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Investigating the components of fintech ecosystem for distributed energy investments with an integrated quantum spherical decision support system

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Abstract

This study aimed to evaluate the components of a fintech ecosystem for distributed energy investments. A new decision-making model was created using multiple step-wise weight assessment ratio analysis and elimination and choice translating reality techniques based on quantum spherical fuzzy sets. First, in this model, the criteria for distributed energy investment necessities were weighted. Second, we ranked the components of the fintech ecosystem for distributed energy investments. The main contribution of this study is that appropriate strategies can be presented to design effective fintech ecosystems to increase distributed energy investments, by considering an original fuzzy decision-making model. Capacity is the most critical issue with respect to distributed energy investment necessities because it has the greatest weight (0.261). Pricing is another significant factor for this condition, with a weight of 0.254. Results of the ranking of the components of the fintech ecosystem indicate that end users are of the greatest importance for the effectiveness of this system. It is necessary to develop new techniques for the energy storage process, especially with technological developments, to prevent disruptions in energy production capacity. In addition, customers' expectations should be considered for the development of effective and user-friendly financial products that are preferred by a wider audience. This would have a positive effect on fintech ecosystem performance.

Keywords: Fintech ecosystems, Innovative financial products, Distributed energy investments, Multi SWARA, ELECTRE

Introduction

A very important part of the global energy demand is met through fossil fuels. However, the problem of carbon emissions arises from the burning of fossil fuels, which threatens the world in many ways. High carbon emissions have led to a climate crisis that has created the problem of global warming. If this problem is not controlled, other problems, such as forest fires and droughts will arise (Olabi and Abdelkareem 2022). In addition, there will be significant reductions in the amount of agricultural production, triggering a food crisis (Mukhtarov et al. 2022). Carbon emissions also cause significant air pollution,

which leads to an increase in diseases and results in both social and economic problems. The increase in the number of sick people causes a loss of labor and decreases industrial production. The budget balance of countries may be adversely affected by the measures required to combat an increasing number of diseases. Therefore, measures to solve the carbon emission problem should be urgently taken (Baloch et al. 2022).

Renewable energy investments can also significantly help solve the fossil fuel-based carbon emission problem. With this type of energy, fuels, such as coal, are not burned; instead, natural resources are used. Thus, the carbon emission problem can be significantly reduced. However, the most important obstacle to increasing renewable energy investments is that the costs are very high compared with fossil fuels (Kou et al. 2022). Therefore, necessary measures should be taken, and it should be ensured that these energy investments can also provide cost advantages. Distributed energy investments can also contribute to reducing the costs of renewable energy projects (Ahmed et al. 2022). This type of generation refers to various technologies that generate electricity near the place where it will be used. In other words, it aims to reduce the cost of the process by producing energy at the point of consumption. Thus, it will be possible to carry out renewable energy projects more efficiently (Dinçer et al. 2022a, b).

Distributed energy investments should be increased to ensure the sustainability of renewable energy projects. In this context, it is necessary to provide financial support for these investments. A large amount of financial support should be provided to realize these investment projects (Zhang et al. 2022). For instance, many governments worldwide can provide tax reductions for these projects. However, financial institutions must provide support for their long-term sustainability (Kebede et al. 2022), and banks and leasing companies may be reluctant to support high-risk projects. Therefore, innovative financial products are required to increase the number of these projects. Owing to properly designed financial products, it is possible to increase distributed energy investments (Li et al. 2022a, b).

Innovative financial products must be developed to increase the distribution of energy investment. In this context, the effective development of fintech ecosystems is vital (Muganyi et al. 2022). There are players in this type of ecosystem, each of whom works independently but also influences each other. For example, startups can help increase technology-based financial investment (Carbó-Valverde et al. 2022). Financial institutions also help the financial system operate more securely. The regulations created by the states also ensure that the system works effectively (Minutolo et al. 2022). To increase the efficiency of the fintech ecosystem, it is necessary to understand which of these players have the most important roles and which are more effective on others. Thus, specific strategies can be determined so that the system can be created efficiently (Fang et al. 2022). Otherwise, the desired efficiency from the fintech ecosystem will not be achieved because of the incorrect strategies to be applied. Therefore, a priority analysis among the players in the fintech ecosystem will contribute significantly to the development of this system and enable effective innovative financial products to be sustainable (Hughes et al. 2022).

This study investigated the components of the fintech ecosystem for distributed energy investments using an integrated quantum spherical decision support system. A novel model consisting of two stages was created. First, the criteria for distributed

energy investment necessities were weighted using the multi-stepwise weight assessment ratio analysis (M-SWARA) method with quantum spherical fuzzy sets. Next, the components of the fintech ecosystem for distributed energy investment were ranked using the elimination and choice translating reality (ELECTRE) with quantum spherical fuzzy sets. The main contribution of this study is that appropriate strategies can be identified to improve distributed energy investment by considering an original fuzzy decision-making model. With the help of this study, significant issues in the development of distributed energy investments can be identified. In addition, a priority analysis can be conducted among the players in the fintech ecosystem. Hence, the analysis results can contribute significantly to the development of fintech ecosystems and generation of effective innovative financial products.

The proposed model has important advantages over previous models. The most important aspect of this study is the development of a new technique called the M-SWARA, which was built by improving the SWARA approach. In the classical SWARA technique, the weights of the criteria can be calculated, but the causal relationship between items cannot be defined. Using the M-SWARA, the impact relation map among the factors can be identified. The criteria for distributed energy investment can influence each other. For instance, because of high energy costs, there is a risk that reasonable prices cannot be offered to users. Neither individuals nor companies prefer products with excessively high prices. Similarly, when there is a high demand for green energy products, it has a positive effect on capacity increases. Moreover, providing reasonable prices to consumers helps increase demand for renewable energy products. Therefore, to determine the most important factor, the factors that influence others should be considered. For instance, minimizing energy investment costs can have an increasing impact on the production potential of plants. Thus, it is understood that the M-SWARA technique is more appropriate for evaluating the necessity of distributed energy investments in comparison with the classical SWARA approach. On the other side, analytical hierarch process and analytical network process methods can also help to weigh the factors. Despite this situation, causality analysis between the items cannot be identified using these approaches (Sztamári 2021; Jorge-García and Estruch-Guitart 2022). However, players in the fintech ecosystem can work independently and influence each other. Thus, the M-SWARA methodology is generated in this proposed model to calculate both the weights and the impact relation map of the criteria.

One of the most important issues affecting the success of decision-making models is the effective management of uncertainty in the process (Albahri et al. 2022). However, the decision-making problems that need to be solved are becoming increasingly complex (Li et al. 2022a, b; Bueno et al. 2021). Classical decision-making methods have started to be insufficient in solving this complexity on their own (Wu et al. 2021). Researchers have aimed to overcome this problem by integrating decision-making techniques with fuzzy numbers (Chao et al. 2021). Within this framework, triangular fuzzy numbers were considered using these techniques. Then interval type-2 fuzzy sets were integrated into these approaches to handle uncertainty more effectively. Next, intuitionistic fuzzy sets and Pythagorean fuzzy sets were considered to minimize the hesitancy problem more effectively. Further on, q-rung orthopair fuzzy sets were generated with the help of the

integration of the intuitionistic fuzzy sets and Pythagorean fuzzy sets to generated more appropriate results.

Accordingly, in this study, the probability of quantum theory is integrated into spherical fuzzy sets. Quantum theory provides an opportunity to understand the probabilities of several conditions using different angles. This situation helps handle the uncertainty in the complex information set more accurately. In addition, the use of spherical fuzzy sets in the analysis process increases the quality of the proposed model. Both the membership and non-membership degrees and the hesitancy parameter were considered in these sets. Under this condition, a larger domain could be used in the analysis process. This situation makes a powerful contribution to the achievement of more appropriate findings. Moreover, the golden ratio is used to compute the degrees in the quantum spherical fuzzy sets. This new implementation aimed to achieve more precise results.

Moreover, compensation between the criteria and the normalization process can be avoided using the ELECTRE methodology. The original data will not be distorted, and a more accurate evaluation can be performed (Fei et al. 2019; Rangel et al. 2009). In addition, using ELECTRE, alternatives can be ranked by considering the priorities among the criteria (Irvanizam et al. 2008). ELECTRE methodology can be applied to different problems in various subjects (Wu and Abdul-Nour 2020). The above demonstrates a significant superiority of the ELECTRE approach over similar methods in the literature (Hatami-Marbini et al. 2013).

The second section of the article includes a literature review. The third section provides information on the methodology. The fourth section presents the results of the study. The final sections offer the discussion and conclusions.

Literature review on the components of fintech ecosystems

The players in this ecosystem have important duties for the successful generation of fintech ecosystems. Technology investment must be increased to achieve this goal. Owing to the development of new technology and its rapid adaptation to the financial sector, it will be possible to develop more successful innovative financial products (Arslan et al. 2021). With the help of technological software, such as artificial intelligence, a more comprehensive financial ecosystem can be created (Rupeika-Apoga and Wendt 2021). Therefore, it is important for countries to provide financial support to technology companies for this ecosystem to be more effective (Maiti and Ghosh 2021; Li and Xu 2021). To achieve this goal, companies must grow and focus on the financial field (Chen and Liao 2021). Kou et al. (2021) examined fintech investments in European banks. A new fuzzy decision-making model was created to achieve this purpose. They observed that new technologies make a powerful contribution to the improvement of fintech ecosystems. Marrara et al. (2021) focused on the fintech investments on small and medium enterprises in Italy. They found that data mining techniques can be helpful in increasing the performance of fintech investments. Similarly, Hussain et al. (2021) determined that a fuzzy logic system can be considered for the performance increase of the fintech ecosystem.

