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Hesitant Linguistic Term Sets-Based Hybrid Analysis for Renewable Energy Investments

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ABSTRACT The aim of this study is to evaluate different renewable energy investments alternatives. Within this framework, six different criteria are chosen to represent financial and non-financial dimensions. Additionally, five renewable energy investment alternatives (biomass, hydropower, geothermal, wind and solar) are selected. Fuzzy AHP and fuzzy DEMATEL methods are considered to weight these criteria whereas alternatives are ranked by using fuzzy TOPSIS and fuzzy VIKOR approaches. The findings show that fuzzy AHP and fuzzy DEMATEL methods also give coherent results. It is concluded that environmental effects and earnings are the most significant criteria. Moreover, wind and solar are the most attractive renewable energy investment alternatives. Therefore, it is recommended that governmental incentives should be widely used for effective location selection of both energy alternatives. This situation could be also attractive for foreign investors in renewable energy market. In addition, large-scale investments should be handled by merger and acquisition to increase overall performance. Hence, it can be possible to raise earnings, improve capital adequacy and enhance organizational capacity with the extensive investments. Furthermore, easy access to the sources and good contract conditions should also be provided for this purpose so that it can be much easier to attract the attention of these investors. Also, customer expectations should be understood effectively with a detailed analysis. With the help of this issue, appropriate products can be presented according to customer needs and it significantly contributes to the success in renewable energy investment.

INDEX TERMS Hesitant linguistic terms, fuzzy logic, AHP, DEMATEL, TOPSIS, VIKOR, decision making, renewable energy, investment, finance.

I. INTRODUCTION

Energy can be classified mainly into two different categories which are non-renewable and renewable energy. Non-renewable energy sources include coal, oil and natural gas. In order to generate this energy, the sources must be subjected to burning process. Hence, this energy has a very negative impact on the environment. Also, the countries, which do not have these energy resources, have to import this energy from other countries. This situation explains that renewable energy resources play a great role in energy production because they provide a cleaner environment and less dependency on the outside countries [1].

Wind energy is one of the renewable energy sources. It refers to the energy of the air in motion [2]. Another type of renewable energy resources is the solar energy that means the providing heat energy from the solar which contributes electricity production [3]. Hydropower energy is also the renewable energy type in which water power is considered [4]. Geothermal energy is provided from the hot water in the ground and its steam [5]. Biomass energy can be obtained while burning biomass wastes [6].

Another important point is that the renewable energy becomes a very nice alternative for the investors [7], [8]. In this regard, there is a great need to address this issue to understand the hierarchy which consequently help in profitable investments. In order to reach this objective, both financial and nonfinancial factors should be considered. With respect to the financial factors, the items, such as earning, cost and equity play a very crucial role. In addition, nonfinancial issues like technological and environmental effects can affect the investment decisions [9].

In this study, it is aimed to evaluate the most influencing factors of energy investments multidimensionally and

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analyze the alternatives. Therefore, this study gives an insight and may attract the investors for the renewable energy industry. For this purpose, financial and non-financial dimensions are defined. In this context, six different criteria are selected based on literature review. These criteria are weighted by both fuzzy DEMATEL and fuzzy AHP. In addition to this issue, fuzzy VIKOR and fuzzy TOPSIS approaches are considered in order to rank the renewable energy alternatives.

The main novelty of this study is that a comparative evaluation is performed to define the optimal renewable energy investment alternatives under the fuzzy environment. Furthermore, in the literature, there are limited studies compute the criteria weights with fuzzy DEMATEL and fuzzy AHP based on hesitant linguistic term sets. DEMATEL provides not only relative importance among the criteria but also gives information on the impact and relation map between them. On the other side, TOPSIS seeks the closest distance to the ideal solution. For that, hybrid analysis using DEMATEL and TOPSIS could give more coherent results than conventional fuzzy decision-making methods. Furthermore, DEMATEL and AHP as well as TOPSIS and VIKOR are used for the robustness check. Additionally, fuzzy VIKOR and fuzzy TOPSIS methods are firstly used in this study comparatively to identify the best renewable energy investment.

II. LITERATURE REVIEW

A. RENEWABLE ENERGY

Renewable energy is a very popular subject in the literature. In this context, some studies aimed to analyze what affects the development of renewable energy projects. Different regions are taken into consideration in these studies, such as China [10], MENA countries [11] and Germany [12]. In these studies, it is defined that the ability of research and development personnel is a significant factor for this purpose. Additionally, it is also identified that technological development is an important indicator for renewable energy project development [13], [14]. In addition, the relationship between the financial development and renewable energy project development was also underlined by many different researchers. Within this framework, different methodologies were used in these studies like using regression and Kao panel cointegration analysis. It is mainly concluded that well-developed financial market has a positive effect on renewable energy development [15]–[17].

On the other side, some studies focused on the effects of the renewable energy consumption on different factors. In some studies, it is aimed to analyze the relationship between renewable energy consumption and output. According to the results, it is determined that renewable energy consumption has a positive impact on output for high-income countries whereas this relationship is negative for low-income countries [18]. In addition to this issue, it is also underlined that renewable energy consumption contributes to the economic development [19]–[22]. Moreover, another important point related to this subject is the decreasing role of the renewable energy consumption on carbon dioxide emission [23]–[25]. They mainly concluded that non-renewable energy usage is a significant factor which increases carbon dioxide emission. Hence, renewable energy consumption should be encouraged in order to minimize this problem.

