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BALANCED SCORECARD-BASED PROJECT PRIORITIES OF SUSTAINABLE ENERGY FINANCING VIA ARTIFICIAL INTELLIGENCE-ENHANCED HYBRID QUANTUM DECISION-MAKING MODELING

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Abstract: The most essential factors should be defined to increase the effectiveness of sustainable energy financing. Otherwise, businesses may face some financial and operational

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problems due to not using resources effectively. However, only a limited number of studies in the literature have identified these important factors. This situation shows a need for a new study to determine the variables that have the greatest impact on the effectiveness of sustainable energy financing. Thus, the purpose of this study is to identify significant determinants that affect the effectiveness of sustainable energy financing. For this situation, a 3-stage model is constructed to reach this purpose. The first stage prioritizes the experts with the help of artificial intelligence (AI). The second stage weights the assessment criteria of sustainable energy financing by quantum spherical fuzzy M-SWARA. Finally, the balanced scorecard-based project priorities of sustainable energy financing are ranked with quantum spherical fuzzy WASPAS.
The main contribution of this study is that a detailed evaluation is performed to understand significant strategies for the improvements of sustainable energy financing with a novel model. Calculation of the expert weights with AI increases the quality and originality of the model. Similarly, considering M-SWARA, WASPAS, quantum theory, and spherical fuzzy sets also increases the effectiveness of the model because of managing uncertainties more effectively. The technical competence of the enterprise and Funding diversification are found as the most important items in increasing the effectiveness of sustainable energy financing. Additionally, according to the ranking results, it is determined that financial issues and customer needs are the most significant alternatives.

Keywords: sustainable energy; energy finance; balanced scorecard; artificial intelligence; fuzzy decision-making.

JEL Codes: D25, E44, F36.

1. Introduction

Sustainable energy financing is a practice that focuses on minimizing negative environmental impacts in energy production. Thanks to these financing practices, it is aimed at businesses and countries to achieve their long-term sustainability goals. Financing of renewable energy projects and instruments such as green bonds can be cited as examples of sustainable energy financing. In this way, it is possible to provide social benefits during the financing process of these projects (Qing et al., 2024). Sustainable energy financing is essential in many ways. Thanks to this financing, renewable energy projects will be able to develop. In this way, countries will be able to produce the energy they need themselves. This contributes significantly to the energy independence of these countries. Similarly, by increasing these energy investments, the environmental pollution problem can be significantly reduced. As a result, the carbon emission problem can be combated much more successfully (Babic, 2024). On the other hand, one of the main problems of renewable energy projects is that the initial investment amount is very high. Thanks to sustainable energy financing, it can be easier to access the high amount of funds needed by these projects.

As can be seen, sustainable energy financing is extremely important and necessary. Therefore, some actions need to be taken to increase the effectiveness of this financing. In this context, carbon emissions need to be reduced in renewable energy production. Although these projects are considered environmentally friendly, in some cases they can cause environmental pollution. For sustainable energy financing to be more successful, these problems must be resolved. In addition to them, improving recycling processes is also very important to achieve this goal (Hosan et al., 2024). In this way, it is possible to achieve significant cost-effectiveness of projects. Moreover, a developed technical infrastructure is also very necessary in this process. This allows energy production to be carried out at a lower cost. Similar to this issue, thanks to the advanced technological infrastructure, credibility analysis of projects can be carried out more successfully (Zeng et al., 2024). This helps to increase the efficiency of the energy financing process. Funding diversification is also very necessary for the success of this financing process. This allows the risks in the process to be better managed. Thus, the financing process of the projects can be much more successful.

To increase the effectiveness of sustainable energy financing, the most important factors need to be determined. By determining these issues, more accurate strategies can be determined for the development of these processes. This contributes to the improvement of the operational efficiency of businesses. Otherwise, businesses may face some financial and operational problems. For example, if these factors are not focused on, it will not be possible to access the right financial resources (Han and Yang, 2024). This situation prevents the development of renewable energy projects. Similarly, sufficient technological development may not be achieved as a result of incorrectly implemented strategies. This situation causes businesses to increase their operational costs (Nepal et al., 2024). Therefore, it is necessary to identify the factors that matter most. In this way, businesses can use their resources more efficiently. However, there are a limited number of studies in the literature to identify these important factors. This situation shows that there is a need for a new study to determine the variables that have the greatest impact on the effectiveness of sustainable energy financing.

This study aims to identify significant determinants that affect the effectiveness of sustainable energy financing. The research question is which indicators should be prioritized while generating appropriate strategies for this financing. In this process, a 3-stage model is constructed to reach this purpose. The first stage prioritizes the experts with the help of AI. The second stage weighs the assessment criteria of sustainable energy financing. Moreover, the balanced scorecard-based project priorities of sustainable energy financing are ranked. The motivation of this study is that there is a need to make a comprehensive evaluation to understand key issues of energy financing. Decision-making models can be taken into consideration for this situation. Nonetheless, many criticisms of these models are mainly related to uncertainties in the examination process. Therefore, in the new model, these criticisms should be satisfied.

