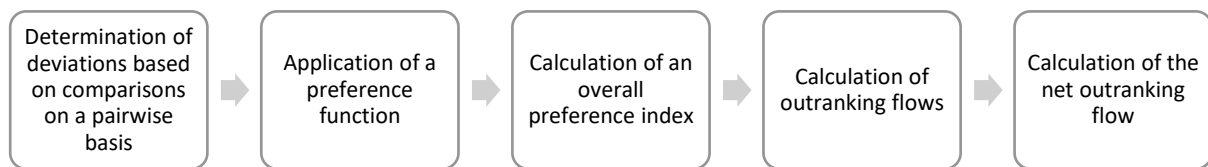


Figure 4. Basic steps in PROMETHEE

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109 The ELECTRE method uses weights of criteria, preference and indifference thresholds and veto
 110 thresholds. ELECTRE was the most commonly used method to undertake waste management
 111 decisions up to 2004 [25], but its use in the last years, although still relevant, has declined. Recent
 112 examples include work by Kazuva and Zhang (2019) [26], who used ELECTRE to analyse management
 113 scenarios for MSW by eliminating options from a list until the best choice, based on specific local
 114 demand and capacities, is reached. ELECTRE has also been successfully combined with other methods.
 115 Geetha et al. (2021) [27] combined ELECTRE with a Hesitant Pythagorean Fuzzy set to assess cost,
 116 technology, safety and environmental impact indicators of plastic waste management. Biluca et al.
 117 (2020) [28] combined AHP, Geographic Information Systems and ELECTRE to develop a selection
 118 method for the location of inert plants for construction and demolition waste. Chen et al. (2020) [29]
 119 presented a case study of health-care waste management in which they combined a probabilistic
 120 linguistic term set tool to represent qualitative data, the Bayesian best–worst method to determine
 121 the aggregated final weights of criteria, ELECTRE combined with distillation algorithm to obtain the
 122 alternatives' ranking of each decision maker, and finally, the weighted convex median voting rule to
 123 integrate the rankings results.

124 5 Technique for Order of Preference by Similarity to Ideal Solution

125 The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) consists of finding the
 126 optimal solution by ranking alternatives based on the shortest distance from the positive ideal solution
 127 and the farthest from the negative ideal solution [30]. There are several examples of the use of TOPSIS
 128 to assess waste management scenarios, mostly in combination with other methods.

129 Aghajani Mir et al. (2016) [31] combined extended versions of TOPSIS and VIKOR to identify the
 130 optimal MSW management option in a certain scenario. Coban et al. (2018) [32] combined TOPSIS
 131 with PROMETHEE to assess different solid waste disposal scenarios (i.e. landfill, incineration,
 132 composting, anaerobic digestion and recycling) based on environmental, economic and technical
 133 criteria defined by experts. Alao et al. (2020) [33] combined TOPSIS with the Entropy Weighted
 134 method to select the optimal solution to manage waste, from anaerobic digestion, pyrolysis, landfill
 135 and incineration, based on technical, economic and environmental indicators. Chen et al. (2020) [34]
 136 applied the Delphi, hybrid best–worst and TOPSIS methods to manage electronic waste in Ghana. They
 137 used each of the methods to identify barriers, pathways, and data collection; analyse the relative
 138 weight and ranking of the barriers; and rank and prioritise solutions; respectively. Sagnak et al. (2021)
 139 [35] applied a similar approach with the best–worst method and TOPSIS to identify the most adequate
 140 location of collection centres for electronic waste based on cost and environmental impact. Luo et al.
 141 (2020) [36] also combined the best–worst method with the Analytic Network Process (an extension of
 142 the AHP method) to obtain criteria weights, and TOPSIS to rank alternatives for selecting the optimal
 143 incineration plant site to manage MSW. Bafail and Abdulaal (2021) [37] integrated AHP and TOPSIS to
 144 select an optimal recycling program for recovered paper and pulp recyclables.

