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Assessment of technical and financial challenges for renewable energy project alternatives

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ABSTRACT

The purpose of this study is to assess technical and financial challenges for renewable energy project alternatives with a novel model. Firstly, a set of technical and financial challenges is created by considering the results of the literature evaluation. After that, the weights of these values are computed by Sine Trigonometric Pythagorean Fuzzy (ST-PFN) DEMATEL. The next step includes the ranking of six renewable energy alternatives with interval valued Spherical fuzzy multicriteria analysis with ratio and categorical data (SF MAIRCA) approach. Entropy and ARAS methodology are also considered to make comparative evaluation. Similarly, sensitivity analysis is also conducted for 10 different cases. It is concluded that the analysis results of all methods are the same. Therefore, it is identified that the findings of the proposed model are reliable and coherent. Identification of the most crucial technical and financial challenges of the renewable energy projects is the most important contribution of this manuscript. Furthermore, preferring the sine trigonometric structure in the proposed model will provide superiority to this model in many respects. It is concluded that difficulty in accessing finance for local projects is the most significant challenge for renewable energy investments. Moreover, competitive pricing of renewable sources is another critical issue in this regard. Additionally, it is identified that solar is the most successful renewable energy alternative to overcome technical and financial challenges.

1. Introduction

Renewable energy investment projects are of great importance as they have many important advantages. Renewable energy sources are naturally regenerated and inexhaustible. Energy from renewable sources can be used endlessly, unlike fossil fuels. This provides a continuous and sustainable source to meet energy needs (Wang et al., 2023). On the other hand, renewable energy sources are less harmful to the environment, unlike fossil fuels. During renewable energy production, greenhouse gas emissions are reduced, and air, water and soil pollution is reduced. This plays an important role in combating climate change and protecting environmental health (Goh et al., 2023). Moreover, renewable energy sources reduce the dependence on energy imports. This issue contributes to the increase of energy security. Due to these advantages, many different countries focused on the development of these projects. China is the world's largest investor and producer of renewable energy. There are very large-scale investments in China, especially for solar and wind energy projects. It makes large investments in solar panels in the USA and Germany. Large-scale projects are carried out in areas such as hydropower and biomass in India. Iceland is a country rich in geothermal energy resources and is making large-scale investments in geothermal energy. Similarly, Turkey has achieved significant increases

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in geothermal energy production in recent years.

There are some challenges in the development of renewable energy projects. These problems can be related to both financial and technical aspects. Manufacturing defects of renewable equipment may present some challenges in the development of renewable energy projects. Performance problems of equipment used in renewable energy projects can affect the efficiency of projects (Feng et al., 2023). Production defects that occur in these projects can reduce the efficiency of the projects, which in turn can reduce energy production. Furthermore, the instability of natural resources can create some difficulties in the development of renewable energy projects. Renewable energy projects are affected by natural resources. Therefore, some fluctuations may occur in energy production. This volatile energy production can cause instability in energy supply (Liu et al., 2023). The design problems of the project setup can also negatively affect the development of renewable energy projects. Renewable energy projects often require large-scale infrastructure. The installation and integration of these infrastructures can be complex and require strengthening of local communication lines.

Additionally, the lack of financial resources in the development of renewable energy projects can create various difficulties. When sufficient financial resources are not provided, renewable energy projects become difficult to realize. Sufficient capital is needed to cover many expenses such as project setup, equipment purchases and operating expenses. If financial resources are not found, projects may be delayed or stopped altogether. Uncertainties in project revenues can create several challenges in the development of renewable energy projects (Ghiara et al., 2023). Renewable energy projects are generally supported by project revenues. Uncertainties in revenues increase financing risk for investors and lenders. In addition, high prices can create several challenges in the development of renewable energy projects. The high prices of renewable energy projects can make it difficult to find financing sources.

For the development of the renewable energy projects, both technical and financial challenges must be minimized. In other words, it is necessary to take the right precautions and manage these risks effectively. On the other hand, implementing these measures has an increasing impact on the costs of the companies (Majeed et al., 2023). Therefore, it is not very possible in terms of financial efficiency to take every single measure together. Therefore, these more important measures should be identified, and businesses should give priority to these issues (Li et al., 2023; An et al., 2023). In this way, it will be easier to deal with these difficulties and the costs will not be incurred while implementing the measures. In summary, there is a strong need to understand which challenges are more critical. With the help of this situation, renewable energy companies can focus on the solutions of these challenges firstly. Hence, they can take measures to solve the challenges by not having high amount of costs. However, there are only limited studies in literature related to this situation.

In this study, it is aimed to evaluate technical and financial challenges for renewable energy project alternatives with a new methodology. Firstly, a set of technical and financial challenges is generated by considering the results of the literature evaluation. In the following step, the weights of these values are calculated by Sine Trigonometric Pythagorean Fuzzy (ST-PFN) DEMATEL. Calculation of criterion weights with the help of DEMATEL method is also beneficial in many ways. The DEMATEL technique uses the causality relationship between these factors while determining the importance weights of the criteria (Zhang et al., 2023). Technical and financial difficulties in renewable energy projects are also factors that have an impact on each other. Therefore, it is thought that the analysis to be made with the DEMATEL method will produce more realistic results. The next step includes the ranking of six renewable energy alternatives with interval valued Spherical fuzzy multicriteria analysis with ratio and categorical data (SF MAIRCA) approach. Owing to its unique linear normalization algorithm, which is the main advantage of MAIRCA, it can obtain very reliable results. In addition, MAIRCA is an effective mathematical tool and solution method that allows combining with other methods. Compared to other methods, MAIRCA method generates theoretical value with uniform statistical distribution (Qahtan et al., 2023). Entropy and ARAS methodology are also considered to make comparative evaluation. Similarly, sensitivity analysis is also conducted for 10 different cases.

The main contributions of this study are denoted below.

(i) Identification of the most crucial technical and financial challenges of the renewable energy projects is the most important contribution of this manuscript. These challenges must be minimized to improve the renewable energy projects. In this framework, the right precautions should be implemented to manage these risks effectively. However, it is not very possible in terms of financial efficiency to take every single measure together because these implementations lead to high costs. Due to this situation, companies should give priority to the most critical items.

(ii) Preferring the sine trigonometric structure in the proposed model will provide superiority to this model in many respects. The main advantage of the sine trigonometric function is that it takes periodicity into account and is symmetrical with respect to the origin. Thus, it can meet the needs of the decision maker on multi-time parameters. Sine trigonometric operators give better results than other classical operators. Especially, when comparing two fuzzy numbers, it can both produce better results and achieve this with less processing. Also, this function is recommended because of the more accurate implementation of defuzzification processes. The sine trigonometric method is more applicable than the classical operators. The use of trigonometric structure provides benefits for many operations. In addition, the technical and financial challenges in renewable energy projects are not linear either. In other words, since there are instantaneous ups and downs in these factors, it would be more appropriate to consider these concepts with a trigonometric structure in the evaluation (Wang et al., 2022). Therefore, it is understood that the weighting of these criteria should be a sinus trigonometric structure rather than a linear function. On the other hand, selecting renewable energy project alternatives is a complex and difficult process. Thus, the linear functions should not be taken into consideration to solve these problems effectively. Instead of them, considering sine trigonometric structure helps to handle the uncertainty in this process more appropriately.

Literature review is taken part in the next section. Methodology is explained in the third section. The following part denotes analysis results. Discussions and conclusions are given finally.

2. Literature review

Some of the studies emphasize that the manufacturing defects of renewable equipment present some difficulties in the development of renewable energy projects. The reliability of renewable energy equipment affects the success of projects. Zhang et al. (2022) claimed that manufacturing defects in equipment can increase the frequency of breakdowns and increase maintenance/repair costs. This can cause projects to encounter difficulties in terms of reliability and continuity. According to Kong et al. (2022), manufacturing defects can increase the costs of renewable energy equipment. Defective parts may need to be remanufactured or replaced, resulting in additional costs. In addition, energy production losses may occur due to defective equipment and the economic sustainability of projects may be affected. On the other hand, Mourad et al. (2023) stated that manufacturing defects can affect the timelines of renewable energy projects. Liao et al. (2022) identified that when equipment defects are detected, manufacturers or project companies may need to spend time on the supply of new equipment or repairs. This may delay projects and prolong the process of reaching planned production capacity. Furthermore, Zheng et al. (2023)

determined that it is important to establish a reliable supply chain for renewable energy equipment. Manufacturing defects can affect the quality and reliability of parts in the supply chain. This creates difficulties in finding reliable suppliers for equipment manufacturers and projects.

