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TRIZ-based green energy project evaluation using innovation life cycle and fuzzy modelling

YUE MENG[1,*], HASAN DİNÇER[2], SERHAT YÜKSEL[2,*]
1 Department of Tourism, Sichuan Agricultural University, Chengdu 611130, China
2 School of Business, Istanbul Medipol University, Istanbul, 34815 Turkey

*Corresponding author: Yue Meng (mengyue@sicau.edu.cn); Serhat Yüksel (serhatyuksel@medipol.edu.tr)

ABSTRACT This study evaluates theory of the solution of inventive problems (TRIZ)-based green energy project network based on innovation life cycle. In this context, TRIZ-based combinations are obtained by integer patterns for green energy projects. In the next phase, activity priorities of TRIZ-based principles are measured for green energy projects with Pythagorean fuzzy (PF) technique for order preference by similarity to ideal solution (TOPSIS). Finally, project evaluation review technique (PERT) and PF decision making trial and evaluation laboratory (DEMATEL) approaches are taken into consideration to score the green energy projects based on innovation life cycle using inventive problem-solving principles. TRIZ-based principles are also ranked by using Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Additionally, all calculations have also been made with Spherical fuzzy (SF) sets in addition to the PF sets. It is concluded that the analysis results are quite reliable. The main contribution of this study is that innovative strategies are identified for green energy investment projects with a novel methodology. The findings indicate that dynamicity and transformation of properties play a crucial role in this process. Therefore, green energy investors should closely follow technological developments in this area and the products used in green energy investments should be easily adapted to these developments. Additionally, the principal of prior action should be considered to reduce the costs instead of periodic action. It is obvious that the necessary controls should be made before the project starts to increase the efficiency and productivity.

INDEX TERMS Green Energy, PERT, TRIZ, Innovation Life Cycle, Integer Code Series, DEMATEL, TOPSIS

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I. INTRODUCTION

Environmental pollution has become a crucial problem throughout the world. Countries have begun to look for the ways to reduce this problem. In this context, energy consumption is one of the issues that cause this problem. In the process of meeting the energy need, a significant amount of carbon gas is released into the atmosphere by using fossil fuels [1]. Due to this problem, many people suffer from the respiratory diseases. It is possible to talk about many disadvantages of this situation for the country. Because of the increase in the number of sick people, there will be a significant loss of workforce. Additionally, with the increasing number of sick people, healthcare spending will go up significantly that causes the countries to have budget deficits. The problems mentioned reveal the importance of green energy projects. In its most general definition, green energy means energy that does not harm the environment while being supplied [2]. Carbon emissions are reduced to minimum levels thanks to the implementation of green energy projects.

Green energy projects play a crucial role for the sustainable economic improvements. Because of this condition, necessary actions should be taken to improve these investments [3]. However, there are some barriers for this situation. For example, green energy investment projects have high initial costs [4]. This condition makes the companies reluctant to make investments in this area. Furthermore, the green energy investments are complex and long-term investments. This situation increases the uncertainty of these projects because it causes liquidity risks. During this process, the companies may have liquidity crisis if an effective planning is not implemented. Moreover, since green energy investments are complex projects, the companies need qualified employees [5]. Otherwise, it will be very difficult to solve the problems quickly. In addition, for green energy projects to be successful, companies should make significant technology investments.

Similarly, the popularity of green energy investments in the literature has increased. Some researchers focused on the impacts of these projects on the economic growth of the countries. Most of them reached a conclusion that green energy investments play a key role for the sustainable economic development because they lead to lower carbon emission. On the other side, some studies highlighted the difficulties in green energy investment projects. A significant part of these studies underlined the significance of the high-cost problem for this situation. It is understood that in the literature, the issue of green energy investments is dealt with mostly from a general point of view. However, there is a need for a new study which can provide specific and cost-effective strategies to improve these projects. Owing to innovative and cost-effective investment strategies, these projects can be increased.

It is aimed to develop green energy project network based on innovation life cycle. A new inventive problem-solving model is suggested for green energy project evaluation which has four different phases. The first phase includes determining the TRIZ-based principles for green energy projects. In the second phase, the TRIZ-based combinations are used. Furthermore, the third phase is related to the measuring the activity priorities of TRIZ-based principles for green energy projects by PF TOPSIS and PF VIKOR. Moreover, the final phase focuses on scoring the green energy project based on innovation life cycle using inventive problem-solving principles. An integrated method of PERT and PF DEMATEL are considered. In addition, all calculations have also been made by using SF sets to check reliability.

The contribution is that strategies are identified for green energy investment projects by a hybrid multi-criteria decision-making (MCDM) model based on integer patterns and PF sets. There are also some superiorities of this proposed model in comparison with the previous ones. A hybrid model is created which means that different MCDM approaches are considered for both ranking the items and finding the influential relationships [6]. This situation provides an objective evaluation [7]. Furthermore, the principles for green energy project activities are defined based on TRIZ technique. In this approach, more than 2 million patents are examined, and important strategies are defined [8]. Hence, by considering this approach, innovative solutions can be identified without wasting too much time [9]. Furthermore, using PF sets provides an opportunity to reflect uncertainty in a more suitable way [10-12].

Another novelty is using TOPSIS to define activity priorities. The main advantage is considering both the distances to positive and negative ideal solutions [13,14] which contribute more reliable results [15]. PERT method is considered in this process [16]. In this technique, the completion times of the activities are not stated precisely, this process is examined in a probabilistic structure [17,18]. This situation gives the information that the analyzes made with the PERT technique are more realistic [18]. However, the main disadvantage of this technique is that there is no analysis on how the ranking of the activities will be [19,20]. Despite this issue, in this study, the green energy project network is constructed by DEMATEL analysis. Therefore, it is obvious that the more objective evaluation can be made [21,22]. Moreover, making comparative evaluations with VIKOR and SF sets, the reliability is measured. Using integer patterns to find the best combinations of TRIZ-based principles for innovation life cycle has also benefits [23,24]. Thus, it can be possible to check the reliability of the evaluations for the patterns [25,26].

The rest of the paper is organized as following. Section 2 includes the literature review for both green energy investments and methods used in the evaluation. Section 3 defines the integer patterns and geometrical recognition,

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Pythagorean fuzzy sets, TOPSIS, DEMATEL and proposed mode. Moreover, analysis results are indicated in the section 4. In the final two sections, conclusions and discussion are explained.

II. LITERATURE REVIEW

Literature evaluation is provided for different subjects.

A. GREEN ENERGY INVESTMENTS

The positive contributions of green energy investment projects are mentioned. It was emphasized that investments increase the energy dependence [27,28]. Bhowmik et al. [29] explained that clean energy projects reduce the current account deficit problem of countries [30]. Poggi et al. [31] underlined that since these projects do not harm the environment, they contribute to the positive development of the image of the countries. Shaikh et al. [32] determined that it becomes easier for companies that do not harm the environment in energy consumption to obtain loans from international financial institutions. In addition, Damette and Marques [33] highlighted that thanks to green energy projects, the number of people sick is decreasing. The decrease in the number of sick people is a factor that increases the quality of life in the country [34].

Another issue examined in green energy investments is the financing difficulty [35,36]. Kaldellis and Zafirakis [37] underlined that high start-up costs also lead to the problem of financing difficulties. It is not possible to obtain a large amount of investment loans from every bank. This problem is regarded as the biggest barrier to the development of green energy projects. Li et al. [38] and Lin et al. [39] concluded that green energy investments are long-term projects involving complex processes. As can be seen, this problem must be solved in order to increase green energy investments. Additionally, Gong et al. [40] and Breetz et al. [41] also claimed that the governments should support green energy investors. Tax cuts to be applied to these projects will provide investors with a significant cost advantage. In addition, governments can provide low interest loans for green energy projects. This will help investors to get the funds they need. In addition, Liu et al. [42] and Nguyen et al. [43] discussed that green bonds are another application that may attract investors' attention.

Risk management is another important issue for green energy investments. In order for these projects to be carried out successfully, the risks encountered in this process must be managed effectively [39]. First, the risks encountered in green energy investments should be clearly defined [44]. One important risk in this process is financial risks [45]. Kocaarslan and Soytas [46] and Jones [47] stated that Some materials used in green energy projects may need to be imported. In this case, these products must be paid in foreign currency. Therefore, a possible increase in the exchange rate may cause these products to be more expensive. This situation is also valid for loans obtained from financial institutions [48,49]. Therefore, an increase in the exchange rate causes the debt of the company to increase. Dutta et al. [50] identified that efforts should be made to minimize these risks by considering financial derivatives. Moreover, Yang et al. [51] defined that the operational risks are also of great importance in this process. In this context, personnel errors and malfunctions that may occur in information technology systems lower the performance. Cheung et al. [52] concluded that it should be ensured that operational risks are minimized by providing the necessary training to the personnel. In addition, thanks to the research and development studies to be carried out, it will be possible to reduce the disruptions in information technologies.

