Development of Wind Energy in the Agricultural Sector of Iran and Investment Priorities of the Decision Maker Groups using Artificial Intelligence-based Quantum Hybrid Picture Fuzzy Rough Modelling

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Abstract— The main purpose of this study is to make evaluations for the indicators of wind energy investments in Iranian agricultural sector. For this purpose, a novel model is constructed that has three different stages. Firstly, expert choices are prioritized with artificial intelligence-based decision-making model. Secondly, performance indicators of the wind energy projects in the agricultural industry are weighted via quantum picture fuzzy rough sets-based M-SWARA. Thirdly, investment priority alternatives are ranked by considering the quantum picture fuzzy rough sets based VIKOR technique. The main contribution of this study is that artificial intelligence methodology is integrated with the fuzzy decision-making analysis. With the help of this analysis, experts can be prioritized according to their qualifications. According to the weighting results, it is identified that regulations play a crucial role for each group. On the other side, the ranking results indicate that storage solutions play the most crucial role for the improvements of the wind energy projects for Iranian agriculture industry.

Keywords—artificial intelligence, fuzzy decision-making, wind energy, agriculture

I. INTRODUCTION

Wind energy investments are very important to ensure the efficiency of the agricultural sector. In these projects, electricity is supplied from renewable energy sources [1]. Therefore, much less natural resources are consumed in wind energy projects compared to fossil fuels [2]. This contributes to increasing environmental sustainability. A very high amount of energy is consumed in the operation of the agricultural sector. Therefore, considering wind energy projects in this sector significantly helps environmental sustainability [3]. Wind energy projects also enable diversification of energy supply. This situation supports the provision of energy security. By taking wind energy projects into consideration in this process, energy resource diversity for the agricultural sector can be increased. In this way, action can be taken more easily against possible changes in energy demand. In this way, possible disruptions in agricultural production can be minimized [4].

Some issues should be improved for the effectiveness of the wind energy projects in agricultural sector. In this process, technological improvement plays a critical role for this issue [5]. Moreover, effective cost management and budgeting should be provided for the performance improvements of the wind projects. Furthermore, social issues are very critical in this framework [6]. The level of knowledge and awareness about wind energy should be increased. Environmental issues should also be taken into consideration for the improvements of the wind energy projects in agricultural sector [7]. In other words, the impact on the local ecosystem should be increased in an effective manner. Furthermore, availability of financial support or subsidies is also critical for the developments of these projects in agricultural industry [8]. Finally, geographical factors are significant to consider wind speed consistently.

These determinants should be improved for the performance development of the wind energy projects in the agricultural industry. However, making improvements leads to cost increase for the investors [9]. Due to this factor, companies cannot make lots of improvements together. The main reason behind this situation is that radical increase in the costs can create some financial problems [10]. Therefore, for the budget effectiveness, these investors should mainly focus on the most essential determinants. With the help of this situation, financial efficiency can be provided while taking these actions [11]. In this scope, it is critical to find the most important determinants of the performance improvements in wind energy projects for agricultural industry [12]. However, in the literature, there are limited studies that try to identify the prior factors. Because of this situation, a new study should be conducted with the aim of finding the most essential performance indicators.

Accordingly, this study aims to make evaluations for the indicators of wind energy investments in Iranian agricultural sector. For this purpose, a novel model is constructed that has three different stages. Firstly, expert choices are prioritized with artificial intelligence-based decision-making model. Secondly, performance indicators of the wind energy projects in the agricultural industry are weighted via quantum picture fuzzy rough sets-based M-SWARA. Thirdly, investment priority alternatives are ranked by considering the quantum picture fuzzy rough sets based VIKOR technique. The main contributions of this study are given below. (i) Artificial intelligence methodology is integrated with the fuzzy decision-making analysis. With the help of this analysis, experts can be prioritized according to their qualifications. This situation helps to reach more effective findings. (ii) Proposing M-SWARA technique plays a critical role for the methodological originality of the manuscript. Some improvements are implemented to the classical SWARA methodology and M-SWARA approach is generated. This new technique helps to make a causality analysis between the indicators.