The instability of natural resources is another challenge in the development of renewable energy projects. The instability of natural resources can create difficulties in meeting energy demand. Liang et al. (2022) explained that wind energy projects may not produce enough energy during periods of low wind speed. This may cause the energy supply to be unable to meet demand and lead to power cuts. According to Adebayo (2022), the instability of natural resources along with variable energy production can also cause energy storage difficulties. This can lead to a significant increase in the costs of the projects. The instability of natural resources can create difficulties in planning and communicating energy projects. Yang et al. (2022) determined that correct planning is important to ensure the balance of energy demand and supply. However, it can be difficult to predict resource fluctuations and plan projects accordingly. Moreover, the variability of energy production requires effective communication between stakeholders in energy systems. Sohail et al. (2022) stated that to effectively manage the problems arising from the instability of natural resources, it is necessary to develop and expand energy storage technologies in renewable energy projects. Yu et al. (2022) claimed that owing to the effective and low-cost execution of these processes, the performance of renewable energy projects will be much less affected by the instability that may occur in natural resources.

In the development of renewable energy projects, the design issues of the project setup can present several challenges. It is important to choose suitable locations for renewable energy projects. However, many factors such as environmental and geographical must be considered to make this site selection successful (Kozlova et al., 2022; Gomaa et al., 2023). Technical and engineering challenges may need to be overcome in the design of renewable energy projects. According to Ahmed et al. (2022), each type of project has its own specific technical requirements. To meet these challenges, specialist engineering knowledge and experience is required. Tomin et al. (2022) mentioned that the design of renewable energy projects should ensure that environmental impacts are minimized. Projects should not have negative impacts on the ecosystem, natural habitats, and biodiversity. Therefore, environmental impact assessments and monitoring activities are important. Lee et al. (2022), Mikhaylov (2022, 2023) explained that considering these factors in design can sometimes lead to additional costs. The installation of renewable energy projects often requires various permits at the local and national level. Marocco et al. (2022) defined that it is necessary to clearly understand the legal rules of the countries. Otherwise, some difficulties may be experienced during the operation of renewable energy projects.

The lack of financial resources is also one of the important difficulties that may be encountered in the development of renewable energy projects. Mikhaylov (2023) defined that renewable energy projects can often require higher investment costs compared to traditional energy sources. However, according to Mukhtarov et al. (2022), it is known that renewable energy projects can be cost effective and reduce energy costs in the long run. If financial resources are not available, the cost-effectiveness and competitiveness of projects may be affected. Yasmeen et al. (2022) identified that renewable energy projects can carry high risks in the early stages. The lack of financial resources creates difficulties in managing the risks of projects. Rasoulinezhad and Taghizadeh-Hesary (2022) claimed that investors may not be willing to take the risk to ensure the success and return of the project. This makes the financing of projects significantly more difficult. The competitiveness of renewable energy projects is related to the availability of financial resources. Dogan et al. (2022) mentioned that if funding is not available, projects become less competitive and less attractive compared to other energy projects. This makes it difficult for projects to come to life and compete in the market.

Uncertainties in project revenues may create some difficulties in the development of renewable energy investments. Shang et al. (2022) highlighted that the fluctuation of natural resources may cause uncertainties in the revenues of these projects. These fluctuations affect energy production and can therefore affect the revenue of the project. Mikhaylov (2022) defined that renewable energy projects often generate revenue tied to electricity prices in energy markets. Energy markets can be complex and dynamic. According to Yan et al. (2022), uncertainties in these factors may adversely affect the revenue of the project. On the other hand, many countries apply tariff and incentive policies to encourage renewable energy projects. Abbas et al. (2023) concluded that changes or uncertainties in these policies may lead to uncertainties in the revenues of projects. These changes can also affect the payback period of the project and reduce investor interest in the project. Tan et al. (2022) defined that the operating and maintenance costs of renewable energy projects are important factors affecting the revenues of the project. However, uncertainties in operating and maintenance costs can affect the financial performance of the project. Unforeseen maintenance needs or cost increases can reduce revenues or reduce project profitability.

High prices can pose several challenges in the development of renewable energy projects. The high prices of renewable energy projects can make it difficult to find financing sources. Borzuei et al. (2022) demonstrated that when project costs are high, investors and lenders can increase risk. In this case, it may demand more assurance and higher returns to obtain financing. This may complicate the financing process of the projects or prevent the realization of the project. On the other hand, Razi and Dincer (2022) concluded that high prices can reduce the competitiveness of renewable energy projects. According to Osman et al. (2023), higher costs compared to traditional energy sources can make it difficult for renewable energy projects to compete in energy markets. This may cause projects not to be preferred over lower-cost energy sources and make the realization of projects more difficult. Moreover, Meng et al. (2022) claimed that high prices can affect the cost-effectiveness of renewable energy projects. Projects with high investment costs can reduce the potential to reduce energy costs. Dinçer et al. 2023a,b indicated that if renewable energy projects are more cost-effective than traditional energy sources, energy consumers and electricity companies may hesitate to invest in these projects. The summary of these studies is presented in Table A1.

By evaluating the details of these studies, the main findings of the literature review are denoted as follows.

(i) Both technical and financial challenges must be minimized to improve renewable energy projects.
(ii) It is necessary to take the right precautions and manage these risks effectively.
(iii) Nevertheless, implementing these measures causes high costs for the companies.
(iv) Hence, it is not very possible in terms of financial efficiency to take every single measure together.
(v) Due to this situation, more important measures should be identified, and businesses should give priority to these issues.
(vi) The studies in literature mainly focused on key challenges in this process. However, there are limited studies in literature regarding this condition. Hence, there is a strong need for a priority analysis in this respect.

For the purpose of satisfying this missing part in literature, this study aims to make a priority examination about the technical and financial challenges of renewable energy investments.

3. Problem Formulation and Modelling

Firstly, necessary information is given related to the problem in this study. The theoretical background of the techniques used in the proposed model is identified as follows.

3.1. Problem Formulation

Renewable energy investment projects are of great importance as they have many important advantages. Firstly, they are less harmful to the environment, unlike fossil fuels. This situation plays an important role in managing climate change and protecting environmental health. Additionally, renewable energy sources reduce the dependence on energy imports. This situation positively affects the current account balance of the countries. In summary, renewable energy projects have a positive influence on both social and economic development. However, there are some challenges in the development of renewable energy projects. These problems can be related to both financial and technical aspects. It is necessary to take the right precautions and manage these risks effectively. On the other hand, the costs of enterprises are increasing to implement these measures. Thus, these more important measures should be identified, and businesses should give priority to these issues. Consequently, there is a strong need to make a priority analysis to find the most critical challenge of renewable energy investments.

3.2. Modelling

In this study, it is aimed to identify the prior technical and financial challenges of renewable energy investments. A new model is constructed for this purpose. The criteria are weighted by ST-PFN DEMATEL, and alternatives are ranked with interval valued SF MAIRCA.

In this study, DEMATEL technique is integrated into ST-PFNs. Pythagorean fuzzy sets are defined by PFS and ST-PFN can be given as in Equation (1).

$$\sin P = \left\{ \left(x, \sin\left(\frac{\pi}{2}\mu_P\right), \sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_P^2}\right)} \right) \middle| x \in X \right\} \tag{1}$$

After that, evaluation matrix is created, and the values are converted into fuzzy numbers with the expressions in Table A2. The fuzzy expert evaluation matrices obtained from each expert are averaged with the help of Equations (2) and (3).

$$ST-PFWA(P_1,\dots,P_n) = \left(\begin{array}{c} \sqrt{1-\prod_{j=1}^{n}\left(1-\sin^2\left(\frac{\pi}{2}\mu_j\right)\right)^{\frac{1}{n}}}, \\ \prod_{j=1}^{n}\left(\sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_j^2}\right)}\right)^{\frac{1}{n}} \end{array} \right) \tag{2}$$

$$Z = \begin{bmatrix} (0,0) & \cdots & \left(\begin{array}{c} \sin\left(\frac{\pi}{2}\mu_{1n}\right), \\ \sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_{1n}^2}\right)} \end{array} \right) \\ \vdots & \ddots & \vdots \\ \left(\begin{array}{c} \sin\left(\frac{\pi}{2}\mu_{n1}\right), \\ \sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_{n1}^2}\right)} \end{array} \right) & \cdots & (0,0) \end{bmatrix} \tag{3}$$