B. LITERATURE REVIEW ON METHODOLOGY

TRIZ is a technique that argues that the effectiveness of the current situation can be increased more easily, considering past experiences [53]. In other words, strategy suggestions are presented for the solution of the existing problem, taking into consideration the methods applied in solving the problems experienced before. In this way, it is possible to solve the problems much faster [9]. Hence, the TRIZ has been considered for many different purposes. Feniser et al. [54] focused on the ways of increasing eco-innovative levels in SMEs with TRIZ. Additionally, Moussa et al. [55] aimed to solve green supply chain problems by using this technique. Furthermore, Čačo et al. [8] made a study to optimize the automated machine for ultrasonic welding. PERT method is also considered in evaluating the effectiveness of a project. In this context, this method is very helpful in matters such as establishing a facility, developing computer systems, and developing a new product [16]. Huynh and Nguyen [17] and Sackey and Kim [18] aimed to make schedule risk analysis with this technique. Furthermore, Simankina et al. [19] focused on energy consumption economy by using PERT analysis. Lee et al. [20] tried to construct an energy plant by this approach. On the other side, the combination of DEMATEL and TOPSIS were also used for various purposes, such as evaluating knowledge transfer effectiveness [15], truck selection [6], medical tourism adoption [14], evaluation of the financial sectors [7] and risk assessment of hydrogen generation [4].

C. THE IMPORTANT POINTS

The literature evaluation indicates that clean energy investments play a crucial role for economic improvement. In addition to them, some researchers also evaluated the factors influencing these projects. It is determined that there is a need for a new study that provide significant strategies for the improvement of the clean energy projects. This manuscript develops a novel inventive problem-solving model for green energy project evaluation based on innovation life cycle using Pythagorean fuzzy sets with integer patterns. The main contribution is that innovative strategies are identified for green energy investment projects with an original methodology.

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III. METHODOLOGY

All methods considered in the analysis are detailed.

A. INTEGER PATTERNS AND GEOMETRICAL RECOGNITION

This methodology considers integer formations to solve complex problems. In this context, I represents an integer alphabet. Additionally, the terms ≥ 2. $\delta > 0$ *and* $\varepsilon > 0$ give information about the spacings of a spacetime lattice (δ, ε). The equation 1 indicates the details of this process [23].

$$I_n = \{s = s_1 \dots s_n, s_i \in I, i = 1, \dots, n\} \quad (1)$$

Moreover, $W_{\delta\varepsilon}([t_m, t_{m+n}])$ is the set of piecewise constant functions. Also, f is constant and can get value of $(t_{i-1}, t_i]$. Equations (2)-(6) are taken into consideration [24].

$$f: [t_m, t_{m+n}] \to \Re^1 \quad (2)$$

$$i = m + 1, \dots, m + n \quad (3)$$

$$f(t_m) = s_1\delta \quad (4)$$

$$f(t) = s_i\delta \quad (5)$$

$$t \in (t_{i-1}, t_i] \text{ and } t_i = i\varepsilon \quad (6)$$

In these equations, m shows an integer and s_i, $i = 1, \dots, n$ show real numbers. Moreover, $f^{[k]}$ defines the kth integral. Also, the equation (7) defines the integer code series provides the kth integral of a function [25].

$$f \in W_{\delta\varepsilon}([t_m, t_{m+n}]) \quad (7)$$

On the other side, kth integral should satisfy the equation (8).

$$f^{[k]}(t_m) = 0 \quad (8)$$

Additionally, this function can also be considered with the code $c(f) = s_1 \dots s_n$ and the powers of integers. This process is detailed in the equations (9)-(11) [26].

$$f^{[k]}(t_{m+l+1}) = \sum_{i=0}^{k-1} \alpha_{kmi}\left((m + l + 1)^i s_1 + \dots + (m + 1)^i s_{l+1}\right)\delta\varepsilon^k + \sum_{i=0}^{k} \beta_{k,l+1,i} f^{[i]}(t_m)\,\varepsilon^{k-i} \quad (9)$$

$$\alpha_{kmi} = \frac{\binom{k}{i}\left((-1)^{k-i-1}(m + 1)^{k-i} + (-1)^{k-i} m^{k-i}\right)}{k!} \quad (10)$$

$$\beta_{k,l+1,i} = \frac{(l + 1)^{k-i}}{(k - i)!} \quad (11)$$

In addition, Figure 1 illustrates patterns.

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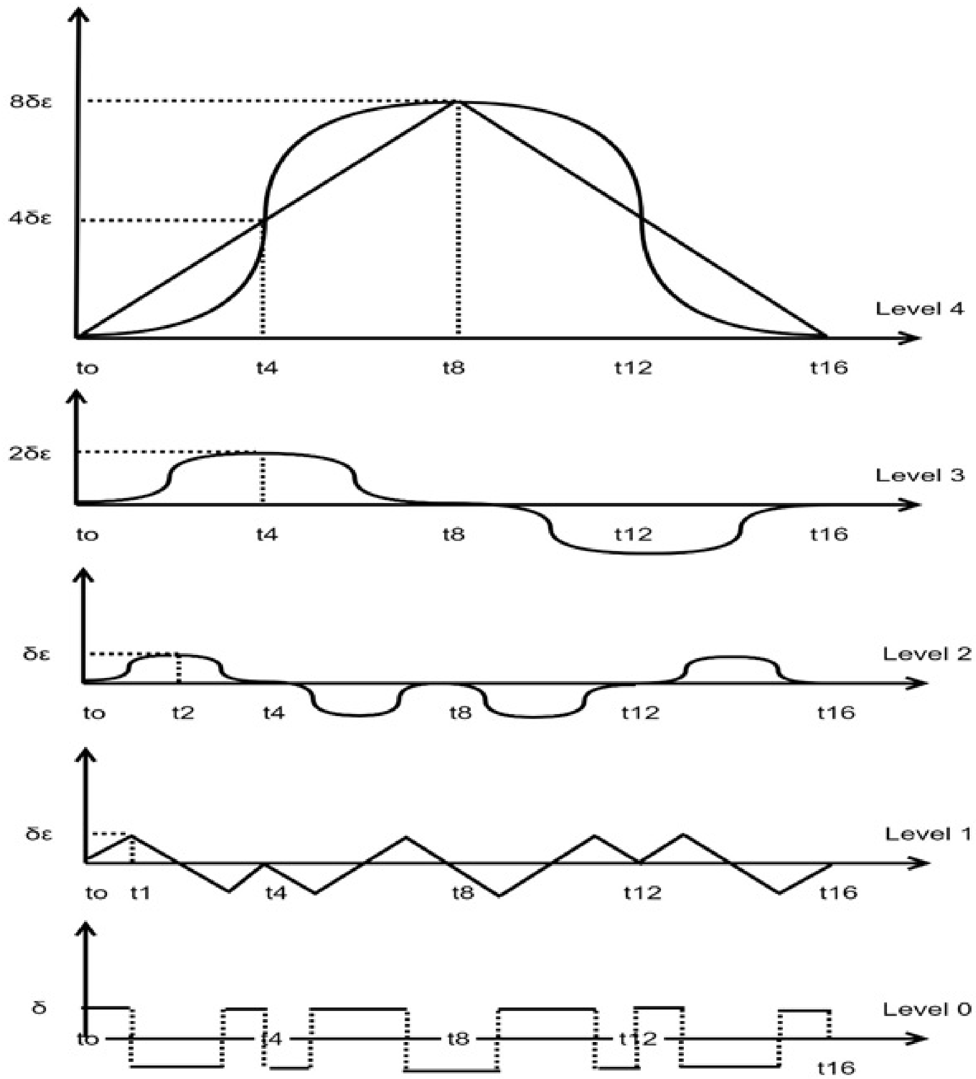

FIGURE 1. Geometrical patterns

Figure 1 gives information about the geometrical patterns. They are generated with the integration of the function $f^{[k]}(t), t_0 \leq t \leq t_{16}$ and k=1,2,3. Equation (12) shows this situation.

$$f^{[0]}(t), t_{j-1} \leq t \leq t_j \qquad t_j = j\varepsilon, \text{j} = 1,2,\dots,16 \tag{12}$$

Moreover, $T_{j0}(t_{j-1}) = t_{j-1} - t_{j-1} = 0$ with respect to the transition from one state into another.

