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Evaluating Recognitive Balanced Scorecard-Based Quality Improvement Strategies of Energy Investments With the Integrated Hesitant 2-Tuple Interval-Valued Pythagorean Fuzzy Decision-Making Approach to QFD

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ABSTRACT This study aims to identify quality improvement strategies for energy investments. For this purpose, a model is proposed which includes 4 different stages. In the first stage, the MCDM problem is identified for evaluating the service development for energy industry. In this framework, quality function deployment (QFD) approach is taken into consideration which includes both customer expectations and technical requirements at the same time to improve the quality in the organization. The second stage is related to the calculation of the correlation coefficients of decision matrices for the criteria by considering hesitant 2-tuple interval-valued Pythagorean fuzzy sets. The third stage includes the weighting of the customer expectations with hesitant 2-tuple interval-valued Pythagorean fuzzy (HIVPF) DEMATEL. In the final stage, TRIZ-based quality improvement strategies of energy investments are ranked by using 2-tuple HIVPF TOPSIS. Thus, the motivation of this study is to figure out the weights of the criteria for quality improvement strategies in energy investments. Also, the most important contribution of this study to the literature is related to the originality in the methodology by proposing a new MCDM model while using hesitant linguistic term sets, linguistic 2-tuple information, interval-valued Pythagorean fuzzy sets properly. The findings indicate that empathy is the most significant criterion for the customer expectations in the energy investments. In addition to this issue, it is also identified that customization is the best factor among the technical requirements of energy investments. Moreover, information and communication facilities and organizational background are found as the best competencies of new service development in energy investments. Furthermore, that prior action and periodic action are the most prominent strategies for quality improvement. While considering these results, it can be said that the pricing policy of the energy companies should be fair to increase customer satisfaction. Additionally, offering flexible payment opportunities on energy bills can have a positive influence on the customer satisfaction in this process. Also, preliminary planning of the project should be done in detail in energy investments. Owing to this issue, customers' preferences can be identified before the product is placed on the market. In addition, it can be possible to identify the risks that may arise in energy investments with the help of the periodical audits.

INDEX TERMS Quality function deployment, TRIZ, 2-tuple interval-valued Pythagorean fuzzy sets, balanced scorecard, hesitant fuzzy DEMATEL, hesitant fuzzy TOPSIS, energy investment.

I. INTRODUCTION

Quality issue is vital for the energy industry. In this context, the energy supplied must meet some expectations to increase the quality. Firstly, the energy offered to consumers must be continuous [1]. Energy is used to meet the daily needs of individuals, such as warming and enlightenment. On the other hand, it plays an important raw material role in the production of companies. Therefore, there will be significant customer dissatisfaction if the energy is not continuous. In addition

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to the issues mentioned, the energy provided must be at economically acceptable costs. The main reason is that too high costs will significantly reduce customer satisfaction [2]. Moreover, a quick solution of the detected problems will increase the quality of the energy provided.

There are many different issues that energy companies should pay attention to increase the quality in the energy sector. Firstly, the technical infrastructure of these companies should be very good. In this context, Kim [3] focused on green energy sector in East Asia and concluded that in order to ensure the uninterrupted energy offered to customers, it is important that companies have high technical equipment. This situation will contribute to meeting the expectations of both individual and commercial customers. In addition, the service network of companies must be very wide for the energy offered to be accessible. In this process, companies with an effective supply chain will have a significant competitive power compared to others. On the other hand, Proskuryakova [4] evaluated the energy market in Russia and identified that it is very significant to establish the necessary infrastructure by the companies to quickly solve the problems that occur in this process. In this way, it will be possible to meet the expectations of the customers by intervening early in the problems.

An important issue in this process is determining which issues energy companies should give priority to increase quality. It is not economically feasible to invest in every matter needed at the same time to increase the quality. Therefore, priority analysis should be made among these specified criteria. In this context, the method to be used in the analysis is also very important. Balanced scorecard (BSC) approach is a preferred method for determining customer expectations in the literature. In this approach, 4 different dimensions are considered that are customer, internal processes, finance and training and development. Therefore, the inclusion of financial issues as well as non-financial factors is considered one of the biggest advantages of the BSC method [5]. In addition, the SERVQUAL scale is a frequently used method to measure service quality. Within this framework, 22 different questions are created by combining 5 different sub-scales. In this process, it is aimed to measure service quality more effectively by considering different aspects such as concreteness, ability to respond, reliability, guarantee and empathy [6].

In addition to these issues, TRIZ (Theory and Innovative Problem Solving) is also the method taken into consideration to solve problems in an innovative way. During the development of this technique, many patents have been studied. Considering how the problems in these patents are solved, it is aimed to develop an effective system for the solution of the problems that will occur after that. As a result of the examination of these patents, it was determined that a total of 40 different solution methods were used to solve the problems [7]. There are some steps in problem solving with TRIZ. TRIZ offers a conflict matrix with 39 conflict parameters for problem solving. The intersection point of the possible contradiction corresponding to the parameter tried to be improved in this matrix is determined. At the intersection points in this matrix, which of the 40 different solution methods will be used to solve the problem. Therefore, it is possible to talk about the many benefits of the TRIZ method. First, thanks to this method, technological innovation strategies for the future can be determined [8]. On the other hand, it is possible to learn an easier and systematic solution of your technical problems.

Quality Function Deployment (QFD) is another approach that is taken into consideration in analyzing the expectations of the customers and determining the technical competence that the company should have regarding these expectations. In the first stage of this application, it is aimed to establish a quality house and to relate the customer characteristics with the quality characteristics determined to meet them. The second phase of QFD combines the design requirements and critical characteristics [9]. On the other side, the third phase of QFD deals with the critical parameters and process of quality improvements. Furthermore, the final phase of QFD is to evaluate the production requirements with respect to the service development process. QFD approach has many advantages. With the help of this method, it is possible to determine customer expectations that change over time effectively. In addition, Deveci *et al.* [10] tried to evaluate service quality in public bus transportation by using QFD methodology. They identified that costs can be reduced, and efficiency can be increased by accurately determining the technical competence required to meet customer expectations. Another benefit of this application is contributing to shortening the application time by determining the effective application.

In this study, it is aimed to identify quality improvement strategies for energy investments. For this purpose, a model has been proposed which includes 4 different stages. In the first stage, the MCDM problem is identified based on QFD approach for evaluating the service development for energy industry. The second stage is related to the calculation of the correlation coefficients of decision matrices for the criteria based on balanced scorecard. In this framework, hesitant 2-tuple interval-valued Pythagorean fuzzy sets are considered. On the other side, in the third stage, customer expectations are weighted by using 2-tuple HIVPF DEMATEL. Moreover, in the final stage, TRIZ-based quality improvement strategies of energy investments are ranked by considering 2-tuple HIVPF TOPSIS. Hence, the motivation of this study is to figure out the weights of the criteria for quality improvement strategies in energy investments.

There are some novelties of this study. The most important contribution of this study to the literature is related to the originality in the methodology. A new MCDM model has been generated by using hesitant linguistic term sets, linguistic 2-tuple information, interval-valued Pythagorean fuzzy sets properly. Because there is a possibility that all decision makers do not have the same opinion, there is a need for an approach in which similar opinions are accepted as the common decision. Hence, the main benefit of considering hesitant fuzzy sets is that hesitant evaluations can be accounted more

comprehensively [11]. In addition, the main advantage of using 2-tuple linguistic values is that intermediate evaluations between two linguistic values can be made more appropriately. Also, it is possible to make more accurate fuzzification with the help of these values.

Additionally, it is also accepted that Pythagorean fuzzy sets provides a strong representation of uncertainty [12], [13]. The main reason is that Pythagorean membership degrees provide a larger area for non-standard membership degrees in comparison with the intuitionistic fuzzy membership grades [14]–[16]. Furthermore, using DEMATEL and TOPSIS approaches in the analysis process is another novelty of this study. The main reason of selecting DEMATEL method is that causality analysis among the factors can be made [17]. In addition, the main advantages of TOPSIS approach is the ability to identify the best alternative quickly and considering the ideal solution distances simultaneously [18].