II. PROPOSED METHODOLOGY

In this study, a novel artificial intelligence-based fuzzy decision-making model is created. This new model consists of three different stages. In the first stage, by using artificial intelligence-based decision-making model, expert choices are prioritized. In the following stage, performance indicators of the wind energy projects in the agricultural industry are evaluated by the help of quantum picture fuzzy rough sets-based M-SWARA. Finally, investment priority alternatives are ranked by considering the quantum picture fuzzy rough sets based VIKOR technique. In this section the details of the methods used in the proposed model are explained.

A. Quantum picture fuzzy rough sets with golden cuts

Quantum theory is integrated to the fuzzy decision-making methodology to minimize uncertainty in the analysis process. Equations (1)-(3) give information about this situation [13].

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

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

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

In these equations, C represents exhaustive events, $|Q(|u>)| = \varphi^2$provides the amplitude-based result and θ^2 defines the phase angle of event $|u>$. In addition, $|\varphi_1|^2$ shows the degree of belief and θ refers to its phase angle, which can range from 0 to 360 degrees.

Picture fuzzy sets are recent extensions of fuzzy sets. Equation (4) defines the classical fuzzy sets.

$$A = \{\langle x, \mu_A(x)\rangle | x \in X\} \tag{4}$$

A refers to the fuzzy sets, X defines a universe of discourse and μ_A shows the membership degree. Equation (5) identifies the intuitionistic fuzzy sets.

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X\} \tag{5}$$

Picture fuzzy sets are given in Equation (6) [14].

$$A = \{\langle x, \mu_A(x), n_A(x), v_A(x), h_A(x)\rangle | x \in X\} \tag{6}$$

General operations are given in Equations (7)-(11).

$$A \subseteq B \text{ if } \mu_A(x) \le \mu_B(x) \text{ and } n_A(x) \le n_B(x) \text{ and } v_A(x) \ge v_B(x), \forall x \in X \tag{7}$$

$$A = B \text{ if } A \subseteq B \text{ and } B \subseteq A \tag{8}$$

$$A \cup B = \left\{\begin{pmatrix} x, max(\mu_A(x), \mu_B(x)), \\ min(n_A(x), n_B(x)), \\ min(v_A(x), v_B(x)) \end{pmatrix} | x \in X\right\} \tag{9}$$

$$A \cap B = \left\{\begin{pmatrix} x, min(\mu_A(x), \mu_B(x)), \\ min(n_A(x), n_B(x)), \\ max(v_A(x), v_B(x)) \end{pmatrix} | x \in X\right\} \tag{10}$$

$$coA = \bar{A} = \left\{\begin{pmatrix} x, v_A(x), \\ n_A(x), \\ \mu_A(x) \end{pmatrix} | x \in X\right\} \tag{11}$$

Rough numbers are also used to decrease uncertainty by considering lower and upper limits as well as a rough boundary interval. Equations (12)-(17) give information about this process [15].

$$\underline{Apr}(C_i) = \cup \{Y \in X/R(Y) \le C_i\} \tag{12}$$

$$\overline{Apr}(C_i) = \cup \{Y \in X/R(Y) \ge C_i\} \tag{13}$$

$$Bnd(C_i) = \cup \{Y \in X/R(Y) \ne C_i\} \tag{14}$$

$$\underline{Lim}(C_i) = \sqrt[N_L]{\prod_{i=1}^{N_L} Y} \in \underline{Apr}(C_i) \tag{15}$$

$$\overline{Lim}(C_i) = \sqrt[N_U]{\prod_{i=1}^{N_U} Y} \in \overline{Apr}(C_i) \tag{16}$$

$$RN(C_i) = [\underline{Lim}(C_i), \overline{Lim}(C_i)] \tag{17}$$

Quantum picture fuzzy rough sets are shown in Equation (18).

$$|C_A> = \left\{\begin{matrix} \langle u, ([\underline{Lim}(C_{i\mu_A}), \\ \overline{Lim}(C_{i\mu_A})] (u), \\ [\underline{Lim}(C_{in_A}), \\ \overline{Lim}(C_{in_A})](u), \\ [\underline{Lim}(C_{iv_A}), \\ \overline{Lim}(C_{iv_A})] \\ (u), [\underline{Lim}(C_{ih_A}), \\ \overline{Lim}(C_{ih_A})](u)) \end{matrix} \middle| u \in 2^{|C_A>}\right\} \tag{18}$$

Equations (19)-(34) explain the details of this process.

