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Multi-Perspective Strategic Analysis of Wind Energy Projects via AI-Integrated Quantum Fuzzy Recommender Approach

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ABSTRACT

This manuscript aims to examine the most important critical indicators of feasibility analysis for wind energy projects. Within this context, experts are weighted using an artificial intelligence (AI) methodology. Secondly, missing evaluations are estimated via an expert recommender system. Thirdly, the balanced scorecard-based feasibility criteria are weighted with the help of Quantum Picture Fuzzy Rough Sets (QPFR)-based M-SWARA. Finally, selected project feasibility items for wind energy firms are ranked using QPFR-VIKOR. The main contribution of this study is the use of an artificial intelligence technique in the proposed model to compute the weights of the experts. This approach provides an opportunity to achieve more effective results. Customer expectation is identified as the most essential criterion in the balanced scorecard-based feasibility analysis. Environmental assessment of long-term effects is the most critical project feasibility item for wind energy firms. Cost-benefit analysis, considering economic, sectoral, and project-based conditions, also plays a critical role in this respect.

1. Introduction

Feasibility analysis is very necessary for the performance improvements of wind energy investments (WEI). Owing to this analysis, cost analysis of projects can be made. Feasibility analysis contributes significantly to the effective management of this problem. Another disadvantage of these projects is that the returns are obtained in the long term. With this feasibility analysis, the net payback period of projects can be calculated accurately. In addition to the mentioned issues, feasibility analysis is also important in evaluating the technical suitability of wind energy projects [1]. In other words, feasibility analyzes have an effective role in determining the most suitable locations for these projects. On the other side, feasibility analysis helps to effectively manage risks for WEI. With the help of this analysis, risks to the project can be accurately determined. For the feasibility analysis of wind energy projects to be perform, some factors need to be improved. First, financial

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performance is very important for these projects to be successful. As long as wind energy investments can be financially successful, they will attract the attention of investors. Customers expect both quality service and low costs. On the other hand, ensuring organizational effectiveness is also necessary for the success of WEI [2]. Thanks to organizational effectiveness, coordination between different departments in the workplace becomes easier. However, the biggest disadvantage of making these improvements is the increase in costs. Considering this, high costs resulting from too many improvements may cause the profitability of the project to decrease [3]. To eliminate this problem, it would be more reasonable to make improvements only for the factors that are very important. Therefore, it is necessary to identify the most important factors affecting the feasibility analysis's success. However, there are few studies focusing on this issue in the literature. This case emerges as the most critical gap in the previous studies regarding the feasibility analysis of wind energy projects.

Accordingly, the purpose of this study is to evaluate the most important items for feasibility analysis for wind energy projects. In this process, experts are evaluated via AI methodology. Secondly, missing evaluation are estimated with the help of expert recommender system. Thirdly, the balanced scorecard-based feasibility criteria are weighted by the help of QPFR-M-SWARA. Finally, selected project feasibility items for wind energy firms are ranked with QPFR-VIKOR. The main motivation of this study is the need to evaluate the feasibility analysis of these projects with a novel and comprehensive decision-making model. Most of the models in the literature do not consider the weights of the experts. However, the evaluations of these people should not be considered with equal weight because of their different demographical factors. To satisfy this problem, artificial intelligence technique is used in this proposed model to compute the weights of the experts.

The basic contributions of this manuscript are given below. (i) Considering collaborative filtering provides some benefits. In most of the decision systems in the literature, the DMs have to give opinions for all questions. In other words, they cannot make empty for some of them. This situation creates some problems when experts do not have sufficient information for some issues. In this process, they give their opinions although they are not sure. This condition has a decreasing effect on the appropriateness of the analysis results. To solve this problem, collaborative filtering technique is adopted to this proposed model so that it becomes possible for the experts not to give evaluations for some questions. (ii) Using M-SWARA method to compute prioritization the criteria has a important contribution to the literature. This technique is constructed by making some improvements to the traditional SWARA approach. Using improvements, the causal directions of the indicators can be taken into consideration while making evaluations. The performance determinants of the feasibility analysis in wind energy projects can have an influence on each other. Because of this condition, considering M-SWARA technique in the analysis process provides some important advantages to the proposed model. (iii) Using balanced scorecard to define the indicators has some advantages. This approach considers both financial and nonfinancial issues, such as customer expectation and organizational effectiveness. Owing to this situation, a more comprehensive evaluation can be conducted.

Previous studies are given in the next section. In the third part, the recommended methodology is defined. Analysis findings are given in the following section. Finally, discussion and conclusion are presented.

