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***Research paper***

# Towards Sustainable Campuses: A Novel Fermatean Fuzzy Decision-Making Model for Evaluating Zero-Waste Strategies in Universities

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**Abstract**

The objective of this study is to identify the most appropriate strategies to increase the effectiveness of zero-waste practices in universities and to fill the existing gap in the literature in this regard. To achieve this objective, a new multi-criteria decision-making model is developed. The model uses the evaluations of eight experts as a dataset; the experts' importance weights are determined using the Euclidean distance-based expert weighting technique, the criteria weights are calculated using the skewness impact through distributional evaluation (SITDE), and the strategic alternatives are ranked using simple additive weighting (SAW). Fermatean fuzzy sets approach is integrated into the model to address process uncertainties more flexibly and realistically. The proposed model contributes to the literature by distinguishing itself from existing models in terms of both expert weighting and the more effective management of uncertainty. The key findings indicate that the most important criterion is policy and governance support (.176), while the most suitable strategy is a strategy focused on education and aware-ness (.721), followed by a technology and digitalization-based strategy (.673). These results reveal that the success of zero waste policies in universities can reach the highest level if individual awareness is increased with strong institutional support.

***Keywords***: *zero-waste practices; sustainable campuses; Euclidean distance-based method; expert weighting; Fermatean fuzzy sets*

## 1. Introduction

Zero-waste practices are a holistic sustainability approach that aims to prevent waste generation at its source during production and consumption processes, recycle and reuse the resulting waste, and thus minimize environmental burdens. These practices stand out with their environmental, economic, and social benefits, particularly in institutional settings like universities, where large populations and intensive resource consumption occur (Fagerholm et al., 2025). Implementing zero-waste policies on university campuses not only helps control the increasing amount of waste but also helps preserve natural resources, save energy, and reduce carbon footprints. Similarly, this also enables the promotion of environmental awareness and a sustainable lifestyle culture among students and staff (Zdonek et al., 2025). In this context, zero-waste practices contribute to solutions to problems such as unregulated landfills, environmental pollution, ecosystem destruction, and inadequate waste management, while also positively impacting the national economy by supporting the circular economy (Kumar et al., 2025). However, failure to implement these practices will lead to multifaceted problems such as increased waste, irreversible resource loss, rising greenhouse gas emissions, increased risks to the environment and human health, and a departure from sustainable development goals. Therefore, zero-waste practices are essential not only for alleviating today's environmental problems but also for building a sustainable and inclusive lifestyle that will ensure the quality of life for future generations (Achuthan and Khobragade, 2025).
To increase the effectiveness of zero-waste practices in universities, a comprehensive and holistic approach must be adopted. Priority should be given to fostering a zero-waste culture through ongoing education and awareness programs for students and staff. Sustainable behaviors should be supported through seminars, environmentally themed student clubs, on-campus competitions, and social responsibility projects (Kaur et al., 2025). As part of infrastructure investments, waste separation units, electronic waste collection centers, and composting facilities for processing organic waste, located at accessible locations in every faculty and unit, will both enhance the functionality of the waste management process and create ecological value (Li et al., 2025). Furthermore, through digitalization and paperless office applications, the electronic processing of paperwork, the expansion of online exam and assignment systems, and the transition of document management to digital platforms will contribute to zero-waste goals by significantly saving resources (Zhao and You, 2025). At the institutional level, political and administrative support from university administrations, the development of official zero-waste policies, the establishment of sustainability coordination units, and the regular monitoring and reporting of performance indicators will ensure the continuity of these practices (Srisathan et al., 2025). Furthermore, sharing best practices across universities, implementing joint projects, and participating in national and international zero-waste networks will facilitate the transfer of experience and enable a zero-waste culture

to be more strongly embedded in institutional identity. The coordinated implementation of all these practices will ensure that zero-waste policies at universities not only provide environmental benefits but also contribute to sustainable development in multiple ways through economic gains and increased public awareness (Siwawa, 2025).

Improving certain institutional criteria is critical to increasing the effectiveness of zero-waste practices in universities. First, policy and governance support should provide a strong framework. University administrations should define zero-waste policies in official documents and ensure the institutionalization of these practices by allocating budgets and human resources (Leslie et al., 2025). For example, establishing sustainability coordination offices and regularly publishing waste management performance reports will increase transparency and accountability (Qian et al., 2025). Furthermore, zero-waste education and awareness programs should be expanded; sustainable behaviors should be encouraged through seminars for students and academic and administrative staff, environmentally themed student societies, on-campus waste separation competitions, and social responsibility projects (Suman et al., 2025). Furthermore, through digitalization and paperless office practices, document processing should be moved to electronic formats, course materials, and exams should be conducted online, minimizing paper consumption (Chen et al., 2025). In addition to these criteria, strengthening infrastructure investments is also crucial; color-coded bins, e-waste collection centers, and composting areas for organic waste should be expanded across campuses to facilitate the easy separation of different types of waste (Kusumawardhani et al., 2025). Finally, using compost generated through green campus practices in on-campus green spaces will complete the recycling cycle and provide students with a tangible sustainability experience (Tian et al., 2025). When implemented within a holistic approach, zero-waste policies will not only provide environmental benefits for universities but also yield lasting gains in terms of economic savings, social awareness, and institutional sustainability (Michaelson et al., 2025).

