

Evaluation of Sustainable Solid Waste Systems Using the ENTROPI-TOPSIS Method

Assoc. Prof. Zeynep Özgüner^{1*}, Assoc. Prof. Mert Özgüner², Asst. Prof. Ahmet Şahin³

¹Department of Business Administration, Hasan Kalyoncu University, Gaziantep, TÜRKİYE

ORCID: <https://orcid.org/0000-0002-8694-7275>; Email: zeynep.ozguner@hku.edu.tr

²Department of Management and Organization, Adıyaman University, Adıyaman, TÜRKİYE

ORCID: <https://orcid.org/0000-0003-4919-9391>; E-mail: mozguner@adiyaman.edu.tr

³Department of Finance, Banking and Insurance, Adıyaman University, Adıyaman, TÜRKİYE

ORCID: <https://orcid.org/0000-0003-2145-8961>; E-mail: a.sahin@adiyaman.edu.tr

*Corresponding Author

Abstract

Solid waste management has become a critical necessity for both developed and developing countries. Globally, socio-economic, demographic, and environmental factors are increasing the volume of solid waste day by day. The lack of consistent waste data reduces the effectiveness of management strategies in this field and creates significant obstacles, particularly in achieving various development goals related to promoting environmental sustainability and the circular economy. This study aims to prioritize solid waste management strategies in line with environmental sustainability, public health, and sustainable development goals, based on various criteria. In this context, five alternative solid waste strategies—incineration, biological treatment, landfilling, composting, and gasification—were weighted using ENTROPI-TOPSIS methods based on nine criteria. The findings indicate that the criteria of greatest importance, in order, are CO₂ emissions, recycling, and energy production. Additionally, the findings reveal that biological treatment, incineration, and composting are the most suitable solution alternatives.

Keywords: Environment, Solid waste, TOPSIS, ENTROPI

1. INTRODUCTION

Solid waste management encompasses the processes of collecting, transporting, and disposing of waste generated by households, workplaces, and industries. (Fedullah et al., 2022; Wong, 2022). Human activities, excessive consumption, and waste disposal practices are making the ecological structure increasingly unsuitable for sustainable living. Waste generated by humans is typically discarded into the environment indiscriminately and is later processed and reintegrated by other living organisms. However, this natural reintegration process is both time-consuming and ecologically challenging (Zhou et al., 2022; Yalçıntaş et al., 2023). The complexity of waste management issues has increased significantly in recent years, particularly due to population growth. As a result, the fundamental objectives of waste management—protecting the environment, safeguarding human health, and conserving natural resources—have become increasingly difficult to achieve. This situation has become even more pronounced due to rising material turnover rates and the growing variety and volume of materials used. A sustainable waste management system must address these evolving

challenges by considering a range of interrelated factors, including the increasing volume of waste generated, existing legal regulations, management capacity, economic implications, public awareness, and levels of public participation (Ding et al., 2021; Tot et al., 2016; Giusti, 2009).

Today's world faces a heterogeneous and rapidly growing portfolio of solid waste, particularly industrial, electronic, and medical waste in recent years. In this complex environment, municipal solid waste continues to pose an increasingly heavy burden on the ecological structure of the environment; while 2020 estimates indicate an annual production of approximately 2.10 billion tons, the amount of solid waste is expected to rise to 3.80 billion tons by 2050 due to urbanization and population growth. Although developing countries have lower per capita solid waste generation compared to developed countries, they account for approximately 66% of global solid waste volume. This figure is expected to at least double by 2050 due to shifting consumption patterns in transition economies. These trends highlight the urgency of integrated waste management strategies to mitigate environmental and health impacts, as recent studies emphasize the need for circular economy models and advanced technological interventions (Minghua et al., 2019; Nanda and Berruti, 2021; UNEP, 2024; Mondal et al., 2026). Without effective waste management strategies, the uncontrolled increase in waste volume will lead to environmental pollution, numerous health issues, and economic pressures on local governments (Ferronato and Torretta, 2019). Approximately 33% of global solid waste is not managed properly and is disposed of in unregulated landfills or illegal dumping sites. This brings with it numerous problems, such as groundwater contamination, increased child mortality rates, and rising disease risks (Omer et al., 2026). This situation underscores the necessity of taking swift and appropriate steps to develop policies and strategies for this process. In this context, the urgency of improving global solid waste management has been emphasized within the framework of the United Nations Sustainable Development Goals. Many countries, from the European Union to the United States, are developing policies aimed at optimizing their systems and enhancing service efficiency to increase the sustainability of solid waste management (Sondh et al., 2024; Feng et al., 2024). However, the lack of reliable solid waste data remains a significant obstacle hindering the development of solid waste management strategies. This situation creates significant barriers to achieving sustainable development goals, particularly regarding the promotion of conscious consumption, environmental sustainability, and the circular economy (Subedi et al., 2025). Through multiple strategic interventions—such as promoting sustainable consumption, integrating renewable energy into waste systems, reducing greenhouse gas emissions, and minimizing toxic outputs— it may become possible to eliminate these barriers and achieve global sustainable solid waste targets (Nickson et al., 2024; Hannan et al., 2020).