Furthermore, some studies tried to understand which factors affect the renewable energy investment decision. In this context, it is concluded that regulatory uncertainty negatively affects the renewable energy investment. Therefore, this uncertainty should be solved by the governments to encourage renewable energy investment [26]. In some other studies, market volatility is accepted as the main factor which affects renewable energy investment decision [27]–[30]. On the other side, research and development potential of the countries can influence the renewable energy investment [31]. Moreover, if the countries have high unemployment ratio, investors can be unwilling to enter these countries with the aim of making renewable energy investment [32]. Some researchers also stated that government policies have an important impact on renewable energy investment [33], [34]. On the other hand, environmental factors can also play an essential role for renewable energy investment decisions [35]–[38].

Green energy was also evaluated by many different researchers in the literature. Some studies examined the positive effects of technological development on green energy [39] while some others assessed an alternative technology with respect to the green energy system such as green energy water-autonomous greenhouse (GEWA) system which aimed to have environmental and resource sustainability [40], [41]. The subject of investment in green energy was also considered in many different studies [42], [43]. In other studies, some significant topics that affect financial performance of the green energy investment, such as corporate social responsibility, understanding investors' expectations and making effective planning are defined [44]–[46]. Additionally, some studies considered the subject of renewable green energy. They mainly aimed to select the base station with renewable green energy to reduce the power consumption [47]–[49]. It is also underlined that renewable energy has important positive effects on the environment [50]–[53].

B. MULTI-CRITERIA DECISION MAKING

Hesitant fuzzy linguistic term sets are very popular in the literature especially in the last years. Within this framework, government strategies were evaluated in different studies [54], [55]. Some studies also focused on the hotel location selection [56], [57]. On the other side, occupational safety risk was evaluated by some researchers [58]. In addition to the hesitant fuzzy linguistic term sets, fuzzy AHP approach is also very popular in the literature. Human resources of the companies were assessed by some researchers with this approach [59], [60]. In these studies, regarding human resource performance, different criteria were mainly defined and weighted. Additionally, supplier selection is another significant topic which was evaluated with the help of fuzzy AHP method [61]–[63].

Similar to the fuzzy AHP, fuzzy DEMATEL is also a preferred multi-criteria decision-making method in the literature. Many different researchers considered this approach to make evaluations related to the supply chain management [64]–[67]. However, it can be seen that this approach was mainly considered to make performance analysis of the companies in different industries, such as printed circuit board [68], cement [69], automobile [70], electric [71], airline [72], logistics [73]. On the other hand, it can be understood that fuzzy DEMATEL method was also used with fuzzy AHP method in some studies to make a comparable analysis [60], [74]–[78]. These studies are mainly related to the analyzing human resource effectiveness, technological development, landfill site selection and agile concept selection.

Furthermore, fuzzy TOPSIS was taken into consideration for various purposes in the literature. It was seen that researchers mainly used this approach with the aim of supplier selection. In other words, firstly, criteria were identified, and the best suppliers were selected based on these factors [62], [79]–[84]. In addition to this issue, fuzzy TOPSIS approach was also used to analyze different industries, such as mining [85], [86], automotive [62], aluminum [87], banking [88], textile [89], energy [90] and manufacturing [91].

Similar to fuzzy TOPSIS, researchers also preferred fuzzy VIKOR approach mainly to find solution for the situation under the complex environment. In many different studies, this methodology was used to make evaluation for green supply chain management [92], [94], [94], [95]. Moreover, banking [96], mine [97], manufacturing [98] and airline [99] are different industries for which fuzzy VIKOR model was taken into consideration in the literature. In addition to them, in some studies, fuzzy TOPSIS and fuzzy VIKOR approaches were used together [100]–[104]. These studies aim to make a comparative analysis for different purposes, such as equipment selection, risk management in the capital markets, facility location problem and service quality of the airports.

To conclude, the main missing part of the literature in this context is that there are limited studies which focus on the ranking of the most favorable renewable energy investment alternatives. Hence, making such an analysis with original methodology like fuzzy logic makes contribution to the literature. Furthermore, different combinations of fuzzy multi-criteria decision methods such as fuzzy DEMATEL and fuzzy TOPSIS could be also considered together to make a comparative analysis including the hesitant linguistic term sets.

III. METHODOLOGY

In this title, first of all, hesitant fuzzy linguistic term sets are defined. After that, fuzzy DEMATEL approach is explained. Next, necessary information is given related to fuzzy AHP. Finally, fuzzy VIKOR and fuzzy TOPSIS methods are identified.

A. HESITANT LINGUISTIC TERM SETS

Hesitant fuzzy linguistic term set provides the flexibility in linguistic expressions. In this circumstance, $S = \{S_0, S_1, \ldots, S_t\}$ represents a linguistic term set. Additionally, $G_H = (V_N, V_T, I, P)$*gives information about the*context-free grammar. Within this framework, following expressions are taken into consideration [105].

