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A hybrid decision making approach for new service development process of renewable energy investment

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ABSTRACT

This study aims at evaluating new service development (NSD) process of renewable energy investments. A novel fuzzy hybrid multi-criteria decision-making model is then introduced. Firstly, selected criteria are weighted with a multi stepwise weight assessment ratio analysis (M-SWARA) methodology based on bipolar q-rung orthopair fuzzy sets (q-ROFSs) and golden cut. Secondly, balanced scorecard (BSC)-based project network for the NSD process of renewable energy investments is constructed. These alternatives are ranked by using the elimination and choice translating reality (ELECTRE) approach with bipolar q-ROFSs and golden cut. Afterwards, the Project Evaluation and Review Technique (PERT) diagram is developed by defining immediate predecessors based on the ranking results. Consequently, different paths are created to understand effective ways to generate NSD process. Our findings will show the crucial processes for the NSD process of renewable energy investments, and the PERT analysis will provide optimal paths to increase the performance of NSD process of the renewable energies. It is concluded that analysis is the most critical NSD process for clean energy investment projects. The findings indicate that the shortest path is defined as Path 2 with 48.6% of the total importance degree. On the other hand, the longest path is determined as Path 1 with 100%. Path 4 has the weakest importance with 65.2% in comparison to Path 3 with 83.4% with respect to the comparison same activity numbers. It is strongly recommended that both technical and financial aspects should be evaluated with necessary research while generating new products. This issue can have a positive contribution to the early solution of any potential problems.

1. Introduction

The global warming problem has become an important risk for human beings around the world. Many countries and associations are trying to determine the necessary regulatory actions by emphasizing the seriousness of this problem. One of the most important reasons for the global warming problem is the preference of fossil fuels in energy production. In the process of energy production by burning fossil fuels such as coal and oil, serious carbon emissions occur [1]. This issue disrupts the natural balance and harms people's health. Therefore, fossil fuels should not be preferred in energy production. Therefore, renewable energy sources play an important role because energy produced by these sources reduces carbon emissions. Consequently, the development of renewable energies projects is crucial to permanently solve the global warming problem [2].

However, there are some obstacles to the development of clean energy projects, such as high installment cost. This has a negative impact on the profitability of the projects. Therefore, investors lose their motivation towards these projects [3]. Unless the high-cost problem of clean energy projects is resolved, investors will pay more attention to fossil fuel investments, which have cost advantages. As a result, it will not be possible to solve the global warming problem caused by carbon emissions. Countries take some actions to solve the high-cost problem [4]. It is aimed to provide cost advantages to clean energy investors with state supports such as tax reductions.

There are some factors that renewable energy investors should pay attention to. These investors should aim to have a competitive advantage by developing effective new products. Despite this situation, new products that are not correctly designed cause serious damage to projects [5]. There are some issues to consider when developing a new product. Benchmarking the market facilities is necessary. Additionally, effective research and development activities should be conducted for renewable services [6]. Moreover, organizational capacity of renewable energy companies should be improved. Furthermore, the expectations of the

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customers should be satisfied. Also, cost and benefit evaluation should be implemented to make future prediction about the projects.

Consequently, some essential issues should be considered to handle this process in a more appropriated way. For instance, the involved criteria should be correctly selected, and the Balanced scorecard (BSC) methodology used to make a performance evaluation of the companies [7] would be a right choice; because BSC considers four different perspectives namely, *customer, finance, internal process*, and *learning* [8]. The main superiority of this approach consists of using both financial and nonfinancial factors in the examination process. Hence, while evaluating the performance of the NSD process of the renewable energy projects, BSC provides an opportunity to make a more comprehensive analysis [9].

Appropriate methodology should be implemented to define significance levels of the factors. Multi-criteria decision-making (MCDM) models are preferred in this respect [10]. Some MCDM models are considered to weight the items, such as decision-making trial and evaluation laboratory (DEMATEL), stepwise weight assessment ratio analysis (SWARA) and analytic hierarchy process (AHP) [11,12]. On the other hand, some techniques are also used with the aim of ranking different alternatives that are technique for order preference by similarity to ideal solution (TOPSIS), elimination and choice translating reality (ELECTRE) and vise kriterijumska optimizacija i kompromisno resenje (VIKOR) [13,14]. In this study, an extension of the SWARA entitled Multi SWARA is proposed to provide the direct-relation map and the weights of the criteria with shorter and simpler computation steps compared to the DEMATEL-ANP. However, the preliminary version of ELECTRE entitled ELECTRE I is considered to rank and construct the directions among the alternatives. Because the method is very simple by not considering any items of indifference and preference thresholds, also applicable when the factors are defined in numerical scales with identical ranges. Accordingly, the extended versions of Multi SWARA and ELECTRE are proposed based on the bipolar q-ROFSs with golden cut to provide more accurate results under the uncertainty and complexity of the real-world problems.

For managing inherent uncertainty and more precise results in MCDM, fuzzy sets have been used to model preferences and compute the processes of MCDM methods. New product development processes in renewable energy investments also involve complex issues. In this process, many different risks must be taken into consideration at the same time. This situation causes the uncertainties in the process to increase even more. Therefore, it would be more appropriate to consider these methods with fuzzy numbers instead of classical decision-making techniques to make a comprehensive analysis on this subject. However, because of increasing complexity in the problems, researchers made significant improvements in the fuzzy sets. Interval type-2 fuzzy sets were generated to handle the uncertainty of type-1 fuzzy sets in a better way [15,16]. Additionally, intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs) were used to cope with the hesitancy problem more effectively [17–19]. On the other side, q-rung orthopair fuzzy sets (q-ROFSs) were also introduced by integrating IFSs and PFSs to obtain more effective solutions [20,21].

Another significant issue is to provide a correct ordering of these matters for the effectiveness of the project. For this purpose, a comprehensive evaluation should be conducted to understand influenced and influencing factors. Project Evaluation and Review Technique (PERT) is an analysis of businesses that applies planning and control methods [22]. Owing to this method, an evaluation can be made for the correct determination of the ordering of the works in the project. It is aimed to obtain a more efficient result by analyzing the activities effectively in terms of time and cost [23]. Therefore, by using the PERT technique, the steps of the NSD in renewable energy projects can be ordered in a correct way. To be able to define the critical paths of the alternatives in terms of the PERT, the possible directions among the alternatives are obtained by using the results of concordance, discordance, and aggregated matrices in the ELECTRE method. Additionally, the overall results computed with the net superior and inferior values are employed to figure out the weights in the activity lists of the PERT. Thus, the construction of PERT network with the ELECTRE is easier than other ranking methods such as TOPSIS and VIKOR.

In the literature, different fuzzy decision-making models were created for the purpose of evaluating renewable energy investments. Ghenai et al. [24] focused on the effectiveness of the renewable energy systems with the help of a new decision-making model. In this study, selected indicators are weighted by using SWARA methodology so that important strategies can be presented. Ijadi Maghsoodi et al. [25] and Yücenur et al. [26] also proposed new decision-making models in which SWARA technique was taken into consideration. However, because of selecting classical SWARA methodology, causal relationship among the factors cannot be examined in these models. The stages of new service development process can have an influence on each other regarding renewable energy projects. Hence, for the effectiveness of this process, new decision-making methodology that can create impact relation map should be considered. Additionally, Heo et al. [27] and Wang et al. [28] also aimed to examine renewable energy investments with the help of creating fuzzy decision-making models. In these models, only one type of fuzzy set was taken into consideration. Because of this issue, it could not be possible to make a comparative evaluation. Hence, the validity and consistency of the results cannot be checked. Nevertheless, generating new products for renewable energy projects is a very critical issue. Therefore, it is quite important to check the appropriateness of the findings. Otherwise, inaccurate analysis results will lead to the presentation of wrong strategies.

This study evaluates the NSD process of renewable energy alternatives by introducing a novel fuzzy decision-making model. At the first stage, the criteria weights of the criteria are computed by an extension of the SWARA method, that is the M-SWARA methodology with bipolar q-ROFSs and golden cut. In the following stage, a bipolar q-ROFSs ELECTRE approach is applied together the golden cut for ranking the alternatives. Subsequently, a PERT diagram is constructed while considering these results. In this process, immediate predecessors are defined, different paths are determined such that, effective ways regarding the generation of NSD process of energy investments can be identified. This situation has a positive influence to create more effective strategies by developing new products for the clean energy projects.

The main novelty of this study is the ability of identifying optimal paths to increase performance of NSD process of the green energies by a new fuzzy hybrid decision-making model. Its results will indicate investors the ways for right development of their new products. By effectively creating new products, the profitability of these projects will increase. Thus, comparative advantage can be obtained for these companies that helps to provide sustainability in the development of the clean energy investments. This issue contributes to the improvements of the renewable energy projects so that carbon emission-based global warming problem can be minimized.

The proposed model has also some essential improvements in comparison to previous models in the literature. The degrees in q-ROFSs are calculated with the help of the golden cut [29,30]. This situation both increases the originality of the proposed model and provides to reach more accurate results. Moreover, SWARA methodology is extended to multi-SWARA (M-SWARA) for measuring the degree of effect and relationship between the variables. In standard SWARA, the relative effectiveness of only one variable on value variables is measured unidirectionally. In our proposal M-SWARA can consider the relationships of the variables with each other in an integrated manner.