Startups play an important role in the development of fintech ecosystems. Owing to these initiatives, technological investments and digitalization will be more easily applied to the financial sector (Albarrak and Alokley 2021). For the development of startups,

which are important for the performance of the fintech ecosystem, some financial support should be provided by countries (Harris 2021). Moreover, these companies need to pay attention to certain issues to be successful in their investments (Tsanis 2021). For example, it is important for entrepreneurs to have sufficient industry knowledge. However, customer satisfaction should be considered when making investments (Baporikar 2021). In this context, it is necessary to define customer expectations clearly. Zarrouk et al. (2021) evaluated the economic and technological indicators of fintech startups' success in the United Arab Emirates. They conclude that customer expectations should be met for this condition. Muthukannan et al. (2021) examined Indonesian fintech ecosystems and find that startups should focus on technological improvements. Hornuf et al. (2021) examined fintech start-ups. The government should provide the necessary financial support to fintech startups for the sustainability of the fintech ecosystem.

Financial institutions are among the most important actors in the system. For a fintech ecosystem to be successful, users must trust the system. Otherwise, customers will not prefer the developed ecosystem (Muthukannan et al. 2021). This endangers the continuity of the system. Developed financial institutions will increase the reliability of fintech ecosystems (Senyo et al. 2022). Financial institutions, such as banks, leasing companies, and insurance companies, are long-standing and trusted institutions (Al-Daya et al. 2022). Effective and efficient operation of these companies will help in the successful development of the financial ecosystem (Turcan and Deák 2021). Muganyi et al. (2022) focused on the effectiveness of fintech ecosystems in China. They found that the performance increase of financial institutions contributed to this purpose. Ascarya and Sakti (2022) studied the micro-fintech model design for Islamic microfinancial institutions in Indonesia. They determined that the performance of financial institutions is significant for the reliability of the fintech ecosystem. In addition, Daud et al. (2022) identified that financial stability in the market is very important for improving the fintech ecosystem. Financial institutions play a crucial role in this process.

One of the most important players in a financial ecosystem is the state that determines the rules. States also play an active role in the creation of competitive conditions and an effective inspection system (Michael and Korolevska 2022). Therefore, the laws of the relevant state should be considered when investing in a fintech ecosystem (Senyo et al. 2022). It may not be appropriate to invest in fintech ecosystems in countries with highly restrictive rules (Chorzempa and Huang 2022). On the other hand, countries aiming to develop their fintech ecosystem should also prepare their regulations accordingly (Muryanto 2022). Xue et al. (2022) examined the relationship between fintech systems and corporate green technology innovation. An effective auditing system should be considered to increase the performance of the fintech system. Merello et al. (2022) examined the key drivers of an effective fintech ecosystem. The results of their study highlighted the importance of effective regulations in this process. A study by Murinde et al. (2022), also showed the significance of government regulations in the performance improvement of the fintech system.

Another player with an important role in the fintech ecosystem is the customer, who are the companies that purchase innovative financial products. Customer demand is important for the successful development of an ecosystem (Mainardes et al. 2022). Within this framework, customer expectations should be understood

correctly (Gunawardane 2022). Innovative financial products that satisfy customers will make it easier to create a fintech ecosystem more effectively (Festa et al. 2022). Otherwise, financial products that do not meet expectations will not be preferred by customers, putting the continuity of the fintech ecosystem at risk (Saraswat and Chouhan 2022). Aysan et al. (2022) evaluated fintech strategies for Islamic banks. They found that customer expectations should be considered under these conditions. Dzogbenuku et al. (2022) also determined that the needs of different customer groups should be understood with the help of comprehensive analysis. Hoang et al. (2022) studied the development of financial technologies. They determined that customer satisfaction should be provided in order to improve the performance of the fintech ecosystem.

As illustrated above, players influence each other in the fintech ecosystem. They play important roles in the effective development of the system. To increase the efficiency of the fintech ecosystem, it is necessary to clearly determine which of these players plays a more important role and which ones are more effective on others. Otherwise, the desired efficiency from the fintech ecosystem will not be achieved because of the incorrect strategies to be applied. A significant majority of the studies in the literature have focused on the importance of these players in the success of the fintech ecosystem. However, few studies have examined which are of greater importance among fintech players. Therefore, there is a serious need for priority analysis among the fintech ecosystem players. In this study, the players in the fintech ecosystem, which will be designed for distributed energy investments, are analyzed using the new integrated decision-making model. Thus, it will be possible to determine appropriate strategies to increase the efficiency of this ecosystem.

In addition, many decision-making models have been created in the literature for renewable energy investments. Solangi et al. (2021) focused on the barriers to renewable energy investments in Pakistan. In this study, a new model was generated by integrating the analytical hierarch process and TOPSIS methods. They define economic and financial issues as the most critical barriers in this respect. Sadat et al. (2021), Liang et al. (2021), and Atwongyeire et al. (2022) generated similar models to evaluate the effectiveness of renewable energy investments in different countries. The main disadvantage of these models is that the causal relationship between criteria cannot be identified. In this study, the M-SWARA methodology was used to show the impact relation map of the criteria. Liu et al. (2021), Pan et al. (2021) and Li et al. (2021) evaluated the performance of renewable energy investments by creating a novel decision-making model. In these models, interval type-2 fuzzy sets were used to manage uncertainty problems more effectively. However, the main drawback of these models is that the hesitancy problem cannot be considered. In the proposed model, spherical fuzzy sets are used so that membership and non-membership degrees and hesitancy parameters are considered.

Methodology

This section includes explanatory information regarding quantum spherical fuzzy sets with the golden cut, M-SWARA, and ELECTRE techniques.

Quantum spherical fuzzy sets with golden cut

The quantum theory provides an opportunity to consider probability more effectively in the decision-making process. In this context, the amplitude and phase angle were considered. Also, for the purpose of identifying the probabilities of various situations, the different angles are used in this theory (Afradi and Ebrahimabadi 2021). This situation helps handle the uncertainty problem of this process in a better way. This situation is formulated in Eqs. (1)–(3) (Bharill et al. 2019).

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

$$|\zeta \rangle = \{|u_1 \rangle, |u_2 \rangle, \dots, |u_n \rangle\} \tag{2}$$

$$\sum_{|u\rangle \subseteq |\zeta\rangle} |Q(|u \rangle)| = 1 \tag{3}$$

The set of collective exhaustive events is given by ζ whereas $|Q(|u \rangle)| = \varphi^2$ represents the amplitude result for probability. The phase angle of the event is demonstrated by θ^2 . The quantum theory can be integrated with fuzzy logic to improve the performance of the analysis process. However, there is a need for new fuzzy sets because decision-making problems become very complex (Wang et al. 2021). Spherical fuzzy sets (\tilde{A}_S) can be considered for this purpose. In these sets, the squared sum of membership μ , non-membership ν , and hesitancy π parameters can take values between 0 and 1 (Kutlu Gündoğdu and Kahraman 2019). With this condition, more accurate results (Mathew et al. 2020). The details of these fuzzy sets are given in Eqs. (4) and (5) (Ashraf et al. 2019).

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

$$0 \leq \mu_{\tilde{A}_S}^2(u) + \nu_{\tilde{A}_S}^2(u) + h_{\tilde{A}_S}^2(u) \leq 1, \quad \forall u \in U \tag{5}$$

In this study, the quantum theory was integrated into spherical fuzzy sets. This situation is indicated in Eq. (6) where $\varsigma_{\mu_{\tilde{A}_S}}$, $\varsigma_{\nu_{\tilde{A}_S}}$, and $\varsigma_{h_{\tilde{A}_S}}$ demonstrate the membership, non-membership hesitant degrees of quantum spherical fuzzy sets.

$$|\varsigma_{\tilde{A}_S} \rangle = \left\{ u, (\varsigma_{\mu_{\tilde{A}_S}}(u), \varsigma_{\nu_{\tilde{A}_S}}(u), \varsigma_{h_{\tilde{A}_S}}(u)) \mid u \in 2^{|\varsigma_{\tilde{A}_S} \rangle} \right\} \tag{6}$$

Equations (7) and (8) indicate the formulation of Quantum Spherical fuzzy numbers with amplitude and phase angles.

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

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

In these equations, ς_{μ} , ς_{ν} , and ς_h give information about the amplitudes of quantum membership, non-membership, and hesitancy degrees. Moreover, α , γ , and β refer to the set of θ phase angles. Furthermore, φ^2 identifies the amplitude of the membership

function ς_μ of quantum fuzzy sets. In addition, to obtain more accurate results, the golden ratio was considered for the calculation of the degrees in this process (Dobrosielski 2020). Equations (9) and (10) show the details in which the golden cut is given by G, and large and small quantities are demonstrated by a and b (Dinçer et al. 2022a, b).

$$G = \frac{a}{b} \tag{9}$$

$$G = \frac{1 + \sqrt{5}}{2} = 1.618 \dots \tag{10}$$

Equation (11) defines the amplitude of the non-membership degrees for quantum spherical fuzzy sets with a golden cut.

$$\varsigma_\nu = \frac{\varsigma_\mu}{G} \tag{11}$$

The amplitude of hesitancy degrees is indicated in Eq. (12).