Many different variables are important for the feasibility analysis of WEI. For example, for these projects to be successful, financial performance must be high. Elkadeem *et al.,* [4] identified that since wind energy projects are large-scale investments, initial investment costs are quite high. When these issues are taken into consideration, it is very necessary to ensure the cost success of the projects. Bimenyimana *et al.,* [5] and Kusuma *et al.,* [6] concluded that it is necessary to perform a comprehensive financial performance analysis and predict the long-term performance of investments [7, 8]. On the other hand, Wang *et al.,* [9] and Al-Sumri *et al.,* [10] underlined that the financial success of the projects also increases investors' interest in these investments. Investors prefer projects with high profitability. Sun *et al.,* [11] and Brunner *et al.,* [12] defined that investments with high performance can find investors more easily. This allows projects to access financial resources more easily.

Meeting customer expectations is another important issue for the successful feasibility analysis of wind energy projects. In this context, primarily, wind energy projects must fully meet the electricity demand of customers. Imam *et al.,* [13] defined that the capacity of the amount of electricity produced in these projects must be sufficient to meet the demand of customers. Otherwise, the dissatisfaction of customers whose needs are not fully met increases. According to le Maitre *et al.,* [14] and Jurasz *et al.,* [15], another expectation of customers in this context is the continuous energy supply. Uninterrupted energy production supports a significant increase in customer satisfaction. Nassar *et al.,* [16] defined that another thing that can be taken into consideration in this regard is the sufficient technical infrastructure of wind energy projects. Otherwise, power outages disrupt the production process of commercial enterprises. Schmidt *et al.,* [17] and le Maitre *et al.,* [18] determined that an important expectation of customers from wind energy investors is reasonable pricing. Too high prices cause customers to turn to other energy sources [19].

Providing organizational effectiveness is another issue that must be taken into consideration to ensure high performance of wind energy projects. Caporale *et al.,* [20] and Ye *et al.,* [21] highlighted that working in coordination with each other to ensure the success of these projects. This allows resources to be used efficiently [22]. Thus, it is possible to increase the operational efficiency of businesses. On the other hand, Gao *et al.,* [23] underlined that ensuring organizational effectiveness also enables risk management to be successful. As a result of the coordinated work of departments, the risks of the business can be determined accurately. Schneider and Rinscheid [24] stated that it is possible for businesses to take the right precautions against these risks in a timely manner. Ramakrishnan *et al.,* [25] and Nymphas and Teliat [26] indicated that since this will contribute significantly to cost efficiency, it may be easier to improve WEI.

Ensuring effective market conditions also supports increasing the performance of wind energy projects. Zhao *et al.,* [27] showed that stability of energy prices can be ensured by ensuring correct market conditions. Since price stability will increase the predictability of projects, investors' uneasiness about the market decreases. In addition, Borissova [28] defined that necessary measures must be taken to ensure fair competition in the market. This situation allows investors to increase their confidence in the market. Moreover, Chen *et al.,* [29] identified that government incentives also contribute significantly to achieving this goal. Such incentives provide significant cost effectiveness to projects. Therefore, investors are more willing to invest in such a market [30]. Bonthu *et al.,* [31] and Parush and Shmueli [32] concluded that technological development in the energy sector will reduce costs, investors will be able to invest more in these markets.

It is possible to reach some conclusions in the literature review regarding the feasibility analysis of wind energy projects. In the analysis, some performance indicators such as financial performance, customer satisfaction and organizational effectiveness come to the fore. This situation informs us that in order for these projects to be successful in the long term, not only financial but also non-financial issues should be taken into account. On the other hand, although there are many studies highlighting the importance of these factors, there are a limited number of studies examining which of these variables are more important. To offer wind energy investors investment strategies that do not cause high costs, a priority analysis must be made for these variables. The lack of sufficient number of studies on this situation is an important missing part on this subject. In order to complete this deficiency mentioned in this study, a priority analysis is carried out for the factors affecting the performance of wind energy projects with a new model.

2. Methodology

In this article, the aim is to determine the most appropriate feasibility analysis in wind energy projects based on balanced scorecard. Ranking the alternatives for feasibility analysis constitutes the main purpose of the study. For ranking analysis, the VIKOR method, one of the multi-criteria decision-making techniques, is preferred. The main reason for this is that the validity of the results is high since the method is based on consensus logic. In the VIKOR method, a list of criteria is required as well as alternatives. A balanced scorecard-based criteria set is created to perform the analysis. In other words, the set of criteria used in the evaluation of feasibility analyzes of WEI is obtained. The M-SWARA method is used to prioritization the balanced scorecard-based criteria set. The stages and steps of the proposed model are detailed in Figure 1.