$$V_N = \{\langle \textit{primary term}\rangle, \langle \textit{composite term}\rangle, \langle \textit{unary term}\rangle, \langle \textit{binary term}\rangle, \langle \textit{conjunction}\rangle\},$$

$$V_T = \{\textit{lower than}, \textit{greater than}, \textit{at least}, \textit{at most}, \textit{between}, \textit{and}, S_0, S_1, \ldots, S_t\}, \quad I \in V_N,$$

$$P = \{I ::= \langle \textit{primary term}\rangle \mid \langle \textit{composite term}\rangle,$$
$$\langle \textit{composite term}\rangle ::= \langle \textit{composite term}\rangle\ \langle \textit{primary term}\rangle$$
$$\mid \langle \textit{binary relation}\rangle\ \langle \textit{primary term}\rangle\ \langle \textit{conjunction}\rangle$$
$$\langle \textit{primary term}\rangle,\ \langle \textit{primary term}\rangle ::= S_0 \mid S_1 \mid \ldots \mid S_t,$$
$$\langle \textit{unary relation}\rangle$$
$$::= \textit{lower than} \mid \textit{greater than} \mid \textit{at least} \mid \textit{at most},$$
$$\langle \textit{binary relation}\rangle ::= \textit{between},$$
$$\langle \textit{conjunction}\rangle ::= \textit{and}\}.$$

Finally, $h_S = \{S_i, S_{i+1}, \ldots, S_j\}$ *indicates the* hesitant fuzzy linguistic term set.

TABLE 1. Linguistic variables of the impact-relationship degrees and pair-wise comparison.

Impact-relation	Pair-wise comparison	Triangular Fuzzy Numbers		
No (N)	Equally important (EI)	0	0	0.25
Low (L)	Weakly more important (WI)	0	0.25	0.5
Medium (M)	Strongly more important (SI)	0.25	0.5	0.75
High (H)	Very strongly more important (VI)	0.5	0.75	1
Very High (VH))	Absolutely more important (AI)	0.75	1	1

Source: [112], [115]

B. FUZZY DEMATEL

The word of DEMATEL is obtained from the expression of "decision making trial and evaluation laboratory". This methodology is mainly used to see the relationship between the criteria. Another important advantage of this approach is that it gives information about interdependence among these factors [72], [106]. The fuzzy DEMATEL model can be obtained in five different steps [107]. Firstly, the evaluation criteria are provided by considering the degree of influences stated in Table 1.

Secondly, the initial direct-relation fuzzy matrix is constructed as in the equations (1) and (2).

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

$$\tilde{Z} = \frac{\tilde{Z}^1 + \tilde{Z}^2 + \tilde{Z}^3 + \ldots \tilde{Z}^n}{n} \quad (2)$$

In the third step, the direct effect matrix is normalized with the help of the equations (3)-(5).

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \cdots & \tilde{x}_{nn} \end{bmatrix} \quad (3)$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (4)$$

$$r = max_{1 \le i \le n}\left(\sum\nolimits_{j=1}^{n} u_{ij}\right) \quad (5)$$

In the fourth step, the total influence fuzzy matrix is calculated by considering the equations (6)-(12).

$$X_l = \begin{bmatrix} 0 & l'_{12} & \cdots & \cdots & l'_{1n} \\ l'_{21} & 0 & \cdots & \cdots & l'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ l'_{n1} & l'_{n2} & \cdots & \cdots & 0 \end{bmatrix}$$

$$X_m = \begin{bmatrix} 0 & m'_{12} & \cdots & \cdots & m'_{1n} \\ m'_{21} & 0 & \cdots & \cdots & m'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ m'_{n1} & m'_{n2} & \cdots & \cdots & 0 \end{bmatrix}$$

$$X_u = \begin{bmatrix} 0 & u'_{12} & \cdots & \cdots & u'_{1n} \\ u'_{21} & 0 & \cdots & \cdots & u'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ u'_{n1} & u'_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (6)$$

$$\tilde{T} = \lim_{k\to\infty} \tilde{X} + \tilde{X}^2 + \ldots + \tilde{X}^k \quad (7)$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \cdots & \tilde{t}_{nn} \end{bmatrix} \quad (8)$$

$$\tilde{t}_{ij} = \left(l''_{ij}, m''_{ij}, u''_{ij}\right) \quad (9)$$

$$\left[l''_{ij}\right] = X_l \times (I - X_l)^{-1} \quad (10)$$

$$\left[m''_{ij}\right] = X_m \times (I - X_m)^{-1} \quad (11)$$

$$\left[u''_{ij}\right] = X_u \times (I - X_u)^{-1} \quad (12)$$

The final step includes the calculation of the defuzzified total influence matrix with the equations (13)-(21). In these equations, $\tilde{D}_i^{def}$ gives information about the sum of all vector rows. On the other hand, the sum of all vector columns is represented by $\tilde{R}_i^{def}$.

$$u_i^{max} = maxu_i, l_i^{min} = \underset{j}{minl_i} \quad (13)$$

$$\Delta_{min}^{max} = u_i^{max} - l_i^{min} \quad (14)$$

$$x_{lj} = \left(l_{ij} - l_i^{min}\right) / \Delta_{min}^{max} \quad (15)$$

$$x_{mj} = \left(l_{ij} - l_i^{min}\right) / \Delta_{min}^{max} \quad (16)$$

$$x_{uj} = \left(u_{ij} - l_i^{min}\right) / \Delta_{min}^{max} \quad (17)$$

$$x_j^{ls} = x_{mj} / \left(1 + x_{mj} - x_{lj}\right) \quad (18)$$

$$x_j^{rs} = x_{uj} / \left(1 + x_{uj} - x_{mj}\right) \quad (19)$$

$$x_j^{crisp} = \left[x_j^{ls}\left(1 - x_j^{ls}\right) + x_j^{rs} x_j^{rs}\right] / \left[1 - x_j^{ls} + x_j^{rs}\right] \quad (20)$$

$$f_{ij} = l_i^{min} + x_j^{crisp} \Delta_{min}^{max} \quad (21)$$

C. FUZZY AHP

Analytical Hierarchy Process (AHP) is a type of multicriteria decision making methodologies which is mainly used to make decisions under complex environment [109]. The main difference of this method by comparing with the similar ones is that hierarchical evaluation of the criteria is considered [110]. In this circumstance, pair-wise comparison decision matrix is used as stated in the equation (22).

