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An Extended Pythagorean Fuzzy Approach to Group Decision-Making With Incomplete Preferences for Analyzing Balanced Scorecard-Based Renewable Energy Investments

YIZHANG XIE[1], YE ZHOU[1], YUE PENG[1], HASAN DİNÇER[2], SERHAT YÜKSEL[2], AND PING AN XIANG[1]
[1]School of Business, Hunan Agricultural University, Changsha 410128, China
[2]School of Business, Istanbul Medipol University, Istanbul 34815, Turkey

Corresponding authors: Serhat Yüksel (serhatyuksel@medipol.edu.tr) and Ping An Xiang (xiangpa@hunau.edu.cn)

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ABSTRACT The aim of this study is to generate appropriate strategies to improve renewable energy investments. Within this framework, a novel model has also been proposed which includes three different stages. Firstly, incomplete preferences of the relation matrixes are calculated. For this purpose, 4 different decision makers evaluate the balanced scorecard-based criteria. In this stage, missing values are estimated by incomplete preferences to complete the relation matrixes. Additionally, the second stage includes the computing the fuzzy preferences by considering the consensus-based group decision-making (CGDM). The final stage is related to the calculation of the weights of the criteria by considering Pythagorean fuzzy decision-making trial and evaluation laboratory (DEMATEL) methodology. Hence, the main motivation of this study is to identify innovative strategies for the renewable energy investments with a novel multi-criteria decision-making (MCDM) model based on incomplete preferences, CGDM and Pythagorean fuzzy sets. The findings indicate that learning and growth is the most important balanced scorecard-based perspective to improve the performance of renewable energy investments. Additionally, the perspective of internal process is identified as another significant factor for this situation. The biggest problem in renewable energy projects is their high initial costs. Hence, technological developments reduce the production costs of renewable energy sources. Additionally, it is also possible to increase the amount of electricity from renewable energy sources owing to the innovative technologies. Thus, renewable energy investors should follow up-to-date technological developments so that it will be possible to reduce the cost of renewable energy investments.

INDEX TERMS Renewable energy investments, incomplete preferences, consensus group decision making, Pythagorean fuzzy sets, balanced scorecard, DEMATEL.

I. INTRODUCTION

People meet their basic needs such as heating and enlightenment with the help of the energy. On the other hand, energy is considered as one of the most important raw materials in industrial production. It is obvious that energy is a crucial factor for the sustainable development of the countries. Therefore, countries develop strategies to increase their energy investments. The popularity of renewable energy investments has increased in the world especially in recent years. In these types of energy, the source is obtained from factors in nature such as the sun and wind. Thanks to this situation, it is possible to decrease the air pollution in the country significantly [1]. Because of this issue, renewable energy

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sources are accepted as environmentally friendly. Another advantage of this energy type is that countries increase their energy independence. Owing to these types of energy, countries will be able to have their own energy resources. Therefore, there will be no need for energy to be imported [2].

Due to these positive aspects, countries are developing several strategies to increase their renewable energy investments. In this context, some incentives are given by the states such as tax cuts and low-interest loans. Since this will provide cost advantage to investors, it will be possible to increase these investments. In addition, renewable energy investors play a number of important roles in this process. For example, the cost-benefit analysis of the renewable energy investment to be made should be done effectively. One of the most important disadvantages of renewable energy investments is the high initial cost [3]. In this context, if the cost analysis is not done correctly, it is very difficult to achieve the profitability of this investment. Another important issue in this process is that companies increase their technological investments. In this way, it will be possible to apply current developments in renewable energy investments quickly. Thus, it will be possible to reduce the high initial cost. In addition, since renewable energy projects involve complex engineering knowledge, it is very important for companies to have qualified personnel [4].

There are many different issues that affect the performance of renewable energy investments. In this process, renewable energy investors need to identify the most important criteria in order to increase their performance. The main reason for this is that these investors should use their resources effectively. In this process, first of all, the factors affecting the efficiency of renewable energy investments should be clearly identified [5]. Balanced scorecard approach is also considered in the literature for this issue. According to this method, there are basically 4 different factors that affect the performance of companies which are finance, customer, internal process and learning and growth [6]. As can be seen, the balanced scorecard approach takes into account both financial and non-financial aspects at the same time. In this way, it will be possible to reach more effective results. After determining these criteria, it is necessary to determine which of these factors are more important. In this way, clearer strategies can be presented to increase efficiency in renewable energy investments. Multi-criteria decision-making (MCDM) methods have also been preferred by many researchers for this purpose. These approaches are used to determine which of the different criteria have more importance [7].

In this study, it is aimed to identify which factors have more powerful influence on the effectiveness of the renewable energy investments. For this purpose, a novel model has been proposed which includes three different stages. In the first stage, incomplete preferences of the relation matrixes are defined. In this scope, balanced scorecard-based criteria are defined for the effectiveness of the renewable energy investments. Later, 4 different decision makers evaluate these factors and missing values are estimated by using incomplete preferences in decision making. Secondly, the fuzzy preferences are computed with CGDM. In the final stage, balanced scorecard-based perspectives are weighted by considering Pythagorean fuzzy DEMATEL methodology.

This study has some significant novelties. Firstly, while making a detailed evaluation, appropriate and effective strategies can be identified for the improvement of the renewable energy investments. Hence, countries can generate their own energy more effectively. This situation minimizes economic and political dependence of these countries. Additionally, considering incomplete preferences in decision making process provides significant advantages. With the help of this methodology, the missing information in the evaluation matrix can be completed [8]. In the decision-making process, one of the significant problems is that decision makers sometimes may not have a clear opinion about the relationship between some factors. Because, an evaluation cannot be conducted with missing information, the decision makers are forced to make evaluations for these items although they do not have sufficient information about them [9]. This situation decreases the effectiveness of the analysis results. In this regard, owing to the incomplete preferences, missing information can be completed which means that the decision makers do not have to make evaluation for the factors if they do not have opinions [10].

Moreover, applying CGDM methodology in the analysis process is accepted another novelty of this study. Different opinions of the experts cause inefficiency in the evaluation process which is considered as an important problem for the decision-making process [11]–[13]. Owing to the CGDM, the feedback mechanism is conducted so that there is a possibility of the revisions of the opinions [14], [15]. While considering this situation for several rounds, the decision makers may offer more similar views regarding the criteria. Hence, it can be seen that opposite decision-maker opinion problem can be minimized by considering CGDM methodology [16]. Furthermore, making evaluations based on Pythagorean fuzzy sets is another novelty of this proposed model. Firstly, they reflect uncertainty better because the analysis is performed by considering both membership and non-membership degrees [17]. Secondly, in these fuzzy sets, there is not a requirement that the sum of these degrees should be at most one unlike the institutional fuzzy sets. Instead of this condition, the sum of the squares of these parameters must be equal to one in the analysis of these sets [18]. Hence, it is obvious that uncertain information can be handled more effectively due to considering these numbers in the analysis process [19]. Finally, DEMATEL approach has some advantages by comparing with other MCDM methods. There are a lot of MCDM models in the literature which can weight the items [20]. However, generation of the impact relation map of the indicators is only possible with DEMATEL methodology [21]. Therefore, with the help of this methodology, the causal relationship among the factors can be identified [22].

This study includes six different sections. In the second part, similar studies in the literature are evaluated. Therefore, the missing part in the literature can be identified. The third section is related to the methodology. Within this framework, firstly, theoretical background of the methods is defined. The fourth section focuses on the findings. Moreover, in the fifth section, discussion and limitations of the study are presented. The final section is related to the conclusion.

II. LITERATURE REVIEW

This section includes the evaluation of the similar studies in the literature. For this purpose, first, the literature is reviewed regarding the renewable energy investments. After that, the usage of MCDM models for the renewable energy subject and new MCDM approaches are examined. Finally, the literature review results are detailed.

