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Fuzzy SIWEC and Fuzzy RAWEC Methods for Sustainable Waste Disposal Technology Selection

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ABSTRACT

Rapid industrialization, population growth, and poor waste management have led to significant environmental and economic challenges. These issues underscore the need for effective disposal technologies to mitigate public health risks, reduce greenhouse gas emissions, and promote resource recovery. This study aims to determine the most suitable sustainable solid waste disposal technology for the planned Çivril Solid Waste Disposal Facility in Denizli Province. To evaluate eight disposal alternatives: landfilling (A_1), composting (A_2), biomethanization (A_3), incineration (A_4), gasification (A_5), plasma treatment (A_6), pyrolysis (A_7), and refuse-derived fuel (RDF) (A_8), we employed fuzzy-based Multi-Criteria Decision-Making (MCDM) methods: the Simple Weight Calculation (SIWEC) and Ranking Alternatives with Weights of Criterion (RAWEC). Twelve criteria, including environmental impact, legal compliance, and operational costs, were weighted using Fuzzy SIWEC, while the alternatives were ranked using Fuzzy RAWEC. The results identified composting (A_2) as the most suitable technology, whereas RDF (A_8) performed the worst. Validation through comparison with other MCDM methods (F-TOPSIS, F-SAW, F-MABAC, and CORASO) demonstrated high consistency. Sensitivity analysis confirmed that composting (A_2) and gasification (A_5) maintained stable rankings across different scenarios, while the rankings of other methods varied depending on decision-maker preferences. The integrated use of fuzzy-based SIWEC and RAWEC provides a reliable and systematic framework for sustainable waste management decision-making.

1. Introduction

Factors such as rapidly increasing industrialization with the industrial revolution, rapid population and economic growth, lack of infrastructure due to population growth, limited financial resources for planning and operation, lack of legal framework and political will for implementation and monitoring, lack of community participation, and lack of knowledge and skills in dealing with or preventing such problems have significantly increased the amount of solid waste [1-3]. Due to the increasing amount of solid waste, poor waste management practices and the proliferation of large amounts of

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uncontrolled landfills have a direct impact on public health and the natural environment [1,4]. In order to eliminate these problems and make the best use of limited resources, the need for an orderly and well-managed system has become more evident in recent years with technological advancements to keep the environment clean and maintain a healthy life in society [5]. In this context, the selection of a suitable sustainable solid waste disposal technology is of great importance.

Solutions for solid waste disposal have different economic, environmental and social benefits. Therefore, the selection of the most appropriate and sustainable solid waste disposal technology must involve different stakeholders such as local communities, managers, scientists, engineers and environmentalists. This leads to the selection of the best or most sustainable scenario being defined as a Multi Criteria Decision Making (MCDM) problem in determining solid waste disposal technology [6].

The aim of this study is to present an alternative for the Çivril Solid Waste Disposal Facility planned by the Provincial Directorate of Environment, Urbanisation and Climate Change of the Denizli Governorate. The most important reason for the selection of this solid waste disposal facility is that it is located in a central location where household waste from municipalities such as Çal, Çivril, Baklan and Bekilli and hazardous/non-hazardous solid waste from various industrial facilities can be disposed of. In this context, the fuzzy SIWEC (Fuzzy SImple WEight Calculation/F-SIWEC) and fuzzy RAWEC (Fuzzy Ranking Alternatives with WEights of Criterion/F-RAWEC) methods were used to determine the most suitable sustainable solid waste disposal technology.

This study consists of six sections. In the first section, a literature review on sustainable solid waste disposal technologies and the F-SIWEC and F-RAWEC methods is presented. The second section provides a theoretical framework on fuzzy logic. The third and fourth sections comprehensively explain the F-SIWEC and F-RAWEC methods, respectively. In the fifth section, the most appropriate sustainable solid waste disposal technology is determined. Finally, in the sixth section, various validation studies are conducted to ensure the accuracy and reliability of the study's findings.

2. Literature review

In this study, the literature search was conducted in three stages. The first stage focused on studies on the selection of waste disposal technologies, the second stage on studies on the F-SIWEC method and the third stage on studies on the F-RAWEC method.

In the first stage of the literature review, studies related to the selection of sustainable solid waste disposal methods were examined. Khan *et al.,* [7] used ANP (Analytic Network Process) to evaluate municipal solid waste disposal options. Roussat *et al.,* [8] selected a sustainable demolition waste management strategy in Lyon, France by using ELECTRE III (ELimination Et Choix Taduisant la REalite) method. Ekmekçioğlu *et al.,* [9] proposed to apply fuzzy AHP (Fuzzy Analytic Hierarchy Process) and fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution/F-TOPSIS) methods to select the site for municipal solid waste. Pires *et al.,* [10] selected the best solid waste management practice for Setúbal Peninsula, Portugal by using an integrated approach based on AHP and fuzzy interval TOPSIS. Şener *et al.,* [11] used Geographic Information System (GIS) and AHP methods for the selection of solid waste disposal site selection in Senirkent–Uluborlu Basin, Türkiye. Koroneos and Nanaki [12] evaluated different municipal solid waste treatment strategies for the city of Thessaloniki, within the frameworks of life cycle assessment and the integrated solid waste management strategy by considering social, environmental and economic effects. Liu *et al.,* [13] evaluated the health-care waste treatment technologies with an integration of 2-tuple DEMATEL (The Decision Making Trial and Evaluation Laboratory) and fuzzy MULTIMOORA (The Multi-Objective Optimization by Ratio Analysis) methods. Vučijak *et al.,* [14] evaluated solid waste scenarios for a municipal in Bosnia and Herzegovina by using a combined method based on AHP and VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) methods. Arıkan *et al.,* [4] selected solid waste disposal methodology with the help of three MCDM methods: TOPSIS, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) and F-TOPSIS. Rahman *et al.,* [15] selected the most appropriate waste-to-energy conversion technology for Dhaka City with the help of AHP method. Coban *et al.,* [16] proposed to use TOPSIS, PROMETHEE I and PROMETHEE II methods for the were utilized for the evaluation of municipal solid waste management scenarios. Wang *et al.,* [6] determined the best municipal solid waste treatment technology by using Interval-valued fuzzy DEMATEL and Interval-valued fuzzy group grey relational analysis Randazzo *et al.,* [17] used AHP and simple additive weighting method to select landfill site for municipal solid waste in Sicily, Italy. Kharat *et al.,* [5] proposed to use fuzzy MDCM methods to select solid waste treatment and disposal technology. Fuzzy Delphi method is used to obtain the critical factors for the evaluation of technology alternatives. Then fuzzy AHP was applied to determine the weights of the criteria and alternatives were evaluated with the F-TOPSIS method. Narayanamoorthy *et al.,* [18] evaluated bio-medical waste disposal methods with the help of newly proposed Fuzzy Subjective and Objective Weight Integrated Approach (HF-SOWIA) and hesitant fuzzy MOOSRA (Multiobjective Optimization on the basis of Simple Ratio Analysis). Torkayesh *et al.,* [19] selected sustainable waste disposal technology by using stratified BWM (Best-Worst Method) that is proposed to consider uncertainty in decision making process. Muhammad *et al.,* [20] proposed hybrid GREY-EDAS (Grey Evaluation based on Distance from Average Solution) method to select the best municipal solid waste management method in Nigeria. Garcia-Garcia [21] proposed using MCDM methods such as AHP, TOPSIS and Multi-Attribute Utility Theory (MAUT) to evaluate the performance of various solutions for solid waste management based on environmental, economic, social and technical metrics.

