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Understanding the financial innovation priorities for renewable energy investors via QFD-based picture fuzzy and rough numbers

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Abstract

This study evaluates financial innovation priorities for renewable energy investors by generating a novel hybrid fuzzy decision-making model. First, SERVQUAL-based customer needs for financial innovation are weighted with decision-making trial and evaluation laboratory based on picture fuzzy sets. Second, the financial innovation priorities are ranked by technique for order preference by similarity to ideal solutions based on picture fuzzy rough sets. In this process, Theory of the solution of inventive problems-based technical characteristics for financial services, the process for innovative services, and competencies for financial innovation are considered using quality function deployment phases. In addition, the Vise Kriterijumska Optimizacija I Kompromisno Resenje method is also considered for an alternative ranking. Similarly, sensitivity analysis is also performed by considering five different cases. It is determined that the ranking priorities based on the proposed model are almost identical, demonstrating the proposed model's validity and reliability. Assurance is the most crucial factor for the customer needs regarding the financial innovation priorities for renewable energy investors. Concerning the financial innovation priorities, the product is the essential priority for financial innovation; hence, it is recommended that companies engage qualified employees to effectively design the financial innovation for renewable energy investors. Additionally, necessary training should be given to the employees who currently work in the company, which can increase the renewable energy investors' trust in the innovative financial products. Companies should mainly focus on the product to provide better financial innovation to attract renewable energy investors. An effectively designed financial innovation product can help solve the financing problem of renewable energy investors.

Keywords: Financial innovation, Investment, QFD, Fuzzy sets, Fuzzy rough numbers, DEMATEL, TOPSIS, Renewable energy

Introduction

Renewable energy projects help countries produce energy to mitigate the energy dependency problem (Alshubiri et al. 2020). Moreover, renewable energy also minimizes carbon emission that leads to global warming (Mustafa et al. 2018); however, the installation cost of renewable energy projects is relatively high compared to fossil fuels (Kösedağlı et al. 2021; Olabi and Abdelkareem 2022), and the amount of energy obtained is not stable. In this framework, the excess energy obtained in some periods must be stored, increasing the costs of these projects (Jiang et al. 2020a, b). Due to the high-cost problems, obtaining the necessary financial resources is vital for developing renewable energy projects. Bank loans are among the most preferred financing types (Ehigiamusoe and Dogan 2022; Chen et al. 2021a, b, c); however, renewable energy projects require a high level of financing (Qamruzzaman and Jianguo 2018). Therefore, banks may be unwilling to support these projects; this problem is also valid for financing methods, such as factoring and leasing (Peter et al. 2022). The equity financing method can also finance renewable energy projects (Khraisha and Arthur 2018). Conversely, the high amount of investment in projects is one of the important obstacles to the use of this method.

Solving the financing problem of renewable energy investors requires developing new financing alternatives. It is important to present new financing types to renewable energy investors by making financial innovations (Chen et al. 2017); however, some issues need to be considered. For instance, customers should make their transactions quickly, and necessary information should be provided (Chishti and Sinha 2022) to reduce the risk of customers making erroneous transactions on the system (Salisu and Obiora 2021). Many studies discussed the subject of financial innovation regarding renewable energy investments; however, limited studies evaluate significant points to make effective financial innovation for investors (Alawi et al. 2022). In this context, there should be a detailed analysis that examines many different factors simultaneously, such as customer expectations, technical requirements, the process for financial services, and competencies of the financial innovation (Hussain and Papastathopoulos 2022).

Another crucial factor in this regard is the selected methodology, and the extant literature prefers the Service Quality Model (SERVQUAL) to evaluate customer service quality. SERVQUAL focuses on some key points, such as reliability, empathy, tangibles, assurance, and responsiveness (Prentkovskis et al. 2018), and by considering multidimensional factors, it can be possible to understand renewable energy investors' expectations (Dinçer et al. 2019; Sam et al. 2018). Similarly, the quality function deployment (QFD) model helps generate effective strategies by considering customer needs and technical requirements together (Abdel-Basset et al. 2019; Ping et al. 2020), and the Theory of the Solution of Inventive Problems (TRIZ) is an important technique applied to develop innovative solutions to problems. This process examined the details of many patents to categorize the questions (Meng et al. 2021a, b), developed specific solution proposals for these problems, and divided them into certain classes (Sharaf et al. 2020) before selecting defined solutions for specific problems (Lee et al. 2020). The biggest advantage of the TRIZ method is that it contributes to increased efficiency in the process (Moussa et al. 2017). Multi-criteria decision-making models are also used to find ideal alternatives (Kaya et al. 2019). In other words, these methods help determine which of the different factors should be prioritized (Bertoni 2019; Deveci et al. 2022a, 2022b).

Effective financing resources should be provided to increase renewable energy investments, and financial innovations are needed to achieve this goal. In this process, many different aspects, such as customer expectations, technological development, and qualified personnel, are needed to effectively design financial innovations (Kabir 2022). In other words, companies that make financial innovations should improve these factors (Surakji et al. 2022); however, any application to develop these elements can create new costs for companies. Therefore, making simultaneous improvements for all factors is not considered possible in practice, as it would cost too much (Sławik and Bohatkiewicz-Czaicka 2022). Therefore, companies that make financial innovations must first identify the more important factors and focus on them. In this context, it would be appropriate to make a priority analysis of the factors affecting the quality of financial innovation. Similar studies in the extant literature emphasized factors affecting financial innovation, such as technological development and service quality (Yu et al. 2021; Xu and Wang 2021). Hence, there is a need for a new study to determine the most important factors among those mentioned.

Accordingly, this study aims to define financial innovation priorities for renewable energy investors. In this context, the main research question is to define which factors play a more critical role in the effectiveness of financial innovation. Within this framework, a novel decision-making model is created. First, SERVQUAL-based customer needs for financial innovation are weighted using a decision-making trial and evaluation laboratory (DEMATEL) methodology based on picture fuzzy sets. In the second stage, the financial innovation priorities are ranked using the QFD-based phases with a technique for order preference by similarity to ideal solutions (TOPSIS) based on picture fuzzy rough sets (PFRSs). In this context, TRIZ-based technical characteristics for financial services, the process for innovative services, and financial innovation competencies are considered. Additionally, the Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method is also considered an alternative ranking, and sensitivity analysis is implemented by considering five different cases. This study's primary motivation is to efficiently identify more significant issues to improve financial innovations by considering a novel fuzzy decision-making model. Therefore, the companies can increase the quality of the financial innovation without having high costs owing to the strategies presented in this study. Moreover, f this study's methods allow the creation of a novel model that is significantly superior to the previous ones.

The rest of the manuscript is detailed as follows. A literature review is conducted in the second part, the methodology is explained in the third part, and the fourth part conducts an application for renewable energy investors. The fifth part presents the discussion, followed by the conclusions.

Literature review

The extant literature broadly examines the key issues of generating innovative financial products for renewable energy investors. For the effectiveness of this financial innovation, first, the expectations of the renewable energy investors should be considered (Croutzet and Dabbous 2021; Boute 2020; Dinçer et al. 2022), and a comprehensive evaluation should be conducted to identify the needs of these investors (Kauffman and Roston 2021). Companies should be willing to solve the problems, which positively influences the views of renewable energy investors (Yu et al. 2021; Sen and von Schickfus 2020). Meng et al. (2021a, b) focused on the fintech-based clean energy investment projects. Pythagorean fuzzy group decision modeling was used in this study's analysis process. They stated that customer expectations should be satisfied to improve financial innovation for renewable energy investment projects. Hamwi and Lizarralde (2017) also evaluated the same topic and concluded that customer satisfaction plays a role in this context. Wang et al. (2022) studied the usage of blockchain technology in renewable energy investments, identifying that renewable energy investors' expectations should be considered.

Financial innovation system security is also crucial to attract the attention of renewable energy investors. This system provides safe services to customers so that renewable energy investors feel secure while using innovative financial products (Jin and Tian 2020; Unsal and Rayfield 2019), and necessary security controls should be designed to minimize risks (Yuan et al. 2021). Essential precautions should minimize the system's hacking risks and reduce investor anxiety (Knuth 2018; Qamruzzaman and Wei 2019). Yu et al. (2022) analyzed the financial innovation performance of renewable energy projects in China, claiming that effective security controls should be implemented to achieve this objective. Khan et al. (2020) tried to identify key issues in reducing carbon emissions and recommended improving security conditions to increase the effectiveness of renewable energy investment projects. Horsch and Richter (2017) also focused on the driving forces of financial innovation in renewable energy investments, highlighting the significance of security conditions.

Employee quality is also a key driver to increasing financial innovation performance for renewable energy investors. Effective financial products should be presented to attract the attention of renewable energy investors (Xu and Wang 2021; Mao and Weathers 2019), and more specific products should be created based on their demands. For this purpose, companies need qualified employees (Yüksel and Ubay 2021; Knyazeva 2019) to solve the problems of renewable energy investors (Hsu et al. 2021). Because financial innovation has a complex process, employees should have sufficient knowledge regarding innovative financial products. Busu and Nedelcu (2018) examined the performance of the companies in the renewable energy sector in Romania, underlining the significance of employee quality in improving financial innovation in renewable energy projects. Zafar et al. (2021) also focused on the financial sources of renewable energy investments, concluding that companies should employ qualified employees to increase the performance of the financial innovation. Haldar (2018) also highlighted the importance of this issue while analyzing the renewable energy sector in Gujarat.

Companies' technological development also plays a key role in improving financial innovation for renewable energy investors. While developing new financial products for these investors, technical infrastructure should be well-designed. In this context, website performance is essential for an online system (Liu et al. 2021a, b). Since renewable energy investors can provide financial resources through an online system, the site should operate smoothly (Xu et al. 2019a, b); otherwise, renewable energy investors can lose confidence in the product (Bai et al. 2020). In this context, the company's technical infrastructure behind the product must be excellent. Xu et al. (2019a, b) focused on the influencing factors of renewable energy development, indicating that companies should have sufficient technical background to effectively finance these projects. Sinsel et al. (2020) and Alam and Murad (2020) reached similar conclusions in their studies.