Another important novelty of this study is that BSC-based criteria are identified regarding the evaluation of customer expectations. With the help of this issue, both financial and nonfinancial factors can be considered at the same time so that more appropriate analysis can be performed [5]. Moreover, QFD approach is considered to evaluate quality improvement and new service development process of energy industry. In this way, it can be possible to determine customer expectations more accurately. This will enable the appropriate technical competencies to be determined more clearly [6]. Thus, it can be contributed to increase customer satisfaction in the energy sector. Furthermore, using TRIZ to identify quality improvement requirements can be accepted a significant novelty of this study. In this way, it will be possible to identify innovative investment strategies for energy investments [8].

There are five different sections in this study. The second section includes literature evaluation regarding the subject. In this scope, firstly, the studies including energy investments are considered. After that, the literature is also reviewed based on Pythagorean fuzzy sets, 2-tuple information, and hesitant linguistic term sets. The third section gives information about the theoretical framework of the methods. In the fourth section, analysis results are shared. In the final section, these results are discussed with the similar studies in the literature.

II. LITERATURE REVIEW

In this part of the study, first, the studies in the literature on energy investments are examined. On the other hand, in the second part of the study, a literature review was conducted for the methodology. In the last part, the deficiency in the literature on this subject is indicated.

A. LITERATURE ON ENERGY INVESTMENT

There are many studies in the literature that examine energy investments. The importance of customer satisfaction was emphasized in an important part of these studies. In this context, it has been stated that the trust of customers should be gained [19]. For this reason, it is advocated that energy companies should avoid the movements that will lose their customers' trust [20]. Otherwise, it will not be possible for energy companies to continue their activities in the sector. Bürer *et al.* [21] analyzed opportunities in the energy sector. It was stated that energy companies should gain the trust of their customers to increase their market shares in the sector. According to a significant number of researchers, the most important factor affecting customer satisfaction in the energy sector is security. In cases where necessary measures are not taken in energy use, there are many important problems such as risk of death [22]. Therefore, energy companies must take the necessary measures to minimize these risks [23]. When customers feel safe by using energy, it will be much easier to increase customer satisfaction. Dinçer *et al.* [24] analyzed issues that increase service quality in energy companies. As a result of the analysis made with fuzzy DEMATEL method, it has been determined that the security issue is very effective on customer satisfaction.

On the other hand, according to many studies in the literature, one of the most important factors affecting customer satisfaction in the energy sector is price. Energy is an essential requirement for both individuals and companies. Therefore, when the price is high, there is an increase in customer dissatisfaction [25]. Dinçer and Yüksel [26] worked on investments to be made for different renewable energy alternatives. The integrated fuzzy decision-making model is proposed under the hesitancy. They reached a conclusion that there should be a fair pricing policy for the success of energy investors. Fonseka *et al.* [27] conducted a similar study for Chinese energy industry and reached a similar conclusion. In addition to the issues mentioned, the quick solution of the problems that arise is another factor affecting customer satisfaction in the energy sector. In this framework, energy companies are required to respond quickly to customers' complaints [28], [29]. Andoni *et al.* [30] examined energy use in blockchain technologies. They stated that for energy companies to achieve customer satisfaction, a platform that responds to the problems of the customers quickly should be created.

Some of the studies in the literature have emphasized the technical competencies that energy companies should have to increase customer satisfaction. It has been argued that the technological infrastructures of energy companies should be developed in a significant part of these studies [3]. One of the most prominent problems in energy investments is the high costs. Thanks to technological developments, new applications can be identified, and this will contribute to lowering costs [31]. Edomah *et al.* [32] conducted an analysis on the energy sector in Nigeria. Semi-structured interviews are used to achieve this objective. They identified that energy companies should follow the technologic development in the market to survive in the competitive market. Customization is also another important customer expectation in energy industry. Offering flexible payment opportunities on energy bills will also contribute to increase customer satisfaction in this process [33], [34]. Şerban and Lytras [35] focused on the European energy sector. According to the results of the analysis conducted using artificial neural networks method,

it has been stated that the services to be provided should be shaped according to customer demands.

There are many researchers who advocate having qualified personnel to be successful in energy investments. Energy investments are projects that contain technical details. Therefore, the personnel working in these investments should have advanced knowledge on some issues [4]. Otherwise, in case of a possible problem in the project, unqualified personnel will not be able to solve this problem easily [36]. This will negatively affect the success of energy investments. Kutsan *et al.* [37] made an evaluation regarding the energy industry in Ukraine. They conducted a simulation analysis and determined that personnel quality is a significant indicator of the effectiveness in energy investment projects. Moreover, accessibility is another important factor that affects the customer satisfaction in the energy industry. Customers mainly demand to access energy anywhere [38]. Hence, energy companies should make necessary investments to provide sustainable energy to the customers [39]. Xu and Lin [40] focused on the Chinese energy industry and concluded that accessibility plays a key role in the effectiveness of the energy investment projects.

B. LITERATURE ON THE METHODOLOGY

Pythagorean fuzzy sets provides a strong representation of uncertainty [14], [41]. Because of this situation, they attracted the attention of many different researchers, especially in the last years. For example, Rani *et al.* [42] evaluated renewable energy technologies in India with the help of these sets. In addition, Karasan *et al.* [43] made a risk assessment by using Pythagorean fuzzy sets. In this study, expert opinions are converted to these fuzzy sets. Furthermore, Oz *et al.* [44] tried to identify the significant risk factors in natural gas pipeline projects. Within this framework, different risk items are ranked with an extended TOPSIS model with Pythagorean fuzzy sets. Moreover, Ejegwa [45] considered these fuzzy sets in career placements based on academic performance.

On the other side, hesitant 2-tuple linguistic fuzzy sets provide opportunities to handle higher levels of uncertainty with the help of expressing the hesitancy of the decision makers [11]. Due to this significant advantage, these fuzzy sets were preferred in various studies in the literature. Zhang *et al.* [46] aimed to determine the main issues that affect the youth employment. In this study, firstly, the main indicators are selected based on a detailed literature review. After that, the most important items are defined with the help of the HIVPF DEMATEL based on 2-tuple linguistic values. Moreover, Wu *et al.* [47] tried to select the best suppliers in nuclear power industry. Within this context, an extended VIKOR methodology is taken into consideration by using hesitant 2-tuple linguistic fuzzy sets. Similarly, Wen *et al.* [48] focused on the solving of the supplier selection problems with integrating the 2-tuple linguistic representation and soft set. Furthermore, Boral *et al.* [49] identified the important factors that affect the effectiveness of the manufacturing industry. For this purpose, hesitant 2-tuple linguistic fuzzy sets are considered.

DEMATEL methodology is mainly preferred to find the weights of the criteria. In other words, it is aimed to identify more significant items that have an influence on a condition [50]. There are some other approaches in the literature which try to calculate the weights of the factors, such as analytic hierarchy process (AHP) and analytic network process (ANP). Nonetheless, DEMATEL method has some superiorities in comparison with other approaches. For instance, with the help of DEMATEL, impact-relation map of the criteria can be generated [51], [52]. This situation provides an opportunity to find out causal relationship among the factors [53]. Because of this advantage, many researchers in the literature considered DEMATEL in the analysis process. For instance, Dinçer and Yüksel [54] aimed to generate impact-relation map for the criteria regarding investment strategies for tourism industry. Similarly, Cui *et al.* [55] focused on the critical factors of green business failure by considering this approach.

TOPSIS is a significant MCDM method which aims to rank alternatives according to their importance [56]. Some other MCDM techniques can also be considered for this purpose, like vlsekriterijumska optimizacija i kompromisno resenje (VIKOR). However, it is possible to talk about some advantages of the TOPSIS method compared to the VIKOR technique [57]. For example, in the analysis process of TOPSIS, the distances to both positive and negative ideal solutions are considered [58]. Nevertheless, VIKOR method also uses the distance to the positive ideal solution in the analysis process. Hence, it is obvious that more appropriate results can be reached by using TOPSIS [59]. Due to this situation, TOPSIS approach was considered by many researchers for different purposes such as supplier selection [60] and sustainable energy planning [61].

