IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received December 16, 2020, accepted December 26, 2020, date of publication December 29, 2020,
date of current version January 8, 2021.

Digital Object Identifier 10.1109/ACCESS.2020.3048016

A Hybrid Hesitant 2-Tuple IVSF Decision Making Approach to Analyze PERT-Based Critical Paths of New Service Development Process for Renewable Energy Investment Projects

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ABSTRACT The purpose of this study is to evaluate PERT-based critical paths of new service development (NSD) process for renewable energy investment projects. In this context, a novel three-stage model has been proposed. In the first stage, 10 different steps in NSD process are weighted by considering 2-tuple hesitant interval-valued Spherical fuzzy IVSF DEMATEL approach. In the second stage, 26 different critical paths for NSD process are identified. Moreover, the third stage includes the ranking the renewable energy alternatives by path scenarios with 2-tuple hesitant IVSF TOPSIS. The findings demonstrate that idea screening and the formation of cross-functional team are the most significant criteria for the NSD process of renewable energy investments. Additionally, while considering all activities of NSD process, it is concluded that solar energy is the most appropriate renewable energy alternative. This result is also similar for considering the longest path by activity number, the longest path by duration and the shortest path by activity number. However, it is also determined that geothermal energy is the most ideal type of renewable energy to invest in while considering the shortest path by duration. Therefore, it is obvious that investors should primarily give importance to generate new products for solar energy projects. In this way, it can be easier for them to provide efficiency in their investments. On the other hand, if there is time constraint or a positive result is expected from the project in a short time, geothermal energy is the most suitable renewable energy type to invest.

INDEX TERMS Renewable energy investments, new service development, spherical fuzzy sets, DEMATEL.

I. INTRODUCTION

Renewable energy refers to energy obtained from natural resources. Therefore, renewable energy sources can be defined as energy sources that can constantly renew themselves and not run out in nature. It is possible to talk about many advantages of renewable energy. Carbon gas is not formed in these types of energy. Therefore, these types of energy have very little damage to the environment [1]. Renewable energy sources also have many benefits for the economies of countries. Energy imports of countries using these resources are decreasing. This situation contributes to the reduction of the current account deficit problem of countries [2]. On the other hand, the use of renewable energy increases the energy supply security of countries. Thanks to these projects, countries will be able to produce their own energy. In other words, countries that can use renewable energy alternatives effectively will not need to buy energy from another country. This situation minimizes the dependence on foreign countries for energy. A country that imports a significant part of the energy it needs from another country becomes politically dependent on that country [3]. The use of renewable energy also contributes to the solution of this problem for countries.

There are mainly 5 different types of renewable energy alternatives which are solar, wind, geothermal, biomass and

The associate editor coordinating the review of this manuscript and approving it for publication was Noor Zaman.

hydropower. All these renewable energy types have positive and negative aspects compared to each other. For example, solar energy does not have any significant costs other than installation financing [4]. This is also true for hydroelectric energy. However, one of the most important disadvantages of wind energy is that initial installation costs are higher compared to other renewable energy sources [5]. Also, solar energy is generally used where it is produced. Therefore, there are not too many problems in transmission and distribution routes. Nonetheless, the installation areas of wind power plants take up less space than solar energy. Another advantage of solar energy is that it is much easier to use compared to other renewable energy sources [6].

On the other hand, the most important advantage of biomass energy is that the production amount can be predicted as long as it is the raw material [7]. Similarly, it is possible to obtain uninterrupted electricity in geothermal energy [8]. However, this is not the case for the sun and wind. In this context, the biggest disadvantage of solar energy is that it is heavily affected by climatic conditions. Low sunlight during winter and at night reduces the efficiency in the electricity generation process. In addition, wind panels can operate both day and night as long as there is wind [9]. Hence, this situation makes it difficult to estimate the amount of electrical energy to be obtained by wind energy.

In addition, the need for too much water while obtaining biomass energy is an important disadvantage. In addition, large areas are needed to utilize biomass energy. This increases the cost of this energy type [10]. On the other hand, in geothermal energy, the facility takes up little space because it is underground. One of the biggest disadvantages of geothermal energy is the presence of harmful substances in the hot water used. Separating these substances also increases the cost of the process [11]. Similarly, during the construction of the hydroelectric power plant, there is a possibility that the trees around it will be cut to provide transportation [12].

It is obvious that no type of renewable energy has absolute advantage over another. This situation increases the uncertainty in the investment decisions of the investors. In other words, it is very difficult for investors to choose among renewable energy alternatives, considering many advantages and disadvantages at the same time. Therefore, the studies to be carried out for this purpose are very important as they will guide investors. PERT (Project Evaluation and Review Technique) is also an approach taken into account in this process. With this technique, the time required for the completion of each phase of the project is estimated [13]. In this way, it is possible to predict the time required for the complete completion of a project. This method is very helpful in sustaining the projects more effectively and efficiently [14]. The biggest advantage of this technique is that it can take into account the uncertainties in the end times of the activities. Therefore, it is accepted that the PERT method is much more realistic compared to the others [15].

In this study, it is aimed to evaluate PERT-based critical paths of NSD process for renewable energy investment projects. For this purpose, a hybrid novel fuzzy MCDM model has been generated. There are three different stages of this proposed model. In the first stage, the immediate predecessors of NSD process for renewable energy investment projects are defined. In this context, 10 different NSD steps are weighted by considering 2-tuple hesitant IVSF DEMATEL. Moreover, the second stage includes the identification of the critical paths for new service development process. Within this framework, NSD-based renewable energy investment project network is constructed. Additionally, the weighted results of durations by paths are calculated. On the other side, in the final stage, the renewable energy alternatives are ranked by path scenarios. In this process, 2-tuple hesitant IVSF TOPSIS methodology is taken into consideration. Furthermore, this evaluation is performed according to different scenarios, such as using all activities, the shortest path by duration, the longest path by activity number, the longest path by duration and the shortest path by activity number.

The main contribution of this study is to propose appropriate investment strategies for renewable energy projects by evaluating different NSD paths with a novel hybrid fuzzy MCDM model. Additionally, ranking renewable energy alternatives with respect to different scenarios is also very helpful to generate investment strategies for different conditions. Hence, renewable energy investments can be directed more appropriately. It is also possible to mention different novelties of this proposed model. First of all, hybrid methodology is preferred in the analysis process. In other words, two different MCDM models (DEMATEL and TOPSIS) are used for both weighting the factors and ranking the alternatives. In other kinds of models, only one MCDM approach is considered to rank the alternatives [16]. However, the weights of the criteria are defined by the authors subjectively [17]. It is obvious that owing to the hybrid model, the evaluations can be made more objectively. This situation has a positive contribution to reach more realistic results [18].

Another important novelty of this proposed model is considering DEMATEL evaluation to define 26 different paths. PERT analysis is mainly considered in the literature to define the predecessors for NSD process. In this analysis, the paths are defined subjectively by the authors or some theoretical information is taken into consideration for this purpose. With the help of DEMATEL methodology, impact relation map between the factors can be identified [19]. By considering this causality analysis, 26 different pats in NSD process for renewable energy investment projects are defined. Thus, more objective and effective evaluations are made in the definition of different paths [20], [21]. Furthermore, renewable energy alternatives are ranked with TOPSIS method. The main advantage of this methodology is using the distances both positive and negative ideal solutions [22], [23]. Therefore, more accurate evaluations can be performed to understand which renewable energy alternatives have higher performance [24]. In addition, considering Spherical fuzzy sets in the analysis process also contributes to this situation because membership, non-membership and hesitancy parameters can be taken into consideration in this process [25]–[27]. Moreover, the loss of the information can be minimized with the help of 2 tuple linguistic evaluation [28], [29]. Additionally, by considering the IVIF sets, it can be possible to differentiate the positive and the negative indications of an element's values more effectively [30]–[32]. The final novelty of this proposed model is using hesitant fuzzy linguistic term sets in the analysis process so that the hesitant information can be expressed more comprehensively [33]–[35].

The rest of the paper is organized as following. The second part of the study includes literature evaluation. In this context, a literature review is conducted for both renewable energy alternatives and methodology. After that, the missing part in the literature is identified. Section 3 gives information about the theoretical information about the methods used in the analysis process. Next, the proposed model is detailed in this section. Section 4 includes the analysis results for NSD process of renewable energy alternatives. Section 5 is related to the conclusion. On the other side, the discussion and limitations of the study are highlighted in the final section.

II. LITERATURE REVIEW

In this section, firstly, the literature for renewable energy investment is reviewed. After that, some studies are evaluated regarding the NSD process. Later, the usage of fuzzy MCDM modelling in renewable energy investments is examined. Next, some studies, which used the PERT technique, are identified. In the final part, the results of the literature review are discussed.

A. LITERATURE REVIEW ON RENEWABLE ENERGY INVESTMENT

There is wide-ranging literature which has investigated the factors that impact renewable energy investments by using different analyzing methods. Wang *et al.* [36] put forward a comprehensive evaluation of renewable energy estimation methods based on deep learning to explore their efficiency and application potential. They underlined the importance of effective cost evaluation in this regard. Assaf and Shabani [37] and Razmjoo *et al.* [38] underlined the significance of this situation. Besides, Zhong *et al.* [39] aimed at identifying innovative strategies suitable for renewable energy investments through the TRIZ technique. Consequently, they found that ease of access and security are the two most important factors for customer needs for renewable energy investments. Viviescas *et al.* [40] and Hamed and Bressler [41] also identified that security is a significant issue for the effectiveness of the renewable energy investment projects. On the one hand, Song *et al.* [42] examined the fossil energy market using the connectivity network approach. In this study, they investigated the dynamic information dissemination of investors' sensitivity towards renewable energy and the turnaround and volatility between the renewable energy exchange. As a result, it has been determined that renewable energy exchange is closely related to the fossil energy market. Additionally, Xia *et al.* [43] investigated the impact of various fossil energy price changes on renewable energy stock returns using the network approach. They reached a conclusion that the fossil energy-renewable energy network system has a relatively high interdependence.

Moreover, the positive results of renewable energy alternatives were also examined by many different researchers. Khan *et al.* [44] investigated the effects of renewable energy on international trade and environmental quality. A dynamic common correlated effect model was taken into consideration for robustness check in this study. They identified that the renewable energy positively associated with international trade in Nordic countries. Additionally, environmental quality can be improved with the help of renewable energy usage. Jurasz *et al.* [45], McGee and Greiner [46] and Yao *et al.* [47] also determined the same results in their studies. On the other side, Xu *et al.* [48] predicted the factors affecting global renewable energy development. A combination of ARIMA, NNM with SVM is used in the analysis process. They underlined that renewable energy consumption is directly related to the economic development. Moreover, Aslani *et al.* [49], Behuria [50] and Mohamed *et al.* [51] stated that countries should give priorities to increase renewable energy investments so that energy dependency can be minimized.

In addition, some other studies in the literature also aimed to evaluate the renewable energy usage in different countries and regions. For example, Poudyal *et al.* [52] examined the current energy crisis in Nepal and Ji and Zhang [53] investigated the contribution of financial development to renewable energy growth in China. They stated that the popularity of renewable energy projects is increasing, especially in the last years. Similarly, Akadiri *et al.* [54] analyzed energy policies in the EU (28 countries). It is concluded that the renewable energy consumption has a powerful impact on pollution reduction and economic sustainability. Because of this situation, they recommended that EU countries should mainly focus on renewable energy projects. Furthermore, Destek and Sinha [55] studied the impact of renewable energy on economic development for economic cooperation and development countries. They discussed that governments should give necessary incentives to the renewable energy projects because they have a significant role to minimize energy dependency.

B. LITERATURE ON NSD PROCESS

There are specific NSD stages in the literature. They were firstly considered as eight processes in a study conducted by Booz and Hamilton [56]. After that, these criteria were also improved in many different studies. For instance, Alam and Perry [57] generated 10-step NSD process while investigating renewable energy investment projects. Additionally, the significance of NSD process on the performance of the companies was also underlined by various researchers. For example, Liu *et al.* [58] analyzed the efficiency of renewable energy policies using a panel data set covering 29 countries in the 2000-2015 period. They found that strategic planning, along with pricing policy and subsidies, has a positive effect on renewable energy development. Similarly, Kim [59] examined 80 developing countries for the period 1996-2016 and reached a conclusion that strategic planning helped developing countries to get private investment, especially for local renewable energy sources. Moreover, Matzembacher *et al.* [60] explored how entrepreneurs generate ideas in the context of sustainable development. For this study, they conducted a case study with eleven organizations in six different countries from different sectors. The findings revealed that the entrepreneurs' previous experiences and skills are strongly associated with their knowledge of similar initiatives, motivation, and generating ideas. Riva [61] developed a techno-economic optimization model by simulating the future business situation of off-grid fuel cell-based hydrogen storage solutions with appropriate data.