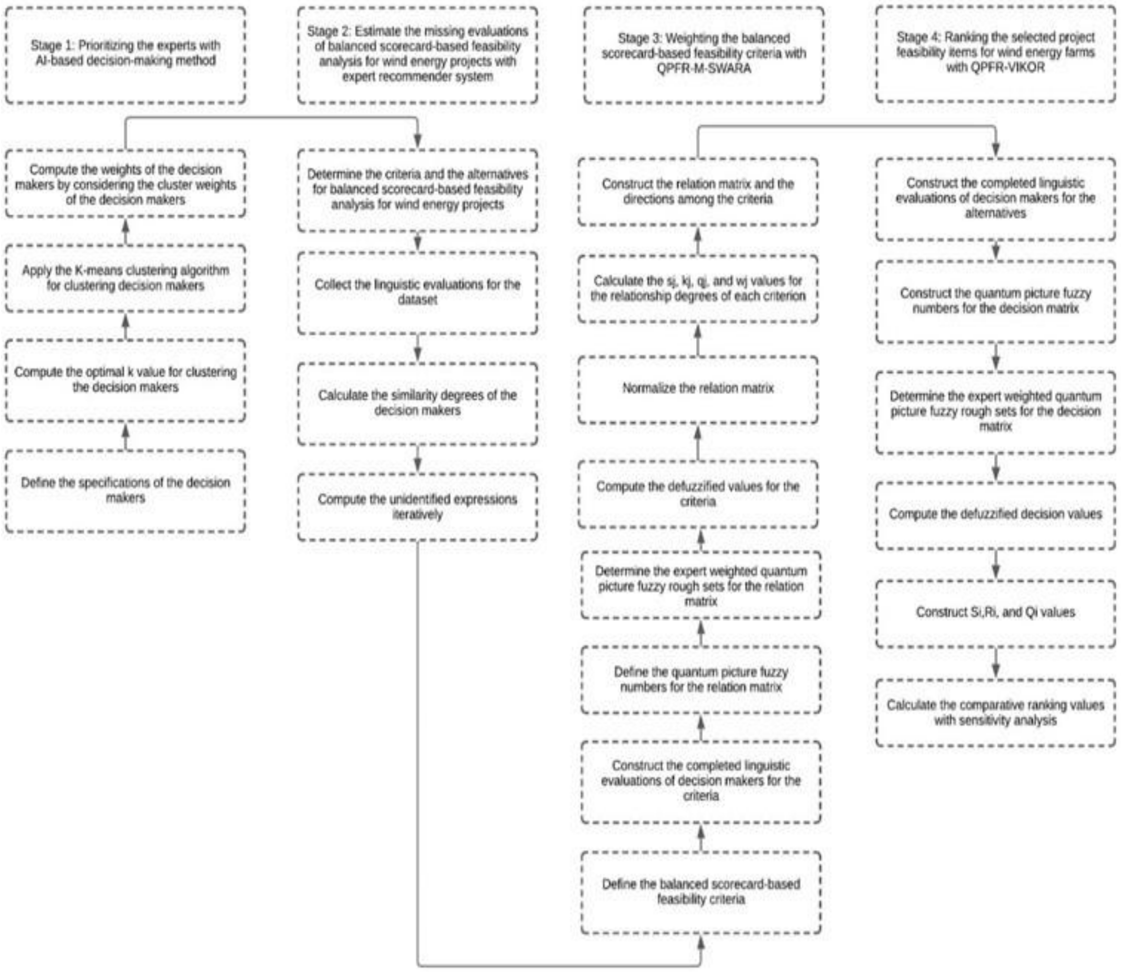

Fig. 1. The flowchart of hybrid model

Each stage in Figure 1 is summarized with subtitles.

2.1 DMs Prioritization

Giving equal importance to experts is a situation that has been frequently criticized recently. WCSS with different values of cluster's number are calculated by Equation (1).

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

Experts are grouped with Equations (2) and (3),

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

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

The mean standard deviations (s_j) are calculated using between Equations (4) to (6).

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

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

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

σ_{jl} represents the standard deviation of l-feature in jth-cluster. $\bar{x}_{jl}$ is the mean of l-feature in jth-cluster. Afterwards, the cluster weights (w_j) are found using Equation (7).

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

Expert weights are defined via Equation (8).