In the second stage of the literature review, studies related to the selection problems using F-SIWEC method were examined. The main advantage of the SIWEC (Simple Weight Calculation) method is manifested in its simplicity, which facilitates decision making. It differs from others in that it uses the evaluation of the criteria by the decision makers, so the criteria should not be ranked and compared, but only evaluated [22]. First, Puška *et al.,* [22] developed a novel method called the SIWEC method to determine the weights of the criteria. They also extended the SIWEC method to fuzzy environment by using linguistic variables in the ratings. They introduced the steps of the SIWEC method in an example of determining the importance of criteria for the sales needs of agricultural products in the Semberija region. Puška *et al.,* [23] proposed to use F-SIWEC and fuzzy COmpromise Ranking from Alternative SOlutions (CORASO) methods to select most suitable spraying drone for the agricultural goods company. The F-SIWEC method was used for determining the weights of the criteria and the fuzzy CORASO method was used for selecting the best drone. According to the results, DJI Agras T30 drone was preferred by the agricultural products company. Gökalp *et al.,* [24] evaluated the factors that affect the investment strategies for green hospitals by using F-SIWEC method. According to the results, effective waste management was determined as the most important factor and reducing the carbon footprint was another important factor. Cao *et al.,* [25] aimed to propose innovative approaches for green digital twin technologies of sustainable smart cities. The weights of the criteria of were determined by using spherical F-SIWEC. Then the innovative alternatives for green digital twin technologies were ranked with the help of spherical fuzzy Simple Additive Weighting (SAW). Puška *et al.,* [26] used an integrated MCDM approach based on Fuzzy-Rough SIWEC and RAWEC methods for tractor selection. As a result of the application Solectrac e25 tractor was determined as the best alternative.

In the third stage of the literature review, studies related to the selection of the F-RAWEC method were examined. Puška *et al.,* [27] proposed a new MCDM method and applied the method to agricultural distribution center location selection problem. The LMAW (Logarithm Methodology of Additive Weights) method was used to determine weights of the criteria, later location alternatives were evaluated using the RAWEC method. Trung *et al.,* [28] proposed an alternative normalization method for RAWEC to overcome the difficulty that arises when there are zero elements in the decision matrix. Demir and Ulusoy [29] used F-WENSLO (Fuzzy Weight by Envelope and Slope) and F-RAWEC methods to evaluate the potential locations for wind power plants. Puška *et al.,* [30] evaluated renewable energy source alternatives in agricultural production with an integrated fuzzy MCDM method based on DiWeC (Direct Weight Calculation) and F-RAWEC methods. Solar energy was found to be the greatest potential for advancing sustainable agricultural production as a result of the RAWEC method. Petrovic *et al.,* [31] assessed the sustainability of transport modes by using RAWEC method. They evaluated employment numbers, turnover, final energy consumption, greenhouse gas emissions, and transport-related fatalities criteria with the help of Standard Deviation, Entropy, and FANMA methods. Nedeljković *et al.,* [32] evaluated the agricultural product sales channels with fuzzy double MEREC (Method based on the Removal Effects of Criteria) and F-RAWEC method. According to the results, best sales channel is determined as online sales followed by producer-sales agent-consumer.

3. Methodology

3.1. Definition of a fuzzy number

The concept of fuzzy logic was first introduced by Zadeh [33] to model uncertainty in natural language. Fuzzy logic is a generalized version of traditional logic and includes all theories that use fuzzy sets. According to traditional set theory, the elements of a set are either members of this set (1) or not (0). The membership function of a fuzzy number, Triangular Fuzzy Number (TFN) $\tilde{A}$, is defined as $\mu_{\tilde{A}}(x): E \rightarrow [0,1]$.

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0, & otherwise \end{cases} \tag{1}$$

According to Equation (1), *l* and *u* represent the lower and upper limits of the fuzzy number $\tilde{A}$, respectively, and *m* represent the modal value for $\tilde{A}$. The TFN is indicated by $\tilde{A} = (l, m, u)$. The operational rules of $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ are shown in Equations (2)-(6).

Addition:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

Multiplication:

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{3}$$

Subtraction:

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{4}$$

Division:

$$\tilde{A}_1 \oslash \tilde{A}_2 = (l_1, m_1, u_1) \ / \ (l_2, m_2, u_2) = (l_1 / u_2, m_1 / m_2, u_1 / l_2) \tag{5}$$

Reciprocal:

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{6}$$

3.2 F-SIWEC Method

The SIWEC method is one of the methods proposed by Puška *et al.,* [22] to calculate the weights of criteria in the decision-making process. The most important feature of the SIWEC method is that it can be evaluated directly by decision-makers without the need for pairwise comparisons as in AHP, DEMATEL (The DEcision MAking Trial and Evaluation Laboratory), PIPRECIA (PIvot Pairwise RElative

Criteria Importance Assessment), or criteria ranking as in SWARA (Step-Wise Weight Assessment Ratio Analysis). This avoids the need for complex calculations and facilitates the decision-making process [22].

The objectives of the SIWEC method for determining the weights of criteria in the decision-making process can be listed as follows [22].

i. Facilitate the process of determining the importance of criteria when they cannot be compared or ranked.
ii. Simplify the process of calculating criteria weights using simple steps.
iii. To explain the process of calculating criterion weights in a simpler way for decision-makers and all interested parties.

In the SIWEC method, alternatives and criteria are presented as net values. However, the decision-making process is inadequate because real-world problems are complex and uncertain. To overcome this situation, Puška *et al.,* [22] developed the F-SIWEC method. This method consists of the following steps [22,23].

Step 1. The criteria are evaluated by the decision-makers using the linguistic variables in Table 1 [22].

Table 1
Linguistic Variables and Corresponding Fuzzy Numbers

Linguistic Variables	Fuzzy Number
Very Bad (VB)	(0, 0, 1)
Bad (B)	(0, 1, 3)
Medium Bad (MB)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Step 2. Then, the fuzzy decision matrix is formed by transforming the linguistic variables into corresponding fuzzy numbers based on the evaluations of each decision makers as given in Equation (7).

$$\tilde{A} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{1n} \\ \cdots & \cdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (7)$$

Equation (7) indicates decision matrix whose columns correspond to the criteria while rows correspond to the decision makers. In this matrix, $\tilde{x}_{ij}$ expresses the evaluations of decision makers as fuzzy numbers. In this study, triangular fuzzy numbers are utilized, and the triangular fuzzy number can be expressed as in Equation (8).

$$\tilde{x}_{ij} = (x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}) \quad (8)$$

Here, $x_{ij}^{l} \leq x_{ij}^{m} \leq x_{ij}^{u}$ and x_{ij}^{l}, x_{ij}^{m} and x_{ij}^{u} denote the lower, modal and upper values of the triangular fuzzy number, respectively [18].

Step 3. After fuzzy decision matrix is constructed, the normalization process is performed with the help of Equation (9).

$$\tilde{n}_{ij} = \frac{x_{ij}^{l}}{max\, x_{ij}^{u}}, \frac{x_{ij}^{m}}{max\, x_{ij}^{u}}, \frac{x_{ij}^{u}}{max\, x_{ij}^{u}} \quad (9)$$

Step 4. After the normalization process, the standard deviation value is calculated for each decision maker.

Step 5. The values in the normalized decision matrix are multiplied with the standard deviation values of the corresponding criterion by using Equation (10).

$$\tilde{v}_{ij} = \tilde{n}_{ij}\ x\ st.dev_j \quad (10)$$

Step 6. $\tilde{s}_{ij}$ values are obtained by calculating the sum of $\tilde{v}_{ij}$ values for each criterion with the help of Equation (11).

$$\tilde{s}_{ij} = \sum_{j=1}^{n} \tilde{v}_{ij} \quad (11)$$

Step 7. The final values of the fuzzy criteria weights are obtained by using Equation (12).

$$\tilde{w}_{ij} = \frac{s_{ij}^{l}}{\sum_{j=1}^{n} s_{ij}^{u}}, \frac{s_{ij}^{m}}{\sum_{j=1}^{n} s_{ij}^{m}}, \frac{s_{ij}^{u}}{\sum_{j=1}^{n} s_{ij}^{l}} \quad (12)$$

3.3 F-RAWEC method

The RAWEC method is one of the MCDM methods proposed by Puška *et al.,* [27] to streamline the decision-making process. While emerging methods complicate decision-making processes by introducing additional steps, the RAWEC method simplifies the process by reducing the steps in the decision-making process and avoids complex calculations [27]. The most important feature that distinguishes the RAWEC method from other MCDM methods is that it uses a double normalization process. In the first normalization process, all criteria are transformed into benefit criteria while all criteria are transformed into cost criteria in the second normalization process. A larger value means greater preference for a benefit criterion and less preference for a cost criterion. The use of the double normalization technique increases the accuracy and reliability of decisions by leveraging the strengths of the different MCDM methods while enabling the best decision to be made by evaluating and comparing alternatives more carefully and comprehensively [28].