A. LITERATURE REVIEW FOR RENEWABLE ENERGY INVESTMENT

It has been determined that the subject of renewable energy investments has a broad literature. In some of these studies, the positive effect of these investments on economic growth has been emphasized. Assab [23] focused on the renewable energy investments in Kenya. It is identified that these investments contribute the economic development of the country in a positive manner. Additionally, Chen [24] also tried to make evaluation for China. It is determined that with the help of the renewable energy investments, new employment opportunities can be created. Moreover, Majid [25] examined the relationship between the renewable energy investments and sustainable economic development in India. It is concluded that by considering the renewable energy investments, the countries can provide their own energy. This issue has a decreasing impact on the current account deficit problems of the countries.

Some researchers discussed that regulations play a key role to increase the renewable energy investments. Boute [26] focused on these investments in Kazakhstan. It is concluded that the regulatory stability is a crucial issue to improve these investments. Liu *et al.* [27] aimed to evaluate the relationship between the renewable energy investments and the effectiveness of the legal system. In this framework, an examination has been conducted by using regression analysis. They reached a conclusion that the effectiveness of the legal system plays a very key role to attract the attentions of the renewable energy investors. Furthermore, Yang *et al.* [28] tried to identify the effects of the government subsidies on renewable energy investments. With the help of the panel threshold effect model, it is stated that because initial costs are very high in the renewable energy investments. governments should give necessary subsidies to improve these projects. Moreover, Yuan *et al.* [29] supported carbon emission regulations to increase renewable energy investments.

On the other hand, some studies discussed the significance of risk management in the performance of the renewable energy investments. Curtin *et al.* [30] made a detailed literature review and reached a conclusion that financial risks should be taken into consideration to increase the effectiveness of the renewable energy investments. They also discussed that these risks should be identified at earlier points in the investment chain so that necessary actions can be taken on time. Additionally, Egli [31] studied onshore wind and solar energy investment risks in Germany, Italy, and the UK. For this purpose, they made interviews with 40 different investors. It is determined that price risks play the most significant role in this respect.

Moreover, Kul *et al.* [32] focused on the renewable energy investments in Turkey. They made an evaluation by considering fuzzy weighted aggregated sum product assessment (FWASPAS) technique. It is identified that macroeconomic risks have a significant impact on the effectiveness of the renewable energy investment projects. Shimbar and Ebrahimi [33] tried to examine the renewable energy investments in developing countries by considering classic risk-adjusted discount rate (RADR) approach. They discussed that political risks should be considered for the investment decisions of these projects. Also, Wu *et al.* [34] aimed to evaluate the renewable energy investment risks in China. In this context, an analysis has been conducted by using analytic hierarchy process (ANP). They underlined the importance of political and economic risks in this framework.

Technological development is also essential for the effectiveness of the renewable energy investment projects according to some researchers. Kim *et al.* [35] focused on the relationship between the technological improvement and renewable energy investments. For this purpose, a real option model has been constructed. They identified that research and development investments should be increased to achieve this objective. Ubay and Karakuş [36] also examined the role of technological development in the performance of the renewable energy investments. Pedroni panel cointegration analysis is taken into consideration to evaluate this situation in MINT countries (Mexico, Indonesia, Nigeria, and Turkey). They reached a conclusion that while making investments on the technological development, it can be more possible to improve these investments. Moreover, Wu *et al.* [37] evaluated the relationship between the technological improvements and the effectiveness of the renewable energy investments projects. Within this framework, the ordinary least squares (OLS) method is used to evaluate this relationship in China. It is stated that governments should give necessary subsidies to improve technological development so that renewable energy investments can be increased.

In addition, some studies also underlined the importance of market conditions in this respect. For example, Cao *et al.* [38] made an evaluation for the renewable energy investments in China. The made an analysis with two-step system-generalized method of moments (GMM) estimator and concluded that oil price volatility has a powerful impact on these investments. Within this context, when oil prices increased dramatically, investments give priorities to the renewable energy investment projects. Also, Koengkan *et al.* [39] focused on the renewable energy investment projects in Latin American countries. For this purpose, a model has been generated by vector autoregression model (VAR) to evaluate this relationship. They determined that financial openness has a positive influence on the development of these investments.

B. MCDM MODELS IN RENEWABLE ENERGY INVESTMENTS

Some researchers focused on the renewable energy investments by MCDM models. Kumar *et al.* [40] focused on the sustainable renewable energy development. For this purpose, technical, economic, social, environmental, and institutional performance indicators are defined and different MCDM models are presented by making comparative evaluation. Additionally, Lee and Chang [41] aimed to rank different renewable energy sources in Taiwan. They aimed to generate appropriate strategies to improve these projects. For this purpose, four different MCDM methods are taken into consideration which are weighted sum method (WSM), visekriterijumsko kompromisno rangiranje (VIKOR), limination et choice translating reality (ELECTRE) and technique for order of preference by similarity to ideal solution (TOPSIS). Moreover, Alizadeh *et al.* [42] aimed to identify effective renewable energy investment projects. Within this context, the parameters are weighted by considering analytic network process (ANP). Similarly, Ishfaq *et al.* [43] aimed to select the optimum renewable energy source in Pakistan. For this purpose, a hybrid MCDM model has been proposed by considering AHP, TOPSIS and VIKOR.

On the other hand, some studies also used MCDM models by considering fuzzy logic. For instance, Wang *et al.* [44] tried to select the best renewable energy sources for Pakistan. For this purpose, SWOT-based criteria are weighted by considering fuzzy AHP methodology. Moreover, Alkan and Albayrak [45] aimed to rank renewable energy sources for different regions of Turkey. Within this framework, the criteria are weighted with fuzzy Entropy method. Additionally, fuzzy COPRAS and fuzzy MULTIMOORA methods are considered to rank different alternatives. Additionally, Rani *et al.* [46] evaluated renewable energy technologies in India with the help of the fuzzy VIKOR methodology. Similarly, Wu *et al.* [47] aimed to optimize the portfolio for renewable energy investment projects. In this context, 16 subordinated criteria are identified and interval type-2 fuzzy AHP approach is taken into consideration to find the significance weights of these factors. Furthermore, Dinçer and Yüksel [48] focused on the evaluation of global investments on the renewable energy. For this purpose, fuzzy DEMATEL and fuzzy TOPISIS approaches are considered in a hybrid way in the analysis process.

C. NEW MCDM APPROACHES

There are also some new MCDM approaches in the literature. These methods can also be considered for the future studies of the renewable energy projects. For instance, the best-worst method (BWM) can be considered for weighting the indicators [49]. In addition to this methodology, simultaneous evaluation of criteria and alternatives (SECA) technique can also be used for this purpose [50]. Moreover, evaluation based on distance from average solution (EDAS) is another methodology which can also be used in this respect [51]–[53]. Furthermore, grey relational projection (GRP) can be preferred to rank different alternatives [54]. TODIM and CODAS methods can also be considered for this purpose [55]–[57].

D. THE RESULTS OF LITERATURE REVIEW

As a result of the literature review, it is possible to reach some results. First of all, there are many studies in the literature on renewable energy. Renewable energy investments are vital for countries' energy independence. In addition, since there is no carbon emission in these energy types, environmental pollution is significantly reduced. In this context, studies to be carried out to increase renewable energy investments are very important for the sustainable energy policies of countries. Furthermore, it was seen that MCDM models were used in some of the studies dealing with renewable energy. Especially in recent years, uncertainty in decision-making processes for too many criteria has increased. This situation made an effective decision-making process even more difficult. Therefore, there is an increasing need for more comprehensive analysis methods for this process. In other words, considering MCDM methods comprehensively with different fuzzy numbers may contribute to increasing the efficiency in this process. In this study, a novel model is proposed which has three different stages. The first stage is related to the calculation of the incomplete preferences of the relation matrixes. For this purpose, selected criteria are evaluated by 4 different experts. In this framework, missing values are estimated to complete the relation matrixes by considering the linguistic preferences. The second stage focuses on the computing the fuzzy preferences by considering the CGDM. Moreover, in the final stage, the criteria are evaluated. Hence, with this original methodology, it is thought that this study makes a contribution to the literature of renewable energy investments.

III. METHODOLOGY

This section gives information about the details of the methods used in the analysis process of this study. Within this context, firstly, incomplete preferences in decision making are explained. After that, necessary information is given regarding the CGDM. Next, Pythagorean fuzzy sets are identified. Later, DEMATEL methodology is indicated.