$$\underline{Lim}(C_{i\mu_A}) = \frac{1}{N_{L\mu_A}} \sum_{i=1}^{N_{L\mu_A}} Y \in \underline{Apr}(C_{i\mu_A}) \tag{19}$$

$$\underline{Lim}(C_{in_A}) = \frac{1}{N_{Ln_A}} \sum_{i=1}^{N_{Ln_A}} Y \in \underline{Apr}(C_{in_A}) \tag{20}$$

$$\underline{Lim}(C_{iv_A}) = \frac{1}{N_{Lv_A}} \sum_{i=1}^{N_{Lv_A}} Y \in \underline{Apr}(C_{iv_A}) \tag{21}$$

$$\underline{Lim}(C_{ih_A}) = \frac{1}{N_{L\pi_A}} \sum_{i=1}^{N_{L\pi_A}} Y \in \underline{Apr}(C_{ih_A}) \tag{22}$$

$$\overline{Lim}(C_{i\mu_A}) = \frac{1}{N_{U\mu_A}} \sum_{i=1}^{N_{U\mu_A}} Y \in \overline{Apr}(C_{i\mu_A}) \tag{23}$$

$$\overline{Lim}(C_{in_A}) = \frac{1}{N_{Un_A}} \sum_{i=1}^{N_{Un_A}} Y \in \overline{Apr}(C_{in_A}) \tag{24}$$

$$\overline{Lim}(C_{iv_A}) = \frac{1}{N_{Uv_A}} \sum_{i=1}^{N_{Uv_A}} Y \in \overline{Apr}(C_{iv_A}) \tag{25}$$

$$\overline{Lim}(C_{ih_A}) = \frac{1}{N_{U\pi_A}} \sum_{i=1}^{N_{U\pi_A}} Y \in \overline{Apr}(C_{ih_A}) \tag{26}$$

$$\underline{Apr}(C_{i\mu_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{i\mu_A}\} \tag{27}$$

$$\underline{Apr}(C_{in_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{in_A}\} \tag{28}$$

$$\underline{Apr}(C_{iv_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{iv_A}\} \tag{29}$$

$$\underline{Apr}(C_{ih_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{ih_A}\} \tag{30}$$

$$\overline{Apr}(C_{i\mu_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{i\mu_A}\} \tag{31}$$

$$\overline{Apr}(C_{in_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{in_A}\} \tag{32}$$

$$\overline{Apr}(C_{iv_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{iv_A}\} \tag{33}$$

$$\overline{Apr}(C_{ih_A}) = \cup \{Y \in X/\tilde{R}(Y) \le C_{ih_A}\} \tag{34}$$

Equations (35) and (36) give information about the general formulation with amplitude and the angle results.

$$C = [C_\mu . e^{j2\pi.\alpha}, C_n . e^{j2\pi.\gamma}, C_v . e^{j2\pi.\beta}, C_h . e^{j2\pi.T}] \tag{35}$$

$$\varphi^2 = |C_\mu(|u_i>)| \tag{36}$$

Golden ration (G) is used to compute the degrees. The details are shown in Equations (37)-(41) [16].

$$C_n = \frac{C_\mu}{G} \quad (37)$$

$$C_h = \frac{C_v}{G} \quad (38)$$

$$\alpha = \left|C_\mu(|u_i>)\right| \quad (39)$$

$$\gamma = \frac{\alpha}{G} \quad (40)$$

$$T = \frac{\beta}{G} \quad (41)$$

The operations of quantum picture fuzzy rough numbers are indicated via Equations (42)-(45).

$$\lambda * \tilde{A}_c = \begin{Bmatrix} \left[\underline{Lim}(C_{\mu_{\tilde{A}}})\lambda, \overline{Lim}(C_{\mu_{\tilde{A}}})\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)\lambda\right]}, \\ \left[\underline{Lim}(C_{n_{\tilde{A}}})\lambda, \overline{Lim}(C_{n_{\tilde{A}}})\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)\lambda\right]}, \\ \left[\underline{Lim}(C_{v_{\tilde{A}}})\lambda, \overline{Lim}(C_{v_{\tilde{A}}})\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)\lambda\right]}, \\ \left[\underline{Lim}(C_{h_{\tilde{A}}})\lambda, \overline{Lim}(C_{h_{\tilde{A}}})\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)\lambda, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)\lambda\right]} \end{Bmatrix}, \quad \lambda > 0 \quad (42)$$