The main contribution of this study is that a detailed evaluation is performed to understand significant strategies for the improvements of sustainable energy financing with a novel model. There are some benefits of this proposed model. (i) Calculation of the expert weights with AI increases the quality and originality of the model. In most of the models, the opinions of different experts are averaged. This situation has been criticized by many researchers. The biggest reason for these criticisms is that the opinions of people with different demographic characteristics are evaluated with the same weight of importance. To solve this problem, the importance weights of experts are calculated with AI in this model. (ii) Considering M-SWARA, WASPAS, quantum theory, and spherical fuzzy sets also increases the effectiveness of the model. In this scope, using Spherical fuzzy sets helps to manage uncertainties more effectively because a wide range of the dataset is taken into consideration. In addition to this issue, with the help of the M-SWARA technique, the causality relationship between the criteria can be evaluated. This situation helps to make more realistic evaluations.

A literature review is explained in the next part. After that, the recommended model is demonstrated. The results of this model and the main conclusions are denoted in the final parts.

2. Literature review

Funding diversification is also very important to increase the effectiveness of sustainable energy financing. It provides great financial flexibility to businesses. By diversifying financial resources, renewable energy businesses can obtain loan opportunities with different maturities (Wang et al., 2024). This situation provides businesses with significant flexibility in terms of payment. On the other hand, funds obtained from different financing sources allow the financial risks of the project to be reduced (Osei et al., 2024). In this context, the negative effects of fluctuations in exchange rates and interest rates on businesses may be much less (Bilal and Shaheen, 2024). Thus, the possibility of possible financial loss is significantly reduced. In addition to this condition, Gawusu et al. (2024) demonstrated that using different financing sources can reduce the financing costs of the project. To achieve this goal, innovative financial products need to be developed. According to Apergi et al. (2024), with the identification of these innovative financial products, it is possible to develop lower-cost products.

Reducing carbon emissions from renewable energy projects is extremely important for the effectiveness of sustainable energy financing. Carbon emissions cause a very serious amount of environmental pollution. Therefore, by reducing this emission, the problem of climate change can be effectively combated (Maliszewska-Nienartowicz, 2024). In this way, it is possible to ensure sustainability in energy financing processes. A significant portion of financial institutions are reluctant to fund projects that cause environmental pollution (Jia and Wu, 2024). Therefore, it is much easier for businesses that implement environmentally friendly projects to find funding. In other words, it is becoming increasingly difficult for businesses that cause carbon emissions to find funding (Chen et al., 2024). Moreover, Zhao et al. (2024) stated that this situation also positively affects the image of businesses in the market. Lee et al. (2024) concluded that businesses that do not cause air pollution are preferred by investors and consumers. This situation significantly supports the increase in the competitiveness of businesses.

Recycling by businesses can increase the effectiveness of sustainable energy financing. The biggest advantage of recycling is reducing the consumption of natural resources. This enables the business to significantly support sustainable development. The financing provided in this process directly supports sustainable energy production (Fatima et al., 2024). In addition to this issue, another benefit of recycling is that it reduces costs for businesses. Thanks to the recycling of products, businesses need fewer new raw materials (Filippini et al., 2024). This condition allows businesses to reduce their costs. Mohazzem Hossain et al. (2024) mentioned that thanks to the recycling process, businesses can increase their financial performance. As a result, financial institutions are more willing to provide funds to these businesses. Moreover, Xu et al. (2024) and Bakhsh et al. (2024) identified that owing to the recycling process, businesses can be more successful in legal compliance. This situation contributes strongly to achieving long-term sustainability goals.

Having a good technical infrastructure for businesses can increase the effectiveness of sustainable energy financing. Thanks to advanced technical infrastructure, the operational efficiency of renewable energy businesses can be increased (Behera et al., 2024). Thus, it is possible to increase the financial performance of these businesses. The high profitability of the business also helps increase the confidence of investors (Hermawan and Khoirunisa, 2024). In other words, financial institutions may be more willing to provide loans to businesses with high financial performance. This situation allows businesses to access the funds they need more quickly (Gao et al., 2024). This significantly increases the effectiveness of sustainable energy financing. Hassan et al. (2024) denoted that a good technical infrastructure helps the

business manage its risks more effectively. There are some risks in the renewable energy production process. Rao et al. (2024) identified that thanks to the advanced technological infrastructure, it is possible for the business to manage these risks more successfully. This situation also allows for fewer disruptions in operational processes.
The literature evaluation provides some critical issues. To increase the effectiveness of sustainable energy financing, appropriate policies need to be developed. Issues such as the development of technical infrastructure, reducing carbon emissions in the energy production process, ensuring cost efficiency and funding diversification are variables that have been determined to have a great impact on this process. To increase the performance of sustainable energy financing, it is necessary to determine the variable that affects this process the most. This allows businesses to use their resources more effectively. Otherwise, the costs of businesses will increase significantly, and this leads to financial inefficiency. However, there are very few studies in which the most important factors affecting the performance of this process are determined. This situation is determined as an important deficiency in the literature on this subject.