Table 13 presents a summary of the literature review results. The literature evaluation helps to reach key issues regarding financial innovation in renewable energy investments. Many studies in the literature identified the influencing factors of financial innovation for renewable energy investors; however, few studies make a comprehensive analysis by considering many factors simultaneously. This study identifies financial innovation priorities for renewable energy investors and provides innovative solutions for renewable energy investors' financing issues. Furthermore, this study constructs a novel decision-making model based on SERVQUAL, TRIZ, and QFD. Moreover, with the help of DEMATEL and TOPSIS methods, this study performs analyses by considering picture fuzzy sets and fuzzy rough numbers.

Methodology

This section includes detailed information about the methods used in the analysis process. Within this framework, picture fuzzy rough sets are first explained. Second, necessary information regarding the DEMATEL approach is given, followed by details concerning the TOPSIS technique. Next, the VIKOR methodology is explained, and a new model is created by considering these approaches. Finally, this generated model is explained in a detailed manner. All equations are stated in "Appendix 2".

Modelling uncertainty with picture fuzzy rough sets

Picture fuzzy rough sets aim to handle uncertainty in the decision-making process, and subjectivity can be reduced with the help of these sets. Picture fuzzy sets (PFSs) refer to the recent extension of fuzzy sets. The positive, neutral, negative, and refusal membership degrees are considered in this process. Equation (1) shows the conventional fuzzy sets. X indicates the universe, A refers to the fuzzy sets, and μ_A is the membership degree (Mathew et al. 2020). Equation (2) demonstrates the intuitionistic fuzzy sets. In this context, ν_A shows the non-membership function and the condition of $0 \leq \mu_A(x) + \nu_A(x) \leq 1$ should be satisfied (Hashmi et al. 2021). The PFSs are indicated in Eq. (3). Within this scope, n_A shows the neutral and π_A represents the refusal degrees. Moreover, the condition of $\mu_A(x) + n_A(x) + \nu_A(x) + \pi_A(x) = 1$ should be met (Zeng et al. 2019). PFSs provide answers to the complex questions, such as "yes" with the membership degree μ_A, "abstain" with a neutral degree n_A, and "no" with a non-membership degree ν_A, "ignoring" with the refusal degree π_A. Equations (4)–(8) indicate the operations of PFS (Cuong and Thong 2018). Rough numbers represent the extension of rough set theory. Lower and upper limits and a rough boundary interval are taken into consideration.

Lower $\left(\underline{Apr}(C_i)\right)$, upper $\left(\overline{Apr}(C_i)\right)$ approximation, and boundary region $(Bnd(C_i))$ of C_i are demonstrated in Eqs. (9)–(11) (Zhan et al. 2020a, b). In this scope, Y is an arbitrary object, R shows the set of N classes $(C_1, .C_N)$, and C represents the objects. Lower $(\underline{Lim}(C_i))$, upper $\left(\overline{Lim}(C_i)\right)$ limits, and the rough number $(RN(C_i))$ of C_i are detailed in Eqs. (12)–(14). In this process, N_L and N_U define the number of objects for $\underline{Apr}(C_i)$ and

$\overline{Apr}(C_i)$. In this study, PFSs are considered with fuzzy rough numbers. Picture fuzzy rough sets (PFRSs) are identified in Eqs. (15)–(22). In this context, $\widetilde{C_i} = (C_{i\mu_A}, C_{in_A}, C_{iv_A}, C_{i\pi_A})$ and $\tilde{R}$ is the collection of $\left\{\widetilde{C_1}, \widetilde{C_2}, \ldots, \widetilde{C_n}\right\}$. The lower $(\underline{Lim}(C_{i\mu_A}), \underline{Lim}(C_{in_A}), \underline{Lim}(C_{iv_A}), \underline{Lim}(C_{i\pi_A}))$ and upper $(\overline{Lim}(C_{i\mu_A}), \overline{Lim}(C_{in_A}), \overline{Lim}(C_{iv_A}), \overline{Lim}(C_{i\pi_A}))$ limits of $\widetilde{C_i}$ are given in Eqs. (23)–(30). In these equations, $N_{L\mu_A}$, N_{Ln_A}, N_{Lv_A}, $N_{L\pi_A}$ represent the number of elements in $\underline{Apr}(C_{i\mu_A})$, $\underline{Apr}(C_{in_A})$, $\underline{Apr}(C_{iv_A})$, $\underline{Apr}(C_{i\pi_A})$. On the other side, $N_{U\mu_A}$,N_{Un_A}, N_{Uv_A}, $N_{U\pi_A}$ are identified for $\overline{Apr}(C_{i\mu_A})$, $\overline{Apr}(C_{in_A})$, $\overline{Apr}(C_{iv_A})$, $\overline{Apr}(C_{i\pi_A})$ (Zhan et al. 2020a, b). Equation (31) states the picture fuzzy rough number of $\widetilde{C_i}$ $PFRN\left(\widetilde{C_i}\right)$.

DEMATEL based on PFRSs

DEMATEL aims to find the significant weights of different items (Xie et al. 2021). In this process, the picture fuzzy direct relationship matrix is first created as in Eq. (32). Secondly, Eq. (33) generates picture fuzzy rough numbers (Jiang et al. 2020a, b). $PFRN\left(\widetilde{C_{ij}}\right) = \underline{Lim}\left(C_{ij\mu_{\tilde{z}_{ij}}}\right)$, $\underline{Lim}\left(C_{ijn_{\tilde{z}_{ij}}}\right)$, $\underline{Lim}\left(C_{ijv_{\tilde{z}_{ij}}}\right)$, and $\underline{Lim}\left(C_{ij\pi_{\tilde{z}_{ij}}}\right)$ represent the minimum values of $\mu_{\tilde{z}_{ij}}, n_{\tilde{z}_{ij}}, v_{\tilde{z}_{ij}}, \pi_{\tilde{z}_{ij}}$, whereas $\overline{Lim}\left(C_{ij\mu_{\tilde{z}_{ij}}}\right)$, $\overline{Lim}\left(C_{ijn_{\tilde{z}_{ij}}}\right)$, $\overline{Lim}\left(C_{ijv_{\tilde{z}_{ij}}}\right)$, and $\overline{Lim}\left(C_{ij\pi_{\tilde{z}_{ij}}}\right)$ show the maximum values of $\mu_{\tilde{z}_{ij}}, n_{\tilde{z}_{ij}}, v_{\tilde{z}_{ij}}, \pi_{\tilde{z}_{ij}}$. Third, normalized matrix is created with Eqs. (34) and (35). Within this framework, $\tilde{X}_{\underset{a}{\prime}} \ldots \tilde{X}_{\underset{h}{\prime}}$ identify $\underline{Lim}(C_{\mu_{\tilde{z}}})$, $\underline{Lim}(C_{n_{\tilde{z}}})$, $\underline{Lim}(C_{v_{\tilde{z}}})$, $\underline{Lim}(C_{\pi_{\tilde{z}}})$, $\overline{Lim}(C_{\mu_{\tilde{z}}})$, $\overline{Lim}(C_{n_{\tilde{z}}})$, $\overline{Lim}(C_{v_{\tilde{z}}})$, and $\overline{Lim}(C_{\pi_{\tilde{z}}})$ (Luo et al. 2021). Equations (36)–(39) explain the ways to obtain a total relation matrix (TRM) (Zhu et al. 2021). Additionally, the defuzzification process is done by Eqs. (40)–(43). The sums of all vector rows and columns are shown as $\tilde{D}_i^{def}$ and $\tilde{R}_i^{def}$. Causality analysis is made with $\left(\tilde{D}_i - \tilde{R}_i\right)^{def}$. Also, the weights are calculated by $\left(\tilde{D}_i + \tilde{R}_i\right)^{def}$ (Zhou et al. 2021).

TOPSIS and VIKOR based on PFRSs

TOPSIS is considered for ranking different alternatives (Zhong et al. 2020), and with this method, the most appropriate item can be found. This study adapts picture fuzzy rough sets to TOPSIS. First, Eq. (44) is considered to create a picture fuzzy decision matrix (DMT) (Zeng et al. 2019). Second, Eq. (45) identifies picture fuzzy rough numbers (Jin et al. 2021). $\underline{Lim}\left(\tilde{X}_{ij\mu_{\tilde{x}_{ij}}}\right)$, $\underline{Lim}\left(\tilde{X}_{ijn_{\tilde{x}_{ij}}}\right)$, $\underline{Lim}\left(\tilde{X}_{ijv_{\tilde{x}_{ij}}}\right)$, and $\underline{Lim}\left(\tilde{X}_{ij\pi_{\tilde{x}_{ij}}}\right)$ explain the minimum values of $\mu_{\tilde{x}_{ij}}, n_{\tilde{x}_{ij}}, v_{\tilde{x}_{ij}}, \pi_{\tilde{x}_{ij}}$, while $\overline{Lim}\left(\tilde{X}_{ij\mu_{\tilde{x}_{ij}}}\right)$, $\overline{Lim}\left(\tilde{X}_{ijn_{\tilde{x}_{ij}}}\right)$, $\overline{Lim}\left(\tilde{X}_{ijv_{\tilde{x}_{ij}}}\right)$, $\overline{Lim}\left(\tilde{X}_{ij\pi_{\tilde{x}_{ij}}}\right)$ indicate the maximum values of $\mu_{\tilde{x}_{ij}}, n_{\tilde{x}_{ij}}, v_{\tilde{x}_{ij}}, \pi_{\tilde{x}_{ij}}$. Equation (46) computes normalized values (Zhan et al. 2020a, b), and a weighted normalized DMT is generated with Eq. (47) (Cheng et al. 2020). Equations (48)–(53) define the distance between the best and worst alternatives. $\underline{Lim}A_{\mu}^{+}$,..., $\overline{Lim}A_{\pi}^{+}$ demonstrate the positive ideals solutions whereas $\underline{Lim}A_{\mu}^{-}$,..., $\overline{Lim}A_{\pi}^{-}$ indicate the negative ideal solutions (Zeng et al. 2019). Finally, Eq. (54) defines the closeness coefficient CC_i values used to compute the weights (Jin et al. 2021). VIKOR is also considered in ranking the alternative to make a comparative analysis. In this process, Eqs. (44)–(51) are used in a similar manner (Emamat et al. 2022). After that, Eq. (55) is considered for computing fuzzy best and worst values $(\tilde{f}_j^*, \tilde{f}_j^-)$. Mean group utility $(\tilde{S}_i)$ and maximal regret $(\tilde{R}_i)$ are calculated by Eqs. (56) and (57), where $\tilde{w}_j$ indicates fuzzy weights (Taghavifard and Majidian 2022). Equation (58) is considered to calculate the value of $\tilde{Q}_i$. The strategy weights are demonstrated by v, whereas 1 − v indicates regret (Zhao et al. 2021). These values are used in an alternative ranking process.