Thus, the ST-PFN-based initial direct relationship matrix is obtained. Then, with the help of Equations (4) and (5), the initial direct relationship matrix (A) is calculated.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{4}$$

$$a_{ij} = \sin^2\left(\frac{\pi}{2}\mu_{ij}\right) - \left(\sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_{ij}^2}\right)}\right)^2 \tag{5}$$

In the next step, the normalized initial direct relationship matrix (B) is created by Equations (6) and (7) (Özdemirci et al., 2023).

$$B = A \text{ X } Y \tag{6}$$

$$Y = \frac{1}{\max_i \sum_{j=1}^{n} |a_{ij}|} \tag{7}$$

Equation (8) is considered to construct total relation matrix (T) (Yüksel and Dinçer, 2022).

$$T = BX(I-B)^{-1} \tag{8}$$

The row (R) and column (C) sums of the T matrix are calculated by Equations (9) and (10).

$$C_i = \sum_{j=1}^{n} t_{ij} \tag{9}$$

$$R_i = \sum_{i=1}^{n} t_{ij} \tag{10}$$

In the last step, the importance degrees (W) of the criteria are computed by using Equations (11) and (12) (Dinçer et al., 2023a,b).

$$w_i = \sqrt{(R_i + C_i)^2 + (R_i - C_i)^2} \tag{11}$$

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{12}$$

The weights are also computed with Entropy model. In this process, firstly, expert opinions are obtained and converted into Pythagorean fuzzy numbers. The decision matrix (X) is formed by taking the average of the expert opinions (Huang et al., 2023). In this framework, Equations (13) and (14) are considered.

$$\boldsymbol{PFWA(P_1, P_2, \dots, P_n) = \left(\sqrt{1-\prod_{j=1}^{n}(1-\mu_j{}^2)^{\frac{1}{n}}}, \prod_{j=1}^{n} v_j^{\frac{1}{n}} \right)} \tag{13}$$

$$\boldsymbol{X = \begin{bmatrix} \mu_{11}, v_{11} & \cdots & \mu_{1n}, v_{1n} \\ \vdots & \ddots & \vdots \\ \mu_{m1}, v_{m2} & \cdots & \mu_{mn}, v_{mn} \end{bmatrix}} \tag{14}$$

The decision matrix is normalized with the help of Equation (15).

$$\boldsymbol{r_{ij} = \begin{cases} (\mu_{ij}, v_{ij}) \ \textit{for benefit criteria} \\ (v_{ij}, \mu_{ij}) \ \textit{for cost criteria} \end{cases}} \tag{15}$$

The entropy value of each criterion is calculated by Equation (16).

$$\boldsymbol{E_j = \frac{1}{(\sqrt{2}-1)m} \sum_{i=1}^{m} \left(sin\left(\frac{\pi}{4}\left(1+\mu_{ij}^2 - v_{ij}^2\right)\right) + sin\left(\frac{\pi}{4}\left(1-\mu_{ij}^2 + v_{ij}^2\right)\right) - 1 \right)} \tag{16}$$

Weight values (w) are calculated using entropy values (Jin et al., 2023). This situation is detailed in Equation (17).

$$w_j = \frac{1-E_j}{n - \sum_{j=1}^{n} E_j} \tag{17}$$

Secondly, alternatives are ranked with interval valued SF MAIRCA. In this process, $\tilde{a}_j = \langle [a_j, b_j], [c_j, d_j], [e_j, f_j] \rangle$ represents interval valued SF set. In Equation (18), the arithmetic value of these sets is computed.

$$IVSWAM(\tilde{a}_1, \tilde{a}_2, \ldots, \tilde{a}_n) = \left\{ \begin{array}{c} \left[\begin{array}{c} \left(1 - \prod_{j=1}^{n} \left(1 - a_j^2\right)^{\frac{1}{k}}\right)^{\frac{1}{2}}, \\ \left(1 - \prod_{j=1}^{n} \left(1 - b_j^2\right)^{\frac{1}{k}}\right)^{\frac{1}{2}} \end{array} \right], \\ \left[\prod_{j=1}^{n} c_j^{\frac{1}{k}}, \prod_{j=1}^{n} d_j^{\frac{1}{k}} \right], \\ \left[\begin{array}{c} \left(\prod_{j=1}^{n} \left(1 - a_j^2\right)^{\frac{1}{k}} - \prod_{j=1}^{n} \left(1 - a_j^2 - e_j^2\right)^{\frac{1}{k}} \right)^{\frac{1}{2}}, \\ \left(\prod_{j=1}^{n} \left(1 - b_j^2\right)^{\frac{1}{k}} - \prod_{j=1}^{n} \left(1 - b_j^2 - f_j^2\right)^{\frac{1}{k}} \right)^{\frac{1}{2}} \end{array} \right] \end{array} \right\} \tag{18}$$

The initial decision matrix (D) is calculated by Equation (19) using the matrices created by the evaluations of each expert.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{19}$$

The preference possibilities (P_{Ai}) are identified with Equation (20).

$$P_{Ai} = \frac{1}{m}; \sum_{i=1}^{m} P_{Ai} = 1 \tag{20}$$

Theoretical rating matrix (TPA) is constructed by multiplying P_{Ai} with the weights computed by ST-PFN DEMATEL as in Equation (21).

$$K_p = \begin{bmatrix} k_{p11} & \cdots & k_{p1n} \\ \vdots & \ddots & \vdots \\ k_{pm1} & \cdots & k_{pmn} \end{bmatrix} = \begin{bmatrix} P_{A1}w_1 & \cdots & P_{A1}w_n \\ \vdots & \ddots & \vdots \\ P_{Am}w_1 & \cdots & P_{Am}w_n \end{bmatrix} \tag{21}$$

Score functions are computed in the following stage by Equation (22).

$$S(\tilde{x}_{ij}) = \frac{a^2 + b^2 - c^2 - d^2 - \left(\frac{e}{2}\right)^2 - \left(\frac{f}{2}\right)^2}{2} + 1 \tag{22}$$

The score values in the decision matrix for each criterion are normalized by Equations (23) and (24).

$$\left(\frac{S(\tilde{x}_{ij}) - \min\left(S(\tilde{x}_{ij})\right)}{\max\left(S(\tilde{x}_{ij})\right) - \min\left(S(\tilde{x}_{ij})\right)} \right) \text{ if x is a benefit factor} \tag{23}$$

$$\left(\frac{S(\tilde{x}_{ij}) - \max\left(S(\tilde{x}_{ij})\right)}{\min\left(S(\tilde{x}_{ij})\right) - \max\left(S(\tilde{x}_{ij})\right)} \right) \text{ if x is a cost factor} \tag{24}$$

Real rating matrix (Kr) is computed by Equations (25) and (26).

$$k_{rij} = k_{pij} \left(\frac{S(\tilde{x}_{ij}) - \min\left(S(\tilde{x}_{ij})\right)}{\max\left(S(\tilde{x}_{ij})\right) - \min\left(S(\tilde{x}_{ij})\right)} \right) \text{ if x is a benefit factor} \tag{25}$$

$$k_{rij} = k_{pij} \left(\frac{S(\tilde{x}_{ij}) - \max\left(S(\tilde{x}_{ij})\right)}{\min\left(S(\tilde{x}_{ij})\right) - \max\left(S(\tilde{x}_{ij})\right)} \right) \text{ if x is a cost factor} \tag{26}$$

In the following stage, gap matrix (G) is identified by the help of Equation (27).

$$G = K_p - K_r = \begin{bmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mn} \end{bmatrix} \tag{27}$$

The final values (Q) for the criteria are calculated by Equation (28).

$$Q_i = \sum_{j=1}^{n} g_{ij} \quad i = 1, 2, \ldots, n \tag{28}$$

According to the final values obtained from the criterion functions, alternatives are listed and the best one is selected. The alternative with the lowest gap distance is selected as the best, while the alternative with the highest gap distance is considered the worst. A comparative evaluation is also performed with SF ARAS. The decision matrix (A) is formed by averaging these evaluations with Equation (29) (Fan et al., 2023).