3. Proposed Model

3.1. Quantum Spherical Fuzzy Sets

Quantum theory makes successful estimations. By considering this advantage, is used in this model to minimize uncertainties. This situation is explained in Equations (1)-(3) (Kou et al., 2024).

$$Q(|u>) = \varphi e^{j\theta} \tag{1}$$

$$|\varsigma> = \{|u_1>, |u_2>, \dots, |u_n>\} \tag{2}$$

$$\sum_{|u>\subseteq|\varsigma>} |Q(|u>)| = 1 \tag{3}$$

Spherical fuzzy sets are used with this theory. These sets are denoted in Equations (4) and (5) (Fetais et al., 2024).

$$\tilde{A}_S = \left\{\langle u, (\mu_{\tilde{A}_S}(u), v_{\tilde{A}_S}(u), h_{\tilde{A}_S}(u)) | u \in U\right\} \tag{4}$$

$$0 \leq \mu^2_{\tilde{A}_S}(u) + v^2_{\tilde{A}_S}(u) + h^2_{\tilde{A}_S}(u) \leq 1 \text{ , } \forall_u \in U \tag{5}$$

In Equations (6)-(8), these sets are explained in the form of phase angle and amplitude.

$$\left|\varsigma_{\tilde{A}_S}\right> = \left\{\langle u, (\varsigma_{\mu_{\tilde{A}_S}}(u), \varsigma_{v_{\tilde{A}_S}}(u), \varsigma_{h_{\tilde{A}_S}}(u)) | u \in 2^{\left|\varsigma_{\tilde{A}_S}\right>}\right\} \tag{6}$$

$$\varsigma = \left[\varsigma_\mu . e^{j2\pi.\alpha}, \varsigma_v . e^{j2\pi.\gamma}, \varsigma_h . e^{j2\pi.\beta}\right] \tag{7}$$

$$\varphi^2 = \left|\varsigma_\mu(|u_i>)\right| \tag{8}$$

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The golden cut is also considered for the calculation of the degrees. Equations (9)-(11) highlight the details of this issue.

$$G = \frac{a}{b} \quad (9)$$

$$G = \frac{1+\sqrt{5}}{2} = 1.618 \ldots \quad (10)$$

$$\varsigma_v = \frac{\varsigma_\mu}{G} \quad (11)$$

The amplitude of hesitancy degrees is shown in Equation (12).

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_v \quad (12)$$

In addition, the phase angles of the degrees are indicated in Equations (13)-(15).

$$\alpha = \left|\varsigma_\mu(|u_i >)\right| \quad (13)$$

$$\gamma = \frac{\alpha}{G} \quad (14)$$

$$\beta = 1 - \alpha - \gamma \quad (15)$$

Mathematical details are demonstrated in Equations (16)-(19).

$$\lambda * \tilde{A}_\varsigma = \left\{ \left(1-\left(1-{\varsigma_{\mu_{\tilde{A}}}}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi.\left(1-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}}, {\varsigma_{v_{\tilde{A}}}}^\lambda e^{j2\pi.\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^\lambda}, \left(\left(1-{\varsigma_{h_{\tilde{A}}}}^2\right)^\lambda - \left(1-{\varsigma_{\mu_{\tilde{A}}}}^2-{\varsigma_{h_{\tilde{A}}}}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \right\}, \quad \lambda > 0 \quad (16)$$

$$\tilde{A}_\varsigma{}^\lambda = \left\{ {\varsigma_{\mu_{\tilde{A}}}}^\lambda e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^\lambda}, \left(1-\left(1-{\varsigma_{v_{\tilde{A}}}}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi.\left(1-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}}, \left(\left(1-{\varsigma_{v_{\tilde{A}}}}^2\right)^\lambda - \right. \right.$$

$$\left(1-\varsigma_{v_{\tilde{A}}}{}^{2}-\varsigma_{h_{\tilde{A}}}{}^{2}\right)^{\lambda}\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}\right)^{\lambda}-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}\right)^{\lambda}\right)^{\frac{1}{2}}}\Bigg\}, \lambda>0 \quad (17)$$

$$\tilde{A}_{\varsigma}\oplus\tilde{B}_{\varsigma}=\Bigg\{\Big(\varsigma_{\mu_{\tilde{A}}}{}^{2}+\varsigma_{\mu_{\tilde{B}}}{}^{2}-\varsigma_{\mu_{\tilde{A}}}{}^{2}\varsigma_{\mu_{\tilde{B}}}{}^{2}\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}+\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}}, \varsigma_{v_{\tilde{A}}}\varsigma_{v_{\tilde{B}}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)\right)}, \Big(\big(1-\varsigma_{\mu_{\tilde{B}}}{}^{2}\big)\varsigma_{h_{\tilde{A}}}{}^{2}+\big(1-\varsigma_{\mu_{\tilde{A}}}{}^{2}\big)\varsigma_{h_{\tilde{B}}}{}^{2}-\varsigma_{h_{\tilde{A}}}{}^{2}\varsigma_{h_{\tilde{B}}}{}^{2}\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}+\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}}\Bigg\} \quad (18)$$

$$\tilde{A}_{\varsigma}\otimes\tilde{B}_{\varsigma}=\Bigg\{\varsigma_{\mu_{\tilde{A}}}\varsigma_{\mu_{\tilde{B}}} e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)}, \Big(\varsigma_{v_{\tilde{A}}}{}^{2}+\varsigma_{v_{\tilde{B}}}{}^{2}-\varsigma_{v_{\tilde{A}}}{}^{2}\varsigma_{v_{\tilde{B}}}{}^{2}\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}+\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}}, \Big(\big(1-\varsigma_{v_{\tilde{B}}}{}^{2}\big)\varsigma_{h_{\tilde{A}}}{}^{2}+\big(1-\varsigma_{v_{\tilde{A}}}{}^{2}\big)\varsigma_{h_{\tilde{B}}}{}^{2}-\varsigma_{h_{\tilde{A}}}{}^{2}\varsigma_{h_{\tilde{B}}}{}^{2}\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}+\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}}\Bigg\} \quad (19)$$

3.2. The extension of M-SWARA

SWARA methodology is quite popular in the literature to weigh the indicators. In this model, M-SWARA is considered. In this scope, evaluations are taken in the first step. The relation matrix is created with Equation (20) (Rahadian et al., 2024).