Identifying the most important criteria and strategy alternatives to increase the effectiveness of zero-waste practices in universities is crucial. Failure to identify which criteria are prioritized can lead to disorganized practices, inefficient resource use, and unmeasurable results (Kumari et al., 2025). For example, if the most critical practices, such as policy and governance support, educational programs, or digitalization are not identified, universities may direct their sustainability investments in the wrong areas (Wang et al., 2025). Problems that arise from this failure include ineffective resource allocation, low participation rates, underachievement of environmental targets, and the failure of long-term sustainability policies. However, there is no full consensus in the literature on this issue, and different approaches are put forward regarding which criteria and strategies should be prioritized (Pandey et al., 2025). This diversity can create uncertainty in practical applications and make it difficult for universities to develop a coherent zero-waste strategy. Furthermore, the limited number of priority analysis studies in this area creates a significant research gap (Suthiluk et al., 2025). This gap creates problems such as a lack of clarity about which criteria contribute more, an inability to compare results across universities, and a lack of scientifically based guidance for policymakers in their decision-making processes (Abumalloh et al., 2025). Therefore, conducting new priority analyses in this area is a critical necessity both to address ambiguities in the existing literature and to ensure more effective, measurable, and sustainable implementation of zero-waste policies at universities.

While prior studies generally agree on the importance of policy support and education in sustainability initiatives, there are also contradictions. For example, some research emphasizes infrastructure and technological investments as the primary drivers of effective zero-waste practices, whereas others highlight the behavioral dimension through awareness and participation as more decisive. This lack of consensus makes it difficult for universities to prioritize strategies consistently. Our study addresses this gap by systematically integrating both dimensions and providing an evidence-based ranking of strategies. Previous decision-making studies in sustainability have largely applied classical MCDM methods such as AHP, TOPSIS, or fuzzy variations to evaluate alternatives. However, most of these models treat expert judgments equally and often fail to account for uncertainty in a flexible manner. By incorporating Euclidean distance-based expert weighting and Fermatean fuzzy sets, our model extends this line of research, offering a more nuanced way to capture expert heterogeneity and uncertainty. This methodological enhancement represents a unique contribution that builds on, but also advances, existing sustainability decision-making studies.

This study focuses on identifying the most appropriate strategies to increase the effectiveness of zero-waste practices in universities and aims to fill a significant gap in the literature. The motivation for this research is that existing studies lack consensus on criteria and strategy prioritization, and comprehensive priority analyses in this area are limited. In this context, an extensive literature review is conducted to identify four strategic alternatives and identify six key criteria affecting their effectiveness. The new multi-criteria decision-making model proposed in the study is specifically developed to evaluate expert opinions more objectively. Within the scope of the model, the evaluations of eight experts are accepted as research data; the importance weights of the experts are calculated using the Euclidean distance-based expert weighting technique, the criteria weights are determined using the SITDE method, and the strategy alternatives are ranked using the SAW method. Furthermore, the entire process is built on the Fermatean fuzzy sets approach to model uncertainties more flexibly and realistically. In this context, the study seeks to answer the following research questions: (1) Which strategies are more prioritized and effective for increasing the effectiveness of zero-waste practices in universities? (2) What are the main criteria that determine the effectiveness of these strategies, and how are their relative importance levels shaped? (3) Considering the different perspectives of experts, what methodological contribution does the proposed model make to the prioritization of zero-waste strategies? The answers to these research questions offer significant contributions not only to the strengthening of zero-waste policies in universities, but also to multi-criteria priority analyses, which are lacking in the literature.

This study contributes methodologically and practically to the limited number of existing studies by developing a new multi-criteria decision-making model to address ambiguities in the literature regarding strategy prioritization to increase the effectiveness of zero-waste practices in universities. The proposed model offers significant methodological advantages over previously developed multi-criteria decision-making approaches in the literature. (1) Calculating experts' importance weights using the Euclidean distance-based expert weighting technique adds a strong innovative dimension to the study. In many models in the literature, experts' opinions are evaluated with equal coefficients, ignoring factors such as different academic backgrounds, professional experience, areas of expertise, and sectoral knowledge. However, assigning the same importance to individuals with different levels of expertise creates a methodological weakness in the decision-making process and can negatively affect the accuracy and reliability of the results. In this context, weighting in the proposed model, which takes into consideration the heterogeneous characteristics of the experts, not only provides a fairer assessment but also increases the validity and consistency of the results. (2) The use of the Fermatean fuzzy set approach in the model allows for more effective management of uncertainty and, in this respect, provides significant advantages over other fuzzy set approaches. Fermatean set theory, thanks to its ability to express degrees of membership and non-membership over a wider range, incorporates decision-makers' uncertain or contradictory judgments into the model in a more flexible, sensitive, and realistic manner. This feature, particularly compared to alternative set approaches such as Pythagorean fuzzy sets and spherical fuzzy sets, provides stronger representational power, reduces information loss in the decision-making process, and contributes to a more robust foundation for evaluations. Therefore, the proposed model distinguishes itself from existing methods in the literature both through its methodological innovation in weighting expert opinions and the Fermatean set approach,

which allows for a clearer and more reliable handling of uncertainties. Thus, it offers a unique and significant contribution to strategic decision-making processes aimed at increasing the effectiveness of zero-waste practices in universities.
The following part explains the steps of the proposed model. The third section highlights the results of this model. The next section gives information about the discussion. The final section identifies the main concluding remarks.