A. INCOMPLETE PREFERENCES IN DECISION MAKING

Preference relation is presented by a $n \times n$ matrix, $P = \left(p_{ij}\right)$, $p_{ij} = \left(x_i, x_j\right)$, $\forall i, j \in \{1, \ldots, n\}$, and $p_{ij} \in S$. $S = \left\{S_0, S_1, \ldots, S_{g-1}, S_g\right\}$ and S defines the linguistic term set and g is the number of the linguistic preferences. The term of incomplete preferences defines the missing information of the experts about the preference p_{ij}. The experts with the incomplete preferences cannot provide the relevant assessment for the criteria and they do not prefer to assign the linguistic priorities for x_i over x_j [8]. Especially, when the expert team including the different experience and educational background is appointed in the decision-making process, some of experts could not define the complete evaluations in the relation matrix [9], [10]. So, incomplete preferences could be raised once the decision makers hesitate to provide the linguistic preferences [58], [59]. Estimation of linguistic preference ep_{ik} $(i \neq k)$ is presented by using the equations (1)-(4).

$$(ep_{ik})^{j1} = \Delta\left(\Delta^{-1}(p_{ij}) + \Delta^{-1}(p_{jk}) - \Delta^{-1}(S_{g/2})\right) \quad (1)$$

$$(ep_{ik})^{j2} = \Delta\left(\Delta^{-1}(p_{jk}) - \Delta^{-1}(p_{ji}) + \Delta^{-1}(S_{g/2})\right) \quad (2)$$

$$(ep_{ik})^{j3} = \Delta\left(\Delta^{-1}(p_{ij}) + \Delta^{-1}(p_{kj}) - \Delta^{-1}(S_{g/2})\right) \quad (3)$$

$$ep_{ik} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}\left(ep_{ik}^{1}\right) + \Delta^{-1}\left(ep_{ik}^{2}\right) + \Delta^{-1}\left(ep_{ik}^{3}\right)\right)\right) \quad (4)$$

B. CGDM

The decision-making process has some difficulties. For instance, the consistency between the decision makers cannot be provided in each condition. Therefore, reaching consensus is necessary to reach optimal decisions [14]. The advantage of this technique is that feedback mechanism can be implemented. It is possible to mention some procedures for the CGDM. A fuzzy preference relation (P) indicates the relation degrees of the items with the help of a membership function $\mu_p : X \times X \rightarrow [0, 1]$. Equation (5) demonstrates the preference matrix [60].

$$P = (P_{ik}) \text{ and } P_{ik} = \mu_p(x_i, x_k), \quad (\forall i, k \in \{1, \ldots, n\}) \quad (5)$$

After that, the corresponding fuzzy preferences between the criteria are calculated. By considering these values, the consistency levels of the criteria can be determined as in the equation (6) [15].

$$CP_{ik} = \frac{\sum_{j=1; i\neq k\neq j}^{n} (CP_{ik})^{j1} + \ldots + (CP_{ik})^{j(n-1)}}{(n-1) * (n-2)} \quad (6)$$

Consistency level can be identified with corresponding fuzzy preferences. The details are shown in the equations (7) and (8) [61].

$$CL_{ik} = 1 - \left(\frac{2 * |CP_{ik} - P_{ik}|}{(n-1)}\right) \quad (7)$$

$$CL_i = \frac{\sum_{k=1; i\neq k}^{n} (CL_{ik} + CL_{ki})}{2(n-1)} \quad (8)$$

Global consistency level (GCL) is defined with formula (9) [15].

$$GCL = \frac{\sum_{i=1}^{n} CL_i}{n} \quad (9)$$

Moreover, collective results and similarity matrixes are identified by considering equations (10) and (11), respectively, [16].

$$SM_{ik}^{hl} = 1 - \left|P_{ik}^{h} - P_{ik}^{l}\right| \quad (10)$$

$$SM_{ik} = \phi\left(SM_{ik}^{hl}\right) \quad (11)$$

In this equation, ϕ represents the aggregation function. Additionally, e_h and e_l give information about decision-makers, $(h < l)$, $\forall h, l = 1, \ldots, m$. Furthermore, global consensus degrees can be identified by considering the equation (12) [62].

$$CR = \frac{\sum_{i=1}^{n} \frac{\sum_{k=1; k\neq i}^{n} (SM_{ik} + SM_{ki})}{2(n-1)}}{n} \quad (12)$$

The consensual degrees are identified by equation (13) [60].

$$Z_{ik}^{h} = (1-\delta) * CL_{ik}^{h} + \delta * \left(\frac{\sum_{l=h+1}^{n} SM_{ik}^{hl} + \sum_{l=1}^{h-1} SM_{ik}^{lh}}{n-1}\right) \quad (13)$$

In this process, δ represents the control parameter. Within this framework, it is defined as 0.75 in this study. Collective fuzzy preference relations P_{ik}^{c} are constructed with the help of the equations (14)-(16) [14]. Within this framework, σ demonstrates a permutation of $\{1, \ldots, m\}$, $Z_{ik}^{\sigma(h)} \geq Z_{ik}^{\sigma(h+1)}$, $\forall h = 1, \ldots, m-1$. Moreover, $\langle Z_{ik}^{\sigma(h)}, P_{\sigma(i)}\rangle$ shows two-tuple with $Z_{ik}^{\sigma(h)}$ the hth largest value in $\left\{Z_{ik}^{1}, \ldots, Z_{ik}^{m}\right\}$.

$$P_{ik}^{c} = \Phi w\left(\langle Z_{ik}^{1}, P_{ik}^{1}\rangle, \ldots, \langle Z_{ik}^{m}, P_{ik}^{m}\rangle\right) = \sum_{h=1}^{m} w_h * P_{ik}^{\sigma(h)} \quad (14)$$

$$w_h = Q(h/n) - Q(h-1)/n) \quad (15)$$

$$(r) = \begin{cases} 0 & \text{if } r < a \\ \dfrac{r-a}{b-a} & \text{if } a \leq r \leq b \\ 1 & \text{if } r > a \end{cases} \quad (16)$$

Additionally, proximity levels PP_{ik}^{h} and the relation between criteria Pr^{h} can be calculated as in the equation (17) and (18), respectively, [15].

$$PP_{ik}^{h} = 1 - \left|P_{ik}^{h} - P_{ik}^{c}\right| \quad (17)$$

$$Pr^{h} = \frac{\sum_{i=1}^{n} \frac{\sum_{k=1; k\neq i}^{n} (PP_{ik}^{h} + PP_{ki}^{h})}{2(n-1)}}{n} \quad (18)$$

Consensus control level (CCL) can be calculated to see the level of the consensus. The details of this process are identified in the equation (19) [61].

$$CCL = (1-\delta) * GCL + \delta * CR \quad (19)$$

The final consensus result should be compared with a threshold value $\gamma \in [0.1]$. Within this context, threshold value is usually considered as 0.85 regarding consensus satisfaction. On the other side, the feedback mechanism is also used for the revised values of fuzzy preference relation. This procedure is repeated in many rounds while changing the preference relations. For this purpose, the directions of feedback mechanism are taken into account. In this scope, the values of EXPCH, ALT, and APS can be computed with the help of the equations (20)–(22) [16].

$$EXPCH = \left\{ h \middle| (1-\delta) * CL^h + \delta * Pr^h < \gamma \right\} \tag{20}$$

$$LT = \left\{ (h, i) \middle| e_h \in EXPCH \wedge (1-\delta) * CL_i^h + \delta * \frac{\sum_{k=1;k\neq i}^{n} (PP_{ik}^h + PP_{ki}^h)}{2(n-1)} < \gamma \right\} \tag{21}$$

$$APS = \left\{ (h, i, k) \middle| (h, i) \in ALT \wedge (1-\delta) * CL_{ik}^h + \delta * PP_{ik}^h < \gamma \right\} \tag{22}$$

C. PYTHAGOREAN FUZZY SETS

Yager [17] introduced Pythagorean fuzzy sets. In this context, they are considered as a set of pairs over a universal set ϑ. Equation (23) gives details about this process [17].