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (20)$$

Aggregated values are determined by Equation (21).

$$\varsigma = \left\{ \left[1 - \prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[1-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}, \prod_{i=1}^{k} \varsigma_{v_i}{}^{\frac{1}{k}} e^{2\pi.\prod_{i=1}^{k}\left(\frac{\gamma_i}{2\pi}\right)^{\frac{1}{k}}}, \left[\prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}} - \prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2 - \varsigma_{h_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}} - \prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2-\left(\frac{\beta_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}} \right\} \quad (21)$$

The defuzzification process is applied via Equation (22).

$$Def\varsigma_i = \varsigma_{\mu_i} + \left(\frac{\varsigma_{\mu_i}}{\varsigma_{\mu_i}+\varsigma_{h_i}+\varsigma_{v_i}}\right) + \left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\left(\frac{\alpha_i}{2\pi}\right)}{\left(\frac{\alpha_i}{2\pi}\right)+\left(\frac{\gamma_i}{2\pi}\right)+\left(\frac{\beta_i}{2\pi}\right)}\right) \quad (22)$$

Important values are computed by Equations (23)-(25).

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (23)$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \quad (24)$$

$$If\ s_{j-1} = s_j,\ q_{j-1} = q_j; If\ s_j = 0,\ k_{j-1} = k_j$$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \quad (25)$$

Stable values are generated while taking the transpose of the matrix to the power of

2t+1. Finally, the causality relationship is identified by considering the threshold.

3.3. The extension of WASPAS

Evaluations are obtained in the first step. The next step is related to the creation of the decision matrix as explained in Equation (26) (Tronnebati et al., 2024).

$$X_k=\begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (26)$$

Later, the values are normalized via Equation (27).

$$r_{ij} = \frac{x_{ij}}{max(x_{ij})} \quad (27)$$

Weighted values are defined in Equation (28).

$$v_{ij} = w_{ij} \times r_{ij} \quad (28)$$

SAW ${Q_i}^{SAW}$ and WPM ${Q_i}^{WPM}$ values are computed by Equations (29) and (30).

$${Q_i}^{SAW} = \sum_{j=1}^{m} v_{ij} \quad (29)$$

$${Q_i}^{WPM} = \prod_{j=1}^{m} {r_{ij}}^{w_{ij}} \quad (30)$$

The combining scores Q_i are calculated for alternative ranking with Equation (31).

$$Q_i = \gamma {Q_i}^{SAW} + (1-\gamma){Q_i}^{WPM} \quad (31)$$

3.4. AI-based evaluations for expert weighting

The squares' totals (SQS) are identified in the first step via Equation (32) (Staartjes et al., 2024).

$$SQS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d(x_i, c_j)^2 \quad (32)$$

In the next step, the elbow is defined. Euclidian distance is defined in the following step as in Equation (33).

$$d(x_i, x_j) = \sqrt{\sum_{l=1}^{n} (x_{il} - x_{jl})^2} \quad (33)$$

Cluster centers are computed via Equation (34).

$$c_j = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_i \tag{34}$$

In the last step, the weights are calculated. Within this framework, first, the mean standard deviation is obtained by Equations (35)-(37).

$$s_j = \frac{1}{n}\sum_{l=1}^{n} \sigma_{jl} \tag{35}$$

$$\sigma_{jl} = \sqrt{\frac{1}{|C_j|}\sum_{x_i \in C_j} (x_{il} - \grave{x}_{jl})^2} \tag{36}$$

$$\grave{x}_{jl} = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_{il} \tag{37}$$

The cluster and expert weights w_j are computed by Equations (38) and (39).

$$w_j = | C_j | \times s_j \tag{38}$$

$$w_{tj} = \frac{1}{|C_j|}\frac{w_j}{\sum_{w_j \in C_j} w_j} \tag{39}$$

4. Analysis

4.1. Prioritizing the experts

The expert team is generated with 5 different people. Necessary information about these people is denoted in Table 1.

Table 1 Specifications of experts

Experts	Education	Working years	Income (USD)	Age	Sector
UZ 1	2 (Master)	16	4000	46	2 (Production)
UZ 2	1 (Bachelor)	14	3750	45	1 (Service)
UZ 3	1 (Bachelor)	19	2500	46	1 (Service)
UZ 4	3 (PhD)	14	4250	44	3 (Education)
UZ 5	3 (PhD)	19	4500	48	3 (Education)

Source: Own processing

Next, WCSS values are identified.