Furthermore, by using bipolar fuzzy sets in the model, fuzzy sets are considered together with positive sets as well as negative membership functions [31]. It is possible to create a further detailed information set [32,33]. The benefit of ELECTRE method is avoiding compensation between criteria and normalization process [34]. Therefore, the original data cannot be distorted which contributes the appropriateness of the findings [35,36]. Additionally, because q-ROFSs consider a wider space by comparing with IFSs and PFSs, more accurate findings can be reached [37]. Moreover, the calculations are also made with IFSs and PFSs in addition to q-ROFSs [38]. Hence, this situation provides the opportunity to measure the reliability of the findings [39].

The construction of PERT network is a complicated process and needs for several integrated analysis results. In some cases, it is difficult to collect the data and process it under the uncertainty of PERT analysis. Accordingly, it is proposed a two-stage decision making approach by combining the extension of M-SWARA and ELECTRE based on bipolar q-ROFSs with Golden Cut. Thus, it is aimed to define the most accurate the weighting results and the direct-relation map of the criteria together with the exact directions of the alternatives into the PERT network.

The following section is related to the evaluation of the literature. Methodology is explained in the third section. The fourth section includes the results of the analysis. In the final section, conclusions and discussions are explained.

2. Literature review

Literature review section includes three different subsections. In the first subsection, the literature regarding the significant issues of new product development process in clean energy investments is explained. On the other hand, in the second subsection of this part, the fuzzy decision-making models for this subject are discussed. In the final subsection, the results of the literature review are explained.

2.1. Literature on NSD process of renewable energy investments

This subsection gives information about the literature review with respect to the important points while preparing a new product for clean energy projects. In each paragraph, different issue to improve the effectiveness of the new product generating process for clean energy investments will be explained. Some studies pointed out the significance of satisfying customer expectations in this process. Dahiru et al. [40] studies clean energy investments. They determined that customer satisfaction should be prioritized. Li et al. [41] also claimed that strategic priorities of customer expectations should be defined to increase the performance of the new products. Bose et al. [42] also studied energy investments in India. It is concluded that the expectations of the customers should be satisfied for the increase in the NSD performance.

Research and development studies are also very important when developing new products for green energy projects. Technologies for renewable energy projects are advancing very rapidly. Therefore, for these projects to be successful, up-to-date technologies must be quickly adapted to the company. This is also vital for the NSD process. Thanks to new technologies, it is possible that the cost of new products to be developed can be low [43]. This situation can provide a competitive advantage to the product, it will be easier to increase the efficiency of the projects [44]. Companies can closely follow current developments in renewable energy technologies by establishing a new research team [45]. Hence, it will be much easier to develop the most successful product. Assi et al. [46] evaluated new products. It is emphasized that companies should increase research and development activities to increase the effectiveness of this process. Pata [47] examined renewable energy investments. It is claimed that companies should give importance to the research and development works to generate new successful products.

Financial issues should also be considered when developing new products for green energy projects. The biggest goal of new product development is to be preferred by customers. If the cost of the new product is high, the market price will also increase [48]. Expensive products will also not be preferred by customers. The chance of success of the new product developed is very low [49]. On the other hand, it is not very possible to reduce the price of a product with a high cost, because the profitability of the product will decrease too much [50]. In such a case, even if the customers prefer the product, success will not be achieved from the sale of the product. Yao et al. [51] examined new products for green energy projects. They identified that cost analysis should be performed for the effectiveness of these projects. Pojadas et al. [52] also defined that cost benefit analysis should be made to increase the performance of these projects. Timilsina [53] also concluded that cost evaluation should be done appropriately to increase competitive advantage of these new products.

For the success of new product developed for green energy projects, it is necessary to pay attention to some company-specific factors. For example, it is very important that the personnel working in the energy company are qualified [54]. Engineers with high technical knowledge are needed in renewable energy projects. It is possible to quickly resolve the problems that may occur in the business processes of the companies [55]. On the other hand, communication between departments within companies should also be high quality [56]. Business processes will be able to progress more effectively, and this will contribute significantly to the efficiency of the projects. Gawusu et al. [57] made an evaluation about green energy investments. They identified that the personnel working in the energy company should be qualified to generate successful new products. Zafar et al. [58] determined that communication between departments within renewable energy companies should be effective to generate high-quality new products. Liu et al. [59] also claimed that organizational effectiveness is significant to generate effective new products.

2.2. Literature on fuzzy decision-making models in renewable energy investments

This subsection states the studies in which fuzzy decision-making models are created for the subject of the renewable energy investments. For instance, Suganthi et al. [60] focused on the applications of the fuzzy logic in renewable energy systems. In this study, models were created by considering fuzzy AHP technique. Ertay et al. [61] also evaluated renewable energy alternatives using MACBETH and fuzzy AHP for Turkey. In these models, the hierarchical relationship between the criteria can be taken into consideration. However, the impact relation map could not be generated for the indicators. Additionally, Bakhtavar et al. [62] created a fuzzy decision-making model for the renewable energy-based mine reclamation strategies. In this study, fuzzy ANP technique was taken into consideration. With the help of this methodology, the networking relationship between the factors can be identified. Hashemizadeh and Ju [63] and Kang et al. [64] used fuzzy ANP method to weight the criteria to find optimal renewable energy portfolios and choose the ideal location for wind energy projects. Similarly, these studies cannot also examine the causality relationship between the items.

In the decision-making models with respect to the renewable energy projects in the literature, different fuzzy sets were taken into consideration. Some studies used triangular fuzzy numbers in this framework. For instance, Asante et al. [65] aimed to generate appropriate strategies to eliminate the barriers to renewable energy adoption in Ghana. In this study, the alternatives are ranked with the help of TOPSIS methodology. In this context, the triangular fuzzy numbers were used in the calculation process. Zhong et al. [66] and Liu et al. [67] determined the key issues to improve the effectiveness of the renewable energy investments. In the proposed models, interval type-2 fuzzy sets were taken into consideration for the aim of handling the uncertainties more appropriately. Li et al. [68] and Dinçer et al. [69] considered q-ROFSs to evaluate the levelized cost of renewable energy alternatives and find significant issues for the performance improvements of the microgeneration energy investments. With the help of using this fuzzy set, it is aimed to reach more appropriate results because q-ROFSs consider a wider range in comparison to other fuzzy sets.

2.3. The results of the literature review

Renewable energy alternatives play an important role to minimize carbon emission-based global warming [70]. However, there are some obstacles behind green energy investments, such as high initial costs. Investors should aim to have a competitive advantage by developing effective new products. For this purpose, some different factors should be taken into consideration that include customer satisfaction, financial issues, technological improvements, and organizational effectiveness. An essential issue is the correct ordering of these matters for the effectiveness of this project. However, while considering the details of the studies in the literature, they mainly focused on the impact of a variable on NSD process in clean energy projects. Nonetheless, there are limited studies in the literature that make a prioritization analysis to define other more significant factors. Therefore, a further detailed evaluation should be conducted to identify influenced and influencing factors. Hence, the activities can be analyzed effectively in terms of time and cost.

The details of the literature review are indicated in Table A.1 in the Appendix part of the study. For the aim of contributing to the literature, a priority analysis has been conducted in this study to identify significant issues in the process of new product development for the renewable energy investment process. For this purpose, NSD process of renewable energy alternatives is examined. A novel fuzzy decision-making model is generated for this purpose by considering BSC, PERT, M-SWARA, ELECTRE based on bipolar q-ROFSs and golden cut. It is possible to mention both theoretical and methodological innovations of this study. With respect to the theoretical contribution, the results obtained in this study are a guide for both researchers and investors. Considering these issues, it will be possible to develop more effective new products for clean energy projects. This will contribute to a significant reduction of the carbon emission problem. On the other side, the proposed model has also some superiorities. For example, a new technique is generated with the name of M-SWARA in this proposed model. Owing to this improvement, the impact relation map of the factors can be created. Additionally, the degrees in q-ROFSs are calculated with the help of the golden cut. These two new issues both increase the originality of the proposed model and help to reach more accurate results. Therefore, it is aimed to satisfy the stated missing parts in the literature with a new and original fuzzy decision-making model.

3. Methodology

This section explains bipolar q-ROFSs with golden cut, M-SWARA, ELECTRE and PERT.

3.1. Bipolar q-ROFSs with golden cut

Atanassov [71] introduced IFSs by extending classical fuzzy sets. With respect to the classical theory, the membership of elements in a set is examined according to two different aspects. This element can either belong to a set or not. However, regarding IFSs, elements can be evaluated with two functions. Thus, both concepts are further expanded [72]. In addition to the degree of membership (MEF), the degree of non-membership (NEF) is also defined. In traditional fuzzy set theory, the sum of membership degree and non-membership degree is calculated as 1. Nevertheless, as for IFSs, the sum of these two parameters does not have to satisfy this condition [73]. Eq. (1) explains the details of these sets in which the degrees are defined as (μ_I, n_I).

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta)\rangle / \vartheta \epsilon U\} \tag{1}$$

The condition of IFSs is demonstrated in Eq. (2).

$$0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1 \tag{2}$$

Yager [74] developed PFSs by the extension of IFSs. Covering a wider area in the analysis process can be accepted as a significant advantage of these sets. It is aimed to manage the uncertain issues more successfully [75]. Similar to IFSs, PFSs are also characterized by MEF and NEF (μ_p, n_p). However, there is a condition that the sum of the squares of the MEF and NEF must be one or less. PFSs can be considered in areas where IFSs cannot be used [76]. Eq. (3) demonstrates the details of PFSs where new degrees are shown as (μ_p, n_p).