B. PYTHAGOREAN FUZZY SETS

PF aims to define a new non-standard fuzzy membership grades. These grades are considered pair sets over U which is the universe of discourse. This situation is explained in equation (13) [56].

$$P = \left\{ \frac{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta) \rangle}{\vartheta \epsilon U} \right\} \tag{13}$$

In this context, $\mu_P(\vartheta): U \rightarrow [0,1]$ is the degree of membership and $n_P(\vartheta): U \rightarrow [0,1]$ explains the degree of non-membership of the element $\vartheta \; \epsilon \; U$. Equation (14) shows the details of this process [57].

$$\left(\mu_P(\vartheta)\right)^2 + \left(n_P(\vartheta)\right)^2 \leq 1 \tag{14}$$

Also, the degree of indeterminacy is calculated by considering equation (15) [10].

$$\pi_P(\vartheta) = \sqrt{1 - \left(\mu_P(\vartheta)\right)^2 - \left(n_P(\vartheta)\right)^2} \tag{15}$$

Furthermore, in equations (16)-(20), the details regarding the operations of Pythagorean fuzzy sets are shown [11].

$$P_1 = \left\{ \frac{\langle \vartheta, P_1(\mu_{P_1}(\vartheta), n_{P_1}(\vartheta)) \rangle}{\vartheta \epsilon U} \right\} \quad \text{and} \quad P_2 = \left\{ \frac{\langle \vartheta, P_2(\mu_{P_2}(\vartheta), n_{P_2}(\vartheta)) \rangle}{\vartheta \epsilon U} \right\} \tag{16}$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^1 + \mu_{P_2}^2 - \mu_{P_1}^1 \mu_2^2}, n_{P_1} n_{P_1} \right) \tag{17}$$

$$P_1 \otimes P_2 = P\left(\mu_{P_1} \mu_{P_2}, \sqrt{n_{P_1}^2 + n_{P_2}^2 - n_{P_1}^2 n_{P_2}^2} \right) \tag{18}$$

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$$\lambda P = P\left(\sqrt{1-\left(1-\mu_p^2\right)^{\lambda}}, \left(n_p\right)^{\lambda}\right), \lambda > 0 \quad (19)$$

$$P^{\lambda} = P\left(\left(\mu_p\right)^{\lambda}, \sqrt{1-\left(1-n_p^2\right)^{\lambda}}\right), \lambda > 0 \quad (20)$$

For defuzzification, the score function (S) is considered as in the equation (21) [12].

$$S(\vartheta) = \left(\mu_P(\vartheta)\right)^2 - \left(n_P(\vartheta)\right)^2 \text{ where } S(\vartheta) \in [-1,1] \quad (21)$$

C. SPHERICAL FUZZY (SF) SETS

The membership, non-membership, and hesitancy parameters (μ, y and π) are taken into account in SF sets ($\widetilde{D}_S$). Equations (22) and (23) are used in this process [58].

$$\widetilde{D}_S = \left\{\langle u, (\mu_{\widetilde{D}_S}(u), y_{\widetilde{D}_S}(u), \pi_{\widetilde{D}_S}(u)) | u \in U\right\} \quad (22)$$

$$0 \le \mu_{\widetilde{D}_S}^2(u) + y_{\widetilde{D}_S}^2(u) + \pi_{\widetilde{D}_S}^2(u) \le 1 \quad (23)$$

In addition, $\widetilde{D}_S = (\mu_{\widetilde{D}_S}, y_{\widetilde{D}_S}, \pi_{\widetilde{D}_S})$ and $\widetilde{E}_S = (\mu_{\widetilde{E}_S}, y_{\widetilde{E}_S}, \pi_{\widetilde{E}_S})$ give information about two Spherical fuzzy sets. Mathematical details are demonstrated in equations (24)-(27) [59].

$$\widetilde{D}_S \oplus \widetilde{E}_S = \left\{ \begin{array}{c} \left(\mu_{\widetilde{D}_S}^2 + \mu_{\widetilde{E}_S}^2 - \mu_{\widetilde{D}_S}^2 \mu_{\widetilde{E}_S}^2\right)^{\frac{1}{2}}, \\ y_{\widetilde{A}_S} y_{\widetilde{B}_S}, \left(\begin{array}{c} (1-\mu_{\widetilde{E}_S}^2)\pi_{\widetilde{D}_S}^2 + \\ (1-\mu_{\widetilde{D}_S}^2)\pi_{\widetilde{E}_S}^2 - \pi_{\widetilde{D}_S}^2 \pi_{\widetilde{E}_S}^2 \end{array} \right)^{\frac{1}{2}} \end{array} \right\} \quad (24)$$

$$\widetilde{D}_S \otimes \widetilde{E}_S = \left\{ \left(\mu_{\widetilde{D}_S}\mu_{\widetilde{E}_S}, (y_{\widetilde{D}_S}^2 + y_{\widetilde{E}_S}^2 - y_{\widetilde{D}_S}^2 y_{\widetilde{E}_S}^2\right)^{\frac{1}{2}}, \left(\left(1-y_{\widetilde{E}_S}^2\right)\pi_{\widetilde{D}_S}^2 + \left(1-y_{\widetilde{D}_S}^2\right)\pi_{\widetilde{E}_S}^2 - \pi_{\widetilde{D}_S}^2\pi_{\widetilde{E}_S}^2\right)^{\frac{1}{2}} \right\} \widetilde{D}_S \otimes \widetilde{E}_S = \left\{ \left(\mu_{\widetilde{D}_S}\mu_{\widetilde{E}_S}, (y_{\widetilde{D}_S}^2 + y_{\widetilde{E}_S}^2 - y_{\widetilde{D}_S}^2 y_{\widetilde{E}_S}^2\right)^{\frac{1}{2}}, \left(\left(1-y_{\widetilde{E}_S}^2\right)\pi_{\widetilde{D}_S}^2 + \left(1-y_{\widetilde{D}_S}^2\right)\pi_{\widetilde{E}_S}^2 - \pi_{\widetilde{D}_S}^2\pi_{\widetilde{E}_S}^2\right)^{\frac{1}{2}} \right\} \quad (25)$$

$$\lambda * \widetilde{D}_S = \left\{ \left(1-\left(1-\mu_{\widetilde{D}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}, y_{\widetilde{D}_S}^{\lambda}, \left(\left(1-\mu_{\widetilde{D}_S}^2\right)^{\lambda} - \left(1-\mu_{\widetilde{D}_S}^2 - \pi_{\widetilde{D}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}} \right\}, \lambda > 0 \quad (26)$$

$$\widetilde{D}_S^{\lambda} = \left\{ \mu_{\widetilde{D}_S}^{\lambda}, \left(1-\left(1-y_{\widetilde{D}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}, \left(\left(1-y_{\widetilde{D}_S}^2\right)^{\lambda} - \left(1-y_{\widetilde{D}_S}^2 - \pi_{\widetilde{D}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}} \right\}, \lambda > 0 \quad (27)$$

The spherical weighted arithmetic mean (SWAM) is considered as in equation (28) [60].

$$SWAM_w(\widetilde{D}_{S1}, .., \widetilde{D}_{Sn}) = w_1\widetilde{D}_{S1} + \cdots + w_n\widetilde{D}_{Sn} = \left\{ \left[1-\prod_{i=1}^{n}\left(1-\mu_{\widetilde{D}_{Si}}^2\right)^{w_i}\right]^{\frac{1}{2}}, \prod_{i=1}^{n} y_{\widetilde{D}_{Si}}^{w_i}, \left[\prod_{i=1}^{n}\left(1-\mu_{\widetilde{D}_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n}\left(1-\mu_{\widetilde{D}_{Si}}^2 - \pi_{\widetilde{D}_{Si}}^2\right)^{w_i}\right]^{\frac{1}{2}} \right\} \quad (28)$$

D. TOPSIS

It is used to rank the alternatives. First, the normalized values are used as in equation (29) [13].

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \quad i = 1,2,3,..m \ \ and\ j = 1,2,3,..n \quad (29)$$

The second step includes weighting the values as in equation (30).

$$s_{ij} = w_{ij} \times r_{ij} \quad (30)$$

Later, the positive (A^+) and negative (A^-) ideal solutions are defined. In this context, equation (31) and (32) are used [14].

$$A^+ = \{s_{1j}, \dots, s_{mj}\} = \{\max s_{1j}\ for\ \forall\ j \in n\} \quad (31)$$

$$A^- = \{s_{1j}, \dots, s_{mj}\} = \{\min s_{1j}\ for\ \forall\ j \in n\} \quad (32)$$

Next, the distances are computed as in equations (33) and (34). In this process, D_i^+ and D_i^- show the distance to the best and the worst items [15].

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(s_{ij} - A_j^+\right)^2} \quad (33)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(s_{ij} - A_j^-\right)^2} \quad (34)$$

Finally, the relative closeness (RC_i) is calculated with equation (35). It is considered to rank the alternatives.

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (35)$$

E. VIKOR

VIKOR approach also ranks different alternatives. The first step of TOPSIS methodology is also similar for VIKOR. Next, fuzzy best and worst values ($\tilde{f}_j^*, \tilde{f}_j^-$) are computed by equation (36) [61].