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \tilde{a}_{23} & & \cdots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & 1 & & \cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \tilde{a}_{23} & & \cdots & \tilde{a}_{2n} \\ 1/\tilde{a}_{13} & 1/\tilde{a}_{23} & 1 & & \cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & 1/\tilde{a}_{3n} & & \cdots & 1 \end{bmatrix} \quad (22)$$

In this equation, $\tilde{a}_{ij}$ represents fuzzy pairwise comparison evaluations. Additionally, with respect to the calculation of the weights of the criteria, Chang's extent analysis method is considered [111]. Equation (23) explains the triangular fuzzy numbers.

$$M_{gi}^1, M_{gi}^2, \ldots M_{gi}^m, \quad i = 1, 2, \ldots n, \quad (23)$$

Moreover, by considering these numbers and linguistic terms, the fuzzy scale of the pair-wise comparison can be constructed as in Table 1.

The extent method includes four different steps. At the first stage, the value of fuzzy synthetic extent is identified as in the equations (24)-(27).

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{24}$$

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{25}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_i, \sum_{j=1}^{m} m_i, \sum_{j=1}^{m} u_i\right) \tag{26}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{27}$$

The second step includes the definition of the degree of the possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$. The details are given in the equations (28) and (29)

$$V\,(M_2 \geq M_1) = sup\left[min(\mu_{M_1}(x), \mu_{M_2}(y))\right]$$

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \tag{28}$$

$$= \begin{cases} 1, & if\ m_2 \geq m_1, \\ 0, & if\ l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{29}$$

Furthermore, the third step gives information about the definition of the degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers. This situation is shown in the equations (30)-(32).

$$\begin{aligned} V(M \geq M_1, M_2, \ldots M_k) &= V\,[(M \geq M_1)\, and \\ &\quad (M \geq M_2)\ and\ \ldots\ and\ (M \geq M_k)] \\ &= minV\,(M \geq M_i)\,, \quad i = 1, 2, \ldots, k \end{aligned} \tag{30}$$

$$d^{'}\,(A_i) = minV\,(S_i \geq S_k) \tag{31}$$

$$W^{'} = \left(d^{'}(A_1), d^{'}(A_2), \ldots, d^{'}(A_n)\right)^T \tag{32}$$

The last step explains the normalized weight vectors as in the equation (33).

$$W^{'} = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{33}$$

D. FUZZY VIKOR

The term "VIseKriterijumska Optimizacija I Kompromisno Resenje" represents the word of VIKOR. This approach was developed by reference [112] mainly for the aim of ranking different alternatives. In this process, positive and negative ideal solutions are defined which contributes to the reaching of the best alternative [113], [114]. Equation (34) gives information about the decision matrix.

$$D = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & X_{13} & & \cdots & X_{1n} \\ X_{21} & X_{22} & X_{23} & & \cdots & X_{2n} \\ X_{31} & X_{32} & X_{33} & & \cdots & X_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ X_{m1} & X_{m2} & X_{m3} & & \cdots & X_{mn} \end{bmatrix} \tag{34}$$

In this equation, A_m indicate alternatives while Cn demonstrate the criteria. There are 6 different steps of the VIKOR approach. Firstly, linguistic variables are identified as in Table 2.

TABLE 2. Linguistic and fuzzy evaluations for the alternatives.

Linguistic Scales	Triangular Fuzzy Numbers		
Worst (W)	0	0	2.5
Poor (P)	0	2.5	5
Fair (F)	2.5	5	7.5
Good (G)	5	7.5	10
Best (B)	7.5	10	10

Source: [120]

In the second step, the fuzzy decision matrix is calculated by considering the equation (35).

$$\tilde{x}_{ij} = \frac{1}{k}\left[\sum_{e=1}^{n} \tilde{x}_{ij}^{e}\right] \tag{35}$$

Thirdly, the fuzzy best ($\tilde{f}_j^*$) and worst ($\tilde{f}_j^-$) values are calculated. In this process, the equation (36) is used.

$$\tilde{f}_J^* = \max_i \tilde{x}_{ij},$$

and

$$\tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{36}$$

The fourth step includes the calculation of mean group utility ($\tilde{S}_i$) and maximal regret ($\tilde{R}_i$). Equations (37) and (38) are considered in order to reach this objective.

$$\tilde{S}_i = \sum_{i=1}^{n} \tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)} \tag{37}$$

$$\tilde{R}_i = max_j\left[\tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)}\right] \tag{38}$$

In the step 5, the value of $\tilde{Q}_i$ is computed as in the equation (39).

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right) / \left(\tilde{S}^- - \tilde{S}^*\right) + (1 - v)\left(\tilde{R}_i - \tilde{R}^*\right) / \left(\tilde{R}^- - \tilde{R}^*\right) \tag{39}$$

In this equation, v shows the weight of the maximum group utility. On the other side, $1 - v$ is the weight of the individual regret. v is assumed to have the value of 0.5 in this study.

Also, $\tilde{R}^{*}$ and $\tilde{R}^{-}$ present the maximum and minimum values of regret whereas $\tilde{S}^{*}$ and $\tilde{S}^{-}$ give information about the maximum and minimum values of group utility. In the final step, the values of S, R, Q are sorted. For this purpose, two different conditions must be satisfied.