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_\nu \tag{12}$$

The phase angles of the quantum spherical fuzzy sets were calculated using Eq. (13).

$$\alpha = |\varsigma_\mu(|u_i >)| \tag{13}$$

The phase angles of non-member degrees γ and hesitancy degrees β are shown in Eqs. (14) and (15).

$$\gamma = \frac{\alpha}{G} \tag{14}$$

$$\beta = 1 - \alpha - \gamma \tag{15}$$

X_1 and X_2 refer to two universes and $\tilde{A}_\varsigma = (\varsigma_{\mu_{\tilde{A}}}, \varsigma_{\nu_{\tilde{A}}}, \varsigma_{h_{\tilde{A}}})$ and $\tilde{B}_\varsigma = (\varsigma_{\mu_{\tilde{B}}}, \varsigma_{\nu_{\tilde{B}}}, \varsigma_{h_{\tilde{B}}})$ define two quantum spherical fuzzy sets. The spherical extension of Akram et al. (2020) is considered for the essential operations of quantum spherical fuzzy sets. Equations (16)-(19) give information about the operations of these numbers.

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

$$\tilde{A}_S^\lambda = \left\{ \begin{array}{l} \varsigma_{\mu_A}^\lambda e^{j2\pi \cdot \left(\frac{\alpha_A^-}{2\pi}\right)^\lambda}, \left(1 - \left(1 - \varsigma_{v_A}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi \cdot \left(1 - \left(1 - \left(\frac{\gamma_A^-}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}}, \\ \left(\left(1 - \varsigma_{v_A}^2\right)^\lambda - \left(1 - \varsigma_{v_A}^2 - \varsigma_{h_A}^2\right)^\lambda\right)^{\frac{1}{2}} \\ e^{j2\pi \cdot \left(\left(1 - \left(\frac{\gamma_A^-}{2\pi}\right)^2\right)^\lambda - \left(1 - \left(\frac{\gamma_A^-}{2\pi}\right)^2 - \left(\frac{\beta_A^-}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \end{array} \right\}, \quad \lambda > 0 \quad (17)$$

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ \begin{array}{l} \left(\varsigma_{\mu_A}^2 + \varsigma_{\mu_B}^2 - \varsigma_{\mu_A}^2 \varsigma_{\mu_B}^2\right)^{\frac{1}{2}} e^{j2\pi \cdot \left(\left(\frac{\alpha_A^-}{2\pi}\right)^2 + \left(\frac{\alpha_B^-}{2\pi}\right)^2 - \left(\frac{\alpha_A^-}{2\pi}\right)^2 \left(\frac{\alpha_B^-}{2\pi}\right)^2\right)^{\frac{1}{2}}}, \\ \varsigma_{v_A} \varsigma_{v_B} e^{j2\pi \cdot \left(\left(\frac{\gamma_A^-}{2\pi}\right) \left(\frac{\gamma_B^-}{2\pi}\right)\right)}, \\ \left(\left(1 - \varsigma_{v_B}^2\right) \varsigma_{h_A}^2 + \left(1 - \varsigma_{v_A}^2\right) \varsigma_{h_B}^2 - \varsigma_{h_A}^2 \varsigma_{h_B}^2\right)^{\frac{1}{2}} \\ e^{j2\pi \cdot \left(\left(1 - \left(\frac{\alpha_B^-}{2\pi}\right)^2\right) \left(\frac{\beta_A^-}{2\pi}\right)^2 + \left(1 - \left(\frac{\alpha_A^-}{2\pi}\right)^2\right) \left(\frac{\beta_B^-}{2\pi}\right)^2 - \left(\frac{\beta_A^-}{2\pi}\right)^2 \left(\frac{\beta_B^-}{2\pi}\right)^2\right)^{\frac{1}{2}}} \end{array} \right\} \quad (18)$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \begin{array}{l} \varsigma_{\mu_A} \varsigma_{\mu_B} e^{j2\pi \cdot \left(\frac{\alpha_A^-}{2\pi}\right) \left(\frac{\alpha_B^-}{2\pi}\right)}, \left(\varsigma_{v_A}^2 + \varsigma_{v_B}^2 - \varsigma_{v_A} \varsigma_{v_B}\right)^{\frac{1}{2}} \\ e^{j2\pi \cdot \left(\left(\frac{\gamma_A^-}{2\pi}\right)^2 + \left(\frac{\gamma_B^-}{2\pi}\right)^2 - \left(\frac{\gamma_A^-}{2\pi}\right)^2 \left(\frac{\gamma_B^-}{2\pi}\right)^2\right)^{\frac{1}{2}}}, \\ \left(\left(1 - \varsigma_{v_B}^2\right) \varsigma_{h_A}^2 + \left(1 - \varsigma_{v_A}^2\right) \varsigma_{h_B}^2 - \varsigma_{h_A}^2 \varsigma_{h_B}^2\right)^{\frac{1}{2}} \\ e^{j2\pi \cdot \left(\left(1 - \left(\frac{\gamma_B^-}{2\pi}\right)^2\right) \left(\frac{\beta_A^-}{2\pi}\right)^2 + \left(1 - \left(\frac{\gamma_A^-}{2\pi}\right)^2\right) \left(\frac{\beta_B^-}{2\pi}\right)^2 - \left(\frac{\beta_A^-}{2\pi}\right)^2 \left(\frac{\beta_B^-}{2\pi}\right)^2\right)^{\frac{1}{2}}} \end{array} \right\} \quad (19)$$

M-SWARA method with quantum spherical fuzzy sets

Kersulienė et al. (2010) introduced the SWARA method with the aim of weighting the various criteria. The hierarchical priorities of experts were considered in this process. The main criticism of the SWARA method is that the causal relationships between items cannot be analyzed. Accordingly, in this study, some improvements are made to this classical SWARA, so that a new technique has been created by the name M-SWARA. The details of the steps in this new technique are provided below.

Step 1: The dependency degrees among the criteria are determined by decision-makers. Linguistic evaluations were collected to construct the relation matrix using Table two. Linguistic evaluations were performed by an expert team.

Step 2: A quantum spherical fuzzy relation matrix is created using these evaluations, as shown in Eq. (20). In this equation, $\varsigma_{\mu_A^-}$ represents the degree of relationship.

$$S_k = \begin{bmatrix} 0 & s_{12} & \cdots & \cdots & s_{1n} \\ s_{21} & 0 & \cdots & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ s_{n1} & s_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{20}$$

The aggregated values were computed in the form of quantum spherical fuzzy numbers using Eq. (21).

$$S = \left\{ \begin{array}{l} \left[1 - \prod_{i=1}^k \left(1 - s_{\mu_i}^2 \right)^{\frac{1}{k}} \right]^{\frac{1}{2}} \\ e^{2\pi \cdot \left[1 - \prod_{i=1}^k \left(1 - \left(\frac{\alpha_i}{2\pi} \right)^2 \right)^{\frac{1}{k}} \right]^{\frac{1}{2}}}, \prod_{i=1}^k s_{\nu_i}^{\frac{1}{k}} e^{2\pi \cdot \prod_{i=1}^k \left(\frac{\gamma_i}{2\pi} \right)^{\frac{1}{k}}}, \\ \left[\prod_{i=1}^k \left(1 - s_{\mu_i}^2 \right)^{\frac{1}{k}} - \prod_{i=1}^k \left(1 - s_{\mu_i}^2 - s_{h_i}^2 \right)^{\frac{1}{k}} \right]^{\frac{1}{2}} \\ e^{2\pi \cdot \left[\prod_{i=1}^k \left(1 - \left(\frac{\alpha_i}{2\pi} \right)^2 \right)^{\frac{1}{k}} - \prod_{i=1}^k \left(1 - \left(\frac{\alpha_i}{2\pi} \right)^2 - \left(\frac{\beta_i}{2\pi} \right)^2 \right)^{\frac{1}{k}} \right]^{\frac{1}{2}}} \end{array} \right. \tag{21}$$

Step 3: The values of s_j , k_j , q_j , and w_j are calculated for the amplitudes and phase angles of quantum membership, non-membership, and hesitancy degrees, respectively. In Eqs. (22)–(24), k_j is the coefficient value, q_j is the recalculated weight, s_j is the comparative importance rate, and w_j represents the weights of the criteria. The significance degrees of the criteria were sorted in descending order.

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{22}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{23}$$

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

$$w_j = \frac{q_j}{\sum_{k=1}^n q_k} \tag{24}$$

Step 4: The defuzzified values ($Def S$) of w_j are calculated for the items of the quantum spherical fuzzy sets using Eq. (25).

$$Def S_i = s_{\mu_i} + s_{h_i} \left(\frac{s_{\mu_i}}{s_{\mu_i} + s_{\nu_i}} \right) + \left(\frac{\alpha_i}{2\pi} \right) + \left(\frac{\gamma_i}{2\pi} \right) \left(\frac{\left(\frac{\alpha_i}{2\pi} \right)}{\left(\frac{\alpha_i}{2\pi} \right) + \left(\frac{\beta_i}{2\pi} \right)} \right) \tag{25}$$

Step 5: Identify stable values of the relation matrix. The normalized values of the defuzzified matrix are used to compute a stable matrix. The stable values of the

relation matrix with the values of w_j are defined by transposing and limiting the matrix to a power of $2t + 1$, where t is an arbitrarily large number. Thus, the weighting results for w_j were obtained using the stabilization process in the M-SWARA method.

Step 6: Identify the impact relation degrees. For this purpose, the threshold value, which is the average value of the relation matrix, was considered.

ELECTRE with quantum spherical fuzzy sets

Benayoun et al. (1966) developed the ELECTRE method to rank different alternatives. In the calculation process, concordance and discordance intervals were considered. There are various extensions of the ELECTRE method in the literature. In this study, this technique is integrated with quantum spherical fuzzy sets. The details of these models are provided below:

Step 1: Linguistic evaluations were conducted by an expert team. Table two was used to collect the evaluations from experts.