Model construction

This study examines financial innovation priorities for renewable energy investors by designing a novel decision-making model. First, SERVQUAL-based customer needs for financial innovation are evaluated using DEMATEL based on picture fuzzy sets. Second, the financial innovation priorities are ranked with QFD-based phases with TOPSIS based on PFRSs. Figure 1 presents the details of the proposed model.

Finding optimal financial resources is essential for improving renewable energy investments because the high initial cost is a critical problem for these projects.

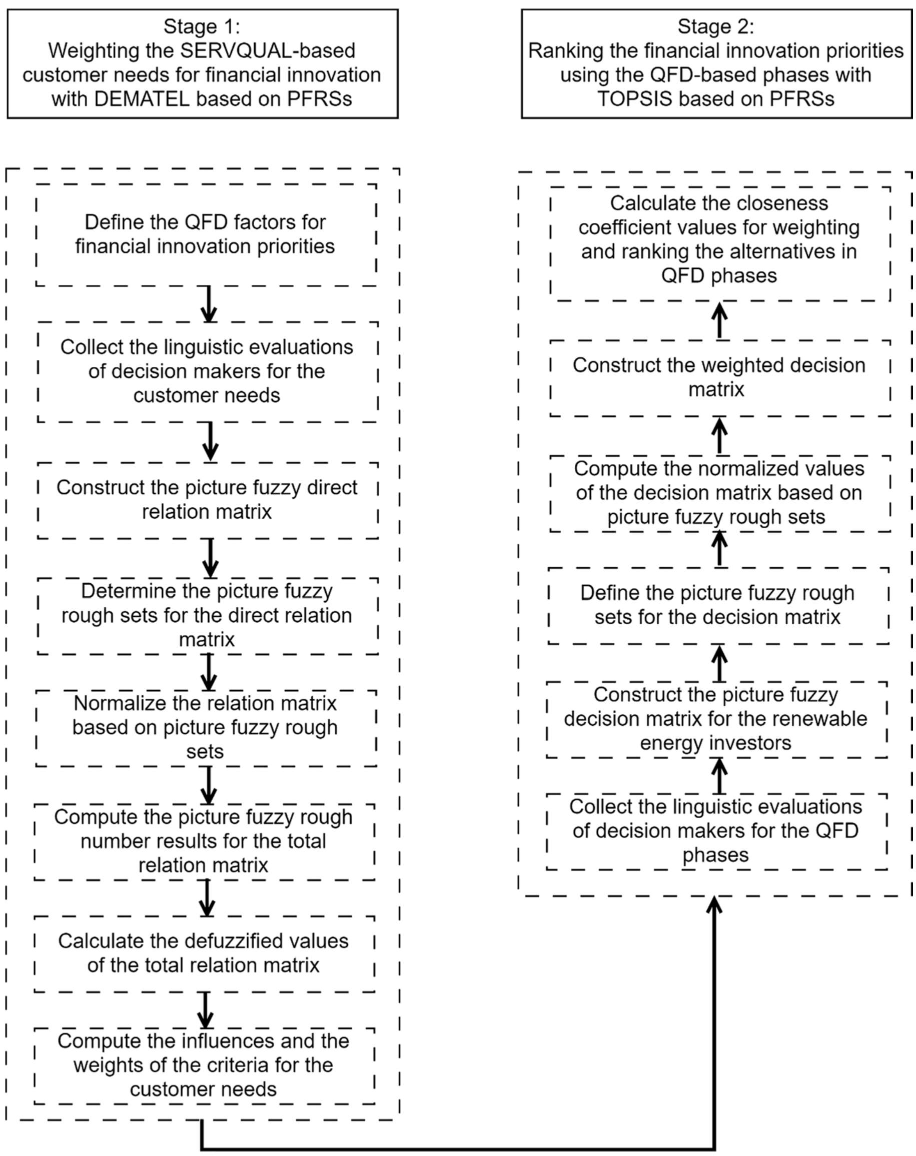

Fig. 1 The hybrid model algorithm

Therefore, financial innovations are necessary to achieve this objective; however, different factors should be considered simultaneously for the effectiveness of the financial innovation, such as customer expectations, technological development, and qualified personnel. Nevertheless, any improvements to increase financial innovation capabilities create new costs. Therefore, it is not efficient for the companies to improve all factors since high costs lead to lower profitability. Thus, companies that make financial innovations need to first identify the more important factors and focus on them. Because of this issue, a priority analysis should be made among the factors that affect the performance of financial innovation. Therefore, there is a need to construct a qualified decision-making model to weigh the leading indicators of financial innovation. Due to this situation, in this study, a novel decision-making model is created by considering DEMATEL, TOPSIS, and VIKOR approaches based on PFRSs, SERVQUAL, and QFD.

This study's model integrates different approaches to reach the objectives, and different fuzzy sets are also considered. There are several reasons for this practice. First, the problems became increasingly complex, and establishing an effective decision-making model has become quite challenging (Kou et al. 2021). Different techniques have been used together in the established models to benefit from their combined advantages (Hu et al. 2021; Kou et al. 2022). In this framework, this study considers the DEMATEL and TOPSIS methods. Moreover, VIKOR is also considered for ranking the alternatives to check the coherency of the analysis results. Thanks to the superiority of each of these techniques, it has been possible to make the model stronger. By comparison, decision-making techniques have also started to be used with fuzzy numbers (Gambetti et al. 2022; Liu et al. 2021a, b) to minimize the uncertainties in the process (Xiao and Ke 2021). In this context, this study considers decision-making techniques with picture fuzzy numbers. Different techniques have been used together and with fuzzy numbers to develop a suitable decision model for increasingly complex problems.

The proposed model has some significant novelties. First, while considering both DEMATEL and TOPSIS methods, a hybrid model is constructed. Since the criteria weights are not considered equal, this contributes to the objectivity of the results. The DEMATEL methodology also has some superiorities over other methods, such as causality analysis between the factors (Bhuiyan et al. 2022). This situation is the main reason for selecting this method to weigh the criteria. While evaluating with TOPSIS, the distances to the negative and positive optimal results are considered. This condition provides an advantage to TOPSIS to reach more relevant findings (Mojaver et al. 2022). The criteria are defined with SERVQUAL perspectives to identify customer expectations more effectively. Technical characteristics for financial services are defined with the TRIZ technique (Yeh et al. 2011), and solutions can be presented more efficiently. Considering the QFD method also has some benefits, such as using customer expectations and technical requirements simultaneously; therefore, a product can be created based on the customer's needs (Haber and Fargnoli 2019; Fargnoli and Sakao 2017).

As the problems increase in complexity, it becomes more difficult to produce effective solution proposals (Siksnelyte et al. 2018); therefore, these methods are considered with fuzzy numbers, making it easier to manage the uncertainty in the process (Shao

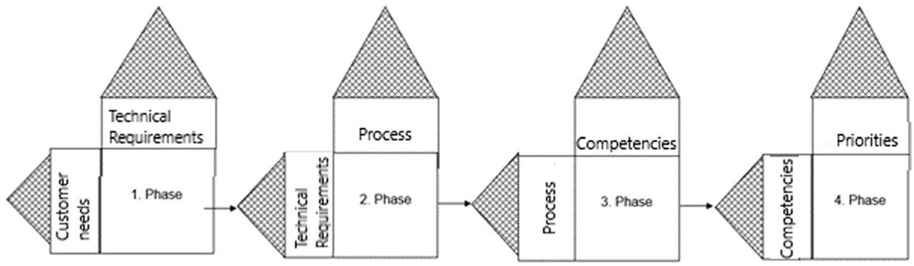

Fig. 2 QFD-based phases of financial innovation priorities

et al. 2020). For example, with PFSs, the uncertainties in the process are analyzed more successfully. Furthermore, considering fuzzy numbers in this situation helps to handle subjectivity more appropriately (Dhiman and Deb 2020). For this purpose, this study introduced different fuzzy numbers, such as triangular and trapezoidal. This model combines PFSs and rough sets, and their advantages are utilized. Owing to using picture fuzzy sets, positive, neutral, negative, and refusal membership degrees are considered. Conversely, by considering rough sets, lower and upper limits and a rough boundary interval are used (Deveci et al. 2021). Combining the advantages of these two methods provides a clearer decision-making method by determining both low and high limits and using positive, natural negative, and rejection membership degrees (Iordache et al. 2022; Akyurt et al. 2021). Therefore, the PFRSs have significant superiorities compared to other fuzzy sets.

An application for renewable energy investors

Stage 1: Weighting the SERVQUAL-based customer needs for financial innovation with DEMATEL based on PFRSs

SERVQUAL-based customer needs are weighted regarding financial innovation. In this framework, the DEMATEL model is considered based on PFRSs. The QFD factors are first defined for the financial innovation priorities in this process. Figure 2 provides information regarding this process.

SERVQUAL-based customer needs are defined in Table 1.