Condition 1: Acceptable Advantage is:

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq 1/(j-1) \tag{40}$$

In this equation, $A^{(2)}$ gives information about the second position in the alternatives.

Condition 2: Acceptable stability in decision making is:

The alternative $A^{(1)}$ should also be the best ranked by S or/and R. If one of the conditions is not satisfied, a set of compromise solutions is considered.

E. FUZZY TOPSIS

TOPSIS represents the expression of "the Technique for Order of Preference by Similarity to Ideal Solution". The main purpose of this approach is to rank the alternatives [114], [115]. In the first step, decision makers' evaluations are obtained as in the equation (41).

$$\tilde{X}_{ij} = \frac{1}{k}\left(\tilde{X}_{ij}^{1} + \tilde{X}_{ij}^{2} + \tilde{X}_{ij}^{3} + \ldots.. + \tilde{X}_{ij}^{k}\right) \tag{41}$$

The second step includes the normalization of the fuzzy decision matrix. In this process, the equations (42) and (43) are used.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_{ij}^{*}}, \frac{b_{ij}}{c_{ij}^{*}}, \frac{c_{ij}}{c_{ij}^{*}}\right) \tag{42}$$

$$c_{ij}^{*} = \sqrt{\sum\nolimits_{i=1}^{m} c_{ij}^{2}} \tag{43}$$

In the third step, the positive (A^{+}) and negative (A^{-}) ideal solutions are identified as in the equation (44).

$$A^{+} = \left(\tilde{v}_{1}^{*}, \tilde{v}_{2}^{*}, \tilde{v}_{3}^{*}, \ldots \tilde{v}_{n}^{*}\right)$$

and

$$A^{-} = \left(\tilde{v}_{1}^{-}, \tilde{v}_{2}^{-}, \tilde{v}_{3}^{-}, \ldots \tilde{v}_{n}^{-}\right) \tag{44}$$

In this equation, $\tilde{v}_{n}^{*}$ and $\tilde{v}_{n}^{-}$ are the identification factors of positive and negative ideal solutions. Additionally, the equations (45) and (46) demonstrate the distances from the positive (D_{i}^{*}) and negative (D_{i}^{-}) ideal solution.

$$D_{i}^{*} = \sum\nolimits_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{j}^{*}) \tag{45}$$

$$D_{i}^{-} = \sum\nolimits_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{j}^{-}) \tag{46}$$

In the final step, alternatives are ranked as in the equation (47).

$$CC_{i} = \frac{D_{i}^{-}}{D_{i}^{+} + D_{i}^{-}} \tag{47}$$

IV. ANALYSIS

A. MODEL CONSTRUCTION

A comparative analysis with FTOPSIS and FVIKOR has been applied for the fuzzy decision-making model under the hesitant linguistic term sets. Moreover, FAHP and FDEMATEL methods have been used for criticizing the hierarchical and mutual effects among the criteria. Thus, a novel comparative approach to the hybrid hesitant modeling is provided by combining the FAHP-FTOPSIS-FVIKOR and FDEMATEL-FTOPSIS-FVIKOR respectively. The flowchart of the model is illustrated as follows

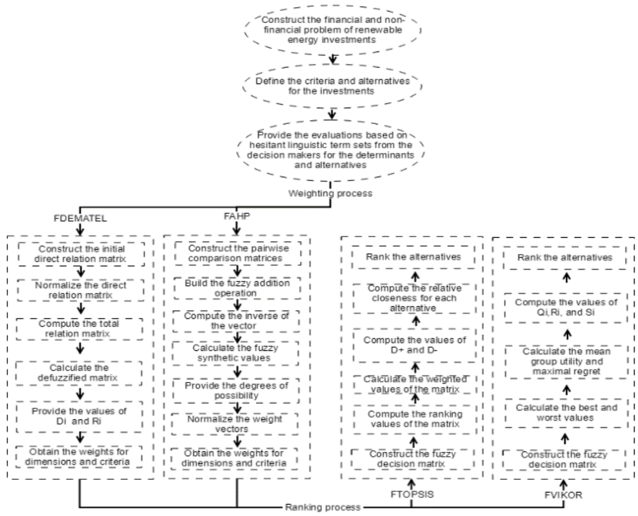

FIGURE 1. Construction of proposed model.

The proposed model is detailed in the following steps respectively:

Step 1: Define the problem: The problem of multi criteria decision making is illustrated by constructing a set of dimensions, criteria, and alternatives. For this purpose, financial and non-financial factors are defined for determining the criteria set. Accordingly, earnings (C1), assets (C2), and equity (C3) are selected as criterion set of financial dimension (D1). Earning is an important indicator of this situation because in order to make a significant renewable energy investment, the companies should have high earnings. Otherwise, it cannot be possible for the companies, which have low profitability, to make such a big investment. In addition, asset amount of the company is accepted as an indicator. The main reason is that it shows the size of the company. Therefore, if the company has high amount of the assets, it means that this company has a significant potential to make renewable energy investment. Similarly, equity amount mainly gives information about the capital adequacy of the company. The company, which has high capital adequacy ratio, does not have very much liquidity risk. Hence, it can make renewable energy investment more effectively.

On the other side, sub-dimensions of non-financial dimension (D2) are listed as environmental effects (C4), organizational capacity (C5), and technological infrastructure (C6).