The variety of technologies—including composting, biological treatment, landfilling, and gasification—requires local governments to make important decisions that balance environmental, economic, and social objectives. Each technology has distinct characteristics and requirements (Seikh and Mandal, 2023; Sarker et al., 2025). For example, composting is cost-effective and suitable for biodegradable waste, but it requires a significant amount of land and may not be financially self-sustaining. Waste-to-energy projects offer high capacity and

energy recovery potential, but they involve significant capital and operating costs as well as strict environmental controls. The complexity of these options is further compounded by irregular waste collection, fluctuating public participation, and the presence of an informal sector that plays a significant role in resource recovery (Atofarati, Adogbeji, & Enweremadu, 2025). Given these realities, there is a clear need for decision-making frameworks capable of accommodating multiple, often conflicting criteria and accounting for uncertainties in expert judgment and data variability. Therefore, the use of advanced Multi-Criteria Decision Making (MCDM) methods (Mondal et al., 2026) has become increasingly important in guiding local government units and policymakers toward selecting optimal solid waste management strategies.

In light of the above, the objective of this study is to identify and weight the criteria influencing environmental waste management strategies and to determine the most suitable solid waste management strategies from among the alternatives based on these criteria. In this context, the ENTROPI-TOPSIS methods will be utilized. In particular, the integrated application of these two methods will enhance the reliability of the findings obtained in this study. The findings emphasize the need to consider multiple criteria and subjective judgments in decision-making processes aimed at selecting sustainable solid waste management solutions. It is anticipated that this will be beneficial for policymakers, producers, and waste management practitioners seeking to improve solid waste management practices and promote sustainable development.

2. LITERATURE REVIEW

The integration of the ENTROPI and TOPSIS methods represents a scientific approach to urban solid waste strategy selection that addresses the inherent uncertainty, multidimensionality, and complexity of solid waste management strategies. This framework supports the selection of technically feasible, economically sound, and environmentally sustainable strategies by providing decision-makers with a transparent, adaptable, and scientifically grounded resource (Sobanaa et al., 2025). Recent research highlights the importance of such integrated approaches, underscoring the need for city-specific solutions that take into account solid waste characteristics, infrastructure, and stakeholder participation. As rapidly urbanizing countries pursue sustainable solid waste management and circular economy goals, the adoption of advanced multi-criteria decision-making (MCDM) methodologies will be indispensable to guide effective, accountable, and future-ready waste management strategies.

Al-Sulbi et al. (2023) evaluated biomedical waste using the TOPSIS method, one of the multi-criteria decision-making methods. The findings demonstrated that recycling is the most advantageous option, highlighting its potential for waste reduction, resource recovery, and environmental sustainability. In their study (Datta, Mohi and Chander, 2018), the authors analyzed the latest waste management strategies using the Fuzzy TOPSIS method. The findings proposed new strategies for separation, storage, and disposal, emphasizing the importance of factors such as financial support, infrastructure enhancement, and government support. Zafaranlouei, Ghouschi and Haseli (2023) evaluated sustainable solid waste alternatives using CCA methods. According to the study's results, the industrial waste sub-alternative is the most

significant waste management option. When examining the ranking of the next sub-alternatives (cell phones, communication equipment, and batteries) under sustainable waste management options, it is evident that the recycling of electronic waste requires greater attention for sustainable waste management. Ahmad et al. (2025) evaluated medical waste treatment options using LCA. The findings highlighted the necessity of developing strategies to reduce greenhouse gas emissions. Ani et al. (2023) examined the impacts of inefficient waste collection methods. The study emphasized the importance of high operational costs and greenhouse gas emissions. Szpilko et al. (2023) noted in their study examining smart waste collection strategies that modern strategies enhance efficiency and sustainability. Modal et al. (2023) evaluated solid waste strategies in India and emphasized the importance of solid waste treatment standards and data-driven planning to strengthen environmental sustainability. Duan et al. (2025) examined the problem of selecting multi-functional machinery for sustainable solid waste systems using CKKV methods. Clasen et al. (2026) highlighted the importance of technological innovations in their study, where they developed a decision-making model for more sustainable municipal solid waste management.