Reliability shows whether the services provided to customers are correct and safe. Moreover, specific attention to the customers represents the criterion of empathy. Conversely, the physical appearance and equipment quality provides information about the tangibles. Additionally, assurance indicates the knowledge of the personnel and how much the customers trust these employees. Finally, responsiveness demonstrates the

Table 1 SERVQUAL-based customer needs for innovative services

Criteria	References
Reliability (CN1)	Alam and Murad (2020), Dinçer et al. (2020)
Empathy (CN2)	Sinsel et al. (2020)
Tangibles (CN3)	Xu et al. (2019a, b)
Assurance (CN4)	Bai et al. (2020), Chen et al. (2021a)
Responsiveness (CN5)	Haldar (2018), Chen et al. (2021b)

Table 2 TRIZ-based technical characteristics for financial services

Factors	References
Speed (TC1)	Zafar et al. (2021)
Information (TC2)	Yüksel and Ubay (2021)
Control (TC3)	Khan et al. (2020)
Capacity (TC4)	Yu et al. (2022)
Conveniency (TC5)	Xu and Wang (2021)

willingness and effort of the staff to solve customer problems. TRIZ-based technical characteristics for the financial services are defined in Table 2.

Financial services should be designed so that customers can make their transactions quickly, enhancing customer satisfaction. Furthermore, the customers should receive the necessary information to mitigate erroneous transactions on the system. Additionally, security controls should be designed to minimize the risks in this process; however, it should be possible to make the desired number of financial transactions. Customers should effortlessly receive financial services through an accordingly designed system. Table 3 gives information about the process for innovative services.

Detailed planning should be conducted for the effectiveness of the innovative services. After planning, necessary observations should be made, followed by an analysis. According to the analysis results, necessary revisions should be made. Final control should be done after the revision process. Table 4 indicates the competencies for financial innovation.

Financial innovations should satisfy the customers' needs, and customer expectations should be identified effectively. Market conditions should also be considered to provide better financial innovation, and institutional capacity plays a key role. Moreover, companies should have the necessary technological infrastructure to provide high-quality financial services. Finally, regulations should also be considered while providing financial innovation. Table 5 defines categories for the financial innovation priorities.

Table 3 Process for innovative services

Factors	References
Planning (P1)	Xu et al. (2019a, b)
Observing (P2)	Sinsel et al. (2020)
Analysing (P3)	Khan et al. (2020)
Revising (P4)	Xu and Wang (2021)
Final Check (P5)	Bai et al. (2020)

Table 4 Competencies for financial innovation

Factors	References
Beneficiaries (COM1)	Qamruzzaman and Jianguo (2018)
Market Conditions (COM2)	Salisu and Obiora (2021)
Institutional Capacity (COM3)	Alshubiri et al. (2020)
Technological Infrastructure (COM4)	Kösedağlı et al. (2021)
Regulations (COM5)	Yu et al. (2021)

Table 5 Categories for financial innovation priorities

Factors	References
Institutional (priority 1)	Khan et al. (2020)
Product (priority 2)	Salisu and Obiora (2021)
Process (priority 3)	Xu and Wang (2021)

Table 5 defines three different categories for the financial innovation priorities: the improvements that can be made for the organizational development, the actions taken to increase the quality of the products, and the process that can be prioritized concerning the quality improvements in the financial innovation. In this process, three different experts (ESs) evaluate the factors. These people have at least 20 years of experience in the finance departments of renewable energy companies, where they work as top managers. Hence, they are considered to have sufficient experience to evaluate the factors concerning the financial innovation in renewable energy investments. Interviews were conducted with the ESs between May and July 2021, where they answered questions regarding the comparisons of these factors. After that, these evaluations were converted into linguistic scales (LSs). The scales and picture fuzzy numbers are detailed in Table 6.

Table 14 demonstrates the linguistic evaluations (LEs) of the ESs. Next, the picture fuzzy direct relation matrix (DRM) is constructed in Table 15. In this framework, the evaluations are converted into the picture fuzzy numbers explained in Table 6. Later, the picture fuzzy rough sets for DRM are determined in Table 16. Table 17 indicates the normalized relation matrix based on picture fuzzy rough sets, and the picture fuzzy rough number results for TRM are calculated as in Table 18. Table 19 provides information

Table 6 LSs and picture fuzzy numbers for evaluation

LSs for criteria	LSs for factors	Picture fuzzy numbers			
		μ	η	N	π
Very low (VO)	Weakest (K)	0.1	0.1	0.5	0.3
Low (O)	Poor (R)	0.2	0.2	0.4	0.2
Middle (D)	Fair (I)	0.3	0.3	0.3	0.1
High (G)	Good (GD)	0.6	0.2	0.2	0
Very High (VG)	Best (S)	0.8	0.1	0.1	0

Table 7 Influences and weights of criteria for the customer needs

Criteria	r	y	(r + y)	(r-y)	Weights
Reliability (CN1)	9.97	8.86	18.84	1.11	0.200
Empathy (CN2)	9.55	9.58	19.13	− 0.03	0.203
Tangibles (CN3)	1.22	8.99	19.21	1.22	0.204
Assurance (CN4)	9.57	9.83	19.40	− 0.27	0.206
Responsiveness (CN5)	7.73	9.76	17.48	− 2.03	0.186

concerning the defuzzified TRM values. Finally, weights are calculated, and the results are given in Table 7.

Table 7 states that assurance is an essential factor for the customer needs regarding the financial innovation priorities for renewable energy investors. Conversely, the criterion of the tangibles also has a high weight. Nevertheless, reliability and responsiveness have a lower influence on the customer needs than other items. Companies should firstly focus on the assurance to satisfy the renewable energy investors' needs for innovative services. For this purpose, personnel should have the necessary knowledge; thus, it would be appropriate to employ qualified people in the companies. Similarly, necessary training should be given to the employees who currently work in the company, thereby increasing customers' trust.

Stage 2: Ranking the financial innovation priorities

Next, the LEs for the QFD phases are collected. Table 20 provides information about the evaluations regarding phase 1 of QFD. In this framework, the scales in Table 6 are considered. Phase 2 of QFD evaluations is presented in Table 21, while Table 22 indicates the evaluations of phase 3 of QFD. The evaluations of phase 4 of QFD are presented in Table 23. After that, the picture of fuzzy DMTs for renewable energy investors is constructed. Table 24 illustrates the matrix for phase 1 of QFD. For this purpose, the picture fuzzy numbers given in Table 6 are considered. The picture fuzzy rough sets for the DMT are defined in the next step, and the sets for phase 1 of QFD are given in Table 25. Normalized values of the DMT are computed based on picture fuzzy rough sets. Table 26 defines these values for phase 1 of QFD, and the weighted DMT is constructed in the next step; this matrix is given in Table 27 for phase 1 of QFD. Ranking results of the TRIZ-based technical characteristics for financial services are shown in Table 8.

Table 8 identifies that information is the most significant technical characteristic for improving financial services. Similarly, convenience has also high weight. Moreover, capacity, control, and speed have lower importance than other factors. Similar analysis procedures are also performed for the process, competencies, and categories of the financial innovation priorities. Customers should receive the required information when companies provide financial services, thereby mitigating the risk of erroneous

Table 8 Analysis results for the phase 1 of QFD

Alternatives	D+	D-	CCi	Weighting results
Speed (TC1)	0.144	0.130	0.474	0.183
Information (TC2)	0.115	0.151	0.569	0.220
Control (TC3)	0.142	0.132	0.482	0.186
Capacity (TC4)	0.135	0.135	0.500	0.194
Conveniency (TC5)	0.125	0.158	0.559	0.217

Table 9 Analysis results for the phase 2 of QFD

Alternatives	D+	D−	CCi	Weighting results
Planning (P1)	0.081	0.073	0.475	0.216
Observing (P2)	0.198	0.106	0.349	0.159
Analysing (P3)	0.218	0.187	0.462	0.211
Revising (P4)	0.180	0.131	0.422	0.192
Final Check (P5)	0.078	0.074	0.487	0.222

Table 10 Analysis results for the phase 3 of QFD

Alternatives	D+	D−	CCi	Weighting results
Beneficiaries (COM1)	0.176	0.133	0.430	0.189
Market Conditions (COM2)	0.182	0.134	0.423	0.186
Institutional Capacity (COM3)	0.126	0.128	0.504	0.222
Technological Infrastructure (COM4)	0.173	0.138	0.445	0.196
Regulations (COM5)	0.166	0.147	0.468	0.206

Table 11 Analysis results for the phase 4 of QFD

Alternatives	D+	D−	CCi	Ranking results
Institutional (priority 1)	0.177	0.117	0.397	3
Product (priority 2)	0.157	0.147	0.482	1
Process (priority 3)	0.144	0.121	0.457	2

transactions on the system. The ranking results process factors for innovative services are indicated in Table 9.

Table 9 demonstrates that final check and planning have the greatest weights. In addition, analysis is another significant factor in innovative services; however, observing and revising have the lowest weights. Thus, detailed planning should be conducted for the effectiveness of the innovative services. In addition, final control should be performed effectively after the revision process. This situation has a positive impact on minimizing potential mistakes in the process. Table 10 represents the weighting results concerning the competencies for financial innovation.

Table 10 shows that institutional capacity is the most critical competency for financial innovation. Regulations and technological infrastructure are other significant items in this respect. Hence, the organizational effectiveness of companies should be increased. In this context, the quality of the communication between the departments can play a critical role. Furthermore, necessary regulations should also be designed to increase the performance of this process, providing quality improvement. Finally, the ranking results of the categories for the financial innovation priorities are indicated in Table 11.

Table 12 Comparative results of final ranking alternatives with sensitivity analysis

Alternatives	**TOPSIS**				
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Institutional (priority 1)	3	3	2	2	3
Product (priority 2)	1	1	1	1	1
Process (priority 3)	2	2	3	3	2
Alternatives	**VIKOR**				
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Institutional (priority 1)	3	3	2	3	3
Product (priority 2)	1	1	1	1	1
Process (priority 3)	2	2	3	2	2

Table 11 indicates that product is an essential priority for financial innovation, while process is on the second rank, indicating that it is the least important item regarding the financial innovation priorities. Hence, companies should focus on the product to provide better financial innovation and attract renewable energy investors more easily. Because of this situation, financial innovation products can be effectively designed, and the needs of renewable energy investors should be considered. In this context, long-term debt repayment can positively impact the financial situation of renewable energy companies. Additionally, the alternatives are also ranked with the VIKOR method. Similarly, sensitivity analysis is also conducted by considering five cases where weighting results change. The results are indicated in Table 12.