## 2. Methods

This section recalls the definition of Fermatean fuzzy sets (FFSs), Euclidean distances-based experts' weighting, SITDE, and SAW. FFSs are used for measuring the uncertainty and Euclidean distances are used for obtaining the important of experts' assessments. Then, the weights of criteria are calculated by SITDE, and the alternatives are ranked with SAW. Before presenting the mathematical details, it is useful to clarify the intuition behind the methods. Fermatean fuzzy sets allow decision-makers to express uncertainty more flexibly by capturing both membership and non-membership degrees simultaneously. This provides a richer way of reflecting expert hesitation or partial agreement. The SITDE method, on the other hand, is designed to determine the importance of criteria by evaluating the distributional characteristics of the data (e.g., skewness). In simpler terms, while the fuzzy set framework addresses the uncertainty in experts' judgments, SITDE helps identify which criteria carry more weight in shaping the final decision. Figure 1 fives information about the details of the proposed model.

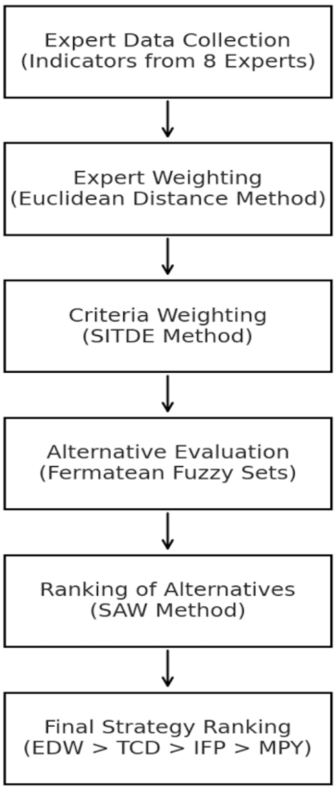


**Fig. 1:** Flowchart of the proposed model

### 2.1 Fermatean fuzzy sets (FFSs)

Let a set $U$ be a universe of discourse. A FFS $(F)$ is an object having the form in Equation (1) (Abu-Lail et al., 2025).

$$F = \{u, (s_F(u), t_F(u)) | u \in U\} \tag{1}$$

Wherein the function $s_F(u), t_F(u)$ and $0 \leq (s_F(u))^3 + (t_F(u))^3 \leq 1$ are the functions of membership and non-membership of u to $F$, respectively. The indeterminacy function is descripted in Equation (2) (Anam et al., 2025).

$$\gamma_F(u) = \sqrt{1 - (s_F(u))^3 - (t_F(u))^3} \tag{2}$$

Assume that $\mathcal{M}$ and $\mathcal{N}$ are two FFNs and $\varphi$ is a positive real number. Then, the arithmetic operators are identified using Equations (3) – (7).

$$\mathcal{M} + \mathcal{N} = \left(\sqrt[3]{s_{\mathcal{M}}{}^3 + s_{\mathcal{N}}{}^3 - s_{\mathcal{M}}{}^3 s_{\mathcal{N}}{}^3}, t_{\mathcal{M}} t_{\mathcal{N}}\right) \tag{3}$$

$$\mathcal{M} \times \mathcal{N} = \left(s_{\mathcal{M}} s_{\mathcal{N}}, \sqrt[3]{t_{\mathcal{M}}{}^3 + t_{\mathcal{N}}{}^3 - t_{\mathcal{M}}{}^3 t_{\mathcal{N}}{}^3}\right) \tag{4}$$

$$\varphi\mathcal{M} = \left(\sqrt[3]{1-(1-s_{\mathcal{M}}{}^3)^{\varphi}}, t_{\mathcal{M}}{}^{\varphi}\right) \tag{5}$$

$$\mathcal{M}^{\varphi} = \left(s_{\mathcal{M}}{}^{\varphi}, \sqrt[3]{1-\left(1-t_{\mathcal{M}}{}^3\right)^{\varphi}}\right) \tag{6}$$

$$\mathcal{M}^C = (t_{\mathcal{M}}, s_{\mathcal{M}}) \tag{7}$$

Let's suppose FFN is $\mathcal{M} = (s_{\mathcal{M}}, t_{\mathcal{M}})$. Equations (8) and (9) define the score and accuracy functions, respectively.

$$sc(\mathcal{M}) = \frac{s_{\mathcal{M}}{}^3 - t_{\mathcal{M}}{}^3 + 1}{2} \tag{8}$$

$$ac(\mathcal{M}) = s_{\mathcal{M}}{}^3 + t_{\mathcal{M}}{}^3 \tag{9}$$

## 2.2 Euclidean distance-based experts' weighting

A dataset $\left(X = [x_{ij}]\right)$ is created. The dataset contains professional indicators of experts such as age, global, sector and teaching experiences, etc. Then, the items of dataset are standardized with the help of Equations (10) – (12) (Kou et al., 2025).