Step 2: The quantum spherical fuzzy decision matrix (X_{ij}) is created, as shown in Eq. (26).

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

Step 3: The normalization process is implemented for the amplitudes and phase angles of quantum membership, non-membership, and hesitancy degrees using Eq. (27).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^m X_{ij}^2}} \tag{27}$$

Step 4: The values are weighted with Eq. (28):

$$v_{ij} = w_{ij} \times r_{ij} \tag{28}$$

Step 5: Concordance C and discordance D interval matrices are created using Eqs. (29)–(34).

$$C = \begin{bmatrix} - & c_{12} & \cdots & \cdots & c_{1n} \\ c_{21} & - & \cdots & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{29}$$

$$D = \begin{bmatrix} - & d_{12} & \cdots & \cdots & d_{1n} \\ d_{21} & - & \cdots & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{30}$$

$$c_{ab} = \{j | v_{aj} \geq v_{bj}\} \tag{31}$$

$$d_{ab} = \{j | v_{aj} < v_{bj}\} \tag{32}$$

$$c_{ab} = \sum_{j \in c_{ab}} w_j \tag{33}$$

$$d_{ab} = \frac{\max_{j \in d_{ab}} |v_{aj} - v_{bj}|}{\max_j |v_{mj} - v_{nj}|} \tag{34}$$

In these equations, c_{ab} and d_{ab} refer to the concordance and discordance interval sets, respectively.

Step 6: The defuzzified values of the interval matrices are calculated using Eq. (25).

Step 7: The concordance E , discordance F and aggregated G index matrices are calculated using Eqs. (35)–(42).

$$E = \begin{bmatrix} - & e_{12} & \cdots & \cdots & e_{1n} \\ e_{21} & - & \cdots & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{35}$$

$$F = \begin{bmatrix} - & f_{12} & \cdots & \cdots & f_{1n} \\ f_{21} & - & \cdots & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{36}$$

$$G = \begin{bmatrix} - & g_{12} & \cdots & \cdots & g_{1n} \\ g_{21} & - & \cdots & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{37}$$

$$\begin{cases} e_{ab} = 1 & \text{if } c_{ab} \geq \bar{c} \\ e_{ab} = 0 & \text{if } c_{ab} < \bar{c} \end{cases} \tag{38}$$

$$\bar{c} = \sum_{a=1}^n \sum_b^n c_{ab} / n(n-1) \tag{39}$$

$$\begin{cases} f_{ab} = 1 & \text{if } d_{ab} \leq \bar{d} \\ f_{ab} = 0 & \text{if } d_{ab} > \bar{d} \end{cases} \tag{40}$$

$$\bar{d} = \sum_{a=1}^n \sum_b^n d_{ab} / n(n - 1) \tag{41}$$

$$g_{ab} = e_{ab} \times f_{ab} \tag{42}$$

In this context, e_{ab} , f_{ab} , g_{ab} show sets of concordance, discordance, and aggregated index matrices, respectively. \bar{c} and \bar{d} refer to the critical values of the concordance and discordance matrixes, respectively.

Step 8: The net superior c_a , inferior d_a , and overall o_a values are identified using Eqs. (43)–(45). These values were used to rank alternatives.

$$c_a = \sum_{b=1}^n c_{ab} - \sum_{b=1}^n c_{ba} \tag{43}$$

$$d_a = \sum_{b=1}^n d_{ab} - \sum_{b=1}^n d_{ba} \tag{44}$$

$$o_a = c_a - d_a \tag{45}$$

Analysis

In this study, a new model is created to evaluate the components of fintech ecosystems for distributed energy investments. Figure 1 illustrates the details of the proposed model.

This model consists of two stages. The analysis results for all stages are presented below.

Stage 1: Weighting the criteria for the distributed energy investment necessities

Step 1: Determine the criteria for the distributed energy investments

Based on a detailed literature review, the factors with respect to distributed energy investment necessities were identified. Details of these items are listed in Table 1.

Table 1 provides information on the four different distributed energy investment necessities. Increasing energy costs owing to environmental and other external problems play a crucial role in this regard. High costs negatively affect the effectiveness of distributed energy investments (Best et al. 2021). Therefore, necessary actions should be taken to minimize the costs of investments (Gunarathna et al. 2022). Current technological developments significantly contribute to sustaining energy production at a lower cost (Gissey et al. 2021). The continuity of projects that cannot provide cost efficiency is risky. Therefore, a comprehensive cost analysis is essential for the sustainability of distributed energy investments (Dzogbenuku et al. 2022).

The excessive production potential of local plants is another critical issue within this framework. Although renewable energy alternatives are environmentally friendly, there must be sufficient demand for sustainable energy production for these investments (Gissey et al. 2021). In this context, a comprehensive analysis of the energy demand is essential. In the absence of sufficient demand, it does not make sense to implement these investments (Harris 2021). This means that the energy produced cannot be sold

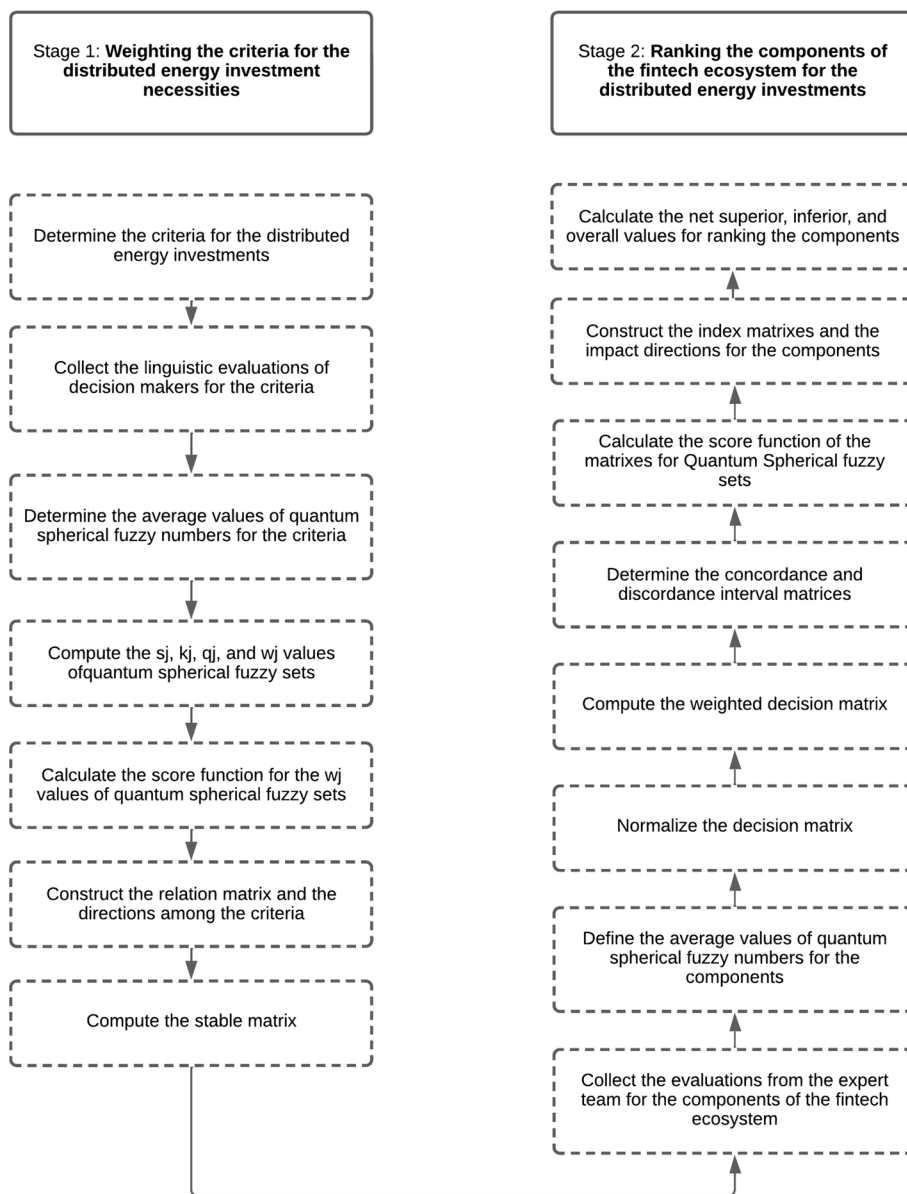


Fig. 1 The flowchart

Table 1 Selected criteria for the distributed energy investment necessities

| Factors | Literature |
|----------------|---|
| Costs (COT) | Dzogbenuku et al. (2022), Mainardes et al. (2022), Gissey et al. (2021), Best et al. (2021), Olleik et al. (2022), Gunarathna et al. (2022) |
| Demand (DAN) | Harris (2021), Muthukannan et al. (2021), Hornuf et al. (2021), Zarrouk et al. (2021), Meng et al. (2021), Lilienthal et al. (2019), Gissey et al. (2021) |
| Pricing (PCN) | Senyo et al. (2022), Daud et al. (2022), Ascarya and Sakti (2022), Tsao et al. (2021), Hussain et al. (2021), Bastian-Pinto et al. (2021), Dinçer et al. (2023) |
| Capacity (CCT) | Rupeika-Apoga and Wendt (2021), Maiti and Ghosh (2021), Kou et al. (2021), Hussain et al. (2021), Meng et al. (2021), Kozlova and Overland (2021), Koengkan et al. (2020), Olleik et al. (2022) |

(Zarrouk et al. 2021). In this environment, it is not possible for distributed energy projects to be financially efficient (Hornuf et al. 2021).

