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Multidimensional assessment of the European Energy Union: Integrating artificial intelligence and quantum fuzzy ranking approaches

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HIGHLIGHTS

- proposed a novel artificial intelligence(AI)-based ranking methodology.
- integrated AI and fuzzy decision-making methodology.
- weights are determined depending on this classification.
- AI-based ranking is made based on the linguistic evaluations of experts
- used AI-based model to select the important dimensions for the European Energy Union

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ABSTRACT

The purpose of this study is to determine the significant indicators of European Energy Union policy. A novel artificial intelligence (AI)-enhanced and hybrid quantum fuzzy ranking approach are taken into consideration in this regard. There are three different stages in this hybrid model. The first stage includes the weighting the dimensions of the European energy union with AI-enhanced prioritization. The second stage consists of measuring the multidimensional performance for European energy union with artificial intelligence-enhanced ranking. In the final stage, the multidimensional performance for European energy union is evaluated by using quantum picture fuzzy rough sets based VIKOR methodology. The main contribution of this study is making a comparative evaluation with both artificial intelligence approach and fuzzy decision-making methodology. This situation provides an opportunity check the validity of the findings. In the analysis process, a novel artificial intelligence-based ranking methodology is proposed. Therefore, more effective evaluations can be conducted. The findings indicate that energy security, market functioning, and innovation have the best priorities. In case of maximum group utility, financial feasibility and technological infrastructure have the best ranking performance among the perspectives. The results with the highest maximum group utility are same with the priority results of the AI-enhanced ranking technique.

1. Introduction

Energy Union refers to the strategies developed by the European Union to have more sustainable and safe energy policies. These strategies focus primarily on the security of energy supply. In this context, it is aimed to reach more energy sources by diversifying energy supply. In this way, there will be no energy supply problem in the event of a possible global crisis. Similarly, a possible sudden increase in energy demands can be responded to more easily. This situation allows the energy supply-demand balance to be achieved more successfully. Additionally, the European Union aims to increase energy efficiency with these strategies [1]. In this context, some measures are taken to

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reduce unnecessary energy consumption. This will significantly reduce the costs of businesses. Thus, long-term sustainability of projects is possible. Moreover, by ensuring energy efficiency, less energy can be consumed. This situation allows natural resources to be consumed less. Green energy is another important consideration in Energy Union strategies. In this context, the aim is to transition to sustainable energy sources through the use of renewable energy [2]. This situation supports the significant reduction of carbon emissions. On the other hand, the European Union focuses on increasing renewable energy technologies with these policies. Within this framework, the development of research and innovation on the subject is encouraged. This issue contributes to reducing costs in renewable energy projects. Thus, it becomes much more possible to develop clean energy projects.

Many criteria have been determined by the European Union in Energy Union policies. Financial feasibility is extremely important for this process to be successful. High initial costs are one of the most important disadvantages of energy projects. That's why businesses need to find high amounts of funding. Therefore, for these projects to be implemented, they must be financially feasible. In this way, they will be able to attract the attention of international financial institutions more easily [3]. Ensuring customer satisfaction is also important for the European Energy Union to be successful. Energy costs are a matter of great importance to customers. In this context, high costs lead to significant customer dissatisfaction. Security of energy supply is another important issue for customers. In this context, experiencing power outages will make customers seriously unhappy. Organizational effectiveness is another factor necessary for the success of these projects [4]. An effective organization allows limited resources to be used in the most efficient way. Thus, it is possible to ensure the cost effectiveness of the projects. Technological development also plays an important role in the success of the European Energy Union. Energy efficiency can be achieved thanks to technological innovations. Similarly, energy storage processes can be implemented more effectively thanks to advanced technologies. This situation allows the development of renewable energy projects.

These criteria generally aim to use energy more effectively and efficiently by countries. However, the application of these criteria also leads to significant increases in financial costs. For example, renewable energy investments need to be increased to implement decarbonization policies. Since the initial investment costs of these projects are very high, a large amount of financial resources is needed to put these projects into operation [5]. Similarly, increasing research studies and ensuring innovation are other goals of these policies. However, to achieve this goal, countries need to allocate very high budgets. In summary, a large amount of financial resources are needed to realize Energy Union policies [6]. Therefore, taking action against too many criteria will put countries in a difficult financial situation. Therefore, instead of focusing on too many variables at the same time, it would be appropriate for countries to prioritize issues that are more important. Therefore, a priority analysis is needed to determine the more important among these factors [7]. Owing to this analysis, effective strategies can be identified to implement these policies without having high costs. This situation has a powerful contribution to use the resources more efficiently.

Accordingly, this study aims to identify the critical determinants of European Energy Union policy. A novel artificial intelligence-enhanced and hybrid quantum fuzzy ranking approach are considered to reach this objective. The hybrid model has three different stages. The first stage is related to the weighting the dimensions of the European energy union with AI-enhanced prioritization. Moreover, the second stage of the proposed model includes measuring the multidimensional performance for European energy union with artificial intelligence-enhanced ranking. Finally, the multidimensional performance for European energy union is evaluated by using Quantum picture fuzzy rough sets based VIKOR methodology. The main motivation of this study is the necessity to make a comprehensive evaluation to understand the prior strategies regarding the European Energy Union policies. To achieve this objective, decision-making models can be taken into consideration. However, there is a need for a new model to make evaluation regarding the indicators of European Energy Union policy. There are some significant criticisms to the existing models in the literature because of some reasons, such as considering the weights of different experts as equal. The proposed model of this study makes both artificial intelligence and fuzzy decision-making methodology-based assessment to overcome this issue.

The main contribution of this study is that prior strategies can be identified for the performance improvements of European Energy Union policies by establishing a novel decision-making model. The proposed model has some essential superiorities by comparing with the previous ones. (i) Making a comparative evaluation with both artificial intelligence approach and fuzzy decision-making methodology provides an opportunity check the validity of the findings. In the analysis process, a novel artificial intelligence-based ranking methodology is proposed. Therefore, more effective evaluations can be conducted. This situation helps to reach more appropriate findings. (ii) Artificial intelligence and fuzzy decision-making methodology are integrated. Previously, a ranking model on multi-criteria decision making integrated with artificial intelligence has not been created in the literature. Using expert opinions, it is tried to measure how compatible artificial intelligence can be with a fuzzy-based model. In the selection of dimensions with artificial intelligence, it provides classification of the most appropriate dimensions depending on the real-world dataset. On the other hand, weights are determined depending on this classification. In addition, artificial intelligence-based ranking is made depending on the linguistic evaluations of experts. (iii) Additionally, an artificial intelligence-based valuation model has been applied for the selection of important dimensions for the European Energy Union. This situation provides significant guidance for policy makers and investors. In European Energy Union strategies, criteria are determined for countries to effectively implement their energy policies. On the other hand, actions to be taken to improve these criteria also cause costs to increase. Therefore, thanks to this priority analysis, it will be possible to focus on more important issues. This allows appropriate energy policies to be implemented more financially efficiently.

The paper is organized as follows. The following section includes literature review. The third part gives information about the proposed methodology. The next section consists of analysis results. Conclusion and discussion are indicated in the final sections.

2. Literature review

This section includes literature evaluation of the determinants of European Energy Union, literature on decision-making models and literature review results.

2.1. Literature on dimensions stated in European Energy Union

In the literature, many different studies focused on the importance of the dimensions stated in European Energy Union. In this section, the studies for each dimension will be summarized. Ensuring energy efficiency has a number of important advantages in terms of the effectiveness of a country's energy policies. Jiang and Raza [8] stated that energy efficiency allows businesses to run their businesses using less energy. This contributes to significantly reducing energy costs. Thus, it is much more possible to achieve sustainable energy policy targets [9]. Peng et al. [10] identified that achieving energy efficiency is especially important for energy importing countries. Countries that cannot produce their own energy supply their needs from other countries. Carayannis et al. [11] mentioned that this situation causes countries to face risks arising from the volatility in energy prices. In this context, countries that use their energy more efficiently can reduce this risk. On the other hand, Zhou [12] demonstrated that energy efficiency also contributes to ensuring environmental sustainability. Baiardi and Soana

[13] underlined that less energy consumption also helps reduce carbon emissions. This allows natural resources to be better protected.

Ensuring energy security is an important factor for the effectiveness of a country's energy policies. In order to ensure energy security, economic stability in the country must first be ensured. In this way, businesses can access the country's energy resources more safely. Yüksel et al. [14] defined that this helps ensure uninterrupted energy supply. Thus, there will be an increase in the country's industrial production, which will contribute to the advancement of economic growth. Rovai et al. [15] discussed that social and political stability are other issues that should be taken into consideration in this process. In a society where there are social conflicts, businesses are reluctant to invest. This situation affects energy security very negatively [16]. On the other hand, Jiang et al. [17] defined that having reliable access to energy resources can also increase a country's political power. A country that is not dependent on other countries in terms of energy policies has very high political power. Otherwise, this country will not be able to make very independent decisions politically [18]. Energy security policies also contribute to achieving environmental sustainability goals. In this way, it is possible to minimize environmental problems arising from the energy production process [19].

Ensuring decarbonization is also of great importance for countries' energy policies to be effective. Babatunde et al. [20] defined that decarbonization means minimizing carbon emissions resulting from the energy production process. This has a very important role in the fight against climate change. Ba et al. [21] identified that reducing carbon emissions is considered an important solution to the global warming problem. Decarbonization policies also encourage the use of sustainable energy sources. This contributes to less consumption of natural resources. Wu et al. [22] concluded that it is possible to minimize environmental problems caused by energy consumption. On the other hand, decarbonization policies also increase the market power of the country's economy in clean energy. According to Simionescu et al. [23], thanks to these policies, countries will invest more in clean energy technologies. This situation increases the market power of the countries and contributes to the advancement of the country's economies. In addition to them, Danish and Senjyu [24] discussed that new job opportunities emerge with the implementation of decarbonization-targeted policies. This situation helps to reduce the unemployment problem of countries [25].