Table 2 WCSS values

K=1		K=2		K=3		K=4		K=5	
SN1	SQS	SN1	SQS	SN1	SQS	SN1	SQS	SN1	SQS
UZ1	40000.20	UZ1	15627.50	UZ1	0	UZ1	0	UZ1	0
UZ2	2508.40	UZ4	15627.50	SN2	SQS	SN2	SQS	SN2	SQS
UZ3	1690008.80	SN2	SQS	UZ2	62502.25	UZ2	0	UZ2	0
UZ4	202511.00	UZ2	27791.56	UZ4	62502.25	SN3	SQS	SN3	SQS
UZ5	490013.60	UZ3	1173614.89	SN3	SQS	UZ3	1000003.00	UZ3	0
		UZ5	840286.89	UZ3	1000003.00	UZ5	1000003.00	SN4	SQS
				UZ5	1000003.00	SN4	SQS	UZ4	0
						UZ4	0	SN5	SQS
								UZ5	0
Total	2425042.00		2072948.33		2125010.50		2000006.00		0
SN: cluster									

Source: Own processing

The results denote that for K=3, the WCSS value can be optimized. Iteration results are given in Table 3.

Table 3 Iteration values

TN (UZ1 SN1; UZ2 SN2; UZ3 SN3)				
Initial SN				
Experts	**DNC C1**	**DNC C2**	**DNC C3**	**SN**
UZ 1	0.00	250.01	1500.00	1
UZ 2	250.01	0.00	1250.01	2
UZ 3	1500.00	1250.01	0.00	3
UZ 4	250.02	500.009	1750.011	1
UZ 5	500.01	750.03	2000.00	1
Average				
Experts	**DNC C1**	**DNC C2**	**DNC C3**	**SN**
UZ 1	250.00	250.01	1500.00	1
UZ 2	500.01	0.00	1250.01	2
UZ 3	1750.00	1250.01	0.00	3
UZ 4	3.11	500.01	1750.01	1
UZ 5	250.02	750.03	2000.00	1
DNC: distance to				

Source: Own processing

In this process, two clusters are defined. The first cluster includes UZ1, UZ4 and UZ5. Moreover, UZ2 and UZ3 are stated in cluster 2. Table 4 explains standard deviations.

Table 4 Weights of clusters

Cluster	Size	Education	Experience	Income	Age	Sector	Mean SD	Weight
#1	3	0.47	2.05	204.12	1.63	0.47	41.75	125.25
#2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
#3	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Own processing

Table 5 identifies the expert weights.

Table 5 Expert Weights

Experts	Weights
UZ 1	0.333
UZ 2	0.000
UZ 3	0.000
UZ 4	0.333
UZ 5	0.333

Source: Own processing

Table 5 demonstrates that UZ2 and UZ3 do not have any weights. Because of this issue, their evaluations are not considered. However, other evaluations are used in the analysis process.

4.2. Weighting the assessment criteria of sustainable energy financing

The evaluations are obtained from these people. In this process, the values in Table 6 are taken into consideration.

Table 6 Scales

for Indicators	for Alternatives	Degrees	Fuzzy Sets
no (n)	lowest (w)	.40	$\begin{bmatrix} \sqrt{0.16}e^{j2\pi.0.4}, \\ \sqrt{0.10}e^{j2\pi.0.25}, \\ \sqrt{0.74}e^{j2\pi.0.35} \end{bmatrix}$
little (s)	low (p)	.45	$\begin{bmatrix} \sqrt{0.20}e^{j2\pi.0.45}, \\ \sqrt{0.13}e^{j2\pi.0.28}, \\ \sqrt{0.67}e^{j2\pi.0.27} \end{bmatrix}$
average (m)	normal (f)	.50	$\begin{bmatrix} \sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.60}e^{j2\pi.0.19} \end{bmatrix}$

adequate (h)	powerful (g)	.55	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$
magnificent (vh)	perfect (b)	.60	$\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.6}, \\ \sqrt{0.22}e^{j2\pi.0.37}, \\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$

Source: Own processing

The Criteria set is determined in Table 7.

Table 7 Criteria

Criteria	**Codes**
Reduction in carbon emissions with renewables	RCEHR
Cost-effective project planning using recycling systems	CEPPR
Social benefits of increasing clean energy	SBBCE
Technical appropriateness with innovative environmental solutions	THWVS
Governmental incentives via energy policies	GMNVN
Funding diversification with new-generation market instruments	FWNGT

Source: Own processing

Assessments for indicators are given in Table 8.

Table 8 Assessments for indicators

UZ 1						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
RCEHR		M	S	M	S	M
CEPPR	M		S	H	S	H
SBBCE	M	S		H	H	M
THWVS	H	H	H		H	H
GMNVN	S	S	S	H		H
FWNGT	M	H	H	H	H	
UZ 2						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
RCEHR		M	M	M	M	M
CEPPR	M		S	VH	S	VH
SBBCE	M	S		VH	H	M
THWVS	VH	H	H		H	H
GMNVN	M	S	S	H		H

FWNGT	M	H	H	H	H	
UZ 3						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
RCEHR		M	M	H	M	H
CEPPR	M		S	H	S	H
SBBCE	M	M		H	H	M
THWVS	H	H	H		H	H
GMNVN	M	M	M	H		H
FWNGT	H	H	H	H	H	

Source: Own processing

Aggregated values are shown in Table 9.