Selling electricity produced at reasonable prices is very important for the efficiency of distributed energy investments. If prices are excessively high, neither individuals nor companies will prefer these products (Senyo et al. 2022). Therefore, the product to be offered should be at reasonable prices, and the volatility of these prices should not be too high (Dinçer et al. 2023). Some factors such as taxes can negatively affect electricity prices. To ensure customer satisfaction, states should avoid these practices (Tsao et al. 2021). On the other hand, issues such as tax reductions and the discovery of new energy sources may also help reduce energy prices (Bastian-Pinto et al. 2021).

The capacity of energy production is another key factor with respect to the necessity of distributed energy investments. In this framework, the constraints and possible corruption of centralized energy generation should be considered (Rupeika-Apoga and Wendt 2021). In other words, the energy production capacity of an enterprise is very important when making a distributed energy investment decision (Maiti and Ghosh 2021). The energy produced will be used by individuals and evaluated as an important raw material for industrial producers (Kozlova and Overland 2021). Therefore, there should be no interruption in energy production. Otherwise, this creates the risk of businesses not being able to supply the energy they need (Koengkan et al. 2020). This can lead to significant customer dissatisfaction. As a result, the efficiency of distributed energy investments decreases.

Step 2: Collect the evaluations from the expert team regarding the criteria

In the second step, evaluations were collected from the expert team regarding the criteria. For this condition, the scales, degrees, and fuzzy numbers listed in Table 2 were considered.

Linguistic scales were adapted from Li et al. (2022a, b) and Meng et al. (2021). The possibility degrees between 0.40–0.60 are proposed by considering the golden cut degree given in Eq. (10). Linguistic evaluations were obtained from decision-makers. The square of the possibility degree was considered for the amplitude of quantum membership degrees, whereas the golden cut degree of the quantum membership numbers was defined as the non-membership degrees of quantum spherical fuzzy sets. In addition, three experts were consulted during this process. They were all senior executives in the field of finance of renewable energy companies. Each had at least 29 years of work experience. They had been managers in both the field of finance and

Table 2 Linguistic scales and golden cut-based quantum spherical fuzzy numbers

| For criteria | For alternatives | Possibility degrees | Quantum spherical fuzzy numbers |
|----------------|------------------|---------------------|---|
| No (n) | Worst (w) | 0.40 | $[\sqrt{0.16}e^{i2\pi \cdot 0.4}, \sqrt{0.10}e^{i2\pi \cdot 0.25}, \sqrt{0.74}e^{i2\pi \cdot 0.35}]$ |
| Some (s) | Bad (p) | 0.45 | $[\sqrt{0.20}e^{i2\pi \cdot 0.45}, \sqrt{0.13}e^{i2\pi \cdot 0.28}, \sqrt{0.67}e^{i2\pi \cdot 0.27}]$ |
| Medium (m) | Normal (f) | 0.50 | $[\sqrt{0.25}e^{i2\pi \cdot 0.50}, \sqrt{0.15}e^{i2\pi \cdot 0.31}, \sqrt{0.60}e^{i2\pi \cdot 0.19}]$ |
| High (h) | Effective (g) | 0.55 | $[\sqrt{0.30}e^{i2\pi \cdot 0.55}, \sqrt{0.19}e^{i2\pi \cdot 0.34}, \sqrt{0.51}e^{i2\pi \cdot 0.11}]$ |
| Very high (vh) | Perfect (b) | 0.60 | $[\sqrt{0.36}e^{i2\pi \cdot 0.6}, \sqrt{0.22}e^{i2\pi \cdot 0.37}, \sqrt{0.42}e^{i2\pi \cdot 0.03}]$ |

Table 3 Linguistic evaluations for the criteria

| | Decision Maker 1 | | | | Decision Maker 2 | | | | Decision Maker 3 | | | |
|-----|------------------|-----|-----|-----|------------------|-----|-----|-----|------------------|-----|-----|-----|
| | COT | DAN | PCN | CCT | COT | DAN | PCN | CCT | COT | DAN | PCN | CCT |
| COT | | M | M | H | | M | M | M | | M | M | M |
| DAN | S | | S | VH | S | | S | VH | N | | M | VH |
| PCN | S | M | | H | S | M | | S | S | M | | N |
| CCT | M | M | VH | | S | S | VH | | M | S | VH | |

Table 4 Average values of quantum spherical fuzzy numbers for the criteria

| | COT | DAN |
|-----|---|---|
| COT | | $[\sqrt{0.25}e^{i2\pi.0.50}, \sqrt{0.15}e^{i2\pi.0.31}, \sqrt{0.60}e^{i2\pi.0.19}]$ |
| DAN | $[\sqrt{0.19}e^{i2\pi.0.43}, \sqrt{0.12}e^{i2\pi.0.27}, \sqrt{0.70}e^{i2\pi.0.30}]$ | |
| PCN | $[\sqrt{0.20}e^{i2\pi.0.45}, \sqrt{0.13}e^{i2\pi.0.28}, \sqrt{0.67}e^{i2\pi.0.27}]$ | $[\sqrt{0.25}e^{i2\pi.0.50}, \sqrt{0.15}e^{i2\pi.0.31}, \sqrt{0.60}e^{i2\pi.0.19}]$ |
| CCT | $[\sqrt{0.24}e^{i2\pi.0.48}, \sqrt{0.14}e^{i2\pi.0.30}, \sqrt{0.62}e^{i2\pi.0.22}]$ | $[\sqrt{0.22}e^{i2\pi.0.47}, \sqrt{0.13}e^{i2\pi.0.29}, \sqrt{0.65}e^{i2\pi.0.25}]$ |
| | PCN | CCT |
| COT | $[\sqrt{0.25}e^{i2\pi.0.50}, \sqrt{0.15}e^{i2\pi.0.31}, \sqrt{0.60}e^{i2\pi.0.19}]$ | $[\sqrt{0.27}e^{i2\pi.0.52}, \sqrt{0.16}e^{i2\pi.0.32}, \sqrt{0.57}e^{i2\pi.0.17}]$ |
| DAN | $[\sqrt{0.22}e^{i2\pi.0.47}, \sqrt{0.13}e^{i2\pi.0.29}, \sqrt{0.65}e^{i2\pi.0.25}]$ | $[\sqrt{0.36}e^{i2\pi.0.60}, \sqrt{0.22}e^{i2\pi.0.37}, \sqrt{0.42}e^{i2\pi.0.03}]$ |
| PCN | | $[\sqrt{0.23}e^{i2\pi.0.47}, \sqrt{0.13}e^{i2\pi.0.29}, \sqrt{0.65}e^{i2\pi.0.26}]$ |
| CCT | $[\sqrt{0.36}e^{i2\pi.0.60}, \sqrt{0.22}e^{i2\pi.0.37}, \sqrt{0.42}e^{i2\pi.0.03}]$ | |

renewable energy investments for many years and were competent in evaluating criteria and alternatives. The evaluations of these participants regarding the criteria are presented in Table 3.

Step 3: Determine the average values of Quantum Spherical fuzzy numbers for the criteria

In the next step, the average values of the Quantum Spherical fuzzy numbers are calculated with respect to the criteria. For this purpose, Eq. (21) is considered. The average values are listed in Table 4.

Step 4: Compute the s_j , k_j , q_j , and w_j values of quantum spherical fuzzy sets for the relationship degrees of each criterion

The critical values are computed in the next process by considering Eqs. (22)–(24). Table 5 lists the w_j values.

Step 5: Calculate the score function for the w_j values of quantum spherical fuzzy sets

Subsequently, defuzzification is performed. Within this context, the score functions are considered in Eq. (25). Details of the calculation results are presented in Table 6.

As an example, the score function value on the axis of the COT and DAN is computed as

$$0.950 = 0.308 + 0.379 \left(\frac{0.308}{0.308 + 0.317} \right) + 0.286 + 0.350 \left(\frac{0.286}{0.286 + 0.302} \right)$$

Step 6: Construct the relation matrix and the directions among the criteria

Table 5 wj values of quantum spherical fuzzy sets

| COT | Wj | DAN | Wj |
|-----|---|-----|---|
| CCT | $[\sqrt{0.39}e^{j2\pi \cdot 0.43}, \sqrt{0.37}e^{j2\pi \cdot 0.40}, \sqrt{0.38}e^{j2\pi \cdot 0.35}]$ | CCT | $[\sqrt{0.40}e^{j2\pi \cdot 0.46}, \sqrt{0.37}e^{j2\pi \cdot 0.42}, \sqrt{0.49}e^{j2\pi \cdot 0.39}]$ |
| DAN | $[\sqrt{0.31}e^{j2\pi \cdot 0.29}, \sqrt{0.32}e^{j2\pi \cdot 0.30}, \sqrt{0.38}e^{j2\pi \cdot 0.35}]$ | PCN | $[\sqrt{0.33}e^{j2\pi \cdot 0.32}, \sqrt{0.33}e^{j2\pi \cdot 0.33}, \sqrt{0.30}e^{j2\pi \cdot 0.31}]$ |
| PCN | $[\sqrt{0.31}e^{j2\pi \cdot 0.29}, \sqrt{0.32}e^{j2\pi \cdot 0.30}, \sqrt{0.24}e^{j2\pi \cdot 0.30}]$ | COT | $[\sqrt{0.28}e^{j2\pi \cdot 0.22}, \sqrt{0.30}e^{j2\pi \cdot 0.26}, \sqrt{0.21}e^{j2\pi \cdot 0.30}]$ |
| PCN | Wj | CCT | Wj |
| DAN | $[\sqrt{0.40}e^{j2\pi \cdot 0.47}, \sqrt{0.38}e^{j2\pi \cdot 0.42}, \sqrt{0.50}e^{j2\pi \cdot 0.41}]$ | PCN | $[\sqrt{0.40}e^{j2\pi \cdot 0.47}, \sqrt{0.38}e^{j2\pi \cdot 0.42}, \sqrt{0.49}e^{j2\pi \cdot 0.38}]$ |
| CCT | $[\sqrt{0.33}e^{j2\pi \cdot 0.32}, \sqrt{0.33}e^{j2\pi \cdot 0.33}, \sqrt{0.31}e^{j2\pi \cdot 0.32}]$ | COT | $[\sqrt{0.33}e^{j2\pi \cdot 0.32}, \sqrt{0.33}e^{j2\pi \cdot 0.33}, \sqrt{0.30}e^{j2\pi \cdot 0.31}]$ |
| COT | $[\sqrt{0.27}e^{j2\pi \cdot 0.22}, \sqrt{0.29}e^{j2\pi \cdot 0.26}, \sqrt{0.19}e^{j2\pi \cdot 0.27}]$ | DAN | $[\sqrt{0.27}e^{j2\pi \cdot 0.22}, \sqrt{0.29}e^{j2\pi \cdot 0.25}, \sqrt{0.21}e^{j2\pi \cdot 0.30}]$ |