$$\bar{x}_j = \frac{\sum_{i=1}^{e} x_{ij}}{e} \tag{10}$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{e}\left(x_{ij}-\bar{x}_j\right)^2}{e}} \tag{11}$$

$$z_{ij} = \frac{x_{ij}-\bar{x}_j}{\sigma_j} \tag{12}$$

Wherein $e$ is the number of experts. Next, the anti-ideal expert is created. The standardized items of anti-ideal expert are determined using Equation (13) (Han et al., 2025).

$$\theta_j = \min_i z_{ij} \tag{13}$$

Afterwards, the Euclidean distance of experts to anti-ideal expert is calculated with Equation (14).

$$\Delta_i = \sqrt{\sum_{j=1}^{v}\left(z_{ij}-\theta_j\right)^2} \tag{14}$$

Wherein $v$ refers to the number of professional indicators. Finally, the Euclidean distances of experts are normalized via Equation (15).

$$\zeta_i = \frac{\Delta_i}{\sum_{i=1}^{e}\Delta_i} \tag{15}$$

## 2.3 SITDE

The alternatives and criteria are identified. Next, the assessments are collected from each expert, and these assessments are transformed into FFNs. The assessment matrix for $k^{th}$ expert is constructed as Equation (16) (Gopisetty and Sama, 2025).

$$D^k = \left[d_{ij}^k\right] \tag{16}$$

Wherein $d_{ij}^k$ is the FFNs and equals assessment of $j^{th}$ criterion of $i^{th}$ alternative for $k^{th}$ expert. Next, the expert-weighted FFNs are computed by multiplying the normalized Euclidean distances using Equation (17) (Yalçın et al., 2025).

$$y_{ij}^k = \zeta_k d_{ij}^k \tag{17}$$

Afterwards, the expert-weighted FFNs are summed with Equation (18). Thus, the decision values are obtained.

$$y_{ij} = \sum_{k=1}^{e} y_{ij}^k \tag{18}$$

The decision values are normalized according to type of criterion. Equation (19) is used for useful attributes and Equation (20) is used for useless attributes.

$$\eta_{ij} = \frac{\min_i\left(sc(y_{ij})\right)}{\left(sc(y_{ij})\right)} \tag{19}$$

$$\eta_{ij} = \frac{\left(sc(y_{ij})\right)}{\max_i\left(sc(y_{ij})\right)} \tag{20}$$

Asymmetry measures of criteria are estimated by Equation (21).

$$S_j = \frac{m}{(m-1)(m-2)} \sum_{i=1}^{m} \left( \frac{\mathfrak{y}_{ij} - \bar{\mathfrak{y}}_j}{\sigma_j} \right)^3 \quad (21)$$

Wherein $m$ presents the number of alternatives. $\bar{\mathfrak{y}}_j$ and $\sigma_j$ refer to the arithmetic mean and standard deviation of $j^{th}$ criterion. These parameters are obtained as like Equations (10) and (11), respectively. Next, asymmetry measures are normalized via Equation (22).

$$\mathfrak{n}_j = \log\left|\left(S_j + 1\right) + \left(\left|\min\left(s_j\right)\right| + 1\right)\right| \quad (22)$$

Finally, the weights of criteria are defined using Equation (23).

$$\mathfrak{w}_j = \frac{\mathfrak{n}_j}{\sum_{j=1}^{n} \mathfrak{n}_j} \quad (23)$$

Wherein $n$ refer to the number of criteria.

### 2.4 SAW

The decision matrix in Equation (24) is constructed by calculating the expert-weighted average of the FFNs of the assessments of alternatives with Equations (17) and (18) (Magableh et al., 2025).

$$\mathcal{Y} = \left[y_{ij}\right] \quad (24)$$

Afterwards, the decision values are normalized according to type of criterion. In normalization process, Equation (25) is used for useful attributes and Equation (26) is used for useless attributes.

$$\hbar_{ij} = y_{ij} \quad (25)$$

$$\hbar_{ij} = \left(y_{ij}\right)^C \quad (26)$$

Wherein, the definition in Equation (7) is used. The weighted performances of the alternatives are computed with the help of Equation (27). The multiplication operation is descripted in Equation (5).

$$g_{ij} = \mathfrak{w}_j \hbar_{ij} \quad (27)$$

Summing the weighted performances of the alternatives, the aggregated performance for each alternative is defined by Equation (28). The addition operation is defined in Equation (3).

$$saw_i = \sum_{j=1}^{n} g_{ij} \quad (28)$$

Finally, the alternatives are ranked according to the magnitude of score functions of aggregated performances of alternatives.

## 3. Results

The results of the ranking of alternatives are summarized in this section.

### 3.1 Determining the experts' weights

Professional indicators such as age, global, teaching and sector experience periods of eight experts are collected, and the dataset is created. The dataset is shown in Table 1.

**Table 1:** Professional Indicators

| | Age | Global Experience | Teaching Experience | Sector Experience |
|---|---|---|---|---|
| P1 | 40 | 20 | 6 | 20 |
| P2 | 45 | 25 | 5 | 20 |
| P3 | 44 | 23 | 6 | 23 |
| P4 | 42 | 20 | 4 | 15 |
| P5 | 48 | 25 | 3 | 22 |
| P6 | 47 | 24 | 4 | 20 |
| P7 | 48 | 24 | 7 | 24 |
| P8 | 49 | 26 | 2 | 15 |

According to professional indicators' values of eight experts in Table 1, the average and standard deviations of age, global, teaching and sector experiences are estimated using Equations (10) and (11). The average values equal to 45.375, 23.375, 4.625, and 19,875, respectively. The standard deviations of professional indicators are 2.997, 2.118, 1.576, and 3.140, respectively. Then, the items of dataset are standardized via Equation (12). The standardized items are given in Table 2.