The comparative and sensitivity analysis results show that the proposed model's ranking priorities are almost the same and coherent with comparative results and different cases. This situation gives information about the proposed model's validity and reliability.

Discussions

The findings demonstrate that companies should focus on the assurance to satisfy the renewable energy investors' needs for innovative services. This situation indicates that the knowledge of the personnel plays a crucial role in achieving this objective. Companies should engage qualified employees to effectively design financial innovations for renewable energy investors. Additionally, necessary training should be given to employees currently working in the company, which can increase customers' trust. Renewable energy investors face a high-cost problem for their investments. Therefore, providing effective financial innovation to these investors play a key role in improving these projects; employing high-quality people helps attract renewable energy investors regarding financial innovation services. Shakeel et al. (2017), Lacerda and van den Bergh (2020), and Sarma and Zabaniotou (2021) also highlighted the significance of the personnel quality to improve financial innovation for renewable energy investors.

In addition, information is the most significant TRIZ-based technical characteristic for improving financial services. This issue demonstrates that necessary information should be provided to the customers receiving financial services. This condition increases confidence and reduces customers' risk of erroneous transactions on the system. Therefore, all information should be presented to customers on the platform where financial innovation occurs, and customers should be able to access all the details of the newly developed financial product. In this context, the system should provide the price of the newly developed product and instructions for its use. Furthermore, contact details should be provided in case of any disruption in the process. Blach (2020), Vemić (2018), and Bucheeri and Hamdan (2020) discussed that necessary information should be provided to the consumers regarding the specific financial innovation. This situation positively affects the customers' confidence in new financial products.

The final check plays a crucial role in the process factors for innovative services. While designing financial innovation, final control should be done after the revision process. Companies should prioritize this process to identify important problems before connecting with the customers. This situation has a positive contribution to minimizing customer complaints. Additionally, regarding the competencies for financial innovation, institutional capacity, regulations, and technological infrastructure should be mainly considered for financial innovation. Finally, the product is the essential priority for the financial innovation and the categories for the financial innovation priorities. Companies should focus on the product to provide better financial innovation and attract renewable energy investors. An effectively designed financial innovation product can help solve the financing problem of renewable energy investors. In this context, it is crucial to develop new products that may attract the attention of these investors, and the needs of renewable energy investors should be considered. In this framework, the financial product to be designed should not have a short-term repayment because the initial cost of renewable energy projects is very high. In this context, long-term debt repayment can positively impact the financial situation of renewable energy companies. Xie et al. (2019), Stucki et al. (2018), and Duque-Grisales et al. (2020) also identified that companies should mainly focus on the product to provide better financial innovation to attract renewable energy investors.

This study's main contribution is providing innovative solutions to the financing problems of renewable energy investors. The analysis results and recommendations show how to improve renewable energy investment projects. A novel decision-making model is constructed based on SERVQUAL, TRIZ, and QFD, and analyses were performed with the help of DEMATEL and TOPSIS methods by considering picture fuzzy sets and fuzzy rough numbers. This study's originality can also be mentioned in terms of the methodology used. For example, a hybrid model is proposed considering both DEMATEL and TOPSIS methods. Subjective assumptions were prevented using different methods at each stage (Xie et al. 2021; Zhong et al. 2020). The main reason for choosing the DEMATEL method is that it allows causality analysis of the factors (Dinçer and Yüksel 2019; Zhou et al. 2021). In some other models, the causal impacts of the items could not be evaluated (Rahiminezhad Galankashi et al. 2020; Bottani et al. 2018). In addition, considering the distances to both positive and negative optimal results in the analysis process is the reason for using the TOPSIS in the analysis process (Cheng et al. 2020; Haiyun et al. 2021). Other models only consider the distance to the positive optimal solutions (Suganthi 2018; Bathaei et al. 2019). Moreover, considering picture fuzzy sets and rough numbers together allows the uncertainties and subjectivity in the analysis process to be handled more appropriately.

Conclusions

This study evaluates financial innovation priorities for renewable energy investors. In this context, a novel decision-making model is constructed. First, SERVQUAL-based customer needs for financial innovation are weighted using the DEMATEL methodology based on picture fuzzy sets. In the second stage, the financial innovation priorities are ranked using the QFD-based phases with TOPSIS based on PFRSs. Moreover, the VIKOR method is also implemented as an alternative ranking. Similarly, sensitivity analysis is also implemented by considering five different cases.

It is defined that the ranking priorities based on the proposed model are almost the same, showing the proposed model's validity and reliability. Assurance is the most crucial factor for the customer needs regarding the financial innovation priorities for renewable energy investors. Furthermore, the criterion of the tangibles also has high importance, and empathy is another significant criterion that impacts customer needs. Nevertheless, reliability and responsiveness have a lower influence on customer needs than other items.

Conversely, information is the most significant technical characteristic for improving financial services, and convenience also weighs high. Moreover, capacity, control, and speed have lower importance than other factors. Final check and planning have the greatest weight regarding the process factors for innovative services. Furthermore, analyzing is another significant factor in the process for innovative services; however, observing and revising have the lowest weights.

Regarding the competencies for financial innovation, institutional capacity is the most important competency in financial innovation, and regulations and technological infrastructure are other significant items. Regarding financial innovation priorities, product is the essential priority for financial innovation. Additionally, process is on the second rank, but it is the least important item regarding the financial innovation priorities.

This study's main limitation is evaluating only the financial innovation priorities of renewable energy investment projects. Future studies can examine the effectiveness of the financial innovation alternatives, such as green bonds and green Sukuk. Furthermore, this study only defined customer needs and technical characteristics by considering SERVQUAL and TRIZ. Future research can further investigate these factors with the help of a comprehensive literature review; a data mining approach can be considered for this purpose. Moreover, the proposed model can also be improved, and new methodologies can be used in future studies. For instance, the COPRAS method can be used instead of TOPSIS. In addition, intuitionistic fuzzy sets can be used to effectively handle the uncertainties in this process.

Appendix 1: Tables

See Tables 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27.

Table 13 Literature review summary

Authors	Results
Croutzet and Dabbous (2021) Kauffman and Roston (2021) Yu et al. (2021) Meng et al. (2021a, b) Hamwi and Lizarralde (2017) Wang et al. (2022)	Expectations of the renewable energy investors should be taken into consideration for the effectiveness of the financial innovation
Jin and Tian (2020) Yuan et al. (2021) Knuth (2018) Yu et al. (2022) Khan et al. (2020) Horsch and Richter (2017)	Security of the financial innovation system is also crucial to attract the attentions of renewable energy investors
Xu and Wang (2021) Yüksel and Ubay (2021) Hsu et al. (2021) Busu and Nedelcu (2018) Zafar et al. (2021) Haldar (2018)	Employee quality is also key driver to increase the performance of financial innovation for renewable energy investors
Liu et al. (2021a, b) Xu et al. (2019a, b) Bai et al. (2020) Xu et al. (2019a, b) Sinsel et al. (2020) Alam and Murad (2020)	Technological development of the companies also plays a key role to generate better financial innovation for the renewable energy investors

Table 14 LEs for the customer needs

	CN1			CN2			CN3			CN4			CN5		
	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3
Reliability (CN1)	–	–	–	D	O	VG	G	VO	O	D	VG	VO	O	G	D
Assurance (CN2)	VG	G	G	–	–	–	G	VO	VG	D	VG	D	VO	O	VG
Tangibles (CN3)	VG	G	O	G	VG	D	–	–	–	VG	D	VG	G	O	D
Empathy (CN4)	D	VO	D	VO	O	G	O	D	G	–	–	–	G	G	D
Responsiveness (CN5)	D	O	D	VG	G	D	VG	G	VG	VG	G	G	–	–	–

Table 15 Picture fuzzy relation matrix

	CN1				CN2				CN3				CN4				CN5			
	μ	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**Π**	**μ**	**η**	**ν**	**π**
ES1																				
CN1	0	0	0	0	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.2	0.2	0.4	0.2
CN2	0.8	0.1	0.1	0	0	0	0	0	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.1	0.1	0.5	0.3
CN3	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0	0	0	0	0.8	0.1	0.1	0	0.6	0.2	0.2	0
CN4	0.3	0.3	0.3	0.1	0.1	0.1	0.5	0.3	0.2	0.2	0.4	0.2	0	0	0	0	0.6	0.2	0.2	0
CN5	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0	0	0	0
	CN1				**CN2**				**CN3**				**CN4**				**CN5**			
	μ	Η	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**
ES2																				
CN1	0	0	0	0	0.2	0.2	0.4	0.2	0.1	0.1	0.5	0.3	0.8	0.1	0.1	0	0.6	0.2	0.2	0
CN2	0.6	0.2	0.2	0	0	0	0	0	0.1	0.1	0.5	0.3	0.8	0.1	0.1	0	0.2	0.2	0.4	0.2
CN3	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0	0	0	0	0.3	0.3	0.3	0.1	0.2	0.2	0.4	0.2
CN4	0.1	0.1	0.5	0.3	0.2	0.2	0.4	0.2	0.3	0.3	0.3	0.1	0	0	0	0	0.6	0.2	0.2	0
CN5	0.2	0.2	0.4	0.2	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0	0	0	0
	CN1				**CN2**				**CN3**				**CN4**				**CN5**			
	μ	Η	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**	**μ**	**η**	**ν**	**π**
ES3																				
CN1	0	0	0	0	0.8	0.1	0.1	0	0.2	0.2	0.4	0.2	0.1	0.1	0.5	0.3	0.3	0.3	0.3	0.1
CN2	0.6	0.2	0.2	0	0	0	0	0	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0
CN3	0.2	0.2	0.4	0.2	0.3	0.3	0.3	0.1	0	0	0	0	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1
CN4	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0	0	0	0	0.3	0.3	0.3	0.1
CN5	0.3	0.3	0.3	0.1	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0	0	0	0