On the other hand, there are also some studies in the literature which focused on the significant steps in NSD process. As an example, Vimal *et al.* [62] aimed to develop a methodology to ensure sustainability in the production process. It has been determined that the application of fuzzy concepts and the creation of a cross-functional team helped managers to work effectively even with limited information available. Furthermore, Hilorme *et al.* [63] explored appropriate strategies to reduce the risks of implementing energy-saving technology projects and improve socioeconomic efficiency. They recommended a staff development strategy, in particular external consulting, to reduce the impact of the procedural risk group. Moreover, Cole *et al.* [64] tested marketing materials to identify the perceived benefits and barriers to home energy efficiency improvements using two separate surveys. As a result, high costs of energy efficiency improvements have been found as the most perceived obstacle. Additionally, Shakeel *et al.* [65] investigated how different renewable energy technologies can be commercialized effectively in Finland. They determined that market comparison is a key issue to improve NSD process. On the other side, Lea *et al.* [66] found that commercialization activities are the most effective step to achieve the strategic goals of companies towards sustainability.

C. LITERATURE ON THE METHODOLOGY

Furthermore, there are also some studies in the literature which focused on the renewable energy investments by the help of fuzzy MCDM methodologies. For instance, Dinçer and Yüksel [67] evaluated global investment alternatives for renewable energy projects. Fuzzy DEMATEL methodology under the hesitancy is used to weight the factors that affect the performance of renewable energy investments. with fuzzy decision-making methods. Additionally, renewable energy alternatives are also ranked with the help of the hesitant fuzzy TOPSIS approach. Also, Li *et al.* [68] carried out Kano-based mapping of innovation strategies for renewable energy alternatives with the hybrid interval type-2 method. Within this framework, the criteria are evaluated by using interval type-2 (IT2) fuzzy DEMATEL. Moreover, renewable energy alternatives are ranked with a comparative evaluation by using IT2 fuzzy TOPSIS and IT2 fuzzy VIKOR. Wang *et al.* [69] conducted a hybrid analysis based on unstable linguistic term clusters. Fuzzy AHP and fuzzy DEMATEL methods are considered for the evaluation of the criteria. On the other hand, alternatives are ranked by considering both fuzzy TOPSIS and fuzzy VIKOR approaches. Similarly, Wang *et al.* [70] aimed to select the most profitable renewable energy alternatives with the help of the IT2 fuzzy DEMATEL and IT2 fuzzy TOPSIS. Rani *et al.* [71] tried to select the optimum renewable energy investment projects with the help of fuzzy TOPSIS methodology. In addition, Alkan and Albayrak [72] ranked renewable energy sources for regions in Turkey. For this purpose, fuzzy COPRAS and fuzzy MULTIMOORA are taken into consideration. Moreover, Solangi *et al.* [73] intended to select the appropriate renewable energy resources in Pakistan. In the analysis process, an integrated Delphi-AHP and fuzzy TOPSIS approach is taken into consideration.

D. PERT ANALYSIS

Businesses aim to have more efficient activities in terms of both time and cost. In this context, effective planning should be made and the performance of the activities in the process should be checked periodically. In other words, to sustain a large project effectively, all steps in the process must be designed in a successive logic. In this way, it is possible to use time effectively. In addition, it may be easier to control the effectiveness of each stage. The important point here is that in order to start some of the steps in the process, others may need to be completed. Therefore, the processes of the project must be defined correctly [74]. PERT analysis includes the effective evaluation and correct analysis of a project. If the exact completion time of a project's activities is not known, time estimation can be made for this project thanks to PERT analysis. In this way, it will be understood whether the project can be completed in a certain time frame [75]. There are many different issues that affect the effectiveness of a project. Some of these issues can be anticipated before starting the project [76]. However, some unpredictable issues can prevent the project from being completed on time. As can be understood from here, it is not possible to know the exact duration of the activities that make up the project. Therefore, it is obvious that PERT analysis is a realistic approach. The one with the longest duration among the stages in PERT analysis is called the critical path [77]. Many researchers in the literature considered PERT analysis for different purposes. For instance, Huynh and Nguyen [78] evaluated common risks in software project scheduling by considering this technique. Yilmaz and Yilmaz [79] aimed to find the optimal capacity for sustainable refrigerated storage buildings by using this approach. Pagalday *et al.* [80] also used PERT technique for the aim of evaluating after sales services.

E. THE LITERATURE REVIEW RESULTS

It is possible to reach some significant issue as a result of the literature review. Firstly, the renewable energy investment projects provide important advantages for the sustainable development of the countries, such as decreasing carbon emission and increasing energy independency. Because of these factors, governments provide some subsidies to attract the attention of the investors. Hence, it is important to provide innovative strategies for these investors. PERT technique is also very appropriate to measure the effectiveness of NSD process for these projects. However, in PERT approach, activity and immediate predecessors for NSD process are mainly selected by the authors subjectively. Therefore, there is a need for a new study which considers NSD process of the renewable energy investments with an objective evaluation. In this study, a 3-stage hybrid fuzzy MCDM model is proposed to generate appropriate strategies regarding the NSD process of renewable energy investment projects. In the first stage, 10 different NSD steps are weighted by using IVSF DEMATEL. In the second stage, 26 different paths of NSD process are identified. In this framework, impact relation map results of IVSF DEMATEL are taken into consideration. With the help of this issue, activity and immediate predecessors for NSD process in PERT technique are determined objectively. On the other side, the third stage includes the ranking of the renewable energy alternatives with IVSF DEMATEL. Therefore, it is believed that owing to the objective and effective methodology, NSD process of renewable energy investment projects can be evaluated more appropriately.

III. METHODOLOGY

This section includes the details of the methods used in the analysis process. For this purpose, the linguistic 2-tuple information, hesitant fuzzy linguistic term sets, interval-valued intuitionistic Spherical fuzzy sets, DEMATEL and TOPSIS approaches are explained. Finally, the proposed model of this study is identified.

A. LINGUISTIC 2-TUPLE INFORMATION

Linguistic 2-tuple information considers the concept of symbolic translation. The details are given in the following 2 different definitions [28].

Definition 1: The symbolic translation is denoted by $s_i \in S = \{s_0, \ldots, s_g\}$ and it can take the value of [−0.5, 0.5). The difference of the information between an amount of information $\beta \in [0, g]$ and the closest value in $\{0, \ldots, g\}$ is supported by this translation. Within this framework, the index of the closest linguistic term is indicated regarding the closest value [81]

In addition, 2-tuples are indicated as (si, αi), si ∈ S and αi ∈ [−0.5, 0.5]. Moreover, the definition regarding this concept is stated below [29].

Definition 2: When $\beta \in [0, g]$ indicates that value which supports the result of a symbolic aggregation operation, 2-tuples can be obtained by considering the equations (1) and (2) [81].

$$\Delta : [0, g] \rightarrow S \times (-0.5, .0.5)\ (1) \tag{1}$$

$$(\boldsymbol{\beta}) = (\boldsymbol{s_i}, \boldsymbol{\alpha}), \quad with \begin{cases} s_i & i = round\ (\beta) \\ \alpha = \beta - i & \alpha \in [-0.5, 0, 5) \end{cases} \tag{2}$$

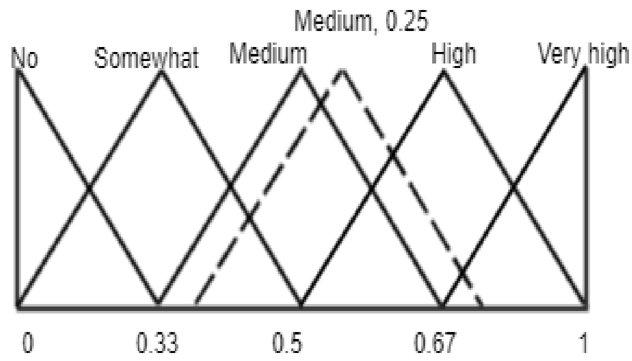

FIGURE 1. **2-tuple linguistic information and sets.**

In these equations, α gives information about the value of the symbolic translation. On the other side, s_i gives information about the closest index label to β.

Proposition: There is always a function of Δ^{-1} which can return its equivalent numerical value $\beta \in [0, g]$ from a 2-tuple [81]

Proof: The equation (3) can be taken into consideration for this regard.

$$\Delta^{-1} : S \times [-0, 5, 0.5) \rightarrow [0, g], \quad \Delta^{-1}(s_i, \alpha) = i + \alpha = \beta \tag{3}$$

The details of 2-tuple linguistic term sets can be demonstrated as in Figure 1.

B. HESITANT FUZZY LINGUISTIC TERM SETS (HFLTS)

For the explanation of HFLTS, two different definitions can be identified.

Definition 3: A linguistic term set can be defined as $S = \{s_0, \cdots, s_\tau\}$. The equation (4) indicates the HFLTS (H_S) [82].

$$H_S = \{s_i, s_{i+1}, \cdots, s_j\}, \quad s_k \in S, k \in \{i, \cdots, j\} \tag{4}$$

On the other side, $G_H = (V_N, V_T, I, P)$ gives information about the context-free grammars which are detailed below [33].

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

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

$$\begin{aligned} I &\in V_N, \\ &= \{I ::= \langle primaryterm \rangle \mid \langle compositeterm \rangle, \\ &\quad \langle compositeterm \rangle ::= \langle compositeterm \rangle \langle primaryterm \rangle \\ &\quad \big| \langle binaryrelation \rangle \langle primaryterm \rangle \\ &\quad \big| \langle conjunction \rangle \langle primaryterm \rangle, \\ &\quad \langle primaryterm \rangle ::= S_0 \,|S_1\, |\ldots |S_t, \\ &\quad \langle unaryrelation \rangle ::= lowerthan\, |greaterthan \\ &\quad |atleast\ |atmost, \\ &\quad \langle binaryrelation \rangle ::= between, \\ &\quad \langle conjunction \rangle ::= and\} \end{aligned}$$

Moreover, these expressions can be transferred to the HFLTS with the help of the definition 4 [34].

Definition 4: E_{G_H} shows the transformation function which converts the comparative linguistic expressions $ll \in S_{ll}$ to HFLTS with the equation (5) [83].

$$E_{G_H} : S_{ll} \rightarrow H_s \tag{5}$$

Additionally, ll can be modelled while considering the trapezoidal fuzzy membership functions as in the equation (6). In this equation, a, b, c and d demonstrate the trapezoidal fuzzy numbers [35].

$$(H_s) = T\,(a, b, c, d) \tag{6}$$

C. INTERVAL-VALUED INTUITIONISTIC SPHERICAL FUZZY SETS

Intuitionistic fuzzy set can be shown as I and it is detailed in the equation (7). In this equation, $\mu_I(\vartheta) : U \rightarrow [0, 1]$ and $n_I(\vartheta) : U \rightarrow [0, 1]$ represent the membership and non-membership degrees and they can be defined as $0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1$ [30].

$$I = \left\{ \frac{\langle \vartheta, \mu_I, (\vartheta), n_I, (\vartheta) \rangle}{\vartheta \epsilon U} \right\} \tag{7}$$

On the other side, the degrees of belongingness and non-belongingness of ϑ can be demonstrated as $\mu_I(\vartheta)$ and $n_I(\vartheta)$. The upper and lower values of $\mu_I(\vartheta)$ are indicated as $\mu_{IU}(\vartheta)$ and $\mu_{IL}(\vartheta)$. Moreover, $n_{IU}(\vartheta)$ and $n_{IL}(\vartheta)$ give information about the upper and lower values of $n_I(\vartheta)$. Hence, the intuitionistic fuzzy set can also be indicated as in the equations (8) and (9) [31].

$$I = \left\{ \vartheta, [\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)], \frac{[n_{IL}(\vartheta), n_{IU}(\vartheta)]}{\vartheta \epsilon U} \right\} \tag{8}$$

$$0 \leq \mu_{IU}(\vartheta) + n_{IU}(\vartheta) \leq 1 \quad \mu_{IL}(\vartheta) \geq 0,\ n_{IL}(\vartheta) \geq 0 \tag{9}$$

Additionally, the equation (10) demonstrates the unknown degree.

$$\tau_I(\vartheta) = 1 - \mu_I(\vartheta) - n_I(\vartheta) \tag{10}$$

Furthermore, the elements of IVIF set can be shown in the equation (11). In this equation, a, b, c, d represent $\mu_{IL}(\vartheta), \mu_{IU}(\vartheta), n_{IL}(\vartheta), n_{IU}(\vartheta)$ [32].