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta)\rangle / \vartheta \epsilon U\} \tag{3}$$

The condition of PFSs is also indicated in Eq. (4).

$$0 \leq (\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{4}$$

Furthermore, Yager [77] introduced q-ROFSs by generalizing IFSs and PFSs. IFSs are expressed as first q-level fuzzy sets, and PFSs are expressed as second q-level fuzzy sets. Hence, with the help of these new sets, it is aimed to find better solutions for complex problems by considering larger grade space than others [78]. It is stated that the q level can take a value from one to infinity. Furthermore, it has been explained that the graphical representation of the fuzzy set at the infinite q level will be square [79]. Eq. (5) gives information about these sets in which (μ_q, n_q) indicate new grades.

$$Q = \left\{\left\langle \vartheta, \mu_Q(\vartheta), n_Q(\vartheta)\right\rangle / \vartheta \epsilon U\right\} \tag{5}$$

Eq. (6) represents the condition of q-ROFSs.

$$0 \leq \left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q \leq 1,\ q \geq 1 \tag{6}$$

The fuzzy number types mentioned above may not be sufficient for all conditions. When current problems become too much complex, the decision makers' preferences may be affected. Therefore, it becomes much more difficult to model such preferences. Further distinctive fuzzy sets are needed to model the uncertainties in the problems. Zhang [80] developed bipolar fuzzy sets for this purpose. For decision makers in the context of uncertainties in a problem-solving process, the positive pole represents the desired situations whereas the undesirable situations are explained by the negative pole [81]. Decision makers do not have to unilaterally evaluate the uncertainties caused by their feelings and thoughts. It is possible to evaluate this process together

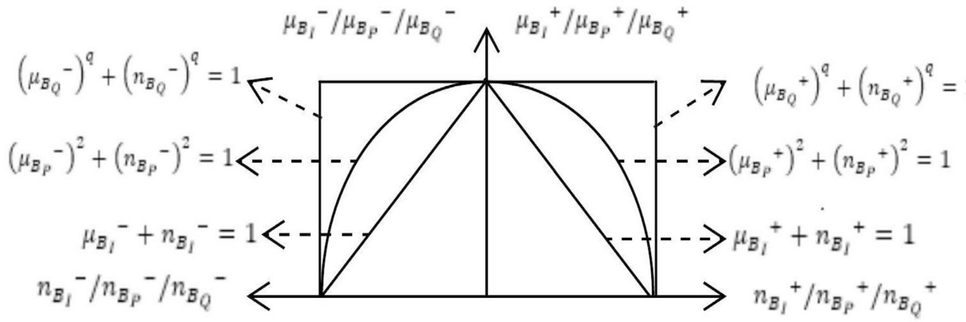

Fig. 1. Degrees of bipolar IFS, PFS, and q-ROFSs.

with the opposite situation [82]. Eq. (7) indicates bipolar fuzzy sets. In this equation, $\mu_B{}^+$ demonstrates the satisfaction degree of an element to the property corresponding B. On the other side, satisfaction of the same element to some implicit counter property regarding B is indicated by $\mu_B{}^-$.

$$B=\left\{\left\langle\vartheta,\mu_B{}^+(\vartheta),\mu_B{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\} \tag{7}$$

IFSs, PFSs and q-ROFSs can be shown with bipolar fuzzy sets in Eqs. (8)–(13).

$$B_I=\left\{\left\langle\vartheta,\mu_{B_I}{}^+(\vartheta),n_{B_I}{}^+(\vartheta),\mu_{B_I}{}^-(\vartheta),n_{B_I}{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\} \tag{8}$$

$$B_P=\left\{\left\langle\vartheta,\mu_{B_P}{}^+(\vartheta),n_{B_P}{}^+(\vartheta),\mu_{B_P}{}^-(\vartheta),n_{B_P}{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\} \tag{9}$$

$$B_Q=\left\{\left\langle\vartheta,\mu_{B_Q}{}^+(\vartheta),n_{B_Q}{}^+(\vartheta),\mu_{B_Q}{}^-(\vartheta),n_{B_Q}{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\} \tag{10}$$

$$\begin{aligned}&0\le\left(\mu_{B_I}{}^+(\vartheta)\right)+\left(n_{B_I}{}^+(\vartheta)\right)\le 1,\\&-1\le\left(\mu_{B_I}{}^-(\vartheta)\right)+\left(n_{B_I}{}^-(\vartheta)\right)\le 0\end{aligned} \tag{11}$$

$$\begin{aligned}&0\le\left(\mu_{B_P}{}^+(\vartheta)\right)^2+\left(n_{B_P}{}^+(\vartheta)\right)^2\le 1,\\&0\le\left(\mu_{B_P}{}^-(\vartheta)\right)^2+\left(n_{B_P}{}^-(\vartheta)\right)^2\le 1\end{aligned} \tag{12}$$

$$\begin{aligned}&0\le\left(\mu_{B_Q}{}^+(\vartheta)\right)^q+\left(n_{B_Q}{}^+(\vartheta)\right)^q\le 1,\\&-1\le\left(\mu_{B_Q}{}^-(\vartheta)\right)^q+\left(n_{B_Q}{}^-(\vartheta)\right)^q\le 0\end{aligned} \tag{13}$$

Fig. 1 explains bipolar IFS, PFS, and q-ROFSs.

Eqs. (14)–(17) define the mathematical operations of bipolar q-ROFSs.

$$B_{Q1}=\left\{\left\langle\vartheta,\mu_{B_{Q1}}{}^+(\vartheta),n_{B_{Q1}}{}^+(\vartheta),\mu_{B_{Q1}}{}^-(\vartheta),n_{B_{Q1}}{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\}$$

and

$$B_{Q2}=\left\{\left\langle\vartheta,\mu_{B_{Q2}}{}^+(\vartheta),n_{B_{Q2}}{}^+(\vartheta),\mu_{B_{Q2}}{}^-(\vartheta),n_{B_{Q2}}{}^-(\vartheta)\right\rangle/\vartheta\epsilon U\right\}$$

$$\begin{aligned}B_{Q1}\oplus B_{Q2}=\Bigg(&\left(\left(\mu_{B_{Q1}}{}^+\right)^q+\left(\mu_{B_{Q2}}{}^+\right)^q-\right.\\&\left.\left(\mu_{B_{Q1}}{}^+\right)^q.\left(\mu_{B_{Q2}}{}^+\right)^q\right)^{\frac{1}{q}},\left(n_{B_{Q1}}{}^+.n_{B_{Q2}}{}^+\right),-\left(\mu_{B_{Q1}}{}^-.\mu_{B_{Q2}}{}^-\right),\\&-\left(\left(n_{B_{Q1}}{}^-\right)^q+\left(n_{B_{Q2}}{}^-\right)^q-\right.\\&\left.\left(n_{B_{Q1}}{}^-\right)^q.\left(n_{B_{Q2}}{}^-\right)^q\right)^{\frac{1}{q}}\Bigg)\end{aligned} \tag{14}$$

$$\begin{aligned}B_{Q1}\otimes B_{Q2}=\Bigg(&\left(\mu_{B_{Q1}}{}^+.\mu_{B_{Q2}}{}^+\right),\left(\left(n_{B_{Q1}}{}^+\right)^q+\left(n_{B_{Q2}}{}^+\right)^q\right.\\&\left.-\left(n_{B_{Q1}}{}^+\right)^q.\left(n_{B_{Q2}}{}^+\right)^q\right)^{\frac{1}{q}},-\left(\left(\mu_{B_{Q1}}{}^-\right)^q+\right.\\&\left.\left(\mu_{B_{Q2}}{}^-\right)^q-\left(\mu_{B_{Q1}}{}^-\right)^q.\left(\mu_{B_{Q2}}{}^-\right)^q\right)^{\frac{1}{q}},-\left(n_{B_{Q1}}{}^-.n_{B_{Q2}}{}^-\right)\Bigg)\end{aligned} \tag{15}$$

$$\begin{aligned}\lambda B_{Q1}=\Bigg(&\left(1-\left(1-\left(\mu_{B_{Q1}}{}^+\right)^q\right)^\lambda\right)^{1/q},\left(n_{B_{Q1}}{}^+\right)^\lambda,-\left(-\mu_{B_{Q1}}{}^-\right)^\lambda,\\&-\left(1-\left(1-\left(-n_{B_{Q1}}{}^-\right)^q\right)^\lambda\right)^{1/q}\Bigg),\lambda>0\end{aligned} \tag{16}$$

$$\begin{aligned}B_{Q1}{}^\lambda=\Bigg(&\left(\mu_{B_{Q1}}{}^+\right)^\lambda,\left(1-\left(1-\left(n_{B_{Q1}}{}^+\right)^q\right)^\lambda\right)^{1/q},\\&-\left(1-\left(1-\left(-\mu_{B_{Q1}}{}^-\right)^q\right)^\lambda\right)^{\frac{1}{q}},-\left(-n_{B_{Q1}}{}^-\right)^\lambda\Bigg),\lambda>0\end{aligned} \tag{17}$$

In the defuzzification process, score functions in Eqs. (18)–(20) are taken into consideration where $S(\vartheta)_{B_I}$, $S(\vartheta)_{B_P}$, $S(\vartheta)_{B_Q}$ indicate the score functions of the bipolar IFSs, PFSs, and q-ROFSs.