$$\tilde{A}_c^{\ \lambda} = \begin{Bmatrix} \left[\underline{Lim}(C_{\mu_{\tilde{A}}})^\lambda, \overline{Lim}(C_{\mu_{\tilde{A}}})^\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)^\lambda, \left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)^\lambda\right]}, \\ \left[\underline{Lim}(C_{n_{\tilde{A}}})^\lambda, \overline{Lim}(C_{n_{\tilde{A}}})^\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)^\lambda, \left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)^\lambda\right]}, \\ \left[\underline{Lim}(C_{v_{\tilde{A}}})^\lambda, \overline{Lim}(C_{v_{\tilde{A}}})^\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)^\lambda, \left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)^\lambda\right]}, \\ \left[\underline{Lim}(C_{h_{\tilde{A}}})^\lambda, \overline{Lim}(C_{h_{\tilde{A}}})^\lambda\right] e^{j2\pi.\left[\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)^\lambda, \left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)^\lambda\right]}, \end{Bmatrix}, \quad \lambda > 0 \quad (43)$$

$$\tilde{A}_c \cup \tilde{B}_c = \begin{Bmatrix} \begin{bmatrix} min\left(\underline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), \\ max\left(\overline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} min\left(\underline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), \\ max\left(\overline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} min\left(\underline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), \\ max\left(\overline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} min\left(\underline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), \\ max\left(\overline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix} \end{Bmatrix} \quad (44)$$

$$\tilde{A}_c \cap \tilde{B}_c = \begin{Bmatrix} \begin{bmatrix} max\left(\underline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right), \\ min\left(\overline{Lim}(C_{\mu_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{\mu_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\alpha}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} max\left(\underline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right), \\ min\left(\overline{Lim}(C_{n_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{n_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\gamma}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} max\left(\underline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{\beta}_{\tilde{B}}}{2\pi}\right)}\right), \\ min\left(\overline{Lim}(C_{v_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{v_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{\beta}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix}, \\ \begin{bmatrix} max\left(\underline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{A}}}{2\pi}\right)}, \underline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\underline{T}_{\tilde{B}}}{2\pi}\right)}\right), \\ min\left(\overline{Lim}(C_{h_{\tilde{A}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{A}}}{2\pi}\right)}, \overline{Lim}(C_{h_{\tilde{B}}})e^{j2\pi.\left(\frac{\overline{T}_{\tilde{B}}}{2\pi}\right)}\right) \end{bmatrix} \end{Bmatrix} \quad (45)$$

B. M-SWARA with Quantum picture fuzzy rough sets

Some improvements are applied to the classical SWARA methodology and M-SWARA technique is generated. Firstly, evaluations are obtained [17]. Relation matrix is created with Equation (46).

$$C_k = \begin{bmatrix} 0 & C_{12} & \cdots & \cdots & C_{1n} \\ C_{21} & 0 & \cdots & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (46)$$

Aggregated values are identified via Equation (47).

$$C = \begin{pmatrix} \left[min_{i=1}^k\left(\underline{Lim}\left(C_{\mu_{ij}}\right)\right), max_{i=1}^k\left(\overline{Lim}\left(C_{\mu_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^k\left(\frac{\underline{\alpha}_{ij}}{2\pi}\right), max_{i=1}^k\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^k\left(\underline{Lim}\left(C_{n_{ij}}\right)\right), max_{i=1}^k\left(\overline{Lim}\left(C_{n_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^k\left(\frac{\underline{\gamma}_{ij}}{2\pi}\right), max_{i=1}^k\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^k\left(\underline{Lim}\left(C_{v_{ij}}\right)\right), max_{i=1}^k\left(\overline{Lim}\left(C_{v_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^k\left(\frac{\underline{\beta}_{ij}}{2\pi}\right), max_{i=1}^k\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^k\left(\underline{Lim}\left(C_{h_{ij}}\right)\right), max_{i=1}^k\left(\overline{Lim}\left(C_{h_{ij}}\right)\right)\right] e^{j2\pi.\left[min_{i=1}^k\left(\frac{\underline{T}_{ij}}{2\pi}\right), max_{i=1}^k\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right]} \end{pmatrix} \quad (47)$$