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta) \rangle / \vartheta \epsilon U\} \tag{23}$$

In this equation, μ_P and n_P: $U \rightarrow [0, 1]$ represent the membership and non-membership of the item $\vartheta \epsilon U$. These factors are defined in the equation (24) [63].

$$(\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{24}$$

On the other side, the degree of indeterminacy is also explained in the equation (25) [18].

$$\pi_P(\vartheta) = \sqrt{1 - (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2} \tag{25}$$

Moreover, the equations (26)-(30) give information about the essential operations of Pythagorean fuzzy sets [64].

$$P_1 = \left\{ \langle \vartheta, P_1(\mu_{P_1}(\vartheta), n_{P_1}(\vartheta)) \rangle / \vartheta \epsilon U \right\} \text{ and } P_2 = \left\{ \langle \vartheta, P_2(\mu_{P_2}(\vartheta), n_{P_2}(\vartheta)) \rangle / \vartheta \epsilon U \right\} \tag{26}$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^1 + \mu_{P_2}^2 - \mu_{P_1}^1 \mu_2^2}, n_{P_1} n_{P_1} \right) \tag{27}$$

$$P_1 \otimes P_2 = P\left(\mu_{P_1} \mu_{P_2}, \sqrt{n_{P_1}^2 + n_{P_2}^2 - n_{P_1}^2 n_{P_2}^2} \right) \tag{28}$$

$$\lambda P = P\left(\sqrt{1 - \left(1 - \mu_p^2\right)^\lambda}, (n_p)^\lambda \right), \quad \lambda > 0 \tag{29}$$

$$P^\lambda = P\left((\mu_p)^\lambda, \sqrt{1 - \left(1 - n_p^2\right)^\lambda} \right), \quad \lambda > 0 \tag{30}$$

In addition, Figure 1 illustrates the relationship between the intuitionistic and Pythagorean fuzzy sets (IFS and PFS) [19].

Finally, the deffuzzified values are computed. Within this context, score function in the equation (31) is taken into consideration [65]

$$S(\vartheta) = (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2 \text{ where } S(\vartheta) \in [-1, 1] \tag{31}$$

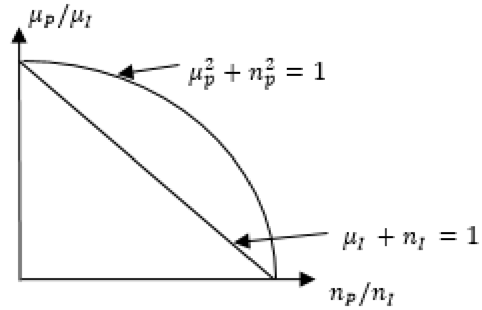

FIGURE 1. Membership and Non-membership degrees of IFS and PFS.

D. DEMATEL

DEMATEL is a MCDM method used to weight different factors regarding their importance. This approach has some benefits by comparing with similar methods. For example, it provides an opportunity to define causal relationship between the criteria [20]. Decision makers make evaluations for the significance of the criteria. By considering these evaluations, the direct relation matrix (A) can be generated. This matrix is demonstrated in the equation (32) [21].

$$A = \begin{bmatrix} 0 & a_{12} & a_{13} & & \cdots & a_{1n} \\ a_{21} & 0 & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & 0 & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & 0 \end{bmatrix} \tag{32}$$

In this equation, a_{ij} represents the influence of criterion i on the criterion j. In the next step, this matrix is normalized by using the equations (33) and (34) [22].

$$B = \frac{A}{max_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}} \tag{33}$$

$$0 \leq b_{ij} \leq 1 \tag{34}$$

In this framework, B demonstrates normalized matrix and b_{ij} represents the elements in this matrix. After that, total relation matrix (C) is generated with the help of the equation (35) [66].

$$C = B(I - B)^{-1} \tag{35}$$

In this equation, I gives information about the identity matrix. Moreover, the sums of rows and columns (D and E) are computed. For this purpose, the equations (36) and (37) are considered [67].

$$D = \left[\sum_{j=1}^{n} e_{ij} \right]_{nx1} \tag{36}$$

$$E = \left[\sum_{i=1}^{n} e_{ij} \right]_{1xn} \tag{37}$$

In this respect, D-E is taken into consideration to understand the causal relationship. Moreover, the value of D+E is used to calculate the weights of the criteria [68]. On the other hand, with respect to the generation of the impact relation

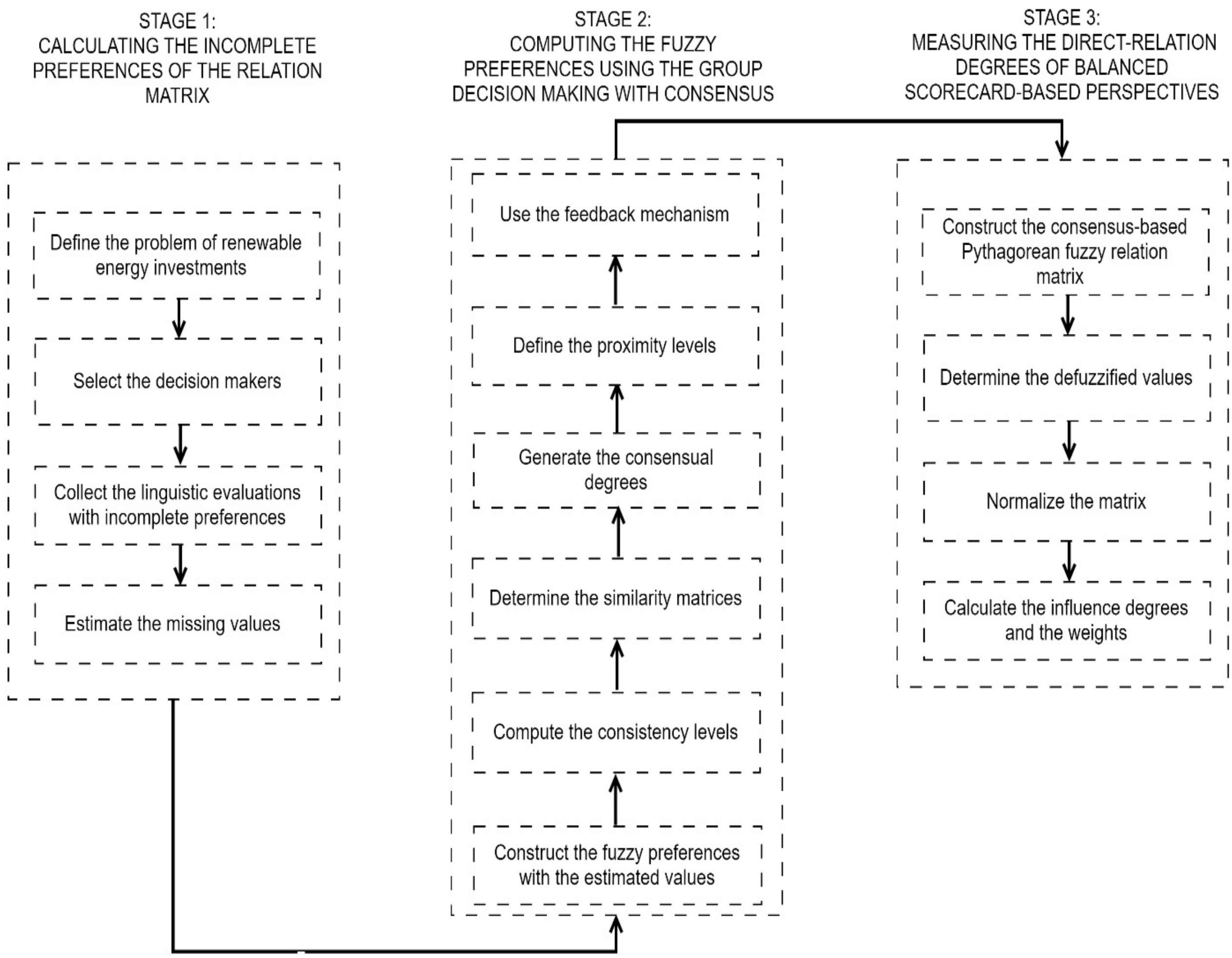

FIGURE 2. A flowchart of the integrated model.

map, threshold value (α) in the equation (38) is taken into account [69].