$$S(\vartheta)_{B_I}=\left(\left(\mu_{B_I}{}^+(\vartheta)\right)-\left(n_{B_I}{}^+(\vartheta)\right)\right)-\left(\left(\mu_{B_I}{}^-(\vartheta)\right)-\left(n_{B_I}{}^-(\vartheta)\right)\right) \tag{18}$$

$$\begin{aligned}S(\vartheta)_{B_P}=&\left(\left(\mu_{B_P}{}^+(\vartheta)\right)^2-\left(n_{B_P}{}^+(\vartheta)\right)^2\right)\\&+\left(\left(\mu_{B_P}{}^-(\vartheta)\right)^2-\left(n_{B_P}{}^-(\vartheta)\right)^2\right)\end{aligned} \tag{19}$$

$$\begin{aligned}S(\vartheta)_{B_Q}=&\left(\left(\mu_{B_Q}{}^+(\vartheta)\right)^q-\left(n_{B_Q}{}^+(\vartheta)\right)^q\right)\\&-\left(\left(\mu_{B_Q}{}^-(\vartheta)\right)^q-\left(n_{B_Q}{}^-(\vartheta)\right)^q\right)\end{aligned} \tag{20}$$

Defining appropriately the degrees in the analysis process plays a crucial role. Some limitations should be taken into consideration. In this study, the assumptions of golden ratio are used to define the degrees in the calculation process. This ratio gives information about the specific patterns of the geometric problems. The assumption of the golden ratio helps to explain the degrees for the fuzzy sets more appropriately. The division of the extreme and mean ratio in a straight line is used to identify golden cut (φ) [83,84]. Hence, the golden cut can be identified by the division of extreme and mean ratio in a straight line. In this process, a and b refer to the large and small quantities in this straight line. Eq. (21) demonstrates the details of the golden cut.

$$\varphi=\frac{a}{b} \tag{21}$$

In this equation, a > b > 0 and a and b are stated in the straight line. Golden cut helps in establishing a coefficient between the previous number and the next number. Therefore, this coefficient is adapted when determining the scale between linguistic variables and expressing these scales with fuzzy numbers. Thus, it is possible to make a more meaningful classification [85,86]. Mathematical demonstration of the golden cut is given in Eq. (22).

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.618\ldots \tag{22}$$

MEF and NEF degrees ($\mu_{G_{B_Q}}$, $n_{G_{B_Q}}$) are explained in Eq. (23).

$$\varphi = \frac{\mu_{G_{B_Q}}}{n_{G_{B_Q}}} \tag{23}$$

where $\mu_{G_{B_Q}}$ and $n_{G_{B_Q}}$ are the golden cut-based member and non-membership degrees of the large (a) and small (b) quantities in the straight line respectively.

Golden cut is adopted to the bipolar q-ROFSs by considering Eqs. (24)–(26).

$$G_{B_Q} = \left\{\left\langle \vartheta, {\mu_{G_{B_Q}}}^{+}(\vartheta), {n_{G_{B_Q}}}^{+}(\vartheta), {\mu_{G_{B_Q}}}^{-}(\vartheta), {n_{G_{B_Q}}}^{-}(\vartheta)\right\rangle / \vartheta \epsilon U\right\} \tag{24}$$

$$\begin{aligned} &0 \le \left({\mu_{G_{B_Q}}}^{+}(\vartheta)\right)^{q} + \left({n_{G_{B_Q}}}^{+}(\vartheta)\right)^{q} \le 1, \\ &-1 \le \left({\mu_{G_{B_Q}}}^{-}(\vartheta)\right)^{q} + \left({n_{G_{B_Q}}}^{-}(\vartheta)\right)^{q} \le 0 \end{aligned} \tag{25}$$

$$\begin{aligned} &0 \le \left({\mu_{G_{B_Q}}}^{+}(\vartheta)\right)^{2q} + \left({n_{G_{B_Q}}}^{+}(\vartheta)\right)^{2q} \le 1, \\ &0 \le \left({\mu_{G_{B_Q}}}^{-}(\vartheta)\right)^{2q} + \left({n_{G_{B_Q}}}^{-}(\vartheta)\right)^{2q} \le 1 \quad q \ge 1 \end{aligned} \tag{26}$$

New degrees are defined as $\mu_{G_{B_Q}}$ and $n_{G_{B_Q}}$.

3.2. M-SWARA method with bipolar q-ROFSs

Keršuliene et al. [87] introduced Stepwise Weight Assessment Ratio Analysis (SWARA) as a decision-making method that is considered in calculating the importance weights of the criteria. One of the biggest advantages of this method is that few pairwise comparisons are possible. This makes a significant contribution to increasing the efficiency of the analysis process. The SWARA method gives the decision maker the chance to choose their priorities [88]. Therefore, this technique is considered an expert-oriented method.

In this study, SWARA model is extended to multi stepwise weight assessment ratio analysis (M-SWARA) in which, the degree of effect and relationship between the variables can be measured. The main improvement of our proposal M-SWARA regarding SWARA is that the relationships among variables can be considered in an integrated manner. The details of M-SWARA methodology for bipolar q-ROFSs are given as following.

Evaluations are provided from decision makers. By using them, dependency degrees can be defined. Later, bipolar q-ROFS relation matrix is constructed [89]. Eq. (27) demonstrates this matrix.

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{27}$$

After that, bipolar q-ROFSs are generated, and the score functions are computed. The fourth stage is related to the calculation of the values of s_j, k_j, q_j, and w_j for the relationship degrees of criteria. For this purpose, Eqs. (28)–(30) are considered where k_j explains the coefficient value, q_j identifies the recalculated weight, s_j represents the comparative importance rate and w_j indicates the weights of the criteria.

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{28}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{29}$$

If $s_{j-1} = s_j, q_{j-1} = q_j$; *If* $s_j = 0, k_{j-1} = k_j$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{30}$$

In the fifth step, stable values are defined by transposing and limiting the matrix to the power of 2t+1. The final stage includes the computation of the impact-relation degrees of the factors. Greater values than the threshold in the column give information about the influenced item. As a result, causal directions can be constructed.

3.3. ELECTRE with bipolar q-ROFSs

Benayoun et al. [90] developed ELECTRE methodology as a multiple decision-making technique. This technique is considered to rank different alternatives for each criterion. Hence, more significant issues can be identified. The method is based on binary superiority comparisons between alternative decision points for each evaluation factor. The concordance and discordance intervals and indexes are used to identify the preferences [91,92]. In the literature, there are different extensions of ELECTRE approach [93]. In this study, this technique is extended with bipolar q-ROFSs to have more accurate results. At the first stage, evaluations are obtained from the experts' team. Owing to these issues, bipolar q-ROF decision matrix is created as in Eq. (31).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{31}$$

The following state is related to the construction of the bipolar q-ROFSs and calculation of the score function values. Next, normalized values are identified according to the vector normalization procedure by considering Eq. (32).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{32}$$

Later, with the help of Eq. (33), weighted values are calculated.

$$v_{ij} = w_{ij} \times r_{ij} \tag{33}$$

The concordance and discordance (C and D) interval matrices are created with Eqs. (34)–(39).

$$C = \begin{bmatrix} - & c_{12} & \cdots & \cdots & c_{1n} \\ c_{21} & - & \cdots & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{34}$$

$$D = \begin{bmatrix} - & d_{12} & \cdots & \cdots & d_{1n} \\ d_{21} & - & \cdots & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{35}$$

$$c_{ab} = \left\{ j | v_{aj} \geq v_{bj} \right\} \tag{36}$$

$$d_{ab} = \left\{ j | v_{aj} < v_{bj} \right\} \tag{37}$$

$$c_{ab} = \sum_{j \in c_{ab}} w_j \tag{38}$$

$$d_{ab} = \frac{max_{j \in d_{ab}} \left| v_{aj} - v_{bj} \right|}{max_j \left| v_{mj} - v_{nj} \right|} \tag{39}$$

The concordance index defines the relative dominance of a certain alternative over a competing or pairwise alternative by considering the relative weight of successive decision criteria. C matrix represents the concordance interval matrix. This matrix is derived from the weighted decision matrix. For this situation, the sum of the larger weights corresponding to the pairwise comparisons of the alternatives in the matrix are taken into consideration [94]. In this context, firstly, the values of c_{ab} are determined for each criterion and the sums of c_{ab} are used in the concordance matrix [95].