Table 6 Score function for the wj values of quantum spherical fuzzy sets

| | COT | DAN | PCN | CCT |
|-----|-------|-------|-------|-------|
| COT | 0.000 | 0.950 | 0.950 | 1.093 |
| DAN | 0.911 | 0.000 | 0.944 | 1.129 |
| PCN | 0.919 | 1.109 | 0.000 | 0.953 |
| CCT | 0.947 | 0.893 | 1.143 | 0.000 |

Table 7 Normalized relation matrix and the impact directions

| | COT | DAN | PCN | CCT | Impact directions |
|-----|-------|-------|-------|-------|-------------------|
| COT | 0.000 | 0.317 | 0.317 | 0.365 | COT → CCT |
| DAN | 0.305 | 0.000 | 0.316 | 0.378 | DAN → CCT |
| PCN | 0.308 | 0.372 | 0.000 | 0.320 | PCN → DAN |
| CCT | 0.317 | 0.299 | 0.383 | 0.000 | CCT → PCN |

In the following step, the score function values of the relation matrix are normalized using the equation, and the directions of the criteria are constructed. Causal relations are identified by considering the threshold value, which is the average of the relation matrix. Table 7 provides information about the relation matrix and impact directions.

The average value of the relation matrix is considered as a threshold value and the higher value than the threshold is assumed that the criterion at the row has an impact on the criterion at the column of the relation matrix. Accordingly, the threshold was computed to be 0.33, and the directions were determined based on this assumption. Table 7 demonstrates that cost and demand have an impact on capacity. This situation indicates that it can be much easier to increase capacity if costs can be reduced and demand can be increased. In addition, the pricing strategy has an influence on demand. In other words, when prices are excessively high, neither individuals nor companies prefer products. Finally, capacity affects pricing strategy in an important way. This shows that capacity plays a very important role in the necessity of distributed energy investments.

Step 7: Compute the stable matrix

Finally, stable values of the relation matrix were defined. In this context, this matrix is transposed and limited to a power of $2t + 1$. A stable matrix was created such that the weights of the factors could be identified. The details of this matrix are listed in Table 8.

Table 8 reveals that capacity is the most critical issue with respect to the distributed energy investment necessities because it has the greatest weight (0.261). Moreover, pricing is another significant issue for this condition with the weight of 0.254. Demand and costs have the lower weights compared with the others. To increase the efficiency of distributed energy projects, first, it is necessary to pay attention to the capacity issue. In this context, there should be no interruptions in electricity production. Because these interruptions will create customer dissatisfaction, it will be very difficult to ensure the continuity of investments in the long run. In addition, some of the renewable energy alternatives can be adversely affected by climatic conditions. This situation affects the continuity of electricity production. Therefore, it is necessary to determine new techniques for the energy storage process, especially with technological developments and to apply them to projects. This will prevent disruptions in energy production capacity.

Stage 2: Ranking the components of the fintech ecosystem for the distributed energy investments

Step 8: Collect the evaluations from the expert team for the components of the fintech ecosystem

In the second stage of the proposed model, the components of the fintech ecosystem are first defined with the help of a literature review. In this study, we aimed to identify the more significant components of this system so that specific strategies could be determined to improve its effectiveness. Table 9 lists the details of the components.

Startups play an important role in the development of fintech ecosystems. Technological investments and digitalization can be more easily applied to the financial sector with the help of startups. Therefore, countries should provide some financial support to startups. They must have sufficient industrial knowledge. Similarly, customer satisfaction should be considered in the investments. Regulatory authority is another important component of fintech ecosystem. Governments have a strong influence on market conditions. In addition, the effectiveness of the fintech ecosystem can be significantly increased with the help of an effective auditing system.

Companies purchasing innovative financial products also play a critical role in this situation. Therefore, customer expectations should be considered. In other words, effective and user-friendly financial products should be developed to increase customer satisfaction. Fintech ecosystems can be generated more effectively with the

Table 8 Stable matrix

| | COT | DAN | PCN | CCT |
|-----|-------|-------|-------|-------|
| COT | 0.237 | 0.237 | 0.237 | 0.237 |
| DAN | 0.248 | 0.248 | 0.248 | 0.248 |
| PCN | 0.254 | 0.254 | 0.254 | 0.254 |
| CCT | 0.261 | 0.261 | 0.261 | 0.261 |

Table 9 Selected components for the fintech ecosystem

| Components | References |
|--------------------------------|--|
| Start-ups (SPS) | Harris (2021), Muthukannan et al. (2021), Hornuf et al. (2021), Zarrouk et al. (2021) |
| Regulatory authorities (RHS) | Chorzempa and Huang (2022), Murinde et al. (2022), Merello et al. (2022), Xue et al. (2022) |
| End users (EUS) | Aysan et al. (2022), Dzogbenuku et al. (2022), Mainardes et al. (2022), Dzogbenuku et al. (2022) |
| Technology investors (TOR) | Rupeika-Apoga and Wendt (2021), Maiti and Ghosh (2021), Kou et al. (2021), Hussain et al. (2021) |
| Financial intermediaries (FNA) | Muganyi et al. (2022), Senyo et al. (2022), Daud et al. (2022), Ascarya and Sakti (2022) |

Table 10 Linguistic evaluations for the components

| | Decision Maker 1 | | | | Decision Maker 2 | | | | Decision Maker 3 | | | |
|-----|------------------|-----|-----|-----|------------------|-----|-----|-----|------------------|-----|-----|-----|
| | COT | DAN | PCN | CCT | COT | DAN | PCN | CCT | COT | DAN | PCN | CCT |
| SPS | G | F | F | G | G | F | F | B | F | F | F | G |
| RHS | F | B | P | B | F | B | P | B | F | B | P | B |
| EUS | G | G | B | F | G | G | B | F | G | G | F | F |
| TOR | W | F | W | F | B | P | W | B | P | F | P | F |
| FNA | F | P | B | G | F | P | P | P | F | P | B | P |

help of this issue. However, when financial products create customer dissatisfaction, it is very difficult to determine the effectiveness of this system. Therefore, a comprehensive evaluation must be conducted to generate innovative financial products.

Technology investments are also an important component of fintech ecosystems. More effective and innovative financial products can be identified through technological improvements. Technological software positively impacts the generation of effective fintech ecosystems. Therefore, governments should provide financial support to technology investors. Within this framework, loans with low interest rates can be provided to investors. Financial institutions are among the most important actors in the system. They have a powerful influence on increasing the reliability of fintech ecosystems. Next, the expert team evaluated these five components using the scales in Table 2. The details of the evaluations are presented in Table 10.

Step 9: Define the average values of quantum spherical fuzzy numbers for the components

The following step is related to the calculation of the average values: The results are presented in Table 11.

Step 10: Normalize the decision matrix

Next, the decision matrix is normalized for the amplitudes and phase angles of the quantum membership, non-membership, and hesitancy degrees, while considering Eq. (27). As an example of the normalization process, Table 12 provides information regarding the normalized decision matrix for the amplitudes of the quantum membership degrees.