C. THE RESULTS OF LITERATURE REVIEW

As a result of the literature review, some conclusions have been reached regarding the energy sector. Primarily, the analysis of customer satisfaction in the energy sector is a vital issue and has been handled by many researchers in the literature. Most studies focused on how to increase customer satisfaction in energy consumption. In this context, in a new study, it is necessary to focus on the technical equipment required to increase customer satisfaction in the energy sector. In this study, QFD approach is considered to evaluate quality improvement. Hence, it is thought that customer expectations can be determined more accurately. Additionally, TRIZ approach is used to identify quality improvement requirements so that it can be possible to identify innovative investment strategies for energy investments. Another result obtained from the examination of the literature is related to the methodology used in the studies. In most of the studies, methods such as survey analysis, DEMATEL and semi-structured interview were considered. On the other side, in this study, a new MCDM model has been generated by

using hesitant linguistic term sets, linguistic 2-tuple information, interval-valued intuitionistic and Pythagorean fuzzy sets properly. Thus, it is believed that this study has methodological originality in comparison with other studies related to the energy industry in the literature.

III. METHODOLOGY

This section includes the theoretical information about the models used in the analysis process. Within this scope, firstly, linguistic 2-tuple information is explained. Later, necessary information is given regarding hesitant fuzzy linguistic term sets. After that, interval-valued intuitionistic and Pythagorean fuzzy sets are detailed. In the final section, the extensions of MCDM models are identified.

A. LINGUISTIC 2-TUPLE INFORMATION

The 2-tuple fuzzy linguistic model includes symbolic models. In this framework, $S = \{s_0, \ldots, s_g\}$ represents the linguistic term set [45], [46]. Additionally, 2-tuple term set is demonstrated as $\langle S \rangle = S \times [-0.5, 0.5)$. Furthermore, the linguistic model based on 2-tuple evaluations can be shown as the functions of Δ and Δ^{-1}. On the other side, β gives information about the symbolic aggregation operation [11], [15], [41]. Equations (1) and (2) demonstrate this situation.

$$\Delta(\beta) = (S_i, \alpha), \quad \text{with} \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases} \tag{1}$$

$$\Delta^{-1} : \langle S \rangle \to [0, g] \quad \text{and } \Delta^{-1}(S_i, \alpha) = i + \alpha \tag{2}$$

In these equations, Δ represents a bijective function where the term of round assigns to β. Moreover, (S_i, α) identifies the decision-making results based on 2-tuple linguistic information.

B. HESITANT FUZZY LINGUISTIC TERM SETS

H_S indicates hesitant fuzzy linguistic term sets. Equation (3) explains the details of these sets [22], [26].

$$H_S = \{s_i, s_{i+1}, \cdots, s_j\}, \quad s_k \in S, k \in \{i, \cdots, j\} \tag{3}$$

These sets create a decision-making model by considering the hesitancy of the experts. They are very helpful to express the opinions of the experts more accurately [46]. In this framework, context-free grammars $G_H = (V_N, V_T, I, P)$ are used as in the following.

$$V_N = \left\{ \begin{array}{l} \langle primary\ term \rangle, \langle composite\ term \rangle \\ \langle unary\ term \rangle, \langle binary\ term \rangle, \langle conjunction \rangle, \end{array} \right\}$$

$$V_T = \left\{ \begin{array}{l} lower\ than, greater\ than, \\ at\ least, at\ most, between, and, S_0, S_1, \ldots, S_t \end{array} \right\}$$

$$I \in V_N$$

$$P = \{I ::= \langle primary\ term \rangle \mid \langle composite\ term \rangle,$$

$$\langle composite\ term \rangle ::= \langle composite\ term \rangle$$

$$\langle primary\ term \rangle$$

$$\left| \begin{array}{l} \langle binary\ relation \rangle\ \langle primary\ term \rangle \\ \langle conjunction \rangle\ \langle primary\ term \rangle, \end{array} \right.$$

$$\langle primary\ term \rangle ::= S_0 \mid S_1 \mid \ldots \mid S_t,$$

$$\langle unary\ relation \rangle ::= lower\ than \mid greater\ than$$

$$\mid at\ least \mid at\ most,$$

$$\langle binary\ relation \rangle ::= between,$$

$$\langle conjunction \rangle ::= and \}.$$

E_{G_H} represents the transformation function which is used to convert context-free grammars to the linguistic information. The main benefit of considering hesitant 2-tuple linguistic fuzzy sets is that uncertainty can be handled more effectively owing to the considering the hesitancy of the experts [22].

C. INTERVAL-VALUED INTUITIONISTIC AND PYTHAGOREAN FUZZY SETS

IVIF set explains the membership and non-membership degrees of the factors. In this context, the extreme values are considered. With the help of this issue, more appropriate results can be reached in the complex environment [12]. The details of the intuitionistic fuzzy set (I) are given on the equation (4).

$$I = \{\langle \vartheta, \mu_1(\vartheta), n_I(\vartheta) \rangle / \vartheta \epsilon U\} \tag{4}$$

In this equation, $\mu_I(\vartheta)$ and $n_I(\vartheta)$ define the degrees of belongingness and non-belongingness. On the other side, $\mu_{IU}(\vartheta)$ and $\mu_{IL}(\vartheta)$ represent the upper and lower values of $\mu_I(\vartheta)$. Additionally, $n_{IU}(\vartheta)$ and $n_{IL}(\vartheta)$ is the upper and lower values of $n_I(\vartheta)$ respectively [37], [38]. Hence, I can also be explained as in the equations (5)-(7).

$$I = \{\vartheta, [\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)], [n_{IL}(\vartheta), n_{IU}(\vartheta)] / \vartheta \epsilon U\} \tag{5}$$

$$0 \leq \mu_{IU}(\vartheta) + n_{IU}(\vartheta) \leq 1 \mu_{IL}(\vartheta) \geq 0, \quad n_{IL}(\vartheta) \geq 0 \tag{6}$$

$$\tau_I(\vartheta) = 1 - \mu_I(\vartheta) - n_I(\vartheta) \tag{7}$$

Pythagorean fuzzy sets include of non-standard fuzzy membership grades [62]. They are explained in the equations (8) and (9).

$$P = \left\{\langle \vartheta, \mu_{fp}(\vartheta), n_p(\vartheta) \rangle / \vartheta \epsilon U\right\} \tag{8}$$

$$(\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{9}$$

In these equations, ϑ demonstrates a universal set. On the other hand, equation (10) indicates the degree of indeterminacy.

$$\pi_P(\vartheta) = \sqrt{1 - (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2} \tag{10}$$

The mathematical operations of the Pythagorean fuzzy sets are detailed on the equations (11)-(16).

$$P_1 = \{\langle \vartheta, P_1(\mu_{P1}(\vartheta), n_{P1}(\vartheta)) \rangle / \vartheta \epsilon U\} \tag{11}$$

$$P_2 = \{\langle \vartheta, P_2(\mu_{P2}(\vartheta), n_{P2}(\vartheta)) \rangle / \vartheta \epsilon U\} \tag{12}$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^2 + \mu_{P_2}^2 - \mu_{P_1}^2 \mu_{P_2}^2}, n_{P_1} n_{P_2}\right) \tag{13}$$

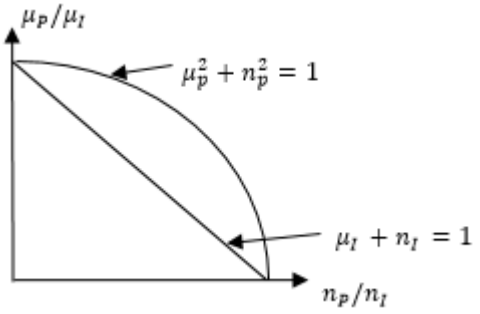


FIGURE 1. Membership and non-membership degrees of IFS and PFS.

$$P_1 \otimes P_2 = P\left(\mu_{P_1}\mu_{P_2}, \sqrt{n_{P_1}^2 + n_{P_2}^2 - n_{P_1}^2 n_{P_2}^2}\right) \quad (14)$$

$$\lambda P = P\left(\sqrt{1-\left(1-\mu_p^2\right)^{\lambda}}, \left(n_p\right)^{\lambda}\right), \quad \lambda > 0 \quad (15)$$

$$P^{\lambda} = P\left(\left(\mu_p\right)^{\lambda}, \sqrt{1-\left(1-n_p^2\right)^{\lambda}}\right), \quad \lambda > 0 \quad (16)$$

Figure 1 illustrates the relationship between intuitionistic and Pythagorean fuzzy sets.