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

2.2. *Collaborative Filtering*

In expert opinion models, experts may sometimes not want to express their opinion or make incomplete evaluations. In two cases, asking for a second opinion from the expert can negatively impact both time and the validity of the analysis. Requiring expert evaluation can be misleading. Therefore, the following method steps are recommended to complete the missing data [33]. Equation (9) indicates the degrees for similarity.

$$sim(u, v) = \frac{\sum_{i \in I} \left(r_{u,i} - \overline{r_u}\right)\left(r_{v,i} - \overline{r_v}\right)}{\sqrt{\sum_{i \in I} \left(r_{u,i} - \overline{r_u}\right)^2} \sqrt{\sum_{i \in I} \left(r_{v,i} - \overline{r_v}\right)^2}} \tag{9}$$

Equation (10) is used to complete the missing assessments.

$$p_{u,i} = \frac{\sum_{j \in S} sim(u,v) r_{u,j}}{\sum_{j \in S} |sim(u,v)|} \tag{10}$$

2.3. *QPFRS*

Quantum theory is used with fuzzy decision-making approach via Equations (11) to (13) [34].

$$Q(|u>) = \varphi e^{j\theta} \tag{11}$$

$$|C> = \{|u_1>, |u_2>, \dots, |u_n>\} \tag{12}$$

$$\sum_{|u> \subseteq |C>} |Q(|u>)| = 1 \tag{13}$$

Equations (14)-(16) focus on different fuzzy sets.

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

$$A=\{\langle x,\mu_A(x),v_A(x)\rangle|x\in X\} \tag{15}$$

$$A=\{\langle x,\mu_A(x),n_A(x),v_A(x),h_A(x)\rangle|x\in X\} \tag{16}$$

Equations (17)-(21) are used for mathematical process.

$$A\subseteq B \text{ if } \mu_A(x)\leq\mu_B(x) \text{ and } n_A(x)\leq n_B(x) \text{ and } v_A(x)\geq v_B(x), \forall x\in X\ ) \tag{17}$$

$$A=B \text{ if } A\subseteq B \text{ and } B\subseteq A \tag{18}$$

$$A\cup B=\left\{\left(x,max\left(\mu_A(x),\mu_B(x)\right),min\left(n_A(x),n_B(x)\right),min\left(v_A(x),v_B(x)\right)\right)|x\in X\right\} \tag{19}$$

$$A\cap B=\left\{\left(x,min\left(\mu_A(x),\mu_B(x)\right),min\left(n_A(x),n_B(x)\right),max\left(v_A(x),v_B(x)\right)\right)|x\in X\right\} \tag{20}$$

$$coA=\bar{A}=\left\{\left(x,v_A(x),n_A(x),\mu_A(x)\right)|x\in X\right\} \tag{21}$$

The rough number includes lower ($\underline{Apr}(C_i)$)-upper ($\overline{Apr}(C_i)$) approximation and rough boundary intervals ($Bnd(C_i)$) as detailed in Equations (22)-(24).

$$\underline{Apr}(C_i)=\cup\left\{Y\in\frac{X}{R(Y)}\leq C_i\right\} \tag{22}$$

$$\overline{Apr}(C_i)=\cup\left\{Y\in\frac{X}{R(Y)}\geq C_i\right\} \tag{23}$$

$$Bnd(C_i)=\cup\left\{Y\in\frac{X}{R(Y)}\neq C_i\right\} \tag{24}$$

Lower ($\underline{Lim}(C_i)$), upper ($\overline{Lim}(C_i)$) limits and the rough number ($RN(C_i)$) of C_i are shown with the help of the Equations (25)-(28).

$$\underline{Lim}(C_i)=\sqrt[N_L]{\prod_{i=1}^{N_L}Y\in\underline{Apr}(C_i)} \tag{25}$$

$$\overline{Lim}(C_i)=\sqrt[N_U]{\prod_{i=1}^{N_U}Y\in\overline{Apr}(C_i)} \tag{26}$$

$$RN(C_i)=\left[\underline{Lim}(C_i),\overline{Lim}(C_i)\right] \tag{27}$$

$$|C_A>=\left\{\begin{matrix}\langle u,(\left[\underline{Lim}\left(C_{i\mu_A}\right),\overline{Lim}\left(C_{i\mu_A}\right)\right](u),\left[\underline{Lim}\left(C_{in_A}\right),\overline{Lim}\left(C_{in_A}\right)\right](u),\\ \left[\underline{Lim}\left(C_{iv_A}\right),\overline{Lim}\left(C_{iv_A}\right)\right](u),\left[\underline{Lim}\left(C_{ih_A}\right),\overline{Lim}\left(C_{ih_A}\right)\right](u))|u\in 2^{|C_A>}\end{matrix}\right\} \tag{28}$$

Equations (29)-(46) identify important items of picture fuzzy sets.