3. RESEARCH METHODOLOGY

A common challenge in Multi-Criteria Decision Making (MCDM) is assigning appropriate weights to evaluation criteria such as cost, environmental impact, operational feasibility, and resource recovery. While expert opinion is the basis, it can introduce bias and reduce the objectivity of the decision-making process. The entropy method addresses this issue by quantifying the information content of each criterion and assigning greater weights to alternatives with higher variability. This data-driven approach ensures that the criteria most critical to the decision context—such as ecological risk or energy recovery—are appropriately prioritized (Martínez-Torres, Rodríguez-Piñero and Toral, 2015). At this point, it is believed that making uncertain and complex data more understandable and achieving more optimal results through integrated models will enable decision-makers to make the most accurate decisions. Accordingly, the data obtained in this study will be analyzed using entropy-based TOPSIS methods.

3.1. Entropy Method

Entropy is one of the MCDM approaches and is a method used to measure the degree of benefit provided by existing data. It falls under the category of objective methods, which are among the weight calculation methods frequently employed in the literature when determining criterion weights in the solution of a multi-criteria problem. In this method, the data in the decision matrix is utilized to weight the criteria in situations requiring multi-criteria decision-making. The fact that no additional subjective evaluation is required demonstrates both the method's ease of application and its reliability. The entropy method consists of a five-step process (Wu et al., 2011: 5163; Wang and Lee, 2009: 8982);

Step 1: Creating the Decision Matrix

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \vdots & \vdots & \dots & \vdots \\ X_{m1} & X_{m2} & \dots & X_{mn} \end{bmatrix}$$

At this stage, the decision matrix is created using Equation (1).

Step 2: Normalizing the Decision Matrix

$$p_{ij} = \frac{X_{ij}}{\sum_{i=1}^m X_{ij}} \quad \forall i, j$$

In this step of the entropy method, the decision matrix is normalized to convert it to a common unit. In this step, the criteria are normalized without distinguishing between benefit and cost functions.

Step 3: Calculating Entropy Values for Criteria

$$e_{ij} = -k \cdot \sum_{j=1}^n p_{ij} \cdot \ln(p_{ij})$$

$$i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n$$

$$k = (\ln(m)^{-1}) e_{(ij)} = 0 \leq e_{(ij)} \leq 1$$

In this step, the entropy values of each criterion are determined using the formula above.

Step 4: Determining the Degrees of Differentiation

$$d_j = 1 - e_j \quad j=1,2,\dots,n$$

In this step of the entropy method, the degree of equality of the information represented by d_j is calculated.

Step 5: Calculating Entropy Criterion Weights and Making Corrections if Negative Data Are Available

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j}$$

In the final step of the method, entropy weights are determined for each criterion. It is expected that the sum of the criterion weights will equal 1.

3.2. TOPSIS Method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) employs the fundamental principles of the Electre method. In the TOPSIS approach, the objective is to propose a solution to the problem by selecting the solution alternative based on the criterion of the shortest distance to the positive ideal solution and the longest distance from the negative ideal solution, within the context of the problem at hand. The solution process is considered to be shorter than that of the Electre method. According to the application of the method, the best criteria that can be obtained from the positive ideal solution; the negative ideal solution is

expressed as the combination of the worst criteria (Wang, Cheng, and Kun-Cheng, 2009: 380). The TOPSIS method involves a solution process consisting of 6 steps (Karami and Johansson, 2014: 523-524);

Step 1: Creating the Decision Matrix (A)

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

In the first step, the decision matrix is created with the assistance of decision makers. The rows of the decision matrix contain decision alternatives, and the columns contain the criteria to be used in the problem.

Step 2: Generating the Normalized Decision Matrix (R)

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^m a_{kj}^2}} \quad (i=1,2,\dots,m \text{ and } j=1,2,\dots,n)$$

The normalized decision matrix is created using the elements of the A matrix with the help of the formula. The purpose of the normalization process is to bring the data to a standard value between 0 and 1, even though they may be from different units.

Step 3: Creating the Weighted Standard Decision Matrix (V)

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \vdots & \vdots & \dots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix}$$

In this step of the method, the normalized decision matrix is multiplied by the importance coefficients of the criteria (w_j) and weighted. It is important to note that the sum of the (w_j) values equals 1.