**Table 2:** Standardized Dataset

| | Age | Global Experience | Teaching Experience | Sector Experience |
|---|---|---|---|---|
| P1 | -1.793 | -1.594 | .872 | .040 |
| P2 | -.125 | .767 | .238 | .040 |
| P3 | -.459 | -.177 | .872 | .995 |
| P4 | -1.126 | -1.594 | -.397 | -1.553 |
| P5 | .876 | .767 | -1.031 | .677 |
| P6 | .542 | .295 | -.397 | .040 |
| P7 | .876 | .295 | 1.507 | 1.314 |
| P8 | 1.209 | 1.240 | -1.665 | -1.553 |

Afterwards, anti-ideal expert created. Anti-ideal expert's standardized items are determined using Equation (13). In this case, the standardized age, global, teaching and sector experiences of anti-ideal expert are -1.793, -1.594, -1.665, and -1.553, respectively. Later, the Euclidean distance of eight experts to anti-ideal expert is calculated with Equation (14). Finally, Euclidean distances are normalized via Equation (15). The distances are shared in Table 3.

**Table 3:** Euclidean Distance and Normalized Euclidean Distance

| | Euclidean | Normalized Euclidean |
|---|---|---|
| P1 | 2.996 | .101 |
| P2 | 3.810 | .128 |
| P3 | 4.089 | .138 |
| P4 | 1.434 | .048 |
| P5 | 4.251 | .143 |
| P6 | 3.629 | .122 |
| P7 | 5.382 | .181 |
| P8 | 4.128 | .139 |

## 3.2 Computing the weights of criteria

A multidimensional and holistic approach is necessary to evaluate the effectiveness of zero-waste practices in universities. Six key criteria have been identified within this framework. Waste Separation Efficiency (WSE) directly impacts the technical success of the implementation, as it forms the first step in the recycling chain. Zero Waste Education and Awareness Programs (ZWA) contribute to the social dimension of sustainability by encouraging behavioral transformation among students and staff. Waste Reduction Rate (WRR), one of the tangible outcomes of the practices, is critical for direct performance measurement. The Digitalization and Paperless Office Practices (DPP) criterion optimizes resource use by reducing paper waste and demonstrates the integration of technology-based sustainability policies. Green Space and Compost Utilization (GSC) enables the creation of both environmental and on-campus ecological value through the recycling of organic waste. Finally, Policy and Governance Support (PGS) plays a decisive role in the institutional adoption, resource allocation, and internalization of zero-waste strategies. Taken together, these criteria enable multi-criteria analysis of zero waste policies in universities with their systematic, behavioral and managerial dimensions.

The effectiveness of zero-waste practices at universities depends on the holistic implementation of various strategic approaches. In this context, the Education and Awareness-Based Strategy (EDW) increases environmental awareness among students and staff, ensuring the permanence of sustainable behaviors and serving as a critical pillar of social transformation. The Technology and Digitalization-Based Strategy (TCD) minimizes waste generation by increasing resource efficiency through innovative solutions such as paperless office systems, digital document management, and smart waste collection sensors. The Infrastructure and Physical Implementation Strategy (IFP) strengthens the operational functioning of the system with concrete applications such as recycling bins, compost areas, and waste separation units, producing measurable environmental gains. Finally, the Management and Policy-Based Strategy (MPY) ensures long-term sustainability and institutionalization by embedding zero-waste practices within a structural framework, drawing on the vision, budget support, and institutional policies of university senior management. The holistic and complementary implementation of these strategies allows zero-waste policies at universities to yield lasting and effective results at both the institutional and individual levels. The alternatives and criteria are identified. Eight experts evaluate the alternatives regarding criteria. The assessment numbers of eight experts are presented in Table 4.