Defuzzified values are computed by Equation (48).

$$Defc_i = \frac{\begin{pmatrix} \underline{Lim}(C_{\mu_i}) - \underline{Lim}(C_{n_i}) + \underline{Lim}(C_{\mu_i}).\left(\underline{Lim}(C_{v_i}) - \underline{Lim}(C_{h_i})\right) \\ + \left(\frac{\underline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\underline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\underline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\underline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\underline{T}_{ij}}{2\pi}\right)\right) + \\ \overline{Lim}(C_{\mu_i}) - \overline{Lim}(C_{n_i}) + \overline{Lim}(C_{\mu_i}).\left(\overline{Lim}(C_{v_i}) - \overline{Lim}(C_{h_i})\right) \\ + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\overline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right).\left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{pmatrix}}{2} \quad (48)$$

The values of s_j , k_j , q_j ,and w_j are computed with Equations (49)-(51).

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (49)$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \quad (50)$$

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

$$w_j = \frac{q_j}{\sum_{k=1}^n q_k} \quad (51)$$

Stable values are identified to weight the values by transposing and limiting the matrix to the power of 2t+1.

C. VIKOR with Quantum picture fuzzy rough sets

VIKOR technique is used for alternative ranking [18]. Evaluations are collected. Decision matrix is obtained with Equation (52).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (52)$$

Defuzzified values are computed. The best $\tilde{f}_j^*$ and worst $\tilde{f}_j^-$ values are computed by Equation (53).

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \text{ and } \tilde{f}_j^- = \min_i \tilde{x}_{ij} \quad (53)$$

The mean group utility and maximal regret are calculated using Equations (54) and (55).

$$\tilde{S}_i = \sum_{i=1}^{n} \tilde{w}_j \frac{(|\tilde{f}_j^* - \tilde{x}_{ij}|)}{(|\tilde{f}_j^* - \tilde{f}_j^-|)} \quad (54)$$

$$\tilde{R}_i = max_j \left[\tilde{w}_j \frac{(|\tilde{f}_j^* - \tilde{x}_{ij}|)}{(|\tilde{f}_j^* - \tilde{f}_j^-|)} \right] \quad (55)$$

Rankings are computed via Equation (56).

$$\tilde{Q}_i = v\,(\tilde{S}_i - \tilde{S}^*)/(\tilde{S}^- - \tilde{S}^*) + (1 - v)\,(\tilde{R}_i - \tilde{R}^*)/(\tilde{R}^- - \tilde{R}^*) \quad (56)$$

Two conditions should be satisfied. The first condition is given in Equation (57).

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{(j-1)} \quad (57)$$

The second condition explains that the alternative must be the best ranked by either S or R, or both.

D. AI-based decision-making for expert prioritization

Artificial intelligence methodology is considered with decision-making methodology for expert prioritization. Firstly, within-cluster sum of squares are calculated by Equation (58) [19].

$$WCSS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d(x_i, c_j)^2 \quad (58)$$

The elbow is defined as an optimal k value. The optimal k value is applied for initial cluster centers via Equation (59) [20].

$$d(x_i, x_j) = \sqrt{\sum_{l=1}^{n} (x_{il} - x_{jl})^2} \quad (59)$$

Cluster centers are updated with Equation (60).

$$c_j = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_i \quad (60)$$

In the last stage of this methodology, the weights of the decision makers are computed. The mean standard deviation of each cluster is calculated with Equations (61)-(63).

$$s_j = \frac{1}{n} \sum_{l=1}^{n} \sigma_{jl} \quad (61)$$

$$\sigma_{jl} = \sqrt{\frac{1}{|C_j|} \sum_{x_i \in C_j} (x_{il} - \bar{x}_{jl})^2} \quad (62)$$

$$\bar{x}_{jl} = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_{il} \quad (63)$$

The cluster weights and weights of the decision makers are computed by Equations (64) and (65), respectively.

$$w_j = |C_j| \times s_j \quad (64)$$

$$w_{tj} = \frac{1}{|C_j|} \frac{w_j}{\sum_{w_j \in C_j} w_j} \quad (65)$$

III. ANALYSIS RESULTS

In the first stage, expert choices are prioritized with artificial intelligence-based decision-making. Table A1 gives information about the specifications of the decision makers by the groups. According to the calculations, it is defined that LG1, LG2, LG3, and LG4 are selected as the prioritized experts for the landowner decision maker group. However, the expert and investor groups have the same expert prioritizations with DM2, DM3 and DM5 for selecting their expert choices in the evaluation process. So, while 4 decision makers (LG2, LG3, LG4, and LG5) are used from landowner group, 3 decision makers are assigned for the expert group (EG2, EG3, and EG5) and investor group (IG2, IG3, and IG5) respectively.