Ensuring innovation is of critical importance for the effectiveness of countries' energy policies. Zha et al. [26] defined that innovation in energy policies enables the development of new technologies. In this way, it is possible to reduce energy production costs. Williams et al. [27] determined that this is particularly important for renewable energy projects due to the high initial costs. Additionally, environmentally friendly energy policies can be generated more effectively by the help of successful innovation [28]. Also, Saeed et al. [29] concluded that innovation has a strong contribution to the energy efficiency. By using energy more efficiently, it is possible to implement sustainable energy policies more easily. On the other hand, Marra and Colantonio [30] identified that innovation provides a competitive advantage in the energy sector. Since new technologies are implemented thanks to innovation, this significantly increases the competitiveness of businesses. Moreover, Azhgaliyeva et al. [31] indicated that with increased innovation, the possibility of international cooperation also goes up.

2.2. Literature on decision-making models

There is a huge literature for decision-making methodology. Most of these models are established with the help of fuzzy sets. Quezada et al. [32], Kumar et al. [33], and Yazo-Cabuya et al. [34] considered triangular fuzzy sets with the decision-making models. However, these models are criticized due to the lack of uncertainty management. Because of this problem, some scholars created models with different fuzzy sets. Akram et al. [35], Ayyildiz et al. [36], Sun and Wang [37] used Pythagorean fuzzy sets in the analysis process. With the help of this situation, they aimed to minimize uncertainty by considering different degrees in the analysis process. In addition to them, Moslem [38], Chang [39] and Garg et al. [40] considered Spherical fuzzy numbers in the decision-making models. Owing to this condition, a wider range of data set can be taken into consideration in the analysis process. This situation has a powerful contribution to handle uncertainties more effectively. On the other side, with respect to the ranking technique, there are different models in the literature such as TOPSIS [41,42], VIKOR [43,44] and MOORA [45]. Nonetheless, there are lots of criticisms regarding these techniques. Because of these criticisms, new ranking models are also recently introduced, such as RATGOS [46].

2.3. Literature Review Results

It is possible to obtain some important points as a result of the literature review. European Energy Union-style strategies are very important for the effective implementation of energy policies. Thanks to these policies, it is possible for countries' energy policies to be more secure and competitive. However, the main missing point in the literature is that there are not enough studies analyzing which of these factors is more important. Improving the variables within the European Energy Union causes costs to increase significantly for countries. Therefore, making many improvements at the same time radically increases the costs. Therefore, it is appropriate for countries to prioritize more important issues. In this context, a priority analysis in which the most important European Energy Union policies will be determined makes a significant contribution to the literature. To fill this missing part in the literature, this study examines the critical determinants of European Energy Union policy via a novel artificial intelligence-enhanced and hybrid quantum fuzzy ranking approach.

3. Methodology

In this study, a novel model has been proposed to understand the significant factors of European Energy Union policy. Fig. 1 demonstrates the details of this model.

The approaches used in this proposed model are explained below.

3.1. Artificial intelligence-based ranking methodology

In the first stage of the proposed model, the dimensions of the European energy union are weighted with artificial intelligence-enhanced prioritization.

To provide a more comprehensive approach with AI methods into the ranking and decision-making process, we collect and preprocess data to ensure it is suitable for AI techniques and choose clustering algorithms in AI methods based on the nature of the problem. We analyze the results to understand the patterns and relationships within the data.

Our proposed model employs an AI-enhanced ranking methodology, specifically utilizing the k-means clustering algorithm. This method is particularly suited for analyzing and prioritizing the dimensions of the European energy union. The k-means clustering process as applied in our study is used for evaluating a dataset representing the dimensions of the European energy union for various countries. Thus, it is possible to define criteria and collect relevant data to represent each dimension more accurately.

For this purpose, we calculate Within-Cluster Sum of Squares for different values of k to determine the optimal number of clusters. The elbow method is used to identify the point where the reduction in WCSS slows down, indicating the optimal k value. First, initial clustering is defined for using the optimal k value, we assign each data point to the nearest cluster center. After that, we calculate the mean standard deviation of each cluster to understand the impact of the criteria in the ranking process.

Step 1: Construct the energy union dimensions for the European countries

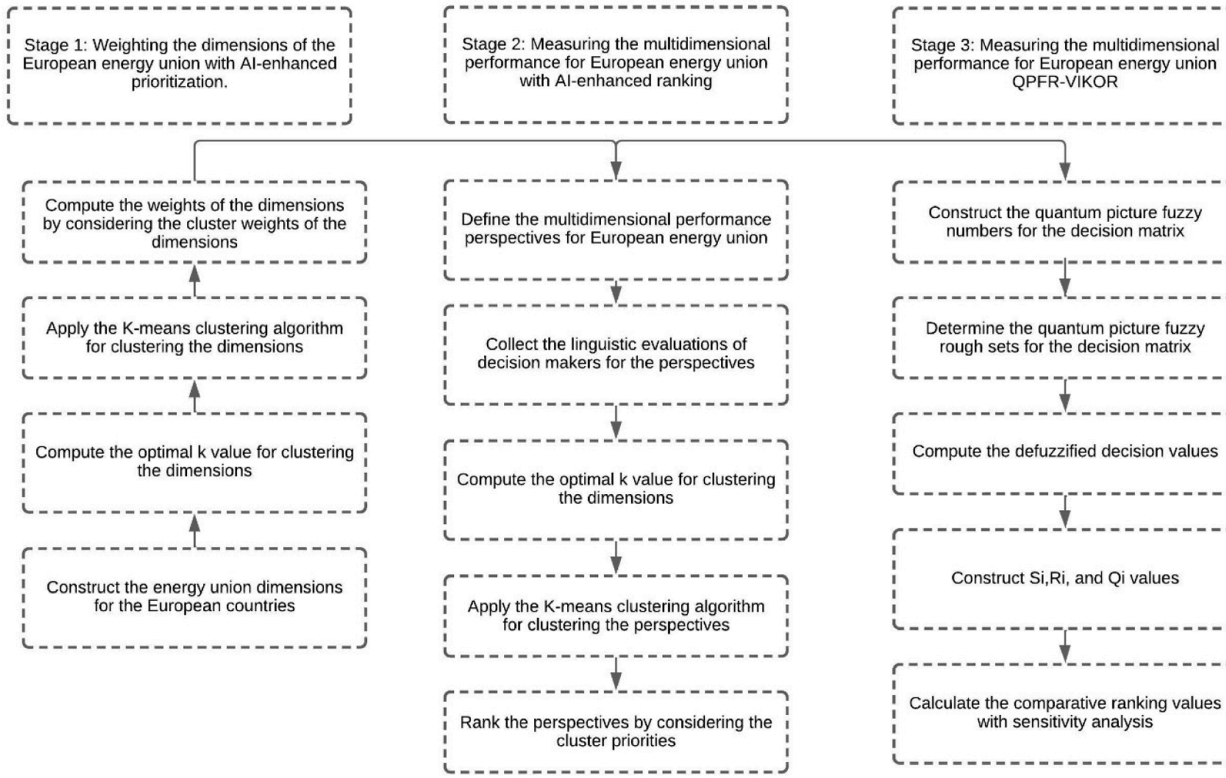

Fig. 1. The flowchart of hybrid model.

Artificial intelligence is one of the most widely used tools to analyse the complex problems of the business and engineering fields. Especially, the decision-making approaches are nowadays extended with different types of the new business analytics including the data mining and artificial intelligence. Therefore, it is possible to increase the coherency of the sophisticated multi-criteria decision-making problems. Artificial intelligence-enhanced ranking approach focuses on the k-means clustering algorithm and the clustering the alternatives in terms of the defined criteria set. The clustered dataset is used to define the possible trade-offs and the heterogeneous between the criteria into the clustering of the alternatives.

For that, the elbow methodology is used to examine the optimization of the cluster number by observing the changes of the dataset entitled Within-Cluster Sum of Squares (WCSS) with different k numbers. Accordingly, the results with the least changes in the WCSS indicate that the optimal number of clusters could be defined in this point [47]. After that, the clusters are processed to measure the variations of the criteria and rank the relative importance of the alternatives in each cluster. Also, the weights of the criteria are considered in the computation process of the weighted standard deviation to be able to understand the impact of the criteria in the ranking process properly.

Step 2: Compute the optimal k value for clustering the dimensions

The Within-Cluster Sum of Squares (WCSS) is calculated for the different values of k as in Eq. (1).

$$WCSS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d(x_i, c_j)^2 \tag{1}$$

In this equation, k is the number of clusters, C_j is the set of data points in cluster j, x_i is a data point, c_j is the cluster center of cluster j, and $d(x_i, c_j)$ is the Euclidean distance between x_i and c_j. The elbow is defined as an optimal k value where the reduction in WCSS slows down by plotting the values of WCSS and k [48].

Step 3: Apply the K-means clustering algorithm for clustering the dimensions.

The optimal k value is applied for initial cluster centres as $c_1, c_2, \ldots, c_k$ and each data point x_i to the nearest cluster center is assigned to define the cluster assignments as in Eq. (2).

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

Where n is the number of features or criteria of the data. The cluster assignment of each data point x_i is denoted by a_i, where $a_i = j$ means that x_i belongs to cluster j. Cluster centres are updated by taking the average of data points in each cluster as in Eq. (3).

$$c_j = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_i \tag{3}$$

In this process, C_j is the set of data points in cluster, and $|C_j|$ is the number of data points in cluster j.

Step 4: Compute the weights of the dimensions by considering the cluster weights of the dimensions.