There is a limit ($\mu_I + n_I = 1$) regarding the membership and non-membership degrees of intuitionistic fuzzy sets. On the other side, membership degrees of Pythagorean fuzzy sets are all points with $\mu_p^2 + n_p^2 = 1$. This situation gives information that Pythagorean membership degrees provide a larger area for non-standard membership degrees in comparison with the intuitionistic fuzzy membership grades.

Furthermore, the Pythagorean fuzzy numbers can be extended with IVIF sets. Hence, more appropriate results can be provided in uncertain environment. The details of the interval-valued Pythagorean fuzzy sets (IP) are shown in the equations (17)-(19).

$$IP = \left\{\langle \vartheta, [\mu_P^L(\vartheta), \mu_P^U(\vartheta)], [\nu_P^L(\vartheta), \nu_P^U(\vartheta)]\rangle / \vartheta \epsilon U\right\} \quad (17)$$

$$0 \le \mu_P^L(\vartheta) \le \mu_P^U(\vartheta) \le 1 \le \nu_P^L(\vartheta) \le \nu_P^U(\vartheta) \le 1 \quad (18)$$

$$\left(\mu_P^U(\vartheta)\right)^2 + \left(\nu_P^U(\vartheta)\right)^2 \le 1 \quad (19)$$

In this process, the defuzzification process has been performed with the help of the equation (20), as shown at the bottom of the next page. In this equation, a and b represent the extreme values for belongingness degree. On the other hand, c and d give information about the lower and upper values of non-belongingness.

D. EXTENSIONS OF MCDM MODELS

DEMATEL method is considered to find significant factors that affect a situation [17]. In other words, firstly, the factors are selected. After that, they are weighted according to their significance. The main benefit of DEMATEL is that causal relationship between the items can be identified with the help of impact relation map [63]. Additionally, in the literature, DEMATEL approach was mainly used with triangular [64] or trapezoidal fuzzy numbers [65], [66]. Moreover, this approach can also be extended with interval-valued Pythagorean fuzzy sets and 2-tuple linguistic information. In the first step, experts' opinions are obtained based on the subject. Secondly, they are converted to interval-valued Pythagorean fuzzy sets. This situation is demonstrated in the equation (21).

$$\tilde{Z}_{ij} = \left(\left(a_{ij}, b_{ij}\right), \left(c_{ij}, d_{ij}\right)\right) \quad (21)$$

In this equation, Z represents direct relation matrix [67]. On the other side, a_{ij} and b_{ij} show the extreme values for belongingness degree. Moreover, the lower and upper values of non-belongingness are shown as c_{ij} and d_{ij}. In the third step, the score function of direct relation matrix is calculated as in the equation (22).

$$A_k = \begin{bmatrix} 0 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ a_{n1k} & \cdots & 0 \end{bmatrix} \quad (22)$$

After that, this matrix is normalized with the help of the equation (23).

$$B = \left[b_{ij}\right]_{nxn} = \frac{A}{max\sum_{j=1}^{n} a_{ij}} \quad (23)$$

Later, the total relation matrix (C) is defined by the equation (24).

$$C = \left[c_{ij}\right]_{nxn} = B\left(I - B\right)^{-1} \quad (24)$$

In this equation, I represents identity matrix. In the final stage, the sum of all vector rows and columns (D, E) is calculated. In this framework, D+E is considered to calculate the weights whereas D-E is used to identify impact relation map. The details are given on the equations (25) and (26).

$$D = \left[\sum_{j=1}^{n} c_{ij}\right]_{nx1} = \left[d_i\right]_{nx1} = \left(d_1, \ldots, d_i, \ldots d_n\right) \quad (25)$$

$$E = \left[\sum_{i=1}^{n} c_{ij}\right]_{1xn}' = \left[e_j\right]_{1xn}' = \left(e_1, \ldots, e_i, \ldots e_n\right) \quad (26)$$

On the other side, TOPSIS approach is another significant MCDM model in the literature. This model is mainly used to rank different alternatives with respect to their importance [18]. The main benefits of TOPSIS approach is the ability to identify the best alternative quickly and considering the ideal solution distances simultaneously [68]. In this study, TOPSIS methodology is extended with the 2-tuple linguistic information and interval-valued Pythagorean fuzzy sets. In the first stage, the evaluations of the experts are converted to the interval-valued Pythagorean fuzzy sets. By using these values, the IVIF decision matrix is generated. Within this framework, the equations (27) and (28) are considered.

$$C1 \quad C2 \quad C3 \quad \ldots \quad Cn$$

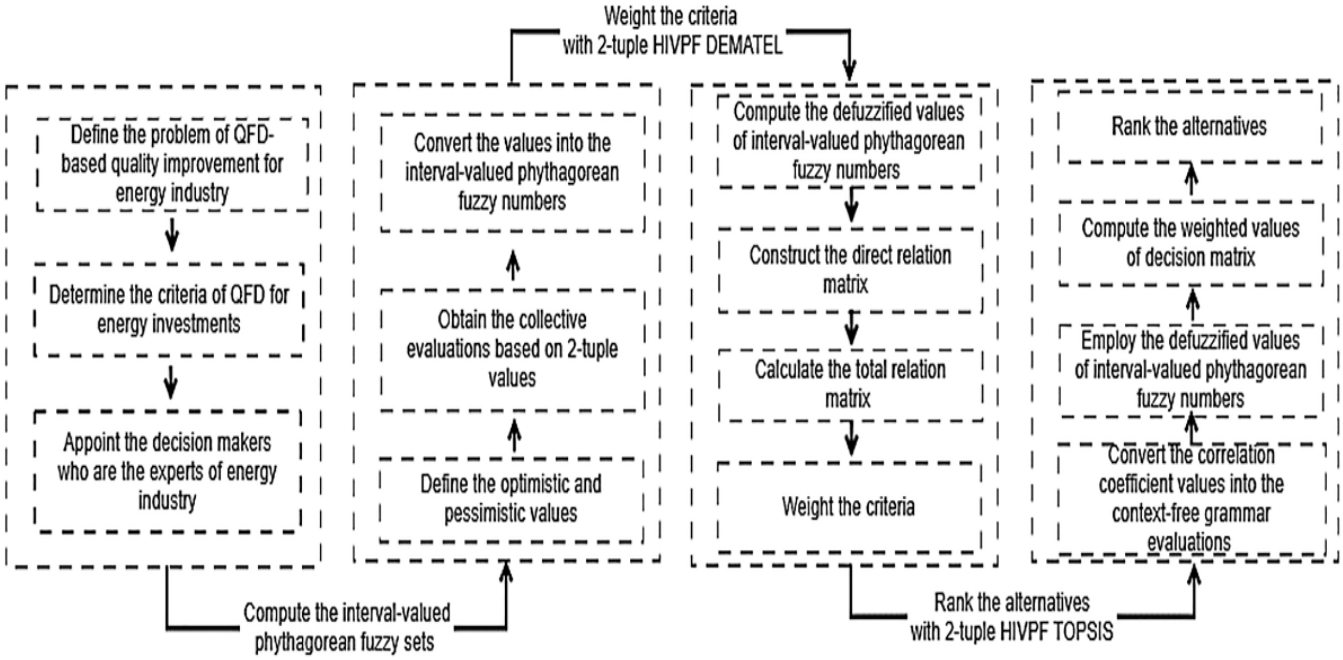


FIGURE 2. Flowchart of proposed model.