Table 9 The aggregated values

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
RCEHR		$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$
CEPPR	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$		$\begin{bmatrix}\sqrt{0.20}e^{j2\pi.0.45},\\ \sqrt{0.13}e^{j2\pi.0.28},\\ \sqrt{0.67}e^{j2\pi.0.27}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.18}e^{j2\pi.0.34},\\ \sqrt{0.52}e^{j2\pi.0.15}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.20}e^{j2\pi.0.45},\\ \sqrt{0.13}e^{j2\pi.0.28},\\ \sqrt{0.67}e^{j2\pi.0.27}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.18}e^{j2\pi.0.34},\\ \sqrt{0.52}e^{j2\pi.0.15}\end{bmatrix}$
SBBCE	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22}e^{j2\pi.0.47},\\ \sqrt{0.13}e^{j2\pi.0.29},\\ \sqrt{0.65}e^{j2\pi.0.25}\end{bmatrix}$		$\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.18}e^{j2\pi.0.34},\\ \sqrt{0.52}e^{j2\pi.0.15}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$
THWVS	$\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.18}e^{j2\pi.0.34},\\ \sqrt{0.52}e^{j2\pi.0.15}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$		$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$
GMNVN	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22}e^{j2\pi.0.47},\\ \sqrt{0.13}e^{j2\pi.0.29},\\ \sqrt{0.65}e^{j2\pi.0.25}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22}e^{j2\pi.0.47},\\ \sqrt{0.13}e^{j2\pi.0.29},\\ \sqrt{0.65}e^{j2\pi.0.25}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$		$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$
FWNGT	$\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$	

Source: Own processing

Defuzzified values are denoted in Table 10.

Table 10 The defuzzified values

	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
RCEHR	.000	1.500	1.437	1.570	1.437	1.570
CEPPR	1.500	.000	1.305	1.776	1.305	1.776

SBBCE	1.500	1.373	.000	1.776	1.705	1.500
THWVS	1.776	1.705	1.705	.000	1.705	1.705
GMNVN	1.437	1.373	1.373	1.705	.000	1.705
FWNGT	1.570	1.705	1.705	1.705	1.705	.000

Source: Own processing

Normalized values are demonstrated in Table 11.

Table 11 Normalized values

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
RCEHR	.000	.200	.191	.209	.191	.209
CEPPR	.196	.000	.170	.232	.170	.232
SBBCE	.191	.175	.000	.226	.217	.191
THWVS	.207	.198	.198	.000	.198	.198
GMNVN	.189	.181	.181	.225	.000	.225
FWNGT	.187	.203	.203	.203	.203	.000

Source: Own processing

Table 12 highlights the significant values.

Table 12 Sj, kj, qj, and wj values

RCEHR	**Sj**	**kj**	**qj**	**wj**	**CEPPR**	**Sj**	**Kj**	**qj**	**Wj**	**SBBCE**	**Sj**	**kj**	**qj**	**wj**
THWVS	.209	1.000	1.000	.243	THWVS	.232	1.000	1.000	.234	THWVS	.226	1.000	1.000	.264
FWNGT	.209	1.000	1.000	.243	FWNGT	.232	1.000	1.000	.234	GMNVN	.217	1.217	.822	.217
CEPPR	.200	1.200	.834	.202	RCEHR	.196	1.196	.836	.196	FWNGT	.191	1.191	.690	.182
SBBCE	.191	1.191	.700	.170	SBBCE	.170	1.170	.715	.168	RCEHR	.191	1.000	.690	.182
GMNVN	.191	1.191	.587	.143	GMNVN	.170	1.000	.715	.168	CEPPR	.175	1.175	.587	.155
THWVS	**Sj**	**kj**	**qj**	**wj**	**GMNVN**	**Sj**	**Kj**	**qj**	**Wj**	**FWNGT**	**Sj**	**kj**	**qj**	**wj**
RCEHR	.207	1.000	1.000	.231	FWNGT	.225	1.000	1.000	.273	CEPPR	.203	1.000	1.000	.207
SBBCE	.198	1.198	.834	.192	THWVS	.225	1.225	.817	.223	SBBCE	.203	1.000	1.000	.207
FWNGT	.198	1.000	.834	.192	RCEHR	.189	1.189	.687	.187	THWVS	.203	1.000	1.000	.207
GMNVN	.198	1.000	.834	.192	CEPPR	.181	1.181	.582	.159	GMNVN	.203	1.000	1.000	.207
CEPPR	.198	1.000	.834	.192	SBBCE	.181	1.000	.582	.159	RCEHR	.187	1.187	.842	.174

Source: Own processing

The relation matrix is shown in Table 13.

Table 13 Relation matrix

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT	Impact directions
RCEHR		.202	.170	.243	.143	.243	RCEHR → CEPPR, THWVS, FWNGT
CEPPR	.196		.168	.234	.168	.234	CEPPR → THWVS, FWNGT
SBBCE	.182	.155		.264	.217	.182	SBBCE → THWVS, GMNVN
THWVS	.231	.192	.192		.192	.192	THWVS → RCEHR
GMNVN	.187	.159	.159	.223		.273	GMNVN → THWVS, FWNGT
FWNGT	.174	.207	.207	.207	.207		FWNGT → CEPPR, SBBCE, THWVS, GMNVN

Source: Own processing

Table 13 defines that funding diversification with new-generation market instruments is the most influencing factor. Additionally, technical appropriateness with innovative environmental solutions is the most influenced item. The weights of the criteria are detailed in Table 14.