**Table 4:** Assessment Numbers

| | WSE | ZWA | WRR | DPP | GSC | PSG | | WSE | ZWA | WRR | DPP | GSC | PSG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EDW | 7 | 8 | 7 | 7 | 7 | 7 | EDW | 8 | 9 | 7 | 8 | 9 | 8 |
| TCD | 6 | 7 | 8 | 6 | 9 | 8 | TCD | 8 | 6 | 6 | 6 | 5 | 6 |
| IFP | 5 | 7 | 5 | 6 | 5 | 5 | IFP | 5 | 7 | 5 | 7 | 7 | 7 |
| MPY | 3 | 4 | 5 | 2 | 4 | 1 | MPY | 5 | 1 | 4 | 3 | 1 | 3 |
| | WSE | ZWA | WRR | DPP | GSC | PSG | | WSE | ZWA | WRR | DPP | GSC | PSG |
| EDW | 9 | 9 | 8 | 7 | 7 | 8 | EDW | 9 | 9 | 8 | 8 | 8 | 8 |
| TCD | 5 | 9 | 6 | 5 | 8 | 6 | TCD | 6 | 8 | 9 | 9 | 5 | 8 |
| IFP | 6 | 5 | 6 | 6 | 5 | 7 | IFP | 6 | 6 | 5 | 5 | 5 | 5 |
| MPY | 5 | 1 | 4 | 3 | 1 | 1 | MPY | 5 | 1 | 1 | 2 | 3 | 4 |
| | WSE | ZWA | WRR | DPP | GSC | PSG | | WSE | ZWA | WRR | DPP | GSC | PSG |
| EDW | 8 | 8 | 8 | 7 | 9 | 7 | EDW | 7 | 8 | 8 | 7 | 8 | 8 |
| TCD | 6 | 5 | 9 | 5 | 9 | 7 | TCD | 8 | 9 | 9 | 8 | 7 | 5 |
| IFP | 6 | 7 | 6 | 6 | 6 | 7 | IFP | 7 | 6 | 7 | 6 | 6 | 7 |
| MPY | 3 | 2 | 5 | 3 | 5 | 3 | MPY | 1 | 5 | 1 | 5 | 5 | 5 |
| | WSE | ZWA | WRR | DPP | GSC | PSG | | WSE | ZWA | WRR | DPP | GSC | PSG |
| EDW | 9 | 8 | 7 | 7 | 9 | 8 | EDW | 7 | 9 | 9 | 7 | 7 | 7 |
| TCD | 6 | 6 | 5 | 8 | 6 | 8 | TCD | 7 | 6 | 7 | 5 | 9 | 9 |
| IFP | 7 | 5 | 5 | 6 | 7 | 6 | IFP | 5 | 5 | 6 | 5 | 6 | 7 |
| MPY | 1 | 2 | 5 | 3 | 2 | 1 | MPY | 5 | 3 | 4 | 4 | 2 | 4 |

The assessment numbers are transformed into FFNs. Next the expert-weighted FFNs are computed using Equation (17). In other words, the FFNs of assessment numbers are multiplied by the normalized Euclidean distances of experts. Later, the expert-weighted FFNs are summed with Equation (18). The decision values are displayed in Table 5.

**Table 5:** Decision Values

| | WSE | | ZWA | | WRR | | DPP | | GSC | | PSG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EDW | .787 | .193 | .823 | .156 | .750 | .193 | .690 | .237 | .787 | .193 | .728 | .193 |
| TCD | .637 | .300 | .719 | .268 | .758 | .240 | .674 | .296 | .754 | .247 | .714 | .240 |
| IFP | .565 | .381 | .580 | .365 | .539 | .408 | .559 | .385 | .565 | .381 | .614 | .327 |
| MPY | .382 | .610 | .280 | .738 | .389 | .602 | .297 | .653 | .327 | .680 | .310 | .693 |

Afterwards, the decision values are normalized according to type of criterion. However, all criteria are useful attributes. In other words, Equation (19) is used for all criteria. Normally, normalized decision values are illustrated in Table 6.

**Table 6:** Normalized Decision Values

| | WSE | ZWA | WRR | DPP | GSC | PSG |
|---|---|---|---|---|---|---|
| EDW | .740 | .777 | .707 | .658 | .740 | .690 |
| TCD | .616 | .676 | .711 | .640 | .707 | .675 |
| IFP | .563 | .573 | .544 | .559 | .563 | .598 |
| MPY | .414 | .310 | .420 | .374 | .360 | .349 |

After normalizing process, asymmetry measure for each criterion is estimated by Equation (21). Then, asymmetry measures of criteria are normalized via Equation (22). Finally, the weights of criteria are defined using Equation (23). The results are summarized in Table 7.

**Table 7:** Asymmetry Measure, Normalized Asymmetry Measure and Weights

| | WSE | ZWA | WRR | DPP | GSC | PSG |
|---|---|---|---|---|---|---|
| Asymmetry | 1.693 | 2.673 | 1.617 | 2.661 | 2.398 | 2.891 |
| Normalized Asymmetry | .725 | .799 | .719 | .798 | .779 | .813 |
| Weight | .157 | .172 | .155 | .172 | .168 | .176 |

As can be seen from the weights in Table 7, the most important criterion is "policy and governance support" (.176). This result highlights that without strong institutional commitment, even the most innovative or well-designed zero waste initiatives are unlikely to achieve sustainable success. Governance structures, budget allocation, formal regulations, and strategic leadership create the framework within which other practices can be effectively implemented. In addition, "zero waste education and awareness programs" play a crucial role by fostering behavioral change among students and staff, ensuring that the policies are not only top-down but also embraced at the individual level. Likewise, "digitalization and paperless office practices" represent a transformative element, reducing paper consumption and demonstrating how technology can directly contribute to waste minimization. Together, these findings suggest that successful zero waste practices in universities require a balance between institutional governance, individual awareness, and technological adaptation, which collectively strengthens the effectiveness and long-term sustainability of zero waste strategies.

## 3.3 Ranking of Alternatives

The values in Table 5 are used for SAW. Moreover, the weight values in Table 7 are used for weight parameters of SAW. Next, decision values are normalized for SAW. For this, Equation (25) is used. Because all criteria are useful attributes. The normalized values are exhibited in Table 8.