Later Nedeljković *et al.,* [32] extended RAWEC method to fuzzy RAWEC (F-RAWEC) to deal with uncertain and vague environment. The F-RAWEC method consists of the following steps [30]:

Step 1. Alternatives are evaluated by decision makers using the linguistic variables in Table 1. Later, evaluation matrices are constructed by converting the linguistic variables into corresponding fuzzy numbers based on the evaluations of each decision makers. Then the values in these evaluation matrices are averaged to obtain average fuzzy decision matrix.

Step 2. After the average fuzzy decision matrix is constructed, two types of normalization operations are performed: maximum and minimum. For the maximum normalization process, the benefit and cost criteria are normalized using Equation (13) and Equation (14), respectively. Minimum normalization is performed by normalizing the benefit and cost criteria using Equation (15) and Equation (16).

Maximum normalization:

$$n_{ij} = \frac{x_{ij}^{l}}{max\ x_j^{u}}, \frac{x_{ij}^{m}}{max\ x_j^{u}}, \frac{x_{ij}^{u}}{max\ x_j^{u}};\ for\ benefit\ criteria \quad (13)$$

$$n_{ij} = \frac{min\ x_j^{l}}{x_{ij}^{u}}, \frac{min\ x_j^{l}}{x_{ij}^{m}}, \frac{min\ x_j^{l}}{x_{ij}^{l}};\ for\ cost\ criteria \quad (14)$$

Minimum normalization:

$$n'_{ij} = \frac{min\ x_j^{l}}{x_{ij}^{u}}, \frac{min\ x_j^{l}}{x_{ij}^{m}}, \frac{min\ x_j^{l}}{x_{ij}^{l}};for\ benefit\ criteria \quad (15)$$

$$n'_{ij} = \frac{x_{ij}^{l}}{max\ x_j^{u}}, \frac{x_{ij}^{m}}{max\ x_j^{u}}, \frac{x_{ij}^{u}}{max\ x_j^{u}};for\ cost\ criteria \quad (16)$$

In these equations, $x_{j\ min}$ denotes the minimum value of a given criterion and $x_{j\ max}$ denotes the maximum value of a given criterion.

Step 3. Using the criteria weights obtained with the F-SIWEC, the deviation value is calculated from these weights. The sum of deviations of all alternatives is calculated with the help of Equation (17) and Equation (18).

$$\tilde{v}_{ij} = \sum_{i=1}^{n} \tilde{w}_j \cdot \left(1 - \tilde{n}_{ij}\right) \tag{17}$$

$$\tilde{v}'_{ij} = \sum_{i=1}^{n} \tilde{w}_j \cdot \left(1 - \tilde{n}'_{ij}\right) \tag{18}$$

In these equations, $\tilde{w}_j$ refers to the weight of the criterion *j*.

Step 4. The fuzzy numbers are converted into crisp numbers by using Equation (19) and Equation (20).

$$v_{ij} = \frac{v_i^l + 4v_i^m + v_i^u}{6} \tag{19}$$

$$v'_{ij} = \frac{v\prime_i^l + 4v\prime_i^m + v\prime_i^u}{6} \tag{20}$$

Step 5. Using Equation (21), the final values of the alternatives are calculated, and the alternatives are evaluated.

$$Q_i = \frac{v\prime_{ij} - v_{ij}}{v\prime_{ij} + v_{ij}} \tag{21}$$

4. Case study

The purpose of this study is to identify the best technology for the solid waste disposal facility that the Denizli Governorship's Provincial Directorate of Environment, Urbanization, and Climate Change plans to build in Çivril. With the exception of the center districts, Çivril is the most densely populated district in Denizli, which is one of the main reasons it was chosen as the site for the facility. Additionally, because of its advantageous position, Çivril should be able to effectively handle the disposal of solid waste from various industrial facilities, both hazardous and non-hazardous, as well as municipal trash from the Çal, Baklan, and Bekilli municipalities. Figure 1 shows the location map of Çivril. The F-SIWEC and F-RAWEC approaches have been used in accordance with a fuzzy MCDM model that has been proposed to identify the best solid waste disposal technology. Twelve criteria were determined by environmental engineers from the Provincial Directorate of Environment, Urbanization, and Climate Change of Denizli Governorate, the Denizli Chamber of Industry, Çivril Municipality, and through a review of the relevant literature. These criteria encompass initial investment costs (C_1), capacity expansion and flexibility (C_2), legal compliance (C_3), waste utilization (C_4), operation and maintenance costs (C_5), environmental risk (C_6), frequency of use (C_7), need for qualified personnel (C_8), type of waste disposed (C_9), energy consumption (C_{10}), infrastructure needs (C_{11}), and transportation costs (C_{12}). Alternatives were determined through an examination of various disposal technologies. The technologies evaluated in this study include: Landfilling (A_1), Composting (A_2), Biomethanization (A_3), Incineration (A_4), Gasification (A_5), Plasma (A_6), Pyrolysis (A_7), and Refuse-Derived Fuel (RDF) (A_8).

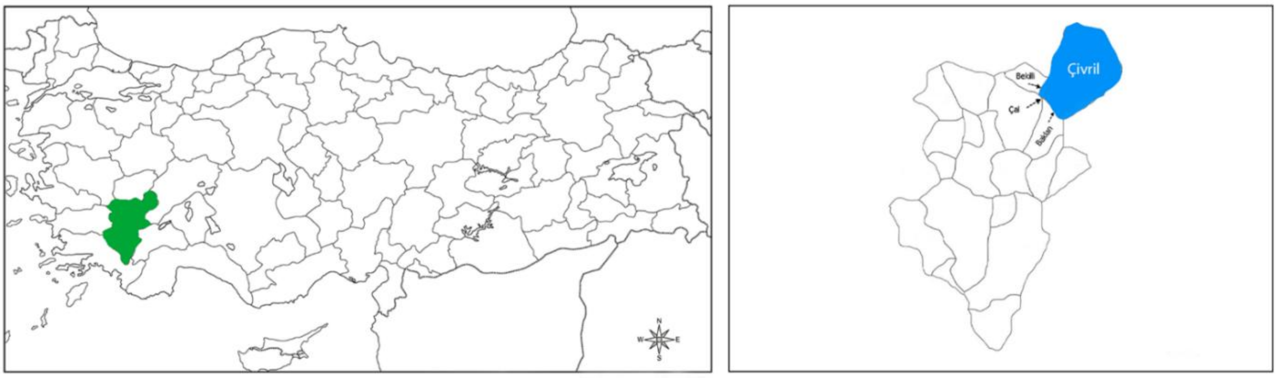

Fig. 1. Location map of Çivril

Before selecting the most suitable sustainable waste disposal technology, it is important to determine the weights of the criteria. The F-SIWEC method was used for this purpose. In the first phase of this method, three decision-makers independently evaluated the criteria listed in Table 2 using the linguistic variables shown in Table 1. The fuzzy decision matrix resulting from the evaluations of the decision makers was expressed as triangular fuzzy numbers and shown in Table 3.