Step 4: Creating Ideal (A+) and Negative Ideal (A-) Solutions

$$A^+ = \left\{ \left(\max_i v_{ij} \mid j \in J \right), \left(\min_i v_{ij} \mid j \in J' \right) \right\}$$

$$A^- = \left\{ \left(\min_i v_{ij} \mid j \in J \right), \left(\max_i v_{ij} \mid j \in J' \right) \right\}$$

At this stage, the weighted normalized positive ideal solution (A^+), which the alternatives are expected to approach in terms of each evaluation criterion, is calculated, as is the weighted normalized negative ideal solution (A^-), which the alternatives are expected to diverge from.

Step 5: Calculation of Separation Measures

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \quad S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}$$

In this step, the distances of each alternative from these values are calculated for each evaluation criterion. This is calculated using the formula in Equation (5). The distance between the positive ideal solution value and the negative ideal solution value is calculated.

Step 6: Calculating Relative Closeness to the Ideal Solution

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}$$

In the final step, the closeness coefficient for each alternative is calculated. The alternatives are then ranked based on these values. The alternative with a closeness coefficient value equal to or closest to 1 is ranked higher than the others.

Within the scope of this study, the decision-making criteria will first be weighted using the Entropy method, and then the Topsis method will be applied using the formulas mentioned above.

4. APPLICATION

4.1. Research Problem

This study emphasizes the need to consider multiple criteria and subjective judgments in decision-making processes aimed at selecting sustainable solid waste management solutions. It is anticipated that this will be beneficial for policymakers, producers, and waste management practitioners seeking to improve solid waste management practices and promote sustainable development. The aim is to obtain reliable data that will serve as a fundamental basis for policies and strategies to be developed regarding the subject by evaluating sustainable solid waste strategies and the criteria believed to influence these strategies using integrated Entropy-TOPSIS methods.

4.2. Generation of Data Related to Sustainable Solid Waste Strategies

This study, which aims to evaluate the numerous criteria and alternative solid waste strategies to be used in the development of sustainable solid waste strategies using integrated Entropy-TOPSIS methods, draws upon extensive literature reviews and expert opinions on the subject. As a result, nine criteria and five alternative solid waste strategies were identified for use in the study. The criteria are listed as Cost, Ecological Risks, CO₂ Emissions, Air Pollution, Reliability, Capacity, Efficiency, Recycling, and Energy Production (Mondal et al., 2026; Ding et al., 2021; Fadhullah et al., 2022; Wong, 2022; Omer et al., 2026; Feng et al., 2024). The alternatives to be used in the study are: Incineration, Biological Treatment, Landfilling, Composting, and Gasification (Parthasarathy et al., 2026; Subedi et al., 2025; Ferronato and Torretta, 2019).

Within the scope of the study, the opinions of three experts—two industry specialists and one faculty member conducting research in the relevant field—were sought. These experts were asked to evaluate the five identified solid waste management strategy alternatives by assigning scores from 1 to 10 based on the established criteria. The arithmetic mean of the expert opinions was calculated to create a Decision Matrix. Importance weights determined using the Entropy

method were used to establish the preference ranking of the alternatives via the TOPSIS method.

4.3. Evaluation of Data Related to Sustainable Solid Waste Strategies

4.3.1. Weighting of Criteria Using the Entropy Method

The first step of the entropy method is the creation of the decision matrix. The rows of the decision matrix contain the five common alternatives within the scope of sustainable waste management practices, and the columns contain the nine evaluation criteria to be used in decision-making.

Table 1. Decision Matrix

Alternative/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	8	8	10	6	4	9	4	10	9
A2	7	7	10	6	4	9	5	10	9
A3	7	8	7	5	6	9	5	7	5
A4	7	8	9	5	4	8	5	9	10
A5	6	7	10	6	2	2	6	9	10
Total	35	38	46	28	20	37	25	45	43

The codes corresponding to the technical terms listed in the table above are: Cost (C1), Ecological Risks (C2), CO₂ Emissions (C3), Air Pollution (C4), Reliability (C5), Capacity (C6), Efficiency (C7), Recycling (C8), and Energy Production (C9). In the second step of the entropy method, there is a normalized decision matrix (). The normalized decision matrix is created by dividing each value in a column of the decision matrix by the sum of the values in that column. Therefore, the Decision Matrix created according to the specified codes is presented in Table 2. The entropy value for each criterion is calculated by multiplying each element of the normalized decision matrix, calculated in the previous step, by its own logarithmic value. The matrix showing these entropy values is presented below.