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \text{and } \tilde{f}_j^- = \min_i \tilde{x}_{ij} \quad (36)$$

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Mean group utility ($\tilde{S}_i$) and maximal regret ($\tilde{R}_i$) are identified as in equations (37) and (38) [62].

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

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

In these equations, $\tilde{w}_j$ represents fuzzy weights. Next, the value of $\tilde{Q}_i$ is calculated as in equation (39) [63].

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

Within this context, the strategy weights are shown as v. On the other side, 1-v indicates the weight of the individual regret. In this process, items are ranked by using the values of S, Q and R. Equation (40) identifies the details of the first requirement.

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

Additionally, the second requirement is related to the acceptable stability.

F. DEMATEL

Firstly, the expert team evaluates the criteria. After that, the direct relation matrix (A) is obtained. Equation (41) explains the details of this matrix [6].

$$A = \begin{bmatrix} 0 & a_{12} & a_{13} & & \cdots & a_{1n} \\ a_{21} & 0 & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & 0 & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & 0 \end{bmatrix} \quad (41)$$

Within this framework, a_{ij} indicates the influence of criterion i on the criterion j. Next, equations (42) and (43) are considered to generate the normalized matrix (B) [7].

$$B = \frac{A}{max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}} \quad (42)$$

$$0 \leq b_{ij} \leq 1 \quad (43)$$

Later, total relation matrix (C) is developed by using equation (44). The identity matrix is denoted by I [21].

$$C = B(I - B)^{-1} \quad (44)$$

The sums of rows and columns (D and E) are computed with equations (45) and (46) [22].

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \quad (45)$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \quad (46)$$

Within this scope, the value of D+E is used for weighting the factors. For this purpose, threshold value (α) is taken into consideration in equation (47).

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij}\right]}{N} \quad (47)$$

G. PROPOSED MODEL

A new 4-stage model has been suggested by integrating the methods explained above. Figure 2 demonstrates all steps of this proposed model.

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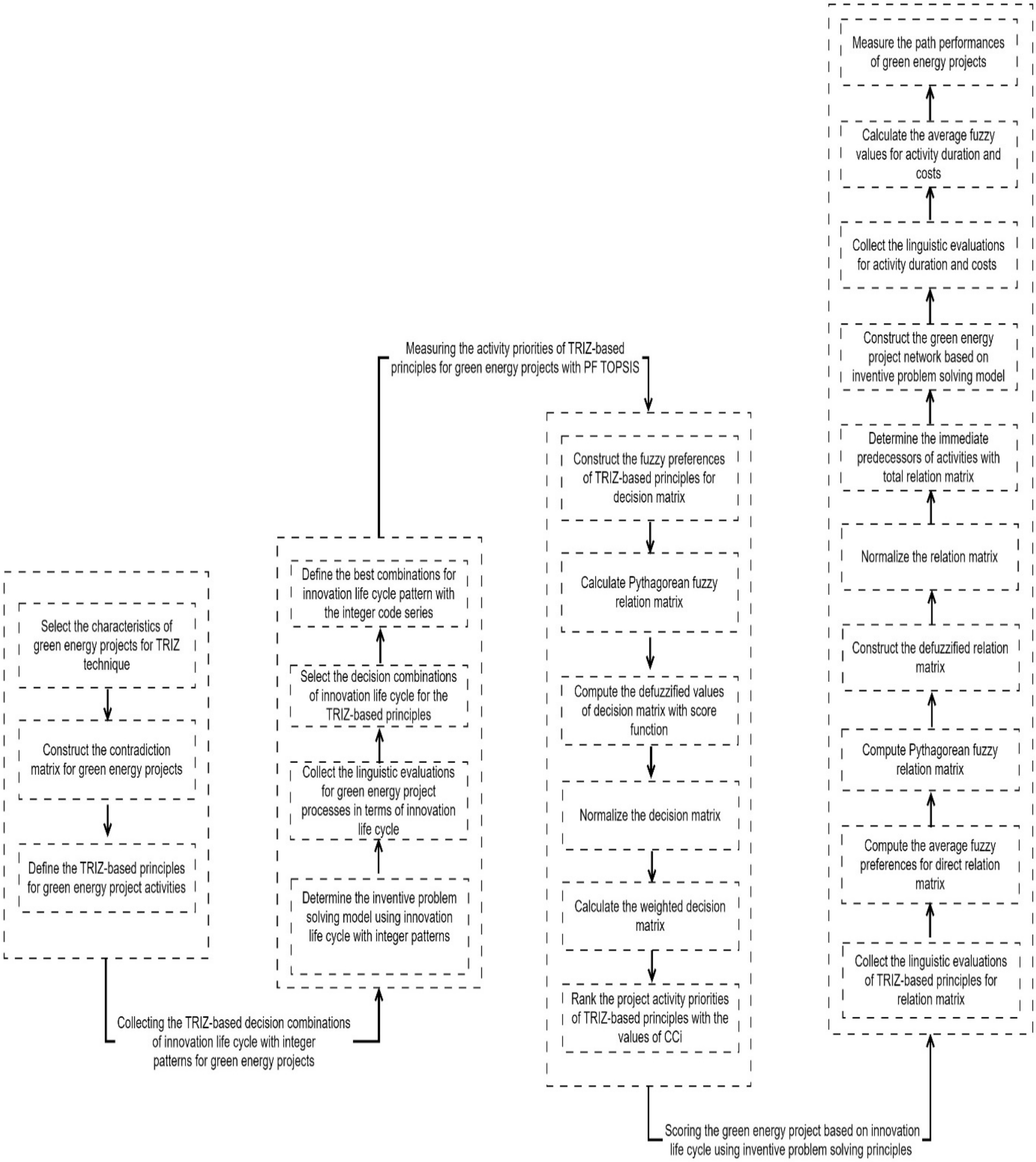

FIGURE 2. The details of proposed model

Phase 1: Determining the TRIZ-based principles for green energy projects.

Step 1: Select the characteristics of green energy projects for TRIZ technique.

Step 2: Construct the contradiction matrix for green energy projects.

Step 3: Define the TRIZ-based principles for green energy project activities.

Phase 2: Collecting the TRIZ-based decision combinations.

Step 4: Determine the inventive problem-solving model using innovation life cycle with integer patterns.

Step 5: Collect the linguistic evaluations for green energy project processes in terms of innovation life cycle.

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Step 6: Select the combinations for TRIZ-based principles.

Step 7: Identify the best combinations with the integer code series.

Phase 3: Measuring the activity priorities of TRIZ-based principles for green energy projects with PF TOPSIS and PF VIKOR. Additionally, the analysis has also been made by considering SF sets.

Step 8: Construct the fuzzy preferences of TRIZ-based principles for decision matrix.

Step 9: Calculate Pythagorean fuzzy relation matrix.

Step 10: Compute the defuzzified values of decision matrix with score function.

Step 11: Normalize the decision matrix.

Step 12: Calculate the weighted decision matrix.

Step 13: Rank the project activity priorities of TRIZ-based principles with the values of CCi.

Phase 4: Scoring the green energy project based on innovation life cycle using inventive problem-solving principles by PF and SF DEMATEL.

Step 14: Collect the linguistic evaluations of TRIZ-based principles for relation matrix.

Step 15: Compute the average fuzzy preferences for direct relation matrix.

Step 16: Compute Pythagorean fuzzy relation matrix.

Step 17: Construct the defuzzified relation matrix.

Step 18: Normalize the relation matrix.

Step 19: Determine the immediate Predecessors of activities with total relation matrix.

Step 20: Construct the green energy project network based on inventive problem-solving model.

Step 21: Collect the linguistic evaluations for activity duration and costs.

Step 22: Calculate the average fuzzy values for activity duration and costs.

Step 23: Measure the path performances of green energy projects.

The main novelty of this proposed model is considering a hybrid methodology. This means that different MCDM models (TOPSIS and DEMATEL) are used in the analysis process [6]. In other words, both ranking the factors and making the causal relationships are performed objectively [7]. On the other side, in some models in the literature, the alternatives are ranked with a MCDM model, but the authors selected the weights [64,65]. Hence, by comparing with these models, the proposed model provides better results [66,67]. Additionally, defining the principles for green energy project activities based on TRIZ technique is another novelty of this model because it provides innovative solutions [8,9]. In other words, specific strategies are developed for the investment decisions. This situation provides a competitive advantage for the green energy investors.

Also, considering PF sets has some benefits. With respect to the intuitionistic fuzzy sets, the sum of membership and non-membership degrees should be maximum 1 [68-71]. However, regarding the Pythagorean fuzzy sets, there is not such a necessity so that owing to these fuzzy sets, uncertainties can be reflected in a more suitable way [10-12]. Additionally, the main advantage of TOPSIS is that more appropriate results can be reached due to considering also negative optimal solutions [13-15]. However, in some similar methods, the shortest distances to positive optimal solutions are only taken into consideration [72-74]. Thus, it is clear that TOPSIS helps to reach more effective ranking results.