In the last stage of this methodology, the weights of the alternatives are computed by considering the cluster weights of the decision makers. The mean standard deviation of each cluster is calculated as in Eqs. (4)-(6).

$$s_j = \frac{1}{n} \sum_{l=1}^{n} \sigma_{jl} \tag{4}$$

$$\sigma_{jl} = \sqrt{\frac{1}{|C_j|} \sum_{x_i \in C_j} \left(x_{il} - \bar{x}_{jl}\right)^2} \tag{5}$$

$$\bar{x}_{jl} = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_{il} \tag{6}$$

In this framework, s_j is the mean standard deviation of cluster. Also, n is the number of features or criteria of the data, and σ_{jl} is the standard deviation of feature l in cluster j. Additionally, $\bar{x}_{jl}$ is the mean of feature l in cluster j. The cluster weights w_j are computed in Eq. (7).

$$w_j = |C_j| \times s_j \tag{7}$$

where $|C_j|$ is the size of cluster j. The weights of the decision makers are computed with Eq. (8).

$$w_{tj} = \frac{1}{|C_j|}\frac{w_j}{\sum_{w_j \in C_j} w_j} \tag{8}$$

In this context, t is the number of alternatives $w_{tj}$is the weight of alternative t in cluster j.

Stage 2 includes measuring the multidimensional performance for European energy union with artificial intelligence-enhanced ranking. The similar procedures defined above are also implemented in this process. *Step 5* defines the multidimensional performance perspectives for European energy union. Moreover, *Step 6* collects the linguistic evaluations of decision makers for the perspectives. On the other side, *Step 7* computes the optimal k value for clustering the dimensions. *Step 8* applies the K-means clustering algorithm for clustering the perspectives. Finally, *Step 9* includes ranking of the perspectives by considering the cluster priorities.

3.2. Quantum picture fuzzy rough sets based VIKOR

In the third stage of the proposed model, the multidimensional performance for European energy union is measured via Quantum picture fuzzy rough sets based VIKOR.

Step 10: Construct the quantum picture fuzzy numbers for the decision matrix

Quantum theory is very successful to make sensitive prediction [49]. Due to this advantage, it is considered in the fuzzy decision-making methodology [50]. In this process, amplitude and phase angles are taken into consideration. Eqs. (9)-(11) state the details of this process [51].

$$Q(|u>) = \varphi e^{j\theta} \tag{9}$$

$$|C> = \{|u_1>, |u_2>, \ldots, |u_n>\} \tag{10}$$

$$\sum_{|u>\subseteq|C>} |Q(|u>)| = 1 \tag{11}$$

In this process, C represents a collection of exhaustive events represented by $|u_i>$. The squared magnitude of the wave function, $|Q(|u>)| = \varphi^2$, provides the amplitude-based result for the probability of occurrence of event $|u>$ as described by the principles of quantum logic. The value of φ^2 must lie within the range of 0–1, and θ^2 represents the phase angle of event $|u>$. Furthermore, $|\varphi_1|^2$ serves as the degree of belief in event $|u>$, with θ representing its phase angle, which can range from 0 to 360 degrees.

Picture fuzzy sets are recent extensions of fuzzy sets. Eq. (12) demonstrates the classical fuzzy sets [52].

$$A = \{\langle x, \mu_A(x)\rangle | x \in X\} \tag{12}$$

Where A defines the fuzzy sets, X is a universe of discourse and μ_A is the membership degree of x in the fuzzy set A. $\mu_A : X \to [0,1]$. Also, by considering both membership and non-membership functions, intuitionistic fuzzy sets are identified as in Eq. (13).

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X\} \tag{13}$$

Where v_A is the non-membership function of fuzzy set, $0 \le \mu_A(x) + v_A(x) \le 1$, $\forall x \in X$. Picture fuzzy sets are also given in Eq. (14).

$$A = \{\langle x, \mu_A(x), n_A(x), v_A(x), h_A(x)\rangle | x \in X\} \tag{14}$$

In this process, n_A defines the neutral and h_A refers to the refusal degrees. General operations are defined in Eqs. (15)-(19) [53].

$$A \subseteq B if \mu_A(x) \le \mu_B(x) and n_A(x) \le n_B(x) and v_A(x) \ge v_B(x), \quad \forall x \in X \tag{15}$$

$$A = B if A \subseteq B and B \subseteq A \tag{16}$$

$$A \cup B = \{(x, \max(\mu_A(x), \mu_B(x)), \min(n_A(x), n_B(x)), \min(v_A(x), v_B(x)))| x \in X\} \tag{17}$$

$$A \cap B = \{(x, \min(\mu_A(x), \mu_B(x)), \min(n_A(x), n_B(x)), \max(v_A(x), v_B(x)))| x \in X\} \tag{18}$$

$$coA = \overline{A} = \{(x, v_A(x), n_A(x), \mu_A(x))| x \in X\} \tag{19}$$

Rough numbers are used to reduce the subjective and uncertain evaluations by considering lower and upper limits as well as a rough boundary interval. Lower ($\underline{Apr}(C_i)$), upper ($\overline{Apr}(C_i)$) approximation, and boundary region ($Bnd(C_i)$) of C_i are given in Eqs. (20)-(22) [54].

$$\underline{Apr}(C_i) = \cup\{Y \in X/R(Y) \le C_i\} \tag{20}$$

$$\overline{Apr}(C_i) = \cup\{Y \in X/R(Y) \ge C_i\} \tag{21}$$

$$Bnd(C_i) = \cup\{Y \in X/R(Y) \ne C_i\} \tag{22}$$

In this context, Y defines an arbitrary object of the universe X, R indicates the set of N classes $(C_1, ..C_N)$ and C refer to the objects in X. However, lower ($\underline{Lim}(C_i)$), upper ($\overline{Lim}(C_i)$) limits and the rough number ($RN(C_i)$) of C_i are shown in Eqs. (23)-(25)

$$\underline{Lim}(C_i) = \sqrt[NL]{\prod_{i=1}^{N_L} Y \in \underline{Apr}(C_i)} \tag{23}$$

$$\overline{Lim}(C_i) = \sqrt[NU]{\prod_{i=1}^{N_U} Y \in \overline{Apr}(C_i)} \tag{24}$$

$$RN(C_i) = \left[\underline{Lim}(C_i), \overline{Lim}(C_i)\right] \tag{25}$$

Within this scope, N_L and N_U are the number of objects for $\underline{Apr}(C_i)$ and $\overline{Apr}(C_i)$. This proposed model includes the integration of picture fuzzy sets and fuzzy rough numbers based on quantum mechanics with golden cuts. Eq. (26) gives information about this process.

$$|C_A> = \left\{ \begin{array}{l} \langle u, \left(\left[\underline{Lim}(C_{i\mu_A}), \overline{Lim}(C_{i\mu_A})\right] (u), \left[\underline{Lim}(C_{in_A}), \overline{Lim}(C_{in_A})\right](u), \right. \\ \left. \left[\underline{Lim}(C_{iv_A}), \overline{Lim}(C_{iv_A})\right](u), \left[\underline{Lim}(C_{ih_A}), \overline{Lim}(C_{ih_A})\right](u) \right) \Big| u \in 2^{|C_A>} \end{array} \right\} \tag{26}$$

In this equation, $C_{i\mu_A}$ identifies the membership, C_{in_A} denotes the neutral degree, C_{iv_A} indicates the non-membership, and C_{ih_A} shows the refusal degrees. Their definitions are stated in Eqs. (27)-(34).

$$\underline{Lim}(C_{i\mu_A}) = \frac{1}{N_{L\mu_A}} \sum_{i=1}^{N_{L\mu_A}} Y \in \underline{Apr}(C_{i\mu_A}) \tag{27}$$

$$\underline{Lim}(C_{in_A}) = \frac{1}{N_{Ln_A}} \sum_{i=1}^{N_{Ln_A}} Y \in \underline{Apr}(C_{in_A}) \tag{28}$$

$$\underline{Lim}(C_{iv_A}) = \frac{1}{N_{Lv_A}} \sum_{i=1}^{N_{Lv_A}} Y \in \underline{Apr}(C_{iv_A}) \tag{29}$$

$$\underline{Lim}(C_{ih_A}) = \frac{1}{N_{L\pi_A}} \sum_{i=1}^{N_{L\pi_A}} Y \in \underline{Apr}(C_{ih_A}) \tag{30}$$

$$\overline{Lim}(C_{i\mu_A}) = \frac{1}{N_{U\mu_A}} \sum_{i=1}^{N_{U\mu_A}} Y \in \overline{Apr}(C_{i\mu_A}) \tag{31}$$

$$\overline{Lim}(C_{in_A}) = \frac{1}{N_{Un_A}} \sum_{i=1}^{N_{Un_A}} Y \in \overline{Apr}(C_{in_A}) \tag{32}$$

$$\overline{Lim}(C_{iv_A}) = \frac{1}{N_{Uv_A}} \sum_{i=1}^{N_{Uv_A}} Y \in \overline{Apr}(C_{iv_A}) \tag{33}$$

$$\overline{Lim}(C_{ih_A}) = \frac{1}{N_{U\pi_A}} \sum_{i=1}^{N_{U\pi_A}} Y \in \overline{Apr}(C_{ih_A}) \tag{34}$$

In this process, $N_{L\mu_A}, N_{Ln_A}, N_{Lv_A}, N_{Lh_A}$ define the number of elements in $\underline{Apr}(C_{i\mu_A})$, $\underline{Apr}(C_{in_A})$, $\underline{Apr}(C_{iv_A})$, $\underline{Apr}(C_{ih_A})$ respectively while $N_{U\mu_A}$, N_{Un_A}, N_{Uv_A}, N_{Uh_A} are given for $\overline{Apr}(C_{i\mu_A})$, $\overline{Apr}(C_{in_A})$, $\overline{Apr}(C_{iv_A})$, $\overline{Apr}(C_{ih_A})$ as in Eqs. (35)-(42).