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij}\right]}{N} \tag{38}$$

E. PROPOSED MODEL

The details of this model are illustrated in Figure 2.

Figure 2 demonstrates that this new model has 3 different stages. The first stage is related to the calculation of the incomplete preferences of the relation matrixes. Within this context, balanced scorecard-based criteria are defined in the first step. After that, 4 different decision makers evaluate these criteria. Next, the linguistic preferences are collected. In the final step, missing values are estimated to complete the relation matrixes. On the other side, the second stage includes the computing the fuzzy preferences by considering the CGDM. Additionally, the third stage focuses on the measurement of the direct-relation degrees of balanced scorecard-based perspectives.

It is possible to mention some novelties of this proposed model. First of all, the missing values of the evaluations are completed by using incomplete preferences in decision making. In decision-making process, the experts are selected among the people who have necessary qualifications about the subject [8]. However, there can be lots of criteria affecting this subject and some experts may not have enough information to evaluate some of these factors [9]. In this regard, the experts may prefer not to give assessment to give opinions for the relationship between some criteria. Hence, there can be missing information in the evaluation matrix. Therefore, the main advantage of using incomplete preferences in decision making process is completing this missing information [10]. Another novelty of this proposed model is that CGDM methodology is applied. Different experts may not have the same opinions about the relationship between the criteria [14]. Thus, it can be possible to reach more effective and appropriate results [15], [16]. Moreover, considering Pythagorean fuzzy sets in the evaluation process also provides some advantages. For instance, these sets provide a better representation of uncertainty by comparing with other sets [17], [18]. Hence, it is obvious that the uncertain and imprecise information can be handled more effectively by considering these fuzzy sets [19]. Finally, using DEMATEL

TABLE 1. Balanced scorecard-based factors of renewable energy investments.

Factors	Supported Literature
Learning and Growth (F1)	[36],[37]
Customer (F2)	[31],[32]
Internal Process (F3)	[27],[28]
Financial (F4)	[24],[25]

TABLE 2. The details of decision makers (DM).

DMs	Industry	Experience	Position	Education
DM 1	Construction	22 years	Chairman of the Board	Civil Engineering
DM 2	Service	18 years	Founder	Economics and Business Administration
DM 3	Manufacturing	20 years	Chairman of the Board	Economics
DM 4	Manufacturing	19 years	Senior Vice Present	Industrial Engineering

TABLE 3. Linguistic scales and fuzzy preference numbers.

Linguistic Scales	Preference Numbers	Fuzzy Preferences
No influence (n)	0	0
weak influence (w)	1	.10
somewhat influence (s)	2	.30
medium influence (m)	3	.50
high influence (h)	4	.70
very high influence (vh)	5	.90
Extremely influence (e)	6	1

TABLE 4. Linguistic evaluations of decision makers for the perspectives.

DM1					DM2				
DM1	F1	F2	F3	F4	DM2	F1	F2	F3	F4
F1	-	n/a	M	VH	F1	-	H	M	VH
F2	n/a	-	n/a	H	F2	M	-	S	H
F3	M	n/a	-	S	F3	H	M	-	H
F4	H	S	H	-	F4	S	M	H	-
DM3					DM4				
DM3	F1	F2	F3	F4	DM4	F1	F2	F3	F4
F1	-	M	H	H	F1	-	n/a	M	H
F2	H	-	S	H	F2	n/a	-	M	VH
F3	M	n/a	-	M	F3	M	M	-	VH
F4	n/a	M	VH	-	F4	H	M	H	-

approach in the calculation process has also some advantages because this method has some superiorities by comparing with other techniques [20]. For example, causality relationship between the criteria can also be identified with DEMATEL methodology owing to the creation of the impact relation map [21], [22].

IV. ANALYSIS RESULTS

The proposed model includes three different stages. The incomplete preferences of the relation matrixes are computed in the first stage. Secondly, the fuzzy preferences are calculated using the CGDM. Thirdly, the direct-relation degrees

TABLE 5. Linguistic evaluations with the estimated values for the perspectives.

DM1					DM2				
DM1	F1	F2	F3	F4	DM2	F1	F2	F3	F4
F1	-	W	M	VH	F1	-	H	M	VH
F2	VH	-	VH	H	F2	M	-	S	H
F3	M	W	-	S	F3	H	M	-	H
F4	H	S	H	-	F4	S	M	H	-
DM3					DM4				
DM3	F1	F2	F3	F4	DM4	F1	F2	F3	F4
F1	-	M	H	H	F1	-	M	M	H
F2	H	-	S	H	F2	M	-	M	VH
F3	M	S	-	M	F3	M	M	-	VH
F4	H	M	VH	-	F4	H	M	H	-

TABLE 6. Collective similarity matrix.

SM	P1	P2	P3	P4
P1		0.70	0.90	0.80
P2	0.80		0.70	0.90
P3	0.90	0.80		0.70
P4	0.80	0.90	0.90	

TABLE 7. Collective fuzzy preference relations.

P^c	F1	F2	F3	F4
F1		0.71	0.91	0.84
F2	0.78		0.68	0.90
F3	0.91	0.79		0.71
F4	0.84	0.89	0.90	

TABLE 8. Fuzzy preference relations for the fifth round.

DM1					DM2				
P^1	F1	F2	F3	F4	P^2	F1	F2	F3	F4
F1	-	.63	.76	.90	F1	-	.70	.79	.90
F2	.90	-	.90	.70	F2	.50	-	.69	.70
F3	.78	.62	-	.65	F3	.70	.82	-	.70
F4	.70	.30	.70	-	F4	.76	.50	.70	-
DM3					DM4				
P^3	F1	F2	F3	F4	P^4	F1	F2	F3	F4
F1	-	.50	.70	.70	F1	-	.50	.82	.70
F2	.70	-	.72	.70	F2	.77	-	.50	.90
F3	.81	.68	-	.50	F3	.84	.50	-	.90
F4	.70	.84	.90	-	F4	.70	.50	.70	-

of balanced scorecard-based perspectives are measured. The details are given in the following subsections.

A. STAGE 1: COMPUTING THE INCOMPLETE PREFERENCES OF THE RELATION MATRIXES

Step 1: The MCDM problem of renewable energy investments is defined. It is aimed to find strategic priorities to improve the effectiveness of the renewable energy investments. For this purpose, the criteria are defined based on the perspectives of the balanced scorecard. This approach has mainly 4 different dimensions which are learning and growth, customer, internal process, and finance. The main advantage of this methodology is considering both

TABLE 9. Total relation matrix and the influence and weights.

Factors	F1	F2	F3	F4	D	E	D+E	D-E	Weights
F1	4.099	2.702	4.412	4.446	15.659	16.656	32.315	-0.998	0.266
F2	4.400	2.580	4.424	4.473	15.877	10.352	26.229	5.525	0.216
F3	4.317	2.708	4.064	4.310	15.399	16.792	32.191	-1.393	0.265
F4	3.841	2.362	3.893	3.636	13.731	16.866	30.597	-3.135	0.252

TABLE 10. Fuzzy preference relations for the perspectives.

DM1					DM2				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.10	.50	.90	F1	-	.70	.50	.90
F2	.90		.90	.70	F2	.50	-	.30	.80
F3	.50	.10	-	.30	F3	.70	.50	-	.70
F4	.70	.30	.70	-	F4	.30	.50	.70	-
DM3					DM4				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.50	.70	.70	F1	-	.50	.50	.70
F2	.70	-	.30	.70	F2	.50	-	.50	.90
F3	.50	.30	-	.50	F3	.50	.50	-	.90
F4	.70	.50	.90	-	F4	.70	.50	.70	-

TABLE 11. Corresponding fuzzy preference relations.

DM1					DM2				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.30	.70	.30	F1	-	.63	.70	.63
F2	.80	-	.90	.90	F2	.43	-	.53	.60
F3	.40	.10	-	.50	F3	.40	.63	-	.83
F4	.70	.20	.60	-	F4	.53	.50	.23	-
DM3					DM4				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.53	.60	.53	F1	-	.47	.53	.73
F2	.53	-	.83	.50	F2	.67	-	.63	.63
F3	.50	.33	-	.53	F3	.63	.53	-	.67
F4	.63	.60	.53	-	F4	.43	.53	.47	-

TABLE 12. Consistency levels of decision makers.