Moreover, the green energy project network is generated by using impact-relation map generated by DEMATEL analysis so that more objective results can be reached [21,22]. However, in most of MCDM techniques, only the weights can be calculated, but the causality analysis cannot be identified. Therefore, this proposed model can generate more effective and reliable strategies in comparison with previous models [75-80]. Finally, considering integer patterns to define the best combinations of TRIZ-based principles for innovation life cycle has a contribution to increase the reliability of the evaluations for the patterns [23-26]. Both VIKOR and TOPSIS approaches are taken into consideration. Similarly, the analyses are also performed with SF sets in addition to the PF sets. With the help of these comparative evaluations, it can be possible to measure the reliability. Therefore, this proposed model has significant superiorities by comparing with the previous models that include only one MCDM approach.

Furthermore, this proposed model is also quite appropriate the purpose of the manuscript. A novel inventive problem-solving model is created for green energy project evaluation. In this context, green energy project activities are generated by considering TRIZ-based principles. Green energy investment projects have many benefits. However, because of high-cost problems, it becomes quite difficult to increase these projects. Hence, in the analysis process, cost effectiveness should be taken into consideration. TRIZ is a

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technique which provides innovative and cost-effective solutions. Thus, preferring TRIZ in this framework contributes to more appropriate results. In addition to this condition, in this study, these activities are ranked to find the best process in green energy project development. Because it is a crucial situation, both TOPSIS and VIKOR methods are considered in the ranking process. With the help of this comparative evaluation, it can be possible to have more reliable results. Moreover, the green energy project network is generated in this study, as well. Due to this situation, DEMATEL method is considered because of the impact relation map.

On the other hand, there are also some limitations of this proposed model. In this model, the criteria are weighted by considering only DEMATEL methodology. In order to make a comparative evaluation, both SF and PF sets are taken into consideration. However, in the proposed model, there is not a comparative analysis for DEMATEL method. Another limitation of the proposed model is that the activities are defined by considering TRIZ-based principles. In this process, the experts are requested to generate items by considering only 39 different TRIZ principles. Finally, immediate predecessors are determined with DEMATEL. Because of this situation, the paths are limited to only 4 different activity sets.

IV. ANALYSIS RESULTS

The proposed model consists of four different phases. Analysis results are given for each phase.

PHASE 1: DETERMINING THE TRIZ-BASED PRINCIPLES FOR GREEN ENERGY PROJECTS

In this phase, firstly, the characteristics of green energy projects are defined for TRIZ technique. Based on this evaluation, 6 different items are selected out of TRIZ-based engineering parameters. Table 1 indicates the details of the selected characteristics.

TABLE 1. The characteristics of green energy projects for TRIZ

Characteristics	Literature
Loss of energy (F1)	[19],[20]
Reliability (F2)	[27],[28]
Convenience of use (F3)	[29],[30]
Repairability (F4)	[31],[32]
Adaptability (F5)	[19],[30]
Capacity (F6)	[27],[32]

Firstly, necessary care should be taken to avoid energy loss in green energy projects. Otherwise, the efficiency of these projects will decrease significantly. On the other hand, the most important point in these projects is that they do not harm the environment. In this context, it should be ensured that people's confidence in these projects is increased by taking necessary measures. In addition, care should be taken to ensure that these projects are user-friendly. In this way, it will be possible for the products to be preferred more by the customers. In addition, in case of a potential problem in the project, this malfunction should be repaired quickly. In this way, uninterrupted electricity will be produced. Very rapid developments are occurring in green energy technologies. Therefore, it is important to design projects so that they can be adapted very easily to these developments. Finally, the electrical energy to be obtained must have a high capacity.

After that, the contradiction matrix is constructed for green energy projects. In this framework, 3 different experts made evaluations. These people consist of academicians and managers who work at the level of directors at least. The expert team also has a minimum of 20 years of experience in the subject. These people have the knowledge to make effective evaluations for green energy projects. With respect to the creating of the contradiction matrix (CM), the expert team made a comparative evaluation for these 6 different factors. The left side of this matrix gives information about the improvement of these items whereas the right side states the worsening conditions. As a result, experts identified significant TRIZ-based principles as in Table 2.

TABLE 2. CM for green energy projects

		Worsening Characteristics					
	Characteristics	F1	F2	F3	F4	F5	F6
Improving Characteristics	F1	-	15	15,19	10,15	15,19,35	10,15,19
	F2	10,15,19	-	10,15,19	10,15,19	19,35	15,19
	F3	10,15	10,15,19	-	15,19	10,15	10,35
	F4	10,15,19	10,15,19	10,15,19,35	-	10	15,35
	F5	10,15	10,15,35	15,19,35	10,19,35	-	15,19,35
	F6	15,19,35	10,15,19	15,19,35	10,15	15,19,35	-

It is obvious that by considering the evaluations emphasized in Table 2, 4 different issues are identified out of 40 different TRIZ principles. Table 3 gives information about these factors.

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TABLE 3. TRIZ-based principles for green energy project activities

Principle Numbers	Definition	Supported Literature
10	Prior Action (Principle 1)	[19],[20]
15	Dynamicity (Principle 2)	[31],[32]
19	Periodic Action (Principle 3)	[29],[30]
35	Transformation of Properties (Principle 4)	[27],[32]

Prior action refers to the pre-planning of a project. In this context, it is aimed to clearly identify the issues affecting the customers' preferences. On the other hand, dynamicity includes the designing the object for the outside environment for the best solution. In this context, improvements are made in the processes of the project by measuring the customers' reactions. In other words, necessary adaptations should be implemented in green energy projects, especially considering technological developments. Moreover, regarding the periodic action, it should be aimed to identify possible malfunctions in green energy projects in a timely manner by conducting audits at irregular intervals. Finally, the transformation of properties refers to changes to be made in the physical properties of the object when necessary.

PHASE 2: COLLECTING THE TRIZ-BASED COMBINATIONS

The inventive problem-solving model is identified using innovation life cycle with integer patterns in the first step of this phase. Figure 3 shows the process of inventive problem-solving model using innovation life cycle with integer patterns.

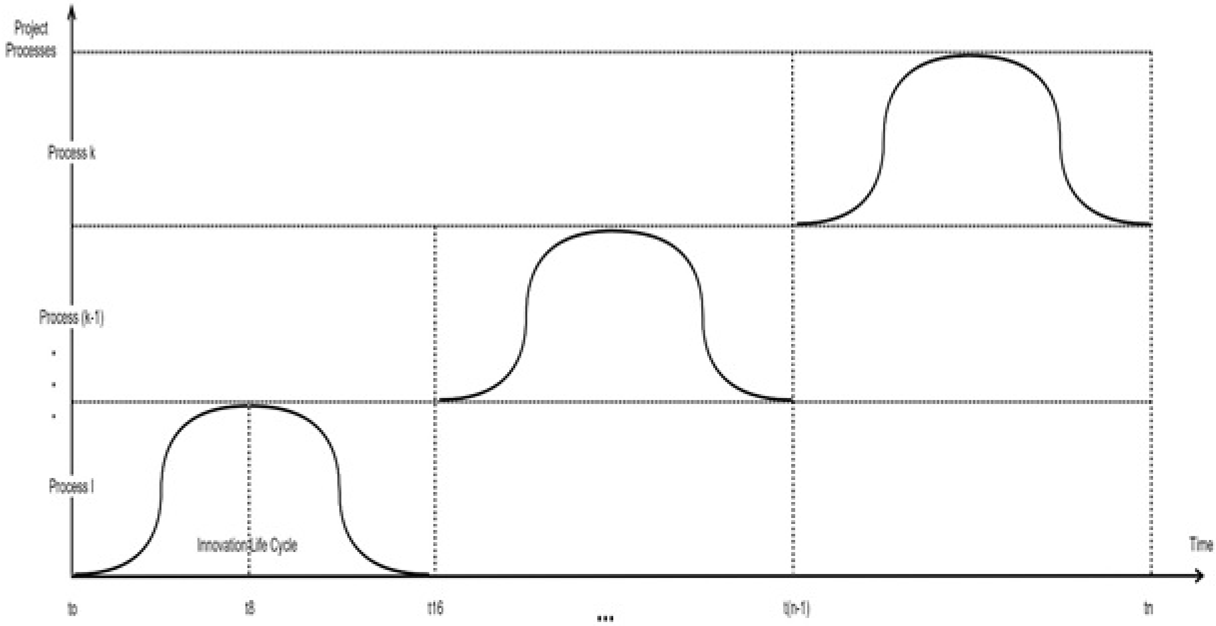

FIGURE 3. Process of inventive problem-solving model using innovation life cycle with integer patterns

Innovation life cycle is defined in 16 periods of time. Accordingly, selected processes of inventive problem-solving model entitled TRIZ approach are analyzed in the time of innovation life cycle, respectively. Figure 4 represents that k number of process is given in n periods of innovation life cycle. Each process is divided into 16 periods of time and k number of process is subject to the innovative researches. At the end of project processes, the most appropriate inventive problem-solving results could be evaluated for the efficient decision-making results of green energy projects. In this study, selected principles from the TRIZ method are considered as a process set and they are applied using innovation life cycle in 64 periods of time for the inventive problem-solving model of green energy projects. In the next step, the linguistic evaluations are obtained for green energy project processes in terms of innovation life cycle. Table 4 defines the preference numbers and integer alphabet for decision matrix.