$$\underline{Apr}(C_{i\mu_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{i\mu_A}\right\} \tag{35}$$

$$\underline{Apr}(C_{in_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{in_A}\right\} \tag{36}$$

$$\underline{Apr}(C_{iv_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{iv_A}\right\} \tag{37}$$

$$\underline{Apr}(C_{ih_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{ih_A}\right\} \tag{38}$$

$$\overline{Apr}(C_{i\mu_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{i\mu_A}\right\} \tag{39}$$

$$\overline{Apr}(C_{in_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{in_A}\right\} \tag{40}$$

where $\widetilde{C_i} = \left(C_{i\mu_A}, C_{in_A}, C_{iv_A}, C_{ih_A}\right)$ and $\widetilde{R}$ is the collection of $\left\{\widetilde{C_1}, \widetilde{C_2}, \ldots, \widetilde{C_n}\right\}$. $C_{i\mu_A}, C_{in_A}, C_{iv_A}, C_{ih_A}$ are the picture fuzzy sets of class $\widetilde{C_i}$. Eqs. (43) and (44) define the details of the general formulation of the quantum picture fuzzy sets with the amplitude and the angle results.

$$C = \left[C_\mu.e^{j2\pi.\alpha}, C_n.e^{j2\pi.\gamma}, C_v.e^{j2\pi.\beta}, C_h.e^{j2\pi.T}\right] \tag{43}$$

$$\varphi^2 = \left|C_\mu(|u_i>\ )\right| \tag{44}$$

The amplitudes of quantum membership, neutral, non-membership, and refusal degrees are shown with C_μ, C_n, C_v and C_h respectively, are represented in terms of phase angles α, γ, β, T. The amplitude of the membership function C_μ of quantum fuzzy sets is defined by φ^2. In this proposed model, the degrees are computed with golden ratio [55]. Eqs. (45) and (46) define the details of this process.

$$C_n = \frac{C_\mu}{G} \tag{45}$$

$$C_h = \frac{C_v}{G} \tag{46}$$

Consequently, the phase angle for the suggested sets is displayed. The phase angle of the membership degrees for the probability of event $|u_i>$ in the realm of quantum picture fuzzy sets is denoted by the symbol α, and the phase angles of the degrees are denoted via Eqs. (47)-(49).

$$\alpha = \left|C_\mu(|u_i>\ )\right| \tag{47}$$

$$\gamma = \frac{\alpha}{G} \tag{48}$$

$$T = \frac{\beta}{G} \tag{49}$$

X_1 and X_2 are two universes, and $\widetilde{A}_c$ and $\widetilde{B}_c$, respectively represented by

$$\left(\begin{array}{ll}\left\lceil \underline{Lim}\left(C_{\mu_{\tilde{A}}}\right), \overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right),\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)\right\rfloor}, & \left\lceil \underline{Lim}\left(C_{n_{\tilde{A}}}\right), \overline{Lim}\left(C_{n_{\tilde{A}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right),\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)\right\rfloor}, \\ \left\lceil \underline{Lim}\left(C_{v_{\tilde{A}}}\right), \overline{Lim}\left(C_{v_{\tilde{A}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right),\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)\right\rfloor}, & \left\lceil \underline{Lim}\left(C_{h_{\tilde{A}}}\right), \overline{Lim}\left(C_{h_{\tilde{A}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right),\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)\right\rfloor}\end{array}\right),$$

$$\left(\begin{array}{ll}\left\lceil \underline{Lim}\left(C_{\mu_{\tilde{B}}}\right), \overline{Lim}\left(C_{\mu_{\tilde{B}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right),\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)\right\rfloor}, & \left\lceil \underline{Lim}\left(C_{n_{\tilde{B}}}\right), \overline{Lim}\left(C_{n_{\tilde{B}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right),\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)\right\rfloor}, \\ \left\lceil \underline{Lim}\left(C_{v_{\tilde{B}}}\right), \overline{Lim}\left(C_{v_{\tilde{B}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right),\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)\right\rfloor}, & \left\lceil \underline{Lim}\left(C_{h_{\tilde{B}}}\right), \overline{Lim}\left(C_{h_{\tilde{B}}}\right)\right\rfloor e^{j2\pi.\left\lceil\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right),\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)\right\rfloor}\end{array}\right)$$

$$\overline{Apr}(C_{iv_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{iv_A}\right\} \tag{41}$$

$$\overline{Apr}(C_{ih_A}) = \cup\left\{Y \in X \middle/ \widetilde{R}(Y) \leq C_{ih_A}\right\} \tag{42}$$

and, they are two quantum picture fuzzy rough sets derived from the universes of discourse X_1 and X_2.

The operations of quantum picture fuzzy rough numbers are demonstrated in Eqs. (50)-(53).

$$\lambda * \widetilde{A}_c = \left\{ \begin{array}{l} \lceil \underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)\lambda \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda \rfloor}, \quad \lceil \underline{Lim}\left(C_{n_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{n_{\tilde{A}}}\right)\lambda \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda \rfloor}, \\ \lceil \underline{Lim}\left(C_{v_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{v_{\tilde{A}}}\right)\lambda \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda \rfloor}, \quad \lceil \underline{Lim}\left(C_{h_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{h_{\tilde{A}}}\right)\lambda \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)\lambda \rfloor} \end{array} \right\}, \lambda > 0 \tag{50}$$

$$\widetilde{A}_c^{\ \lambda} = \left\{ \begin{array}{l} \lceil \underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)^{\lambda} \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)^{\lambda} \rfloor}, \quad \lceil \underline{Lim}\left(C_{n_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{n_{\tilde{A}}}\right)^{\lambda} \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)^{\lambda} \rfloor}, \\ \lceil \underline{Lim}\left(C_{v_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{v_{\tilde{A}}}\right)^{\lambda} \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)^{\lambda} \rfloor}, \quad \lceil \underline{Lim}\left(C_{h_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{h_{\tilde{A}}}\right)^{\lambda} \rfloor \quad e^{j2\pi.\lceil \left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)^{\lambda} \rfloor} \end{array} \right\}, \lambda > 0 \tag{51}$$

$$\widetilde{A}_c \cup \widetilde{B}_c = \left\{ \begin{array}{l} \lceil \min\left(\underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{\mu_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), \max\left(\overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{\mu_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \min\left(\underline{Lim}\left(C_{n_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{n_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), \max\left(\overline{Lim}\left(C_{n_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{n_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \min\left(\underline{Lim}\left(C_{v_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{v_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), \max\left(\overline{Lim}\left(C_{v_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{v_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \min\left(\underline{Lim}\left(C_{h_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{h_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), \max\left(\overline{Lim}\left(C_{h_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{h_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor \end{array} \right\} \tag{52}$$

$$\widetilde{A}_c \cap \widetilde{B}_c = \left\{ \begin{array}{l} \lceil \max\left(\underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{\mu_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), \min\left(\overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{\mu_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \max\left(\underline{Lim}\left(C_{n_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{n_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), \min\left(\overline{Lim}\left(C_{n_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{n_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \max\left(\underline{Lim}\left(C_{v_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{v_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), \min\left(\overline{Lim}\left(C_{v_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{v_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor, \\ \lceil \max\left(\underline{Lim}\left(C_{h_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}\left(C_{h_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), \min\left(\overline{Lim}\left(C_{h_{\tilde{A}}}\right)e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}\left(C_{h_{\tilde{B}}}\right)e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right) \rfloor \end{array} \right\} \tag{53}$$

VIKOR aims to rank different alternatives. This methodology is also extended with quantum picture fuzzy rough sets in this proposed model. The evaluations are collected [56]. The decision matrix is created as in Eq. (54).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & \end{bmatrix} \tag{54}$$

The decision matrix is defined as X, with X_{ij} representing the alternative i with respect to criterion j based on the QPFRNs-based linguistic evaluations for k number of decision makers.

Step 11: Determine the quantum picture fuzzy rough sets for the decision matrix

In this process, the quantum picture fuzzy rough direct relation matrix is denoted in Eq. (55).

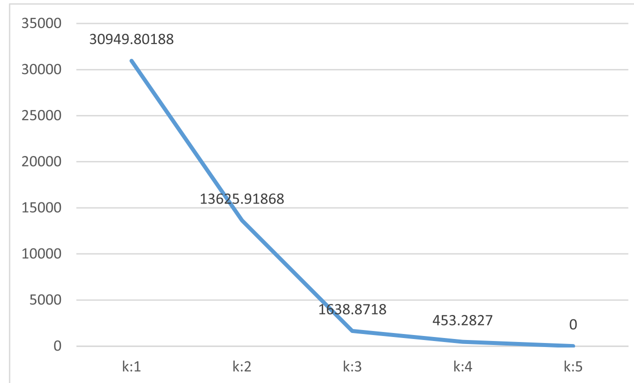

Fig. 2. The plot of the WCSS values and k numbers.