Table 2. Entropy Values for the Criteria

Alternative Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.337 4	0.337 4	0.357 9	0.302 3	0.247 9	0.349 2	0.247 9	0.357 9	0.349 2
A2	0.321 9	0.321 9	0.357 9	0.302 3	0.247 9	0.349 2	0.278 0	0.357 9	0.349 2
A3	0.321 9	0.337 4	0.321 9	0.278 0	0.302 3	0.349 2	0.278 0	0.321 9	0.278 0

A4	- 0.321 9	- 0.337 4	- 0.349 2	- 0.278 0	- 0.247 9	- 0.337 4	- 0.278 0	- 0.349 2	- 0.357 9
A5	- 0.302 3	- 0.321 9	- 0.357 9	- 0.302 3	- 0.163 6	- 0.163 6	- 0.302 3	- 0.349 2	- 0.357 9

At this stage, the weight values for each selection criterion are calculated. First, the degree of differentiation (d_j) is determined by subtracting the calculated entropy value from 1. The criterion weights (w_j) are calculated by dividing the differentiation degree of each criterion by the total differentiation degree. The sum of the importance weights must always equal 1. The table below lists the differentiation degrees (d_j) and importance weights (w_j) for the relevant criteria.

Table 3. Differentiation degrees and importance weights of the criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9
e_j	-0.731	-0.754	-0.794	-0.666	-0.550	-0.705	-0.630	-0.790	-0.770
d_j	1.731	1.754	1.794	1.666	1,550	1,705	1,630	1,790	1,770
w_j	0.1125	0.1139	0.1166	0.1082	0.1007	0.1108	0.1059	0.1163	0.1150

The ranking of importance weights calculated using the entropy method is as follows: co.emissions (C3) rank first, followed by Recycling (C8) and Energy Production (C9) as the second most important weights. The other criteria in the ranking are determined as follows: Ecological Risks (C2), Cost (C1), Capacity (C6), Air Pollution (C4), Efficiency (C7), Price (C1), and Energy Production (C5). It was determined that the difference in importance weights between the highest and lowest values is significant.

4.3.2. Ranking of Alternatives According to the TOPSIS Method

In this stage, the importance weights determined using the Entropy method are integrated with the TOPSIS method.

Table 4. TOPSIS Decision Matrix (A)

Alternati ve/ Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	64	64	100	36	16	81	16	100	81
A2	49	49	100	36	16	81	25	100	81
A3	49	64	49	25	36	81	25	49	25
A4	49	64	81	25	16	64	25	81	100
A5	36	49	100	36	4	4	36	81	100
Sum of Squares	247	290	430	158	88	311	127	411	387
Square root	15.716 2	17.029 4	20.736 4	12.569 8	9.380 8	17.635 2	11.269 4	20.273 1	19.672 3

The squares of each decision matrix are calculated according to the method's stages. Subsequently, the values in each column are summed, the square root is taken, and the result is divided by the corresponding matrix value to create the normalized decision matrix. The matrix below is formed by multiplying the normalized decision matrix by the importance weights (w_j) calculated using the entropy method.

Table 5. Weighted Normalized Decision Matrix (V)

Alternative Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.057 2	0.053 5	0.056 2	0.051 7	0.043 0	0.056 5	0.037 6	0.057 4	0.052 6
A2	0.050 1	0.046 8	0.056 2	0.051 7	0.043 0	0.056 5	0.047 0	0.057 4	0.052 6
A3	0.050 1	0.053 5	0.039 4	0.043 1	0.064 4	0.056 5	0.047 0	0.040 2	0.029 2
A4	0.050 1	0.053 5	0.050 6	0.043 1	0.043 0	0.050 3	0.047 0	0.051 6	0.058 5
A5	0.042 9	0.046 8	0.056 2	0.051 7	0.021 5	0.012 6	0.056 4	0.051 6	0.058 5

To create the ideal A+ solution set, the largest value is selected from the relevant column of the weighted decision matrix by applying the desired min/max constraints. To create the negative A- solution set, the smallest value is selected from the relevant column of the weighted decision matrix by applying the desired min/max constraints. The distances of each criterion from the ideal and negative ideal solutions are determined.

Table 6. Determination of the Ideal (A+) and Negative Ideal (A-) Solutions

A+	0.0572	0.0535	0.0562	0.0517	0.0644	0.0565	0.0564	0.0574	0.0585
A-	0.0429	0.0468	0.0394	0.0431	0.0215	0.0126	0.0376	0.0402	0.0292

Table 7. Calculation of Distance Measures Between Alternatives

No	Alternatives	S+	S-
1	A1	0.0291	0.0620
2	A2	0.0261	0.0611
3	A3	0.0406	0.0630
4	A4	0.0279	0.0564
5	A5	0.0637	0.0412

The option closest to the positive ideal solution is determined as the optimal decision option. The C_i^+ value ranges between 0 and 1. A value of 1 represents the ideal solution, while 0 represents the negative ideal value. To determine the ideal solution option, the one closest to the value of 1 is selected. Finally, a ranking is performed.