Step 11: Compute the weighted decision matrix

Table 11 Average values of quantum spherical fuzzy numbers for the components

| | COT | DAN |
|-----|--|--|
| SPS | $[\sqrt{0.29}e^{i2\pi.053}, \sqrt{0.18}e^{i2\pi.033}, \sqrt{0.54}e^{i2\pi.014}]$ | $[\sqrt{0.25}e^{i2\pi.050}, \sqrt{0.15}e^{i2\pi.031}, \sqrt{0.60}e^{i2\pi.019}]$ |
| RHS | $[\sqrt{0.25}e^{i2\pi.050}, \sqrt{0.15}e^{i2\pi.031}, \sqrt{0.60}e^{i2\pi.019}]$ | $[\sqrt{0.36}e^{i2\pi.060}, \sqrt{0.22}e^{i2\pi.037}, \sqrt{0.42}e^{i2\pi.003}]$ |
| EUS | $[\sqrt{0.30}e^{i2\pi.055}, \sqrt{0.19}e^{i2\pi.034}, \sqrt{0.51}e^{i2\pi.011}]$ | $[\sqrt{0.30}e^{i2\pi.055}, \sqrt{0.19}e^{i2\pi.034}, \sqrt{0.51}e^{i2\pi.011}]$ |
| TOR | $[\sqrt{0.26}e^{i2\pi.050}, \sqrt{0.14}e^{i2\pi.029}, \sqrt{0.63}e^{i2\pi.025}]$ | $[\sqrt{0.24}e^{i2\pi.048}, \sqrt{0.14}e^{i2\pi.030}, \sqrt{0.62}e^{i2\pi.022}]$ |
| FNA | $[\sqrt{0.25}e^{i2\pi.050}, \sqrt{0.15}e^{i2\pi.031}, \sqrt{0.60}e^{i2\pi.019}]$ | $[\sqrt{0.20}e^{i2\pi.045}, \sqrt{0.13}e^{i2\pi.028}, \sqrt{0.67}e^{i2\pi.027}]$ |
| | PCN | CCT |
| SPS | $[\sqrt{0.25}e^{i2\pi.050}, \sqrt{0.15}e^{i2\pi.031}, \sqrt{0.60}e^{i2\pi.019}]$ | $[\sqrt{0.32}e^{i2\pi.056}, \sqrt{0.18}e^{i2\pi.034}, \sqrt{0.52}e^{i2\pi.015}]$ |
| RHS | $[\sqrt{0.20}e^{i2\pi.045}, \sqrt{0.13}e^{i2\pi.028}, \sqrt{0.67}e^{i2\pi.027}]$ | $[\sqrt{0.36}e^{i2\pi.060}, \sqrt{0.22}e^{i2\pi.037}, \sqrt{0.42}e^{i2\pi.003}]$ |
| EUS | $[\sqrt{0.33}e^{i2\pi.057}, \sqrt{0.20}e^{i2\pi.035}, \sqrt{0.49}e^{i2\pi.011}]$ | $[\sqrt{0.25}e^{i2\pi.050}, \sqrt{0.15}e^{i2\pi.031}, \sqrt{0.60}e^{i2\pi.019}]$ |
| TOR | $[\sqrt{0.18}e^{i2\pi.042}, \sqrt{0.11}e^{i2\pi.026}, \sqrt{0.72}e^{i2\pi.033}]$ | $[\sqrt{0.29}e^{i2\pi.053}, \sqrt{0.18}e^{i2\pi.033}, \sqrt{0.54}e^{i2\pi.014}]$ |
| FNA | $[\sqrt{0.32}e^{i2\pi.056}, \sqrt{0.18}e^{i2\pi.034}, \sqrt{0.52}e^{i2\pi.015}]$ | $[\sqrt{0.24}e^{i2\pi.049}, \sqrt{0.14}e^{i2\pi.030}, \sqrt{0.63}e^{i2\pi.023}]$ |

Table 12 Normalized decision matrix for the amplitudes of quantum membership degrees

| | COT | DAN | PCN | CCT |
|-----|-------|-------|-------|-------|
| SPS | 0.474 | 0.406 | 0.427 | 0.487 |
| RHS | 0.414 | 0.584 | 0.346 | 0.543 |
| EUS | 0.501 | 0.491 | 0.561 | 0.377 |
| TOR | 0.427 | 0.382 | 0.299 | 0.441 |
| FNA | 0.414 | 0.328 | 0.543 | 0.363 |

Table 13 Weighted decision matrix for the amplitudes of quantum membership degrees

| | COT | DAN | PCN | CCT |
|-----|-------|-------|-------|-------|
| SPS | 0.112 | 0.101 | 0.108 | 0.127 |
| RHS | 0.098 | 0.145 | 0.088 | 0.142 |
| EUS | 0.119 | 0.122 | 0.142 | 0.099 |
| TOR | 0.101 | 0.095 | 0.076 | 0.115 |
| FNA | 0.098 | 0.081 | 0.138 | 0.095 |

The weighted values were computed using Eq. (28), and the weighted matrices are presented in Table 13.

Step 12: Determine the concordance and discordance interval matrices

The next step includes the generation of concordance and discordance interval matrices for the quantum membership degrees by considering Eqs. (29)–(34). For instance, Table 14 provides information regarding the details of these matrices on the amplitudes of the quantum membership degrees. Table 15 presents the overall concordance and discordance interval matrices for the quantum spherical fuzzy sets.

Step 13: Calculate the score function of the matrixes for quantum spherical fuzzy sets

Table 14 Concordance and discordance interval matrixes for the amplitudes of quantum membership degrees

| | Concordance matrix | | | | | Discordance matrix | | | | |
|-----|--------------------|-------|-------|-------|-------|--------------------|-------|-------|-------|-------|
| | SPS | RHS | EUS | TOR | FNA | SPS | RHS | EUS | TOR | FNA |
| SPS | 0.000 | 0.491 | 0.261 | 1.000 | 0.254 | 0.000 | 1.000 | 1.000 | 0.000 | 0.910 |
| RHS | 0.509 | 0.000 | 0.509 | 0.763 | 0.746 | 0.465 | 0.000 | 1.000 | 0.062 | 0.789 |
| EUS | 0.763 | 0.491 | 0.000 | 0.739 | 1.000 | 0.849 | 0.795 | 0.000 | 0.251 | 0.000 |
| TOR | 0.000 | 0.237 | 0.261 | 0.000 | 0.746 | 1.000 | 1.000 | 1.000 | 0.000 | 1.000 |
| FNA | 0.254 | 0.491 | 0.000 | 0.254 | 0.000 | 1.000 | 1.000 | 1.000 | 0.326 | 0.000 |

Table 15 Concordance and discordance interval matrixes for the quantum spherical fuzzy sets

| | SPS | RHS | EUS | TOR | FNA |
|---------------------------|---|---|---|---|---|
| <i>Concordance matrix</i> | | | | | |
| SPS | | $\begin{bmatrix} \sqrt{0.49}e^{j2\pi.049} \\ \sqrt{0.49}e^{j2\pi.049} \\ \sqrt{0.51}e^{j2\pi.051} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.26}e^{j2\pi.026} \\ \sqrt{0.26}e^{j2\pi.026} \\ \sqrt{0.74}e^{j2\pi.074} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.25}e^{j2\pi.0.75} \\ \sqrt{0.75}e^{j2\pi.0.75} \\ \sqrt{0.25}e^{j2\pi.0.25} \end{bmatrix}$ |
| RHS | $\begin{bmatrix} \sqrt{0.51}e^{j2\pi.0.51} \\ \sqrt{0.51}e^{j2\pi.0.51} \\ \sqrt{0.49}e^{j2\pi.0.49} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{0.51}e^{j2\pi.0.51} \\ \sqrt{0.51}e^{j2\pi.0.51} \\ \sqrt{0.49}e^{j2\pi.0.49} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.76}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.75}e^{j2\pi.0.75} \\ \sqrt{0.75}e^{j2\pi.0.75} \\ \sqrt{0.49}e^{j2\pi.0.49} \end{bmatrix}$ |
| EUS | $\begin{bmatrix} \sqrt{0.76}e^{j2\pi.0.76} \\ \sqrt{0.74}e^{j2\pi.0.74} \\ \sqrt{0.26}e^{j2\pi.0.26} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.49}e^{j2\pi.0.49} \\ \sqrt{0.49}e^{j2\pi.0.49} \\ \sqrt{0.51}e^{j2\pi.0.51} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{0.74}e^{j2\pi.0.74} \\ \sqrt{0.74}e^{j2\pi.0.74} \\ \sqrt{0.26}e^{j2\pi.0.26} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ |
| TOR | $\begin{bmatrix} \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.24}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.26}e^{j2\pi.0.26} \\ \sqrt{0.26}e^{j2\pi.0.26} \\ \sqrt{0.74}e^{j2\pi.0.74} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{0.75}e^{j2\pi.0.51} \\ \sqrt{0.51}e^{j2\pi.0.51} \\ \sqrt{0.49}e^{j2\pi.0.49} \end{bmatrix}$ |
| FNA | $\begin{bmatrix} \sqrt{0.25}e^{j2\pi.0.25} \\ \sqrt{0.25}e^{j2\pi.0.25} \\ \sqrt{0.75}e^{j2\pi.0.75} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.49}e^{j2\pi.0.49} \\ \sqrt{0.49}e^{j2\pi.0.49} \\ \sqrt{0.75}e^{j2\pi.0.75} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.25}e^{j2\pi.0.49} \\ \sqrt{0.49}e^{j2\pi.0.49} \\ \sqrt{0.51}e^{j2\pi.0.51} \end{bmatrix}$ | |
| <i>Discordance matrix</i> | | | | | |
| SPS | | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.42}e^{j2\pi.0.42} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.91}e^{j2\pi.0.75} \\ \sqrt{0.59}e^{j2\pi.0.56} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ |
| RHS | $\begin{bmatrix} \sqrt{0.47}e^{j2\pi.0.53} \\ \sqrt{0.48}e^{j2\pi.0.53} \\ \sqrt{1.00}e^{j2\pi.0.48} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.06}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.79}e^{j2\pi.0.76} \\ \sqrt{0.67}e^{j2\pi.0.68} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ |
| EUS | $\begin{bmatrix} \sqrt{0.85}e^{j2\pi.0.92} \\ \sqrt{0.92}e^{j2\pi.0.98} \\ \sqrt{0.83}e^{j2\pi.0.64} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.80}e^{j2\pi.0.80} \\ \sqrt{0.85}e^{j2\pi.0.83} \\ \sqrt{0.90}e^{j2\pi.0.68} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{0.25}e^{j2\pi.0.23} \\ \sqrt{0.20}e^{j2\pi.0.20} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ |
| TOR | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.25}e^{j2\pi.0.25} \end{bmatrix}$ | | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.48}e^{j2\pi.0.62} \end{bmatrix}$ |
| FNA | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.44}e^{j2\pi.0.20} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.57}e^{j2\pi.0.41} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{1.00}e^{j2\pi.1.00} \\ \sqrt{0.00}e^{j2\pi.0.00} \end{bmatrix}$ | $\begin{bmatrix} \sqrt{0.33}e^{j2\pi.0.34} \\ \sqrt{0.37}e^{j2\pi.0.37} \\ \sqrt{1.00}e^{j2\pi.1.00} \end{bmatrix}$ | |

In the next step, the score functions of the matrices are computed using Eq. (25). The details are listed in Table 16.