TABLE 4. Preference numbers and integer alphabet for decision matrix

Linguistic Scales	Preference Numbers	Integer Alphabet
Weakest	.10	-2
Poor	.25	-1
Fair	.50	0
Good	.75	+1
Best	1	+2

The evaluations regarding different activities are obtained. Later, the best combinations are determined. With respect

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to the principal 1, the calculations of the 4 different combinations are indicated below.

Combination 1:

At the level 1, $f^{[0]}(t_1,t_2)=(1)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(2)^0-(2)^0=0$, $f^{[0]}(t_5,t_6)=(2)^0-(2)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(1)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(1)^1-(2)^1+(2)^1-(2)^1\neq 0$, $f^{[1]}(t_5,t_8)=(2)^1-(2)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

Because $f^{[1]}(t_1,t_4)\neq 0$, it is seen that the combination 1 does not satisfy the innovation life cycle pattern.

Combination 2:

At the level 1, $f^{[0]}(t_1,t_2)=(2)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(2)^0-(2)^0=0$, $f^{[0]}(t_5,t_6)=(2)^0-(2)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(1)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(2)^1-(2)^1+(2)^1-(2)^1=0$, $f^{[1]}(t_5,t_8)=(2)^1-(2)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

At the level 3, $f^{[2]}(t_1,t_8)=(2)^2-(2)^2+(2)^2-(2)^2+(2)^2-(2)^2+(1)^2-(1)^2=0$, $f^{[2]}(t_9,t_{16})=(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2=0$

At the level 4, $f^{[3]}(t_1,t_{16})=(2)^3-(2)^3+(2)^3-(2)^3+(2)^3-(2)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3=0$

It is concluded that the combination 2 is consistent at the level 4 for the geometrical patterns of innovation life cycle in terms of TRIZ-based principle 1. Accordingly, combination 2 is selected as a best decision combination of principle 1.

Combination 3:

At the level 1, $f^{[0]}(t_1,t_2)=(1)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(2)^0-(2)^0=0$, $f^{[0]}(t_5,t_6)=(2)^0-(2)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(2)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(1)^1-(2)^1+(2)^1-(2)^1\neq 0$, $f^{[1]}(t_5,t_8)=(2)^1-(2)^1+(1)^1-(2)^1\neq 0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

Since $f^{[1]}(t_1,t_4)\neq 0$ and $f^{[1]}(t_5,t_8)\neq 0$, it is determined that the combination 3 does not provide the hierarchical form of innovation life cycle pattern at the level 2.

Combination 4:

At the level 1, $f^{[0]}(t_1,t_2)=(2)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(2)^0-(2)^0=0$, $f^{[0]}(t_5,t_6)=(2)^0-(2)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(2)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(2)^1-(2)^1+(2)^1-(2)^1=0$, $f^{[1]}(t_5,t_8)=(2)^1-(2)^1+(1)^1-(2)^1\neq 0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

The computation process of integer code series cannot continue because $f^{[1]}(t_5,t_8)\neq 0$.

Additionally, regarding the principal 2, the hierarchical forms are also computed for other TRIZ-based principles at the different levels of integer codes. The best decision combination of principle 2 is selected as combination 1. The results are given as follows.

Combination 1:

At the level 1, $f^{[0]}(t_1,t_2)=(2)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(1)^0-(1)^0=0$, $f^{[0]}(t_5,t_6)=(2)^0-(2)^0=0$, $f^{[0]}(t_7,t_8)=(2)^0-(2)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(2)^1-(2)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_5,t_8)=(2)^1-(2)^1+(2)^1-(2)^1=0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

At the level 3, $f^{[2]}(t_1,t_8)=(2)^2-(2)^2+(1)^2-(1)^2+(2)^2-(2)^2+(2)^2-(2)^2=0$, $f^{[2]}(t_9,t_{16})=(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2=0$

At the level 4, $f^{[3]}(t_1,t_{16})=(2)^3-(2)^3+(1)^3-(1)^3+(2)^3-(2)^3+(2)^3-(2)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3=0$

For the principle 3, the best decision set of innovation life is combination 7. The consistency results of this combination are given below.

Combination 7:

At the level 1, $f^{[0]}(t_1,t_2)=(1)^0-(2)^0=0$, $f^{[0]}(t_3,t_4)=(2)^0-(1)^0=0$, $f^{[0]}(t_5,t_6)=(1)^0-(1)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(1)^0=0$, $f^{[0]}(t_9,t_{10})=$

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$(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(2)^0-(2)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(1)^1-(2)^1+(2)^1-(1)^1=0$, $f^{[1]}(t_5,t_8)=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(2)^1-(2)^1+(1)^1-(1)^1=0$

At the level 3, $f^{[2]}(t_1,t_8)=(1)^2-(2)^2+(2)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2=0$, $f^{[2]}(t_9,t_{16})=(1)^2-(1)^2+(1)^2-(1)^2+(2)^2-(2)^2+(1)^2-(1)^2=0$

At the level 4, $f^{[3]}(t_1,t_{16})=(1)^3-(2)^3+(2)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(2)^3-(2)^3+(1)^3-(1)^3=0$

Moreover, with respect to the principle 4, the combination 7 presents the best decision set of innovation life cycle with integer codes. Four level computation results of this combination are defined as following.

Combination 7:

At the level 1, $f^{[0]}(t_1,t_2)=(1)^0-(1)^0=0$, $f^{[0]}(t_3,t_4)=(1)^0-(1)^0=0$, $f^{[0]}(t_5,t_6)=(1)^0-(1)^0=0$, $f^{[0]}(t_7,t_8)=(1)^0-(1)^0=0$, $f^{[0]}(t_9,t_{10})=(1)^0-(1)^0=0$, $f^{[0]}(t_{11},t_{12})=(1)^0-(1)^0=0$, $f^{[0]}(t_{13},t_{14})=(1)^0-(1)^0=0$, $f^{[0]}(t_{15},t_{16})=(1)^0-(1)^0=0$,

At the level 2, $f^{[1]}(t_1,t_4)=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_5,t_8)=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_9,t_{12})=(1)^1-(1)^1+(1)^1-(1)^1=0$, $f^{[1]}(t_{13},t_{16})=(1)^1-(1)^1+(1)^1-(1)^1=0$

At the level 3, $f^{[2]}(t_1,t_8)=(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2=0$, $f^{[2]}(t_9,t_{16})=(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2+(1)^2-(1)^2=0$

At the level 4, $f^{[3]}(t_1,t_{16})=(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3+(1)^3-(1)^3=0$

PHASE 3: MEASURING THE ACTIVITY PRIORITIES OF TRIZ-BASED PRINCIPLES FOR GREEN ENERGY PROJECTS WITH PF TOPSIS

Firstly, the fuzzy preferences of TRIZ-based principles are constructed for decision matrix as in Table 5.

TABLE 5. Fuzzy preferences of TRIZ-based principles for decision matrix

Time	Process	Phase	Principle I	Principle II	Principle III	Principle IV
T1	Emerging	Phase 1	1	1	.75	.75
T2		Phase 2	.10	.10	.10	.25
T3	Growth	Phase 1	1	.75	1	.75
T4		Phase 2	.10	.25	.25	.25
T5	Maturity	Phase 1	1	1	.75	.75
T6		Phase 2	.10	.10	.25	.25
T7	Aging	Phase 1	.75	1	.75	.75
T8		Phase 2	.25	.10	.25	.25
T9	Emerging	Phase 1	.75	.75	.75	.75
T10		Phase 2	.25	.25	.25	.25
T11	Growth	Phase 1	.75	.75	.75	.75
T12		Phase 2	.25	.25	.25	.25
T13	Maturity	Phase 1	.75	.75	1	.75
T14		Phase 2	.25	.25	.10	.25
T15	Aging	Phase 1	.75	.75	.75	.75
T16		Phase 2	.25	.25	.25	.25

The Pythagorean fuzzy relation matrix is generated. The normalized matrix is constructed by considering the boundaries of $\mu_p^2+n_p^2=1$ The matrix is shown in Table 6.