Spherical fuzzy sets ($\tilde{A}_S$) consider the hesitancy degree of fuzzy set. Within this framework, the squared sum of membership, non-membership, and hesitancy are denoted as μ, ν, and π, respectively [25]. The equations (11) and (12) identify the details of this process.

$$\tilde{A}_S = \left\{ \langle u, (\mu_{\tilde{A}_S}(u), \nu_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(u)) | u \in U \right\} \tag{11}$$

$$0 \leq \mu^2_{\tilde{A}_S}(u) + \nu^2_{\tilde{A}_S}(u) + \pi^2_{\tilde{A}_S}(u) \leq 1 \tag{12}$$

In addition, Figure 2 also illustrates this situation.

$\tilde{A}_S = \left(\mu_{\tilde{A}_S}, \nu_{\tilde{A}_S}, \pi_{\tilde{A}_S}\right)$ and $\tilde{B}_S = \left(\mu_{\tilde{B}_S}, \nu_{\tilde{B}_S}, \pi_{\tilde{B}_S}\right)$ give information about two Spherical fuzzy sets from two different universes of X_1 and X_2 [26]. The details of them are given in the equations (13)-(16).

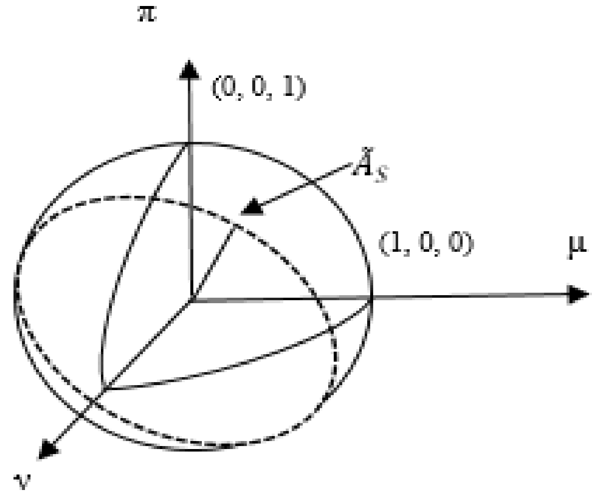

FIGURE 2. Illustration of Spherical fuzzy sets.

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ \left(\mu^2_{\tilde{A}_S} + \mu^2_{\tilde{B}_S} - \mu^2_{\tilde{A}_S}\mu^2_{\tilde{B}_S} \right)^{\frac{1}{2}}, \nu_{\tilde{A}_S}\nu_{\tilde{B}_S}, \left(\left(1 - \mu^2_{\tilde{B}_S}\right)\pi^2_{\tilde{A}_S} + \left(1 - \mu^2_{\tilde{A}_S}\right)\pi^2_{\tilde{B}_S} - \pi^2_{\tilde{A}_S}\pi^2_{\tilde{B}_S} \right)^{\frac{1}{2}} \right\} \tag{13}$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \left(\mu_{\tilde{A}_S}\mu_{\tilde{B}_S}, (\nu^2_{\tilde{A}_S} + \nu^2_{\tilde{B}_S} - \nu^2_{\tilde{A}_S}\nu^2_{\tilde{B}_S} \right)^{\frac{1}{2}}, \left(\left(1-\nu^2_{\tilde{B}_S}\right)\pi^2_{\tilde{A}_S} + \left(1-\nu^2_{\tilde{A}_S}\right)\pi^2_{\tilde{B}_S} - \pi^2_{\tilde{A}_S}\pi^2_{\tilde{B}_S} \right)^{\frac{1}{2}} \right\} \tag{14}$$

$$\lambda * \tilde{A}_S = \left\{ \left(1 - \left(1 - \mu^2_{\tilde{A}_S}\right)^{\lambda} \right)^{\frac{1}{2}}, \nu^{\lambda}_{\tilde{A}_S}, \left(\left(1 - \mu^2_{\tilde{A}_S}\right)^{\lambda} - \left(1 - \mu^2_{\tilde{A}_S} - \pi^2_{\tilde{A}_S}\right)^{\lambda} \right)^{\frac{1}{2}} \right\}, \quad \lambda > 0 \tag{15}$$

$$\tilde{A}^{\lambda}_S = \left\{ \mu^{\lambda}_{\tilde{A}_S}, \left(1 - \left(1 - \nu^2_{\tilde{A}_S}\right)^{\lambda} \right)^{\frac{1}{2}}, \left(\left(1 - \nu^2_{\tilde{A}_S}\right)^{\lambda} - \left(1 - \nu^2_{\tilde{A}_S} - \pi^2_{\tilde{A}_S}\right)^{\lambda} \right)^{\frac{1}{2}} \right\}, \quad \lambda > 0 \tag{16}$$

Furthermore, Spherical fuzzy numbers based on IVIFSs can be illustrated as in the equations (17) and (18).

$$IS = \left\{ \frac{\langle \vartheta, [\vartheta^L_P(\vartheta), \mu^U_P(\vartheta)], [\nu^L_P(\vartheta), \nu^U_P(\vartheta)], [\pi^L_P(\vartheta), \pi^U_P(\vartheta)] \rangle}{\vartheta \epsilon U} \right\} \tag{17}$$

$$0 \leq \left(\mu^U_P(\vartheta)\right)^2 + \left(\nu^U_P(\vartheta)\right)^2 + \left(\pi^U_P(\vartheta)\right)^2 \leq 1 \tag{18}$$

Additionally, the equation (19) gives information about the elements of interval-valued spherical fuzzy sets (IVSFSs). In this equation, a, b, c, d, ef indicate $\mu_P^L(\vartheta)$, $\mu_P^U(\vartheta)$, $v_P^L(\vartheta)$, $v_P^U(\vartheta)$, $\pi_P^L(\vartheta)$, $\pi_P^U(\vartheta)$.

$$IS = \langle [a, b], [c, d], [e, f] \rangle \tag{19}$$

Finally, the defuzzified values of IVSFSs are calculated with the help of a score function as in the equation (20) [27].

$$Score(\tilde{A}_S) = \left(\mu_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 - \left(v_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 \tag{20}$$

D. DEMATEL

DEMATEL methodology can be considered to find the importance levels of different factors. Additionally, impact relation map between these items can also be generated with the help of this approach. Hence, the cause-and-effect analysis of the factors can be identified [19]. In the first stage, the direct relation matrix (A) is created by using the evaluations of the experts. The equation (21) indicates the details of this matrix. In this equation, the influence of criterion i on the criterion j is shown as a_{ij}.

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

Later, this matrix is normalized with the equations (22) and (23).

$$B = \frac{A}{max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}} \tag{22}$$

$$0 \leq b_{ij} \leq 1 \tag{23}$$

The next step is related to the generation of the total relation matrix (C). For this purpose, the equation (24) is taken into consideration. The term I represents the identity matrix in this equation [20].

$$C = B(I - B)^{-1} \tag{24}$$

Furthermore, the sums of rows and columns (D and E) are calculated by using the equations (25) and (26).

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \tag{25}$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \tag{26}$$

In order to compute the weights of the criteria, D+E is considered. Additionally, the causal relationship can be identified with the help of D-E. Also, threshold value (α) is also considered in the generation of impact relation map and this value is calculated as in the equation (27) [21].

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij}\right]}{N} \tag{27}$$

E. TOPSIS

TOPSIS approach is used to rank the alternatives. In this framework, the distances from the negative and positive ideal solutions are taken into consideration [22]. The normalized values are defined in the first step as in the equation (28).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{28}$$

In the second step, these values are weighted with the help of the equation (29).

$$v_{ij} = w_{ij} \times r_{ij} \tag{29}$$

In this equation, w gives information about the significance weight. Additionally, the third step includes the calculation of the positive ($\boldsymbol{A}^+$) and negative ($\boldsymbol{A}^-$) ideal solutions [23]. These values are calculated as in the equations (30) and (31).

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j} for \forall j \in n\} \tag{30}$$

$$\boldsymbol{A}^- = \{\boldsymbol{v_{1j}}, \boldsymbol{v_{2j}}, \ldots, \boldsymbol{v_{mj}}\} = \{\min \boldsymbol{v_{1j}}\ \boldsymbol{for}\ \forall \boldsymbol{j} \in \boldsymbol{n}\} \tag{31}$$

The next step is related to the identification of the distances to the best ($\boldsymbol{D_i^+}$) and the worst alternative ($\boldsymbol{D_i^-}$) by considering the equations (32) and (33) [24].

$$\boldsymbol{D_i^+} = \sqrt{\sum_{j=1}^{n} \left(\boldsymbol{v_{ij}} - \boldsymbol{A_j^+}\right)^2} \tag{32}$$

$$\boldsymbol{D_i^-} = \sqrt{\sum_{j=1}^{n} \left(\boldsymbol{v_{ij}} - \boldsymbol{A_j^-}\right)^2} \tag{33}$$

In the final step, the relative closeness to the ideal solution (RC_i) is calculated as in the equation (34) to rank the alternatives.

$$\boldsymbol{RC_i} = \frac{\boldsymbol{D_i^-}}{\boldsymbol{D_i^+} + \boldsymbol{D_i^-}} \tag{34}$$

F. PROPOSED MODEL

By considering the methods explained in this section, a novel model is generated. Figure 3 shows the details of this new model.

Figure 3 gives information that this model has three different stages. The first stage is related to the constructing the immediate predecessors of new service development process for renewable energy investment projects. Firstly, 10 different items of NSD process are defined for renewable energy investments projects. Next, 4 different experts are appointed for the linguistic evaluations and evaluations are collected from this people based on hesitant fuzzy linguistic term sets. After that, the collective envelopes based on 2-tuple linguistic information are defined. Later, the interval valued Spherical Fuzzy evaluations are calculated, and the defuzzificated values of relation matrix are generated. These values are normalized in the next step. Finally, the weights of the criteria are calculated by using IVIFS DEMATEL. Moreover, in the second stage, the critical paths are identified

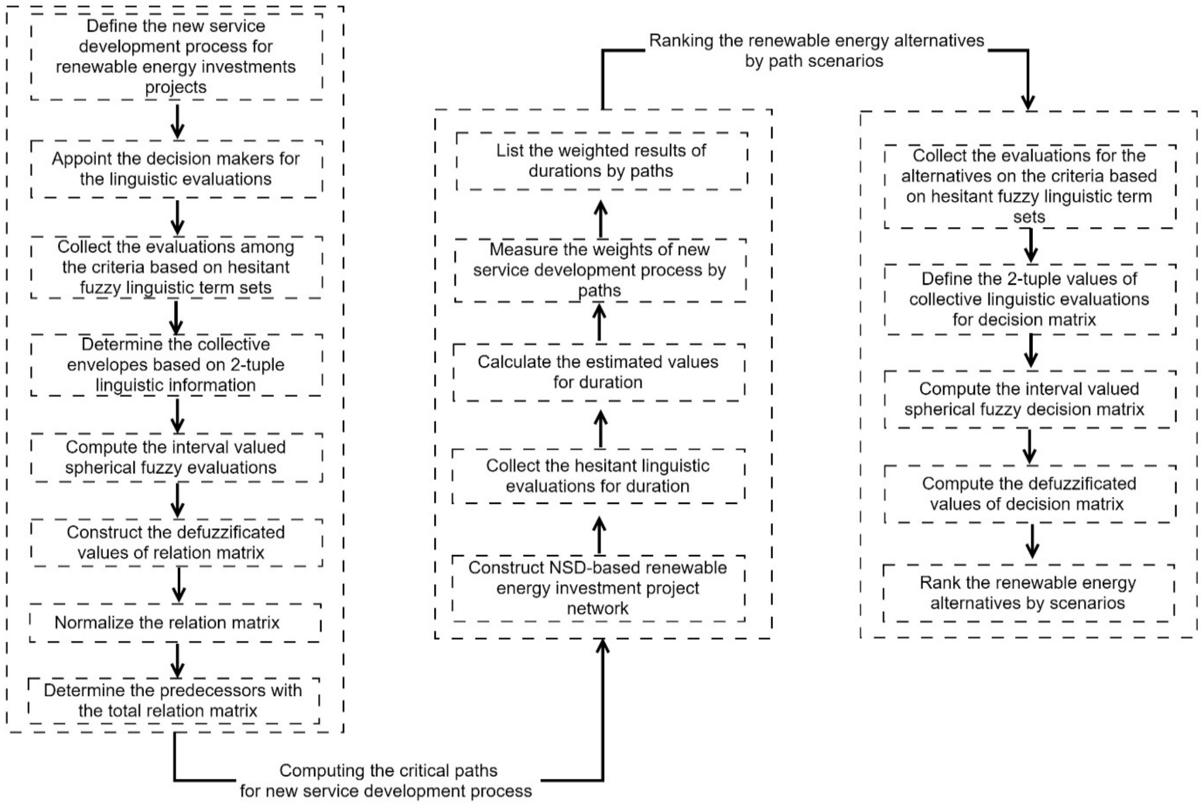

FIGURE 3. Algorithm of proposed model.