X is the aggregated values of the decision makers are computed in the form of quantum picture fuzzy rough numbers.

$$X_{ij} = \begin{pmatrix} \left[\underline{Lim}\left(X_{\mu_{ij}}\right), \overline{Lim}\left(X_{\mu_{ij}}\right)\right] e^{j2\pi.\left[\left(\frac{\alpha_{ij}}{2\pi}\right),\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)\right]}, & \left[\underline{Lim}\left(X_{n_{ij}}\right), \overline{Lim}\left(X_{n_{ij}}\right)\right] e^{j2\pi.\left[\left(\frac{\gamma_{ij}}{2\pi}\right),\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)\right]}, \\ \left[\underline{Lim}\left(X_{v_{ij}}\right), \overline{Lim}\left(X_{v_{ij}}\right)\right] e^{j2\pi.\left[\left(\frac{\beta_{ij}}{2\pi}\right),\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)\right]}, & \left[\underline{Lim}\left(X_{h_{ij}}\right), \overline{Lim}\left(X_{h_{ij}}\right)\right] e^{j2\pi.\left[\left(\frac{T_{ij}}{2\pi}\right),\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right]} \end{pmatrix} \tag{55}$$

The aggregated values are calculated in Eq. (56) [57].55

$$X = \begin{pmatrix} \left[\min_{i=1}^{k}\left(\underline{Lim}\left(X_{\mu_{ij}}\right)\right), \max_{i=1}^{k}\left(\overline{Lim}\left(X_{\mu_{ij}}\right)\right)\right] e^{j2\pi.\left[\min_{i=1}^{k}\left(\frac{\alpha_{ij}}{2\pi}\right), \max_{i=1}^{k}\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)\right]}, \\ \left[\min_{i=1}^{k}\left(\underline{Lim}\left(X_{n_{ij}}\right)\right), \max_{i=1}^{k}\left(\overline{Lim}\left(X_{n_{ij}}\right)\right)\right] e^{j2\pi.\left[\min_{i=1}^{k}\left(\frac{\gamma_{ij}}{2\pi}\right), \max_{i=1}^{k}\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)\right]}, \\ \left[\min_{i=1}^{k}\left(\underline{Lim}\left(X_{v_{ij}}\right)\right), \max_{i=1}^{k}\left(\overline{Lim}\left(X_{v_{ij}}\right)\right)\right] e^{j2\pi.\left[\min_{i=1}^{k}\left(\frac{\beta_{ij}}{2\pi}\right), \max_{i=1}^{k}\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)\right]}, \\ \left[\min_{i=1}^{k}\left(\underline{Lim}\left(X_{h_{ij}}\right)\right), \max_{i=1}^{k}\left(\overline{Lim}\left(X_{h_{ij}}\right)\right)\right] e^{j2\pi.\left[\min_{i=1}^{k}\left(\frac{T_{ij}}{2\pi}\right), \max_{i=1}^{k}\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right]} \end{pmatrix} \tag{56}$$

Step 12: Compute the defuzzified decision values

The defuzzified values are provided via Eq. (57).

$$Defc_i = \frac{\begin{pmatrix} \underline{Lim}(C_{\mu_i}) - \underline{Lim}(C_{n_i}) + \underline{Lim}(C_{\mu_i}).\left(\underline{Lim}(C_{v_i}) - \underline{Lim}(C_{h_i})\right) + \left(\frac{\alpha_{ij}}{2\pi}\right) - \left(\frac{\gamma_{ij}}{2\pi}\right) + \left(\frac{\alpha_{ij}}{2\pi}\right).\left(\left(\frac{\beta_{ij}}{2\pi}\right) - \left(\frac{T_{ij}}{2\pi}\right)\right) + \\ \overline{Lim}(C_{\mu_i}) - \overline{Lim}(C_{n_i}) + \overline{Lim}(C_{\mu_i}).\left(\overline{Lim}(C_{v_i}) - \overline{Lim}(C_{h_i})\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\overline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{pmatrix}}{2} \tag{57}$$

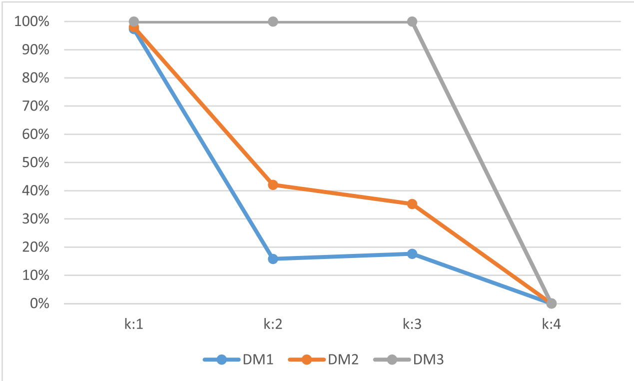

Fig. 3. The plot of the WCSS values and k numbers for decision makers.

Table 1
Selected energy union dimensions for the European countries.

Dimensions/Countries	Germany	France	Italy	Spain	Sweden
D1: Energy Efficiency (Energy intensity in industry-toe/Million EUR GVA 2015 (by 2020))	73.75	82.77	81.84	109.31	128.98
D2: Energy Security (Supplier Concentration Index–0–100 (by 2020))	30	15	18	11	10
D3: Market Functioning (Electricity Interconnection-% of installed capacity (by 2020))	11.43	8.5	8.8	6.49	24.24
D4: Decarbonization of the economy (Renewable energy share-%–2020)	17.35	17.22	18.16	18.36	56.39
D5: Innovation (Share of energy R&D-% of GDP–2018)	0.03	0.05	0.02	0.01	0.03

Source: European Commission, Energy Union Indicators Webtool, https://energy.ec.europa.eu/data-and-analysis/energy-union-indicators-webtool/scoreboard_en

The best $\widetilde{f}_J^*$ and worst $\widetilde{f}_j^-$ values are computed by Eq. (58).

$$\widetilde{f}_J^* = \max_i \widetilde{x}_{ij}, \text{and} \widetilde{f}_j^- = \min_i \widetilde{x}_{ij}, \tag{58}$$

Step 13: Construct Si, Ri, and Qi values

The mean group utility and maximal regret are calculated by Eqs. (59) and (60). Where the weights of the criteria and the distance of the best value with respect to each criterion are considered.

Table 3
Iteration results of optimal cluster value.

Dimensions	Distance to C1	Distance to C2	Distance to C3	Cluster Assignment
Iteration 1 (D1 is in Cluster 1; D2 is in Cluster 2; D3 is in Cluster 3)				
Initial Cluster Centres				
Dimensions	**Distance to C1**	**Distance to C2**	**Distance to C3**	**Cluster Assignment**
D1	0.00	185.48	190.47	1
D2	185.48	0.00	26.36	2
D3	190.47	26.36	0.00	3
D4	158.35	48.69	37.06	2
D5	218.05	40.81	30.11	2
Average of Data Points				
Dimensions	**Distance to C1**	**Distance to C2**	**Distance to C3**	**Cluster Assignment**
D1	0.00	186.37	190.47	1
D2	185.48	20.10	26.36	2
D3	190.47	7.08	0.00	3
D4	158.35	36.44	37.06	2
D5	218.05	33.05	30.11	3
Iteration 2 (D1 is in Cluster 1; D2 is in Cluster 2; D4 is in Cluster 3)				
Initial Cluster Centres				
Dimensions	**Distance to C1**	**Distance to C2**	**Distance to C3**	**Cluster Assignment**
D1	0.00	185.48	158.35	1
D2	185.48	0.00	48.69	2
D3	190.47	26.36	37.06	2
D4	158.35	48.69	0.00	3
D5	218.05	40.81	66.61	2
Average of Data Points				
Dimensions	**Distance to C1**	**Distance to C2**	**Distance to C3**	**Cluster Assignment**
D1	0.00	197.60	158.35	1
D2	185.48	20.58	48.69	2
D3	190.47	13.07	37.06	2
D4	158.35	48.62	0.00	3
D5	218.05	22.23	66.61	2

$$\widetilde{S}_i = \sum_{i=1}^{n} \widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)} \tag{59}$$

$$\widetilde{R}_i = \max_j \left[\widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)}\right] \tag{60}$$

The final ranking can be identified Eq. (61), where the weight of the strategy of maximum group utility (v = 0.5) and the weight of individual regret (1 – v) are both considered.

$$\widetilde{Q}_i = v\left(\widetilde{S}_i - \widetilde{S}^*\right) / \left(\widetilde{S}^- - \widetilde{S}^*\right) + (1-v)\left(\widetilde{R}_i - \widetilde{R}^*\right) / \left(\widetilde{R}^- - \widetilde{R}^*\right) \tag{61}$$

After sorting the values of S, R, and Q in decreasing order, two conditions should be satisfied. According to the first condition, Eq. (62)

Table 2
The set of WCSS values for different k values.

K= 1		K= 2		K= 3		K= 4		K= 5	
Cluster 1	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**
D1	22470.24	D1	6268.529	D1	0	D1	0	D1	0
D2	1636.974	D4	6268.529	**Cluster 2**	**WCSS**	**Cluster 2**	**WCSS**	**Cluster 2**	**WCSS**
D3	1660.381	**Cluster 2**	**WCSS**	D2	592.7946	D2	0	D2	0
D4	461.1457	D2	423.72	D4	592.7946	**Cluster 3**	**WCSS**	**Cluster 3**	**WCSS**
D5	4721.059	D3	170.85	**Cluster 3**	**WCSS**	D3	226.6414	D3	0
		D5	494.29	D3	226.6414	D5	226.6414	**Cluster 4**	**WCSS**
				D5	226.64	**Cluster 4**	**WCSS**	D4	0
						D4	0	**Cluster 5**	**WCSS**
								D5	0
Total	**30949.8**	**Total**	**13625.92**	**Total**	**1638.872**	**Total**	**453.2827**	**Total**	**0**

Also, the elbow point is defined for selecting the optimal number of clusters for the dataset. Accordingly, Fig. 2 illustrate the plot of the values of WCSS against the number of k.

Table 4
The standard deviations of the European countries and the weights by clusters.

Cluster centre	Size	Germany	France	Italy	Spain	Sweden	Mean SD	Weight
C1	1	0	0	0	0	0	0	0
C2	3	12.35	6.12	7.34	4.51	9.93	8.051669	24.15501
C3	1	0	0	0	0	0	0	0

Table 5
The weights of the dimensions with pareto principle.