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TABLE 6. Pythagorean fuzzy decision matrix

Time	Principle I	Principle II	Principle III	Principle IV
T1	[.90,.05]	[.90,.05]	[.68,.16]	[.68,.16]
T2	[.09,.46]	[.09,.46]	[.09,.46]	[.23,.39]
T3	[.90,.05]	[.68,.16]	[.90,.05]	[.68,.16]
T4	[.09,.46]	[.23,.39]	[.23,.39]	[.23,.39]
T5	[.90,.05]	[.90,.05]	[.68,.16]	[.68,.16]
T6	[.09,.46]	[.09,.46]	[.23,.39]	[.23,.39]
T7	[.68,.16]	[.90,.05]	[.68,.16]	[.68,.16]
T8	[.23,.39]	[.09,.46]	[.23,.39]	[.23,.39]
T9	[.68,.16]	[.68,.16]	[.68,.16]	[.68,.16]
T10	[.23,.39]	[.23,.39]	[.23,.39]	[.23,.39]
T11	[.68,.16]	[.68,.16]	[.68,.16]	[.68,.16]
T12	[.23,.39]	[.23,.39]	[.23,.39]	[.23,.39]
T13	[.68,.16]	[.68,.16]	[.90,.05]	[.68,.16]
T14	[.28,.39]	[.23,.39]	[.09,.46]	[.23,.39]
T15	[.68,.16]	[.68,.16]	[.68,.16]	[.68,.16]
T16	[.23,.39]	[.23,.39]	[.23,.39]	[.23,.39]

After defuzzification and normalization, the weights of time are considered equally as 6.25% and weighted decision matrix is given in Table 7.

TABLE 7. Weighted decision matrix

Time	Principle I	Principle II	Principle III	Principle IV
T1	.039	.039	.021	.021
T2	.035	.035	.035	.017
T3	.039	.021	.039	.021
T4	.047	.024	.024	.024
T5	.039	.039	.021	.021
T6	.040	.040	.020	.020
T7	.024	.046	.024	.024
T8	.024	.047	.024	.024
T9	.031	.031	.031	.031
T10	.031	.031	.031	.031
T11	.031	.031	.031	.031
T12	.031	.031	.031	.031
T13	.024	.024	.046	.024
T14	.024	.024	.047	.024
T15	.031	.031	.031	.031
T16	.031	.031	.031	.031

In the final step, the project activity priorities of TRIZ-based principles are ranked with the values of CCi. The ranking results of TRIZ-based principles are indicated in Table 8.

TABLE 8. Ranking the priorities of TRIZ-based principles

Principles	D+	D-	CCi	Ranking of Project activity Priorities
(Principle 1)	.045	.047	.512	(A2)
(Principle 2)	.044	.049	.527	(A1)
(Principle 3)	.051	.041	.442	(A3)
(Principle 4)	.066	.000	.000	(A4)

Table 8 states that dynamicity is the first activity. After that, the prior action is considered. Also, the third activity is the periodic action. Furthermore, the transformation of properties is on the last rank. In addition to this situation, these items are also ranked by considering VIKOR. Moreover, the analysis is also performed by using SF sets in addition to PF sets. The comparative analysis results ae summarized in Table 9.

TABLE 9. Comparative ranking results

Principles	SF VIKOR	SF TOPSIS	PF VIKOR	PF TOPSIS
P1	2	2	2	2
P2	1	1	1	1
P3	3	3	3	3
P4	4	4	4	4

It is defined that the findings of both techniques are almost the same for both SF and PF sets. This situation explains that the findings of PF TOPSIS are reliable.

PHASE 4: SCORING THE GREEN ENERGY PROJECT BASED ON INNOVATION LIFE CYCLE USING INVENTIVE PROBLEM-SOLVING PRINCIPLES

Green energy projects are evaluated based on innovation life cycle and TRIZ-based principles using an integrated method of PERT and PF DEMATEL. PF DEMATEL is used for defining the immediate predecessors of activity in the project evaluation. Critical paths as well as the cost and duration scores are assessed by using PERT. On the other side, the linguistic relation evaluations for TRIZ-based principles are stated on Table 10.

TABLE 10. Linguistic relation evaluations for TRIZ-based principles

	A1			A2			A3			A4		
	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
A1				M	H	H	M	M	M	S	S	M
A2							M	H	H	S	S	M
A3										H	H	M
A4												

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Average fuzzy preferences are computed as in Table 11.

TABLE 11. Average fuzzy preferences for direct relation matrix

	A1	A2	A3	A4
A1		0.67	0.50	0.33
A2			0.67	0.33
A3				0.67
A4				

The normalized matrix is constructed by considering the boundaries of $\mu_p^2 + n_p^2 = 1$ The matrix is shown in Table 12.

TABLE 12. Pythagorean fuzzy relation matrix

	A1	A2	A3	A4
A1		[0.45,0.28]	[0.45,0.28]	[0.23,0.39]
A2			[0.45,0.28]	[0.23,0.39]
A3				[0.68,0.16]
A4				

The average values of membership and non-membership degrees are computed, and the score function values are calculated for obtaining the defuzzified values of Pythagorean fuzzy relation matrix. Table 13 shows the details.

TABLE 13. Defuzzified relation matrix

	A1	A2	A3	A4
A1	.000	.320	.127	.033
A2	.000	.000	.320	.033
A3	.000	.000	.000	.320
A4	.000	.000	.000	.000

After that, the normalized matrix is created as in Table 14.

TABLE 14. Normalized relation matrix

	A1	A2	A3	A4
A1	.000	.668	.265	.068
A2	.000	.000	.668	.068
A3	.000	.000	.000	.668
A4	.000	.000	.000	.000

Next, the immediate predecessors of activities are determined with total relation matrix. The activity impacts for immediate predecessors are defined as in Table 15.

TABLE 15. Activity impacts for immediate Predecessors

	A1	A2	A3	A4
A1	.000	**.668**	**.710**	.587
A2	.000	.000	**.668**	.513
A3	.000	.000	.000	**.668**
A4	.000	.000	.000	.000

In Table 15, the bold values are the higher values than threshold. Thus, it is possible to illustrate the immediate predecessors of green energy projects in Table 16.

TABLE 16. Immediate predecessors of the TRIZ-based principles

TRIZ-based Principles	Activity	Immediate Predecessors
Dynamicity	A1	-
Prior Action	A2	A1
Periodic Action	A3	A1, A2
Transformation of Properties	A4	A2, A3

In the following step, the green energy project network is generated based on inventive problem-solving model. Figure 4 indicates the flowchart of green energy project network.

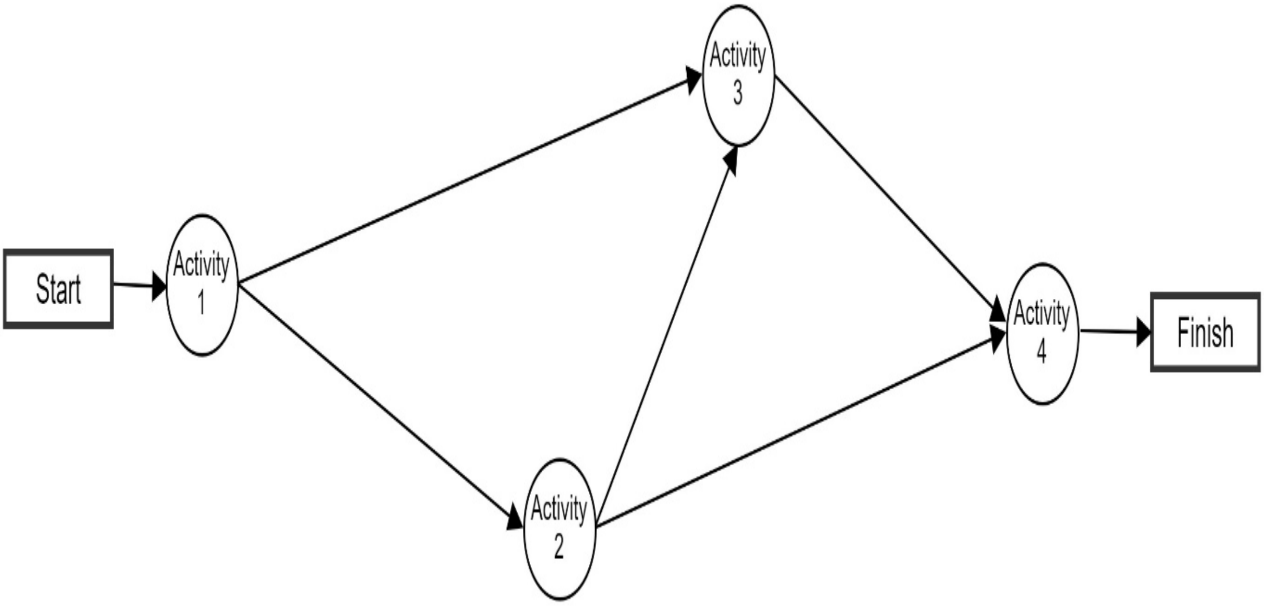

FIGURE 4. The flowchart of green energy project network

Evaluations for activity duration and costs or provided. Table 17 demonstrates evaluations for activity duration and costs.