Table 16 Picture fuzzy rough sets for DRM

	CN1	CN2	CN3	CN4	CN5
CN1	(·0,0·,·0,0·,·0,0·,·0,0·)	(·0.2,0.8·,·0.1,0.3·,·0.1,0.4·,·0,0.2·)	(·0.1,0.6·,·0.1,0.2·,·0.2,0.5·,·0,0.3·)	(·0.1,0.8·,·0.1,0.3·,·0.1,0.5·,·0,0.3·)	(·0.2,0.6·,·0.2,0.3·,·0.2,0.4·,·0,0.2·)
CN2	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0,0·,·0,0·,·0,0·,·0,0·)	(·0.1,0.8·,·0.1,0.2·,·0.1,0.5·,·0,0.3·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.1,0.8·,·0.1,0.2·,·0.1,0.5·,·0,0.3·)
CN3	(·0.2,0.8·,·0.1,0.2·,·0.1,0.4·,·0,0.2·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0,0·,·0,0·,·0,0·,·0,0·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.2,0.6·,·0.2,0.3·,·0.2,0.4·,·0,0.2·)
CN4	(·0.1,0.3·,·0.1,0.3·,·0.3,0.5·,·0.1,0.3·)	(·0.1,0.6·,·0.1,0.2·,·0.2,0.5·,·0,0.3·)	(·0.2,0.6·,·0.2,0.3·,·0.2,0.4·,·0,0.2·)	(·0,0·,·0,0·,·0,0·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)
CN5	(·0.2,0.3·,·0.2,0.3·,·0.3,0.4·,·0.1,0.2·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0,0·,·0,0·,·0,0·,·0,0·)

Table 17 Normalized element matrixes of picture fuzzy rough sets

M min

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.12	0.06	0.06	0.12
CN2	0.25	0.00	0.06	0.18	0.06
CN3	0.12	0.18	0.00	0.18	0.12
CN4	0.06	0.06	0.12	0.00	0.18
CN5	0.09	0.18	0.25	0.25	0.00

M max

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.25	0.19	0.25	0.19
CN2	0.35	0.00	0.25	0.25	0.25
CN3	0.25	0.25	0.00	0.25	0.19
CN4	0.09	0.19	0.19	0.00	0.19
CN5	0.12	0.25	0.35	0.35	0.00

n min

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.17	0.17	0.17	0.27
CN2	0.17	0.00	0.17	0.17	0.17
CN3	0.17	0.17	0.00	0.17	0.27
CN4	0.17	0.17	0.27	0.00	0.27
CN5	0.27	0.17	0.17	0.17	0.00

n max

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.27	0.18	0.33	0.27
CN2	0.18	0.00	0.18	0.27	0.18
CN3	0.18	0.27	0.00	0.27	0.33
CN4	0.27	0.18	0.33	0.00	0.33
CN5	0.33	0.27	0.18	0.18	0.00

v min

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.11	0.22	0.11	0.22
CN2	0.11	0.00	0.11	0.11	0.11
CN3	0.11	0.11	0.00	0.11	0.22
CN4	0.28	0.22	0.22	0.00	0.17
CN5	0.22	0.11	0.11	0.11	0.00

v max

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.22	0.28	0.28	0.22
CN2	0.11	0.00	0.28	0.17	0.28
CN3	0.22	0.17	0.00	0.17	0.22
CN4	0.33	0.28	0.22	0.00	0.22
CN5	0.33	0.17	0.11	0.11	0.00

t min

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.00	0.00	0.00	0.00
CN2	0.00	0.00	0.00	0.00	0.00
CN3	0.00	0.00	0.00	0.00	0.00
CN4	0.30	0.00	0.00	0.00	0.00
CN5	0.20	0.00	0.00	0.00	0.00

t max

	CN1	CN2	CN3	CN4	CN5
CN1	0.00	0.20	0.30	0.30	0.20
CN2	0.00	0.00	0.30	0.10	0.30
CN3	0.20	0.10	0.00	0.10	0.20
CN4	1.00	0.30	0.20	0.00	0.10
CN5	1.00	0.10	0.00	0.00	0.00

Table 18 Picture fuzzy rough sets for the TRM

	CN1	CN2	CN3	CN4	CN5
CN1	(·0.13,0.90·,·0.91,3.23·,·0.35,0.974·,·0,0.45·)	(·0.21,1.36·,·0.85,3.66·,·0.32,1.14·,·0,0.60·)	(·0.17,1.26·,·0.97,3.10·,·0.45,1.24·,·0,0.72·)	(·0.20,1.43·,·0.85,3.66·,·0.29,1.08·,·0,0.56·)	(·0.20,1.20·,·1.34,3.66·,·0.50,1.21·,·0,0.67·)
CN2	(·0.47,1.2·,·0.88,2.91·,·0.34,0.90·,·0,0.29·)	(·0.14,1.30·,·0.59,2.94·,·0.16,0.79·,·0,0.24·)	(·0.20,1.44·,·0.83,2.67·,·0.29,1.05·,·0,0.51·)	(·0.34,1.58·,·0.73,3.16·,·0.23,0.84·,·0,0.26·)	(·0.20,1.37·,·1.08,3.10·,·0.32,1.07·,·0,0.56·)
CN3	(·0.29,1.16·,·1.05,3.38·,·0.41,0.96·,·0,0.44·)	(·0.30,1.43·,·0.85,3.66·,·0.29,0.92·,·0,0.35·)	(·0.16,1.17·,·0.83,2.94·,·0.23,0.82·,·0,0.30·)	(·0.36,1.51·,·0.85,3.66·,·0.26,0.83·,·0,0.30·)	(·0.25,1.26·,·1.39,3.66·,·0.45,1.01·,·0,0.48·)
CN4	(·0.19,0.80·,·1.20,3.47·,·0.75,1.15·,·0.64,1 ·)	(·0.18,1.07·,·0.97,3.64·,·0.50,1.15·,·0,0.65·)	(·0.25,1.03·,·1.24,3.19·,·0.57,1.17·,·0,0.65·)	(·0.18,0.97·,·0.83,3.48·,·0.27,0.83·,·0,0.32·)	(·0.27,0.98·,·1.59,3.70·,·0.63,1.14·,·0,0.58·)
CN5	(·0.39,0.97·,·1.16,3.19·,·0.61,0.82·,·0.31,1 ·)	(·0.40,1.33·,·0.85,3.40·,·0.32,0.78·,·0,0.24·)	(·0.56,1.28·,·0.97,2.87·,·0.38,0.78·,·0,0.19·)	(·0.63,1.40·,·0.85,3.34·,·0.29,0.67·,·0,0.14·)	(·0.24,1.019·,·1.14,3.18·,·0.32,0.68·,·0,0.19·)

Table 19 Defuzzified values of TRM

	CN1	CN2	CN3	CN4	CN5
CN1	1.66	2.10	1.93	2.14	2.14
CN2	1.89	1.70	1.88	2.05	2.02
CN3	1.98	2.14	1.72	2.20	2.18
CN4	1.89	1.94	1.90	1.76	2.08
CN5	1.45	1.70	1.56	1.68	1.34

Table 20 LEs for the phase 1 of QFD

Criteria/alternatives	Speed (TC1)			Information (TC2)			Control (TC3)			Capacity (TC4)			Conveniency (TC5)		
	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3
Reliability (CN1)	GD	GD	I	GD	GD	S	GD	GD	I	GD	I	S	S	GD	S
Empathy (CN2)	GD	GD	GD	GD	I	GD	S	S	GD	S	GD	S	S	S	GD
Tangibles (CN3)	S	S	GD	S	GD	GD	GD	GD	I	S	S	GD	S	I	I
Assurance (CN4)	GD	GD	I	GD	GD	S	S	GD	S	I	I	GD	GD	I	GD
Responsiveness (CN5)	I	GD	S	S	GD	S	I	I	S	S	GD	S	I	GD	GD

Table 21 LEs for the phase 2 of QFD

Criteria/alternatives	Planning (P1)			Observing (P2)			Analysing (P3)			Revising (P4)			Final Check (P5)		
	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3
Speed (TC1)	GD	GD	I	GD	GD	I	I	GD	I	GD	I	I	I	GD	S
Information (TC2)	I	I	GD	GD	I	GD	S	S	GD	S	GD	S	I	I	GD
Control (TC3)	S	I	I	GD	GD	GD	GD	GD	I	S	S	GD	S	I	I
Capacity (TC4)	GD	GD	I	GD	I	I	GD	GD	S	I	I	GD	GD	I	GD
Conveniency (TC5)	I	I	GD	S	GD	S	I	I	I	I	GD	S	I	GD	GD

Table 22 LEs for the phase 3 of QFD

Criteria/alternatives	Beneficiaries (COM1)			Market Conditions (COM2)			Institutional Capacity (COM3)			Technological Infrastructure (COM4)			Regulations (COM5)		
	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3
Planning (P1)	GD	GD	I	GD	GD	GD	S	I	I	GD	I	GD	GD	GD	S
Observing (P2)	I	GD	GD	GD	S	I	S	S	GD	S	GD	S	GD	S	I
Analysing (P3)	S	GD	S	I	GD	GD	GD	GD	I	S	S	GD	S	I	I
Revising (P4)	GD	GD	I	GD	I	I	GD	S	I	I	I	GD	GD	I	GD
Final Check (P5)	I	I	GD	GD	GD	S	I	GD	S	I	GD	S	I	GD	GD

Table 23 LEs for the phase 4 of QFD

Criteria/alternatives	Institutional (priority 1)			Product (priority 2)			Process (priority 3)		
	ES1	ES2	ES3	ES1	ES2	ES3	ES1	ES2	ES3
Beneficiaries (COM1)	S	GD	I	GD	GD	GD	S	S	GD
Market conditions (COM2)	I	S	GD	GD	S	I	S	S	GD
Institutional capacity (COM3)	S	GD	S	S	GD	GD	GD	GD	I
Technological infrastructure (COM4)	GD	GD	I	GD	I	S	GD	S	I
Regulations (COM5)	I	GD	GD	GD	GD	S	S	GD	S