$$SWAM(A_{s1}, A_{s2}, \ldots, A_{Sn}) = \left\{ \left[1 - \prod_{i=1}^{n} \left(1 - \mu_{A_{si}}^2\right)^{1/n} \right]^{1/2}, \prod_{i=1}^{n} v_{A_{si}}^{1/n}, \left[\prod_{i=1}^{n} \left(1 - \mu_{A_{si}}^2\right)^{1/n} - \prod_{i=1}^{n} \left(1 - \mu_{A_{si}}^2 - \pi_{A_{si}}^2\right)^{1/n} \right]^{1/2} \right\}$$

$$A = \begin{bmatrix} (\mu_{11}, v_{11}\pi_{11}) & \cdots & (\mu_{m1}, v_{m1}, \pi_{m1}) \\ \vdots & \ddots & \vdots \\ (\mu_{1n}, v_{1n}, \pi_{1n}) & \cdots & (\mu_{mn}, v_{mn}, \pi_{1mn}) \end{bmatrix}$$

The values in this matrix are multiplied by the criteria weights (w) as in Equations (30) and (31) to obtain the weighted decision matrix (X). Multiplying the spherical fuzzy number by a fixed real number is written by Equation (31) where lambda is a positive real number and A is a spherical fuzzy number.

$$X = w.A \tag{30}$$

$$\tilde{A}_s = \left\{ \left(1 - \left(1 - \mu_{A_s}^2\right)^{\lambda}\right)^{\frac{1}{2}}, v_{A_s}^{\lambda}, \left(\left(1 - \mu_{A_s}^2\right)^{\lambda} - \left(1 - \mu_{A_s}^2 - \pi_{A_s}^2\right)^{\lambda}\right)^{2} \right\} \tag{31}$$

In the next step, optimal values are determined for each criterion. For the benefit criteria, the highest value is considered the optimal value. On the other hand, for the cost criteria, the smallest value is considered the optimal value. In spherical fuzzy numbers, the larger of these two numbers is determined over the score and accuracy values. In this framework, the number with a large score value is calculated as large. In addition, if the score values are equal, the number with the greater accuracy value is considered large (Zhu et al., 2023). These details are given in Equations (32) and (33).

$$Score = (\mu - \pi)^2 - (v - \pi)^2 \tag{32}$$

$$Accuracy = \mu^2 + v^2 + \pi^2 \tag{33}$$

The spherical fuzzy optimality function value is calculated by summing the optimal values and alternatives on the basis of criteria by Equation (34).

$$\tilde{S}_{Si} = \sum_{i=1}^{m} ((\mu_1, v_1, \pi_1) + (\mu_2, v_2, \pi_2) + \ldots + (\mu_m, v_m, \pi_m)) \tag{34}$$

These values are defuzzified with the help of score and accuracy functions. Using Equation (35), utility degree (Ki) is calculated by dividing the sums of the alternatives by the sum of the optimal value.

$$K_i = \frac{S_i}{S_0} \tag{35}$$

In this process, the alternative with a high Ki value is considered the best alternative. Fig. 1 denotes the details of the proposed model.

4. Analysis results

This part consists of two different sections that are criteria weighting and alternative ranking.

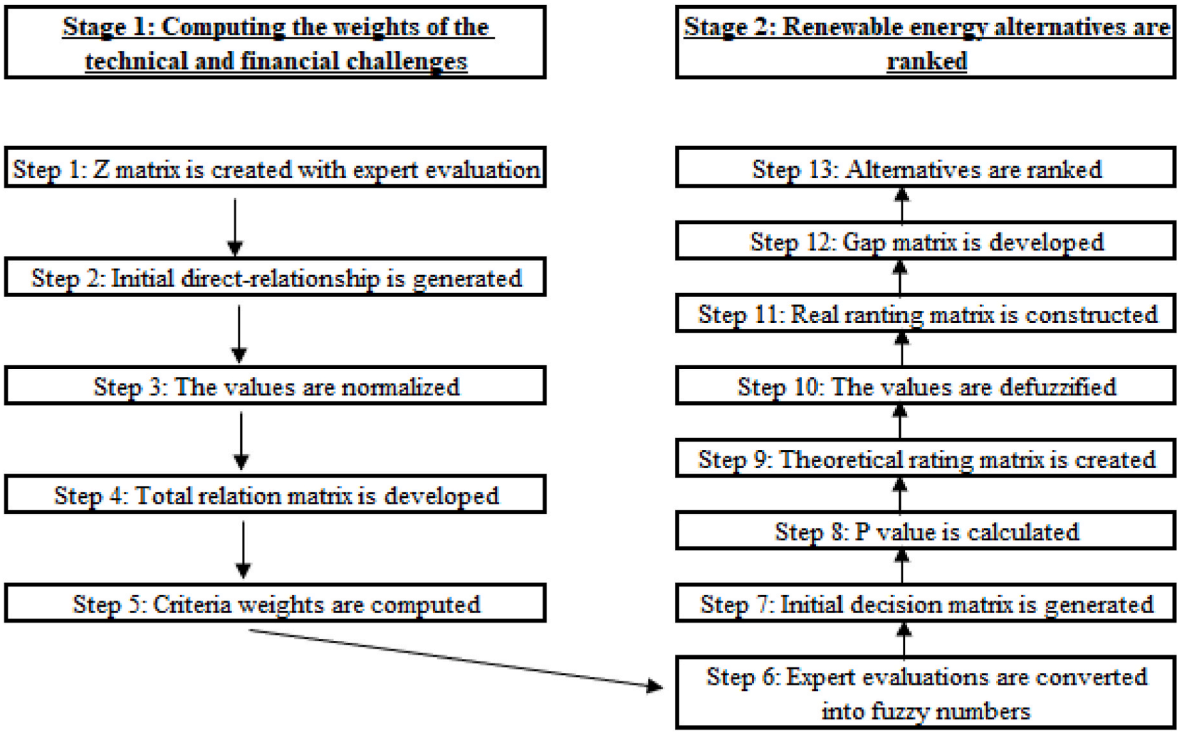

Fig. 1. Model.

4.1. Computing the weights of the technical and financial challenges

Firstly, a set of technical and financial challenges is created by considering the results of the literature evaluation. These factors are explained in Table 1.

After identifying the set of technical and financial challenges for renewable energy projects, expert opinions are collected from three people. The first and second experts are academicians that have lots of essential publications regarding renewable energy investments. The third expert is the general manager of an international renewable energy company. In this framework, 30 different questions are created by comparing six criteria with each other. After that, online meetings are conducted with these experts. In these meetings, these people made evaluations by using the scales stated in Table A2 while answering these questions. The evaluations for the criteria are shown in Table A3 in the appendix part. After that, Z matrix is obtained with the help of Equation (2) (Table A4). After that, the initial direct relationship matrix (A) is obtained with the help of Equation (5) (Table A5). Moreover, this matrix is normalized by Equation (6) (Table A6). Furthermore, the total relationship matrix is calculated with the help of Equation (8) (Table A7). In the last step, row and column totals are obtained using Equations (9) and (10). Criteria weights are calculated using Equations (11) and (12) over these values. The weights of the challenges are illustrated in Fig. 2.

It is concluded that difficulty in accessing finance for local projects is the most significant challenge for renewable energy investments. Moreover, competitive pricing of renewable sources is another critical issue in this regard. However, the weights of manufacturing defects of renewable equipment and design issues of the project installation are much lower than other challenges. A comparative analysis is also performed by using Entropy methodology. The results are demonstrated in Fig. 3.

Fig. 3 explains that the results of both two methods are quite similar. Hence, this situation gives information about the reliability and coherency of the findings.

Table 1
Technical and financial challenges.

Challenges	Literature
Manufacturing defects of renewable equipment (MDRE)	Wang et al. (2023)
Instability of natural resources (IONR)	Ghiara et al. (2023)
Design issues of the project installation (DIPI)	Zhang et al. (2023)
Difficulty in accessing finance for local projects (DFLP)	Liang et al. (2022)
Uncertainty of project income for the long-term (UPIL)	Dogan et al. (2022)
Competitive pricing of renewable sources (CPRS)	Dinçer et al. (2023)

4.2. Ranking renewable energy project alternatives

In the second part of the proposed model, renewable energy alternatives are ranked according to their success in overcoming the technical and financial challenges they face. For this purpose, six different renewable energy types are defined as wind, solar, hydro, geothermal, biomass and wave. The evaluations with respect to the alternatives are obtained from the expert team as stated in Table A8. After that, they are converted to the fuzzy numbers by considering the values given in Table 2.