DM1 (CL^1:.90)					DM2 (CL^2:.88)				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.87	.87	.60	F1	-	.96	.87	.82
F2	.93	-	1.00	.87	F2	.96	-	.84	.93
F3	.93	1.00	-	.87	F3	.80	.91	-	.91
F4	1.00	.93	.93	-	F4	.84	1.00	.69	-
DM3 (CL^3:.90)					DM4 (CL^4:.91)				
	F1	F2	F3	F4		F1	F2	F3	F4
F1	-	.98	.93	.89	F1	-	.98	.98	.98
F2	.89	-	.64	.87	F2	.89	-	.91	.82
F3	1.00	.98	-	.98	F3	.91	.98	-	.84
F4	.96	.93	.76	-	F4	.82	.98	.84	-

financial and nonfinancial issues in the analysis process. Table 1 gives information about the balanced scorecard-based factors to improve the performance of renewable energy investments.

Learning and growth is the first perspective which focuses on the technological innovation for the progressive energy projects. Renewable energy projects have high initial cost that is accepted as a significant barrier for the development of these projects. Hence, learning and growth refers to the considering technological improvements in this area to manage this cost problem much easily. The second perspective identifies the ways to increase customer satisfaction. For this purpose, the customer feedback should be considered for designing the renewable energy products. In addition to this issue, customer expectations should also be taken into account to increase the retention of the customers. Moreover, internal process is the third perspective which focuses on providing the organizational competency in the new service development for the renewable energies. Because renewable energy investments are long-term and complex projects, the

TABLE 13. Similarity matrixes for pairs of decision makers.

DM1-DM3					DM1-DM4				
SM^{13}	F1	F2	F3	F4	SM^{14}	F1	F2	F3	F4
F1		.60	.80	.80	F1		.60	1.00	.80
F2	.80		.40	1.00	F2	.60		.60	.80
F3	1.00	.80		.80	F3	1.00	.60		.40
F4	1.00	.80	.80		F4	1.00	.80	1.00	
DM2-DM3					DM2-DM4				
SM^{23}	F1	F2	F3	F4	SM^{24}	F1	F2	F3	F4
F1		.80	.80	.80	F1		1.00	1.00	.80
F2	.80		1.00	1.00	F2	1.00		.80	.80
F3	.80	.80		.80	F3	.80	1.00		.80
F4	.60	1.00	.80		F4	.60	1.00	1.00	

TABLE 14. Consensual fuzzy preference degrees of decision makers.

DM1					DM2				
Z^1	F1	F2	F3	F4	Z^2	F1	F2	F3	F4
F1		.62	.92	.80	F1		.74	.92	.86
F2	.73		.60	.92	F2	.84		.76	.93
F3	.93	.75		.67	F3	.80	.83		.78
F4	.90	.83	.93		F4	.66	.95	.87	
DM3					DM4				
Z^3	F1	F2	F3	F4	Z^4	F1	F2	F3	F4
F1		.84	.83	.87	F1		.84	.94	.89
F2	.82		.71	.92	F2	.82		.78	.81
F3	.95	.84		.79	F3	.93	.84		.66
F4	.89	.93	.79		F4	.86	.94	.91	

TABLE 15. Proximity levels of decision makers.

DM1 (Pr^1: 0.66)					DM2 (Pr^2: 0.75)				
PP^1	F1	F2	F3	F4	PP^2	F1	F2	F3	F4
F1		.39	.59	.94	F1		.99	.59	.94
F2	.88		.78	.80	F2	.72		.62	.80
F3	.59	.31		.59	F3	.79	.71		.99
F4	.86	.41	.80		F4	.46	.61	.80	
DM3 (Pr^3: 0.76)					DM4 (Pr^4: 0.76)				
PP^3	F1	F2	F3	F4	PP^4	F1	F2	F3	F4
F1		.79	.79	.86	F1		.79	.59	.86
F2	.92		.62	.80	F2	.72		.82	1.00
F3	.59	.51		.79	F3	.59	.71		.81
F4	.86	.61	1.00		F4	.86	.61	.80	

coherency between the departments of the company plays a crucial role. Finally, financial factors should also be taken into consideration. In this respect, the return on renewable energy investments should be calculated. In this process, financial evaluation of the projects should be conducted in a detailed manner so that liquidity and market risks can be handled more effectively. This situation makes an essential contribution to the profitability of the investments.

Step 2: The expert team is generated. For this purpose, 4 different decision makers evaluate the criteria. The details of these people are indicated on Table 2.

Table 2 gives information that all 4 different decision makers have necessary qualifications to evaluate the factors regarding renewable energy investments. In the literature, there are lots of studies regarding the fuzzy MCDM models. In most of these studies, 3 or 4 different experts were taken into consideration [70]–[75]. Hence, considering the opinions of 4 different experts is appropriate to make evaluations with fuzzy MCDM models.

Step 3: The linguistic preferences for the criteria are collected from the decision makers. For this purpose, the linguistic scales and fuzzy preference numbers are taken into consideration. The details of them are demonstrated on Table 3.

On the other side, the details of the evaluations of the decision makers are given on Table 4.

In this table, n/a demonstrates that the decision makers do not provide opinions about the relationship of these perspectives.

Step 4: The missing values for completing the relation matrixes are estimated. For this purpose, iteration technique is taken into consideration. With respect to DM1, ep_{23}, ep_{32}, ep_{12} and ep_{21} are the missing values. Equations (39)-(46) gives information about the iteration 1 (ep_{23} and ep_{32}).

$$(ep_{23})^{41} = \Delta\left(\Delta^{-1}(p_{24}) + \Delta^{-1}(p_{43}) - \Delta^{-1}(S_3)\right) = 5\,(\text{VH}) \tag{39}$$

$$(ep_{23})^{42} = \Delta\left(\Delta^{-1}(p_{43}) - \Delta^{-1}(p_{42}) + \Delta^{-1}(S_3)\right) = 5\,(\text{VH}) \tag{40}$$

$$(ep_{23})^{43} = \Delta\left(\Delta^{-1}(p_{24}) + \Delta^{-1}(p_{34}) - \Delta^{-1}(S_3)\right) = 5\,(\text{VH}) \tag{41}$$

$$ep_{23} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}\left(ep_{23}^{1}\right) + \Delta^{-1}\left(ep_{23}^{2}\right) + \Delta^{-1}\left(ep_{23}^{3}\right)\right)\right) = 5\,(\text{VH}) \tag{42}$$

$$(ep_{32})^{41} = \Delta\left(\Delta^{-1}(p_{34}) + \Delta^{-1}(p_{42}) - \Delta^{-1}(S_3)\right) = 1(\text{W}) \tag{43}$$

$$(ep_{32})^{42} = \Delta\left(\Delta^{-1}(p_{42}) - \Delta^{-1}(p_{43}) + \Delta^{-1}(S_3)\right) = 1(\text{W}) \tag{44}$$

$$(ep_{32})^{43} = \Delta\left(\Delta^{-1}(p_{34}) + \Delta^{-1}(p_{24}) - \Delta^{-1}(S_3)\right) = 1(\text{W}) \tag{45}$$

$$ep_{32} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}\left(ep_{32}^{1}\right) + \Delta^{-1}\left(ep_{32}^{2}\right) + \Delta^{-1}\left(ep_{32}^{3}\right)\right)\right) = 1\,(\text{W}) \tag{46}$$

TABLE 16. Fuzzy preference relations for the second round.

DM1					DM2				
P^1	F1	F2	F3	F4	P^2	F1	F2	F3	F4
F1	-	.10	.50	.90	F1	-	.70	.50	.90
F2	.90	-	.90	.70	F2	.50	-	.30	.70
F3	.78	.62	-	.65	F3	.70	.50	-	.70
F4	.70	.30	.70	-	F4	.30	.50	.70	-
DM3					DM4				
P^3	F1	F2	F3	F4	P^4	F1	F2	F3	F4
F1	-	.50	.70	.70	F1	-	.50	.82	.70
F2	.70	-	.72	.70	F2	.50	-	.50	.90
F3	.81	.68	-	.50	F3	.84	.50	-	.90
F4	.70	.50	.90	-	F4	.70	.50	.70	-

TABLE 17. Fuzzy preference relations for the third round.