TABLE 17. Linguistic evaluations for activity duration and costs

	Duration			Costs		
Activity	E1	E2	E3	E1	E2	E3
A1	M	H	H	M	VH	H
A2	H	VH	M	L	VH	M
A3	VH	H	H	VH	H	H
A4	H	L	M	H	H	M

Additionally, the optimistic and pessimistic values for activity duration and costs are demonstrated in Table 18.

TABLE 18. Optimistic and pessimistic values for activity duration and costs

	Duration		Costs	
Activity	Optimistic	Pessimistic	Optimistic	Pessimistic
A1	M	H	M	VH
A2	M	VH	L	VH
A3	H	VH	H	VH
A4	L	H	M	H

After that, the average fuzzy values for activity duration and costs are calculated as in Table 19.

TABLE 19. Average fuzzy values for activity duration and costs

Activity	Average fuzzy preferences	
	Duration	Costs
A1	0.67	0.75
A2	0.75	0.58
A3	0.83	0.83
A4	0.50	0.67

Later, the path performances of green energy projects are measured as in Table 20.

TABLE 20. The weights (Ws) of TRIZ-based activities

Activity	D	E	D+E	D-E	Ws
A1	1.965	.000	1.965	1.965	.258
A2	1.181	.668	1.848	.513	.242
A3	.668	1.378	2.045	-.710	.268
A4	.000	1.768	1.768	-1.768	.232

Table 20 identifies that activity 3 (periodic action) has the greatest weight. Also, the activity 1 (dynamicity) is another significant principle. Activity 2 (prior action) and activity 4 (transformation of properties) have low weights. Table 21 indicates the path performances of green energy projects with respect to the duration and costs.

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TABLE 21. Path performances of green energy projects by duration and costs

Paths	Activity Set	Weighted preference of duration	Ranking by duration	Weighted preference of costs	Ranking by costs
Path 1	A1, A2, A4	.641	1	.668	1
Path 2	A1, A3, A4	.675	2	.754	3
Path 3	A1, A2, A3, A4	.693	3	.713	2

Activity fuzzy preferences are multiplied with their weights for the activity set of paths. Thus, the weighted preference results are obtained to measure the path performances by the duration and costs. It is concluded that path 1 is the shortest path by duration. On the other side, path 3 is the longest path by duration/CPM. Additionally, path 1 has the lowest cost whereas path 2 has the highest cost. These calculations are also made by using SF sets. Table 22 explains the details of these calculations.

TABLE 22. Comparative ranking results by duration and costs

Paths	Activity Set	Ranking by duration (SF)	Ranking by costs (SF)	Ranking by duration (PF)	Ranking by costs (PF)
Path 1	A1, A2, A4	1	1	1	1
Path 2	A1, A3, A4	2	3	2	3
Path 3	A1, A2, A3, A4	3	2	3	2

Table 22 demonstrates that the ranking results are the same for both SF and PF sets. Hence, the findings are consistent.

V. CONCLUSION

It is aimed to identify green energy project network based on innovation life cycle by using PF sets with integer patterns. For this purpose, four phase-hybrid decision making approach is applied by considering the TRIZ, integer code series, PERT, Pythagorean fuzzy TOPSIS and DEMATEL, respectively. The novelty of this study is to propose a hybrid decision support system for green energy projects and integrate the inventive problem-solving model into the PERT using PF sets properly. TRIZ technique is used for designing the inventive problem-solving model, PERT is applied for illustrating the critical paths of green energy projects, PF TOPSIS is employed for defining the activity priorities of green energy projects, and PF DEMATEL is computed for figuring out the immediate predecessors of activities. Additionally, TRIZ-based principles are also ranked by using VIKOR. Moreover, all calculations have also been made with Spherical fuzzy (SF) sets in addition to the PF sets. The results explain that dynamicity is the initial activity of green energy projects while transformation of properties is the final activity. However, dynamicity, prior action, and transformation of properties are the set of activities with the shortest path by duration as well as the lowest cost.

VI. LIMITATIONS AND IMPLICATIONS

It is identified that dynamicity and transformation of properties take place in all paths. This situation gives information that these activities are crucial in this condition. By considering these issues, it is understood that for the best solution, products should be designed in accordance with the external environment. Green energy investments have high initial costs. This situation creates a barrier for investors to focus on this area as it negatively affects profitability. In this context, technological developments regarding green energy investments create an opportunity to reduce these costs. Therefore, green energy investors should closely follow technological developments in this area. The important point here is that the products used in green energy investments should be easily adapted to these developments. Otherwise, these technological developments will not be easily applicable to projects. Thus, companies that cannot gain a cost advantage will also lose a significant competitive advantage. In this context, green energy companies must be ready for technological developments that will emerge in every sense. Hence, departments within the company should be designed to be able to react quickly. In this way, it will be possible for the company to adapt to innovations very quickly. Similarly, Månberger et al. [81], Gallagher et al. [82] and Egli et al. [83] made an evaluation to understand the significant indicators to affect the performance of the green energy investment projects. They underlined that these companies should follow technological improvements to have sustainable success in these investments.

Another important result of this study is that the principal of prior action is important to reduce the costs instead of periodic action. It is essential to make the necessary controls before the project starts in order to increase the efficiency and productivity. The inspections to be made after the project is implemented will contribute to the identification of problems. However, correcting these problems will cost the company. In this context, these problems should be reduced as much as possible in order to reduce these costs. The most helpful aspect to this situation is that the necessary controls are made before the project is implemented. It is vital that costs can be reduced. In the literature, lots of researchers highlighted the significance of this situation. For instance, Khan et al. [84], Adefarati and Bansal [85] and Bellotti et al. [86] defined that preliminary planning plays a crucial role to reduce the costs of these projects so that the efficiency and the effectiveness of these projects can be increased.

The main contribution is that innovative strategies are identified for green energy investment projects with a novel hybrid MCDM model based on integer patterns and Pythagorean fuzzy sets. Nonetheless, there are also some limitations of the proposed model in this study. The main limitation is that innovative factors are defined by only TRIZ principles. Hence, in the future studies, different methodologies can be considered to determine the criteria. For instance, the criteria can be generated by considering SWOT analysis. Hence, different factors can be considered at the same time. Also, the results of DEMATEL are not compared with other MCDM models. In the future studies, analytic hierarchy process (AHP) can also be considered so that it can be possible to make robustness check. Additionally, immediate predecessors are determined with DEMATEL. Due to this issue, the paths are limited to only 4 different activity sets. On the other hand, a more specific analysis of green energy types can be made. In addition to this condition, different approaches can also be used in the analysis process. The results could be widened for the future studies by using the different MCDM approaches such as Entropy and considering the cross-industrial analysis.

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YUE MENG was born in Xi'an, Shaanxi Province in 1987. She received the PhD degree in Economic and Management in 2020 from Sichuan Agricultural University, Chengdu, China. Since 2012, she has become a Lecturer in Department of Tourism, Sichuan Agricultural University, Sichuan province. She has been published 13 theses and coauthored two books. Her research interests include mathematical modeling, Principal Component Analysis, System optimization.

HASAN DİNÇER is Professor of finance at Istanbul Medipol University, Faculty of Economics and Administrative Sciences, Istanbul-Turkey. Dr. Dincer has BAs in Financial Markets and Investment Management from Marmara University. He received his PhD in Finance and Banking with his thesis entitled "The Effect of Changes on the Competitive Strategies of New Service Development in the Banking Sector". He has work experience in the finance industry as a portfolio specialist and his major academic studies focusing on financial instruments, performance evaluation, and economics. He is the executive editor of the International Journal of Finance and Banking Studies (IJFBS) and the founder member of the Society for the Study of Business and Finance (SSBF). He has about 200 scientific articles and some of them is indexed in SSCI, SCI-Expended and Scopus. In addition to them, he is also editor of many different books published by Springer and IGI Global.

SERHAT YÜKSEL is Associate Professor of finance in İstanbul Medipol University. Before this position, he worked as a senior internal auditor for seven years in Finansbank, Istanbul-Turkey and 1 year in Konya Food and Agriculture University as an assistant professor. Dr. Yüksel has a BS in Business Administration (in English) from Yeditepe University (2006) with full scholarship. He got his master degree from the economics in Boğaziçi University (2008). He also has a PhD in Banking from Marmara University (2015). His research interests lie in energy economics, banking, finance and financial crisis. He has more than 140 scientific articles and some of them are indexed in SSCI, SCI, Scopus and Econlit. Also, he is the editor of some books that will be published by Springer and IGI Global.