$$\underline{Lim}\left(C_{i\mu_A}\right)=\frac{1}{N_{L\mu_A}}\sum_{i=1}^{N_{L\mu_A}}Y\in\underline{Apr}\left(C_{i\mu_A}\right) \tag{29}$$

$$\underline{Lim}\left(C_{in_A}\right)=\frac{1}{N_{Ln_A}}\sum_{i=1}^{N_{Ln_A}}Y\in\underline{Apr}\left(C_{in_A}\right) \tag{30}$$

$$\underline{Lim}\left(C_{iv_A}\right)=\frac{1}{N_{Lv_A}}\sum_{i=1}^{N_{Lv_A}}Y\in\underline{Apr}\left(C_{iv_A}\right) \tag{31}$$

$$\underline{Lim}\left(C_{ih_A}\right)=\frac{1}{N_{L\pi_A}}\sum_{i=1}^{N_{L\pi_A}}Y\in\underline{Apr}\left(C_{ih_A}\right) \tag{32}$$

$$\overline{Lim}\left(C_{i\mu_A}\right)=\frac{1}{N_{U\mu_A}}\sum_{i=1}^{N_{U\mu_A}}Y\in\overline{Apr}\left(C_{i\mu_A}\right) \tag{33}$$

$$\overline{Lim}\left(C_{in_A}\right)=\frac{1}{N_{Un_A}}\sum_{i=1}^{N_{Un_A}}Y\in\overline{Apr}\left(C_{in_A}\right) \tag{34}$$

$$\overline{Lim}\left(C_{iv_A}\right) = \frac{1}{N_{Uv_A}} \sum_{i=1}^{N_{Uv_A}} Y \in \overline{Apr}\left(C_{iv_A}\right) \tag{35}$$

$$\overline{Lim}\left(C_{ih_A}\right) = \frac{1}{N_{U\pi_A}} \sum_{i=1}^{N_{U\pi_A}} Y \in \overline{Apr}\left(C_{ih_A}\right) \tag{36}$$

$$\underline{Apr}\left(C_{i\mu_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{i\mu_A}\right\} \tag{37}$$

$$\underline{Apr}\left(C_{in_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{in_A}\right\} \tag{38}$$

$$\underline{Apr}\left(C_{iv_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{iv_A}\right\} \tag{39}$$

$$\underline{Apr}\left(C_{ih_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{ih_A}\right\} \tag{40}$$

$$\overline{Apr}\left(C_{i\mu_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{i\mu_A}\right\} \tag{41}$$

$$\overline{Apr}\left(C_{in_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{in_A}\right\} \tag{42}$$

$$\overline{Apr}\left(C_{iv_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{iv_A}\right\} \tag{43}$$

$$\overline{Apr}\left(C_{ih_A}\right) = \cup \left\{Y \in \frac{X}{\tilde{R}(Y)} \leq C_{ih_A}\right\} \tag{44}$$

$$C = \left[C_{\mu}.\, e^{j2\pi.\alpha}, C_{n}.\, e^{j2\pi.\gamma}, C_{v}.\, e^{j2\pi.\beta}, C_{h}.\, e^{j2\pi.T}\right] \tag{45}$$

$$\varphi^2 = \left|C_{\mu}(|u_i >)\right| \tag{46}$$

Degree calculation details are shown in Equations (47)-(51).

$$C_n = \frac{C_{\mu}}{G} \tag{47}$$

$$C_h = \frac{C_v}{G} \tag{48}$$

$$\alpha = \left|C_{\mu}(|u_i >)\right| \tag{49}$$

$$\gamma = \frac{\alpha}{G} \tag{50}$$

$$T = \frac{\beta}{G} \tag{51}$$

Equations (52)-(55). λ is a positive value.

$$\lambda * \tilde{A}_c = \begin{Bmatrix} \left[\underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)\lambda\right|\, e^{j2\pi.\left[\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda\right|}, \left[\underline{Lim}\left(C_{n_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{n_{\tilde{A}}}\right)\lambda\right|\, e^{j2\pi.\left[\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda\right|}, \\ \left[\underline{Lim}\left(C_{v_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{v_{\tilde{A}}}\right)\lambda\right|\, e^{j2\pi.\left[\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda\right|}, \left[\underline{Lim}\left(C_{h_{\tilde{A}}}\right)\lambda, \overline{Lim}\left(C_{h_{\tilde{A}}}\right)\lambda\right|\, e^{j2\pi.\left[\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)\lambda\right|} \end{Bmatrix} \tag{52}$$