Environmental factors include customers, government and suppliers. Hence, it is obvious that customer expectations should be identified to make more effective renewable energy investment. Similar to this aspect, the legal regulations made by the government in the country where the investment will be made are very important for the success of the renewable energy investment. Moreover, organizational capacity can be accepted as an important indicator of the successful renewable energy investment. In this scope, the effectiveness of the internal communication plays a very crucial role. On the other side, companies should make technological development to increase the performance of renewable energy investment. Moreover, Biomass (A1), Hydropower (A2), Geothermal (A3), Wind (A4), and Solar (A5) are selected as alternative set for the renewable energy investments.

Step 2: Appoint the decision makers and collect the evaluations: In the following process, the linguistic evaluations of decision makers that are experts in the industry are provided for dimensions, criteria, and alternatives. For that, 3 decision makers provide their linguistic choices for each dimension, criteria and alternative. Table 3-6 represent the evaluation results of decision makers collectively.

TABLE 3. Linguistic evaluations of decision makers for the dimensions.

	Dimension 1			Dimension 2		
	DM1	DM2	DM3	DM1	DM2	DM3
D1	-	-	-	N	N	L
D2	N	N	N	-	-	-

TABLE 4. Linguistic evaluations of decision makers for the criteria of D1.

	Criterion 1			Criterion 2			Criterion 3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	-	-	-	L	L	L	H	L	H
C2	M	M	M	-	-	-	M	M	M
C3	VH	VH	VH	VH	H	VH	-	-	-

TABLE 5. Linguistic evaluations of decision makers for the criteria of D2.

	Criterion 4			Criterion 5			Criterion 6		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C4	-	-	-	N	L	M	N	N	N
C5	M	M	M	-	-	-	M	M	M
C6	H	H	H	L	H	H	-	-	-

By using the linguistic evaluations of decision makers, hesitant linguistic term sets-based evaluations of dimensions, criteria, and alternatives are presented in Table 7-10 respectively.

Step 3: Weight the dimensions and criteria: Fuzzy DEMATEL and fuzzy AHP based on hesitant linguistic term sets are used for weighting the dimensions and criteria with equations (1)-(21) and (22)-(33).

Step 4: Rank the alternatives: Fuzzy TOPSIS and fuzzy VIKOR with the hesitant linguistic term sets are applied to measure the performances of each alternative by the formulas (34)-(40) and (41)-(47).

TABLE 6. Linguistic evaluations of decision makers for the alternatives.

	Alternative 1			Alternative 2			Alternative 3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	F	F	F	F	B	B	F	G	G
C2	F	F	F	G	G	G	F	F	G
C3	F	G	G	G	G	G	F	G	F
C4	P	P	P	F	F	F	P	F	F
C5	P	F	F	F	F	F	F	F	F
C6	F	F	F	G	G	G	F	G	G

	Alternative 4			Alternative 5		
	DM1	DM2	DM3	DM1	DM2	DM3
C1	F	G	B	B	G	B
C2	F	G	B	F	G	B
C3	G	G	B	G	G	G
C4	G	G	B	B	B	B
C5	F	G	G	F	G	G
C6	G	G	G	F	G	G

TABLE 7. Hesitant linguistic term sets-based evaluations for the dimensions.

Dimension	D1	D2
D1	-	$\{N, L\}$
D2	$\{N\}$	-

TABLE 8. Hesitant linguistic term sets-based criterion evaluations for D1.

Criterion	C1	C2	C3
C1	-	$\{L,\}$	$\{L, H\}$
C2	$\{M\}$	-	$\{M\}$
C3	$\{VH\}$	$\{H, VH\}$	-

TABLE 9. Hesitant linguistic term sets-based criterion evaluations for D2.

Criterion	C4	C5	C6
C4	-	$\{N, L, M\}$	$\{N\}$
C5	$\{M\}$	-	$\{M\}$
C6	$\{H\}$	$\{L, H\}$	-

TABLE 10. Hesitant linguistic term sets-based alternative evaluations.

Alternative/ Criterion	A1	A2	A3	A4	A5
C1	$\{F\}$	$\{F, B\}$	$\{F, G\}$	$\{F, G, B\}$	$\{G, B\}$
C2	$\{F\}$	$\{G\}$	$\{F, G\}$	$\{F, G, B\}$	$\{F, G, B\}$
C3	$\{F, G\}$	$\{G\}$	$\{F, G\}$	$\{G, B\}$	$\{G\}$
C4	$\{P\}$	$\{F\}$	$\{P, F\}$	$\{G, B\}$	$\{B\}$
C5	$\{P, F\}$	$\{F\}$	$\{F\}$	$\{F, G\}$	$\{F, G\}$
C6	$\{F\}$	$\{G\}$	$\{F, G\}$	$\{G\}$	$\{F, G\}$

In the following section, the analysis results of step 3 and 4 are represented consecutively.

B. ANALYSIS RESULTS

1) WEIGHT THE DIMENSIONS AND CRITERIA

Firstly, FDEMATEL method is considered for measuring the relative importance of dimensions and criteria. Direct-relation fuzzy matrix is constructed by converting the linguistic values into the fuzzy numbers as seen in table 1. Average values are used with the equations (1) and (2) and the results for dimensions are given in Table 11.

TABLE 11. Direct relation fuzzy matrix.

	Dimension 1			Dimension 2		
D1	0.00	0.00	0.00	0.00	0.13	0.38
D2	0.00	0.00	0.25	0.00	0.00	0.00

The normalization procedure is applied for the normalized matrix by using the formulas (3)-(5) and the results are seen in Table 12.