DM1					DM2				
P^1	F1	F2	F3	F4	P^2	F1	F2	F3	F4
F1	-	.10	.50	.90	F1	-	.70	.50	.90
F2	.90	-	.90	.70	F2	.50	-	.30	.70
F3	.78	.62	-	.65	F3	.70	.82	-	.70
F4	.70	.30	.70	-	F4	.30	.50	.70	-
DM3					DM4				
P^3	F1	F2	F3	F4	P^4	F1	F2	F3	F4
F1	-	.50	.70	.70	F1	-	.50	.82	.70
F2	.70	-	.72	.70	F2	.50	-	.50	.90
F3	.81	.68	-	.50	F3	.84	.50	-	.90
F4	.70	.84	.90	-	F4	.70	.50	.70	-

TABLE 18. Fuzzy preference relations for the fourth round.

DM1					DM2				
P^1	F1	F2	F3	F4	P^2	F1	F2	F3	F4
F1	-	.10	.50	.90	F1	-	.70	.79	.90
F2	.90	-	.90	.70	F2	.50	-	.30	.70
F3	.78	.62	-	.65	F3	.70	.82	-	.70
F4	.70	.30	.70	-	F4	.76	.50	.70	-
DM3					DM4				
P^3	F1	F2	F3	F4	P^4	F1	F2	F3	F4
F1	-	.50	.70	.70	F1	-	.50	.82	.70
F2	.70	-	.72	.70	F2	.50	-	.50	.90
F3	.81	.68	-	.50	F3	.84	.50	-	.90
F4	.70	.84	.90	-	F4	.70	.50	.70	-

On the other side, the equations (47)-(54) give information about the second iteration (ep_{12} and ep_{21}).

$$(ep_{12})^{31} = \Delta\left(\Delta^{-1}(p_{13}) + \Delta^{-1}(p_{32}) - \Delta^{-1}(S_3)\right) = 1\,(\mathrm{W}) \tag{47}$$

$$(ep_{12})^{32} = \Delta\left(\Delta^{-1}(p_{32}) - \Delta^{-1}(p_{31}) + \Delta^{-1}(S_3)\right) = 1\,(\mathrm{W}) \tag{48}$$

$$(ep_{12})^{33} = \Delta\left(\Delta^{-1}(p_{13}) + \Delta^{-1}(p_{23}) - \Delta^{-1}(S_3)\right) = 1\,(\mathrm{W}) \tag{49}$$

$$ep_{12} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}\left(ep_{12}^{1}\right) + \Delta^{-1}\left(ep_{12}^{2}\right) + \Delta^{-1}\left(ep_{12}^{3}\right)\right)\right) = 1\,(\mathrm{W}) \tag{50}$$

$$(ep_{21})^{31} = \Delta\left(\Delta^{-1}(p_{23}) + \Delta^{-1}(p_{31}) - \Delta^{-1}(S_3)\right) = 5\,(\mathrm{VH}) \tag{51}$$

$$(ep_{21})^{32} = \Delta\left(\Delta^{-1}(p_{31}) - \Delta^{-1}(p_{32}) + \Delta^{-1}(S_3)\right) = 5\,(\mathrm{VH}) \tag{52}$$

$$(ep_{21})^{33} = \Delta\left(\Delta^{-1}(p_{23}) + \Delta^{-1}(p_{13}) - \Delta^{-1}(S_3)\right) = 5\,(\mathrm{VH}) \tag{53}$$

$$ep_{21} = \Delta\left(\frac{1}{3}\left(\Delta^{-1}\left(ep_{21}^{1}\right) + \Delta^{-1}\left(ep_{21}^{2}\right) + \Delta^{-1}\left(ep_{21}^{3}\right)\right)\right) = 5\,(\mathrm{VH}) \tag{54}$$

Furthermore, it can be seen that there is no missing value for the DM2. However, ep_{32} and ep_{41} are missing for the DM3.

The iteration for DM is indicated in the equations (55)-(62).

$$\left(ep_{32}\right)^{41} = 3\,(\mathrm{M}) \tag{55}$$
$$\left(ep_{32}\right)^{42} = 1(\mathrm{W}) \tag{56}$$
$$\left(ep_{32}\right)^{43} = 2(\mathrm{S}) \tag{57}$$
$$ep_{32} = 2(\mathrm{S}) \tag{58}$$
$$\left(ep_{41}\right)^{31} = 5(\mathrm{VH}) \tag{59}$$
$$\left(ep_{41}\right)^{32} = 3(\mathrm{M}) \tag{60}$$
$$\left(ep_{41}\right)^{33} = 4(\mathrm{H}) \tag{61}$$
$$ep_{41} = 4(\mathrm{H}) \tag{62}$$

Moreover, as for DM4, ep_{12} and ep_{21} are missing. In this regard, the equations (63)-(70) are considered for the iteration.

$$\left(ep_{12}\right)^{31} = 3(\mathrm{M}) \tag{63}$$
$$\left(ep_{12}\right)^{32} = 3(\mathrm{M}) \tag{64}$$
$$\left(ep_{12}\right)^{33} = 3(\mathrm{M}) \tag{65}$$
$$ep_{12} = 3(\mathrm{M}) \tag{66}$$
$$\left(ep_{21}\right)^{31} = 3(\mathrm{M}) \tag{67}$$
$$\left(ep_{21}\right)^{32} = 3(\mathrm{M}) \tag{68}$$
$$\left(ep_{21}\right)^{33} = 3(\mathrm{M}) \tag{69}$$
$$ep_{21} = 3(\mathrm{M}) \tag{70}$$

Finally, the linguistic evaluations with the estimated values for the perspectives are demonstrated on Table 5.

B. STAGE 2: COMPUTING THE FUZZY PREFERENCES USING THE CGDM

Step 1: The fuzzy preferences and corresponding fuzzy preferences for the factors are constructed. The details are shown in the appendix part (Tables 10-11).

Step 2: The consistency levels are identified. The details are given on Table 12.

Step 3: The similarity matrixes are generated as in Table 13. On the other side, collective similarity matrix is generated and detailed in Table 6.

Step 4: The consensual degrees are generated. Within this context, the global consensus (CR) is accepted as 0.82. These values are demonstrated in Table 14. Additionally, the collective fuzzy preference relations are shown in Table 7.

Step 5: The proximity levels are defined. These values are illustrated on Table 15. CCL is 0.84 and it is less than the threshold with the value of 0.85. Therefore, the new rounds are implemented.

Step 6: The feedback mechanism is implemented. In the second round, the value of CCL is calculated as 0.84. Because this value is lower than 0.85, the third round is implemented. In the third round, the value of CCL is computed as 0.82. Because of this situation, the fourth round is also applied. In this process, the CCL value is calculated as 0.84. Since it does not satisfy the requirement, the fifth round is implemented. Furthermore, fuzzy preference relations for the fifth round are indicated in Table 8. Additionally, the results of the second, third and fourth rounds are given in Tables 16–18

In this regard, the value of CCL is found as 0.87. Because this value is greater than 0.85, it can be said that the consensus is provided for the group decision making approach.

TABLE 19. Degrees for the Pythagorean fuzzy sets.

	DM1							
	F1		F2		F3		F4	
	M	ν	M	ν	μ	ν	μ	ν
F1			.57	.22	.68	.16	.81	.10
F2	.81	.10			.81	.10	.63	.19
F3	.70	.15	.56	.22			.59	.21
F4	.63	.19	.27	.37	.63	.19		
	DM2							
	F1		F2		F3		F4	
	M	ν	M	ν	μ	ν	μ	ν
F1			.63	.19	.72	.14	.81	.10
F2	.45	.28			.62	.19	.63	.19
F3	.63	.19	.74	.13			.63	.19
F4	.69	.16	.45	.28	.63	.19		
	DM3							
	F1		F2		F3		F4	
	M	ν	M	ν	μ	ν	μ	ν
F1			.45	.28	.63	.19	.63	.19
F2	.63	.19			.64	.18	.63	.19
F3	.72	.14	.61	.19			.45	.28
F4	.63	.19	.75	.12	.81	.10		
	DM4							
	F1		F2		F3		F4	
	M	ν	μ	ν	μ	ν	μ	ν
F1			.45	.28	.73	.13	.63	.19
F2	.69	.15			.45	.28	.81	.10
F3	.75	.12	.45	.28			.81	.10
F4	.63	.19	.45	.28	.63	.19		

C. STAGE 3: MEASUREMENT OF THE DIRECT-RELATION DEGREES OF BALANCED SCORECARD-BASED PERSPECTIVES

Step 1: The consensus-based Pythagorean fuzzy relation matrix is constructed. Table 19 explains the degrees for the Pythagorean fuzzy sets.