Similarly, for the discordance matrix, differences are considered in pairwise alternative comparisons for each criterion. Accordingly, the values of d_{ab}, that are the absolute value sums of the results that are small in pairwise comparisons, are considered. The discordance matrix is created according to the ratio between the maximum result in the small ones and the maximum result in all criteria [96]. Thresholds indicating the critical values of concordance and discordance interval matrices are provided by the column and row sums of matrices as well as the number of alternatives as seen in Eqs. (44) and (46) [97]. The following stage focuses on the generation of the concordance E, discordance F and aggregated G index matrixes by Eqs. (40)–(47).

$$E = \begin{bmatrix} - & e_{12} & \cdots & \cdots & e_{1n} \\ e_{21} & - & \cdots & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{40}$$

$$F = \begin{bmatrix} - & f_{12} & \cdots & \cdots & f_{1n} \\ f_{21} & - & \cdots & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{41}$$

$$G = \begin{bmatrix} - & g_{12} & \cdots & \cdots & g_{1n} \\ g_{21} & - & \cdots & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{42}$$

$$\begin{cases} e_{ab} = 1 & if\ c_{ab} \geq \overline{c} \\ e_{ab} = 0 & if\ c_{ab} < \overline{c} \end{cases} \tag{43}$$

$$\overline{c} = \sum_{a=1}^{n} \sum_{b}^{n} c_{ab} / n(n-1) \tag{44}$$

$$\begin{cases} f_{ab} = 1 & if\ d_{ab} \leq \overline{d} \\ f_{ab} = 0 & if\ d_{ab} > \overline{d} \end{cases} \tag{45}$$

$$\overline{d} = \sum_{a=1}^{n} \sum_{b}^{n} d_{ab} / n(n-1) \tag{46}$$

$$g_{ab} = e_{ab} \times f_{ab} \tag{47}$$

The sets of concordance, discordance and aggregated index matrixes are indicated by e_{ab}, f_{ab}, g_{ab}. Additionally, $\overline{c}$ and $\overline{d}$ demonstrate the critical parameters of the matrixes C and D respectively. Finally, the net superior c_a, inferior d_a, and overall o_a values are identified for the aim of ranking the alternatives. Eqs. (48)–(50) are taken into consideration.

$$c_a = \sum_{b=1}^{n} c_{ab} - \sum_{b=1}^{n} c_{ba} \tag{48}$$

$$d_a = \sum_{b=1}^{n} d_{ab} - \sum_{b=1}^{n} d_{ba} \tag{49}$$

$$o_a = c_a - d_a \tag{50}$$

3.4. PERT

PERT is a technique used to evaluate a corporate project. It is aimed to implement an effective planning and control process by the companies [98]. Owing to the analysis, the most accurate sequence of the steps of a project can be determined. This situation helps businesses to save both time and money. Thus, it will be possible for companies to become more profitable by increasing the efficiency of projects. To maintain the PERT technique effectively, some steps must be followed [99]. Fig. 2 gives information about the details of these steps.

First, the details of the project are determined, and the necessary work is distributed among the departments. In this way, the expected work will be carried out by the specialized department within the company. This situation contributes both to the most accurate performance of the work and to saving time during this process. After that, the activities are correlated with each other. In this way, the priority order of the work steps of the project can be determined. In other words, it will be possible to understand which work steps should be done earlier than others. In this way, it will be possible to carry out the process more effectively. Otherwise, inconsistencies will occur in the process. This will both waste time and increase costs for companies.

The next process is about making time and cost estimates for activities [100]. Thanks to the previous steps, both the priority status between the process steps were determined and it was decided by which departments the work tasks would be carried out. In this process, how long it will take to complete this work and how much it will cost will be defined. This will help companies to clearly define their projections about the project. Later, the longest path (critical path) in this process is calculated. The slightest delay in this path causes the project to be prolonged. In this context, determining the critical path is of vital importance for the project to be followed effectively. The last step is about planning the project, sequencing the work steps, and performing the necessary controls [101].

The application of the PERT method provides some advantages to companies. Firstly, thanks to this application, companies will be able to perform cost management more successfully. Effective cost management will contribute to increasing the efficiency of companies. In this way, the probability of the projects to be

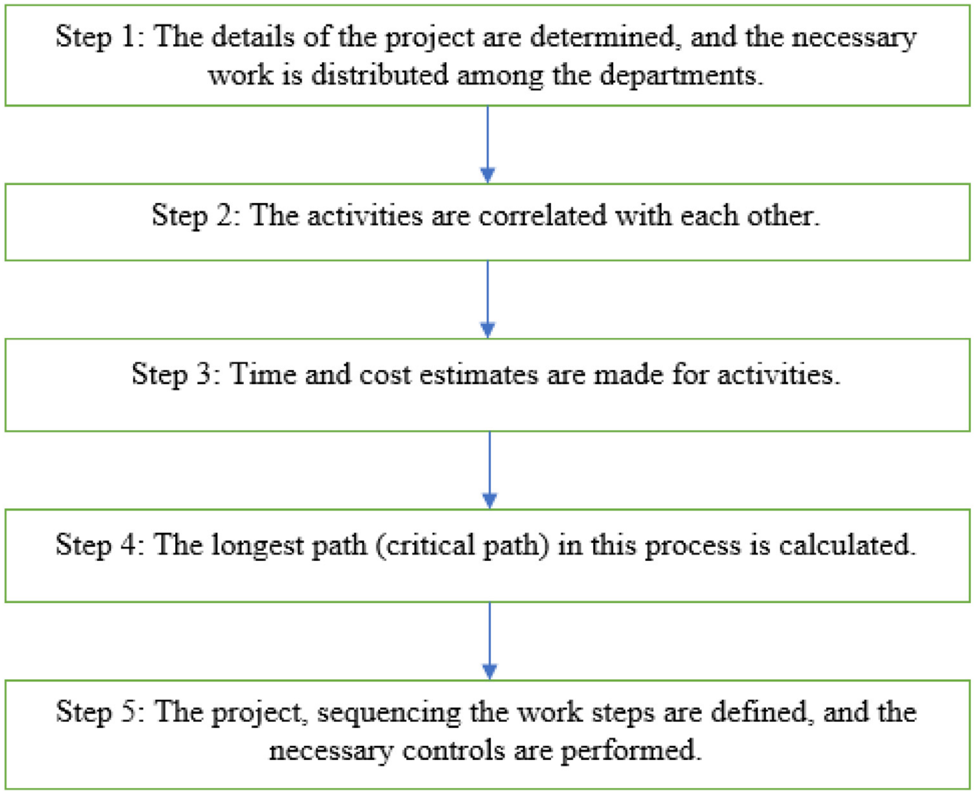

Fig. 2. Steps of PERT.

Table 1
Selected criteria.

Criteria	References
Design (DGN)	[58]
Analysis (AYS)	[57]
Testing (TST)	[60]
Commercialization (CMR)	[39]

Table 2
Scales and degrees.

Scales		POS		NGT	
Criteria	Alternatives	MEF	NEF	MEF	NEF
No influence (n)	Weakest (w)	.40	.25	−.60	−.37
Somewhat influence (s)	Poor (p)	.45	.28	−.55	−.34
Medium influence (m)	Fair (f)	.50	.31	−.50	−.31
High influence (h)	Good (g)	.55	.34	−.45	−.28
Very high influence (vh)	Best (b)	.60	.37	−.40	−.25

Table 3
Evaluations.

Decision Maker 1								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
DSG			H	VH	M	H	S	VH
AYS	M	H			S	S	S	S
TST	M	VH	M	M			VH	N
CMR	VH	S	H	N	S	N		
Decision Maker 2								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
DSG			H	VH	S	H	S	VH
AYS	H	M			S	S	S	M
TST	M	VH	M	M			VH	N
CMR	S	S	H	N	S	M		
Decision Maker 3								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
DSG			VH	M	H	N	M	M
AYS	VH	H			M	S	M	S
TST	VH	H	M	M			VH	N
CMR	VH	N	H	N	M	N		

successful will increase [99]. Moreover, the application of PERT technique helps companies to manage their time more successfully. This ensures that important things can be done first. With good time management, it is possible to do more work in less time [100]. In addition to them, project managers can better estimate the completion date of the project with the help of PERT approach.

4. Developing the model and analyzing results

A novel fuzzy decision-making model is introduced for evaluating NSD process of green energies as detailed in Fig. 3.

The analysis results for weighting the criteria and ranking the alternatives are given in the following subsections.

4.1. Stage 1: Weighting criteria

The first stage is related to the weighing criteria. There are eight different steps in this stage.

Step 1 It includes the identification of the factors. Criteria regarding NSD are given in Table 1.

Four different criteria of NSD are given in Table 1. In this process, the first criterion is "design" that gives information about identifying new ideas for renewable energy services. Within this

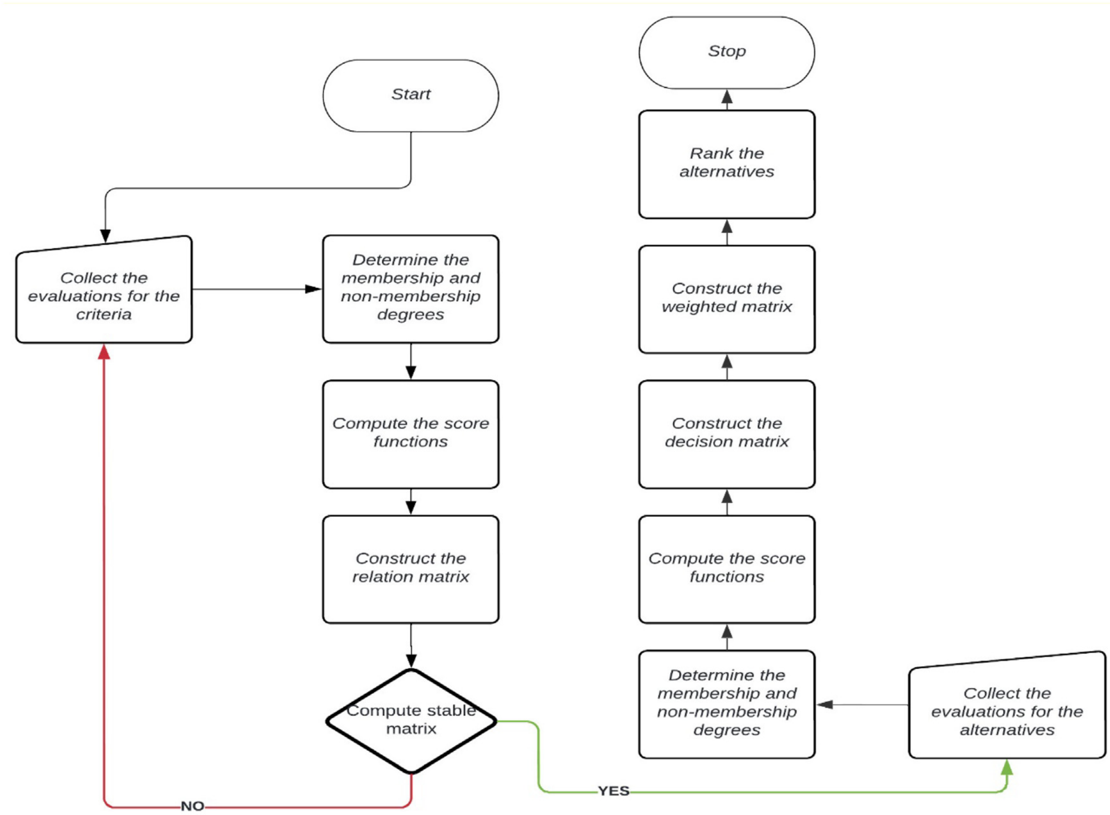

Fig. 3. Proposed model.