The second stage is related to the weighting the criteria for the development of wind energy in the agricultural sector. For this purpose, six criteria are selected that are technology (C1), finance (C2), social (C3), environmental (C4), regulations (C5) and geography (C6). Table 1 gives information about the weights of the criteria by the decision maker groups.

Table 1: Weights of the criteria by the decision maker groups

	Landowner Group	Expert Group	Investor Group
C1	0.165	0.168	0.166
C2	0.167	0.166	0.165
C3	0.166	0.165	0.165
C4	0.168	0.167	0.169
C5	0.171	0.170	0.170
C6	0.164	0.164	0.165

Table 1 states that regulations play a crucial role for each group. The final stage consists of ranking the investment priority alternatives for wind energy in the agricultural sector of Iran. Within this context, 6 different alternatives are defined that are risk level (A1), time horizon (A2), return on investment (A3), growth (A4), social responsibilities (A5) and storage solutions (A6). Ranking results are shown in Table 2.

Table 2: Comparative ranking values by the decision maker groups

Alternatives	Landowner Group	Expert Group	Investor Group
A1	2	3	3
A2	4	5	4
A3	5	6	5
A4	3	2	2
A5	6	4	6
A6	1	1	1

Ranking results demonstrate that storage solutions play the most crucial role for the improvements of the wind energy projects for Iranian agriculture industry.

IV. CONCLUSION

This study examines wind energy investments in Iranian agricultural sector with a novel artificial intelligence-based fuzzy decision-making model. In the first stage, expert choices are prioritized with artificial intelligence-based decision-making model. Next, performance indicators of the wind energy projects in the agricultural industry are weighted via quantum picture fuzzy rough sets-based M-SWARA. Thirdly, investment priority alternatives are ranked by considering the quantum picture fuzzy rough sets based VIKOR technique. According to the calculations, it is defined that LG1, LG2, LG3, and LG4 are selected as the prioritized experts for the landowner decision maker group. However, the expert and investor groups have the same expert prioritizations with DM2, DM3 and DM5 for selecting their expert choices in the evaluation process. So, while 4 decision makers (LG2, LG3, LG4, and LG5) are used from landowner group, 3 decision makers are assigned for the expert group (EG2, EG3, and EG5) and investor group (IG2, IG3, and IG5) respectively. According to the weighting results, it is identified that regulations play a crucial role for each group. On the other side, the ranking results indicate that storage solutions play the most crucial role for the improvements of the wind energy projects for Iranian agriculture industry.

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Appendix

Table A1: Specifications of the decision makers by the groups

Landowner Group					
Expert	Education	Experience (year)	Salary (USD)	Age	Industry
LG1	1 (Bachelor)	20	5000	45	1 (Service)
LG2	1 (Bachelor)	18	4000	52	1 (Service)
LG3	2 (Master)	15	3500	48	2 (Production)
LG4	1 (Bachelor)	12	2000	40	2 (Production)
LG5	1 (Bachelor)	19	2000	44	2 (Production)
Expert Group					
Expert	Education	Experience (year)	Salary (USD)	Age	Industry
EG1	1 (Bachelor)	18	2000	50	1 (Service)
EG2	1 (Bachelor)	16	2500	48	2 (Production)
EG3	1 (Bachelor)	16	2500	46	1 (Service)
EG4	3 (PhD)	12	3500	44	3 (Education)
EG5	2 (Master)	20	3000	51	2 (Production)
Investor Group					
Expert	Education	Experience (year)	Salary (USD)	Age	Industry
EG1	3 (PhD)	30	7000	58	2 (Production)
EG2	2 (Master)	23	5000	44	2 (Production)
EG3	1 (Bachelor)	21	5000	45	1 (Service)
EG4	3 (PhD)	20	6000	50	3 (Education)
EG5	2 (Master)	20	5000	47	2 (Production)