Dimensions	Weights	Normalized weights with pareto principle
D1	0.00	0.10
D2	0.33	0.27
D3	0.33	0.27
D4	0.00	0.10
D5	0.33	0.27

is considered. On the other side, the second condition requires that the alternative must be the best ranked by either S or R, or both.

$$Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(j-1) \tag{62}$$

If one of these conditions is not satisfied, a set of compromise solutions is selected. The compromise solutions could consist of alternatives and if only condition 2 is not satisfied, or alternatives and, …, if condition 1 is not satisfied. These alternatives are selected based on the close positions of their rankings and calculated by the relation for maximum M.

Step 14: Calculate the comparative ranking values with sensitivity analysis

Finally, the results of both artificial intelligence-based ranking and VIKOR analysis are compared. Similarly, a sensitivity analysis has also been conducted by considering four different cases for the purpose of measuring the reliability and coherency of the findings.

Table 6
Balanced scorecard-based performance perspectives for European energy union.

Perspectives	Codes
Financial Feasibility	P1
Customer Expectations	P2
Organizational Competency	P3
Technological Infrastructure	P4

Table 7
Linguistic scales and quantum picture fuzzy numbers for evaluation.

Scales for Alternatives	Possibility Degrees	Fuzzy Numbers
Weakest (w)	0.40	$\begin{bmatrix} \sqrt{0.16}\, e^{j2\pi.0.4}, \\ \sqrt{0.10}\, e^{j2\pi.0.25}, \\ \sqrt{0.46}\, e^{j2\pi.0.22}, \\ \sqrt{0.28}\, e^{j2\pi.0.13} \end{bmatrix}$
Poor (p)	0.45	$\begin{bmatrix} \sqrt{0.20}\, e^{j2\pi.0.45}, \\ \sqrt{0.13}\, e^{j2\pi.0.28}, \\ \sqrt{0.42}\, e^{j2\pi.0.17}, \\ \sqrt{0.25}\, e^{j2\pi.0.10} \end{bmatrix}$
Fair (f)	0.50	$\begin{bmatrix} \sqrt{0.25}\, e^{j2\pi.0.50}, \\ \sqrt{0.15}\, e^{j2\pi.0.31}, \\ \sqrt{0.37}\, e^{j2\pi.0.12}, \\ \sqrt{0.23}\, e^{j2\pi.0.07} \end{bmatrix}$
Good (g)	0.55	$\begin{bmatrix} \sqrt{0.30}\, e^{j2\pi.0.55}, \\ \sqrt{0.19}\, e^{j2\pi.0.34}, \\ \sqrt{0.32}\, e^{j2\pi.0.07}, \\ \sqrt{0.19}\, e^{j2\pi.0.04} \end{bmatrix}$
Best (b)	0.60	$\begin{bmatrix} \sqrt{0.36}\, e^{j2\pi.0.6}, \\ \sqrt{0.22}\, e^{j2\pi.0.37}, \\ \sqrt{0.26}\, e^{j2\pi.0.02}, \\ \sqrt{0.16}\, e^{j2\pi.0.01} \end{bmatrix}$

The evaluations for these alternatives are denoted in Table 8.

4. Analysis results

The proposed model has three different stages. In this framework, the details of the analysis results are presented for each stage separately.

4.1. Weighting the dimensions of the European energy union with AI-enhanced prioritization (Stage 1)

Step 1 is related to the construction of the energy union dimensions for the European countries. For this purpose, the data of five different European countries are taken into consideration. According to the OECD dataset, the best 5 European countries in Electricity Generation by 2021 are selected as Germany, France, Italy, Spain, Sweeden for weighting the dimensions of European energy union with Artificial Intelligence-based priorities Table 1 gives information about the selected energy union dimensions.

Step 2 includes the calculation of the optimal k value for clustering the dimensions. The values of the WCSS are computed for the different number of clusters. In this case, the number of clusters is 5, from 1 to 5, the set of WCSS values are presented for the different k values as seen in Table 2.

According to the results, for k = 3, the WCSS value is minimized and optimized as adding more clusters will not significantly reduce the WCSS value.

Step 3 includes the application of the K-means clustering algorithm for clustering the dimensions. The optimal value for K number is applied for defining the clusters of dimensions. In this example, the optimal value of K is 3. The iteration results of different 3 clusters are given in Table 3.

As seen in Table 3, the cluster assignment results are same with initial cluster centres and average of data points for iteration 2. So, the clusters of the dimensions are considered as D1 is considered in cluster 1; D2, D3 and D5 are listed in cluster 2; D4 is stated in cluster 3.

Step 4 is related to the construction of the weights of the dimensions

Table 8
Linguistic evaluations of decision makers for the multidimensional performance of the European energy union.

	D1	D2	D3	D4	D5
DM1					
P1	G	B	G	B	G
P2	G	B	F	G	F
P3	G	G	F	G	F
P4	F	B	G	B	F
DM2	**D1**	**D2**	**D3**	**D4**	**D5**
P1	G	B	G	B	G
P2	G	B	G	G	G
P3	G	G	F	G	F
P4	B	B	G	B	F
DM3	**D1**	**D2**	**D3**	**D4**	**D5**
P1	B	B	G	B	B
P2	G	F	F	G	F
P3	G	G	F	G	F
P4	F	B	B	F	G

The linguistic evaluations are collected from the decision makers as seen in Table 8 and these values are converted to the possibility degrees in Table 7 to be able to process the evaluations properly with artificial intelligence-based ranking measurement.

Table 9
The set of WCSS values for different k values by the decision makers.

DM1							
K= 1		**K= 2**		**K= 3**		**K= 4**	
Cluster 1	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**
D1	0.0030	D1	0.0013	D1	0.0000	D1	0.0000
D2	0.0017	D4	0.0013	**Cluster 2**	**WCSS**	**Cluster 2**	**WCSS**
D3	0.0030	**Cluster 2**	**WCSS**	D2	0.0019	D2	0.0000
D4	0.0030	D2	0.0006	D4	0.0019	**Cluster 3**	**WCSS**
		D3	0.0006	**Cluster 3**	**WCSS**	D3	0.0000
				D3	0.0000	**Cluster 4**	**WCSS**
						D4	0.0000
Total	**1.5136**	**Total**	**0.0038**	**Total**	**0.0038**	**Total**	**0.0000**
DM2							
K= 1		**K= 2**		**K= 3**		**K= 4**	
Cluster 1	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**
D1	0.0017	D1	0.0013	D1	0.0000	D1	0.0000
D2	0.0017	D4	0.0013	**Cluster 2**	**WCSS**	**Cluster 2**	**WCSS**
D3	0.0042	**Cluster 2**	**WCSS**	D2	0.0019	D2	0.0000
D4	0.0030	D2	0.0019	D4	0.0019	**Cluster 3**	**WCSS**
		D3	0.0019	**Cluster 3**	**WCSS**	D3	0.0000
				D3	0.0000	**Cluster 4**	**WCSS**
						D4	0.0000
Total	**0.0106**	**Total**	**0.0063**	**Total**	**0.0038**	**Total**	**0.0000**
DM3							
K= 1		**K= 2**		**K= 3**		**K= 4**	
Cluster 1	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**	**Cluster 1**	**WCSS**
D1	0.0105	D1	0.0062	D1	0.0000	D1	0.0000
D2	0.0067	D4	0.0063	**Cluster 2**	**WCSS**	**Cluster 2**	**WCSS**
D3	0.0030	**Cluster 2**	**WCSS**	D2	0.0069	D2	0.0000
D4	0.0105	D2	0.0006	D4	0.0069	**Cluster 3**	**WCSS**
		D3	0.0006	**Cluster 3**	**WCSS**	D3	0.0000
				D3	0.0000	**Cluster 4**	**WCSS**
						D4	0.0000
Total	**0.0306**	**Total**	**0.0138**	**Total**	**0.0138**	**Total**	**0.0000**

Also, the elbow point is defined for selecting the optimal number of clusters by the dataset from the decision makers. Accordingly, Fig. 3 illustrates the plot of the values of WCSS against the number of k for the decision makers.

by considering the cluster weights of the dimensions. These values are presented in Table 4.

On the other side, the weights of the dimensions are defined based on the pareto principle. These values are demonstrated in Table 5.

In Table 5, it is seen that D2, D3, and D5 have the best priorities with the value of 0.33. To be able to illustrate the relative importance of all dimensions together, the normalized weights of the dimensions are also computed with the pareto principle. The Pareto Principle, also known as the 80/20 rule, is a powerful concept used in various fields, including decision-making and resource allocation. It states that for many phenomena, about 80 % of the consequences are produced by 20 % of the causes. Accordingly, the Pareto Principle helps identify the most significant factors in a set of data. For instance, it can help determine which dimensions (the 20 %) are contributing to the majority (80 %) of the effect. When it comes to computing the relative importance of dimensions among them, the Pareto Principle can be particularly useful. The normalized weights will be considered for ranking the alternatives in the following stage.

Table 5 states that energy security, market functioning, and innovation should be prioritized. Ensuring energy security is of strategic importance for European countries. The critical issue in this process is that these countries can access uninterrupted energy. Energy is one of the important raw materials in the industrial production process. Therefore, it is very vital to provide this energy need uninterruptedly. On the other hand, ensuring energy security also reduces the dependence of European countries on foreign energy. This situation helps to manage many problems such as oil price volatility more effectively. In this process, European countries need to take actions that can produce their own energy. Renewable energy projects should be given significant consideration here. In this way, countries will be able to both produce clean energy and achieve energy independence.