Furthermore, using Equation (18), expert opinions are averaged, and the initial decision matrix (D) is obtained (Table A9). After that, the P value is calculated as 0.17 with the help of Equation (20). Next, TPA matrix is constructed while considering Equation (21) (Table A10). In the following stages, these values are defuzzified by Equation (22) (Table A11). Real rating matrix (Kr) is computed by Equations (25) and (26) (Table A12). After that, Equation (27) is considered to create gap matrix (Table A13). Finally, the Q values are calculated by summing the rows of the gap matrix. Table A14 gives information about the Q values. Minimum Q values refer to the best alternatives. In this framework, Fig. 4 demonstrates the details of alternative ranking.

It is identified that that solar is the most successful renewable energy alternative to overcome technical and financial challenges. Wind and biomass are other significant energy types in this respect. However, it is also seen that these challenges have higher negative influence on hydro and wave. These alternatives are also ranked with the ARAS methodology. The comparative ranking results are denoted in Fig. 5.

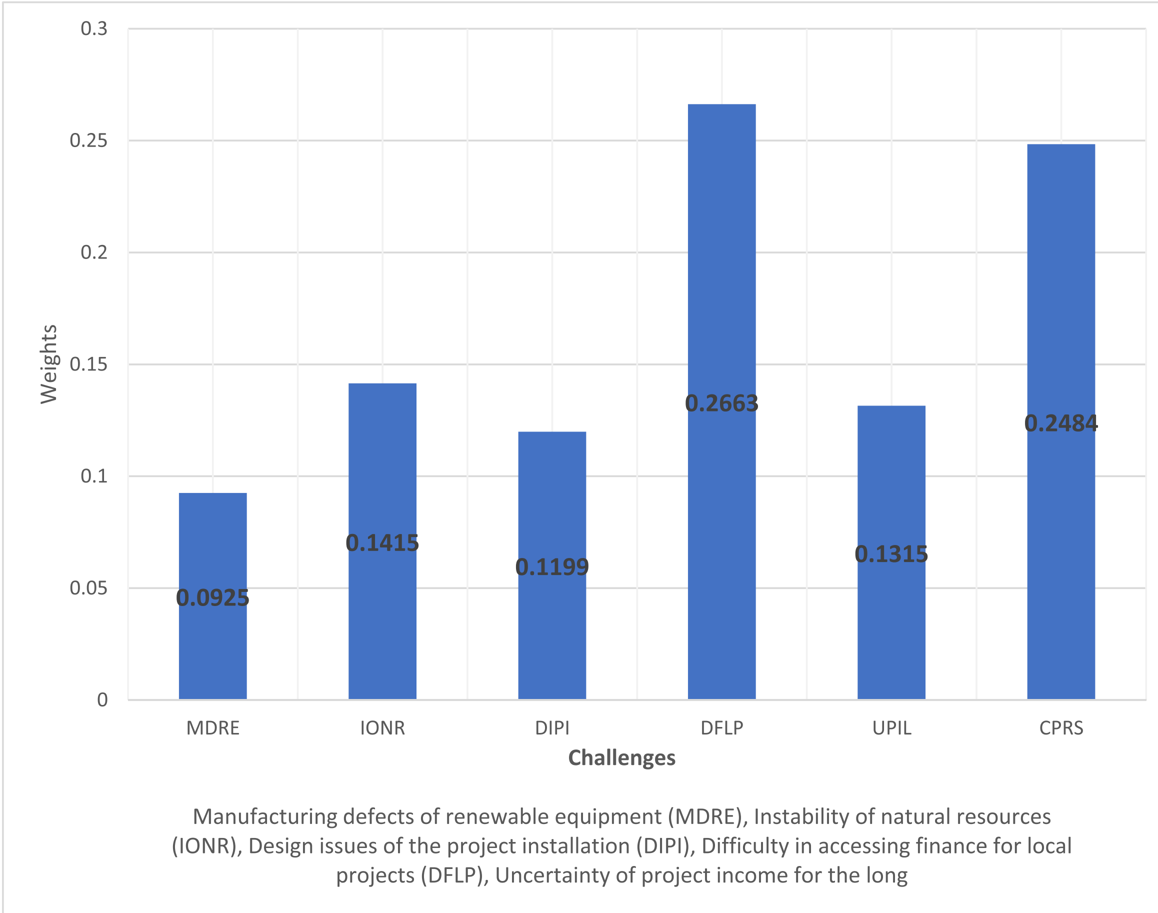

Fig. 2. Weights.

Fig. 5 demonstrates that the results of both MAIRCA and ARAS are quite similar. This condition indicates that the proposed model provides consistent results. Similarly, sensitivity analysis is also conducted for 10 different cases. The results are presented in Fig. 6.

Fig. 6 indicates that the results are almost the same for 10 different cases. Thus, it is understood that the proposed model gives coherent and reliable findings.

5. Discussions

In this study, the determination of the technical and financial problems experienced in generating renewable energy projects according to the degree of importance has been analyzed. Subsequently, it has been specifically tried to determine which renewable energy alternative can be managed more efficiently in these difficulties under current conditions. Based on the research findings, difficulty in accessing finance for local projects is identified as the most significant barrier to the development of these projects. Due to the lengthy duration and long-term economic/financial return, financial institutions are unwilling to fund these initiatives. As financing these projects is the greatest challenge, the state should provide short-term support for these funds, such as tax breaks and incentives. Further, innovative financial products should be developed for the long term. Otherwise, government support will not be permanent, and these project investments will not be able to sustain themselves. Moreover, when the second-most significant factor (competitive pricing of renewable sources) is also taken into consideration, both the energy and the production process must be priced competitively.

Financing renewable energy projects is of great importance to reduce the negative health effects of carbon emissions, develop nature-compatible infrastructure for cities and ensure sustainability (Li et al., 2022). However, renewable energy projects face two main obstacles that are a lower short-term rate of return compared to conventional energy projects and a higher investment risk for institutional reasons. Due to these factors, financial institutions may be reluctant to invest in these projects (Taghizadeh-Hesary et al., 2020). In this regard, supplying funding for renewable energies is a crucial issue that facilitates and accelerates the transition to eco-friendly energy. As Jackson and Jackson (2021) specified that decreases in the energy return on investment due to technological transition can increase the risks by causing energy prices to rise and economic growth to lower. Moreover, Yoshino et al. (2019) remarked that the initial rate of return for private investors in local projects is notably low and requires a significant amount of time to increase, and accordingly, they instructed the implementation of government incentives, such as subsidies and tax reductions, to stimulate sustainability of investments.

In the subsequent phase of the research, it has been determined that the most efficient one in coping with financial difficulties, considering today's developments, is solar energy and right after wind energy. Thorough research and development investigations are conducted pertaining to the production of solar and wind energies (Ma et al., 2021). In this context, advancements and breakthroughs in technology have resulted in heightened levels of production efficiency for these forms of energy, while simultaneously decreasing associated costs. Hence, technical and financial problems can be managed relatively more economically (Wu, 2023). Also, Kyriakarakos and Dounis (2020) found out that solar energy systems have always been crucial to green building development, therefore proper application of these sources, such as solar

