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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].

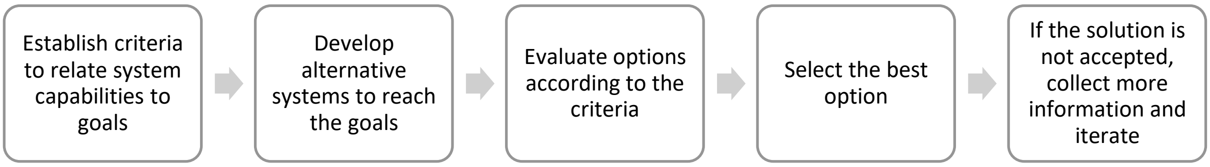

Figure 1. Basic steps in MCDM methods

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].

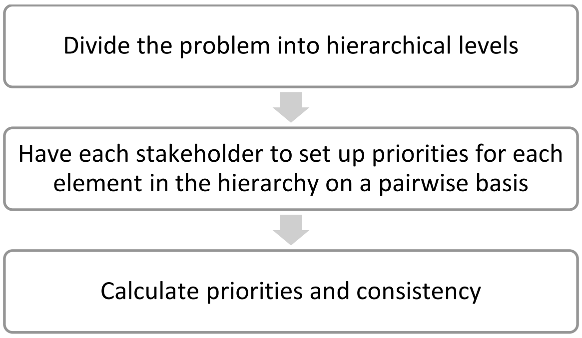

Figure 2. Basic steps in AHP

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

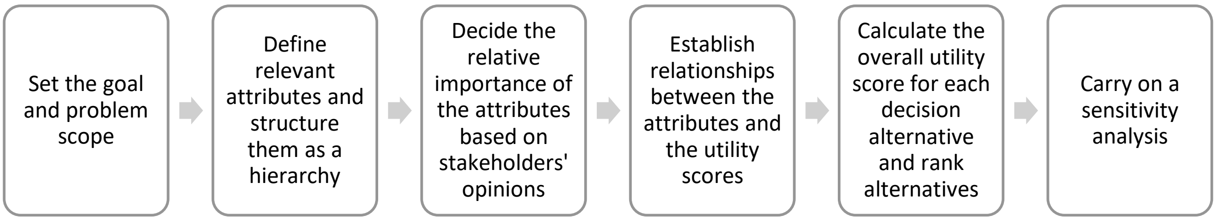

Figure 3. Basic steps in MAUT

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

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

4 Outranking

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

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

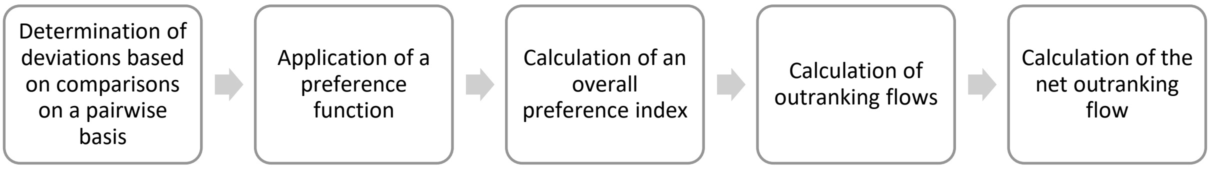

Figure 4. Basic steps in PROMETHEE

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

5 Technique for Order of Preference by Similarity to Ideal Solution

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

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

6 Other methodologies

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

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

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

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

7 Discussion and conclusions

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

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

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

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

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

Declaration of interest

None.

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This paper reviews MCDM methods along other methodologies used to improve decision-making of waste management systems. The authors recommend using game theory to complement other reviewed methods.

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