TABLE 1. New service development process for renewable energy investment projects.

Criteria
Strategic planning (Criterion 1)
Idea generation (Criterion 2)
Idea screening (Criterion 3)
Business analysis (Criterion 4)
Formation of cross-functional team (Criterion 5)
Service design and process/system design (Criterion 6)
Personnel training (Criterion 7)
Service testing and pilot run (Criterion 8)
Test marketing (Criterion 9)
Commercialization (Criterion 10)

TABLE 2. The details of the experts (E).

Es	Industry	Experience	Title	Education
E1	Manufacturing	19 years	General Manager	Business Management
E2	Construction	23 years	General Manager	Industrial Engineering
E3	Manufacturing	26 years	Founder	Industrial Engineering
E4	Retailing	17 years	Deputy General Manager	Industrial Engineering

for NSD process. Within this framework, first, NSD-based renewable energy investment project network is developed.

TABLE 3. Linguistic scales and fuzzy preference numbers.

Linguistic Scales	Preference Numbers
No influence (n)	0
somewhat influence (s)	0.25
medium influence (m)	0.50
high influence (h)	0.75
very high influence (vh)	1

The hesitant linguistic evaluations for duration are obtained in the second step. With the help of them, the estimated values for activity duration are computed. Next, the weights of NSD process are calculated according to the paths and duration. Furthermore, the third stage of this model includes the ranking of the renewable energy alternatives. At first, the evaluations are collected for the alternatives. After that, the 2-tuple values of collective linguistic evaluations for decision matrix are identified. In the next step, the interval valued Spherical fuzzy decision matrix is created. Later, the defuzzificated values of decision matrix are computed. In the final step, the renewable energy alternatives are ranked according to different scenarios with the help of the IVIFS TOPSIS.

There are many different novelties of this proposed model. The first important novelty of this model is considering

TABLE 4. Context-free grammar evaluations of the experts.

	E1								
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	at least “h”	at least “h”	between “m” and “h”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”
C2		between “m” and “vh”	greater than “m”	between “s“ and “m”	between “s“ and “m”	at most “s”	at most “s”	between “s“ and “m”	at most “s”
C3			at least “m”	between “m“ and “vh”	between “m“ and “h”	between “s“ and “m”	between “s“ and “m”	at most “s”	at most “s”
C4				between “m“ and “vh”	between “m“ and “h”	at most “m”	between “n“ and “m”	between “s“ and “m”	between “s“ and “m”
C5					between “m“ and “h”	between “m“ and “vh”	between “n“ and “m”	between “s“ and “m”	between “s“ and “m”
C6						between “m“ and “vh”	at least “m”	between “s“ and “m”	between “s“ and “m”
C7							at most “m”	between “s“ and “m”	between “n“ and “m”
C8								at least “h”	at most “m”
C9									at least “h”
	E2								
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	between “m” and “vh”	at least “h”	between “m” and “vh”	between “s“ and “m”	between “s“ and “m”	at most “s”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”
C2		between “m” and “vh”	between “m” and “vh”	at most “s”	at most “s”	at most “s”	at most “s”	between “s“ and “m”	at most “m”
C3			between “m” and “vh”	between “m“ and “vh”	between “m“ and “h”	between “s“ and “m”	at most “s”	at most “s”	at most “s”
C4				between “m“ and “vh”	between “m“ and “h”	at most “m”	between “n“ and “m”	between “s“ and “m”	at most “m”
C5					between “m“ and “h”	between “m“ and “vh”	at least “m”	between “n“ and “m”	between “s“ and “m”
C6						between “m“ and “vh”	at most “s”	between “s“ and “m”	between “n“ and “m”
C7							at least “h”	at most “m”	at most “s”
C8								between “h“ and “vh”	at most “s”
C9									at least “h”
	E3								
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	between “m” and “vh”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	at most “s”	at most “s”	at most “s”	at most “s”
C2		between “m” and “vh”	between “n“ and “m”	between “n“ and “m”	at most “s”	at most “s”	at most “s”	at most “s”	at most “s”
C3			between “m“ and “vh”	between “m“ and “vh”	between “m“ and “h”	between “s“ and “m”	at most “s”	at most “s”	at most “s”
C4				between “m“ and “vh”	between “n“ and “m”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “n“ and “m”
C5					between “m“ and “vh”	between “s“ and “m”	at least “m”	between “n“ and “m”	between “s“ and “m”
C6						between “m“ and “vh”	at most “s”	between “s“ and “m”	between “s“ and “m”
C7							between “m“ and “vh”	at most “m”	at most “s”
C8								between “h“ and “vh”	at most “s”
C9									between “m“ and “vh”
	E4								
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	between “h” and “vh”	between “h” and “vh”	at most “s”	at most “s”	between “s“ and “m”	at most “s”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”

TABLE 4. *(Continued.)* **Context-free grammar evaluations of the experts.**

C2		between “h” and “vh”	between “h“ and “vh”	between “n“ and “m”	at most “s”	between “s“ and “m”	between “s“ and “m”	at most “s”	between “s“ and “m”
C3			between “h“ and “vh”	between “h“ and “vh”	between “s“ and “m”	between “s“ and “m”	at most “s”	between “s“ and “m”	between “s“ and “m”
C4				between “h“ and “vh”	between “h“ and “vh”	between “s“ and “m”	between “s“ and “m”	between “s“ and “m”	between “n“ and “m”
C5					between “h“ and “vh”	between “h“ and “vh”	between “s“ and “m”	between “n“ and “m”	between “s“ and “m”
C6						between “m“ and “vh”	between “h“ and “vh”	between “s“ and “m”	between “s“ and “m”
C7							between “h“ and “vh”	between “h“ and “vh”	between “s“ and “m”
C8								between “h“ and “vh”	between “s“ and “m”
C9									between “h“ and “vh”

hybrid methodology. In other types of models, only one MCDM technique is considered to rank the alternatives [16]. In this process, the weights of the criteria are defined by the researchers subjectively. Nonetheless, with respect to the hybrid MCDM model, MCDM approaches are considered for both weighting the criteria and ranking the alternatives [17]. Thus, the main benefit of hybrid MCDM model is making objective evaluations in all stages [18]. Another important novelty of this model is considering DEMATEL approach to list of activity and immediate predecessors for NSD process. In most of the studies that consider PERT analysis, these factors are defined by the authors in a subjective manner. However, in this study, these paths are identified by considering the impact relation map of DEMATEL analysis [19], [20]. It is obvious that more effective paths can be defined in this way [21]. Furthermore, the main advantage of TOPSIS is considering the distances to both positive and negative ideal solutions [22]. Hence, by ranking renewable energy alternatives with this methodology in this study, more appropriate results can be achieved [23], [24]. Additionally, using Spherical fuzzy sets in the analysis process contributes to make more effective evaluations because they consider both membership, non-membership and hesitancy parameters [25]–[27]. On the other side, the data can be fuzzified more accurately with the help of 2 tuple linguistic evaluation [28]. Owing to this issue, the loss of the information can be minimized [29]. Furthermore, the positive and the negative indications of an element's values can be differentiated more effectively with the help of the IVIF sets [30]–[32]. Additionally, ranking the renewable energy alternatives by considering different scenarios is very helpful to generate appropriate investment strategies for different conditions. Finally, using hesitant fuzzy linguistic term sets provides opportunity to express the hesitant information more comprehensively [33]–[35].

IV. ANALYSIS RESULTS

The results of proposed hybrid hesitant 2-tuple IVSF decision making approach are given in the stages to analyze the critical paths of new service development process for renewable energy investment projects as follows.

STAGE 1: CONSTRUCTING THE IMMEDIATE PREDECESSORS OF NEW SERVICE DEVELOPMENT PROCESS FOR RENEWABLE ENERGY INVESTMENT PROJECTS

In this stage, there are 8 different steps. Firstly, the new service development process is defined for renewable energy investments projects. Within this framework, 10 different new service development stages emphasized by Alam and Perry [57] and Alam [84] are determined as criteria. The details of these items are given on Table 1.

The step two includes the appointment of the experts for the linguistic evaluations. The details of 4 different experts are demonstrated in Table 2.

Table 2 explains necessary details of the experts, such as experience, title, and education. These experts consist of people who have at least 17-year experience in this area. Additionally, they are top level managers. By considering these factors, it is obvious that these experts have wide knowledge to evaluate the criteria. In step 3, the evaluations are collected among the criteria based on hesitant fuzzy linguistic term sets. In this scope, the linguistic scales and fuzzy preference numbers are considered as in Table 3.

The context-free grammar evaluations among criteria are collected from the experts based on hesitant linguistic term sets. Hierarchical directions are considered among the criteria to construct the immediate predecessors for PERT-based factors. Accordingly, the results are shown in Table 4.

Additionally, the linguistic limits of decision makers are employed for each pairwise comparison in Table 5.

Moreover, in the step 4, the collective envelopes based on 2-tuple linguistic information is determined. For this purpose, 2-tuple values of collective linguistic evaluations for membership and non-membership degrees are defined in Table 6.

The fifth step is related to the calculation of the interval valued Spherical Fuzzy evaluations. The normalized values are obtained with the boundaries of $0\leq \mu_p^2(u) + v_p^2(u) +$

TABLE 5. Boundaries of linguistic term sets.