Table 24 Picture fuzzy DMT for the phase 1 of QFD

	TC1				TC2				TC3				TC4				TC5			
	μ	η	ν	π	μ	η	ν	π	μ	η	ν	π	μ	Η	ν	Π	μ	η	ν	π
ES1																				
CN1	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0
CN2	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0
CN3	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0
CN4	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0
CN5	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1
	TC1				TC2				TC3				TC4				TC5			
	μ	η	ν	π	μ	η	ν	π	μ	η	ν	π	μ	Η	ν	π	μ	η	ν	π
ES2																				
CN1	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0
CN2	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0
CN3	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1
CN4	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.3	0.3	0.3	0.1
CN5	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0	0.6	0.2	0.2	0
	TC1				TC2				TC3				TC4				TC5			
	μ	η	ν	π	μ	η	ν	π	μ	η	ν	π	μ	η	ν	π	μ	η	ν	π
ES3																				
CN1	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.8	0.1	0.1	0
CN2	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.8	0.1	0.1	0	0.6	0.2	0.2	0
CN3	0.6	0.2	0.2	0	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1	0.6	0.2	0.2	0	0.3	0.3	0.3	0.1
CN4	0.3	0.3	0.3	0.1	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.6	0.2	0.2	0	0.6	0.2	0.2	0
CN5	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.8	0.1	0.1	0	0.6	0.2	0.2	0

Table 25 Picture fuzzy rough sets for the phase 1 of QFD

	TC1	TC2	TC3	TC4	TC5
CN1	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)
CN2	(·0.6,0.6·,·0.2,0.2·,·0.2,0.2·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)
CN3	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)
CN4	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)
CN5	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.8·,·0.1,0.3·,·0.1,0.3·,·0,0.1·)	(·0.6,0.8·,·0.1,0.2·,·0.1,0.2·,·0,0·)	(·0.3,0.6·,·0.2,0.3·,·0.2,0.3·,·0,0.1·)

Table 26 Normalized values for the phase 1 of QFD

	TC1	TC2	TC3	TC4	TC5
CN1	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.375,1·,·0.125,0.375·,·0.125,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)
CN2	(·0.75,0.75·,·0.25,0.25·,·0.25,0.25·,·0,0·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)
CN3	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,1·,·0.125,0.375·,·0.125,0.375·,·0,0.125·)
CN4	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)
CN5	(·0.375,1·,·0.125,0.375·,·0.125,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,1·,·0.125,0.375·,·0.125,0.375·,·0,0.125·)	(·0.75,1·,·0.125,0.25·,·0.125,0.25·,·0,0·)	(·0.375,0.75·,·0.25,0.375·,·0.25,0.375·,·0,0.125·)

Table 27 Weighted DMT for the phase 1 of QFD

	TC1	TC2	TC3	TC4	TC5
CN1	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.07,0.20·,·0.02,0.07·,·0.02,0.07·,·0,0.02·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)
CN2	(·0.15,0.15·,·0.05,0.05·,·0.05,0.05·,·0,0·)	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)
CN3	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.07,0.20·,·0.02,0.07·,·0.02,0.07·,·0,0.02·)
CN4	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.15,0.20·,·0.02,0.05·,·0.02,0.05·,·0,0·)	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)	(·0.07,0.15·,·0.05,0.07·,·0.05,0.07·,·0,0.02·)
CN5	(·0.06,0.18·,·0.02,0.06·,·0.02,0.06·,·0,0.02·)	(·0.13,0.18·,·0.02,0.04·,·0.02,0.04·,·0,0·)	(·0.06,0.18·,·0.02,0.06·,·0.02,0.06·,·0,0.02·)	(·0.13,0.18·,·0.02,0.04·,·0.02,0.04·,·0,0·)	(·0.06,0.13·,·0.04,0.06·,·0.04,0.06·,·0,0.02·)

Appendix 2: Equations

$$A = \{\langle x, \mu_A(x)\rangle | x \in X\} \tag{1}$$

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle | x \in X\} \tag{2}$$

$$A = \{\langle x, \mu_A(x), n_A(x), \nu_A(x), \pi_A(x)\rangle | x \in X\} \tag{3}$$

$$A \subseteq B \ \text{ if } \mu_A(x) \leq \mu_B(x) \text{ and } n_A(x) \leq n_B(x) \text{ and } \nu_A(x) \geq \nu_B(x), \ \forall x \in X \tag{4}$$

$$A = B \text{ if } A \subseteq B \text{ and } B \subseteq A \tag{5}$$

$$A \cup B = \{(x, max(\mu_A(x), \mu_B(x)), min(n_A(x), n_B(x)), min(\nu_A(x), \nu_B(x)))| x \in X\} \tag{6}$$

$$A \cap B = \{(x, min(\mu_A(x), \mu_B(x)), min(n_A(x), n_B(x)), max(v_A(x), v_B(x)))|x \in X\} \quad (7)$$

$$coA = \overline{A} = \{(x, v_A(x), n_A(x), \mu_A(x))|x \in X\} \quad (8)$$

$$\underline{Apr}(C_i) = \cup\{Y \in X/R(Y) \leq C_i\} \quad (9)$$

$$\overline{Apr}(C_i) = \cup\{Y \in X/R(Y) \geq C_i\} \quad (10)$$

$$Bnd(C_i) = \cup\{Y \in X/R(Y) \neq C_i\} \quad (11)$$

$$\underline{Lim}(C_i) = \sqrt[N_L]{\prod_{i=1}^{N_L} Y \in \underline{Apr}(C_i)} \quad (12)$$

$$\overline{Lim}(C_i) = \sqrt[N_U]{\prod_{i=1}^{N_U} Y \in \overline{Apr}(C_i)} \quad (13)$$

$$RN(C_i) = \lceil \underline{Lim}(C_i), \overline{Lim}(C_i) \rfloor \quad (14)$$

$$\underline{Apr}\left(C_{i\mu_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{i\mu_A}\right\} \quad (15)$$

$$\underline{Apr}\left(C_{in_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{in_A}\right\} \quad (16)$$

$$\underline{Apr}\left(C_{iv_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{iv_A}\right\} \quad (17)$$

$$\underline{Apr}\left(C_{i\pi_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{i\pi_A}\right\} \quad (18)$$

$$\overline{Apr}\left(C_{i\mu_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{i\mu_A}\right\} \quad (19)$$

$$\overline{Apr}\left(C_{in_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{in_A}\right\} \quad (20)$$

$$\overline{Apr}\left(C_{iv_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{iv_A}\right\} \quad (21)$$

$$\overline{Apr}\left(C_{i\pi_A}\right) = \cup\left\{Y \in X/\tilde{R}(Y) \leq C_{i\pi_A}\right\} \quad (22)$$

$$\underline{Lim}\left(C_{i\mu_A}\right) = \frac{1}{N_{L\mu_A}} \sum_{i=1}^{N_{L\mu_A}} Y \in \underline{Apr}\left(C_{i\mu_A}\right) \quad (23)$$

$$\underline{Lim}\left(C_{in_A}\right) = \frac{1}{N_{Ln_A}} \sum_{i=1}^{N_{Ln_A}} Y \in \underline{Apr}\left(C_{in_A}\right) \tag{24}$$

$$\underline{Lim}\left(C_{iv_A}\right) = \frac{1}{N_{Lv_A}} \sum_{i=1}^{N_{Lv_A}} Y \in \underline{Apr}\left(C_{iv_A}\right) \tag{25}$$

$$\underline{Lim}\left(C_{i\pi_A}\right) = \frac{1}{N_{L\pi_A}} \sum_{i=1}^{N_{L\pi_A}} Y \in \underline{Apr}\left(C_{i\pi_A}\right) \tag{26}$$

$$\overline{Lim}\left(C_{i\mu_A}\right) = \frac{1}{N_{U\mu_A}} \sum_{i=1}^{N_{U\mu_A}} Y \in \overline{Apr}\left(C_{i\mu_A}\right) \tag{27}$$

$$\overline{Lim}\left(C_{in_A}\right) = \frac{1}{N_{Un_A}} \sum_{i=1}^{N_{Un_A}} Y \in \overline{Apr}\left(C_{in_A}\right) \tag{28}$$

$$\overline{Lim}\left(C_{iv_A}\right) = \frac{1}{N_{Uv_A}} \sum_{i=1}^{N_{Uv_A}} Y \in \overline{Apr}\left(C_{iv_A}\right) \tag{29}$$

$$\overline{Lim}\left(C_{i\pi_A}\right) = \frac{1}{N_{U\pi_A}} \sum_{i=1}^{N_{U\pi_A}} Y \in \overline{Apr}\left(C_{i\pi_A}\right) \tag{30}$$

$$\begin{aligned} PFRN\left(\tilde{C}_i\right) = \Big(& \left\lceil \underline{Lim}\left(C_{i\mu_A}\right), \overline{Lim} \right\rfloor \left(C_{i\mu_A}\right), \left\lceil \underline{Lim}\left(C_{in_A}\right), \overline{Lim} \right\rfloor \left(C_{in_A}\right), \\ & \left\lceil \underline{Lim}\left(C_{iv_A}\right), \overline{Lim} \right\rfloor \left(C_{iv_A}\right), \left\lceil \underline{Lim}\left(C_{i\pi_A}\right), \overline{Lim} \right\rfloor \left(C_{i\pi_A}\right) \Big) \end{aligned} \tag{31}$$

$$\tilde{Z}_k = \begin{bmatrix} 0 & \tilde{z}_{12} & \cdots & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & 0 & \cdots & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{32}$$