Step 14: Construct the index matrixes and the impact directions for the components

This step demonstrates the creation of index matrices and the impact directions of the components. The defuzzied values that imply the score function of the matrices are considered for computing the index values. Equations (35)–(42) are considered for this issue, and the details are presented in Table 17.

The impact-relation directions of the components were illustrated using the results of the aggregated index matrix. Table 17 shows that regulatory authorities influence startups and technology investors. Similarly, end users also affect financial intermediaries and technological investors. It is understood that in the case of an increase in the effectiveness of regulatory authorities and end users, many different components can be improved. Governments can focus on these issues to create an effective fintech ecosystem.

Step 15: Calculate the net superior, inferior, and overall values for ranking the components

The final step is related to the ranking of components. In this process, Eqs. (43)–(45) were considered. The analysis results are indicated in Table 18.

The overall values were used to rank the components. However, the net superior and inferior values were also consistent with the overall values for ranking the components. End-users were found to be of the greatest importance to the effectiveness of the fintech ecosystem. Regulatory authorities are also important for improving the performance of this ecosystem. It is understood that the companies that will purchase innovative financial products have a critical role in this situation. Hence, customer expectations should be considered. In other words, effective and user-friendly financial products should be generated to achieve customer satisfaction. This will help improve the performance of fintech ecosystems. The robustness check of the proposed model, the comparative ranking results, and the impact relations of the Pythagorean and Spherical fuzzy sets are also given in Table 19.

The comparative results demonstrated that the ranking and impact directions of the components were similar. Using the advantages of quantum mechanics and its extension to fuzzy-based techniques, the decision-making process under uncertainty can be managed more accurately. However, it can also be concluded that the proposed model is coherent and applicable to further extensions of real-world complex decision-making approaches.

Table 16 Score function of the matrixes for quantum spherical fuzzy sets

| | Concordance Matrix | | | | | Discordance Matrix | | | | |
|-----|--------------------|-------|-------|-------|-------|--------------------|-------|-------|-------|-------|
| | SPS | RHS | EUS | TOR | FNA | SPS | RHS | EUS | TOR | FNA |
| SPS | 0.000 | 1.491 | 1.261 | 2.000 | 1.191 | 0.000 | 2.420 | 3.000 | 0.000 | 2.842 |
| RHS | 1.509 | 0.000 | 1.509 | 1.763 | 1.983 | 1.724 | 0.000 | 3.000 | 0.000 | 2.623 |
| EUS | 1.765 | 1.491 | 0.000 | 1.739 | 2.000 | 2.481 | 2.363 | 0.000 | 1.581 | 0.000 |
| TOR | 0.000 | 0.000 | 1.261 | 0.000 | 1.792 | 2.000 | 2.000 | 2.254 | 0.000 | 2.552 |
| FNA | 1.254 | 1.728 | 0.000 | 1.173 | 0.000 | 2.319 | 2.490 | 2.000 | 1.619 | 0.000 |

Table 17 Index matrices and the impact directions for the components

| | Concordance Matrix | | | | | Discordance Matrix | | | | | Aggregated Matrix | | | | | Impact Directions |
|-----|--------------------|-----|-----|-----|-----|--------------------|-----|-----|-----|-----|-------------------|-----|-----|-----|-----|------------------------|
| | SPS | RHS | EUS | TOR | FNA | SPS | RHS | EUS | TOR | FNA | SPS | RHS | EUS | TOR | FNA | |
| SPS | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | SPS → TOR |
| RHS | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | RHS → SPS RHS → TOR |
| EUS | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | EUS → TOR EUS → FNA |
| TOR | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| FNA | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | - |

Table 18 Net superior, inferior, and overall values of the components

| Components | Net superior values | Net inferior values | Overall values | Ranking |
|------------|---------------------|---------------------|----------------|---------|
| SPS | 1.415 | -0.262 | 1.677 | 3 |
| RHS | 2.056 | -1.926 | 3.981 | 2 |
| EUS | 2.963 | -3.829 | 6.792 | 1 |
| TOR | -3.621 | 5.605 | -9.226 | 5 |
| FNA | -2.813 | 0.412 | -3.224 | 4 |

Table 19 Comparative ranking results and impact relations of the components

| Components | Pythagorean fuzzy sets | | Spherical fuzzy sets | | Quantum spherical fuzzy sets | |
|------------|------------------------|---------|------------------------|---------|------------------------------|---------|
| | Impact directions | Ranking | Impact directions | Ranking | Impact directions | Ranking |
| SPS | - | 3 | SPS → TOR | 3 | SPS → TOR | 3 |
| RHS | RHS → TOR | 2 | RHS → TOR RHS → SPS | 2 | RHS → SPS RHS → TOR | 2 |
| EUS | EUS → TOR EUS → FNA | 1 | EUS → TOR EUS → FNA | 1 | EUS → TOR EUS → FNA | 1 |
| TOR | - | 4 | - | 5 | - | 5 |
| FNA | - | 5 | - | 4 | - | 4 |

Discussions

Distributed energy projects are vital for increasing clean energy use. Renewable energy projects have a cost disadvantage compared with fossil fuels. Therefore, to increase the use of clean energy, the financing problem of distributed energy projects must first be solved. In this context, the development of an effective fintech ecosystem can help create innovative financial products, allowing distributed energy investors to reach the funds they need more quickly and effectively (Gawusu et al. 2022). The successful design of a fintech ecosystem is vital for the sustainability of innovative financial products offered to distributed energy investors. For this ecosystem to be successfully developed, the need for distributed energy investments must first be determined. Subsequently, the most important players in the fintech ecosystem should be identified (Ren et al. 2022). With these two different analyses, it is possible to establish an ecosystem that meets customer expectations and is financially efficient.

It was concluded that capacity is the most critical issue with respect to distributed energy investment necessities because it has the greatest weight (0.261). Pricing is another significant issue for this condition, with a weight of 0.254. Considering the results obtained in this study, it is understood that energy generation capacity is the most important requirement for distributed energy investments. One of the most important problems in renewable energy projects is disruption of the energy production process (Murshed et al. 2022). However, renewable energy alternatives can be affected by climate-related issues. This situation causes disruptions in electricity generation over time (Pilou et al. 2022). As energy is an important raw material in industrial production, these disruptions create significant problems. To solve this problem, it is necessary to increase the efficiency of the energy storage processes. It was concluded that end-users are of the greatest importance to the effectiveness of the fintech ecosystem, suggesting

that customer expectations should be considered when generating innovative financial products. To achieve this objective, effective and user-friendly financial products should be developed to increase customer satisfaction.

Most studies have yielded similar results. Dadashi et al. (2022) and Singh et al. (2022) examined the effectiveness of renewable energy investment. They found that a high capacity for electricity production should be provided for these investments to be effective. Dhar and Chakraborty (2022), Arsad et al. (2022), and Gordon (2022) evaluated the key indicators for improving the performance of renewable energy investments. It was determined that uninterrupted energy should be provided to achieve customer satisfaction for these projects. In this framework, the necessary investments should be made, especially for energy storage technologies. These measures can improve the cost-effectiveness of clean energy projects.

Conclusions

A new model was developed to examine the components of fintech ecosystems for distributed energy investments. It was concluded that capacity is the most critical issue with respect to distributed energy investment necessities. This situation indicates that if there is no disruption in the renewable energy production process, projects will be more efficient. Because these interruptions create customer dissatisfaction, it is very difficult to ensure the continuity of investments in the long run. Pricing is another significant issue under this condition. In addition, capacity affects the pricing strategy in an important way. This shows that capacity plays a very important role in the necessity of distributed energy investments.

On the other hand, with respect to the ranking of the components of the fintech ecosystem, end users are of the greatest importance for the effectiveness of this system. Hence, customers' expectations should be considered when generating effective and user-friendly financial products. This situation helps increase customer satisfaction. Moreover, the comparative results demonstrate that the ranking and impact directions of the components are similar. Thus, it can be concluded that the proposed model is coherent and applicable to further extensions of real-world complex decision-making approaches.

The main novelty of this study is that specific and effective strategies can be presented to improve distributed energy investments by using an original fuzzy decision-making model. Moreover, a priority analysis among the players in the fintech ecosystem can contribute significantly to the development of the fintech ecosystem and the generation of effective innovative financial products. However, the main limitation of this study is that a general evaluation was performed to evaluate the effectiveness of distributed energy investments. In future research, different renewable energy types can be specifically examined. For example, a new fuzzy decision-making model can be created to generate innovative financial products for solar energy investments.

Author contributions

RA conceived of the study and participated in its design and coordination and helped to draft the manuscript. YZ participated in the design of the study and performed the statistical analysis. SY conceived of the study and participated in its design and coordination and helped to draft the manuscript. HD participated in the design of the study and performed the statistical analysis. All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare that they have no competing interests.

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