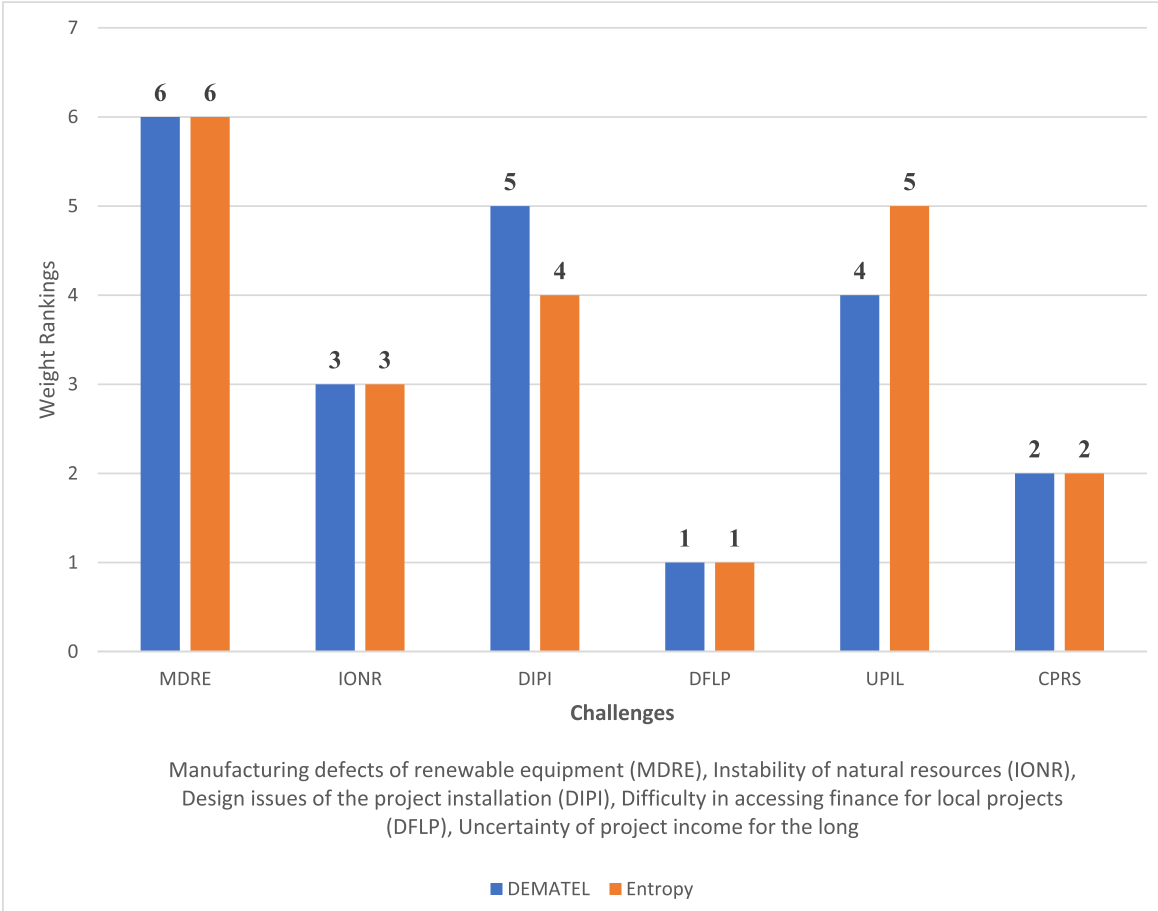

Fig. 3. Comparative weighting results.

Table 2
Scales and fuzzy values.

	a	b	c	d	e	f
1	.1	.15	.85	.95	.05	.15
2	.15	.2	.75	.85	.15	.2
3	.2	.25	.65	.75	.2	.25
4	.25	.3	.55	.65	.15	.3
5	.5	.55	.45	.55	.3	.4
6	.55	.65	.25	.3	.25	.3
7	.65	.75	.2	.25	.2	.25
8	.75	.85	.15	.2	.15	.2
9	.85	.95	.1	.15	.05	.15

projects are a key energy efficiency criterion. Additionally, researching the link between these investments and sustainable development, He et al. (2023), Kozlova and Overland (2022), Taghizadeh-Hesary and Yoshino (2020) stated that financing solar energy investments through green bonds is the best strategy to ensure sustainability.

Consequently, public-private financial collaborations should be encouraged to expand renewable energy investment opportunities by using green finance instruments such as green bonds and crowdfunding for financial efficiency (Alsagr, 2023). Further, the reduction of economic inequalities has also the potential to foster environmental awareness by alleviating financial concerns among individuals and a facilitating effect on the increase of local renewable energy investments. It is recommended that governments provide support for investments in renewable energy through tax incentives and credit opportunities. As the provision of subsidies and other incentives for carbon reduction technology will lead to an increase in the proportion of, specifically solar and wind investments in energy.

The proposed model also has some methodological superiorities by comparing with the previously generated ones. For instance, considering DEMATEL to weight the items provides some benefits. The main reason is that the causality relationship between these factors is taken into consideration by identifying the significance of the items (Khatun et al., 2023). Technical and financial difficulties in renewable energy projects are also factors that have an impact on each other. In other words, improvements to one difficulty can also help solve problems related to other difficulties (Vern et al., 2023). In this context, it would be appropriate to consider this causality relationship in determining the most important difficulties. However, in some previous decision-making models, the cause-and-effect directions among the items are not considered while computing the weights (Ghaderi et al., 2023; Lin et al., 2023). Therefore, it is thought that the analysis made with the DEMATEL method will produce more realistic results.

Furthermore, using MAIRCA to rank the alternatives also increases the quality of the proposed model. Compared to other methods, MAIRCA method generates theoretical value with uniform statistical distribution (Haq et al., 2023). By comparing expert opinions with this, it obtains the most optimal value. Methods such as TOPSIS and VIKOR take the optimal value based on the maximum and minimum values of the same experts (Paul et al., 2023; Deveci et al., 2023). The fact that the theoretical value, that is, the base value, is objective in MAIRCA shows the superiority and universality of the method. Competition in renewable energy projects is very high. In this context, the dynamics of this market can constantly change in proportion to the speed of technology. Therefore, it would be more appropriate to take the theoretical evaluation part based on the comparisons from a universal pattern rather than

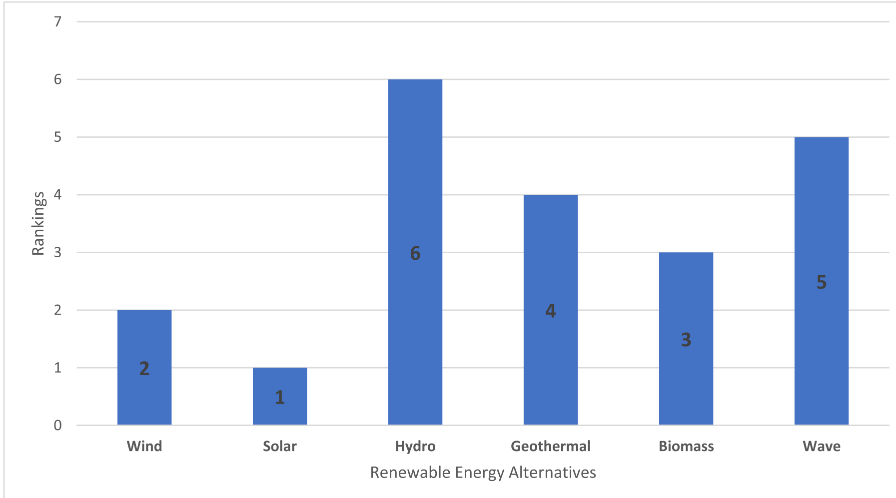

Fig. 4. Alternative ranking.

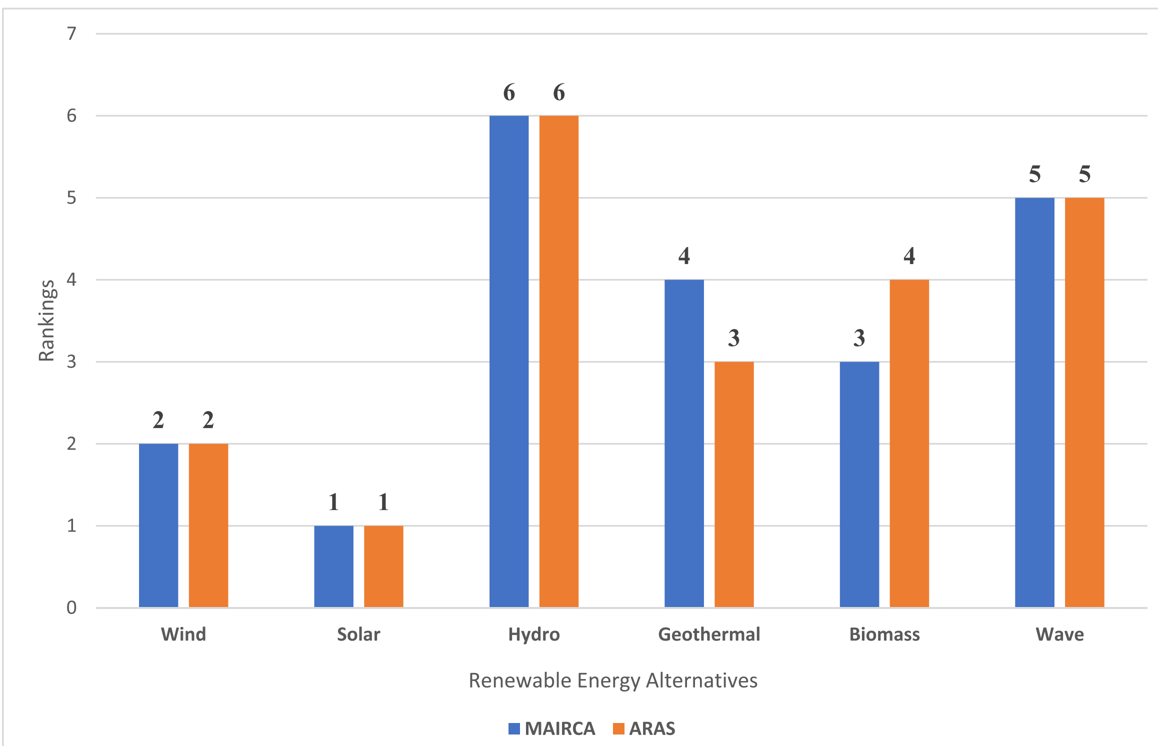

Fig. 5. Comparative ranking results.

expert opinions. This will allow the analysis results to produce solutions in the longer term. In this context, MAIRCA method is thought to be more suitable for the subject analyzed in the study.