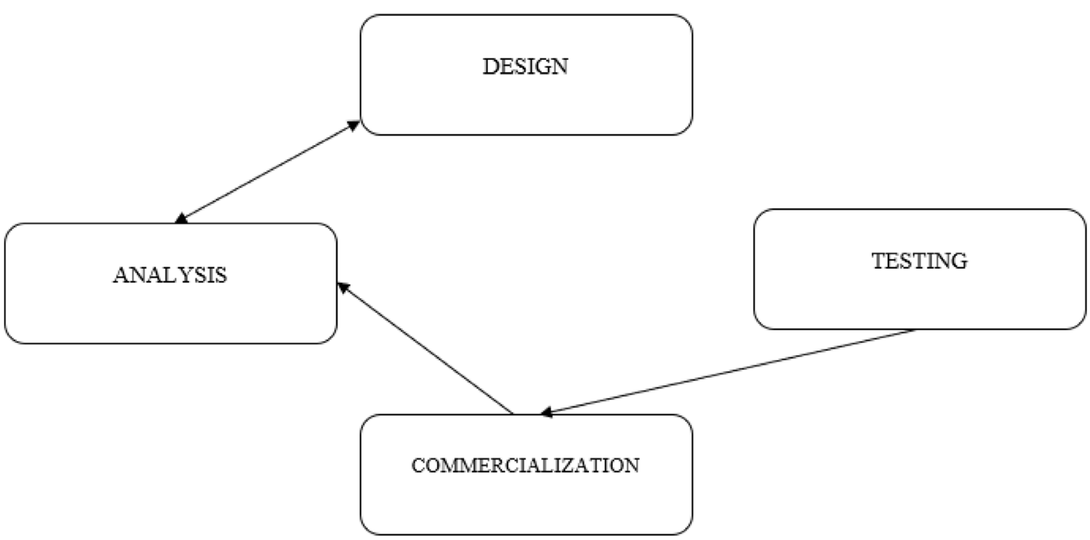

Fig. 4. Impact-relation map.

framework, ideas can be collected from different parties, such as employees and customers. Moreover, the second criterion "analysis" refers to the constructing the feasibility for the proposed service of renewable sources. Based on the ideas collected in the first stage, the product or service is designed in this stage. Furthermore, testing is the third criterion that includes providing the feedback for the potential performance of the renewable energy projects. In other words, the performance of the new generated product or service is tested in this stage. Additionally, "commercialization" is the final criterion that explains measuring the full launch performance of renewable energy services.

Step 2 It focuses on the collection of the evaluations of decision makers for the criteria. Table 2 includes the degrees and scales in which POS and NGT identify positive and negative degrees.

The questions are created by comparing selected criteria stated in Table 1. The expert team makes evaluations regarding these questions. In this framework, five different scales explained in Table 2 are taken into consideration for the evaluation of the

Table 4
Average values.

	DGN				AYS				TST				CMR			
	POS		NGT		POS		NGT		POS		NGT		POS		NGT	
	μ	n	μ	n	μ	N	μ	n	μ	n	M	n	μ	n	μ	n
DSG					.57	.35	−.43	−.27	.50	.31	−.50	−.31	.47	.29	−.43	−.27
AYS	.55	.34	−.47	−.29					.47	.29	−.55	−.34	.47	.29	−.53	−.33
TST	.53	.33	−.42	−.26	.50	.31	−.50	−.31					.60	.37	−.60	−.37
CMR	.55	.34	−.57	−.35	.55	.34	−.60	−.37	.47	.29	−.57	−.35				

Table 5
Score function values.

	DGN	AYS	TST	CMR
DSG	.000	.201	.191	.140
AYS	.205	.000	.205	.194
TST	.171	.191	.000	.330
CMR	.266	.292	.217	.000

Table 6
Sj, kj, qj, and wj values for the relationship degrees of each criterion.

DSG	Sj	Kj	qj	wj	AYS	Sj	Kj	qj	wj
AYS	.201	1.000	1.000	.388	DSG	.205	1.000	1.000	.396
TST	.191	1.191	.840	.326	TST	.205	1.205	.830	.329
CMR	.140	1.140	.737	.286	CMR	.194	1.194	.695	.275
TST	Sj	Kj	qj	wj	CMR	Sj	Kj	qj	wj
CMR	.330	1.000	1.000	.391	AYS	.292	1.000	1.000	.410
AYS	.191	1.191	.840	.328	DSG	.266	1.266	.790	.324
DSG	.171	1.171	.717	.280	TST	.217	1.217	.649	.266

Table 7
REX with the values of wj.

	DGN	AYS	TST	CMR
DSG		.388	.326	.286
AYS	.396		.329	.275
TST	.280	.328		.391
CMR	.324	.410	.266	

Table 8
Stable matrix.

	DGN	AYS	TST	CMR
DSG	.252	.252	.252	.252
AYS	.273	.273	.273	.273
TST	.236	.236	.236	.236
CMR	.239	.239	.239	.239

criteria and alternatives. On the other side, the expert team consists of three different decision makers. These people work as top managers in the renewable energy investments companies. Because they have minimum 26-year of experience, they had a chance to work in different departments of the companies. Therefore, the expert team has sufficient experience to make evaluation. Table 3 includes the evaluations of expert team.

Step 3 It computes the average values as in Table 4.

Step 4 It includes the calculation of the score function values in Table 5.

Step 5 It identifies the sj, kj, qj, and wj values as in Table 6. In this study, SWARA approach is extended with the name of M-SWARA. For this purpose, some improvements have been performed. These values are computed for the aim of defining the relationship degrees of criteria. In this context, Eqs. (28)–(30) are taken into consideration.

Step 6 It builds the relation matrix (REX) as in Table 7.

Step 7 The stable matrix is constructed in Table 8.

Step 8 The impact relation map is generated as in Fig. 4 by considering threshold value.

Table 9
Comparative weighting priorities.

	Bipolar IFSs	Bipolar PFSs	Bipolar q-ROFSs
DSG	2	2	2
AYS	1	1	1
TST	4	4	4
CMR	3	3	3

Table 10
Selected alternatives of BSC-based process for the NSD of renewable energy projects.

Perspectives of balanced scorecard	Alternatives for proposed process	References
Learning and Growth	Benchmarking the market facilities and research and development activities for renewable services (BRD)	[73]
Finance	Defining the potential costs and earnings of service development (CBA)	[24]
Customer	Determining the customized services of energy projects (DCS)	[54]
Internal Process	Specifying the organizational capacity of NSD for renewable sources (SOC)	[44]

Table 11
Linguistic evaluations of alternatives.

Decision Maker 1								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
BRD	B	G	B	P	P	F	B	G
CBA	G	P	P	P	B	G	P	F
DCS	P	B	P	F	P	F	F	F
SOC	B	G	F	P	F	G	F	G
Decision Maker 2								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
BRD	F	P	B	P	F	F	F	G
CBA	G	P	P	P	B	G	F	P
DCS	F	G	P	F	P	G	F	F
SOC	F	G	F	P	F	G	F	G
Decision Maker 3								
	DGN		AYS		TST		CMR	
	POS	NGT	POS	NGT	POS	NGT	POS	NGT
BRD	G	G	B	W	P	F	G	W
CBA	P	W	P	P	B	G	P	F
DCS	P	B	P	W	P	F	G	W
SOC	G	G	F	W	P	W	G	G

Design and analysis have a mutual impact. Moreover, commercialization affects analysis criterion. Finally, testing has an influence on the commercialization. This impact relation map gives opportunity to provide effective strategies. For instance, when analysis process is improved, it will have a positive influence on the improvement of the design process. Moreover, in case of any developments to the commercialization and design

Table 12
Average values for the alternatives.

	DGN				AYS				TST				CMR			
	POS		NGT		POS		NGT		POS		NGT		POS		NGT	
	μ	n	μ	n	μ	n	M	N	μ	n	μ	n	μ	n	μ	n
BRD	.55	.34	−.48	−.30	.60	.37	−.57	−.35	.47	.29	−.50	−.31	.55	.34	−.50	−.31
CBA	.52	.32	−.57	−.35	.45	.28	−.55	−.34	.60	.37	−.45	−.28	.47	.29	−.52	−.32
DCS	.47	.29	−.42	−.26	.45	.28	−.53	−.33	.45	.28	−.48	−.30	.52	.32	−.53	−.33
SOC	.55	.34	−.45	−.28	.50	.31	−.57	−.35	.48	.30	−.50	−.31	.52	.32	−.45	−.28

Table 13
Score function values of the alternatives.