Table 2
Initial Decision Matrix for Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
DM_1	MB	G	G	G	MB	M	MG	MG	G	B	G	MB
DM_2	B	G	MG	G	MB	M	M	MG	VG	MB	MG	MB
DM_3	MB	G	G	G	B	MB	M	G	VG	MB	G	MB

Table 3
Initial Fuzzy Decision Matrix for Criteria

	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
DM_1	(1,3,5)	(7,9,10)	(7,9,10)	…	(0,1,3)	(7,9,10)	(1,3,5)
DM_2	(0,1,3)	(7,9,10)	(5,7,9)	…	(1,3,5)	(5,7,9)	(1,3,5)
DM_3	(1,3,5)	(7,9,10)	(7,9,10)	…	(1,3,5)	(7,9,10)	(1,3,5)

After forming the average fuzzy decision matrix, the normalized fuzzy decision matrix was obtained using Equations (9). Based on the obtained data, the standard deviation values for each decision maker were calculated, and the results are shown in Table 4.

Table 4
Average Fuzzy Decision Matrix

	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}	$st.dev_j$
DM_1	(0.1,0.3,0.5)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	…	(0.0,0.1,0.3)	(0.7,0.9,1.0)	(0.1,0.3,0.5)	0.311
DM_2	(0.0,0.1,0.3)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	…	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	0.302
DM_3	(0.1,0.3,0.5)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	…	(0.1,0.3,0.5)	(0.7,0.9,1.0)	(0.1,0.3,0.5)	0.335

After multiplying the normalization values by the standard deviation values using Equation (10), the individual sum of weights was calculated using Equation (11). The final weight values of the criteria were determined using Equation (12). These values were listed in Table 5.

Table 5
Criterion Importance Values

	$\tilde{s}i_j$	$\widetilde{w}_{ij}$
C_1	(0.06,0.22,0.41)	(0.01,0.03,0.09)
C_2	(0.66,0.85,0.95	(0.08,0.12,0.20)
C_3	(0.60,0.79,0.92)	(0.07,0.12,0.19)
C_4	(0.66,0.85,0.95)	(0.08,0.12,0.20)
C_5	(0.06,0.22,0.41)	(0.01,0.03,0.09)
C_6	(0.22,0.41,0.60)	(0.03,0.06,0.13)
C_7	(0,35,0.54,0.73)	(0.04,0.08,0.15)
C_8	(0.54,0.73,0.89)	(0.06,0.12,0.19)
C_9	(0.79,0.92,0.95)	(0.09,0.13,0.20)
C_{10}	(0.06,0.22,0.41)	(0.01,0.03,0.09)
C_{11}	(0.60,0.79,0.92)	(0.07,0.12,0.19)
C_{12}	(0.09,0.28,0.47)	(0.01,0.04,0.10)

After determining the weights of the criteria using the F-SIWEC method, the steps of the F-RAWEC approach were applied to evaluate the most appropriate sustainable solid waste disposal technology. In the first step of the F-RAWEC method, the alternatives were evaluated by the decision makers using the linguistic variables shown in Table 1, and these evaluations are summarized in Table 6. The average fuzzy decision matrix was then created by averaging the decision makers' individual ratings. The results are shown in Table 7.

Table 6
Initial Decision Matrix for Alternatives

DM_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	B	M	G	MB	MB	MG	G	MB	B	M	MB	B
A_2	MB	MG	VG	G	M	MB	G	MG	MG	MB	M	MB
A_3	M	M	MG	MG	M	MB	MG	M	M	M	MB	MB
A_4	MB	MB	B	B	M	G	MG	MB	MB	G	B	M
A_5	M	MB	M	M	MG	M	M	MG	M	MG	MB	MG
A_6	MG	B	MB	MB	G	MG	MB	G	MB	G	M	G
A_7	M	MB	M	M	MG	M	M	M	M	M	MB	M
A_8	M	MB	MB	MB	M	G	M	M	MB	M	MB	M
DM_2	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	MB	MG	MB	VB	G	MB	VG	MB	VG	MB	MB	MB
A_2	M	MB	MG	MB	G	G	G	MG	VG	M	M	M
A_3	MB	MG	MG	MG	M	M	MG	M	MB	M	M	MB
A_4	G	MB	MB	MG	M	M	MB	MG	VG	MG	MG	M
A_5	MG	MG	M	M	M	G	MB	MG	MG	MG	MG	MG
A_6	MB	MB	MG	MG	MG	M	MB	B	MB	MG	M	MG
A_7	MB	M	MB	M	M	M	M	M	M	M	M	MG
A_8	MB	M	M	MB	M	MG	MB	M	MG	MG	M	M
DM_3	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	MB	MG	M	B	MB	MB	VG	MB	MB	MB	M	MB
A_2	M	MB	MG	MB	G	G	MG	MG	VG	M	M	M
A_3	MB	MG	MG	MG	M	M	MG	M	M	M	M	MB
A_4	G	MB	MB	MG	M	M	MB	MB	VG	VG	B	M
A_5	MG	MG	M	M	M	G	MB	MG	MG	MG	MB	MG
A_6	MG	B	MG	MG	MG	MG	MB	B	MB	MG	MB	G
A_7	M	MB	M	M	MG	M	M	M	M	M	M	MG
A_8	MB	M	MB	MB	M	MB	M	MB	MB	M	MB	M

Table 7
Average Fuzzy Decision Matrix

Alt.	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
A_1	(0.67,2.33,4.33)	(4.33,6.33,8.33)	(3.67,5.67,7.33)	…	(1.67,3.67,5.67)	(1.67,3.67,5.67)	(0.67,2.33,4.33)
A_2	(2.33,4.33,6.33)	(2.33,4.33,6.33)	(6.33,8.00,9.33)	…	(2.33,4.33,6.33)	(3.00,5.00,7.00)	(2.33,4.33,6.33)
A_3	(1.67,3.67,5.67)	(4.33,6.33,8.33)	(5.00,7.00,9.00)	…	(3.00,5.00,7.00)	(2.33,4.33,6.33)	(1.00,3.00,5.00)
A_4	(5.00,7.00,8.33)	(1.00,3.00,5.00)	(0.67,2.33,4.33)	…	(6.33,8.33,9.67)	(0.33,1.67,3.67)	(3.00,5.00,7.00)
A_5	(4.33,6.33,8.33)	(3.67,5.67,7.67)	(3.00,5.00,7.00)	…	(5.00,7.00,9.00)	(1.00,3.00,5.00)	(5.00,7.00,9.00)
A_6	(3.67,5.67,7.67)	(0.33,1.67,3.67)	(3.67,5.67,7.67)	…	(5.67,7.67,9.33)	(2.33,4.33,6.33)	(6.33,8.33,9.67)
A_7	(2.33,4.33,6.33)	(1.37,3.67,5.67)	(2.33,4.33,6.33)	…	(3.00,5.00,7.00)	(2.33,4.33,6.33)	(4.33,6.33,8.33)
A_8	(1.37,3.67,5.67)	(2.33,4.33,6.33)	(1.67,3.67,5.67)	…	(2.33,4.33,6.33)	(1.67,3.67,5.67)	(3.00,5.00,7.00)
Min AS	(0.67,2.33,4.33)	(0.33,1.67,3.67)	(0.67,2.33,4.33)	…	(1.67,3.67,5.67)	(0.33,1.67,3.67)	(0.67,2.33,4.33)
Max AS	(5.00,7.00,8.33)	(4.33,6.33,8.33)	(6.33,8.00,9.33)	…	(6.33,8.33,9.67)	(3.00,5.00,7.00)	(6.33,8.33,9.67)

After obtaining the average fuzzy decision matrix, since all criteria are considered as benefit criteria, Equation (13) was used for the process of maximum normalization and the results were summarized in Table 8. Equation (15) was used for minimum normalization and the results were given in Table 9. Since linguistic values are in the form of 'very bad' to 'very good', all criteria are used in this study are considered as benefit criteria. While decision makers evaluated the cost criteria such as initial investment costs (C_1) used linguistic variables like Very Bad, Bad, Medium Bad if the cost is high so these cost criteria can be considered as benefit criteria. This was also applied to other cost criteria like C_5, C_6, C_8, C_{10}, C_{11} and C_{12}.