$$\begin{aligned} & \left(\left\lceil \underline{Lim}\left(C_{ij\mu_{\tilde{z}_{ij}}}\right), \overline{Lim}\left(C_{ij\mu_{\tilde{z}_{ij}}}\right) \right\rfloor, \left\lceil \underline{Lim}\left(C_{ijn_{\tilde{z}_{ij}}}\right), \overline{Lim}\left(C_{ijn_{\tilde{z}_{ij}}}\right) \right\rfloor, \right. \\ & \left. \left\lceil \underline{Lim}\left(C_{ijv_{\tilde{z}_{ij}}}\right), \overline{Lim}\left(C_{ijv_{\tilde{z}_{ij}}}\right) \right\rfloor, \left\lceil \underline{Lim}\left(C_{ij\pi_{\tilde{z}_{ij}}}\right), \overline{Lim}\left(C_{ij\pi_{\tilde{z}_{ij}}}\right) \right\rfloor \right) \end{aligned} \tag{33}$$

$$\tilde{X}_{\underset{a}{'}} = \begin{bmatrix} 0 & a'_{12} & \cdots & \cdots & a'_{1n} \\ a'_{21} & 0 & \cdots & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \ldots \tilde{X}_{\underset{h}{'}} = \begin{bmatrix} 0 & h'_{12} & \cdots & \cdots & h'_{1n} \\ h'_{21} & 0 & \cdots & \cdots & h'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h'_{n1} & h'_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{34}$$

$$\tilde{X} = \frac{X_{\underset{a}{'}}}{max_{1 \le i \le n} \sum_{j=1}^{n} \overset{'}{\underset{ij}{a}}}, \cdots \frac{X_{\underset{h}{'}}}{max_{1 \le i \le n} \sum_{j=1}^{n} \overset{'}{\underset{ij}{h}}} \tag{35}$$

$$\tilde{T} = \lim_{s \to \infty} \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^s \tag{36}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \cdots & \tilde{t}_{nn} \end{bmatrix} \tag{37}$$

$$\tilde{t}_{ij} = \left(a''_{ij}, b''_{ij}, c''_{ij}, d''_{ij}\right), \left(e''_{ij}, f''_{ij}, g''_{ij}, h''_{ij}\right) \tag{38}$$

$$\left[a''_{ij}\right] = \tilde{X}_{\underset{a}{'}} \times \left(I - \tilde{X}_{\underset{a}{'}}\right)^{-1}, \ldots \left[h''_{ij}\right] = \tilde{X}_{\underset{h}{'}} \times \left(I - \tilde{X}_{\underset{h}{'}}\right)^{-1} \tag{39}$$

$$Def_T = \frac{\left(a'' + \frac{c''}{2} + \frac{\left(1 + a'' + \frac{c''}{2} - e'' + \frac{c''}{2}\right)}{2} \times g''\right) + \left(b'' + \frac{d''}{2} + \frac{\left(1 + b'' + \frac{d''}{2} - e'' + \frac{d''}{2}\right)}{2} \times h''\right)}{2} \tag{40}$$

$$Def_T = T = \left[t_{ij}\right]_{n \times n}, \ i, j = 1, 2, \ldots, n \tag{41}$$

$$\tilde{D}_i^{def} = r = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} = (r_i)_{n \times 1} = (r_1, \ldots, r_i, \ldots, r_n) \tag{42}$$

$$\tilde{R}_i^{def} = y = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1 \times n} = \left(y_j\right)'_{1 \times n} = \left(y_1, \ldots, y_i, \ldots, y_n\right) \tag{43}$$

$$\tilde{X}_{ij} = \begin{matrix} & \begin{bmatrix} C_1 & C_2 & C_3 & \ldots & C_n \end{bmatrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & x_{13} & \ldots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \ldots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \ldots & x_{3n} \\ \vdots & \vdots & \ddots & \ldots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \ldots & x_{mn} \end{bmatrix} \end{matrix} \tag{44}$$

$$\begin{aligned} PFRN\left(\tilde{X}_{ij}\right) = &\left(\left[\underline{Lim}\left(\tilde{X}_{ij\mu_{\tilde{x}_{ij}}}\right), \overline{Lim}\left(\tilde{X}_{ij\mu_{\tilde{x}_{ij}}}\right)\right], \left[\underline{Lim}\left(\tilde{X}_{ijn_{\tilde{x}_{ij}}}\right), \overline{Lim}\left(\tilde{X}_{ijn_{\tilde{x}_{ij}}}\right)\right],\right. \\ &\left.\left[\underline{Lim}\left(\tilde{X}_{ijv_{\tilde{x}_{ij}}}\right), \overline{Lim}\left(\tilde{X}_{ijv_{\tilde{x}_{ij}}}\right)\right], \left[\underline{Lim}\left(\tilde{X}_{ij\pi_{\tilde{x}_{ij}}}\right), \overline{Lim}\left(\tilde{X}_{ij\pi_{\tilde{x}_{ij}}}\right)\right]\right) \end{aligned} \tag{45}$$

$$\tilde{r}_{ij} = \frac{\underline{Lim}\left(\tilde{X}_{ij\mu_{\tilde{x}_{ij}}}\right)}{max\tilde{X}_i}, \ldots, \frac{\overline{Lim}\left(\tilde{X}_{ij\pi_{\tilde{x}_{ij}}}\right)}{max\tilde{X}_i} \tag{46}$$

$$\tilde{v}_{ij} = w_j \times \underline{Lim}\left(\tilde{r}_{ij\mu_{\tilde{x}_{ij}}}\right), \ldots, w_j \times \overline{Lim}\left(\tilde{r}_{ij\pi_{\tilde{x}_{ij}}}\right) \tag{47}$$

$$\underline{Lim}A^+_\mu = \left\{\underline{Lim}\left(\tilde{v}_{1j_\mu}\right), \ldots, \underline{Lim}\left(\tilde{v}_{mj_\mu}\right)\right\} = \left\{max\underline{Lim}\left(\tilde{v}_{1j_\mu}\right) for\ \forall j \in n\right\} \tag{48}$$

$$\overline{Lim}A^+_\pi = \left\{\overline{Lim}\left(\tilde{v}_{1j_\pi}\right), \ldots, \overline{Lim}\left(\tilde{v}_{mj_\pi}\right)\right\} = \left\{max\overline{Lim}\left(\tilde{v}_{1j_\pi}\right) for\ \forall j \in n\right\} \tag{49}$$

$$\underline{Lim}A^-_\mu = \left\{\underline{Lim}\left(\tilde{v}_{1j_\mu}\right), \ldots, \underline{Lim}\left(\tilde{v}_{mj_\mu}\right)\right\} = \left\{min\underline{Lim}\left(\tilde{v}_{1j_\mu}\right) for\ \forall j \in n\right\} \tag{50}$$

$$\overline{Lim}A^-_\pi = \left\{\overline{Lim}\left(\tilde{v}_{1j_\pi}\right), \ldots, \overline{Lim}\left(\tilde{v}_{mj_\pi}\right)\right\} = \left\{min\overline{Lim}\left(\tilde{v}_{1j_\pi}\right) for\ \forall j \in n\right\} \tag{51}$$

$$D^+_i = \sqrt{\sum_{j=1}^{n}\left(\tilde{v}_{1j_\mu} - \underline{Lim}A^+_{j\mu}\right)^2 +, .., + \sum_{j=1}^{n}\left(\tilde{v}_{1j_\pi} - \overline{Lim}A^+_{j\pi}\right)^2} \tag{52}$$

$$D^-_i = \sqrt{\sum_{j=1}^{n}\left(\tilde{v}_{1j_\mu} - \underline{Lim}A^-_{j\mu}\right)^2 +, .., + \sum_{j=1}^{n}\left(\tilde{v}_{1j_\pi} - \overline{Lim}A^-_{j\pi}\right)^2} \tag{53}$$

$$CC_i = \frac{D^-_i}{D^+_i + D^-_i} \text{ for i} = 1, 2, ..., \text{m and } 0 \le CC_i \le 1 \tag{54}$$

$$\tilde{f}^*_j = \frac{max\underline{Lim}\left(\tilde{v}_{1j_\mu}\right) + max\overline{Lim}\left(\tilde{v}_{1j_\pi}\right)}{2}, \text{ and } \tilde{f}^-_j = \frac{min\underline{Lim}\left(\tilde{v}_{1j_\mu}\right) + min\overline{Lim}\left(\tilde{v}_{1j_\pi}\right)}{2} \tag{55}$$

$$\tilde{\boldsymbol{S}}_{\boldsymbol{i}} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \tilde{\boldsymbol{w}}_{\boldsymbol{j}} \frac{\left(\left|\tilde{\boldsymbol{f}}^*_{\boldsymbol{j}} - \tilde{\boldsymbol{x}}_{\boldsymbol{ij}}\right|\right)}{\left(\left|\tilde{\boldsymbol{f}}^*_{\boldsymbol{j}} - \tilde{\boldsymbol{f}}^-_{\boldsymbol{j}}\right|\right)} \tag{56}$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j \frac{\left(\left| \tilde{f}_j^* - \tilde{x}_{ij} \right| \right)}{\left(\left| \tilde{f}_j^* - \tilde{f}_j^- \right| \right)} \right] \tag{57}$$

$$\tilde{\boldsymbol{Q}}_{\boldsymbol{i}} = \boldsymbol{v}\left(\tilde{\boldsymbol{S}}_{\boldsymbol{i}} - \tilde{\boldsymbol{S}}^*\right) / \left(\tilde{\boldsymbol{S}}^- - \tilde{\boldsymbol{S}}^*\right) + (1 - \boldsymbol{v})\left(\tilde{\boldsymbol{R}}_{\boldsymbol{i}} - \tilde{\boldsymbol{R}}^*\right) / \left(\tilde{\boldsymbol{R}}^- - \tilde{\boldsymbol{R}}^*\right) \tag{58}$$

Author contributions

WL conducted a literature evaluation and made statistical analysis. SY participated in the design of the study and performed the statistical analysis. HD conceived of the study and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

In this study, 3 different experts made evaluations about the criteria. These evaluations are considered as input data in the study. The data used to support the findings of this study are included within the article.

Declarations

Competing interests

The authors declare that they have no competing interests.

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