$$\tilde{A}_c{}^{\lambda} = \begin{Bmatrix} \left[\underline{Lim}\left(C_{\mu_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{\mu_{\tilde{A}}}\right)^{\lambda}\right|\, e^{j2\pi.\left[\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)^{\lambda}\right|}, \left[\underline{Lim}\left(C_{n_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{n_{\tilde{A}}}\right)^{\lambda}\right|\, e^{j2\pi.\left[\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)^{\lambda}\right|}, \\ \left[\underline{Lim}\left(C_{v_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{v_{\tilde{A}}}\right)^{\lambda}\right|\, e^{j2\pi.\left[\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)^{\lambda}\right|}, \left[\underline{Lim}\left(C_{h_{\tilde{A}}}\right)^{\lambda}, \overline{Lim}\left(C_{h_{\tilde{A}}}\right)^{\lambda}\right|\, e^{j2\pi.\left[\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)^{\lambda}, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)^{\lambda}\right|}, \end{Bmatrix} \tag{53}$$

$$\tilde{A}_c \cup \tilde{B}_c =$$

$$\left\{\begin{array}{l} \left[min\left(\underline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), max\left(\overline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[min\left(\underline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), max\left(\overline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[min\left(\underline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), max\left(\overline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[min\left(\underline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), max\left(\overline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right)\right] \end{array}\right\} \quad (54)$$

$$\tilde{A}_c \cap \tilde{B}_c =$$

$$\left\{\begin{array}{l} \left[max\left(\underline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), min\left(\overline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[max\left(\underline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), min\left(\overline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[max\left(\underline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), min\left(\overline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right)\right], \\ \left[max\left(\underline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), min\left(\overline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right)\right] \end{array}\right\} \quad (55)$$

2.4. M-SWARA

The QPFRS integrated version of the M-SWARA method is mentioned below [35]. Equation (56) identifies relation matrix obtained by considering the assessments of the experts.

$$C_k = \begin{bmatrix} 0 & C_{12} & \cdots & \cdots & C_{1n} \\ C_{21} & 0 & \cdots & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (56)$$

Expert weighted version of this matrix can be constructed by Equations (57) and (58).

$$w_k \times \mathrm{C} \quad (57)$$

$$\mathrm{C} = \left(\begin{array}{l} \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{\mu_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{\mu_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^{k}\left(\frac{\underline{\alpha}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{n_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{n_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^{k}\left(\frac{\underline{\gamma}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{v_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{v_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^{k}\left(\frac{\underline{\beta}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{h_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{h_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^{k}\left(\frac{\underline{T}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right]} \end{array}\right) \quad (58)$$

Defuzzified values are determined via Equation (59).

$$Defc_i = \frac{\begin{pmatrix} \underline{Lim}\left(C_{\mu_i}\right)-\underline{Lim}\left(C_{n_i}\right)+\underline{Lim}\left(C_{\mu_i}\right).\left(\underline{Lim}\left(C_{v_i}\right)-\underline{Lim}\left(C_{h_i}\right)\right)+\left(\frac{\underline{\alpha}_{ij}}{2\pi}\right)-\left(\frac{\underline{\gamma}_{ij}}{2\pi}\right)+\left(\frac{\underline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\underline{\beta}_{ij}}{2\pi}\right)-\left(\frac{\underline{T}_{ij}}{2\pi}\right)\right)+ \\ \overline{Lim}\left(C_{\mu_i}\right)-\overline{Lim}\left(C_{n_i}\right)+\overline{Lim}\left(C_{\mu_i}\right).\left(\overline{Lim}\left(C_{v_i}\right)-\overline{Lim}\left(C_{h_i}\right)\right)+\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)-\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)+\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)-\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{pmatrix}}{2} \tag{59}$$

Comparative significance (sj), coefficient (kj), recomputed weight (qj) and weights (wj) are identified by Equations (60) to (62).

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{60}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \qquad If\ s_{j-1} = s_j,\ q_{j-1} = q_j \quad If\ s_j = 0,\ k_{j-1} = k_j \tag{61}$$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{62}$$

2.5. VIKOR

The QPFRS integrated version of the VIKOR method, which uses metric distance like TOPSIS, is given below [36]. Decision matrix is created by Equation (63).

$$X_k = \begin{bmatrix} X_{11} & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & X_{\mathrm{nm}} \end{bmatrix} \tag{63}$$

Mean group utility (Si), maximal regret (Ri) and final ranking (Qi) cen be identified via Equations (64)-(67).