**Table 8:** Normalized Values

| | WSE | | ZWA | | WRR | | DPP | | GSC | | PSG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EDW | .787 | .193 | .823 | .156 | .750 | .193 | .690 | .237 | .787 | .193 | .728 | .193 |
| TCD | .637 | .300 | .719 | .268 | .758 | .240 | .674 | .296 | .754 | .247 | .714 | .240 |
| IFP | .565 | .381 | .580 | .365 | .539 | .408 | .559 | .385 | .565 | .381 | .614 | .327 |
| MPY | .382 | .610 | .280 | .738 | .389 | .602 | .297 | .653 | .327 | .680 | .310 | .693 |

Afterwards, the weighted performance score for each alternative is computed with the help of Equation (27). In other words, normalized values in Table 8 are multiplied by the weights in Table 7. The weighted performance scores of alternatives are expressed in Table 9.

**Table 9:** Weighted Performance Scores

| | WSE | | ZWA | | WRR | | DPP | | GSC | | PSG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EDW | .463 | .773 | .508 | .726 | .434 | .774 | .405 | .781 | .473 | .758 | .435 | .749 |
| TCD | .357 | .828 | .425 | .797 | .440 | .802 | .394 | .811 | .448 | .791 | .425 | .779 |
| IFP | .313 | .860 | .332 | .841 | .296 | .870 | .319 | .849 | .320 | .850 | .356 | .822 |
| MPY | .207 | .926 | .156 | .949 | .211 | .924 | .166 | .929 | .181 | .937 | .174 | .938 |

Summing the weighted performance scores in Table 9, the aggregated performance scores of alternatives are defined by Equation (28). Finally, the score function of the aggregated performance score for each alternative is computed for ranking of alternatives. The results are displayed in Table 10.

**Table 10:** Aggregated Performance Score and Score Function

| | SAW | | sc(SAW) |
|---|---|---|---|
| EDW | .766 | .193 | .7211 |
| TCD | .714 | .264 | .6728 |
| IFP | .572 | .373 | .5677 |
| MPY | .334 | .663 | .373 |

According to the score function of the aggregated performance scores in Table 10, the most suitable alternative is the "education and awareness-based strategy" (.721). This outcome indicates that fostering environmental consciousness among students and staff has the strongest and most direct influence on the long-term success of zero waste practices. Awareness and behavioral change ensure that waste reduction efforts are not only institutional directives but also internalized by the campus community, thereby creating a culture of sustainability. The second suitable alternative is the "technology and digitalization-based strategy" (.673), which reflects the importance of innovative solutions such as paperless office systems, smart waste collection, and digital monitoring tools. These practices enhance efficiency and reduce resource consumption, complementing the behavioral dimension of zero waste with tangible technological support. Taken together, the findings suggest that while governance and infrastructure remain essential, zero waste effectiveness in universities is maximized when individuals actively participate through awareness and education, and when these efforts are reinforced by digital transformation and technological innovations.

## 4. Discussion

It is concluded that policy and governance support are the most critical criteria for increasing the effectiveness of zero-waste practices in universities. This result demonstrates that zero-waste policies can be achieved not only through technical or individual efforts, but also through a strong institutional framework and governance mechanisms. Decisive factors for the institutionalization of zero-waste strategies include the vision of university senior management, budget and resource allocation, the preparation of official guidelines, the establishment of sustainability coordination units, and performance reporting. Without institutional ownership, zero-waste practices remain short-term, fragmented, and limited-impact initiatives. Achieving long-term sustainability goals is impossible. Therefore, the findings carry a critical message for policymakers and university administrators. Integrating zero-waste initiatives into strategic plans, regularly monitoring performance indicators, developing governance models that increase student and staff participation, and actively participating in national or international zero-waste networks are among the key policy recommendations that will increase the effectiveness of these practices (Fikru, 2025). In this respect, the study aligns with the findings of many studies in the literature. Previous studies on environmental sustainability and waste management frequently emphasize institutional support as a critical success factor (Zhou et al., 2025). However, a crucial point to note here is that prioritizing policy and governance support alone can overshadow the multifaceted nature of zero-waste practices. Indeed, zero-waste processes produce more lasting and powerful results not only with senior management support but also with the coordinated implementation of complementary criteria such as training and awareness programs, digitalization and paperless office practices, infrastructure and physical investments, and green campus practices such as composting (Feng et al., 2025). Therefore, the findings of this study confirm the general trend in the literature and emphasize that the success of zero-waste practices cannot be reduced to a single criterion; rather, policy and governance support play a vital role as an umbrella mechanism supporting other criteria (Gou et al., 2025). This holistic perspective reveals that for zero-waste strategies to be more effectively implemented in universities, simultaneous investments are necessary not only in institutional governance but also in individual awareness, technological transformation, and infrastructural development.
A critical point emerging from our findings is that education- and awareness-based strategies outrank infrastructure investments, even though the latter provide more tangible outcomes such as recycling bins or composting facilities. This result aligns with studies emphasizing that sustainable practices depend not only on physical systems but also on individuals' willingness to use them effectively. For instance, infrastructure without behavioral change often results in underutilization, as seen in campuses where waste separation units exist but participation remains low. Conversely, strong awareness and education foster a cultural shift, ensuring that infrastructure is actively and properly used. In this sense, education-based strategies function as a catalyst, amplifying the benefits of infrastructure and technology investments. Therefore, our results extend previous research by showing that while infrastructure is indispensable, its effectiveness is contingent upon the behavioral engagement that education and awareness generate.
One of the study's striking findings is that the most prioritized strategy for increasing the effectiveness of zero-waste practices at universities is an education- and awareness-focused strategy. This finding demonstrates that the success of zero-waste policies is not solely dependent on investments in technical infrastructure or institutional governance support but is also directly related to the integration of environmental awareness and a culture of sustainability into the daily practices of students and staff (Myint et al., 2025). University communities' ability to contribute to zero-waste goals depends on individuals transforming their waste management behaviors, assuming responsibility, and actively participating in this process. In this context, education and awareness strategies can be implemented through a wide range of practices, such as zero-waste-themed seminars, environmental club activities, on-campus waste separation competitions, volunteering projects, and sustainability-focused course content (van Reenen et al., 2025). Thus, zero-waste policies can go beyond mere institutional mandates and transform into a culture of sustainability that is internalized by individuals and becomes a way of life. For policymakers, this finding highlights the need to integrate zero-waste-themed educational programs into university curricula, organize periodic awareness campaigns for all stakeholders, encourage environmental volunteering, and develop projects that instill zero-waste awareness in campus life. This result is consistent with the findings of many studies in the literature; previous research has emphasized the critical role of individual behavioral change and increased social awareness in the lasting success of environmental sustainability practices (Passe, 2025). However, prioritizing only education and awareness strategies risks reducing the multidimensional nature of zero waste practices to a single dimension. Raising individual awareness and training alone is not sufficient; this awareness must be supported by concrete practices. Therefore, for this strategy to be effective, complementary elements such as digitalization and paperless office applications, infrastructure and physical investments, and strong policy and governance support must also be integrated into the process (Ling et al., 2025). While an education and awareness-focused strategy is the most powerful catalyst for zero waste practices by initiating change from the grassroots level, it is only when implemented with institutional support and technological transformation that the long-term and holistic success of zero waste policies in universities becomes possible.