4.2. *Measuring the multidimensional performance for European energy union with AI-enhanced ranking (Stage 2)*

Step 5 defines the multidimensional performance perspectives for European energy union. In this process, the results of the literature review and balanced scorecard perspectives are taken into consideration. Table 6 explains the details of these perspectives

Step 6 consists of the collection of the linguistic evaluations of decision makers for the perspectives. The expert team consists of three people. Two of these people work in an international energy investment companies as a top manager. They have more than 29 years of working experience. In addition to them, the third decision maker is the academician that has lots of publications related to the energy economics, renewable energy investments and risk management in energy industry. The questions are created based on the perspectives given in Table 6. After that, online meetings are made with these people and their evaluations can be obtained. The scales and fuzzy numbers in Table 7 are used.

Step 7 computes the optimal k value for clustering the dimensions. The values of the WCSS are computed for the different number of clusters. In this case, the number of clusters is 4, from 1 to 4, the set of WCSS values for the decision makers are presented by the different k values as seen in Table 9.

According to the results, for K= 2, the WCSS value is minimized and optimized as adding more clusters will not significantly reduce the WCSS value.

Step 8 applies the K-means clustering algorithm for clustering the perspectives. The optimal value for K number is applied for defining the clusters of perspectives. In this example, the optimal value of K is 2. The iteration results of different 2 clusters are given in Table 10.

As seen in Table 10, the cluster assignment results are same with

Table 10
Iteration results of optimal cluster value.

Perspectives	Distance to C1	Distance to C2	Cluster Assignment
DM1			
Iteration 1 (P1 is in Cluster 1; P2 is in Cluster 2)			
Initial Cluster Centres			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.00	0.09	1
P2	0.09	0.00	2
P3	0.10	0.05	2
P4	0.07	0.09	1
Average of Data Points			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.04	0.09	1
P2	0.08	0.03	2
P3	0.09	0.02	2
P4	0.04	0.09	1
DM2			
Iteration 1 (P1 is in Cluster 1; P2 is in Cluster 2)			
Initial Cluster Centres			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.00	0.05	1
P2	0.05	0.00	2
P3	0.10	0.09	2
P4	0.07	0.09	1
Average of Data Points			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.04	0.07	1
P2	0.06	0.04	2
P3	0.09	0.04	2
P4	0.04	0.08	1
DM3			
Iteration 1 (P1 is in Cluster 1; P2 is in Cluster 2)			
Initial Cluster Centres			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.00	0.17	1
P2	0.17	0.00	2
P3	0.14	0.05	2
P4	0.16	0.17	1
Average of Data Points			
Perspectives	**Distance to C1**	**Distance to C2**	**Cluster Assignment**
P1	0.08	0.15	1
P2	0.15	0.03	2
P3	0.12	0.03	2
P4	0.08	0.15	1

initial cluster centres and average of data points for iteration 1. Thus, the clusters of the perspectives are considered as P1 and P4 are considered in cluster 1; P2 and P3 are listed in cluster 2.

Step 9 includes ranking the perspectives by considering the cluster priorities. The weighted standard deviations of the dimensions and the priorities by clusters are indicated in Table 11.

As seen in Table 11, the weighted standard deviations are computed by using the weights of the dimensions from stage 1. The priorities of the clusters are constructed by multiplying the values of the weighted mean SD and size of the cluster. The priorities of the perspectives and ranking results by the decision makers are identified in Table 12.

The priorities of the perspectives are computed by considering the size and the priority value in its cluster for each perspective. By listing in the descending order of the priorities, the ranking performances of the perspectives are defined for the decision makers. Overall priorities and ranking values are computed by considering the average values of the decision makers. Table 12 shows the priorities and the ranking results of the perspectives by the decision makers as well as the overall assessment.

4.3. Measuring the multidimensional performance for European energy union QPFR-VIKOR (Stage 3)

Step 10 gives information about the construction of the quantum picture fuzzy numbers for the decision matrix. The details of this matrix are shown in Table 13.

Step 11 identifies the quantum picture fuzzy rough sets for the decision matrix. The values are denoted in Table 14.

Step 12 computes the defuzzified decision values. Table 15 explains the details of these values.

Step 13 is related to the construction of Si, Ri, and Qi values. These values are presented in Table 16.

In case of maximum group utility (v: 0.9 and v:1), P1 and P4 have the best ranking performance among the perspectives. The results with the highest maximum group utility are same with the priority results of the AI-enhanced ranking technique.

Step 14 calculates the comparative ranking values with sensitivity analysis. Table 17 explains the details of these values.

With respect to the comparative evaluation, RATGOS model is taken into consideration. It is a very new ranking model that is created based on the main criticisms to the existing ranking approaches. Geometrical

Table 11
The weighted standard deviations of the dimensions and the priorities by clusters.

Cluster centre	Size	D1	D2	D3	D4	D5	Weighted Mean SD	Priorities
DM1								
Cluster centre	**Size**	**D1**	**D2**	**D3**	**D4**	**D5**	**Weighted Mean SD**	**Priorities**
C1	2	0.025	0	0	0	0.025	0.0093	0.0185
C2	2	0.00	0.03	0.00	0.00	0.00	0.0067	0.0135
DM2								
Cluster centre	**Size**	**D1**	**D2**	**D3**	**D4**	**D5**	**Weighted Mean SD**	**Priorities**
C1	2	0.025	0	0	0	0.025	0.0093	0.0185
C2	2	0.00	0.03	0.03	0.00	0.03	0.0203	0.0405
DM3								
Cluster centre	**Size**	**D1**	**D2**	**D3**	**D4**	**D5**	**Weighted Mean SD**	**Priorities**
C1	2	0.05	0	0.025	0.05	0.025	0.0235	0.0470
C2	2	0.00	0.03	0.00	0.00	0.00	0.0068	0.0135

Table 12
The priorities of the perspectives and ranking results by the decision makers.

Perspectives	DM1		DM2		DM3		Overall	
	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking	Priorities	Ranking
P1	0.289	1	0.157	2	0.388	1	0.278	1
P2	0.211	2	0.343	1	0.112	2	0.222	2
P3	0.211	2	0.343	1	0.112	2	0.222	2
P4	0.289	1	0.157	2	0.388	1	0.278	1

Table 13
Quantum picture fuzzy numbers for the decision matrix.

	D1	D2	D3	D4	D5
DM1					
P1	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$
P2	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
P3	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
P4	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
DM2	**D1**	**D2**	**D3**	**D4**	**D5**
P1	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$
P2	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$
P3	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
P4	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
DM3	**D1**	**D2**	**D3**	**D4**	**D5**
P1	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$
P2	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
P3	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$
P4	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.36}e^{j2\pi\cdot 0.6}, \sqrt{0.22}e^{j2\pi\cdot 0.37}, \sqrt{0.26}e^{j2\pi\cdot 0.02}, \sqrt{0.16}e^{j2\pi\cdot 0.01}\right]$	$\left[\sqrt{0.25}e^{j2\pi\cdot 0.50}, \sqrt{0.15}e^{j2\pi\cdot 0.31}, \sqrt{0.37}e^{j2\pi\cdot 0.12}, \sqrt{0.23}e^{j2\pi\cdot 0.07}\right]$	$\left[\sqrt{0.30}e^{j2\pi\cdot 0.55}, \sqrt{0.19}e^{j2\pi\cdot 0.34}, \sqrt{0.32}e^{j2\pi\cdot 0.07}, \sqrt{0.19}e^{j2\pi\cdot 0.04}\right]$

mean is taken into consideration in the analysis process [46]. Comparative results demonstrate that both QPFR-VIKOR, AI-enhanced ranking and RATGOS provide the same issues. This situation gives information about the consistency of the proposed model. On the other side, sensitivity analysis indicate that the results are the same for different cases. Hence, it is understood that the proposed model generates reliable findings. It is identified that financial feasibility and technological infrastructure have the best ranking performance. The main issues of importance in the European Energy Union project are ensuring energy efficiency and developing clean energy projects. In order to increase these investments, a large amount of financial resources are needed. In this process, the financial performance of projects is of vital importance. Financial institutions are more willing to provide funds for investments with high financial performance. In this way, countries can more easily achieve the goals of the energy union project. For the European energy union to be successful, technological development is also essential. Thanks to technological developments, it is possible to reduce the costs of renewable energy production. In this way, these energy types will be able to compete financially with fossil fuels. Thus, countries will be able to both achieve energy independence and increase clean energy production.

5. Discussion

It is very important that the financial performance of investments is high to effectively implement the European Energy Union strategies. Sustainability of projects can be ensured by ensuring that investments have high financial performance. This allows Energy Union strategies to be implemented more successfully. On the other hand, Rahi et al. [58] identified that financially successful businesses can attract more investors' attention. This contributes to these projects being able to access financial resources more easily. In this context, another important issue is the development of innovative financial products. According to Ferriani and Gazzani [59], this issue increases the alternatives for energy investment projects to find the financial resources they need more easily. Moreover, Sandberg et al. [60] identified that to increase the

Table 14
Quantum picture fuzzy rough sets for the decision matrix.