Table 8. Calculation of Proximity to the Ideal Solution

No	Alternatives	C+	Rank
1	A1	0.680	2
2	A2	0.701	1
3	A3	0.608	4
4	A4	0.669	3
5	A5	0.393	5

The alternatives determined through calculations using the TOPSIS method have been ranked according to their importance. It was found that the option with the highest importance, based on its proximity to the ideal solution, is Biological Remediation (A2) among the sustainable waste management strategies. Based on the subsequent importance levels, the options were identified as Incineration (A1), Composting (A4), Landfilling (A3), and Gasification (A5), in that order. The analysis indicates that, within the framework of environmentally friendly practices, waste management should prioritize the benefits of biological treatment.

5. CONCLUSION

Sustainable solid waste management is one of the most significant challenges facing developing countries, as it directly impacts the environment and public health. Rapid population growth and urbanization have led to a steady increase in waste generation, making waste management processes—particularly collection systems—increasingly difficult. Outdated and inefficient solid waste systems lead to ineffective collection and disposal programs and illegal dumping. These inefficiencies not only negatively impact the ecological environment but also pose serious health risks. Inefficient solid waste collection exacerbates air and water pollution, further endangering ecosystems and public welfare (Mondal and Mandal, 2024).

The findings of this research study are highly significant in terms of their potential for recycling, reducing solid waste, recovering resources, and protecting the environment. Multi-Criteria Decision Making (MCDM) methods assist decision-makers in accounting for uncertainties and subjectivity, enhance transparency and consistency in decision-making, and help select the optimal waste management system. The findings provide reliable data for decision-makers and practitioners regarding the development of sustainable waste management practices and the improvement of waste management systems. In this context, the Entropy-TOPSIS methods were applied in an integrated manner as part of the MCDM approaches. To provide solution recommendations to decision-makers, 9 criteria and 5 alternatives were identified and included in the analysis.

As a result of the ENTROPI application conducted to determine the weights of the criteria used in vehicle selection, it was determined that the criterion of greatest importance is CO₂ emissions. This criterion is followed, in order, by Recycling and Energy Production. The other criteria were ranked as follows: Ecological Risks, Cost, Capacity, Air Pollution, Efficiency, Price, and Energy Production. It was found that the difference in importance weights between the highest and lowest values was significant.

Within the scope of the study, the preference rankings of solid waste strategies based on the criteria with determined weights were established using the TOPSIS method. According to the TOPSIS method results, biological treatment, incineration, and composting are presented as the most suitable solution alternatives, in that order. According to Vaverková (2019), landfilling is frequently preferred globally due to its practicality and low cost compared to alternative methods. However, prior to waste disposal, the U.S. Environmental Protection Agency (EPA, 2022) recommends prioritizing waste reduction at the source, followed by recycling, composting, or energy recovery.

Bibliography

- Ahmad, J., Mahmood, T., Pamucar, D., & Waqas, H. M. (2025). A novel complex q-rung orthopair fuzzy Yager aggregation operators and their applications in environmental engineering. *Heliyon*, 11(1): e41668. <https://doi.org/10.1016/j.heliyon.2025.e41668>
- Al-Sulbi, K., Chaurasia, P. K., Attaallah, A., Agrawal, A., Pandey, D., Verma, V. R., Kumar, V. & Ansari, T. J. (2023). A fuzzy TOPSIS-based approach for comprehensive evaluation of bio-medical waste management: Advancing sustainability and decision-making. *Sustainability*, 15(16): 12565. <https://doi.org/10.3390/su151612565>
- Ani, L. S., Budovich, L., Klunko, N. S., Jumanazarova, G. U., Nasurova, K. & Asatullaev, K. (2023). Reduction of cost and emissions by using recycling and waste management system. *Braz. J. Biol.* 83, 1–8. <https://doi.org/10.1590/1519-6984.279565>
- Atofarati, E. O., Adogbeji, V. O., & Enweremadu, C. C. (2025). Sustainable smart waste management solutions for rapidly urbanizing African cities. *Utilities Policy*, 95: 101961. <https://doi.org/10.1016/j.jup.2025.101961>
- Clasen, A. P., Agostinho, F., Almeida, C. M. V. B. & Giannetti, B. F. (2026). A decision-making model for more sustainable municipal solid waste management. *Environmental Impact Assessment Review*. 118: 108258. <https://doi.org/10.1016/j.eiar.2025.108258>
- Datta, P., Mohi, G. K. & Chander, J. (2018). Biomedical waste management in India: Critical appraisal. *J. Lab. Physicians*. 10(1): 6-14. https://doi.org/10.4103/JLP.JLP_89_17
- Ding, Y., Zhao, J., Liu, J. W., Zhou, J., Cheng, L., Zhao, J., Shao, Z., Iris, Ç., Pan, B., Li, X. & Hu, Z. T. (2021). A review of China's municipal solid waste (MSW) and comparison with international regions: management and technologies in treatment and resource utilization. *J. Clean. Prod.* 293(10): 126144. <https://doi.org/10.1016/j.jclepro.2021.126144>
- Duan, Y., Stević, Ž., Novarić, B., Zolfani, S. H., Görçün, Ö. F. & Subotić, M. (2025). Application of the fuzzy MCDM model for the selection of a multifunctional machine for sustainable waste management. *Sustainability*, 17(6): 2723. <https://doi.org/10.3390/su17062723>
- EPA (2022). United States Environmental Protection Agency. Sustainable Materials Management: Non-Hazardous Materials and Waste Management Hierarchy. <https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy> (accessed 28 fev 2024).