## 5. Conclusion

This study aims to identify the most appropriate strategies for increasing the effectiveness of zero-waste practices in universities and, in this regard, aims to fill a significant gap in the literature. A new multi-criteria decision-making model was developed for this purpose, based on the opinions of eight experts. Expert weights were determined using the Euclidean distance-based expert weighting technique, criteria weights were calculated using the SITDE method, and strategy alternatives were ranked using the SAW method. The model was built on the Fermatean fuzzy sets approach to ensure more flexible and realistic management of uncertainties in the process. The study's findings reveal that the most critical criterion for zero-waste practices is policy and governance support, while the most effective strategy is education and awareness-based, followed by technology and digitalization-based strategies. These results demonstrate that zero-waste practices in universities are more effective when supported not only by institutional policies but also by individual awareness and technological transformation. The novelty of this study lies in its introduction of a weighting mechanism that considers the heterogeneous characteristics of experts, transcending the common expert coefficient approach in the literature, and its integration of the Fermatean cluster approach, which is more robust in representing uncertainties, into the model. In these respects, the research offers original contributions to the literature at both methodological and applied levels. Although this study focuses on zero-waste strategies, the proposed MCDM model has broader applicability. The integration of expert weighting with Fermatean fuzzy sets can be adapted to other sustainability challenges such as energy efficiency, water conservation, or carbon reduction strategies, where multiple criteria and uncertainty play a decisive role. Thus, the framework contributes not only to waste management research but also to the wider sustainability decision-making literature. While education and awareness strategies emerge as the most effective, their successful implementation faces potential barriers. Resource constraints, such as limited budgets for training programs, and stakeholder resistance, particularly from individuals reluctant to change established behaviors, may hinder effectiveness. Overcoming these barriers requires long-term institutional commitment, innovative communication strategies, and the integration of sustainability into the core values of university governance and curricula.

However, the study has several limitations. First, the number of experts used in the model is limited to eight, which may yield different results when expanded to include different expert profiles. Furthermore, the criteria and strategy alternatives were selected based on literature review and expert opinions; the addition of new criteria or strategies may be necessary in different contexts. Given these limitations, it is recommended that future research be implemented with larger expert groups, in different geographical and institutional contexts, conduct comparative analyses using different decision-making methods, and focus on measuring the long-term performance of zero-waste practices. Thus, the model presented in this study can be further developed and make stronger contributions to both the theoretical literature and practice. In addition to the limited number of experts and the context-specific nature of the selected criteria, this study has further limitations. First, although Fermatean fuzzy sets provide strong flexibility in modeling uncertainty, they may also be sensitive to the quality and consistency of expert input data. Potential biases or inconsistencies in the assessments could affect the robustness of the results. Second, the generalizability of the findings may be limited, as the analysis was conducted in a single institutional and cultural context. Future research should test the proposed model across a wider range of universities, including both public and private institutions, and in different geographical settings, to assess the external validity of the results. Addressing these limitations would provide stronger empirical support and enhance the applicability of the proposed decision-making model. The expert evaluations in this study were obtained from professionals affiliated with Turkish universities. As such, the results primarily reflect the perspectives of higher education institutions in Turkey. Nonetheless, the criteria used in the analysis were identified through a comprehensive international literature review, suggesting that the proposed framework may also be applied in broader contexts. Future studies should test the model across universities in different countries and cultural settings to further validate its generalizability and adaptability.

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