	D1	D2	D3	D4	D5
P1	$\lceil\sqrt{0.30},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$	$\lceil\sqrt{0.36},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.60,0.60\rfloor}$, $\lceil\sqrt{0.22},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.37,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.26}\rfloor\ e^{j2\pi.\lceil 0.02,0.02\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.16}\rfloor\ e^{j2\pi.\lceil 0.01,0.01\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.36},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.60,0.60\rfloor}$, $\lceil\sqrt{0.22},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.37,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.26}\rfloor\ e^{j2\pi.\lceil 0.02,0.02\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.16}\rfloor\ e^{j2\pi.\lceil 0.01,0.01\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$
P2	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.37},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.23},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.50,0.55\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.31,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.37}\rfloor\ e^{j2\pi.\lceil 0.07,0.12\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.23}\rfloor\ e^{j2\pi.\lceil 0.04,0.07\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.50,0.55\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.31,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.37}\rfloor\ e^{j2\pi.\lceil 0.07,0.12\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.23}\rfloor\ e^{j2\pi.\lceil 0.04,0.07\rfloor}$
P3	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.25}\rfloor\ e^{j2\pi.\lceil 0.50,0.50\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.15}\rfloor\ e^{j2\pi.\lceil 0.31,0.31\rfloor}$, $\lceil\sqrt{0.37},\sqrt{0.37}\rfloor\ e^{j2\pi.\lceil 0.12,0.12\rfloor}$, $\lceil\sqrt{0.23},\sqrt{0.23}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.55,0.55\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.34,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.04,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.25}\rfloor\ e^{j2\pi.\lceil 0.50,0.50\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.15}\rfloor\ e^{j2\pi.\lceil 0.31,0.31\rfloor}$, $\lceil\sqrt{0.37},\sqrt{0.37}\rfloor\ e^{j2\pi.\lceil 0.12,0.12\rfloor}$, $\lceil\sqrt{0.23},\sqrt{0.23}\rfloor\ e^{j2\pi.\lceil 0.07,0.07\rfloor}$
P4	$\lceil\sqrt{0.25},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.37},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.23},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$	$\lceil\sqrt{0.36},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.60,0.60\rfloor}$, $\lceil\sqrt{0.22},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.37,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.26}\rfloor\ e^{j2\pi.\lceil 0.02,0.02\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.16}\rfloor\ e^{j2\pi.\lceil 0.01,0.01\rfloor}$	$\lceil\sqrt{0.30},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.26},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.16},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.36}\rfloor\ e^{j2\pi.\lceil 0.55,0.60\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.22}\rfloor\ e^{j2\pi.\lceil 0.34,0.37\rfloor}$, $\lceil\sqrt{0.37},\sqrt{0.32}\rfloor\ e^{j2\pi.\lceil 0.02,0.07\rfloor}$, $\lceil\sqrt{0.23},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.01,0.04\rfloor}$	$\lceil\sqrt{0.25},\sqrt{0.30}\rfloor\ e^{j2\pi.\lceil 0.50,0.55\rfloor}$, $\lceil\sqrt{0.15},\sqrt{0.19}\rfloor\ e^{j2\pi.\lceil 0.31,0.34\rfloor}$, $\lceil\sqrt{0.32},\sqrt{0.37}\rfloor\ e^{j2\pi.\lceil 0.07,0.12\rfloor}$, $\lceil\sqrt{0.19},\sqrt{0.23}\rfloor\ e^{j2\pi.\lceil 0.04,0.07\rfloor}$

Table 15
The defuzzified decision values.

	D1	D2	D3	D4	D5
P1	0.396	0.409	0.381	0.409	0.396
P2	0.381	0.382	0.365	0.381	0.365
P3	0.381	0.381	0.346	0.381	0.346
P4	0.382	0.409	0.396	0.382	0.365

Table 16
Si, Ri, and Qi values.

	Si	Ri	Qi (v:0.1)	Qi (v:0.2)	Qi (v:0.3)	Qi (v:0.4)
P1	0.395	0.157	0.275	0.264	0.252	0.241
P2	0.426	0.113	0.021	0.043	0.064	0.086
P3	1.000	0.267	1.000	1.000	1.000	1.000
P4	0.269	0.156	0.252	0.224	0.196	0.168
	Qi (v:0.5)	**Qi (v:0.6)**	**Qi (v:0.7)**	**Qi (v:0.8)**	**Qi (v:0.9)**	**Qi (v:1)**
P1	0.229	0.218	0.207	0.195	0.184	0.173
P2	0.107	0.129	0.150	0.172	0.193	0.215
P3	1.000	1.000	1.000	1.000	1.000	1.000
P4	0.140	0.112	0.084	0.056	0.028	0.000

financial performance of investments, risk management must be carried out successfully. In this context, it is important to take the necessary measures against liquidity, exchange rate and operational risks. In this way, the possibility of financial losses arising from risks can be minimized. Adamkaite et al. [61] concluded that this situation has a powerful impact on the performance improvements of the energy investments. Owing to this condition, it can be much easier to implement the European Union's Energy Union strategies.

A high technological infrastructure of businesses is also necessary for the effective implementation of the European Union's Energy Union strategies. Thanks to high technological infrastructure, businesses can operate more efficiently in energy production and consumption. This significantly contributes to reducing the operational costs of businesses. This will affect the financial profitability of the projects in a very positive way. On the other hand, Aydin and Degirmenci [62] mentioned that owing to the high technological infrastructure, businesses can implement renewable energy projects more successfully. Projects such as wind and solar energy require a high degree of technological competence. Markowski and Kotliński [63] defined that in this context, it is possible to increase the performance of these projects by increasing technological investments. Similarly, Bashir et al. [64] identified that the performance of energy storage processes can increase due to high technological development. In this way, it is possible to store renewable energy in higher capacity at lower cost [65]. Thus, it is much more possible to increase the effectiveness and efficiency of energy investments.

On the other hand, some researchers in the literature have also emphasized the importance of customer satisfaction, contrary to the results of this study. High customer satisfaction contributes to the effective implementation of Energy Union strategies in many respects. Masoomi et al. [66] discussed that customer satisfaction enables energy policies to be accepted by society. This makes it easier for policies to be implemented more successfully. In addition to them, businesses should offer some technological solutions to ensure customer satisfaction. Owing to these actions, it is possible to achieve energy efficiency. This significantly supports the financial sustainability of the projects. Moreover, Ong et al. [67] identified that customer satisfaction provides competitive advantage to businesses in the energy sector. In this way, the sales volumes of companies that can reach more customers can also increase.

6. Conclusion

This study tries to find the important indicators of European Energy Union policy. A novel artificial intelligence-enhanced and hybrid quantum fuzzy ranking approach are taken into consideration in this regard. There are three different stages in this hybrid model. The first stage is related to the weighting the dimensions of the European energy union with AI-enhanced prioritization. The second stage consists of

Table 17
Comparative ranking values with sensitivity analysis.

QPFR-VIKOR (v:1)					
Perspectives	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
P1	Best	Best	Best	Best	Best
P2	Worst	Worst	Worst	Worst	Worst
P3	Worst	Worst	Worst	Worst	Worst
P4	Best	Best	Best	Best	Best
AI-enhanced ranking					
Perspectives	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
P1	Best	Best	Best	Best	Best
P2	Worst	Worst	Worst	Worst	Worst
P3	Worst	Worst	Worst	Worst	Worst
P4	Best	Best	Best	Best	Best
RATGOS ranking					
Perspectives	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
P1	Best	Best	Best	Best	Best
P2	Worst	Worst	Worst	Worst	Worst
P3	Worst	Worst	Worst	Worst	Worst
P4	Best	Best	Best	Best	Best

measuring the multidimensional performance for European energy union with artificial intelligence-enhanced ranking. In the final stage, the multidimensional performance for European energy union is evaluated by using Quantum picture fuzzy rough sets based VIKOR methodology. It is identified that energy security, market functioning, and innovation have the best priorities. In case of maximum group utility, financial feasibility and technological infrastructure have the best ranking performance among the perspectives. The results with the highest maximum group utility are same with the priority results of the AI-enhanced ranking technique.

For the European Energy Union to be successful, financial feasibility is critical to the economic sustainability of projects. It is possible to determine some policy and strategy recommendations to achieve this goal. Diversification of financial sources is essential to achieve this goal. In this way, it is possible to reduce the financial risks of businesses. Moreover, it is very important to develop innovative financial products in order to increase financial feasibility. With the development of more products, financing options for businesses can increase. This allows financing costs to be significantly reduced. In addition to them, government incentives should be offered for the development of renewable energy projects. The high initial costs of these projects negatively affect the development of these projects. To combat this problem more successfully, it is important to offer tax reductions by the state. Thus, businesses have an opportunity to reduce their operational costs.

The development of technological infrastructure is also very important for the performance development of this energy union. To achieve this goal, the most basic policy recommendation that can be offered is to invest in energy storage technologies. One of the most important problems in renewable energy projects is that they are negatively affected by different climatic conditions. This situation causes interruptions in energy production. The energy storage system is very critical for solving this problem. However, these storage systems may also create new costs. Therefore, it is important to reduce these costs by investing in energy storage technologies. On the other hand, in order to develop the technological infrastructure, legal regulations regarding energy production must also be made more effective. Thanks to these regulations, the confidence of both investors and consumers in the market and projects increases. As a result, it becomes much more possible to develop energy technology investments.

The main contribution of this study is making a comparative evaluation with both artificial intelligence approach and fuzzy decision-making methodology. This situation provides an opportunity check the validity of the findings. In the analysis process, a novel artificial intelligence-based ranking methodology is proposed. Therefore, more effective evaluations can be conducted. This situation helps to reach more appropriate findings. Additionally, an artificial intelligence-based valuation model has been applied for the selection of important dimensions for the European Energy Union. This situation provides significant guidance for policy makers and investors. The main limitation of this study is making an evaluation for only European countries. However, effective energy policies also play a critical role for developing economies. On the other side, the proposed model has also some limitations. In this model, the weights of the experts are considered as equal. Hence, in the future studies, the weights of the experts can be computed based on their qualifications, such as educational level and working experience.

CRediT authorship contribution statement

Serhat Yüksel: Writing – review & editing, Visualization, Validation, Resources, Investigation, Formal analysis. **peide liu:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis. **Hasan Dinçer:** Writing – original draft, Validation, Resources, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

(1) Disclosure of potential conflicts of interest

We declare that we do have no commercial or associative interests that represent a conflict of interests in connection with this manuscript. There are no professional or other personal interests that can inappropriately influence our submitted work.

(2) Research involving human participants and/or animals

This article does not contain any studies with human participants or animals performed by any of the authors.

Data availability

No data was used for the research described in the article.

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