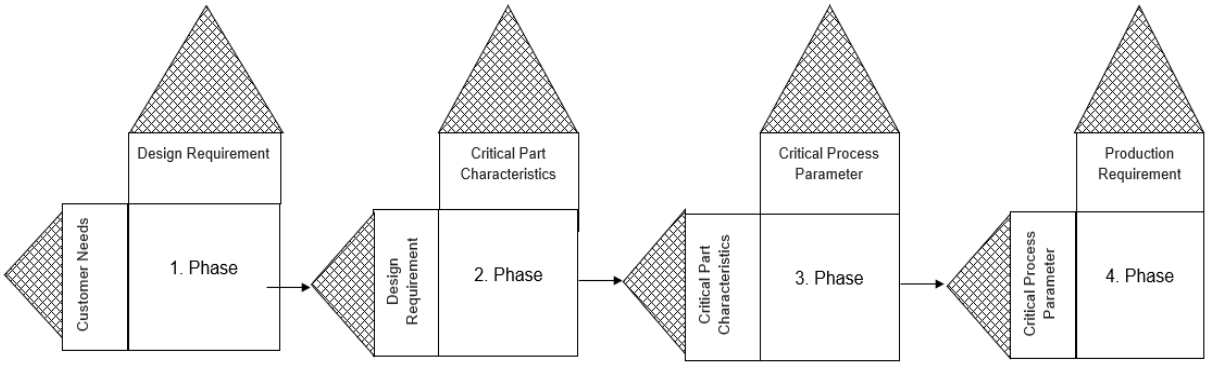


FIGURE 3. Phases of QFD approach.

$$\mathrm{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{array} \begin{bmatrix} h_{11} & h_{12} & h_{13} & \cdots & h_{1n} \\ h_{21} & h_{22} & h_{23} & \cdots & h_{2n} \\ h_{31} & h_{32} & h_{33} & \cdots & h_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & h_{m3} & \cdots & h_{mn} \end{bmatrix} \tag{27}$$

$$h_{ij} = \frac{1}{k}\left[\sum_{e=1}^{n} h_{ij}^{e}\right] \tag{28}$$

In the next process, the weighted decision matrix is created. In this context, the positive (A^+) and negative (A^-) values for the ideal solutions are calculated [69]. For this purpose, the equations (29) and (30) are considered. In these equations, v indicates the normalized fuzzy numbers.

$$A^+ = max\,(v_1, v_2, v_3, \ldots v_n) \tag{29}$$

$$A^- = min\,(v_1, v_2, v_3, \ldots v_n) \tag{30}$$

In the final stage, the distances positive and negative ideal solutions (D+ and D-) and the closeness coefficient (CC_i)

$$S(\vartheta) = \frac{\left(\left(a^2 - c^2\right)\left(1 + \sqrt{1 - a^2 - c^2}\right) + \left(b^2 - d^2\right)\left(1 + \sqrt{1 - b^2 - d^2}\right)\right)}{2} \tag{20}$$

are calculated by using the equations (31)-(33).

$$D_i^+ = \sqrt{\sum_{i=1}^{m}(v_i - A_i^+)^2} \quad (31)$$

$$D_i^- = \sqrt{\sum_{i=1}^{m}(v_i - A_i^-)^2} \quad (32)$$

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (33)$$

IV. ANALYSIS FOR ENERGY INVESTMENT STRATEGIES

In this study, balanced scorecard-based quality improvement strategies of energy investments are analyzed with QFD approach. For this purpose, an integrated hesitant 2-tuple interval-valued Pythagorean fuzzy decision-making model are proposed, and it is adapted to the QFD together with recognition technique to obtain more comprehensive results under the fuzzy environment. Algorithm of proposed model is illustrated in Figure 2.

Proposed model consists of four integrated stages to analyze the QFD-based evaluation of energy investments. Initially, MCDM problem of QFD-based quality improvement is defined based on literature review. Essential phases of QFD is presented in Figure 3 and selected criteria of QFD are given in Tables 1-5. However, 3 decision makers that are the experts in the field of energy industry are appointed to obtain the context-free grammar evaluations for each phase of QFD. Second stage of proposed model is to compute the interval-valued Pythagorean fuzzy sets. For this purpose, the optimistic and pessimistic values are constructed and the collective evaluations for direct relation matrix are defined based on 2-tuple values. Hesitant linguistic evaluations are converted into the interval-valued Pythagorean fuzzy numbers to weight the criteria.

TABLE 1. SERVQUAL-based expectations of customers for energy investments.

Criteria	References
Reliability (CE1)	[19],[20],[21]
Assurance (CE 2)	[22],[23],[24]
Empathy (CE 3)	[25],[26],[27]
Responsiveness (CE 4)	[28],[29],[30]

TABLE 2. Technical requirements of quality development for energy investments.

Criteria	References
Technological infrastructure (TR 1)	[31],[32]
Customization (TR 2)	[33],[34],[35]
Monitoring (TR 3)	[36],[37]
Accessibility (TR 4)	[38],[39],[40]

TABLE 3. New service development competencies for energy investments.

Criteria	References
Strategy and planning (NC 1)	[25],[32]
Information and communication facilities (NC 2)	[31],[34]
Process management (NC 3)	[28],[29]
Organizational background (NC 4)	[31],[37]

Third stage is to weight the criteria of customer expectations in the first stage of QFD. Within this context, the interval-valued Pythagorean fuzzy numbers are defuzzified and then the procedures of DEMATEL method are applied for measuring the relative importance among the criteria. The final stage of proposed model is to rank each phase of QFD. For that, the technical requirements of energy investments are evaluated with respect to the customer expectations using 2-tuple HIVPF TOPSIS. The weighted values of decision matrices are obtained from 2-tuple HIVPF DEMATEL and they are used consecutively in each phase of QFD. The final phase of QFD provides the final rank of TRIZ-based quality improvement strategies of energy investments. The details of analysis are given in the following stages, respectively.

TABLE 4. New service development process for energy investments.

Criteria	References
Design (NP 1)	[28],[29]
Analysis (NP 2)	[30],[37]
Development (NP 3)	[31],[34]
Initiating (NP 4)	[36],[37]

TABLE 5. TRIZ-based quality improvement strategies for energy investments.

Criteria	References
Local Quality (TS 1)	[26],[27],[32]
Prior Action (TS 2)	[30],[36],[37]
Partial or Excessive Action (TS 3)	[29],[37],[40]
Periodic Action (TS 4)	[33],[34],[35]

The main benefit of this proposed model is that a hybrid MCDM methodology is taken into consideration. In the process of ranking different alternatives, experts evaluate these alternatives by considering a set of criteria. In this process, if a hybrid method is not used, the importance of the criteria is either considered equal or determined subjectively. With the help of hybrid methodology, firstly, the criteria are weighted with a MCDM model. After that, these weighted criteria are considered to rank the alternatives by another MCDM technique. Therefore, in the literature, there are lots of studies in which hybrid MCDM methodology is used [70], [71]. Similarly, in this study, a hybrid model is proposed to evaluate quality improvement strategies for energy investments.

The selected criteria are weighted by DEMATEL approach whereas the strategies are ranked with TOPSIS. The combination of DEMATEL and TOPSIS was also considered by different researchers in the literature [72]. However, in the literature, there is not a model in which this combination is taken into account with HIVPF sets. Additionally, there are limited studies which used QFD approach and TRIZ technique to evaluate quality improvement strategies regarding energy investments. This situation can be accepted as another advantage of this study.

TABLE 6. Linguistic scales and numbers for criteria.

Criteria	Evaluation Numbers
No influence (n)	1
somewhat influence (s)	2
medium influence (m)	3
high influence (h)	4
very high influence (vh)	5

A. STAGE 1: DEFINING THE MCDM PROBLEM

QFD-based MCDM approach is applied for evaluating the service development for energy industry. The phases of QFD approach are illustrated in Figure 3.

Balanced scorecard-based quality improvement strategies of energy investments are adapted to the phases of QFD properly. The first phase of QFD is decision matrix including the customer needs and design requirements. Accordingly, SERVQUAL-based expectations of customers and technical requirements of quality development for energy investments are defined for the first phase. The criteria of customer expectations and technical requirements are represented in Tables 1 and, respectively.