145 6 Other methodologies

146 There are a number of other methodologies to support decision making which can be used to find
 147 sustainable solutions for solid waste management. The most relevant ones are reviewed below.

148 Game theory is often used to analyse conflict and cooperation between rational decision makers [38]
149 and can be successfully used to find sustainable solutions for waste management [39]. Soltani et al.
150 (2016) [40] designed a framework for the selection of MSW treatment options, which models
151 conflicting priorities of stakeholders over sustainability criteria. They applied game theory to support
152 stakeholders to decide how to share the costs and benefits fairly, guiding them towards an agreement
153 on a sustainable solution.

154 Inghels et al. (2019) [41] developed a method to valorise green waste via compost and waste-to-
155 energy based on examining the Pareto front of optimal trade-off combinations. The authors used the
156 ϵ -constraint method to solve the multi-objective optimization problem and then applied LCA to
157 quantify the environmental impact of the solution. Boffardi et al. (2021) [42] applied a linear
158 programming method to reach decisions regarding urban waste management. Wang et al. (2018) [43]
159 developed a group multi-attribute decision analysis method (DEMATEL) based on the interval-valued
160 fuzzy set theory for selecting the best MSW treatment option. Rodrigues et al. (2018) [44] adapted
161 the Multi-criteria Decision Aid – Constructivist method to enable the comparison of objectives and
162 performance of solid waste management in small cities. Perteghella et al. (2020) [45] used the
163 Integrated Assessment Scheme tool to assess economic, environmental and social indicators to
164 identify the most sustainable waste management solution in low and middle-income countries.

165 The Analysis and Synthesis of Parameters under Information Deficiency methodology (ASPID) is a
166 mathematical method based on the synthesis of fuzzy sets to determine weighting factors given in a
167 form of equality or inequality, and can use non-numerical, inexact and incomplete information to
168 generate results [2]. These authors used ASPID to assess environmental, economic and social
169 performance of recycling, anaerobic digestion, composting, thermal treatment and disposal of waste,
170 obtaining similar results as with the AHP method.

171 **7 Discussion and conclusions**

172 This review has shown that MCDM methods have been widely used to study solid waste management.
173 They are very useful to study systems in which there is a number of very different criteria. The
174 challenge of identifying the optimal solution for solid waste management is a multi-criteria problem,
175 since different and often conflicting goals exist, which can be classified into environmental, economic
176 and social goals. Another category of indicators to consider is the technical maturity of the
177 technologies needed to treat the waste.

178 In spite the increasing number of MCDM methods reported in the literature, these methods are
179 eventually relatively similar. Decision makers often choose a method mostly based on their familiarity
180 and available opportunities, rather than based on a thorough study of the existing methods.
181 Furthermore, developing frameworks and tools which are case and site specific, for instance for food-
182 waste management or for one particular company, may provide additional benefits.

183 MCDM methods have an important weakness: the evaluation criteria by decision makers and,
184 specifically, the weight assigned in each criterion is generally subjective. Therefore, it is important that
185 all stakeholders involved in the decision participate in the MCDM study, along with as many experts
186 as possible from different specialities.

187 Generally, methodologies and tools focus on different aspects of reality. Therefore, a combination of
188 them can provide a more holistic description of the real situation and offer additional advantages.
189 Consequently, it is recommended an integration of methods and tools. Such integration has already
190 been observed in a number of studies, which combine different MCDM methods, or a MCDM method
191 with a method from a different category. Nevertheless, this brings the challenge of collecting and
192 managing large amounts of data, due to the assessment needed to analyse different aspects of waste
193 management, i.e. environmental, economic, social and technical considerations.

194 In conclusion, MCDM methods have been successfully used to study the performance of various
195 solutions for solid waste management based on environmental, economic, social and technical
196 indicators. It is recommended to use such methods in future studies to make sure all stakeholders'
197 opinions and criteria are considered.

198 **Declaration of interest**

199 None.

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