				E1					
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	$[h, vh]$	$[h, vh]$	$[m, h]$	$[s, m]$	$[s, m]$	$[s, m]$	$[s, m]$	$[s, m]$	$[s, m]$
C2		$[m, vh]$	$[h, vh]$	$[s, m]$	$[s, m]$	$[n, s]$	$[n, s]$	$[s, m]$	$[n, s]$
C3			$[m, vh]$	$[m, vh]$	$[m, h]$	$[s, m]$	$[s, m]$	$[n, s]$	$[n, s]$
C4				$[m, vh]$	$[m, h]$	$[n, m]$	$[n, m]$	$[s, m]$	$[s, m]$
C5					$[m, h]$	$[m, vh]$	$[m, vh]$	$[s, m]$	$[s, m]$
C6						$[m, vh]$	$[n, m]$	$[s, m]$	$[n, m]$
C7							$[h, vh]$	$[n, m]$	$[s, m]$
C8								$[h, vh]$	$[n, m]$
C9									$[h, vh]$
				E2					
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	$[m, vh]$	$[h, vh]$	$[m, vh]$	$[s, m]$	$[s, m]$	$[n, s]$	$[s, m]$	$[s, m]$	$[s, m]$
C2		$[m, vh]$	$[m, vh]$	$[n, m]$	$[n, s]$	$[n, s]$	$[n, s]$	$[s, m]$	$[n, m]$
C3			$[m, vh]$	$[m, vh]$	$[m, h]$	$[s, m]$	$[n, s]$	$[n, s]$	$[n, s]$
C4				$[m, vh]$	$[m, h]$	$[n, m]$	$[s, m]$	$[s, m]$	$[n, m]$
C5					$[m, h]$	$[m, vh]$	$[m, vh]$	$[n, m]$	$[s, m]$
C6						$[m, vh]$	$[n, s]$	$[s, m]$	$[n, m]$
C7							$[h, vh]$	$[n, m]$	$[n, s]$
C8								$[h, vh]$	$[n, s]$
C9									$[h, vh]$
				E3					
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	$[m, vh]$	$[s, m]$	$[s, m]$	$[s, m]$	$[s, m]$	$[n, s]$	$[n, s]$	$[n, s]$	$[n, s]$
C2		$[m, vh]$	$[n, m]$	$[n, m]$	$[n, s]$	$[n, s]$	$[n, s]$	$[n, s]$	$[n, s]$
C3			$[m, vh]$	$[m, vh]$	$[m, h]$	$[s, m]$	$[n, s]$	$[n, s]$	$[n, s]$
C4				$[m, vh]$	$[n, m]$	$[s, m]$	$[s, m]$	$[s, m]$	$[n, m]$
C5					$[m, vh]$	$[s, m]$	$[m, vh]$	$[n, m]$	$[s, m]$
C6						$[m, vh]$	$[n, s]$	$[s, m]$	$[s, m]$
C7							$[m, vh]$	$[n, m]$	$[n, s]$
C8								$[h, vh]$	$[n, s]$
C9									$[m, vh]$
				E4					
	C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	$[h, vh]$	$[h, vh]$	$[n, s]$	$[n, s]$	$[s, m]$	$[n, s]$	$[s, m]$	$[s, m]$	$[s, m]$
C2		$[h, vh]$	$[h, vh]$	$[n, m]$	$[n, s]$	$[s, m]$	$[s, m]$	$[n, s]$	$[s, m]$
C3			$[h, vh]$	$[h, vh]$	$[s, m]$	$[s, m]$	$[n, s]$	$[s, m]$	$[s, m]$
C4				$[h, vh]$	$[h, vh]$	$[s, m]$	$[s, m]$	$[s, m]$	$[n, m]$
C5					$[h, vh]$	$[h, vh]$	$[s, m]$	$[n, m]$	$[s, m]$
C6						$[m, vh]$	$[h, vh]$	$[s, m]$	$[s, m]$
C7							$[h, vh]$	$[h, vh]$	$[s, m]$
C8								$[h, vh]$	$[s, m]$
C9									$[h, vh]$

$\pi_p^2(u) \leq 1$ for the member, non-membership, and hesitant degrees of interval valued Spherical fuzzy sets. Table 7 gives information about the relation matrix based on interval valued Spherical fuzzy sets.

Furthermore, in the sixth step, the defuzzificated values of relation matrix are constructed. The defuzzifaction procedure is applied and the averages of lower and upper values are considered for the membership, non-membership, and hesitant degrees are the defuzzified direct relation matrix for the criteria is given in Table 8.

In the seventh step, the relation matrix is normalized. Table 9 represents the normalized relation matrix.

TABLE 6. 2-tuple values of collective linguistic evaluations.

	C2		C3		C4		C5		C6		C7		C8		C9		C10	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
C1	(vh,0)	(m,0.33)	(h,0.33)	(h,-0.33)	(m,0.33)	(m,-0.33)	(h,-0.33)	(s,-0.33)	(m,0.33)	(s,0)	(s,0.33)	(n,0.33)	(m,-0.33)	(s,-0.33)	(m,-0.33)	(s,-0.33)	(m,-0.33)	(s,-0.33)
C2			(vh,0)	(m,0.33)	(h,0.33)	(m,0)	(m,0)	(n,0.33)	(s,0.33)	(n,0.33)	(s,0.33)	(n,0.33)	(s,0.33)	(n,0.33)	(s,0.33)	(s,-0.33)	(m,-0.33)	(n,0.33)
C3					(vh,0)	(m,0.33)	(vh,0)	(m,0.33)	(h,-0.33)	(m,-0.33)	(m,0)	(s,0)	(s,0.33)	(n,0.33)	(s,0.33)	(n,0.33)	(m,-0.33)	(n,0.33)
C4							(vh,0)	(m,0.33)	(h,0)	(m,-0.33)	(m,0)	(s,-0.33)	(m,0)	(s,-0.33)	(m,0)	(s,0)	(m,0)	(n,0.33)
C5									(vh,-0.33)	(m,0.33)	(vh,-0.33)	(m,0)	(vh,-0.33)	(m,-0.33)	(m,0)	(n,0.33)	(m,0)	(s,0)
C6											(vh,0)	(m,0)	(m,0)	(s,-0.33)	(m,0)	(s,0)	(m,0)	(s,-0.33)
C7													(vh,0)	(h,-0.33)	(m,0.33)	(s,-0.33)	(m,-0.33)	(s,-0.33)
C8															(vh,0)	(h,0)	(m,-0.33)	(n,0.33)
C9																	(vh,0)	(h,-0.33)

TABLE 7. Relation matrix based on interval valued spherical fuzzy sets.

	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	([0.80,0.90], [0.10,0.19], [0.10,0.19])	([0.60,0.79], [0.10,0.19], [0.10,0.19])	([0.40,0.56], [0.05,0.09], [0.05,0.09])	([0.20,0.39], [0.05,0.06], [0.05,0.06])	([0.40,0.45], [0.05,0.08], [0.05,0.08])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.39], [0.05,0.06], [0.05,0.06])	([0.20,0.39], [0.05,0.06], [0.05,0.06])	([0.20,0.39], [0.05,0.06], [0.05,0.06])
C2		([0.80,0.90], [0.10,0.17], [0.10,0.17])	([0.60,0.79], [0.10,0.15], [0.10,0.15])	([0.40,0.45], [0.01,0.02], [0.01,0.02])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.34], [0.01,0.04], [0.01,0.04])	([0.20,0.34], [0.01,0.02], [0.01,0.02])
C3			([0.80,0.90], [0.10,0.17], [0.10,0.17])	([0.80,0.90], [0.10,0.17], [0.10,0.17])	([0.60,0.62], [0.10,0.13], [0.10,0.13])	([0.40,0.45], [0.05,0.08], [0.05,0.08])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.28], [0.01,0.02], [0.01,0.02])	([0.20,0.28], [0.01,0.02], [0.01,0.02])
C4				([0.80,0.90], [0.10,0.17], [0.10,0.17])	([0.60,0.68], [0.10,0.13], [0.10,0.13])	([0.40,0.45], [0.01,0.04], [0.01,0.04])	([0.40,0.45], [0.05,0.06], [0.05,0.06])	([0.40,0.45], [0.05,0.08], [0.05,0.08])	([0.40,0.45], [0.05,0.08], [0.05,0.08])
C5					([0.60,0.79], [0.10,0.17], [0.10,0.17])	([0.60,0.79], [0.10,0.15], [0.10,0.15])	([0.60,0.79], [0.10,0.13], [0.10,0.13])	([0.40,0.45], [0.01,0.02], [0.01,0.02])	([0.40,0.45], [0.01,0.04], [0.01,0.04])
C6						([0.80,0.90], [0.10,0.15], [0.10,0.15])	([0.40,0.45], [0.05,0.06], [0.05,0.06])	([0.40,0.45], [0.05,0.08], [0.05,0.08])	([0.40,0.45], [0.01,0.04], [0.01,0.04])
C7							([0.80,0.90], [0.20,0.21], [0.20,0.21])	([0.40,0.56], [0.05,0.06], [0.05,0.06])	([0.20,0.34], [0.01,0.04], [0.01,0.04])
C8								([0.80,0.90], [0.20,0.23], [0.20,0.23])	([0.20,0.34], [0.01,0.02], [0.01,0.02])
C9									([0.80,0.90], [0.20,0.21], [0.20,0.21])

The final step in this stage is related to the definition of the predecessors with the total relation matrix. The average value of total relation matrix is defined as the threshold and the higher value than the threshold shows that there is an impact on the other criteria. In other word, the criteria listed in rows effects the criteria stated in columns hierarchically. The threshold is computed as the value of 0.254. The impact results are indicated with bold in Table 10.

In addition, with the help of the values in Table 10, the predecessors for the criteria are identified as in Table 11. In this framework, the criteria, which have an impact on a factor, are defined as immediate predecessors. For instance, on Table 10, it can be seen that C1, C2 and C3 have an influence on C4. Hence, the activities A, B and C are determined as the predecessors of the activity D.

STAGE 2: COMPUTING THE CRITICAL PATHS FOR NEW SERVICE DEVELOPMENT PROCESS

This section has 5 different steps. Firstly, NSD-based renewable energy investment project network is constructed. Investment project network is constructed with several alternative paths by using the immediate predecessors of new service development process in renewable energy investment projects. Figure 4 illustrates the project network with several activities of new service development process.

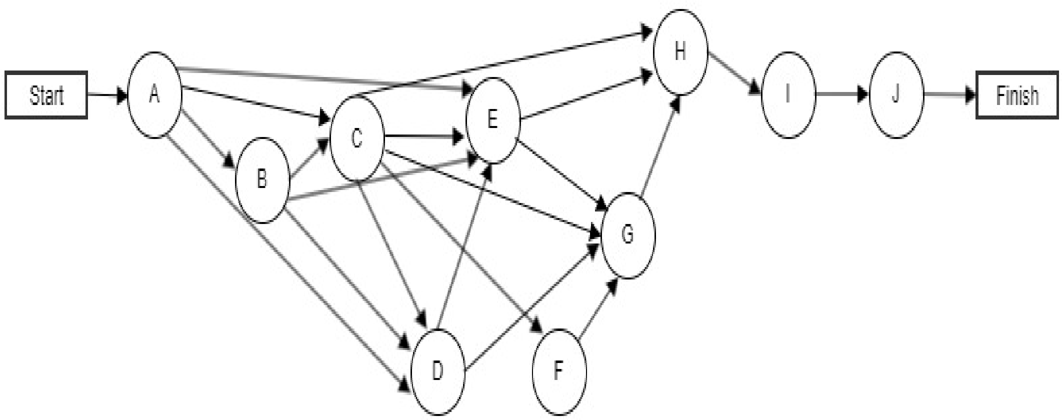

FIGURE 4. NSD-based renewable energy investment project network.

TABLE 8. Defuzzified direct relation matrix.

Criteria	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.5	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.07
C2	0	0.5	0.3	0.2	0.1	0.1	0.1	0.1	0.07
C3	0	0	0.5	0.5	0.2	0.1	0.1	0.1	0.05
C4	0	0	0	0.5	0.3	0.2	0.1	0.1	0.17
C5	0	0	0	0	0.3	0.3	0.3	0.2	0.13
C6	0	0	0	0	0	0.5	0.1	0.2	0.16
C7	0	0	0	0	0	0	0.4	0.2	0.06
C8	0	0	0	0	0	0	0	0.4	0.07
C9	0	0	0	0	0	0	0	0	0.42

TABLE 9. Normalized direct relation matrix.

Criteria	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.3	0.2	0.1	0	0.1	0	0	0	0.04
C2	0	0.3	0.2	0.1	0	0	0	0	0.04
C3	0	0	0.3	0.3	0.2	0.1	0	0	0.03
C4	0	0	0	0.3	0.2	0.1	0.1	0.1	0.11
C5	0	0	0	0	0.2	0.2	0.2	0.1	0.08
C6	0	0	0	0	0	0.3	0.1	0.1	0.1
C7	0	0	0	0	0	0	0.3	0.1	0.04
C8	0	0	0	0	0	0	0	0.3	0.04
C9	0	0	0	0	0	0	0	0	0.27

TABLE 10. The impact map.