	DGN	AYS	TST	CMR
BRD	.213	.304	.173	.223
CBA	.244	.197	.235	.183
DCS	.133	.186	.156	.221
SOC	.197	.234	.182	.175

Table 14
Normalized matrix.

	DGN	AYS	TST	CMR
BRD	.531	.647	.459	.552
CBA	.608	.419	.622	.454
DCS	.331	.395	.413	.549
SOC	.489	.499	.482	.434

Table 15
Weighted decision matrix.

	DGN	AYS	TST	CMR
BRD	.134	.177	.108	.132
CBA	.153	.114	.146	.109
DCS	.083	.108	.097	.131
SOC	.123	.136	.113	.104

processes, analysis stage will be affected from this situation in a positive manner. In addition to bipolar q-ROFSs, the calculations are also made with IFSs and PFSs. Weighting priorities are indicated in Table 9.

Table 9 states that analysis is the most critical NSD process for clean energy investment projects. In addition, design also has an importance for this situation. Commercialization and testing have lower significance. It is determined that green energy investors should mainly focus on constructing the feasibility for the proposed service of renewable sources. Therefore, during the process of the project, both technical and financial aspects should be evaluated with necessary research. Possible problems and threats should be investigated, and it should be tried to predict whether the investment will bring profit or not. This situation contributes to the early resolution of problems. It is not possible for unprofitable clean energy projects to be sustainable. Therefore, it will be possible for the project to be profitable by making an effective feasibility analysis.

4.2. Second stage: Constructing project network for the NSD process

In the second stage, project network for the NSD process is constructed. BSC-based stages are identified as in Table 10.

Step 9 The expert team evaluate these factors as in Table 11.

Step 10 Table 12 includes average values for the alternatives. After the defuzzification process, the table was created by considering the average values of the experts' opinions.

The score function values of the alternatives are given in Table 13.

Step 12 This matrix is normalized as in Table 14.

Step 13 Table 15 indicates weighted decision matrix.

Table 16
Concordance and discordance interval matrixes.

Alternatives	Concordance matrix				Discordance matrix			
	BRD	CBA	DCS	SOC	BRD	CBA	DCS	SOC
BRD	.000	.513	1.000	.764	.000	.615	.000	.133
CBA	.487	.000	.761	.727	1.000	.000	.325	.666
DCS	.000	.239	.000	.239	1.000	1.000	.000	1.000
SOC	.236	.273	.761	.000	1.000	1.000	.688	.000

Step 14 It includes the identification of the concordance and discordance interval matrixes as in Table 16.

Step 15 It is related to the creation of the concordance, discordance, and aggregated index matrixes as in Table 17.

Step 16, net superior, inferior, and overall values are determined for ranking the alternatives as in Table 18.

This analysis has also been performed with IFSs and PFSs.

Step 17 The comparative ranking results are demonstrated in Table 19.

It is concluded that research and development is the most crucial alternative. Furthermore, cost and benefit analysis should also be prioritized. By considering these results, PERT diagram is constructed for the BSC-based renewable energy project evaluation. For the purpose of checking the reliability of the analysis results, the alternatives are also ranked with TOPSIS approach based on the bipolar IFSs, PFSs and q-ROFSs. Comparative analysis results are given in Table 20.

Table 20 compares the results of ELECTRE and TOPSIS. It is seen that the ranking results of the ELECTRE are quite similar with the results of TOPSIS. This situation gives information about the reliability of the analysis results. Additionally, a sensitivity analysis has been performed with four different cases by changing the weighting results of the criteria consecutively and considering the different values of q parameters to test the coherency of the findings. The results of the sensitivity analysis are given in Table 21.

Table 21 gives information that the ranking results are similar with the different q parameters and the cases. Hence, it is understood that the results of the proposed models are quite coherent. Immediate predecessors and weights are demonstrated in Table 22.

Alternative order is constructed by using the results of overall values. Moreover, immediate predecessors are defined by using the directions of the aggregated index matrix. Finally, weights of overall values are determined by normalizing the overall values between 0 and 1. PERT network is created as in Fig. 5.

The performance of these paths is given in Table 23.

It is identified that the shortest path is defined as Path 2 with 48.6% of the total importance degree for BSC-based project items. On the other hand, the longest path by the highest total importance degree is determined as Path 1 with 100%. When same activity numbers are compared, Path 4 has the weakest importance with 65.2% in comparison to Path 3 with 83.4%. Another important finding is that benchmarking the market facilities and research and development activities for renewable services and determining the customized services should be mainly implemented in all different paths. Additionally, defining the potential

Table 17
Concordance, discordance and aggregated index matrixes.

Alternatives	Concordance matrix				Discordance matrix				Aggregated matrix			
	BRD	CBA	DCS	SOC	BRD	CBA	DCS	SOC	BRD	CBA	DCS	SOC
BRD	0	1	1	1	1	1	1	1	0	1	1	1
CBA	0	0	1	1	0	1	1	1	0	0	1	1
DCS	0	0	0	0	0	0	1	0	0	0	0	0
SOC	0	0	1	0	0	0	1	1	0	0	1	0

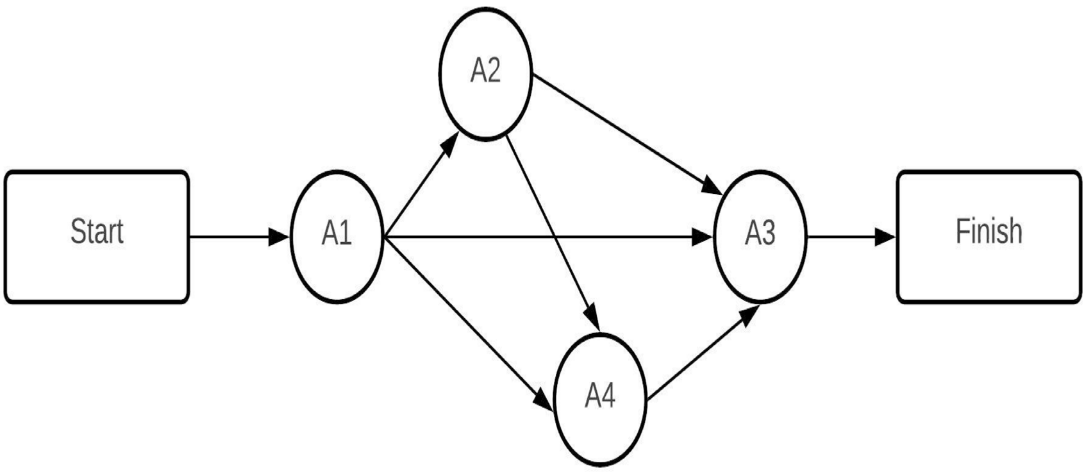

Fig. 5. PERT network for the BSC-based project items.

Table 18
Net superior, inferior, and overall values of the alternatives.

Alternatives	Net superior values	Inferior values	Overall values
BRD	1.554	−2.252	3.807
CBA	.949	−.623	1.572
DCS	−2.042	1.987	−4.029
SOC	−.461	.888	−1.349

Table 19
Comparative overall ranking results.

Alternatives	Bipolar q-ROFS Multi SWARA-ELECTRE	Bipolar PF Multi SWARA-ELECTRE	Bipolar IF Multi SWARA-ELECTRE
BRD	1	1	1
CBA	2	2	2
DCS	4	4	4
SOC	3	3	3

costs and earnings of service development provides more benefit than specifying the organizational capacity.

4.3. Analysis and discussions

It is identified that green energy investors should mainly focus on constructing the feasibility for the proposed service of renewable sources. Therefore, during the process of the project, both technical and financial aspects should be evaluated with necessary research. Possible problems and threats should be investigated, and it should be tried to predict whether the investment will bring profit or not. This situation contributes to the early resolution of problems. It is not possible for unprofitable clean energy projects to be sustainable. Therefore, it will be possible for the project to be profitable by making an effective feasibility analysis. Usman and Hammar [102], Wali et al. [103] and Elia et al. [104] focused on the effectiveness of the renewable energy projects. They claimed that research and development analysis should be prioritized to achieve this objective. Similarly, Xie et al. [105], Meng et al. [106] and Dinçer et al. [107] also highlighted the significance of the technology investments to minimize the costs of the green energy investments. Nonetheless, some scholars also underlined the importance of other factors. For example, Nyangon and Byrne [108] and Li et al. [41] also identified that for the effectiveness of the NSD process for green energy investments, customer expectations should be met.

It is concluded that the best path to generate new services for clean energy investment is Path 1. The main disadvantage of this path is taking too much time. This path can be considered in cases where the investor does not have time constraints while developing a new product. Firstly, necessary research and development activities for renewable services should be conducted. Secondly, a comprehensive cost and benefit analysis should be performed to make predictions for the future of the investment projects. Thirdly, the organizational capacity should be improved regarding the NSD process. Finally, new services should be customized according to the expectations of the customers. This ranking, which is produced according to the results of the analysis, will contribute to the success of new products to be developed for green energy projects.