6. Conclusions

In this study, it is aimed to evaluate technical and financial challenges for renewable energy project alternatives with a novel model. Firstly, a set of technical and financial challenges is created by considering the results of the literature evaluation. After that, the weights of these values are computed by Sine Trigonometric Pythagorean Fuzzy (ST-PFN) DEMATEL. The next step includes the ranking of six renewable energy alternatives with interval valued Spherical fuzzy multicriteria analysis with ratio and categorical data (SF MAIRCA) approach. Entropy and ARAS methodology are also considered to make comparative evaluation. Similarly, sensitivity analysis is also conducted for 10 different cases. The findings of this study demonstrate that difficulty in accessing finance for local projects is the most significant challenge for renewable energy investments. Furthermore, competitive pricing of renewable sources is another critical issue in this regard. In addition, it is determined that solar is the most successful renewable energy alternative to overcome technical and financial challenges. Wind and biomass are other significant energy types in this respect. However, it is also seen that these challenges have higher negative influence on hydro and wave.

The main contribution of this study is the integration of the sine trigonometric structure with the fuzzy decision-making methodology. With the help of this situation, defuzzification process can be conducted in a more effective manner. This situation helps to reach more

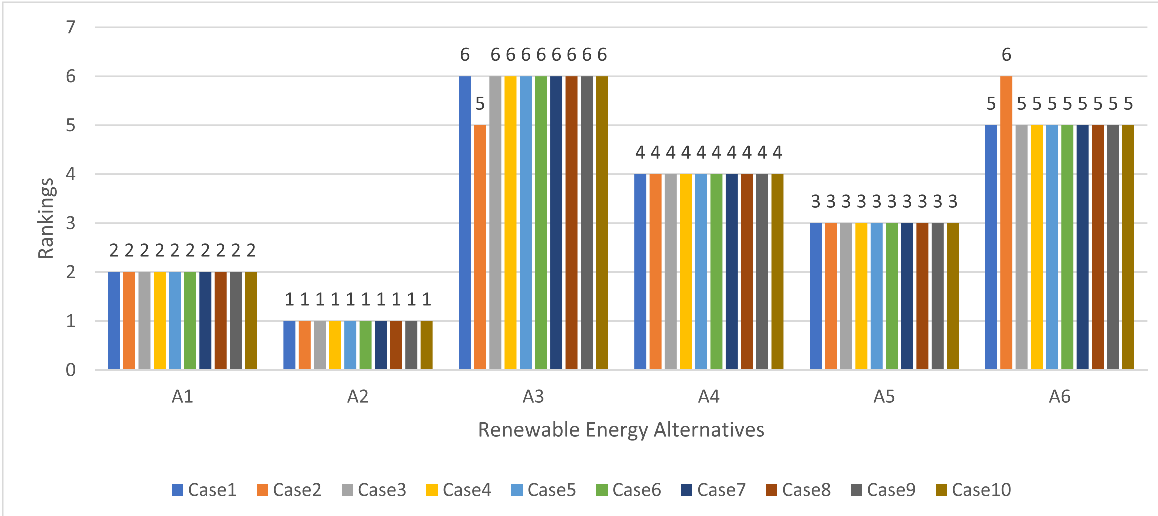

Fig. 6. Sensitivity analysis results.

appropriate results. In addition to this issue, identification of the most crucial technical and financial challenges of the renewable energy projects is also another contribution of this manuscript. These challenges must be minimized to improve the renewable energy projects. However, it is not very possible in terms of financial efficiency to take every single measure together because these implementations lead to high costs. Due to this situation, companies should give priority to the most critical items. The findings of the manuscript can pave the way for both investors and policy makers for their strategic decisions. The results indicate that countries should give importance to improve their financial systems for the developments of the renewable energy projects.

The main limitation of this study is that only technical and financial challenges are taken into consideration. However, political challenges can have a strong influence on the performance of renewable energy projects. Hence, for future research directions, these issues can be evaluated. Moreover, in this study, a general evaluation is conducted. However, the results can be changed for different geographies. Because of this issue, in the next studies, a specific country groups can be taken into consideration. Another critical limitation of this study is that sine trigonometric structure is integrated into only Pythagorean fuzzy sets. In the following studies, this structure can also be used with Spherical fuzzy sets. Owing to considering a wider range, this situation helps to reach more appropriate findings in complex situations. On the other side, in this proposed model, the weights of the expert evaluations are assumed as equal. However, these people may have different qualification. This situation can also be accepted another significant limitation of the proposed model. Hence, in the following decision-making models, the importance weights of the experts can also be computed. This situation has a powerful contribution to the appropriateness of the findings.

CRediT authorship contribution statement

Serkan Eti: Conceptualization. **Serhat Yüksel:** Data curation. **Hasan Dinçer:** Formal analysis. **Hakan Kalkavan:** Investigation. **Umit Hacioglu:** Methodology. **Alexey Mikhaylov:** Writing – review & editing, Writing – original draft. **Mir Sayed Shah Danish:** Software. **Gabor Pinter:** Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

TABLE A1
Literature Review Results

Studies	Results
Zhang et al. (2022) Kong et al. (2022) Mourad et al. (2023) Liao et al. (2022) Zheng et al. (2023)	The manufacturing defects of renewable equipment present some difficulties in the development of renewable energy projects.
Liang et al. (2022) Adebayo (2022) Yang et al. (2022) Sohail et al. (2022) Yu et al. (2022)	The instability of natural resources is a critical challenge in the development of renewable energy projects.
Ahmed et al. (2022) Tomin et al. (2022) Lee et al. (2022) Marocco et al. (2022)	Design issues of the project installation should be taken into consideration to improve renewable energy projects.

(continued on next page)

TABLE A1 (*continued*)

Studies	Results
Mikhaylov (2023) Mukhtarov et al. (2022) Yasmeen et al. (2022) Rasoulinezhad and Taghizadeh-Hesary (2022) Dogan et al. (2022)	The lack of financial resources is a significant challenge of renewable energy projects.
Shang et al. (2022) Mikhaylov (2022) Yan et al. (2022) Abbas et al. (2023) Tan et al. (2022)	Uncertainties in project revenues is an important risk in the development of renewable energy investments.
Borzuei et al. (2022) Razi and Dincer (2022) Osman et al. (2023) Meng et al. (2022) Dinçer et al. (2023)	Price uncertainties can pose several challenges in the development of renewable energy projects.