TABLE 12. Normalized relation fuzzy matrix.

	Dimension 1			Dimension 2		
D1	0.00	0.00	0.00	0.00	0.33	1.00
D2	0.00	0.00	0.67	0.00	0.00	0.00

The following step is to construct the total influence fuzzy matrix with the equations (6)-(12) and the matrix is illustrated in Table 13.

TABLE 13. Total influence fuzzy matrix.

	Dimension 1			Dimension 2		
D1	0.00	0.00	2.00	0.00	0.33	3.00
D2	0.00	0.00	2.00	0.00	0.00	2.00

At the final step of fuzzy DEMATEL, defuzzification procedure is used for obtaining the influences and weights of each dimension by the equations (13)-(21). Table 14 shows the defuzzified values of the total relation matrix and the weights of dimensions.

TABLE 14. Defuzzified total influence matrix.

	D1	D2	$\tilde{D}_i^{def}$	$\tilde{R}_i^{def}$	Weights
D1	0.34	0.78	1.12	0.68	0.503
D2	0.33	0.33	0.67	1.11	0.497

Similar procedures are also applied for the criteria of Dimension 1 and 2 respectively and accordingly, the local and global weights are computed in Table 15.

TABLE 15. Weighting results of criteria.

Criteria	Criteria Weights		Global Weights	
	FDEMATEL	FAHP	FDEMATEL	FAHP
C1	0,343	0,392	0,172	0,196
C2	0,326	0,269	0,164	0,135
C3	0,331	0,338	0,166	0,169
C4	0,351	0,397	0,175	0,199
C5	0,314	0,280	0,156	0,140
C6	0,335	0,323	0,166	0,162

However, to robustness check, fuzzy AHP method is used for the weights of criteria with the formulas (22)-(33) and the results are presented in Table 15 comparatively.

The results represent that financial and non-financial dimensions of renewable energy investments are equally important for ranking alternatives. According to the weighting results, dimensions weights are almost same in the hierarchical and mutual dependency conditions between the dimensions. However, the importance results of the criteria are different for the selected methods. Environmental effects (C4) is the most important criteria for both methods while assets (C2) in the FAHP and organizational capacity (C5) in the FDEMATEL are the weakest factors. These results indicate that companies should mainly give importance to the environmental factors, such as supplier, customer, government in order to be successful in renewable energy investment. In this framework, these companies should understand the local regulations effectively because they can provide many incentives for the investment. Additionally, there can also be some obstacles created by the government to some aspects of renewable energy investment. While evaluating these aspects, the companies can make more effective plan for long-term renewable energy investment.

Additionally, the impact relation map of the criteria is illustrated by using the defuzzified values of total relation matrix. For that, average value of the matrix is defined as a threshold and the higher values than the threshold presents the influencing factors. Figure 2 and 3 illustrate the impact and relation directions among the criteria for dimension 1 (financial criteria) and dimension 2 (Non-financial criteria) respectively.

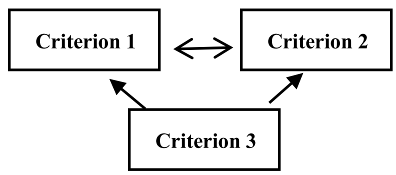

FIGURE 2. Impact relation map for the financial criteria.

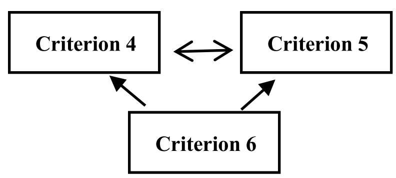

FIGURE 3. Impact relation map for the non-financial criteria.

Figure 2 and 3 illustrate that criterion 1 (earnings) and criterion 2 (assets) have a mutual effect in the financial criteria while criterion 4 (environmental effects) and criterion 5 (organizational capacity) influence each other in the non-financial criteria. And also, the impact-relation directions of financial criteria demonstrate that criterion 3 (equity) has a direct impact on both criterion 2 (assets) and criterion 1 (earnings) whereas none of financial criteria have no influence on the criterion of equity. Criterion 6 (technological infrastructure) affects the other non-financial criteria as criterion 4 and criterion 5 have no impact on the technological infrastructure.

2) RANK THE ALTERNATIVES

The second phases of the comparative analysis is to rank the alternatives with FTOPSIS and FVIKOR. For that, decision matrix based on triangular fuzzy numbers is constructed with the equations (34) and (35) and averaged matrix is seen in Table 16.

TABLE 16. Fuzzy decision matrix.

	Criterion 1			Criterion 2			Criterion 3		
A1	2.50	5.00	7.50	2.50	5.00	7.50	3.75	6.25	8.75
A2	5.00	7.50	8.75	5.00	7.50	10.00	5.00	7.50	10.00
A3	3.75	6.25	8.75	3.75	6.25	8.75	3.75	6.25	8.75
A4	5.00	7.50	9.17	5.00	7.50	9.17	6.25	8.75	10.00
A5	6.25	8.75	10.00	5.00	7.50	9.17	5.00	7.50	10.00
	Criterion 4			Criterion 5			Criterion 6		
A1	0.00	2.50	5.00	1.25	3.75	6.25	2.50	5.00	7.50
A2	2.50	5.00	7.50	2.50	5.00	7.50	5.00	7.50	10.00
A3	1.25	3.75	6.25	2.50	5.00	7.50	3.75	6.25	8.75
A4	6.25	8.75	10.00	3.75	6.25	8.75	5.00	7.50	10.00
A5	7.50	10.00	10.00	3.75	6.25	8.75	3.75	6.25	8.75

TABLE 17. Weighted fuzzy decision matrix.