Criteria	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	**0.320**	**0.301**	**0.276**	**0.269**	0.245	0.238	0.234	0.233	0.229
C2	0.000	**0.329**	**0.319**	**0.322**	0.206	0.232	0.225	0.220	0.217
C3	0.000	0.000	**0.329**	**0.437**	**0.303**	**0.313**	**0.270**	0.246	0.229
C4	0.000	0.000	0.000	**0.329**	0.242	**0.255**	0.251	0.240	0.247
C5	0.000	0.000	0.000	0.000	0.203	**0.279**	**0.312**	0.243	0.196
C6	0.000	0.000	0.000	0.000	0.000	**0.338**	0.180	0.182	0.174
C7	0.000	0.000	0.000	0.000	0.000	0.000	**0.270**	0.192	0.104
C8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.262**	0.115
C9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.270**

In addition, the hesitant linguistic evaluations for duration are collected. Collective linguistic evaluations from the decision makers are obtained to evaluate the duration of each activity by using Table 12.

TABLE 11. The list of activity and immediate predecessors for new service development process.

Criteria	New Service Development Process	Activity	Immediate Predecessors
C1	Strategic planning	A	-
C2	Idea generation	B	A
C3	Idea screening	C	A,B
C4	Business analysis	D	A,B,C
C5	Formation of cross-functional team	E	A,B,C,D
C6	Service design and process/system design	F	C
C7	Personnel training	G	C,D,E,F
C8	Service testing and pilot run	H	C,E,G
C9	Test marketing	I	H
C10	Commercialization	J	I

TABLE 12. Linguistic scales and fuzzy preference numbers for duration.

Linguistic Scales	Preference Numbers
very low (vl)	0
low (l)	0.25
moderate (m)	0.50
high (h)	0.75
very high (vh)	1

Moreover, in Table 13, the collective hesitant linguistic evaluations are presented for the activity duration.

The third step is related to the calculation of the estimated values for duration. In this context, the linguistic evaluations are computed by using 2-tuple hesitant IVSF decision making. For this issue, similar procedures in the first stage

TABLE 13. Collective hesitant linguistic evaluations for activity duration.

Activity	Linguistic evaluation	Optimistic Duration	Pessimistic Duration
A	Between "l" and "m"	l	m
B	greater than "l"	m	vh
C	at least "m"	m	vh
D	Between "m" and "h"	m	h
E	Between "m" and "vh"	m	vh
F	at least "l"	l	vh
G	at least "h"	h	vh
H	Between "l" and "m"	l	m
I	greater than "m"	h	vh
J	Between "l" and "m"	l	m

are applied and the results of IVSFSs as well as the estimated values with the defuzzified preferences are presented in Table 14.

TABLE 14. Estimated values for activity duration.

Activity	IVSFSs	Estimated Duration
A	([0.40,0.45],[0.05,0.08],[0.05,0.08])	0.13
B	([0.80,0.90],[0.10,0.15],[0.10,0.15])	0.52
C	([0.80,0.90],[0.10,0.15],[0.10,0.15])	0.52
D	([0.60,0.68],[0.10,0.15],[0.10,0.15])	0.26
E	([0.80,0.90],[0.10,0.15],[0.10,0.15])	0.52
F	([0.80,0.90],[0.05,0.08],[0.05,0.08])	0.62
G	([0.80,0.90],[0.20,0.23],[0.20,0.23])	0.39
H	([0.40,0.45],[0.05,0.08],[0.05,0.08])	0.13
I	([0.80,0.90],[0.20,0.23],[0.20,0.23])	0.39
J	([0.40,0.45],[0.05,0.08],[0.05,0.08])	0.13

On the other side, the fourth step explains the calculation of the weights of new service development process by paths. Within this framework, the values of D and E are computed from the total relation matrix and the values of D+E are considered as the weights of new service development process. Table 15 shows the weighting results for the criteria.

Table 15 states that idea screening (C3) is the most significant factor for NSD process of the renewable energy investments because it has the highest weight (0.121). Additionally, it is also identified that the formation of cross-functional team plays a very crucial role in this regard with the weight of 0.113. However, test marketing and commercialization have the lowest weights (0.091 and 0.078). Renewable energy investments are projects that have high initial costs and involve complex processes. For this reason, it is obvious that the most attention should be paid to the idea generation stage in order to ensure efficiency from these publications. In this context, it should be aimed to make the most creative investment decision possible by obtaining ideas from different segments such as employees, customers and academics. 26 paths are determined with the different combinations based on the immediate predecessors of activities. The overall weights of new service development process are normalized for the activities of each path. The weights of criteria defining the activities by the paths are represented in Table 16.

TABLE 15. The weights of NSD process.

Criteria	D	E	D+E	D-E	Weights
C1	2.35	0.00	2.35	2.35	0.103
C2	2.07	0.32	2.39	1.75	0.105
C3	2.13	0.63	2.76	1.50	0.121
C4	1.56	0.92	2.49	0.64	0.109
C5	1.23	1.36	2.59	-0.12	0.113
C6	0.87	1.20	2.07	-0.33	0.091
C7	0.57	1.65	2.22	-1.09	0.097
C8	0.38	1.74	2.12	-1.37	0.093
C9	0.27	1.82	2.09	-1.55	0.091
C10	0.00	1.78	1.78	-1.78	0.078

The fifth step is related to the listing the weighted results of durations by paths. The activity weights of each path are multiplied with the estimated preference values of activities for the weighted preference results of durations by the paths. The weighted preference results are listed in increasing order to rank the path durations. The results are given in Table 17.

In Table 17, 5 critic paths are determined to rank the renewable energy alternatives in terms of new service development process. Path 6 is the shortest path by duration while Path 15 has the longest duration that is also called as critical path. Path 7 is the longest path by activity number whereas Path 24 and 26 have the least activity numbers.

STAGE 3: RANKING THE RENEWABLE ENERGY ALTERNATIVES BY PATH SCENARIOS

This stage includes 5 different steps. In the first step, the evaluations are collected for the alternatives on the criteria based on hesitant fuzzy linguistic term sets. For this purpose, Linguistic scales and fuzzy preference numbers are considered as in Table 18.

The context-free grammar evaluations are obtained for the renewable energy alternatives in terms of the criteria. The evaluation results of renewable energy alternatives are illustrated by considering all activities of new service development process. The linguistic results including all activities for decision matrix are seen in Table 19.

Moreover, the linguistic limits for decision matrix are determined in Table 20.

On the other side, the second step is related to the definition of the 2-tuple values of collective linguistic evaluations for decision matrix. The results for membership and non-membership degrees are given in Table 21.

Additionally, the step 3 includes the calculation of the interval valued Spherical fuzzy decision matrix. The normal-

TABLE 16. The activity weights (W) by paths (P).

P1	Ws	P2	Ws	P3	Ws	P4	Ws	P5	Ws	P 6	Ws	P7	Ws	P8	Ws	P9	Ws
A	0.149	A	0.176	A	0.129	A	0.148	A	0.152	A	0.180	A	0.113	A	0.128	A	0.130
B	0.152	C	0.207	B	0.131	C	0.174	B	0.155	D	0.191	B	0.115	C	0.150	B	0.133
C	0.176	G	0.167	C	0.152	D	0.157	D	0.161	G	0.170	C	0.133	D	0.135	D	0.138
G	0.141	H	0.159	D	0.137	G	0.141	G	0.144	H	0.162	D	0.120	E	0.141	E	0.144
H	0.135	I	0.157	G	0.122	H	0.134	H	0.137	I	0.160	E	0.125	G	0.121	G	0.123
I	0.133	J	0.134	H	0.116	I	0.132	I	0.135	J	0.137	G	0.107	H	0.115	H	0.118
J	0.113			I	0.115	J	0.113	J	0.115			H	0.102	I	0.114	I	0.116
				J	0.098							I	0.100	J	0.097	J	0.099
												J	0.086				
P10	**Ws**	**P11**	**Ws**	**P12**	**Ws**	**P13**	**Ws**	**P14**	**Ws**	**P15**	**Ws**	**P16**	**Ws**	**P17**	**Ws**	**P18**	**Ws**
A	0.150	A	0.128	A	0.147	A	0.151	A	0.178	A	0.132	A	0.152	A	0.126	A	0.145
D	0.159	B	0.131	C	0.173	B	0.154	E	0.197	B	0.134	C	0.179	B	0.129	C	0.171
E	0.166	C	0.151	E	0.163	E	0.167	G	0.169	C	0.155	F	0.135	C	0.149	D	0.154
G	0.142	E	0.142	G	0.140	G	0.143	H	0.161	F	0.117	G	0.144	D	0.134	E	0.160
H	0.136	G	0.121	H	0.133	H	0.136	I	0.159	G	0.125	H	0.138	E	0.140	H	0.131
I	0.134	H	0.116	I	0.131	I	0.134	J	0.136	H	0.119	I	0.136	H	0.114	I	0.129
J	0.114	I	0.114	J	0.112	J	0.115			I	0.117	J	0.116	I	0.113	J	0.110
		J	0.097							J	0.100			J	0.096		
P19	**Ws**	**P 20**	**Ws**	**P 21**	**Ws**	**P22**	**Ws**	**P23**	**Ws**	**P24**	**Ws**	**P 25**	**Ws**	**P 26**	**Ws**		
A	0.148	A	0.175	A	0.146	A	0.171	A	0.176	A	0.215	A	0.174	A	0.211		
B	0.151	D	0.185	B	0.149	C	0.202	B	0.179	E	0.237	B	0.177	C	0.249		
D	0.157	E	0.193	C	0.172	E	0.189	E	0.195	H	0.194	C	0.205	H	0.191		
E	0.164	H	0.158	E	0.161	H	0.155	H	0.159	I	0.191	H	0.157	I	0.188		
H	0.134	I	0.156	H	0.132	I	0.153	I	0.157	J	0.163	I	0.155	J	0.161		
I	0.132	J	0.133	I	0.130	J	0.130	J	0.134			J	0.132				
J	0.113			J	0.111												

ized values are obtained with the boundaries of $0\leq \mu_p^2(u) + v_p^2(u) + \pi_p^2(u) \leq 1$ for the member, non-membership, and hesitant degrees of interval valued Spherical fuzzy sets. The results are shown in Table 22.

On the other side, in the step 4, the defuzzificated values of decision matrix are calculated. The defuzzifaction procedure is applied and the averages of lower and upper values are considered for the membership, non-membership, and hesitant degrees are the defuzzified decision matrix is given in Table 23.

The final step is related to the ranking of the renewable energy alternatives by scenarios. Within this context, the ranking process is applied with 2-tuple hesitant IVSF TOPSIS.

Scenario 1 (Ranking the Alternatives by Using All Activities of New Service Development Process):

In this scenario, all items of new service development process are used in Table 23. In other words, in this scenario, without path analysis, all ten different steps are taken into account. And then, normalized, and weighted decision matrices are constructed in Tables 24 and 25, respectively.

The values of D+ and D- as well as CCi are computed for ranking the alternatives. Table 26 shows the ranking results for scenario 1.

Table 26 gives information that solar energy is the most appropriate investment alternative while considering all items of NSD process. Similarly, hydropower is also found as another significant investment opportunity. However, biomass and wind have the last ranks.

Scenario 2 (Ranking the Alternatives by Using Path 6):

This scenario consists of the activities entitled "A", "D", "G", "H", "I" and "J". Path 6 is also the shortest path by

TABLE 17. Duration list of new service development process by paths.

Path Alternatives	Activities	Weighted Preference Results for Duration	Rank
Path 1	A,B,C,G,H,I,J	0.329	19
Path 2	A,C,G,H,I,J	0.295	9
Path 3	A,B,C,D,G,H,I,J	0.319	14
Path 4	A,C,D,G,H,I,J	0.289	7
Path 5	A,B,D,G,H,I,J	0.283	5
Path 6	A,D,G,H,I,J	0.240	1
Path 7	A,B,C,D,E,G,H,I,J	0.345	23
Path 8	A,C,D,E,G,H,I,J	0.322	16
Path 9	A,B,D,E,G,H,I,J	0.317	13
Path 10	A,D,E,G,H,I,J	0.286	6
Path 11	A,B,C,E,G,H,I,J	0.356	25
Path 12	A,C,E,G,H,I,J	0.332	20
Path 13	A,B,E,G,H,I,J	0.327	18
Path 14	A,E,G,H,I,J	0.292	8
Path 15	A,B,C,F,G,H,I,J	0.363	26
Path 16	A,C,F,G,H,I,J	0.339	21
Path 17	A,B,C,D,E,H,I,J	0.339	22
Path 18	A,C,D,E,H,I,J	0.312	11
Path 19	A,B,D,E,H,I,J	0.308	10
Path 20	A,D,E,H,I,J	0.270	2
Path 21	A,B,C,E,H,I,J	0.352	24
Path 22	A,C,E,H,I,J	0.322	17
Path 23	A,B,E,H,I,J	0.317	12
Path 24	A,E,H,I,J	0.272	3
Path 25	A,B,C,H,I,J	0.319	15
Path 26	A,C,H,I,J	0.276	4

TABLE 18. Linguistic scales and fuzzy preference numbers for alternatives.