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \text{ and } \tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{64}$$

$$\tilde{S}_i = \sum_{i=1}^{n} \widetilde{w}_j \frac{\left(\left|\tilde{f}_j^{\,*} - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^{\,*} - \tilde{f}_j^{\,-}\right|\right)} \tag{65}$$

$$\tilde{R}_i = max_j \left[\widetilde{w}_j \frac{\left(\left|\tilde{f}_j^{\,*} - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^{\,*} - \tilde{f}_j^{\,-}\right|\right)}\right] \tag{66}$$

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right)/\left(\tilde{S}^- - \tilde{S}^*\right) + (1-v)\left(\tilde{R}_i - \tilde{R}^*\right)/\left(\tilde{R}^- - \tilde{R}^*\right) \tag{67}$$

3. Results

The findings are given below.

3.1. Defining the significance coefficients of the experts

Experts are tabulated in Table 1.

Table 1
Specifications of the Decision Makers

Decision Maker	Education	Experience (year)	Salary (USD)	Age
DM1 (Landowner)	Bachelor	18	2000	44
DM2 (Landowner)	Bachelor	19	2100	46
DM3 (Investor)	PhD	14	2400	42
DM4 (Investor)	Master	16	2300	40
DM5 (Expert)	Master	12	2300	42
DM6 (Expert)	PhD	14	2100	46

Equations (1)-(8) are implemented in this process. The weights of them are demonstrated in Table 2.

Table 2
Experts' weights

Decision Makers	Weights
DM1	0.00
DM2	0.10
DM3	0.27
DM4	0.27
DM5	0.27
DM6	0.10

DM3, DM4, and DM5 are found as the most significant experts. However, there is no significance weight for DM1. Because of this issue, the assessments of DM1 are not taken into consideration.

3.2. Completing blank assessments

Balanced scorecard-based feasibility analysis for wind energy projects are coded in Table 3.

Table 3
Criteria set for balanced scorecard-based feasibility analysis for wind energy projects

Criteria	Codes
Financial performance	FINPER
Customer expectations	CUSEXP
Organizational competency	ORGCOM
Market conditions	MARCON

Selected project feasibility items for wind energy farms are coded in Table 4.

Table 4
Selected project feasibility items for wind energy firms

Alternatives	Codes
Site selection ensuring optimal placement	SITE
Technical evaluation including technology and design	TCDG
Cost-benefit analysis considering economic, sectoral and project-based conditions	CSPC
Environmental assessment for the long-term effects	EALT

In this process, Equations (9) and (10) are implemented. Completed assessments are presented.

3.3. Evaluating the balanced scorecard-based feasibility criteria

Assessments regarding the criteria are collected. Relation matrix and expert weighted values are given. Defuzzification and normalization procedures are applied. Critical values and relation matrix are obtained. The weights are displayed in Table 5.

Table 5
Stable Matrix

	FINPER	CUSEXP	ORGCOM	MARCON
FINPER	0.208	0.208	0.208	0.208
CUSEXP	0.276	0.276	0.276	0.276
ORGCOM	0.263	0.263	0.263	0.263
MARCON	0.253	0.253	0.253	0.253

Customer expectations and organizational competency are found as the most essential determinants. On the other side, the weight of market conditions is .253. In addition to them, financial performance is the last criterion via a weight of 0.208.

3.4. Ranking the selected project feasibility items for wind energy firms

Completed assessments for the selected project feasibility items are demonstrated in Table 6.

Table 6
Completed opinions for the selected project feasibility items

	FINPER	CUSEXP	ORGCOM	MARCON
DM2				
SITE	B	G	G	F
TCDG	B	F	F	B
CSPC	G	B	G	B
EALT	G	G	B	G
DM3				
SITE	B	G	G	F
TCDG	G	B	G	B
CSPC	G	B	G	B
EALT	F	B	F	B
DM4				
SITE	G	G	F	G
TCDG	F	F	G	F
CSPC	G	F	G	F
EALT	B	G	G	F
DM5				
SITE	B	B	G	F
TCDG	G	B	G	G
CSPC	G	G	F	B
EALT	F	G	F	F
DM6				
SITE	G	G	B	G
TCDG	F	B	G	F
CSPC	G	B	F	G
EALT	B	G	G	F

Picture fuzzy and tough values are explained. After that, defuzzified values are indicated. S, R and Q values are illustrated. After that, comparative examinations are conducted with TOPSIS. Table 7 summarizes the comparative evaluation results.

Table 7
Sensitivity and comparison results

Extended VIKOR (v:.5)				
	Case			
	#1	#2	#3	#4
SITE	3	3	3	3
TCDG	4	4	4	4
CSPC	2	2	2	2
EALT	1	1	1	1

Table 7
Continued

Extended TOPSIS				
	Case			
	#1	#2	#3	#4
SITE	3	3	3	3
TCDG	4	4	4	4
CSPC	2	2	2	2
EALT	1	1	1	1

The most optimal project feasibility item for wind energy farms is environmental assessment for the long-term effects. The next optimal item is cost-benefit analysis considering economic, sectoral and project-based conditions.