	Criterion 1			Criterion 2			Criterion 3		
A1	0.02	0.04	0.07	0.02	0.04	0.06	0.03	0.05	0.07
A2	0.04	0.07	0.08	0.04	0.06	0.08	0.04	0.06	0.08
A3	0.03	0.05	0.08	0.03	0.05	0.07	0.03	0.05	0.07
A4	0.04	0.07	0.08	0.04	0.06	0.08	0.05	0.07	0.08
A5	0.05	0.08	0.09	0.04	0.06	0.08	0.04	0.06	0.08
	Criterion 4			Criterion 5			Criterion 6		
A1	0.00	0.02	0.05	0.01	0.03	0.06	0.02	0.04	0.06
A2	0.02	0.05	0.07	0.02	0.04	0.07	0.04	0.06	0.08
A3	0.01	0.04	0.06	0.02	0.04	0.07	0.03	0.05	0.07
A4	0.06	0.09	0.10	0.03	0.06	0.08	0.04	0.06	0.08
A5	0.07	0.10	0.10	0.03	0.06	0.08	0.03	0.05	0.07

The following step is to compute the weighted values of decision matrix. For this purpose, the weighting results from fuzzy DEMATEL and fuzzy AHP are used to construct the weighted decision matrix. Table 17 represents the weighted fuzzy decision matrix with the weighting results of fuzzy DEMATEL.

The values of S_i, R_i, and Q_i are computed by the formulas (36)-(40) to rank the alternatives with fuzzy VIKOR. The results are presented in Table 18.

However, the values of D_i^*, D_i^-, and CC_i are calculated to measure the performance results of alternatives with fuzzy TOPSIS by using the formulas (42)-(47). The results are given in Table 19 respectively.

In the following process, to robustness check, global weighting results provided from the FDEMATEL and FAHP are used for weighted decision matrix and ranking results of FTOPSIS and FVIKOR are summarized in Table 20.

TABLE 18. The values of S_i, R_i, and Q_i.

Alternatives	S_i	R_i	Q_i
A1	1.000	0.175	1.000
A2	0.307	0.107	0.327
A3	0.656	0.166	0.775
A4	0.095	0.057	0.000
A5	0.157	0.083	0.144

TABLE 19. The values of D_i^*, D_i^-, and CC_i.

Alternatives	D_i^*	D_i^-	CC_i
A1	5.769	0.257	0.0426
A2	5.664	0.352	0.0586
A3	5.714	0.306	0.0509
A4	5.615	0.397	0.0660
A5	5.614	0.398	0.0663

TABLE 20. Ranking results of alternatives.

Alternatives	FDEMATEL		FAHP	
	FTOPSIS	FVIKOR	FTOPSIS	FVIKOR
Alternative 1 (Biomass)	5	5	5	5
Alternative 2 (Hydropower)	3	3	3	3
Alternative 3 (Geothermal)	4	4	4	4
Alternative 4 (Wind)	2	1	2	1
Alternative 5 (Solar)	1	2	1	2

Comparative ranking results show that there is no significant difference between the hierarchical and mutual effects of the criteria. Alternative 5 is the best alternative for the FDEMATEL-FTOPSIS and FAHP-FTOPSIS as Alternative 4 has the highest rank for the FDEMATEL-FVIKOR and FAHP-FVIKOR in the renewable energy investments. However, alternative 1 has the worst ranking result for all the integrated decision-making models. Overall results illustrate that alternative 4 and 5 are among the most attractive renewable energy alternatives.

V. DISCUSSION AND CONCLUSION

This study aims to evaluate different renewable energy investments alternatives. In this context, the dimensions are identified as financial and non-financial. For these dimensions, six different criteria are identified according to the literature review results. Fuzzy AHP and fuzzy DEMATEL methods are considered to weight these dimensions and criteria. Additionally, renewable energy investment alternatives are defined as five different categories, such as biomass, hydropower, geothermal, wind and solar. Moreover, these alternatives are ranked by using fuzzy TOPSIS and fuzzy VIKOR approaches.

It is identified that financial and non-financial dimensions of renewable energy investments are equally important for ranking alternatives. Fuzzy AHP and fuzzy DEMATEL methods also give coherent results for the criteria. In this framework, it is concluded that environmental effects and earnings are the most significant criteria. On the other side, assets and organizational capacity have the lowest importance. This situation shows that environmental factors, such as government, suppliers and customers play a key role. Also, wind and solar are the most attractive renewable energy investment alternatives.

By considering these results, it is recommended that governments should give necessary incentives to the investors to increase renewable energy investment. Within this framework, governmental incentives should be widely used for effective location selection of both wind and solar energy investment alternatives. On the other side, large-scale investments should be made to increase earnings and improve organizational capacity. For this purpose, merger and acquisition can be the alternatives for the companies regarding renewable energy investment.

In addition, with respect to the supplier factor, easy access to the sources and good contract conditions should be provided. With the help of this situation, investors can become more willing to make investments. Finally, customer expectations should be understood effectively in order to be successful in renewable energy investment. In the future studies, a new analysis can also be made for this subject by considering interval type-2 fuzzy sets.

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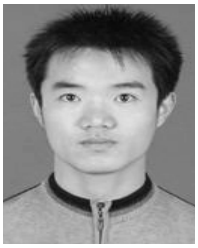

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