Table 8
Maximum Normalization Matrix

Alt.	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
A_1	(0.08,0.28,0.52)	(0.52,0.76,1.00)	(0.39,0.61,0.79)	…	(0.17,0.38,0.59)	(0.24,0.52,0.81)	(0.07,0.24,0.45)
A_2	(0.28,0.52,0.76)	(0.28,0.52,0.76)	(0.68,0.86,1.00)	…	(0.24,0.45,0.66)	(0.43,0.71,1.00)	(0.24,0.45,0.66)
A_3	(0.20,0.44,0.68)	(0.52,0.76,1.00)	(0.54,0.75,0.96)	…	(0.31,0.52,0.72)	(0.33,0.62,0.90)	(0.10,0.31,0.52)
A_4	(0.60,0.84,1.00)	(0.12,0.36,0.60)	(0.07,0.25,0.46)	…	(0.66,0.86,7.00)	(0.05,0.24,0.52)	(0.31,0.52,0.72)
A_5	(0.52,0.76,1.00)	(0.44,0.68,0.92)	(0.32,0.54,0.75)	…	(0.52,0.72,0.93)	(0.14,0.43,0.71)	(0.52,0.72,0.93)
A_6	(0.44,0.68,0.92)	(0.04,0.20,0.44)	(0.39,0.61,0.82)	…	(0.59,0.79,0.97)	(0.33,0.62,0.90)	(0.66,0.86,1.00)
A_7	(0.28,0.52,0.76)	(0.20,0.44,0.68)	(0.25,0.46,0.68)	…	(0.31,0.52,0.72)	(0.33,0.62,0.90)	(0.45,0.66,0.86)
A_8	(0.20,0.44,0.68)	(0.28,0.52,0.76)	(0.18,0.39,0.61)	…	(0.24,0.45,0.66)	(0.24,0.52,0.81)	(0.31,0.52,0.72)

Table 9
Minimum Normalization Matrix

Alt.	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
A_1	(0.15,0.29,1.00)	(0.04,0.05,0.08)	(0.09,0.12,0.18)	…	(0.29,0.45,1.00)	(0.06,0.09,0.20)	(0.15,0.29,1.00)
A_2	(0.11,0.15,0.29)	(0.05,0.08,0.14)	(0.07,0.08,0.11)	…	(0.26,0.38,0.71)	(0.05,0.07,0.11)	(0.11,0.15,0.29)
A_3	(0.12,0.18,0.40)	(0.04,0.05,0.08)	(0.07,0.10,0.13)	…	(0.24,0.33,0.56)	(0.05,0.08,0.14)	(0.13,0.22,0.67)
A_4	(0.08,0.10,0.13)	(0.07,0.11,0.33)	(0.15,0.29,1.00)	…	(0.17,0.20,0.26)	(0.09,0.20,1.00)	(0.10,0.13,0.22)
A_5	(0.08,0.11,0.15)	(0.04,0.06,0.09)	(0.10,0.13,0.22)	…	(0.19,0.24,0.33)	(0.07,0.11,0.33)	(0.07,0.10,0.13)
A_6	(0.09,0.12,0.18)	(0.09,0.20,1.00)	(0.09,0.12,0.18)	…	(0.18,0.22,0.29)	(0.05,0.08,0.14)	(0.07,0.08,0.11)
A_7	(0.11,0.15,0.29)	(0.06,0.09,0.20)	(0.11,0.15,0.29)	…	(0.24,0.33,0.56)	(0.05,0.08,0.14)	(0.08,0.11,0.15)
A_8	(0.12,0.18,0.40)	(0.05,0.08,0.14)	(0.12,0.18,0.40)	…	(0.26,0.38,0.71)	(0.06,0.09,0.20)	(0.10,0.13,0.22)

The deviations from the maximum criterion weights were calculated using Equation (17) and the deviations from the minimum criterion weights were obtained using Equation (18) and shown in Table 10 and Table 11 respectively.

Table 10
Deviation Values from the Criterion Weight (Maximum)

Alt.	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
A_1	(0.00,0.02,0.08)	(0.00,0.03,0.10)	(0.02,0.05,0.12)	…	(0.00,0.02,0.07)	(0.01,0.06,0.15)	(0.01,0.03,0.09)
A_2	(0.00,0.02,0.06)	(0.02,0.06,0.14)	(0.00,0.02,0.06)	…	(0.00,0.02,0.07)	(0.00,0.03,0.11)	(0.00,0.02,0.08)
A_3	(0.00,0.02,0.07)	(0.00,0.03,0.10)	(0.00,0.03,0.09)	…	(0.00,0.02,0.06)	(0.01,0.04,0.13)	(0.01,0.03,0.09)
A_4	(0.00,0.01,0.04)	(0.03,0.08,0.18)	(0.04,0.09,0.18)	…	(0.00,0.00,0.03)	(0.03,0.09,0.19)	(0.00,0.02,0.07)
A_5	(0.00,0.01,0.04)	(0.01,0.04,0.11)	(0.02,0.05,0.13)	…	(0.00,0.01,0.04)	(0.02,0.07,0.17)	(0.00,0.01,0.05)
A_6	(0.00,0.01,0.05)	(0.04,0.10,0.19)	(0.01,0.05,0.12)	…	(0.00,0.01,0.04)	(0.01,0.04,0.13)	(0.00,0.01,0.03)
A_7	(0.00,0.02,0.06)	(0.02,0.07,0.16)	(0.02,0.06,0.15)	…	(0.00,0.02,0.06)	(0.01,0.04,0.13)	(0.00,0.01,0.06)
A_8	(0.00,0.02,0.07)	(0.02,0.06,0.14)	(0.03,0.07,0.16)	…	(0.00,0.02,0.07)	(0.01,0.06,0.15)	(0.00,0.02,0.07)

Table 11
Deviation Values from the Criterion Weight (Minimum)

Alt.	C_1	C_2	C_3	…	C_{10}	C_{11}	C_{12}
A_1	(0.00,0.02,0.07)	(0.07,0.12,0.19)	(0.06,0.10,0.18)	…	(0.00,0.02,0.06)	(0.06,0.11,0.18)	(0.00,0.03,0.09)
A_2	(0.01,0.03,0.08)	(0.07,0.12,0.19)	(0.06,0.11,0.18)	…	(0.00,0.02,0.06)	(0.06,0.11,0.19)	(0.01,0.04,0.09)
A_3	(0.00,0.03,0.08)	(0.07,0.12,0.19)	(0.06,0.11,0.18)	…	(0.00,0.02,0.07)	(0.06,0.11,0.18)	(0.00,0.03,0.09)
A_4	(0.01,0.03,0.08)	(0.05,0.11,0.19)	(0.00,0.08,0.16)	…	(0.01,0.03,0.07)	(0.00,0.09,0.18)	(0.01,0.04,0.09)
A_5	(0.01,0.03,0.08)	(0.07,0.12,0.19)	(0.05,0.10,0.18)	…	(0.00,0.02,0.07)	(0.05,0.10,0.18)	(0.01,0.04,0.09)
A_6	(0.01,0.03,0.08)	(0.00,0.10,0.18)	(0.06,0.10,0.18)	…	(0.01,0.03,0.07)	(0.06,0.11,0.18)	(0.01,0.04,0.09)
A_7	(0.01,0.03,0.08)	(0.06,0.11,0.19)	(0.05,0.10,0.17)	…	(0.00,0.02,0.07)	(0.06,0.11,0.18)	(0.01,0.04,0.09)
A_8	(0.00,0.03,0.08)	(0.07,0.12,0.19)	(0.04,0.09,0.17)	…	(0.00,0.02,0.06)	(0.06,0.11,0.18)	(0.01,0.04,0.09)

Equation (19) and Equation (20) were used to convert the deviation values from the criteria weights into the crisp numbers shown in Table 12. Finally, the final values of the alternatives were calculated using Equation (21) and shown in Table 12.