Linguistic Scales	Preference Numbers
weak (w)	0
poor (p)	0.25
fair (f)	0.50
good (g)	0.75
best (b)	1

duration. According to this scenario, the ranking results are presented in Table 27.

Table 27 indicates that geothermal is the best renewable energy investment alternative while considering the shortest path by the duration. Moreover, solar energy has the second-best alternative in this regard. It is understood that in case of the time constraint, investors should give priority to the geothermal energy projects.

Scenario 3 (Ranking the Alternatives by Using Path 7):

This scenario considers the longest path by activity number. The results are seen in Table 28.

Table 28 demonstrates that solar is the most significant renewable energy investment alternative when the longest path by activity number is taken into consideration. Additionally, hydropower and geothermal are other important alternatives for this purpose. Another important issue is that the ranking results of scenarios 1 and 3 are the same. Scenario 1 includes all 10 steps of NSD process whereas in scenario 3, the path with the highest number of activities is considered. The main difference between these two scenarios is that service design and process/system design (activity F) is not used in scenario 3. Hence, it is obvious that this step can be ignored for NSD process of renewable energy investments. With the help of this situation, it can be possible to save time so that more efficient results can be achieved.

Scenario 4 (Ranking the Alternatives by Using Path 15):

The longest path by duration (critical path) is taken into consideration in this scenario. The results are indicated in Table 29.

Table 29 states that solar and hydropower are the best renewable energy investment alternatives when the longest path by duration is considered.

Scenario 5 (Ranking the Alternatives by Using Paths 24 and 26):

The shortest path by activity number is evaluated within this framework. The results are demonstrated in Table 30.

Table 30 gives information that solar energy is the ideal investment opportunity for both paths 24 and 26. However, geothermal is the second-best alternative for path 24, but hydropower takes the second place for path 26. The main difference between these two paths is that path 24 considers the formation of cross-functional team (activity E) whereas the idea screening (activity C) is used in path 26. Therefore, it is obvious that when the investment company has a sufficient number of qualified personnel, it should focus on geothermal energy projects. However, hydropower energy will be better investment alternative when the company does not have these personnel

V. CONCLUSION

In this study, it is aimed to examine PERT-based critical paths of NSD process regarding renewable energy investment projects. For this purpose, a novel hybrid MCDM model has been generated which includes 3 different stages. The first stage is related to the finding the significance weights of 10 different steps in NSD process. Within this context, 2-tuple hesitant interval-valued intuitionistic Spherical fuzzy IVSF DEMATEL methodology is taken into consideration. Moreover, the second stage includes the definition of 26 different critical paths for NSD process. Furthermore, the third stage focuses on the ranking the renewable energy alternatives by path scenarios with 2-tuple hesitant IVSF TOPSIS.

TABLE 19. Context-free grammar evaluations for decision matrix.

	E1									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	at most “f”	at least “p”	at least “p”	between “p“ and “f”	between “h“ and “g”	between “f“ and “g”	between “f“ and “g”	between “f“ and “g”	at least “f”	at most “g”
A2	between “p“ and “g”	at most “f”	between “p“ and “g”	greater than “f”	between “p“ and “g”	between “f“ and “g”	at most “g”	at least “f”	between “p“ and “g”	between “p“ and “g”
A3	at least “p”	at most “f”	between “p“ and “f”	at least “f”	between “f“ and “g”	between “f“ and “g”	at least “f”	between “p“ and “g”	at most “g”	at least “f”
A4	at most “f”	between “p“ and “g”	between “p“ and “g”	between “p“ and “f”	between “p“ and “f”	at least “f”	at most “f”	between “f“ and “g”	between “f“ and “g”	between “g“ and “b”
A5	between “g“ and “b”	between “f“ and “b”	at least “g”	at least “g”	between “f“ and “b”	between “g“ and “b”	between “f“ and “g”	at least “f”	between “g“ and “b”	at least “f”
	E2									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	between “p“ and “g”	at least “p”	between “p“ and “g”	between “p“ and “g”	between “p“ and “g”	between “f“ and “g”	between “f“ and “g”	at least “f”	at least “f”	at most “g”
A2	between “p“ and “g”	at least “f”	between “p“ and “g”	greater than “f”	between “p“ and “g”	at least “f”	at most “g”	at least “f”	between “p“ and “b”	at most “g”
A3	between “f“ and “g”	at most “f”	between “p“ and “f”	at least “f”	between “p“ and “g”	between “f“ and “g”	at least “f”	between “p“ and “g”	at most “g”	at least “f”
A4	between “f“ and “g”	between “f“ and “g”	at least “f”	at most “g”	at least “f”	at most “g”	at most “f”	between “f“ and “g”	between “f“ and “g”	between “g“ and “b”
A5	at least “g”	between “f“ and “b”	at most “f”	between “g“ and “b”	between “f“ and “g”	between “g“ and “b”	between “f“ and “g”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”
	E3									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	between “p“ and “b”	between “p“ and “g”	between “f“ and “g”	between “f“ and “g”	at most “g”	at least “f”	between “f“ and “g”	between “f“ and “g”	at least “f”	at least “f”
A2	at most “g”	at least “f”	at most “g”	at least “f”	between “f“ and “g”	between “f“ and “g”	at most “g”	at least “f”	between “f“ and “g”	at most “f”
A3	at least “f”	between “p“ and “g”	between “f“ and “g”	between “f“ and “g”	at most “g”	at least “f”	at least “f”	at least “f”	at least “f”	at least “f”
A4	greater than “f”	between “p“ and “g”	between “p“ and “f”	at least “f”	between “f“ and “g”	between “f“ and “g”	at most “f”	between “f“ and “g”	at most “f”	between “g“ and “b”
A5	at least “f”	between “g“ and “b”	between “g“ and “b”	between “f“ and “g”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”
	E 4									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	between “p“ and “f”	between “p“ and “g”	at least “p”	at least “f”	between “f“ and “g”	between “f“ and “g”	between “f“ and “g”	between “f“ and “g”	between “p“ and “f”	at least “f”
A2	between “p“ and “f”	between “p“ and “f”	between “p“ and “g”	between “g“ and “b”	between “f“ and “g”	at least “f”	between “f“ and “g”	at least “f”	between “p“ and “g”	between “p“ and “f”
A3	between “p“ and “g”	between “p“ and “g”	between “p“ and “f”	at least “f”	between “f“ and “g”	between “g“ and “b”	between “f“ and “g”	at least “f”	between “f“ and “g”	at least “f”
A4	between “p“ and “f”	between “p“ and “f”	between “p“ and “g”	between “p“ and “f”	between “p“ and “f”	at least “f”	between “f“ and “g”	between “g“ and “b”	between “f“ and “g”	at least “f”
A5	at least “g”	between “g“ and “b”	at least “g”	at least “g”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”	between “g“ and “b”

The main contribution of this study is to generate appropriate investment strategies for renewable energy projects by evaluating different NSD paths with a novel hybrid fuzzy MCDM model. It is concluded that idea screening is the most important criterion for NSD process of the renewable energy investments. In addition, it is also defined that investors should also focus on the formation of cross-functional team. The ranking results also show that solar energy is the most appropriate investment alternative while considering all items of NSD process, the longest path by activity and the longest path by duration. Similarly, hydropower is also found as another significant investment opportunity. However, it is also seen that geothermal is the best renewable energy investment alternative while considering the shortest path by the duration.

TABLE 20. Boundaries of linguistic term sets for decision matrix.

	E1									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	[w,f]	[p,b]	[p,b]	[p,f]	[p,g]	[f,g]	[f,g]	[f,g]	[f,b]	[w,g]
A2	[p,g]	[w,f]	[p,g]	[g,b]	[p,g]	[f,g]	[w,g]	[f,b]	[p,b]	[p,g]
A3	[p,b]	[w,f]	[p,f]	[f,b]	[f,g]	[f,g]	[f,b]	[p,g]	[w,g]	[f,b]
A4	[w,f]	[p,g]	[p,g]	[p,f]	[p,f]	[f,b]	[w,fg]	[f,g]	[f,g]	[g,b]
A5	[g,b]	[f,b]	[g,b]	[g,b]	[f,b]	[g,b]	[f,b]	[f,b]	[g,b]	[f,b]
	E2									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	[p,g]	[p,b]	[p,g]	[p,g]	[p,g]	[f,g]	[f,g]	[f,b]	[f,b]	[w,g]
A2	[p,g]	[f,b]	[p,g]	[g,b]	[p,g]	[f,b]	[w,g]	[f,b]	[p,b]	[w,g]
A3	[f,g]	[w,f]	[p,f]	[f,b]	[p,g]	[f,g]	[f,b]	[p,g]	[w,g]	[f,b]
A4	[f,g]	[f,g]	[f,g]	[w,g]	[f,b]	[w,g]	[w,f]	[f,g]	[f,g]	[g,b]
A5	[g,b]	[f,b]	[w,f]	[g,b]	[f,g]	[g,b]	[f,b]	[g,b]	[g,b]	[g,b]
	E3									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	[p,b]	[p,g]	[f,g]	[f,g]	[w,g]	[f,b]	[f,g]	[f,g]	[f,b]	[f,b]
A2	[w,g]	[f,b]	[w,g]	[f,b]	[f,g]	[f,g]	[w,g]	[f,b]	[f,g]	[w,f]
A3	[f,b]	[p,g]	[f,g]	[f,g]	[w,g]	[f,b]	[f,b]	[f,b]	[f,b]	[f,b]
A4	[g,b]	[p,g]	[p,f]	[f,b]	[f,g]	[f,g]	[w,g]	[f,g]	[w,f]	[g,b]
A5	[f,b]	[g,b]	[g,b]	[f,g]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]
	E4									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	[p,f]	[p,g]	[p,f]	[f,b]	[f,g]	[f,g]	[f,g]	[f,g]	[p,f]	[f,b]
A2	[p,f]	[p,f]	[p,g]	[g,b]	[f,g]	[f,g]	[f,g]	[f,b]	[p,g]	[p,f]
A3	[p,g]	[p,g]	[p,f]	[f,b]	[f,g]	[f,g]	[f,g]	[f,b]	[f,g]	[f,b]
A4	[p,f]	[p,f]	[p,g]	[p,f]	[p,f]	[f,g]	[f,g]	[g,b]	[f,g]	[f,b]
A5	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]	[g,b]

TABLE 21. 2-tuple values of collective linguistic evaluations for decision matrix.