The second phase of QFD combines the design requirements and critical characteristics. Therefore, the new service development competencies for energy investments are determined as seen in Table 3.

The third phase of QFD deals with the critical parameters and process of quality improvements. Hence, the new service development process for energy investments are given in Table 4.

The final phase of QFD is to evaluate the production requirements with respect to the service development process. TRIZ-based quality improvement requirements are presented as a set of strategies for energy investments. Thus, an integrated approach to the quality improvement strategies for energy investments is proposed for measuring the criteria of quality function deployment.

B. STAGE 2: COMPUTING THE CORRELATION COEFFICIENTS OF DECISION MATRICES FOR THE CRITERIA BASED ON BSC

Correlation coefficients of QFD-based criteria in terms of the perspectives of BSC are computed for illustrating the relation degrees of factors. Thus, it is possible to appoint the hesitant and 2-tuple linguistic evaluations more accurately by using a recognitive approach to the fuzzy MCDM modelling. For this purpose, initially, the linguistic evaluations of 3 decision makers are collected by using linguistic scales as seen in Table 6 and the BSC-based evaluation results of customer expectations for energy investments are given in the appendix (Table 19).

TABLE 7. Correlation coefficient values for the first phase of QFD (mean value:0.967).

Technical Requirements/ Customer Expectations	CE1	CE2	CE3	CE4
TR1	0.964	0.970	0.971	0.982
TR2	0.903	0.987	0.980	0.991
TR3	0.941	0.978	0.978	0.995
TR4	0.890	0.978	0.973	0.991

TABLE 8. Direct relation matrix for customer expectations.

CE	CE1	CE2	CE3	CE4
CE1		0.449	0.631	0.331
CE2	0.663		0.663	0.388
CE3	0.661	0.601		0.601
CE4	0.601	0.663	0.663	

TABLE 9. Normalized relation matrix for customer expectations.

CE	CE1	CE2	CE3	CE4
CE1		0.233	0.328	0.172
CE2	0.344		0.344	0.201
CE3	0.343	0.312		0.312
CE4	0.312	0.344	0.344	

TABLE 10. Total relation matrix for customer expectations.

CE	CE1	CE2	CE3	CE4
CE1	1.755	1.772	2.014	1.458
CE2	2.285	1.827	2.299	1.678
CE3	2.431	2.201	2.193	1.855
CE4	2.482	2.283	2.518	1.670

At the following step, the boundaries linguistic term sets and 2-tuple values of collective linguistic evaluations for customer expectations are determined to construct the interval-valued Pythagorean fuzzy sets. At the next step, interval-valued Pythagorean fuzzy sets are computed with the help of the equations (17)-(19). Later, the defuzzification process has been performed. The details of them are explained on Tables 20-23. The defuzzified values are used for computing the correlation coefficients and illustrating the relation results of QFD phases. The correlation of BSC-based factor

A evaluation is given as in the equation (34).

$$C(A,A) = \sum_{i=1}^{n} \left(\frac{1}{l_i} \sum_{j=1}^{l_i} h^2_{A\sigma(j)}(x_i) \right) \tag{34}$$

On the other hand, the correlation between BSC-based factors A and criteria B is shown in the equation (35).

$$C(A,B) = \sum_{i=1}^{n} \left(\frac{1}{l_i} \sum_{j=1}^{l_i} h_{A\sigma(j)}(x_i) h_{B\sigma(j)}(x_i) \right) \tag{35}$$

Additionally, the correlation coefficient between the factor A and the criteria B is illustrated as in the equation (36).

$$\begin{aligned} &\rho(A,B) \\ &= \frac{C(A,B)}{\sqrt{C(A,A)}\sqrt{C(B,B)}} \\ &= \frac{\sum_{i=1}^{n} \left(\frac{1}{l_i} \sum_{j=1}^{l_i} h_{A\sigma(j)}(x_i) h_{B\sigma(j)}(x_i) \right)}{\sum_{i=1}^{n} \left(\frac{1}{l_i} \sum_{j=1}^{l_i} h^2_{A\sigma(j)}(x_i) \right) \sum_{i=1}^{n} \left(\frac{1}{l_i} \sum_{j=1}^{l_i} h^2_{B\sigma(j)}(x_i) \right)} \end{aligned} \tag{36}$$

The values of correlation coefficients are computed by using the formulas above and the BSC-based results among the customer expectations and technical requirements in the first phase of QFD are given in Table 7.

TABLE 11. The values of D and E for customer expectations.

CE	D	E	D+E	D-E	Weights
CE1	6.999	8.954	15.953	-1.954	0.244
CE2	8.089	8.082	16.171	0.007	0.247
CE3	8.680	9.024	17.704	-0.344	0.271
CE4	8.953	6.661	15.614	2.291	0.239

TABLE 12. Linguistic scales and numbers for alternatives.

Alternatives	Evaluation Numbers
Worst (w)	1
Poor (p)	2
Fair (f)	3
Good (g)	4
Best (b)	5

Similar procedures are also applied for other QFD-based criteria of renewable energy investments. The BSC-based values of correlation coefficient for other phases of QFD are given in Tables 24-26 respectively.

C. STAGE 3: WEIGHTING THE CUSTOMER EXPECTATIONS USING 2-TUPLE HIVPF DEMATEL

Linguistic evaluations of customer expectations from the decision makers are used for weighting the criteria using 2-tuple HIVPF DEMATEL. Table 27 shows the context free grammar evaluations for customer expectations by the decision makers.

TABLE 13. Interval-valued Pythagorean fuzzy sets for the first stage of QFD.

CE	TR1	TR2	TR3	TR4
CE1	([0.20,0.40], [0.10,0.20])	([0.40,0.60], [0.20,0.40])	([0.40,0.60], [0.20,0.40])	([0.60,0.80], [0.10,0.20)
CE2	([0.10,0.20], [0.10,0.20])	([0.60,0.80], [0.10,0.20])	([0.40,0.60], [0.20,0.40])	([0.60,0.80], [0.10,0.20)
CE3	([0.20,0.40], [0.10,0.20])	([0.40,0.60], [0.20,0.40])	([0.40,0.60], [0.20,0.40])	([0.60,0.80], [0.10,0.20)
CE4	([0.10,0.20], [0.05,0.10])	([0.40,0.60], [0.20,0.40])	([0.40,0.60], [0.20,0.40])	([0.60,0.80], [0.10,0.20)

TABLE 14. Decision matrix for the first stage of QFD.

CE	TR1	TR2	TR3	TR4
CE1	0.143	0.283	0.283	0.784
CE2	0.000	0.784	0.283	0.784
CE3	0.143	0.283	0.283	0.784
CE4	0.037	0.283	0.283	0.784

TABLE 15. Ranking and weighting results of technical requirements for the first stage of QFD.

TR	D+	D-	CCi	Ranks	Weights
TR1	0.124	0.035	0.220	2	0.172
TR2	0.035	0.124	0.780	1	0.611
TR3	0.124	0.035	0.220	2	0.172
TR4	0.150	0.009	0.057	4	0.045

TABLE 16. Ranking and weighting results for the second stage of QFD.

NC	D+	D-	CCi	Ranks	Weights
NC1	0.601	0.086	0.125	4	0.055
NC2	0.086	0.601	0.875	1	0.381
NC3	0.397	0.291	0.422	3	0.184
NC4	0.086	0.601	0.875	1	0.381

TABLE 17. Ranking and weighting results for the third stage of QFD.

NP	D+	D-	CCi	Ranks	Weights
NP1	0.601	0.086	0.125	4	0.055
NP2	0.086	0.601	0.875	1	0.381
NP3	0.397	0.291	0.422	3	0.184
NP4	0.086	0.601	0.875	1	0.381

TABLE 18. Ranking and weighting results for the fourth stage of QFD.

TS	D+	D-	CCi	Ranks	Weights
TS1	0.601	0.086	0.125	4	0.055
TS2	0.086	0.601	0.875	1	0.381
TS3	0.397	0.291	0.422	3	0.184
TS4	0.086	0.601	0.875	1	0.381

TABLE 19. Context-free grammar balanced scorecard-based evaluations for customer expectations (CE).

