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Multi-Criteria Decision-Making Approaches for Evaluating Waste-to-Energy Scenarios

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Abstract

1. INTRODUCTION

The Multi-Criteria Decision Making (MCDM) methodology and Multi-Criteria Decision Analysis (MCDA) are closely related concepts, differing slightly in scope and application. MCDM represents a broader field focused on decision-making involving multiple, often conflicting criteria, commonly used in engineering, business, and policymaking. It includes both optimization techniques and decision analysis tool and allows for the integration of diverse stakeholder priorities. MCDA is a more structured subfield within MCDM, concentrating specifically on analytical methods for evaluating and comparing alternatives. It is frequently applied in fields like environmental management, healthcare, and public policy. Common MCDA methods include AHP, TOPSIS, ELECTRE, PROMETHEE, and MAUT, which help rank or prioritize options. The main distinction is that MCDM encompasses both optimization and analysis, while MCDA focuses on evaluation and ranking. MCDA is flexible and can be combined with tools such as Life Cycle Assessment (LCA), Ecological Footprint Analysis, and environmental indicators [1].

2. MATERIALS AND METHODS

The methodology consists of comprehensive literature review of the most common MCDA method(s), choosing most suitable method and evaluating of offered WtE scenarios according to them. A comparison of these methods examined during the literature review is shown in Table 1.

Table 1: Literature review on the MDCA methods

Method	Definition	Reference
AHP	Analytic Hierarchy Process (AHP) is a structured method that uses pairwise comparisons and a hierarchical model to rank alternatives based on subjective preferences.	[2, 3, 5]
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a method that ranks alternatives by measuring their distance from an ideal and a negative-ideal solution.	[3]
ELECTRE	ELECTRE is an outranking method that compares alternatives in pairs using concordance and discordance indices to eliminate weaker options.	[3]
PROMETHEE	PROMETHEE is ranking method that evaluates alternatives using preference functions and calculates net flows to determine their overall desirability.	[4]
MAUT	MAUT serves as a theoretical reference for decision-making under uncertainty. It involves assigning utility values and weights to each criterion and aggregating them using additive or multiplicative models.	[5]

The study evaluates four WtE scenarios: (S1) landfill disposal (baseline), (S2) uncontrolled open-air burning, (S3) controlled incineration with energy recovery, and (S4) co-incineration in cement kilns.

These scenarios are assessed based on four main criteria – environmental impact (35%), economic impact (15%), technological impact (20%), and social impact (30%). Each criterion includes relevant sub-criteria such as emissions, CAPEX/OPEX, energy conversion, public health, and social acceptance. The selected method for this paper is AHP.

3. RESULTS

Four waste management scenarios were evaluated using the Analytic Hierarchy Process (AHP): landfilling, uncontrolled open burning, controlled incineration with energy recovery, and co-incineration in cement kilns. These were assessed based on environmental, economic, technological, and social impact, each with detailed sub-criteria such as emissions, investment costs, technological maturity, and public acceptance [6]. The scores were given according to a deeper analysis of the for North Macedonia's current and future WtE infrastructure. The conducted AHP analysis is shown in Table 2.

Table 2: Literature review on the MDCA methods

Scenario	Ecological impact	Economic impact	Technology impact	Social impact
(S1) landfill disposal	9	1	3	9
(S2) uncontrolled open-air burning	6	1	3	9
(S3) controlled incineration with energy recovery	3	9	9	6
(S4) co-incineration in cement kilns	3	9	6	6

The weighting factors for the selected criteria are as follows: environmental impact 35%, economic impact 15%, technological impact 20%, and social impact 30%. Based on these criteria and their respective weights, the resulting ranking of the scenarios is presented in Figure 1. According to the AHP results, the most preferred waste treatment option is controlled incineration (Scenario 3), followed by co-incineration in cement kilns (Scenario 4), while open burning (Scenario 2) and landfilling (Scenario 1) rank significantly lower., impact assessments, and high-efficiency energy recovery [4].

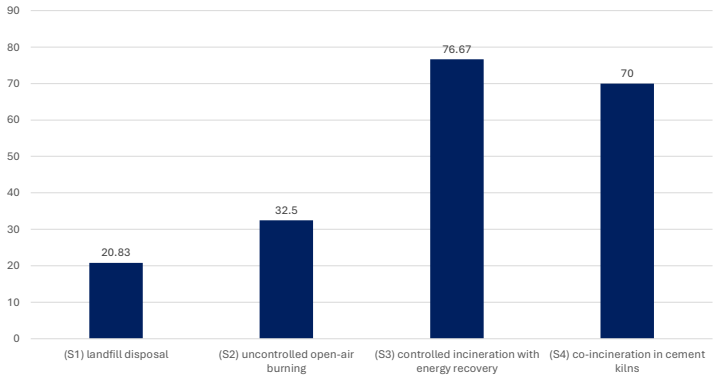

Figure 1. Results after applying the weighting factors

4. CONCLUSIONS AND RECOMMENDATIONS

The application of AHP demonstrates the robustness and reliability of MCDM approaches for evaluating WtE strategies. Its ability to integrate diverse and conflicting criteria makes them essential tools in sustainable waste management planning. Scenario 3 is recommended as a strategic direction for North Macedonia's future WtE infrastructure, promoting energy recovery while mitigating environmental and social risks. The study highlights the importance of stakeholder involvement, transparent criteria weighting, and ongoing sensitivity assessments for credible decision support in WtE policy development.

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