Table 12
Defuzzification of Deviation from the Criterion Weight

Alt.	$\tilde{v}_j$	v_j	$\tilde{v}'_j$	v'_j	Q_i	*Rank*
A_1	(0.18,0.50,1.28)	0.575	(0.29,0.78,1.55)	0.827	0.179	7
A_2	(0.05,0.29,0.93)	0.355	(0.46,0.87,1.62)	0.928	0.447	1
A_3	(0.08,0.38,1.13)	0.459	(0.40,0.83,1.59)	0.886	0.318	3
A_4	(0.17,0.50,1.26)	0.575	(0.29,0.81,1.57)	0.849	0.192	6
A_5	(0.09,0.39,1.10)	0.456	(0.42,0.85,1.61)	0.906	0.330	2
A_6	(0.17,0.49,1.24)	0.563	(0.26,0.80,1.58)	0.839	0.197	5
A_7	(0.13,0.47,1.25)	0.542	(0.40,0.83,1.59)	0.884	0.240	4
A_8	(0.17,0.53,1.37)	0.612	(0.36,0.81,1.57)	0.861	0.169	8

The analysis of the results in Table 12 leads to the conclusion that alternative A_2 (composting) is the best sustainable waste disposal technology and alternative A_8 (RFD) has the lowest performance.

5. Validation of the results

In this section, the results obtained with the F-RAWEC method were validated. The validation was carried out in two stages. In the first stage, the results obtained with the F-RAWEC method were compared with other methods. In the second stage, the sensitivity analysis of the model was carried out by changing the weighting coefficients.

5.1 Comparison of the result obtain by the F-RAWEC with other methods

The results obtained with the F-RAWEC method were compared with the F-TOPSIS, F-SAW, F-MABAC and CORASO methods. Figure 2 shows the alternative rankings resulting from the application of the different MCDM methods. The results of the comparative analysis indicate that alternatives A_2, A_4, A_7 and A_8 have the same rank in all methods. In contrast, alternatives A_1, A_3, A_5 and A_6 have the same rank for methods F-RAWEC, F-TOPSIS, F-SAW and F-MABAC (Fuzzy Multi-Attributive Border Approximation Area Comparison), while small differences were observed for the CORASO method. The main reason for this difference is that the CORASO method has its own unique implementation steps. Consequently, the F-RAWEC method was found to provide comparable results to the other methods, confirming its validity.

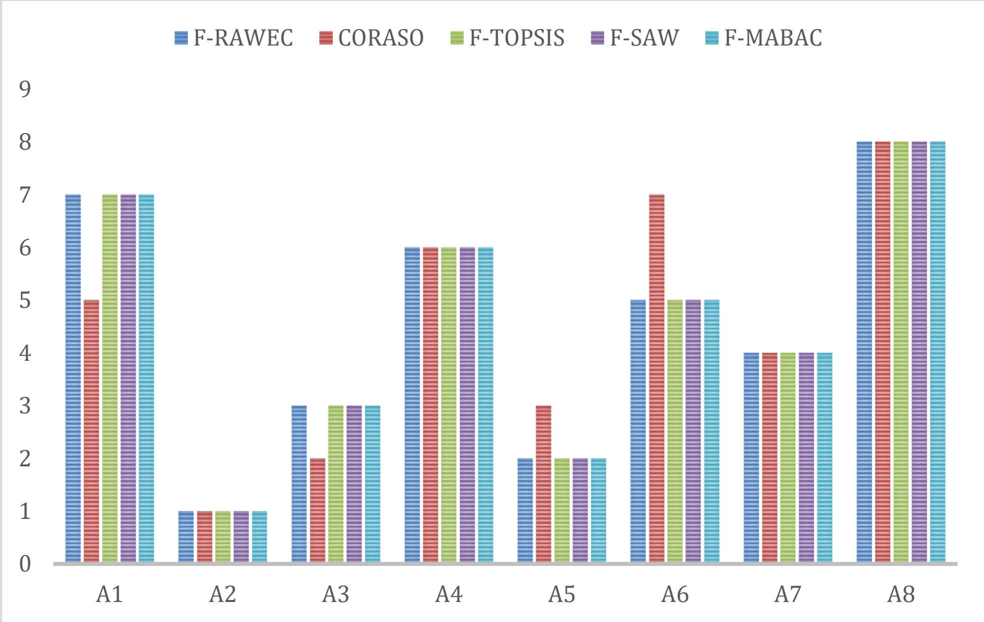

Fig. 2. Rank of Alternatives by Applying Different MCDM Methods.

The ranking results obtained with the F-RAWEC and the ranking results obtained with other MCDM methods were verified by applying the Spearman correlation coefficient (SCC) [34]:

$$SCC = 1 - \frac{6\sum_{i=1}^{n} D_i^2}{n(n^2-1)} \tag{22}$$

In this equation, D_i is the difference between the ranking of an item in the vector *w* and the ranking of the corresponding item in the reference vector, and *n* is the number of ranked items [34]. The SCC value varies between -1 and +1. SCC value of 1 indicates a perfect positive relationship. SCC value of -1 indicates a perfect negative relationship. SCC value of 0 means that there is no relationship between the variables. The SCC values are given in Table 13.

Table 13
SCC Values for Alternative Ranks Obtained by Different MCDM Methods

	F-RAWEC	CORASO	F-TOPSIS	F-SAW	F-MABAC
F-RAWEC	1.00				
CORASO	0.88	1.00			
F-TOPSIS	1.00	0.88	1.00		
F-SAW	1.00	0.88	1.00	1.00	
F-MABAC	1.00	0.88	1.00	1.00	1.00

As seen in Table 13, the SCC values are between 0.88 and 1, which indicates a high correlation value. It can be concluded that the results of the F-RAWEC method are satisfactory and the robustness of this study in selecting the most appropriate sustainable waste disposal technology has been proven.

5.2 Change of weight coefficients of criteria

After the results obtained with the F-RAWEC method were validated with other fuzzy MCDM methods, a sensitivity analysis was performed. Sensitivity analysis is an approach for checking the consistency and robustness of solutions. According to another definition, sensitivity analysis is an analysis that helps to identify the variables that have the greatest influence on the results obtained based on input data that are influenced by various factors such as personal opinions, biases and measurement errors [35].

Although there are various approaches to sensitivity analysis, analysis by changing the weighting coefficients of the criteria is widely used in the literature [36]. In this study, considering the sensitivity analysis method used by Puška *et al.,* [23], the weighting of one criterion after another was changed and how the rankings differ was investigated. In this context, the weighting of each criterion was reduced by 30%, 60% and 90% respectively, while the weighting of the remaining criteria was increased proportionally. As part of this approach, three scenarios were created for each criterion, and as there are twelve criteria in total, thirty-six scenarios were created as part of the sensitivity analysis. Figure 3 shows the results.