4. Conclusions

It is determined that meeting customer expectations is very important for wind energy projects to be successful. Although these projects are environmentally friendly, customer satisfaction is essential to ensure long-term continuity. One of the biggest expectations of customers from these projects is to meet the need for quality and safe electricity. Electricity plays an important raw material role, especially for industrial producers. Therefore, the electricity provided especially to businesses must be uninterrupted. Otherwise, it may cause disruptions in the uninterrupted electricity production process. Dugstad *et al.,* [37] discussed that this situation causes significant financial losses to businesses. To prevent these problems from occurring, wind energy investors need to invest in the development of their technical infrastructure. Li *et al.,* [38] concluded that disruptions in the operation of wind energy projects can be minimized by using up-to-date technology and employing qualified personnel. On the other hand, Christodoulou *et al.,* [39] and Rybak *et al.,* [40] highlighted that customers often want to purchase energy at economical, and competitive prices. To achieve this goal, investors need to take measures to reduce operational costs. This allows investors to offer reasonable prices to customers while preserving their profit margin.

Organizational effectiveness is another issue required for wind energy projects to be successful. There are quite complex processes in wind energy projects. To avoid disruptions in these different processes, departments within the company must operate in an integrated manner with each other. In this context, the top management of the business should take the necessary measures to ensure this coordination. Similarly, organizational effectiveness ensures that risks the project may face are effectively managed. Batablinlè *et al.,* [41] and Jalili *et al.,* [42] demonstrated that it is possible to take appropriate measures against existing risks in a timely manner. In addition to them, another issue that is important for the success of wind energy investments is technological competence. Mohamed *et al.,* [43] concluded that for these projects to be successful in the long term, innovative technologies must be implemented. Shao *et al.,* [44] and Dhoska *et al.,* [45] identified that organizational effectiveness also contributes significantly to wind energy investors' ability to achieve technological development. Bououbeid *et al.,* [46] underlined that coordinated work of different departments operating within the business helps to effectively continue research on the development of innovative technology.

The results obtained in this study show that nonfinancial variables are more important. The profitability of these projects must be high to ensure long-term performance increase. Otherwise, investors are reluctant towards these projects. In this context, businesses must first perform a comprehensive cost analysis. In this way, it is possible to reduce costs to a reasonable level. This also contributes to increasing the profit margin of the business. Rosales-Valladares *et al.,* [47] determined that minimizing liquidity risk is also necessary to ensure the financial improvements of WEI. In this context, it is important for businesses to conduct a comprehensive cash flow analysis. Cacciuttolo *et al.,* [48] and Wang *et al.,* [49] highlighted that this situation allows businesses to increase their liquidity power. Similarly, exchange rate risk is another important issue for wind energy investors. Some raw materials of these investments may be imported from other countries. Abdullah-Al-Mahbub and Islam [50] showed that this condition causes the exchange rate risk of businesses to increase. According to Zhang *et al.,* [51] and Obane *et al.,* [52], to manage these risks effectively, necessary precautions must be taken by using financial derivative products.

In this study, it is aimed to identify the most important performance indicators of feasibility analysis for wind energy projects. The expert weights are computed via AI methodology. Secondly, missing evaluation are estimated with the help of expert recommender system. Thirdly, the balanced scorecard-based feasibility criteria are weighted by the help of QPFR-M-SWARA. Finally, selected project feasibility items for wind energy firms are ranked with QPFR-VIKOR. The findings denote that customer expectation is the most essential item for balanced scorecard-based feasibility analysis. Environmental assessment for the long-term effects is the most critical project feasibility item for wind energy firms. Cost-benefit analysis considering economic, sectoral and project-based conditions plays also a key role in this process.

The main contribution of this study is that artificial intelligence technique is used in this proposed model to compute the weights of the experts. This situation provides an opportunity to reach more effective results. Considering collaborative filtering provides some benefits. With the help of this issue, it becomes possible for the experts not to give evaluations for some questions. The basic limitation of this manuscript is that only wind energy companies are evaluated. However, other renewable energy types also play an important role for sustainable energy production. Therefore, solar energy projects can be examined in the following studies. Project feasibility item for wind energy firms are ranked by considering VIKOR technique. Nonetheless, this methodology is also criticized in some studies due to some reasons. Thus, a novel ranking model can be introduced in the next studies by satisfying these disadvantages.

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Conflicts of Interest

The authors declare no conflicts of interest.

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