Table 14 Weights

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
RCEHR	.163	.163	.163	.163	.163	.163
CEPPR	.156	.156	.156	.156	.156	.156
SBBCE	.153	.153	.153	.153	.153	.153
THWVS	.189	.189	.189	.189	.189	.189
GMNVN	.157	.157	.157	.157	.157	.157
FWNGT	.183	.183	.183	.183	.183	.183

Source: Own processing

Table 14 underlines that technical appropriateness with innovative environmental solutions is the most significant indicator of improving sustainable energy financing. Additionally, funding diversification with new-generation market instruments also plays an important role in this framework.

4.3. Ranking the project priorities

Project priorities are defined as financial issues (FINSSE), customer needs (CTENND), technical infrastructure (TNFRTT) and market conditions (MTDTNS).

Table 15 gives information about these priorities.

Table 15 Assessments for priorities

UZ 1						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
FINSSE	F	B	F	G	B	B
CTENND	G	F	B	G	G	G
TNFRTT	G	G	F	B	F	F
MTDTNS	F	G	F	F	G	G
UZ 2						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
FINSSE	G	B	F	G	G	G
CTENND	G	P	B	G	G	G
TNFRTT	G	G	F	B	P	P
MTDTNS	F	G	F	G	G	G
UZ 3						
	RCEHR	**CEPPR**	**SBBCE**	**THWVS**	**GMNVN**	**FWNGT**
FINSSE	G	G	F	G	G	B
CTENND	G	F	B	G	G	G
TNFRTT	G	G	F	G	F	F
MTDTNS	F	G	F	F	G	G

Source: Own processing

Table 16 denotes average values.

Table 16 Average values

	A1	**A2**	**A3**	**A4**
RCEHR	$\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54}, \\ \sqrt{0.18}e^{j2\pi.0.33}, \\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$
CEPPR	$\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58}, \\ \sqrt{0.21}e^{j2\pi.0.36}, \\ \sqrt{0.45}e^{j2\pi.0.07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48}, \\ \sqrt{0.14}e^{j2\pi.0.30}, \\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$
SBBCE	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.60}, \\ \sqrt{0.22}e^{j2\pi.0.37}, \\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$

THWVS	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.21}e^{j2\pi.0.36},\\ \sqrt{0.45}e^{j2\pi.0.07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$
GMNVN	$\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.57},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.48}e^{j2\pi.0.09}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$
FWNGT	$\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.21}e^{j2\pi.0.36},\\ \sqrt{0.45}e^{j2\pi.0.07}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.10}e^{j2\pi.0.13}\end{bmatrix}$

Source: Own processing

Score values are computed in Table 17.

Table 17 Score values

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
FINSSE	1.638	1.846	1.500	1.705	1.776	1.846
CTENND	1.705	1.437	1.920	1.705	1.705	1.705
TNFRTT	1.705	1.705	1.500	1.846	1.437	1.437
MTDTNS	1.500	1.705	1.500	1.570	1.705	1.705

Source: Own processing

Normalized values are indicated in Table 18.

Table 18 Normalized values

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
FINSSE	0.961	1.000	0.781	0.924	1.000	1.000
CTENND	1.000	0.779	1.000	0.924	0.960	0.924
TNFRTT	1.000	0.924	0.781	1.000	0.809	0.779
MTDTNS	0.880	0.924	0.781	0.851	0.960	0.924

Source: Own processing

Table 19 defines the weighted matrix.

Table 19 Weighted matrix

	RCEHR	CEPPR	SBBCE	THWVS	GMNVN	FWNGT
FINSSE	.157	.156	.119	.175	.157	.183
CTENND	.163	.121	.153	.175	.150	.169
TNFRTT	.163	.144	.119	.189	.127	.142

MTDTNS	.143	.144	.119	.161	.150	.169

Source: Own processing

The ranks of the alternatives are demonstrated in Table 20.

Table 20 Ranking results

Alternatives	**SAW**	**WPN**	**Combining Scores ($\gamma = 0.5$)**
FINSSE	.946	.942	.9441
CTENND	.931	.928	.9295
TNFRTT	.884	.879	.8817
MTDTNS	.887	.885	.8858

Source: Own processing

The highest combining score explains the best alternative. Financial issues (A1) play the most critical role in this context. Customer needs (A2) should also be taken into consideration for this purpose. Table 21 identifies these results for different parameters.

Table 21 Ranking results with different combination parameters

	γ										
Alternatives	**0**	**.1**	**.2**	**.3**	**.4**	**.5**	**.6**	**.7**	**.8**	**.9**	**1**
FINSSE	1	1	1	1	1	1	1	1	1	1	1
CTENND	2	2	2	2	2	2	2	2	2	2	2
TNFRTT	4	4	4	4	4	4	4	4	4	4	4
MTDTNS	3	3	3	3	3	3	3	3	3	3	3

Source: Own processing

The ranking results are the same with different numbers of combination parameters. It is understood that the findings are reliable. In addition to this issue, comparative evaluation and sensitivity analysis are performed. The results are given in Table 22.