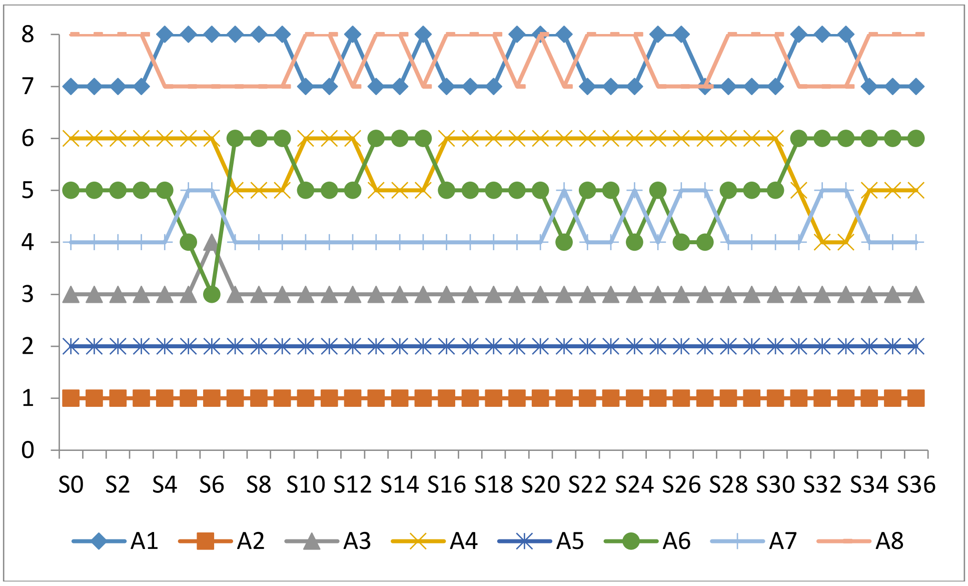

Fig. 3. Sensitivity Analysis Results

When the results of the sensitivity analysis in Figure 3 were analyzed, it was observed that A_2 and A_5 waste disposal methods maintained their ranking in all scenarios. While disposal method A_3 maintained its ranking in thirty-five scenarios, it was only overtaken by disposal method A_7 in one scenario. Waste management methods A_1 and A_8 were ranked last in all scenarios. On the other hand, waste disposal methods A_7, A_6 and A_4 were subject to different evaluations depending on the preferences of the decision-makers, which led to changes in the rankings depending on the scenario. Overall, the fact that the study was conducted with three decision-makers and a limited number of scenarios shows the validity of the results obtained under certain conditions and provides a basis for a more comprehensive analysis in the future.

6. Conclusions

This study addresses the environmental and economic challenges stemming from rising industrialization, population growth, and ineffective waste management practices. The main objective is to determine the most suitable sustainable waste disposal technology for the planned solid waste disposal facility in Çivril district of Denizli province. Since the selection of an appropriate waste disposal method is a multidimensional problem involving environmental, economic, and social factors, MCDM methods, Fuzzy SIWEC and Fuzzy RAWEC, were applied in the decision-making process. In the study, 12 criteria were considered to evaluate waste disposal technologies. These criteria are initial investment costs (C_1), capacity expansion and flexibility (C_2), legal compliance

(C_3), waste utilization (C_4), operation and maintenance costs (C_5), environmental risk (C_6), frequency of use (C_7), need for qualified personnel (C_8), type of waste disposed (C_9), energy consumption (C_{10}), infrastructure needs (C_{11}), and transportation costs (C_{12}). Eight different alternatives were assessed, including Landfilling (A_1), Composting (A_2), Biomethanization (A_3), Incineration (A_4), Gasification (A_5), Plasma (A_6), Pyrolysis (A_7), and Refuse-Derived Fuel (RDF) (A_8). The weights of the criteria were determined using the Fuzzy SIWEC method, while the alternatives were ranked using the Fuzzy RAWEC method.

According to the results, type of waste disposed (C_9) was identified as the most important criterion, indicating its high significance in the decision-making process. On the other hand, initial investment costs (C_1), operation and maintenance costs (C_5), and energy consumption (C_{10}) were determined to be the least important criteria. This highlights the relatively lower impact of initial costs, operational expenses, and energy consumption compared to the type of waste disposed when evaluating waste disposal technologies. Moreover, Composting (A_2) was determined to be the most suitable and sustainable waste disposal technology, while RDF (A_8) was identified as the lowest-performing alternative. The rankings obtained using the Fuzzy RAWEC method were highly consistent with other MCDM methods such as F-TOPSIS, F-SAW, F-MABAC, and CORASO. The sensitivity analysis showed that the Composting (A_2) and Gasification (A_5) methods maintained their positions in the ranking across all scenarios. Landfilling (A_1) and RDF (A_8) methods consistently ranked at the bottom in all scenarios. On the other hand, the rankings of Incineration (A_4), Plasma (A_6), and Pyrolysis (A_7) methods varied depending on the preferences of the decision-makers, indicating the flexibility and adaptability of the applied methods in the decision-making process.

The contributions of this study lie in the combined use of Fuzzy SIWEC and Fuzzy RAWEC methods, which provided a more systematic approach to the selection process of solid waste disposal technologies. The study significantly contributes to the literature on sustainable waste management, particularly by demonstrating the robustness and consistency of the applied methods through sensitivity analyses. The following suggestions can be made for future research:

i. Increasing the number of criteria could make the results more comprehensive.
ii. The generalizability of the results could be tested by applying similar models in different geographical and economic contexts.
iii. The decision-making process could be made more inclusive by encouraging the participation of more decision makers.
iv. Evaluating new technologies and incorporating artificial intelligence (AI) supported decision models into waste disposal processes could enhance the efficiency of the process.

In conclusion, this study proposes a strategic model for sustainable waste disposal in Denizli, Türkiye and provides a solid foundation for future research. The consistency of the findings obtained through different decision-making models and sensitivity analyses confirms the reliability and applicability of the proposed model in this study.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Yousif, D. F., & Scott, S. (2007). Governing solid waste management in Mazatenango, Guatemala: Problems and prospects. International Development Planning Review, 29(4), 433-450. https://doi.org/10.3828/idpr.29.4.2

[2] Mmereki, D., Baldwin, A., & Li, B. (2016). A comparative analysis of solid waste management in developed, developing and lesser developed countries. Environmental Technology Reviews, 5(1), 120-141. https://doi.org/10.1080/21622515.2016.1259357

[3] Saketa, Y., Tamene, N., & Melknew, M. (2023). Municipal solid waste disposal site suitability analysis using multi-criteria evaluation in Assosa, Ethiopia. International Journal of Environmental Science and Technology, 20(4), 3815-3830. https://doi.org/10.1007/s13762-022-04221-9

[4] Arıkan, E., Şimşit-Kalender, Z. T., & Vayvay, Ö. (2017). Solid waste disposal methodology selection using multi-criteria decision making methods and an application in Turkey. Journal of Cleaner Production, 142, 403-412. https://doi.org/10.1016/j.jclepro.2015.10.054

[5] Kharat, M. G., Murthy, S., Kamble, S. J., Raut, R. D., Kamble, S. S., & Kharat, M. G. (2019). Fuzzy multi-criteria decision analysis for environmentally conscious solid waste treatment and disposal technology selection. Technology in Society, 57, 20-29. https://doi.org/10.1016/j.techsoc.2018.12.005

[6] Wang, Z., Ren, J., Goodsite, M. E., & Xu, G. (2018). Waste-to-energy, municipal solid waste treatment, and best available technology: comprehensive evaluation by an interval-valued fuzzy multi-criteria decision making method. Journal of Cleaner Production, 172, 887-899. https://doi.org/10.1016/j.jclepro.2017.10.184

[7] Khan, S., & Faisal, M. N. (2008). An analytic network process model for municipal solid waste disposal options. Waste Management, 28(9), 1500-1508. https://doi.org/10.1016/j.wasman.2007.06.015

[8] Roussat, N., Dujet, C., & Méhu, J. (2009). Choosing a sustainable demolition waste management strategy using multicriteria decision analysis. Waste management, 29(1), 12-20. https://doi.org/10.1016/j.wasman.2008.04.010

[9] Ekmekçioğlu, M., Kaya, T., & Kahraman, C. (2010). Fuzzy multicriteria disposal method and site selection for municipal solid waste. Waste Management, 30(8-9), 1729-1736. https://doi.org/10.1016/j.wasman.2010.02.031

[10] Pires, A., Chang, N. B., & Martinho, G. (2011). An AHP-based fuzzy interval TOPSIS assessment for sustainable expansion of the solid waste management system in Setúbal Peninsula, Portugal. Resources, Conservation and Recycling, 56(1), 7-21. https://doi.org/10.1016/j.resconrec.2011.08.004