Step 2: The defuzzied values of matrix is determined as in Table 20.

Step 3: The direct relation matrix is normalized. This new matrix is demonstrated in Table 21.

Step 4: The influence degrees and the weights are calculated. The analysis results are shown in Table 9.

Table 9 states that the learning and growth is the most significant balanced scorecard-based perspective to improve the effectiveness of renewable energy investments. Similarly, it is also concluded that the perspective of internal process plays a critical role in this respect. On the other hand, financial issues and customer perspective have lower weights by comparing with others. Additionally, it is also identified that customer is the most influencing perspective whereas finance is the most influenced one.

TABLE 20. Defuzified relation matrix.

Factors	F1	F2	F3	F4
F1	.000	.218	.453	.499
F2	.386	.000	.363	.429
F3	.472	.305	.000	.348
F4	.383	.163	.429	.000

TABLE 21. Normalized relation matrix.

Factors	F1	F2	F3	F4
F1	.000	.185	.384	.423
F2	.327	.000	.308	.364
F3	.401	.259	.000	.295
F4	.325	.139	.364	.000

V. LIMITATIONS AND IMPLICATIONS

The results of this study demonstrate that learning and growth is the most significant balanced scorecard perspective for the improvement of the renewable energy investment projects. The biggest disadvantage of renewable energy projects is their high initial costs. This situation reduces the profitability of investments. Therefore, investors may be reluctant to invest in these projects. Technological developments reduce the production costs of renewable energy sources. In addition, thanks to the developing technology, the amount of electricity that can be produced from renewable energy sources will increase. This issue contributes to the increase of energy efficiency. Another disadvantage of renewable energy investments is that they cannot provide uninterrupted energy. For example, electricity generation cannot be made with solar energy at certain times of the day. Additionally, depending on the differences in wind blowing speed, the amount of electricity generated from wind energy may not be the same in all cases. In this framework, with the developing technology, it will be possible to store electricity obtained from renewable energy. This will help to obtain uninterrupted electricity from renewable energies.

Most of the researchers in the literature highlighted similar issues in this regard. For instance, Dinçer and Yüksel [76] focused on the effectiveness of the renewable energy investment projects. They evaluated the indicators to provide suggestions to the renewable energy investors. They reached a conclusion that research and development is the most important criterion for this situation. Additionally, Xu *et al.* [77] tried to evaluate the influencing factors of the effectiveness of the renewable energy investment projects. Autoregressive integrated moving average model (ARIMA), neural network model (NNM) and support vector machine model (SVM) are taken into consideration in the analysis process of this study. They determined that companies should have necessary technological background to have high performance in renewable energy investments. Furthermore, Lin and Zhu [78] aimed to identify the determinants of renewable energy technological innovation in China. They suggested that governments should give necessary supports to the research and development investments for the renewable energy projects. Wu *et al.* [37] also focused on the same country and determined that government subsidies for research and development have positive impact on the development of renewable energy investments. These recommendations are of a guiding nature for both companies and researchers. Considering the results obtained, it is vital that companies considering investing in renewable energy projects are technologically competent. It is very difficult for companies that do not have the necessary technological equipment to be successful in this process. On the other hand, it would be appropriate for renewable energy investors to also follow up-to-date technological developments regarding the subject. Thanks to the innovative technologies developed for the subject, it will be possible to reduce the cost of renewable energy investments. Therefore, renewable energy investors who do not follow these innovations will lose a significant competitive advantage.

Owing to these suggestions, it will be possible to increase the renewable energy production in countries. Thus, air pollution will not occur in the process of meeting the energy needs of countries. This situation will help people not to get sick. Hence, labor loss in countries can be reduced. Moreover, with the decrease in the number of sick people, the health expenditures of the countries will decrease [79]. This situation will contribute positively to the budget balance of the countries [80]. In addition, renewable energy projects enable countries to have their own energy resources. This situation reduces the dependence of countries on other countries in terms of energy [81]. The most important limitation of this study is the general handling of renewable energy projects. Therefore, it would be appropriate to consider renewable energy types separately in new studies. As an example, strategies for solar energy investors can be developed. Also, different MCDM methods can be used in the analysis process of the study. This will guide the consistency of the results.

VI. CONCLUSION

In this study, it aimed to propose an extended Pythagorean fuzzy approach to group decision making with incomplete preferences for renewable energy investments based on balanced scorecard. It is concluded that learning and growth is the most important balanced scorecard-based perspective to improve the performance of renewable energy investments. Additionally, the perspective of internal process is found another significant factor for this situation. Nonetheless, customer and financial perspective have lower weights. Moreover, while considering impact relation map, it is determined that customer is the most influencing perspective. On the other side, it is also defined that finance is the most influenced criterion.

APPENDIX

See (Tables 10–21).

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YIZHANG XIE born in Hunan, China, in 1986. He received the B.A. degree from the Hunan University of Science and Engineering in 2011, the master's degree in management from the Central South University of Forestry and Technology in 2015, and the Ph.D. degree in ecological economy and management from Hunan Agricultural University in 2018. He is currently working as a Teacher and Master Supervisor of Hunan Agricultural University. He has published more than 20 academic articles. His main research interests include industrial economics, energy economy, ecological economy, and management.

YE ZHOU born in Heilongjiang, China, in 1997. She received the degree in industrial engineering from Northeast Forestry University, in 2019. She is currently pursuing the master's degree with the Business School, Hunan Agricultural University. Her main research interests include enterprise management, industrial economics, and energy economy.

YUE PENG born in Hunan, China, in 1976. He received the Ph.D. degree in ecological economy and management from Hunan Agricultural University, in 2019. His main research interests include energy economy and sustainable development.

HASAN DİNÇER received the B.A. degree in financial markets and investment management from Marmara University, and the Ph.D. degree in finance and banking with his thesis entitled The Effect of Changes on the Competitive Strategies of New Service Development in the Banking Sector. He has work experience in the finance industry as a Portfolio Specialist. His major academic studies focusing on financial instruments, performance evaluation, and economics. He is the Executive Editor of the *International Journal of Finance and Banking Studies* (IJFBS) and the Founder Member of the Society for the Study of Business and Finance (SSBF). He has about 200 scientific articles and some of them are indexed in SSCI, SCI-Expended, and Scopus. In addition to them, he is also an Editor of many different books published by Springer and IGI Global.

SERHAT YÜKSEL received the B.S. degree in business administration (in English) from Yeditepe University, in 2006, with full scholarship, the master's degree in economics from Boğaziçi University, in 2008, and the Ph.D. degree in banking from Marmara University in 2015. He is currently an Associate Professor of finance with İstanbul Medipol University. Before this position, he worked as a Senior Internal Auditor for seven years in Finansbank, Istanbul-Turkey, and one year in Konya Food and Agriculture University as an Assistant Professor. His research interests include energy economics, banking, finance, and financial crisis. He has more than 140 scientific articles and some of them are indexed in SSCI, SCI, Scopus, and Econlit. Also, he is an Editor of some books that will be published by Springer and IGI Global.

PING AN XIANG born in Hunan, China, in 1972. He received the bachelor's degree from Hunan Agricultural University, in 1994, and the master's and Ph.D. degree, in 1997 and 2004, respectively. In 1998, he studied at the Shanghai Institute of Biochemistry, Chinese Academy of Sciences. He is currently a Professor and a Ph.D. Supervisor of Hunan Agricultural University. His main research interests include ecological economics and energy economy.