Moreover, path 2 can be applied where the investor company has a time constraint on the new product to be developed. However, the main weakness of this path is having lower performance result in comparison with other paths. Firstly, research and development examination should be implemented. Finally, a detailed cost benefit analysis should be conducted. Nanayakkara et al. [109] and Uwineza et al. [110] studied the ways to increase the effectiveness of the green energy investments. They reached a conclusion that a detailed cost evaluation should be made. Furthermore, path 3 is also another important way to generate new services. The main benefit of this path is that it is shorter than path 1 and its performance result is greater than path 2. In addition to the research and development and cost benefit

Table 20
Comparison of the results of ELECTRE with TOPSIS.

Alternatives	Bipolar q-ROFS Multi SWARA-ELECTRE	Bipolar q-ROFS Multi SWARA-TOPSIS	Bipolar PF Multi SWARA-ELECTRE	Bipolar PF Multi SWARA-TOPSIS	Bipolar IF Multi SWARA-ELECTRE	Bipolar IF Multi SWARA-TOPSIS
BRD	1	1	1	1	1	1
CBA	2	2	2	2	2	2
DCS	4	4	4	4	4	4
SOC	3	3	3	3	3	3

Table 21
Sensitivity analysis results.

Q values	Alternatives	Bipolar Multi SWARA-ELECTRE				Bipolar Multi SWARA-TOPSIS			
		Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Q:1	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:2	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:3	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:4	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:5	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	3	4	4	3	3	4
	SOC	3	3	4	3	3	4	4	3
Q:6	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	3	4	4	3	3	4
	SOC	3	3	4	3	3	4	4	3
Q:7	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	3	3	4	4	4	3	4
	SOC	3	4	4	3	3	3	4	3
Q:8	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	3	3	4	4	3	3	4
	SOC	3	4	4	3	3	4	4	3
Q:9	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	3	3	4	4	3	4
	SOC	3	3	4	4	3	3	4	3
Q:10	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:15	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3
Q:20	BRD	1	1	1	1	1	1	1	1
	CBA	2	2	2	2	2	2	2	2
	DCS	4	4	4	4	4	4	4	4
	SOC	3	3	3	3	3	3	3	3

Table 22
Activity list, immediate predecessors, and weights of overall values for BSC-based project network.

Activity number	Alternative order	Immediate predecessors	Weights of overall values
1	BRD	–	.486
2	CBA	BRD	.348
3	SOC	BRD, CBA	.000
4	DCS	BRD, CBA, SOC	.166

Table 23
BSC-based project performance by the overall weights.

Path alternatives	Activity order	Total overall weight (%)
Path 1	BRD, CBA, SOC, DCS	100
Path 2	BRD, DCS	48.6
Path 3	BRD, CBA, DCS	83.4
Path 4	BRD, SOC, DCS	65.2

analysis, product should be customized based on the expectations of the customers.

This study has also some important contributions to the fuzzy multi-criteria decision-making literature. The proposed model has some superiorities in comparison with the similar models previously generated in the literature. Keleş et al. [111] evaluated renewable energy sources in Turkey. In this model, the criteria are weighted by using fuzzy SWARA approach. Nonetheless, the causal relationship between the items cannot be defined in these studies because classical SWARA approach does not have this property. This problem is also present in some other similar models [112,113]. Due to this situation, in this proposed model, some improvements are made to the classical SWARA methodology. As a result, a new technique is created by the name of M-SWARA. By the help of this new model, the causal relationship between the criteria can also be identified.

5. Conclusions and future work discussions

In this study, a novel fuzzy decision-making model has been introduced for NSD for green energy projects. Primarily, selected criteria are weighted with M-SWARA methodology based on bipolar q-ROFSs and golden cut. Secondly, BSC-based project network for the NSD process is constructed. These alternatives are ranked by considering ELECTRE approach with bipolar q-ROFSs and golden cut. Owing to these results, PERT diagram is constructed by defining immediate predecessors. Finally, different paths are created to understand effective ways to generate NSD process of clean energy investments.

It is concluded that analysis is the most important process. In addition, design also has a significance. However, commercialization and testing have lower importance. It is also determined that research and development is the most critical alternative. Moreover, cost and benefit analysis should also be prioritized. According to the results of the PERT analysis, it is identified that the shortest path is defined as Path 2 (research and development, cost benefit analysis). Moreover, the longest path by the highest total importance degree is determined as Path 1 (research and development, cost benefit analysis, specifying organizational capacity, providing customized services). When same activity numbers are compared, Path 4 (research and development, specifying organizational capacity, providing customized services) has lower importance in comparison to Path 3 (research and development, cost benefit analysis, providing customized services). It is defined that cost benefit analysis should be considered to provide efficiency in NSD process.

The main novelty of this study is identifying the optimal paths to increase efficiency and effectiveness of the NSD process by a novel fuzzy hybrid decision-making model. The proposed model has some significant superiorities over the previously generated models in the literature. Firstly, some improvements are made to the SWARA model, and a new methodology is created with the name of M-SWARA. This new technique gives opportunity to identify causal relationship between the criteria. Secondly, the degrees of the q-ROFSs are computed by using golden ratio. Hence, it is aimed to reach more appropriate results. These two implications have an increasing impact on the originality and superiority of the proposed model.

In spite of this situation, the most important limitation of this study is the general consideration of renewable energy projects. On the other hand, each of the renewable energy alternatives has its own advantages and disadvantages. The results are also indicative for investors. Nevertheless, more specific analyses can be done in new reviews. As an example, the NSD process can only be considered for solar projects. Thus, it will be possible to produce investment strategies specific to solar energy investors. Additionally, according to the future research directions, the proposed model can also be improved with new techniques.

Nomenclature

AHP	Analytic hierarchy process
BSC	Balanced scorecard
DEMATEL	Decision-making trial and evaluation laboratory
ELECTRE	The elimination and choice translating reality
IFSs	Intuitionistic fuzzy sets
MCDM	Multi-criteria decision-making
M-SWARA	Multi stepwise weight assessment ratio analysis
NSD	New service development
PERT	Project Evaluation and Review Technique
PFSs	Pythagorean fuzzy sets
q-ROFSs	q-rung orthopair fuzzy sets
SWARA	Stepwise weight assessment ratio analysis
TOPSIS	Technique for order preference by similarity to ideal solution
VIKOR	Vise kriterijumska optimizacija i kompromisno resenje

CRediT authorship contribution statement

Luis Martínez: Validation, Writing – original draft, Writing – review & editing. **Hasan Dinçer:** Conceptualization, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Serhat Yüksel:** Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix

See Table A.1.

Table A.1
The summaries of the literature review.

Authors	Results
Dahiru et al. [40] Li et al. [41] Bose et al. [42]	They defined that the expectations of the customers should be satisfied for the increase in the NSD performance. Within this framework, firstly, the customer needs should be identified. In this process, necessary evaluations should be made for different customer groups, such as old and young people. With the help of this issue, the products of the companies should be preferred more, and this situation has an increasing impact on the competitive power of these companies.
Assunção et al. [43] Maasoumi et al. [44] Haldar and Sethi [45] Assi et al. [46] Pata [47]	It is claimed that companies should give importance to the research and development works to generate new successful products. The main problem of renewable energy investment projects is the high costs by comparing with the fossil fuels. For the solution of this problem, technological developments should be prioritized. With the help of the adoption of this new technology, the costs can be decreased. This situation has a positive contribution to the effectiveness of the new products.
Kempa et al. [48] Razmjoo et al. [49] Ogunmodede et al. [50] Yao et al. [51] Pojadas et al. [52] Timilsina [53]	They concluded that cost evaluation should be done appropriately to increase competitive advantage of these new products. For this purpose, an effective financial analysis should be made by considering potential incomes and costs of the new products. Although new products are environment-friendly, they cannot be sustainable if they are not financially efficient. Due to this situation, there is a need to make a comprehensive financial evaluation to understand whether these new products have cost advantage.
Stober et al. [54] Surya et al. [55] Karatop et al. [56] Gawusu et al. [57] Zafar et al. [58] Liu et al. [59]	They claimed that organizational effectiveness is significant to generate effective new products. For a newly developed product to be successful, the departments within the company must work in a coordinated manner. The finance department must determine whether this product is profitable. Moreover, the purchasing department is responsible for the supply of raw materials and other materials required for this new product with both high quality and low cost. The marketing department, on the other hand, should take the necessary actions to introduce this new product to the customers in an accurate and effective manner. As can be seen, the performance of the new product developed because of the failure of any of the departments to perform their duties successfully will also be low.
Suganthi et al. [60] Ertay et al. [61]	These studies integrated AHP methodology with triangular fuzzy sets. In these models, the hierarchical relationship between the criteria can be taken into consideration. However, the impact relation map could not be generated for the indicators. This situation is accepted as the main disadvantage of these proposed models.
Bakhtavar et al. [62] Hashemizadeh and Ju [63] Kang et al. [64]	They used fuzzy ANP method to weight the criteria to find optimal renewable energy portfolios and choose the ideal location for wind energy projects. With the help of this methodology, the networking relationship between the factors can be identified. However, the causal directions between the criteria cannot be identified.
Asante et al. [65] Zhong et al. [66] Liu et al. [67] Li et al. [68] Dinçer et al. [69]	Decision-making problems become very complex so that there is a need to make improvements to the existing techniques. For this purpose, the triangular fuzzy numbers are taken into consideration in the calculation process in some studies. Hence, it is aimed to reach more appropriate results. On the other side, in some other proposed models, interval type-2 fuzzy sets are used for the aim of handling the uncertainties more appropriately. Moreover, some scholars considered q-ROFSs to evaluate the levelized cost of renewable energy alternatives and find significant issues for the performance improvements of the microgeneration energy investments.

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