CE	BSC 1 (Finance)		
	DM1	DM2	DM3
CE1	at least "m"	between "m" and "vh"	between "m" and "vh"
CE2	at least "m"	between "m" and "vh"	between "m" and "vh"
CE3	at least "m"	between "s" and "h"	at most "h"
CE4	between "m" and "h"	between "m" and "h"	at least "m"
CE	**BSC 2 (Customer)**		
	DM1	**DM2**	**DM3**
CE1	at most "h"	between "m" and "h"	at most "m"
CE2	between "m" and "h"	at least "m"	between "m" and "vh"
CE3	between "m" and "h"	between "m" and "vh"	between "s" and "h"
CE4	at most "h"	between "s" and "h"	between "m" and "vh"
CE	**BSC 3 (Internal Process)**		
	DM1	**DM2**	**DM3**
CE1	at most "h"	at most "h"	between "m" and "vh"
CE2	between "m" and "h"	between "s" and "h"	at least "m"
CE3	at most "h"	at least "m"	at least "m"
CE4	at least "m"	at most "h"	between "m" and "vh"
CE	**BSC 4 (Learning and Growth)**		
	DM1	**DM2**	**DM3**
CE1	at most "m"	at most "m"	between "m" and "h"
CE2	between "m" and "vh"	at least "m"	at most "m"
CE3	at least "m"	at least "m"	at most "h"
CE4	between "m" and "vh"	at least "m"	at most "h"

In the following steps, the boundaries of linguistic term sets, 2-tuple values of collective evaluations, interval-valued Pythagorean fuzzy sets, their defuzzified values are computed for constructing the direct relation matrix for customer expectations of energy investments and the results are given in Table 8.

Next steps continue with the normalized values of relation matrix and total relation matrix. The normalization values and total relation matrix are illustrated in Tables 9 and 10, respectively.

The final step is to define the influencing and influenced criteria of customer expectations for energy investments. Table 11 presents the values of D, E, (D+E), and (D-E) as well as the weights.

In Table 11, CE4 is the most influencing criterion whereas CE1 is the most influenced factor among the customer expectations for energy investments. However, CE3 is the most important criterion as CE4 is the weakest item of customer expectations.

D. STAGE 4: RANKING THE PHASES OF QFD USING 2-TUPLE HIVPF TOPSIS

In this stage, firstly, the values of correlation coefficient for each phase of QFD are converted into five-point linguistic scales. Within this context, the averaged values of correlation coefficients are considered as medium influence (m) and the lower and higher values than the mean values of decision matrices are scaled into the context-free grammar evaluations properly. Table 12 shows the five-point scales of linguistic evaluations for decision matrix and Tables 28-31 gives the context free grammar evaluations for the stages of QFD.

TABLE 20. Boundaries of linguistic term sets for customer expectations.

CE	BSC 1			BSC 2		
	DM1	DM2	DM3	DM1	DM2	DM3
CE1	$[m, vh]$	$[m, vh]$	$[m, vh]$	$[n, h]$	$[m, h]$	$[n, m]$
CE2	$[m, vh]$	$[m, vh]$	$[m, vh]$	$[m, h]$	$[m, vh]$	$[m, vh]$
CE3	$[m, vh]$	$[s, h]$	$[n, h]$	$[m, h]$	$[m, vh]$	$[s, h]$
CE4	$[m, h]$	$[m, h]$	$[m, vh]$	$[n, h]$	$[s, h]$	$[m, vh]$
CE	**BSC 3**			**BSC 4**		
	DM1	**DM2**	**DM3**	**DM2**	**DM1**	**DM3**
CE1	$[n, h]$	$[n, h]$	$[m, vh]$	$[m, h]$	$[n, m]$	$[n, m]$
CE2	$[m, h]$	$[s, h]$	$[m, vh]$	$[n, m]$	$[m, vh]$	$[m, vh]$
CE3	$[n, h]$	$[m, vh]$	$[m, vh]$	$[n, h]$	$[m, vh]$	$[m, vh]$
CE4	$[m, vh]$	$[n, h]$	$[m, vh]$	$[n, h]$	$[m, vh]$	$[m, vh]$

For the first stage of QFD, similarly, the interval-valued Pythagorean fuzzy sets are calculated by considering the equations (17)-(19). The details are demonstrated on Table 13.

After that, the defuzzified values of decision matrix are calculated as in Table 14.

In this process, the weights of customer expectations from 2-tuple HIVPF DEMATEL are used for obtaining the decision matrix. In the following step, the values of D+, D-, and the closeness coefficient (CCi) are computed to rank and weight the technical requirements of energy investments with respect to customer expectations. The results are given in Table 15.

TABLE 21. 2-tuple values of collective linguistic evaluations for customer expectations.

CE	BSC 1		BSC 2	
	Opt.	Pess.	Opt.	Pess.
CE1	(vh,0)	(m,0)	(h,-0.33)	(s,-0.33)
CE2	(vh,0)	(m,0)	(vh,-0.33)	(m,0)
CE3	(h,0.33)	(s,0)	(h,0.33)	(m,-0.33)
CE4	(h,0.33)	(m,0)	(h,0.33)	(s,0)
CE	BSC 3		BSC 4	
	Opt.	Pess.	Opt.	Pess.
CE1	(h,0.33)	(s,-0.33)	(m,0.33)	(s,-0.33)
CE2	(h,0.33)	(m,-0.33)	(h,0.33)	(s,0.33)
CE3	(vh,-0.33)	(s,0.33)	(vh,-0.33)	(s,0.33)
CE4	(vh,-0.33)	(s,0.33)	(vh,-0.33)	(s,0.33)

TABLE 22. Interval-valued Pythagorean fuzzy sets for customer expectations.

CE	BSC 1	BSC 2	BSC 3	BSC 4
CE1	([0.60,0.80], [0.20,0.40])	([0.40,0.53], [0.10,0.13])	([0.60,0.67], [0.10,0.13])	([0.40,0.47], [0.10,0.13)
CE2	([0.60,0.80], [0.20,0.40])	([0.60,0.73], [0.20,0.40])	([0.60,0.67], [0.20,0.33])	([0.60,0.67], [0.20,0.27])
CE3	([0.60,0.67], [0.10,0.20])	([0.60,0.67], [0.20,0.33])	([0.60,0.73], [0.20,0.27])	([0.60,0.73], [0.20,0.27])
CE4	([0.60,0.67], [0.20,0.40])	([0.60,0.67], [0.10,0.20])	([0.60,0.73], [0.20,0.27])	([0.60,0.73], [0.20,0.27])

TABLE 23. Defuzzified values for customer expectations.

CE	BSC 1	BSC 2	BSC 3	BSC 4
CE1	0.631	0.388	0.684	0.331
CE2	0.631	0.577	0.562	0.601
CE3	0.661	0.562	0.663	0.663
CE4	0.516	0.661	0.663	0.663

According to the results, TR2 is the best factor among the technical requirements of energy investments while TR4 has the worst performance with respect to customer expectations of energy investments in the first stage of QFD. However, the weighting results are computed by using the normalized values of CCi and it is also seen that TR2 has the highest importance as TR4 is the weakest importance among them. Similar computation process is also applied for other stages of QFD and the weighting results of each stage are used for constructing the weighted decision matrices of QFD. Thus, the integrated effects of the quality improvement strategies in energy investments can be analyzed by considering consecutively the weighting results for each stage of QFD. The ranking and weighting results are given for the remaining stages of QFD in Tables 16-18.

At the second stage of QFD, NC2 and NC4 are the best competencies of new service development in energy investments while NC1 is the worst factor.

Table 17 shows that NP2 and NP4 are among the most successful process of new service development for energy investments whereas NP1 has the weakest performance.

TRIZ-based quality improvement strategies for energy investments are ranked based on QFD approach. In Table 18, TS2 and TS4 are the most prominent strategies for quality improvement and TS4 has the weakest priority among the quality improvement strategies.