- Fadhullah, W., Imran, N. I. N., Ismail, S. N. S., Jaafar, M. H. & Abdullah, H. (2022). Household solid waste management practices and perceptions among residents in the east coast of Malaysia. *BMC Public Health* 22(1), 1–20.
<https://doi.org/10.1186/s12889-021-12274-7>
- Feng, R., Shen, C. & Guo, Y., (2024). Digital finance and labor demand of manufacturing enterprises: theoretical mechanism and heterogeneity analysis. *Int. Rev. Econ. Finance* 89: 17–32. <https://doi.org/10.1016/j.iref.2023.07.065>
- Ferronato, N. & Torretta, V. (2019). Waste mismanagement in developing countries: a review of global issues. *Int. J. Environ. Res. Public Health* 16(6): 1060.
<https://doi.org/10.3390/ijerph16061060>
- Giusti, L. (2009). A review of waste management practices and their impact on human health. *Waste Manag.* 29(8), 2227–2239. <https://doi.org/10.1016/j.wasman.2009.03.028>
- Hannan, M. A., Hossain Lipu, M. S., Akhtar, M., Begum, R. A., Mamun, M. A. A., Hussain, A., Mia, M. S. & Basri, H. (2020). Solid waste collection optimization objectives, constraints, modeling approaches, and their challenges toward achieving sustainable development goals, *Journal of Cleaner Production.* 277: 123557.
<https://doi.org/10.1016/j.jclepro.2020.123557>
- Karami, A. & Johansson, R. (2014). Utilization of multi attribute decision making techniques to integrate automatic and manual ranking of options. *Journal of Information Science and Engineering.* 30(2): 519-534. <https://doi.org/10.6688/JISE.2014.30.2.14>
- Martínez-Torres M. D. R., Rodríguez-Piñero F. & Toral S. L. (2015) Customer preferences versus managerial decision-making in open innovation communities: the case of Starbucks. *Technology Analysis & Strategic Management.* 27(10): 1226–1238.
<https://doi.org/10.1080/09537325.2015.1061121>
- Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A. & Yi., L. (2009). Municipal solid waste management in Pudong new area, China, *Waste Manag.* 29 12, 27–1233. <https://doi.org/10.1016/j.wasman.2008.07.016>
- Mondal, A., Manogna Reddy, N. R., Dubey, K. B. & Yadav, B. (2026). Pathways to sustainable municipal solid waste management: An LCA of integrated approaches and product circularity in Nashik, India. *Journal of Environmental Management*, 398.
<https://doi.org/10.1016/j.jenvman.2025.128424>
- Nanda, S. & Berruti, F., (2021). Municipal solid waste management and landfilling technologies: a review. *Environ. Chem. Lett.* 19(2), 1433–1456.
<https://doi.org/10.1007/s10311-020-01100-y>
- Nickson, O., Ukundimana, Z., Wamyil, F. B., Yusuf, A. A., Pierre, M. J., Kagabo, A. S. & Rizinde, T. (2024). Quantification and characterization of municipal solid waste at aler dumpsite, lira city, Uganda: assessing pollution levels and health risks. *Cleaner Waste Systems.* 9: 100177. <https://doi.org/10.1016/j.clwas.2024.100177>
- Omer, S. N., Saravanan, P., Kumar, P., Moniga, M., Rajeshkannan, R., Reddy, M., Rajasimman, M. & Venkat Kumar, S. (2026). Artificial intelligence and machine learning techniques in solid waste management: A sustainable way toward future. *Computer Science Review*, 60: 100889. <https://doi.org/10.1016/j.cosrev.2025.100889>