	C1		C2		C3		C4		C5		C6		C7		C8		C9		C10	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
A1	(g,-0.33)	(p,-0.33)	(b,-0.33)	(p,0)	(g,0)	(p,0.33)	(g,0)	(p,0.33)	(g,0)	(p,0)	(g,0.33)	(f,0)	(g,0)	(f,0)	(g,0.33)	(f,0)	(b,-0.33)	(f,-0.33)	(b,-0.33)	(p,0)
A2	(g,-0.33)	(p,-0.33)	(g,0)	(p,0.33)	(g,0)	(p,-0.33)	(b,0)	(g,-0.33)	(g,0)	(p,0.33)	(g,0.33)	(f,0)	(g,0)	(p,-0.33)	(b,0)	(f,0)	(b,-0.33)	(f,0.33)	(f,0.33)	(w,0.33)
A3	(g,0.33)	(f,-0.33)	(g,-0.33)	(p,-0.33)	(f,0.33)	(p,0.33)	(b,-0.33)	(f,0)	(g,0)	(p,0.33)	(g,0.33)	(f,0)	(b,-0.33)	(f,0)	(b,-0.33)	(f,-0.33)	(g,0.33)	(f,0)	(b,0)	(f,0)
A4	(g,-0.33)	(f,-0.33)	(g,-0.33)	(p,0.33)	(g,0)	(p,0.33)	(g,-0.33)	(p,0)	(g,-0.33)	(p,0.33)	(g,0.33)	(f,-0.33)	(g,-0.33)	(w,0.33)	(g,0.33)	(f,0.33)	(g,-0.33)	(f,-0.33)	(b,0)	(g,-0.33)
A5	(b,0)	(g,-0.33)	(b,0)	(f,0.33)	(b,-0.33)	(f,0.33)	(b,-0.33)	(g,-0.33)	(b,-0.33)	(f,0.33)	(b,0)	(g,0)	(b,-0.33)	(f,0.33)	(b,0)	(g,-0.33)	(b,0)	(g,0)	(b,0)	(g,-0.33)

This situation gives information that in case of the time constraint, investors should give priority to the geothermal energy projects. Another important conclusion is that the ranking results of the scenario of considering all 10 items of NSD process (scenario 1) and the scenario of using the longest path by activity number are the same. The main difference between these two scenarios is that service design and process/system design (activity F) is not taken into consideration in scenario 3. Thus, it can be concluded that with respect to the NSD process of renewable energy investments, this step can be ignored. This situation can have a positive contribution on the efficiency and effectiveness of the renewable energy investment projects with the help of saving time. For the future studies, the subject of the renewable energy technologies can

TABLE 22. Decision matrix based on interval valued spherical fuzzy sets.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A 1	([0.60,0.62], [0.05,0.06], [0.05,0.06])	([0.60,0.79], [0.05,0.08], [0.05,0.08])	([0.60,0.68], [0.05,0.09], [0.05,0.09])	([0.60,0.68], [0.10,0.11], [0.10,0.11])	([0.60,0.68], [0.05,0.08], [0.05,0.08])	([0.60,0.73], [0.10,0.15], [0.10,0.15])	([0.60,0.68], [0.10,0.11], [0.10,0.11])	([0.60,0.73], [0.10,0.15], [0.10,0.15])	([0.60,0.79], [0.10,0.13], [0.10,0.13])	([0.60,0.73], [0.05,0.08], [0.05,0.08])
A 2	([0.60,0.62], [0.05,0.06], [0.05,0.06])	([0.60,0.68], [0.05,0.09], [0.05,0.09])	([0.60,0.68], [0.05,0.06], [0.05,0.06])	([0.80,0.90], [0.20,0.21], [0.20,0.21])	([0.60,0.68], [0.10,0.11], [0.10,0.11])	([0.60,0.73], [0.10,0.15], [0.10,0.15])	([0.60,0.68], [0.01,0.04], [0.01,0.04])	([0.80,0.90], [0.10,0.15], [0.10,0.15])	([0.60,0.79], [0.05,0.09], [0.05,0.09])	([0.40,0.56], [0.01,0.04], [0.01,0.04])
A 3	([0.60,0.79], [0.10,0.11], [0.10,0.11])	([0.40,0.56], [0.01,0.04], [0.01,0.04])	([0.40,0.51], [0.05,0.09], [0.05,0.09])	([0.80,0.84], [0.10,0.15], [0.10,0.15])	([0.60,0.68], [0.05,0.09], [0.05,0.09])	([0.60,0.73], [0.10,0.15], [0.10,0.15])	([0.80,0.84], [0.10,0.15], [0.10,0.15])	([0.60,0.79], [0.10,0.11], [0.10,0.11])	([0.60,0.73], [0.05,0.08], [0.05,0.08])	([0.80,0.90], [0.10,0.15], [0.10,0.15])
A 4	([0.60,0.62], [0.10,0.11], [0.10,0.11])	([0.60,0.62], [0.05,0.09], [0.05,0.09])	([0.60,0.68], [0.05,0.09], [0.05,0.09])	([0.60,0.62], [0.05,0.08], [0.05,0.08])	([0.60,0.62], [0.10,0.11], [0.10,0.11])	([0.60,0.73], [0.10,0.15], [0.10,0.15])	([0.40,0.56], [0.01,0.04], [0.01,0.04])	([0.60,0.73], [0.10,0.17], [0.10,0.17])	([0.60,0.62], [0.10,0.11], [0.10,0.11])	([0.80,0.90], [0.20,0.21], [0.20,0.21])
A 5	([0.80,0.90], [0.20,0.21], [0.20,0.21])	([0.80,0.90], [0.10,0.19], [0.10,0.19])	([0.60,0.79], [0.10,0.17], [0.10,0.17])	([0.80,0.84], [0.20,0.21], [0.20,0.21])	([0.80,0.84], [0.10,0.19], [0.10,0.19])	([0.80,0.90], [0.20,0.23], [0.20,0.23])	([0.60,0.79], [0.10,0.19], [0.10,0.19])	([0.80,0.90], [0.20,0.21], [0.20,0.21])	([0.80,0.90], [0.20,0.23], [0.20,0.23])	([0.80,0.90], [0.20,0.21], [0.20,0.21])

be taken into consideration. With the help of these technological improvements, the high initial cost problem of these projects can be minimized. Thus, by making this study, it can also be possible to generate innovative strategies to improve renewable energy investments.

TABLE 23. Defuzzified decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
A2	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.5	0.4	0.2
A3	0.4	0.2	0.2	0.5	0.3	0.3	0.5	0.4	0.4	0.5
A4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.4
A5	0.4	0.5	0.3	0.4	0.5	0.4	0.3	0.4	0.4	0.4

TABLE 24. Normalized decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.4	0.5	0.5	0.3	0.4	0.4	0.3	0.3	0.4	0.4
A2	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.6	0.5	0.2
A3	0.5	0.3	0.2	0.6	0.4	0.4	0.6	0.4	0.5	0.6
A4	0.3	0.4	0.5	0.4	0.3	0.4	0.3	0.3	0.3	0.5
A5	0.6	0.6	0.5	0.5	0.6	0.6	0.4	0.5	0.5	0.5

TABLE 25. Weighted decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.04	0.05	0.06	0.04	0.05	0.04	0.03	0.03	0.04	0.03
A2	0.04	0.04	0.06	0.05	0.04	0.04	0.05	0.06	0.04	0.02
A3	0.05	0.03	0.03	0.06	0.05	0.04	0.06	0.04	0.04	0.04
A4	0.03	0.04	0.06	0.04	0.04	0.04	0.03	0.03	0.03	0.04
A5	0.06	0.06	0.06	0.05	0.07	0.05	0.04	0.05	0.05	0.04

VI. LIMITATIONS AND IMPLICATIONS

While considering PERT-based critical paths, it is concluded that solar energy is the most appropriate renewable energy investment alternative in most of the scenarios. With the increasing environmental awareness around the world, the importance of renewable energy alternatives has increased significantly in recent years. This situation has also attracted

TABLE 26. Ranking the alternatives for scenario 1.

Alternatives	D+	D-	CCi	Ranking
Biomass(A1)	0.057	0.047	0.453	4
Hydropower (A2)	0.052	0.057	0.524	2
Geothermal (A3)	0.061	0.055	0.475	3
Wind (A4)	0.072	0.038	0.342	5
Solar (A5)	0.030	0.072	0.702	1

TABLE 27. Ranking the alternatives for scenario 2.

Alternatives	D+	D-	CCi	Ranking
Biomass(A1)	0.087	0.038	0.302	4
Hydropower (A2)	0.061	0.073	0.546	3
Geothermal (A3)	0.037	0.096	0.719	1
Wind (A4)	0.102	0.031	0.234	5
Solar (A5)	0.053	0.072	0.576	2

TABLE 28. Ranking the alternatives for scenario 3.

Alternatives	D+	D-	CCi	Ranking
Biomass(A1)	0.061	0.052	0.461	4
Hydropower (A2)	0.054	0.062	0.534	2
Geothermal (A3)	0.065	0.061	0.482	3
Wind (A4)	0.079	0.041	0.344	5
Solar (A5)	0.034	0.077	0.698	1

TABLE 29. Ranking the alternatives for scenario 4.

Alternatives	D+	D-	CCi	Ranking
Biomass(A1)	0.060	0.059	0.493	3
Hydropower (A2)	0.056	0.069	0.553	2
Geothermal (A3)	0.074	0.062	0.456	4
Wind (A4)	0.078	0.048	0.381	5
Solar (A5)	0.035	0.082	0.698	1

TABLE 30. Ranking the alternatives for scenario 5.

	Alternatives	D+	D-	CCi	Ranking
P 24	Biomass(A1)	0.078	0.050	0.388	4
	Hydropower (A2)	0.085	0.067	0.439	3
	Geothermal (A3)	0.063	0.073	0.538	2
	Wind (A4)	0.106	0.037	0.257	5
	Solar (A5)	0.030	0.101	0.770	1
P 26	**Alternatives**	**D+**	**D-**	**CCi**	**Ranking**
	Biomass(A1)	0.066	0.078	0.539	3
	Hydropower (A2)	0.063	0.098	0.607	2
	Geothermal (A3)	0.085	0.069	0.446	5
	Wind (A4)	0.083	0.074	0.472	4
	Solar (A5)	0.031	0.099	0.760	1

the attention of investors. However, one of the most important problems in renewable energy investments is the very high initial cost. This stated situation also makes investors uneasy. Thanks to the developments in technology in recent years, the costs of solar energy investments have started to decrease significantly. Considering this situation, it has been concluded that it would be more profitable for investors to focus on solar energy projects during the NSD process. With decreasing costs, it will be possible to increase the profitability and efficiency of solar energy projects. This will provide investors with a significant competitive advantage.

Many different researchers underlined the similar conclusions in their studies. Creutzig *et al.* [85] focused on the effectiveness of the solar energy investments. They identified that solar energy projects have a significant influence on the reduction of carbon emission. However, in previous years, many investors became reluctant to make investments on these projects because of high initial costs. Nevertheless, they also stated that especially in the last years, there is a significant development in the solar energy technology. This situation has a decreasing impact on the costs. Dobrotkova *et al.* [86] made evaluations regarding the cost analysis of the solar energy investments. They reached a conclusion that technological innovation leads to decline in costs of solar energy projects. Kabir *et al.* [87] tried to examine the future of the solar energy investments. They discussed that with the help of the technological development, the cost of the solar energy projects will decline. Hence, in the future, it is expected that solar energy investments will increase in a significant percentage.

One of the biggest problems in renewable energy investments is that uninterrupted electrical energy cannot be obtained. The reason for this is that natural factors such as sun and wind are not at the same level at all times of the day. This situation causes changes in the amount of energy obtained. The important point here is that the excess energy obtained in times when the sun and wind are excessive must be stored. On the other hand, the storage of excess electricity generated from renewable energies also causes significant costs. Especially thanks to new technological developments, it has become possible to store the excess electrical energy obtained from solar energy. Therefore, it would be appropriate for investors to focus on this issue in new products to be developed. As this stated situation will reduce the cost in the energy storage process, it will contribute to obtaining uninterrupted electricity in a more efficient way. Wang *et al.* [88], Lehtola and Zahedi [89] and Mofijur *et al.* [90] focused on the effectiveness of the solar energy investment projects. They mainly discussed the importance of cost reduction for these projects. Owing to the technological improvement, the storage cost of solar energy projects can decrease. This situation attracts the attentions of the solar energy investors.

On the other hand, long periods of time may be needed to make a profit from solar energy investments. The analysis results obtained in this study also show that the most efficient renewable energy alternative is solar energy projects, considering the longest path in the NSD process. On the other hand, it has been determined that geothermal energy will be more suitable for investors when there is a shorter expectation. The biggest advantage of geothermal energy is that it is possible to obtain uninterrupted electricity. The main reason is that this type of energy is not affected much by climatic conditions. In this way, the problem of storing excess energy can be minimized. This contributes to the cost advantage of geothermal energy. Due to these positive aspects, geothermal energy is a more beneficial alternative to other renewable energy types, especially when it is aimed to achieve positive results in the short term.

It is thought that the results obtained in this study will guide investors and academics. It is aimed to contribute to investors to make effective investment decisions under different conditions, especially by considering different scenarios in the analysis process. However, the most important limitation of this study is that it only focuses on NSD in renewable energy projects. It is also important to make an analysis of the developing renewable energy technologies in new studies. In this way, it will be possible to guide renewable energy investors from different angles. Additionally, some new methodology can also be considered in the analysis process, such as Pythagorean fuzzy sets [91].

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