Table 22 Comparative evaluation and sensitivity analysis results

QSF-WASPAS ($\gamma = 0.5$)						
Case						
	#1	**#2**	**#3**	**#4**	**#5**	**#6**
FINSSE	1	1	1	1	1	1
CTENND	2	2	2	2	2	2
TNFRTT	4	4	4	4	4	4

MTDTNS	3	3	3	3	3	3
QSF-TOPSIS						
Case						
	#1	**#2**	**#3**	**#4**	**#5**	**#6**
FINSSE	1	1	1	1	1	1
CTENND	2	2	2	2	2	2
TNFRTT	4	4	4	4	4	4
MTDTNS	3	3	3	3	3	3

Source: Own processing

All results are quite similar. It is identified that the findings of the proposed model are coherent and consistent.

5. Discussion

The technical competence of the enterprise is extremely important in increasing the effectiveness of sustainable energy financing. One of the most critical advantages of this situation is that it enables projects to be managed effectively. A business with high technical competence can plan its projects more successfully. This contributes significantly to the success of the projects. Thus, it will be much easier to obtain the funds they need. Gao et al. (2024) denoted that there may be very complex processes in energy production projects. Therefore, some operational disruptions may occur in production processes. In this process, the high technical competence of the company allows these complex processes to be managed more effectively. Mhadhbi (2024) indicated that financing companies are also more willing to provide funds to companies that are successful in the risk management process. In addition to them, Danish et al. (2024) concluded that the optimization of renewable energy production processes can be achieved with a good technical infrastructure. Since this will support increased efficiency, costs can be significantly reduced. This situation helps businesses reduce their need for financial resources.

Funding diversification has also an important impact on sustainable energy financing. There are many advantages to obtaining funds from different financing sources. The biggest contribution of this situation is that it reduces the financial risks of the projects. Thus, it is possible to carry out renewable energy production more effectively. On the other hand, considering different financing sources also provides financial flexibility to businesses. Musah et al. (2024) indicated that by using different products, businesses can manage their cash flows more effectively. This contributes significantly to minimizing liquidity risk. In addition to this, the use of different financing sources can reduce the financing costs of the project. In this process, many new financial products can be developed. Tee et al. (2024) mentioned that having many financing alternatives also allows businesses to reduce their funding costs. Moreover, Sampene et al. (2024) stated that access to different sources of financing ensures that the project is competitive. Thanks to the availability of different alternatives, projects can access financial resources more easily. This issue also contributes to increasing the performance of the projects.

6. Conclusions

This study tries to define important indicators that affect the effectiveness of sustainable energy financing. In this scope, a 3-stage model is constructed to reach this purpose. The findings show that funding diversification with new-generation market instruments is the most influencing factor. Additionally, technical appropriateness with innovative environmental solutions is the most influenced item. The technical competence of the enterprise and Funding diversification are found as the most important items in increasing the effectiveness of sustainable energy financing. Additionally, according to the ranking results, it is determined that financial issues and customer needs are the most significant alternatives. Some policies need to be implemented to increase the technical competence of the business. In this context, the knowledge of the technical staff of the enterprise needs to be increased. To achieve this goal, comprehensive training should be provided to personnel regarding operational processes. This allows disruptions in the process to be minimized. Similarly, businesses' emphasis on research studies also enables them to increase their technical competence. Thanks to these studies, businesses can access innovative technologies. This helps minimize disruptions in the process. On the other hand, it is possible to identify policy recommendations focusing on funding diversification to increase the effectiveness of sustainable energy financing. States should implement practices that will facilitate access to different financing sources. In this context, restrictions that make it difficult for investors to access these products should be avoided. In addition to this condition, trainings can be organized that emphasize the importance of financing diversification strategies. In this way, the financing diversification potential of projects is increased.

The main contribution of this study is that a detailed evaluation is performed to understand significant strategies for the improvements of sustainable energy financing with a novel model. Calculation of the expert weights with AI increases the quality and originality of the model. Similarly, considering M-SWARA, WASPAS, quantum theory and spherical fuzzy sets also increases the effectiveness of the model because of managing uncertainties more effectively. The main limitation of this study is the selection of alternatives based on the balanced scorecard approach. Although this theory has some advantages, the alternatives in this study are limited according to the perspectives of this theory. In future studies, a different methodology can be taken into consideration so that more variables can be used in the evaluation process. The proposed model has also some limitations, such as considering only five different determinants to weigh the experts. In the following models, more factors can be used for this situation.

Data Availability Statement: There is no data in the manuscript

Abbreviations

$\tilde{A}_S$: Spherical fuzzy numbers
$h_{\tilde{A}_S}(u))|$: hesitancy degree
C_j: data points
$|Q(|u>)| = \varphi^2$: amplitude result
c_j: cluster center
s_j: mean standard deviation
$v_{\tilde{A}_S}(u)$: non-membership degree
w_j: weights
$\mu_{\tilde{A}_S}(u)$: membership degree
$\varsigma_{h_{\tilde{A}_S}}$: hesitancy degree
$\varsigma_{v_{\tilde{A}_S}}$: non-membership degree
$\varsigma_{\mu_{\tilde{A}_S}}$: membership degree
a: large quantity
b: small quantity
DNC: distance to
G: golden cut
n: number of dimensions
SN: cluster
TN: Iteration
UZ: expert
X: decision matrix
$d(x_i, c_j)$: Euclidean distance
k: cluster number
θ: phase angle
ς: aggregated values
ς: collective events

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