[11] Şener, Ş., Sener, E., & Karagüzel, R. (2011). Solid waste disposal site selection with GIS and AHP methodology: A case study in Senirkent–Uluborlu (Isparta) Basin, Turkey. Environmental Monitoring and Assessment, 173, 533-554. https://doi.org/10.1007/s10661-010-1403-x

[12] Koroneos, C. J., & Nanaki, E. A. (2012). Integrated solid waste management and energy production-a life cycle assessment approach: the case study of the city of Thessaloniki. Journal of Cleaner Production, 27, 141-150. https://doi.org/10.1016/j.jclepro.2012.01.010

[13] Liu, H. C., You, J. X., Lu, C., & Chen, Y. Z. (2015). Evaluating health-care waste treatment technologies using a hybrid multi-criteria decision making model. Renewable and Sustainable Energy Reviews, 41, 932-942. https://doi.org/10.1016/j.rser.2014.08.061

[14] Vučijak, B., Kurtagić, S. M., & Silajdžić, I. (2016). Multicriteria decision making in selecting best solid waste management scenario: A municipal case study from Bosnia and Herzegovina. Journal of Cleaner Production, 130, 166-174. https://doi.org/10.1016/j.jclepro.2015.11.030

[15] Rahman, S. S., Azeem, A., & Ahammed, F. (2017). Selection of an appropriate waste-to-energy conversion technology for Dhaka City, Bangladesh. International Journal of Sustainable Engineering, 10(2), 99-104. https://doi.org/10.1080/19397038.2016.1270368

[16] Coban, A., Ertis, I. F., & Cavdaroglu, N. A. (2018). Municipal solid waste management via multi-criteria decision making methods: A case study in Istanbul, Turkey. Journal of Cleaner Production, 180, 159-167. https://doi.org/10.1016/j.jclepro.2018.01.130

[17] Randazzo, L., Cusumano, A., Oliveri, G., Di Stefano, P., Renda, P., Perricone, M., & Zarcone, G. (2018). Landfill site selection for municipal solid waste by using AHP method in GIS environment: Waste management decision-support in Sicily (Italy). Detritus, 2(1), 78. https://doi.org/10.31025/2611-4135/2018.13656

[18] Narayanamoorthy, S., Annapoorani, V., Kang, D., Baleanu, D., Jeon, J., Kureethara, J. V., & Ramya, L. (2020). A novel assessment of bio-medical waste disposal methods using integrating weighting approach and hesitant fuzzy MOOSRA. Journal of Cleaner Production, 275, 122587. https://doi.org/10.1016/j.jclepro.2020.122587

[19] Torkayesh, A. E., Malmir, B., & Asadabadi, M. R. (2021). Sustainable waste disposal technology selection: The stratified best-worst multi-criteria decision-making method. Waste Management, 122, 100-112. https://doi.org/10.1016/j.wasman.2020.12.040

[20] Muhammad, L. J., Badi, I., Haruna, A. A., & Mohammed, I. A. (2021). Selecting the best municipal solid waste management techniques in Nigeria using multi criteria decision making techniques. Reports in Mechanical Engineering, 2(1), 180-189. https://doi.org/10.31181/rme2001021801b

[21] Garcia-Garcia, G. (2022). Using Multi-Criteria Decision-Making to optimise solid waste management. Current Opinion in Green and Sustainable Chemistry, 37, 100650. https://doi.org/10.1016/j.cogsc.2022.100650

[22] Puška, A., Nedeljković, M., Pamučar, D., Božanić, D., & Simić, V. (2024a). Application of the new simple weight calculation (SIWEC) method in the case study in the sales channels of agricultural products. MethodsX, 13, 102930. https://doi.org/10.1016/j.mex.2024.102930

[23] Puška, A., Nedeljković, M., Božanić, D., Štilić, A., & Muhsen, Y. R. (2024b). ‘‘Evaluation of agricultural drones based on the compromise ranking from alternative solutions (CORASO) methodology. Engineering Review, 44(4), 77-90. https://doi.org/10.30765/er.2653
[24] Gökalp, Y., Eti, S., Yüksel, S., & Dinçer, H. (2025). Towards Sustainable Healthcare: A Fuzzy Multi-Criteria Framework for Green Hospital Investments. Computer and Decision Making: An International Journal, 2, 419-424. https://doi.org/10.59543/comdem.v2i.10969
[25] Cao, J., Spulbar, C., Eti, S., Horobet, A., Yüksel, S., & Dinçer, H. (2025). Innovative approaches to green digital twin technologies of sustainable smart cities using a novel hybrid decision-making system. Journal of Innovation & Knowledge, 10(1), 100651. https://doi.org/10.1016/j.jik.2025.100651
[26] Puška, A., Božanić, D., Štilić, A., Nedeljković, M., & Khalilzadeh, M. (2025). Application of Fuzzy-Rough Methodology to the Selection of Electric Tractors for Small Farms in Semberija. Journal of Fuzzy Extension and Applications.
[27] Puška, A., Štilić, A., Pamučar, D., Božanić, D., Nedeljković, M. (2024c). Introducing a novel multi-criteria ranking of alternatives with weights of criterion (RAWEC) model. MethodsX, 12, 1-13. https://doi.org/10.1016/j.mex.2024.102628
[28] Trung, D. D., Truong, N. X., Duc, D. V., & Bao, N. C. (2024). Data normalization in RAWEC method: Limitations and remedies. Yugoslav Journal of Operations Research, 1-17. https://doi.org/10.2298/YJOR240315020T
[29] Demir, G., & Ulusoy, E. I. (2024). Wind power plant location selection with fuzzy logic and multi-criteria decision-making methods. Computer and Decision Making: An International Journal, 1, 211-234. https://doi.org/10.59543/comdem.v1i.10713
[30] Puška, A., Nedeljković, M., Dudić, B., Štilić, A., & Mittelman, A. (2024d). Improving agricultural sustainability in Bosnia and Herzegovina through renewable energy integration. Economies, 12(8), 1-15. https://doi.org/10.3390/economies12080195
[31] Petrovic, N., Jovanovic, V., Markovic, S., Marinkovic, D., & Petrovic, M. (2024). Multicriteria sustainability assessment of transport modes: A European Union case study for 2020. Journal of Green Economy and Low-Carbon Development, 3(1), 36-44. https://doi.org/10.56578/jgelcd030104
[32] Nedeljković, M., Puška, A., Pamučar, D., & Marinković, D. (2024). Selection of agricultural product sales channels using fuzzy double MEREC and fuzzy RAWEC method. Agriculture and Forestry, 70(3), 45-58. https://doi.org/10.17707/AgricultForest.70.3.03
[33] Zadeh, L.A. (1965). Fuzzy sets. Information and Control, 8, 338-353. https://doi.org/10.1016/S0019-9958(65)90241-X
[34] Božanić, D., Pamučar, D., Milić, A., Marinković, D., & Komazec, N. (2022). Modification of the logarithm methodology of additive weights (LMAW) by a triangular fuzzy number and its application in multi-criteria decision making. Axioms, 11(3), 89. https://doi.org/10.3390/axioms11030089
[35] Demir, G., Chatterjee, P., & Pamučar, D. (2024). Sensitivity analysis in multi-criteria decision making: A state-of-the-art research perspective using bibliometric analysis. Expert Systems with Applications, 237, 121660. https://doi.org/10.1016/j.eswa.2023.121660
[36] Radovanović, M., Petrovski, A., Cirkin, E., Behlić, A., Jokić, Ž., Chemezov, D., ... & Jana, C. (2024). Application of the new hybrid model LMAW-G-EDAS multi-criteria decision-making when choosing an assault rifle for the needs of the army. Journal of Decision Analytics and Intelligent Computing, 4(1), 16-31. https://doi.org/10.31181/jdaic10021012024r