V. CONCLUSION

This study tries to define quality improvement strategies for energy investments. Within this scope, a model has been proposed which includes 4 different stages. First of all, the MCDM problem is determined to evaluate the service development for energy industry. Secondly, the correlation coefficients of decision matrices for the criteria are calculated based on hesitant 2-tuple interval-valued Pythagorean fuzzy sets are considered. Thirdly, customer expectations are weighted with 2-tuple HIVPF DEMATEL. Finally, TRIZ-based quality improvement strategies of energy investments are ranked by using 2-tuple HIVPF TOPSIS. It is concluded that empathy is the most significant criterion for the customer expectations in the energy investments. Additionally, it is also defined that customization is the best factor among the technical requirements of energy investments. Another important conclusion is that information and communication facilities and organizational background are the best competencies of new service development in energy investments. Finally, it is identified that prior action and periodic action are the most prominent strategies for quality improvement.

VI. LIMITATIONS AND IMPLICATIONS

The findings indicate that the one of the most important factors affecting customer satisfaction in the energy sector is price. It is understood that there is a negative correlation between the price of the energy and customer satisfaction. Hence, the pricing policy of the companies should be fair. Energy must be used continuously by both individuals and companies. Therefore, rising prices will make customers seriously unhappy. The main reason for this is that rising energy prices affect the budget of both individuals and companies negatively. Thus, there should not be radical differences in the pricing policies of the energy companies according to different customer types. Otherwise, this unfair policy can lead to customer dissatisfaction. Yüksel and Dinçer [73] aimed to identify the best renewable energy investment alternatives. They underlined the importance of the fair price to increase customer satisfaction. They also discussed that energy companies should not prefer price differences for different customer groups. They claimed that with the help of this implication, fair pricing policy can be implemented. Drosos *et al.* [74] focused on the ways to increase customer satisfaction for the electricity market in Greece. They reached a conclusion that when the price is high, there is an increase in customer dissatisfaction. Hence, they stated that companies should not have a right to increase the price levels radically. For this purpose, they recommended that there should be legal regulation which limits the electricity price.

TABLE 24. Correlation coefficient values for the second phase of QFD (mean value:0.977).

NSD Competencies/ Technical Requirements	TR1	TR2	TR3	TR4
NC1	0.988	0.954	0.976	0.942
NC2	0.979	0.985	0.985	0.978
NC3	0.991	0.970	0.986	0.961
NC4	0.979	0.988	0.987	0.983

TABLE 25. Correlation coefficient values for the third phase of QFD (mean value:0.992).

NSD Process/ NSD Competencies	NC1	NC2	NC3	NC4
NP1	0.987	0.980	0.991	0.979
NP2	0.987	1.000	0.994	0.999
NP3	0.998	0.993	1.000	0.991
NP4	0.984	1.000	0.992	1.000

TABLE 26. Correlation coefficient values for the fourth phase of QFD (mean value:0.983).

TRIZ-based strategies / NSD Process	NP1	NP2	NP3	NP4
TS1	0.990	0.984	0.998	0.981
TS2	0.941	0.987	0.971	0.988
TS3	0.975	0.984	0.970	0.986
TS4	0.976	0.999	0.990	1.000

TABLE 27. Context-free grammar evaluations for direct relation matrix of customer expectations.

CE	CE1		
	DM1	DM2	DM3
CE1			
CE2	at most “h”	at least “m”	between “m” and “vh”
CE3	between “m” and “vh”	at most “h”	between “s” and “h”
CE4	between “s” and “h”	between “s” and “h”	between “m” and “vh”
CE	**CE2**		
	DM1	**DM2**	**DM3**
CE1	at most “h”	at least “m”	at most “m”
CE2			
CE3	at least “m”	at most “m”	between “m” and “vh”
CE4	between “m” and “vh”	at most “h”	at least “m”
CE	**CE3**		
	DM1	**DM2**	**DM3**
CE1	at least “m”	between “m” and “vh”	between “m” and “vh”
CE2	at most “h”	at least “m”	at least “m”
CE3			
CE4	at least “m”	at most “h”	at least “m”
CE	**CE4**		
	DM1	**DM2**	**DM3**
CE1	between “m” and “h”	at most “m”	at most “m”
CE2	at most “m”	between “m” and “vh”	at most “m”
CE3	at least “m”	at least “m”	at least “m”
CE4			

TABLE 28. Context-free grammar evaluations for the first stage of QFD.

CE	TR1	TR2	TR3	TR4
CE1	between "p" and "f"	between "f" and "g"	between "f" and "g"	between "g" and "b"
CE2	"p"	between "g" and "b"	between "f" and "g"	between "g" and "b"
CE3	between "p" and "f"	between "f" and "g"	between "f" and "g"	"b"
CE4	"p"	between "f" and "g"	between "f" and "g"	between "g" and "b"

TABLE 29. Context-free grammar evaluations for the second stage of QFD.

TR	NC1	NC2	NC3	NC4
TR1	between "g" and "b"	"p"	between "p" and "f"	"p"
TR2	between "f" and "g"	between "g" and "b"	between "g" and "b"	between "f" and "g"
TR3	"b"	between "p" and "f"	between "g" and "b"	between "p" and "f"
TR4	between "f" and "g"	between "g" and "b"	between "g" and "b"	between "f" and "g"

TABLE 30. Context-free grammar evaluations for the third stage of QFD.

NC	NP1	NP2	NP3	NP4
NC1	between "p" and "f"	"p"	between "f" and "g"	"p"
NC2	between "p" and "f"	"b"	between "f" and "g"	between "g" and "b"
NC3	between "g" and "b"	between "f" and "g"	"b"	between "p" and "f"
NC4	"p"	"b"	"f"	"b"

TABLE 31. Context-free grammar evaluations for the fourth stage of QFD.

NP	TS1	TS2	TS3	TS4
NP1	between "f" and "g"	between "f" and "g"	between "g" and "b"	between "p" and "f"
NP2	"p"	between "f" and "g"	between "p" and "f"	between "f" and "g"
NP3	between "p" and "f"	between "f" and "g"	between "p" and "f"	between "f" and "g"
NP4	between "p" and "f"	between "g" and "b"	between "f" and "g"	"b"

It is also identified that customization is also another important customer expectation in energy industry. Within this framework, offering flexible payment opportunities on energy bills can have a positive influence on the customer satisfaction in this process. In this context, the due dates of energy bills can be arranged according to the salary dates of the users. In this way, it is possible to minimize the risk of non-payment of invoices. Similarly, customers may also be able to pay their electricity bills in installments. In this way, it will be possible to reduce the burden of paying very high bills during the seasons with high electricity usage. Şerban and Lytras [35] aimed to evaluate the effectiveness of the energy market in Europe. They identified that the services to be provided should be shaped according to customer demands. Within this framework, Moreover, they stated that flexible payment opportunities should be provided to the customers. Morganti and Garofalo [75] made a detailed literature analysis regarding the relationship between renewable energy and economic growth. They underlined the importance of the customization for the effectiveness of the energy market. Additionally, they discussed the importance of the arrangement of the electricity bills according to the salary dates of the customers.

Furthermore, it is defined that there should be prior action and periodic action for quality improvement in the energy industry. As can be understood from here, preliminary planning of the project should be done in detail in energy investments. In this context, customers' preferences should be analyzed before the product is placed on the market. Energy investments are long-term projects with high initial costs. Therefore, all analysis should be done in detail before the product reaches the customers. This stated situation will contribute to the effectiveness of energy investments. In addition, it will be possible to detect the risks that may arise in energy investments in advance thanks to the audits to be carried out at certain intervals. This will enable the necessary measures to be taken early to manage these risks effectively.

The main limitation of this study is focusing on energy market in a general manner. Hence, in the future studies, some specific areas can be evaluated. For instance, an analysis can be conducted to examine the effectiveness in renewable energy market. In addition to this situation, in this study, there is not a country-based evaluation. Because the conditions can vary according to the profile of the customers, some country or country groups can be examined in new studies. Another important limitation of this study is related to the

methodology. In this study, only DEMATEL and TOPSIS approaches are considered. Thus, in a new study, a comparative evaluation can be performed by considering different models, such as AHP and VIKOR. This situation provides an opportunity to make a comparative analysis.

APPENDIX

See Tables 19–31.

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