TABLE A2
Scales for Weighting

Linguistic Term	Abb	Score	PFNs		ST-PFNs	
			μ	v	$\sin\left(\frac{\pi}{2}\mu_P\right)$	$\sqrt{1-\sin^2\left(\frac{\pi}{2}\sqrt{1-v_P^2}\right)}$
Very Low	VL	1	.15	.85	.2334	.5136
Moderately	M	2	.35	.65	.5225	.2651
High	H	3	.65	.35	.8526	.0702
Very High	VH	4	.85	.15	.9724	.0126

TABLE A3
Expert opinions for the challenges

Expert 1						
	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
MDRE	0	2	2	1	2	1
IONR	2	0	2	1	3	2
DIPI	2	3	0	1	1	1
DFLP	4	4	4	0	4	4
UPIL	1	1	2	1	0	1
CPRS	4	4	3	3	4	0
Expert 2						
	MDRE	**IONR**	**DIPI**	**DFLP**	**UPIL**	**CPRS**
MDRE	0	1	3	1	1	1
IONR	1	0	2	1	2	1
DIPI	2	2	0	1	1	1
DFLP	4	4	4	0	4	3
UPIL	1	2	1	2	0	1
CPRS	4	3	3	3	4	0
Expert 3						
	MDRE	**IONR**	**DIPI**	**DFLP**	**UPIL**	**CPRS**
MDRE	0	2	1	1	2	1
IONR	2	0	2	1	3	2
DIPI	1	2	0	2	1	1
DFLP	4	4	3	0	4	4
UPIL	1	2	1	2	0	1
CPRS	3	4	3	4	3	0

TABLE A4
Z Matrix

	MDRE		IONR		DIPI		DFLP		UPIL		CPRS	
MDRE	.0000	.0000	.4544	.3305	.6538	.2122	.2334	.5136	.4544	.3305	.2334	.5136
IONR	.4544	.3305	.0000	.0000	.5225	.2651	.2334	.5136	.7884	.1093	.4544	.3305
DIPI	.4544	.3305	.6896	.1702	.0000	.0000	.3658	.4120	.2334	.5136	.2334	.5136
DFLP	.9724	.0126	.9724	.0126	.9522	.0223	.0000	.0000	.9724	.0126	.9522	.0223
UPIL	.2334	.5136	.4544	.3305	.3658	.4120	.4544	.3305	.0000	.0000	.2334	.5136
CPRS	.9522	.0223	.9522	.0223	.8526	.0702	.9168	.0396	.9522	.0223	.0000	.0000

TABLE A5
Initial Direct Relationship Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
MDRE	.0000	.0972	.3824	−.2093	.0972	−.2093
IONR	.0972	.0000	.2027	−.2093	.6096	.0972
DIPI	.0972	.4465	.0000	−.0359	−.2093	−.2093
DFLP	.9453	.9453	.9063	.0000	.9453	.9063
UPIL	−.2093	.0972	−.0359	.0972	.0000	−.2093
CPRS	.9063	.9063	.7221	.8389	.9063	.0000

TABLE A6
Normalized Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
MDRE	.0000	.0209	.0823	−.0450	.0209	−.0450
IONR	.0209	.0000	.0436	−.0450	.1311	.0209
DIPI	.0209	.0961	.0000	−.0077	−.0450	−.0450
DFLP	.2034	.2034	.1950	.0000	.2034	.1950
UPIL	−.0450	.0209	−.0077	.0209	.0000	−.0450
CPRS	.1950	.1950	.1553	.1805	.1950	.0000

TABLE A7
Total Relation Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
MDRE	−.0208	.0039	.0611	−.0552	−.0042	−.0573
IONR	.0086	−.0014	.0359	−.0421	.1220	.0052
DIPI	.0114	.0815	−.0063	−.0211	−.0470	−.0455
DFLP	.2375	.2734	.2527	.0111	.2680	.1687
UPIL	−.0493	.0141	−.0141	.0156	−.0029	−.0387
CPRS	.2276	.2602	.2161	.1633	.2584	.0057

TABLE A8
Expert opinions for the alternatives

Expert 1						
	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Wind	6	6	7	6	7	6
Solar	7	7	7	7	7	7
Hydro	2	3	2	1	2	2
Geothermal	3	1	3	2	1	3
Biomass	2	3	1	2	2	2
Wave	3	2	3	1	1	1
Expert 2						
	MDRE	**IONR**	**DIPI**	**DFLP**	**UPIL**	**CPRS**
Wind	6	5	7	6	5	5
Solar	6	7	7	7	6	7
Hydro	1	2	2	1	1	2
Geothermal	3	1	2	1	1	2
Biomass	2	2	1	1	2	2
Wave	2	2	1	1	2	1

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TABLE A8 (*continued*)

Expert 1	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Expert 3	**MDRE**	**IONR**	**DIPI**	**DFLP**	**UPIL**	**CPRS**
Wind	5	6	6	7	5	5
Solar	7	7	6	7	6	7
Hydro	3	1	1	2	3	1
Geothermal	2	2	3	2	2	2
Biomass	2	3	1	3	3	2
Wave	2	3	2	3	2	1

TABLE A9
D Matrix

	MDRE						IONR						DIPI					
	a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
Wind	.53	.62	.30	.37	.27	.33	.53	.62	.30	.37	.27	.33	.62	.72	.22	.27	.22	.27
Solar	.62	.72	.22	.27	.22	.27	.65	.75	.20	.25	.20	.25	.62	.72	.22	.27	.22	.27
Hydro	.16	.20	.75	.85	.15	.21	.16	.20	.75	.85	.15	.21	.14	.18	.78	.88	.13	.19
Geothermal	.18	.23	.68	.78	.19	.23	.12	.17	.82	.92	.10	.17	.18	.23	.68	.78	.19	.23
Biomass	.15	.20	.75	.85	.15	.20	.18	.23	.68	.78	.19	.23	.10	.15	.85	.95	.05	.15
Wave	.17	.22	.72	.82	.17	.22	.17	.22	.72	.82	.17	.22	.16	.20	.75	.85	.15	.21
	DFLP						**UPIL**						**CPRS**					
	a	**b**	**c**	**d**	**e**	**f**	**a**	**b**	**c**	**d**	**e**	**f**	**a**	**b**	**c**	**d**	**e**	**f**
Wind	.59	.69	.23	.28	.23	.28	.56	.63	.34	.42	.27	.35	.52	.59	.37	.45	.28	.37
Solar	.65	.75	.20	.25	.20	.25	.59	.69	.23	.28	.23	.28	.65	.75	.20	.25	.20	.25
Hydro	.12	.17	.82	.92	.10	.17	.16	.20	.75	.85	.15	.21	.14	.18	.78	.88	.13	.19
Geothermal	.14	.18	.78	.88	.13	.19	.12	.17	.82	.92	.10	.17	.17	.22	.72	.82	.17	.22
Biomass	.16	.20	.75	.85	.15	.21	.17	.22	.72	.82	.17	.22	.15	.20	.75	.85	.15	.20
Wave	.14	.19	.78	.88	.12	.19	.14	.18	.78	.88	.13	.19	.10	.15	.85	.95	.05	.15

TABLE A10
TPA Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Wind	.015	.024	.020	.044	.022	.041
Solar	.015	.024	.020	.044	.022	.041
Hydro	.015	.024	.020	.044	.022	.041
Geothermal	.015	.024	.020	.044	.022	.041
Biomass	.015	.024	.020	.044	.022	.041
Wave	.015	.024	.020	.044	.022	.041

TABLE A11
Defuzzified Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Wind	1.1987	1.1987	1.3794	1.3258	1.1854	1.1102
Solar	1.3794	1.4284	1.3794	1.4284	1.3258	1.4284
Hydro	.3892	.3892	.3252	.2652	.3892	.3252
Geothermal	.4953	.2652	.4953	.3252	.2652	.4405
Biomass	.3809	.4953	.2006	.3892	.4405	.3809
Wave	.4405	.4405	.3892	.3340	.3252	.2006

TABLE A12
Real Rental Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Wind	.0126	.0189	.0200	.0405	.0190	.0307
Solar	.0154	.0236	.0200	.0444	.0219	.0414
Hydro	.0001	.0025	.0021	.0000	.0026	.0042

(*continued on next page*)

TABLE A12 (*continued*)

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Geothermal	.0018	.0000	.0050	.0023	.0000	.0081
Biomass	.0000	.0047	.0000	.0047	.0036	.0061
Wave	.0009	.0036	.0032	.0026	.0012	.0000

TABLE A13
Gap Matrix

	MDRE	IONR	DIPI	DFLP	UPIL	CPRS
Wind	.0028	.0047	.0000	.0039	.0029	.0107
Solar	.0000	.0000	.0000	.0000	.0000	.0000
Hydro	.0153	.0211	.0179	.0444	.0194	.0372
Geothermal	.0136	.0236	.0150	.0421	.0219	.0333
Biomass	.0154	.0189	.0200	.0397	.0183	.0353
Wave	.0145	.0200	.0168	.0418	.0207	.0414

TABLE A14
Q values

Alternatives	Q values
Wind	.0250
Solar	.0000
Hydro	.1552
Geothermal	.1495
Biomass	.1476
Wave	.1551

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