- Parthasarathy, T. N., Athira, T. M., Bhoopalan, R. & Tirkolae, E. B. (2026). Hybrid fuzzy multi-criteria decision-making model for assessing sustainable waste management strategies. *Expert Systems with Applications*, 318: 131937.
<https://doi.org/10.1016/j.eswa.2026.131937>
- Sarker, T. R., Ethen, D. Z., Asha, H. H., Islam, S. & Ali, M. R. (2025). Transformation of municipal solid waste to biofuel and bio-chemicals—a review. *International Journal of Environmental Science and Technology*, 22(5), 3811–3832.
<https://doi.org/10.1007/s13762-024-05975-0>
- Seikh, M. R. & Mandal, U. (2023). Interval-valued Fermatean fuzzy Dombi aggregation operators and SWARA based PROMETHEE II method to bio-medical waste management. *Expert Systems with Applications*. 226: 120082.
<https://doi.org/10.1016/j.eswa.2023.120082>
- Sobanaa, M., Prathiviraj, R., Prathaban, M., Kiran, G. S., & Selvin, J. (2025). Closing the loop: Circular economy solutions for long-term environmental health. *Evolving Earth*, 3: 100071. <https://doi.org/10.1016/j.eve.2025.100071>
- Sondh, S., Upadhyay, D. S., Patel, S. & Patel, R. N. (2024). Strategic approach towards sustainability by promoting circular economy-based municipal solid waste management system- a review. *Sustain. Chem. Pharm.* 37: 101337.
<https://doi.org/10.1016/j.scp.2023.101337>
- Subedi, A., Shrestha, S., Ghimire, A. & Raj Paudel, S. (2025). Leveraging machine learning for sustainable solid waste management: A global perspective. *Sustainable Futures*. 10: 101098. <https://doi.org/10.1016/j.sfr.2025.101098>
- Szpilko, D., de la Torre Gallegos, A., Jimenez Naharro, F., Rzepka, A. & Remiszewska, A. (2023). Waste management in the smart city: current practices and future directions. *Resources* 12 (10): 115. <https://doi.org/10.3390/resources12100115>
- UNEP (2024). *Global Waste Management Outlook 2024: Beyond an Age of Waste - Turning Rubbish into a Resource*.
- Vaverková, M. D. (2019). Landfill impacts on the environment. *Geosciences*. 9(10): 431.
<https://doi.org/10.3390/geosciences9100431>
- Wang, T. C. & Lee, H. D. (2009). Developing a fuzzy Topsis approach based on subjective weights and objective weights. *Expert Systems with Applications*. 36(5): 8980-8985.
<https://doi.org/10.1016/j.eswa.2008.11.035>
- Wang, J. W., Cheng, C. H. & Kun-Cheng, H. (2009). Fuzzy hierarchical TOPSIS for supplier selection. *Applied Soft Computing*. 9(1): 377-386.
<https://doi.org/10.1016/j.asoc.2008.04.014>
- Wong, M. H. (2022). Integrated sustainable waste management in densely populated cities: the case of Hong Kong. *Sustain. Horiz.* 2 (January), 100014.
<https://doi.org/10.1016/j.horiz.2022.100014>
- Wu, J., Sun, J., Liang, L. & Zha, Y. (2011). Determination of weights for ultimate cross efficiency using Shannon entropy. *Expert Systems with Applications*. 38(5): 5162-5165. <https://doi.org/10.1016/j.eswa.2010.10.046>

Yalçıntaş, D., Oğuz, S., Yaşa Özeltürkay, E. & Gülmez, M. (2023). Bibliometric analysis of studies on sustainable waste management. *Sustainability* 15(2), 1414.

<https://doi.org/10.3390/su15021414>

Zafaranlouei, N., Ghouschi, S. J., & Haseli, G. (2023). Assessment of sustainable waste management alternatives using the extensions of the base criterion method and combined compromise solution based on the fuzzy z-numbers. *Environmental Science and Pollution Research*, 30(22), 62121–62136.

<https://doi.org/10.1007/s11356-023-26380-z>

Zhou, C., Huang, N., Yang, G. & Ma, S. (2022). Assessing the sustainability of municipal solid waste management in China 1980-2019. *Sustainable Horizons* 2(3): 100020.

<https://doi.org/10.1016/j.horiz.2022.100020>