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Pattern Recognition of Green Energy Innovation Investments Using a Modified Decision Support System

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ABSTRACT This study examines the fintech innovation life cycle of green energy investments with a new model by using integer patterns, geometrical recognition methodology, Pythagorean fuzzy decision-making trial and evaluation laboratory (DEMATEL) and technique for order preference by similarity to ideal solution (TOPSIS). It is concluded that aging and declining are the most significant phases for the innovation life cycle process for the fintech-financing alternatives in clean energy investments. Furthermore, the finding funds from the shareholders is the most appropriate fintech-based financing alternatives for green energy investment projects. Thus, it is recommended that green energy investors must make a strategic decision in the last stages of the life cycle of innovation. In this framework, either this investment should be terminated, or new technological developments should be adapted to the investments. Moreover, it is also identified that they should mainly prefer equity financing.

INDEX TERMS Clean energy, renewable energy, fintech-project financing, integer code series.

I. INTRODUCTION

One of the biggest causes of environmental pollution is high energy consumption. Therefore, the concept of clean energy becomes more significant every day. In this context, it is aimed to provide the needed energy from natural resources, not from fossil fuels. There are many benefits of using clean energy. First of all, thanks to the green energy, the amount of carbon emissions is reduced which helps to decrease air pollution. Living in a cleaner environment positively affects people's health [1]. Hence, clean energy production has a positive impact on the social development of the countries. In addition, this issue will also help to reduce the loss of labor and health expenditures. Therefore, sustainable economic development purposes can be reached more easily.

High cost of clean energy projects compared to other energy types is considered as an important disadvantage. If measures are not taken to solve this problem, it is obvious that investors will continue to prefer fossil fuels in energy production. In this context, it is vital to increase innovations for clean energy. Thanks to these innovations, it will be possible to decrease the costs of clean energy projects so that innovations for clean energy projects are constantly developing [2]. In this context, it is not possible for companies that do not follow these changes and apply them to their company to survive in a competitive environment. Hence, it is obvious that innovation life curves in clean energy projects need to be analyzed effectively [3], [4].

In this study, fintech innovation life cycle of clean energy investment projects is evaluated by proposing a 3-stage model. Furthermore, the main contribution of the manuscript is defining the appropriate fintech-based financial alternative regarding the innovation performance for the clean energy projects with a novel model. Hence, it can be possible to provide appropriate strategies to increase innovations in clean energy investment projects. The main reason is that new technological improvements provide to decrease costs of these projects. Additionally, understanding the appropriate financing alternative also contributes to solve high-cost problem of the clean energy investments projects.

Also, this manuscript also has some methodological novelties. For instance, a hybrid decision-making methodology is preferred. In other words, subjective judgements of the authors are not taken into consideration. Because all analyses are based on the MCDM evaluations, the objectivity of the results can be increased. Additionally, since problems in the

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real life become quite complex, there is a strong need for new extended models to increase the effectiveness in decision-making process. Thus, in this model, it is aimed to consider new techniques to reach more reliable results.

For instance, with the help of the integer code series, it can be possible to test the patterns [5]. Also, considering Pythagorean fuzzy numbers helps to manage uncertainties more appropriately [6], [7]. Furthermore, the main reason of selecting DEMATEL approach is understanding the causal relationship among the criteria in addition to the weighting them [8], [9]. Moreover, negative solution is considered in TOPSIS methodology in addition to the positive optimal solution [10]. Thus, more sensitive results can also be reached [11].

The manuscript is organized as below. Clean energy innovation literature is examined is the second section. Section 3 focuses on the methodological information. Moreover, the fourth section gives information about the findings. Finally, discussions and conclusions are made.

II. LITERATURE REVIEW

It is claimed that technological improvements of the companies play a crucial role to make innovations for clean energy projects. Clean energy investments include complex procedures so that companies should have sufficient technological power to make effective innovations. Wang *et al.* [12] made an evaluation for different hydrogen production technologies. They indicated that hydrogen should be mainly produced from the clean energy sources instead of fossil fuels. They stated that in order to reach this objective, the companies should have sufficient technological background. In addition to this study, Noailly and Smeets [13] aimed to examine renewable energy innovation by considering 5471 European firms over 1978–2006. It is stated that there is a strong competition in the renewable energy market so that companies should give priorities to technological improvements. Li *et al.* [14] evaluated the innovativeness and clean energy productivity. In this framework, OECD economies are evaluated for the periods between 1990 and 2017. As a result of the Durbin Hausman group mean cointegration test, it is defined that eco-innovation is an important driver for the energy productivity, and for this situation, the companies need qualified employee. Urpelainen and Van de Graaf [15], Pitelis *et al.* [16] and Tabrizian [17] also highlighted the significance of technologic improvements to make innovations for these projects.

Moreover, the influence of clean energy innovation on the carbon emission was examined. Carbon emission is a very important problem that threatens the environment. In order to solve this problems, renewable energy alternatives should be preferred instead of the fossil fuels [18]. However, due to some advantages, most countries use fossil fuels nowadays [19]. Khattak *et al.* [20] examined clean energy innovation and carbon emission problem for BRICS countries. In this framework, Dumitrescu Hurlin panel causality test has been applied in the analysis process. It is stated that innovations in green energy production have an essential impact to reduce carbon emission in Russia, India, China, and South Africa. However, an empirical result could not be found for Brazil. Similarly, Lin and Zhu [21] examined this situation for China. It is identified that the innovations in the renewable energy help to reduce global warming problem owing to lower carbon emission. Additionally, Zhu *et al.* [22] and Nabat *et al.* [23] also determined that investments of clean energy innovations should be improved so that carbon emission problems can be reduced.

In addition to these studies, clean energy innovations have also significant impact on the financial issues. Although renewable energy alternatives have essential benefits, some investors cannot make investments on these alternatives due to the high initial cost problems [24]. This situation increases uncertainty in the market so that anxiety of the investors increased very much [25]. Because of this issue, innovations can be improved to manage this process with a lower cost [26]. Alvarez-Herranz *et al.* [27] focused on 17 OECD countries for the period of 1990–2012. The governments should increase the budget to attract the attentions of the investors to make innovation. This situation positively affects environmental quality. Elia *et al.* [2] focused on the influence of innovations on the reductions of the clean energy technology costs. Improvements in the clean energy technology leads to the developments in the manufacturing process. Thus, it can be possible to minimize the costs of these projects. Additionally, He *et al.* [28] underlined the importance of government incentives to decrease high-cost problems of the clean energy projects.

The literature review enables many important issues to be understood. The biggest obstacle to the development of these projects is the high costs. Therefore, to minimize this problem, innovations towards these projects should be increased. On the other hand, technological developments for clean energy investments are constantly increasing. This situation shows that innovations must be constantly renewed. In this framework, a new study is needed to analyze the life curve of innovations for clean energy investments. A new model is created that makes an important contribution to the clean energy literature.

III. METHODOLOGY

In this scope, the explanations of the methods are given. Next, the suggested model is also presented.

A. INTEGER PATTERNS AND GEOMETRICAL RECOGNITION

Integer formation (I) is considered to solve decision-making problems effectively. The equation (1) gives information about this issue [5].

$$I_n = \{s = s_1 \ldots s_n,\ s_i \in I,\ i = 1, \ldots, n\} \tag{1}$$

On the other side, f represents the constant function that can take values as $(t_{i-1}, t_i]$. This term is demonstrated on the

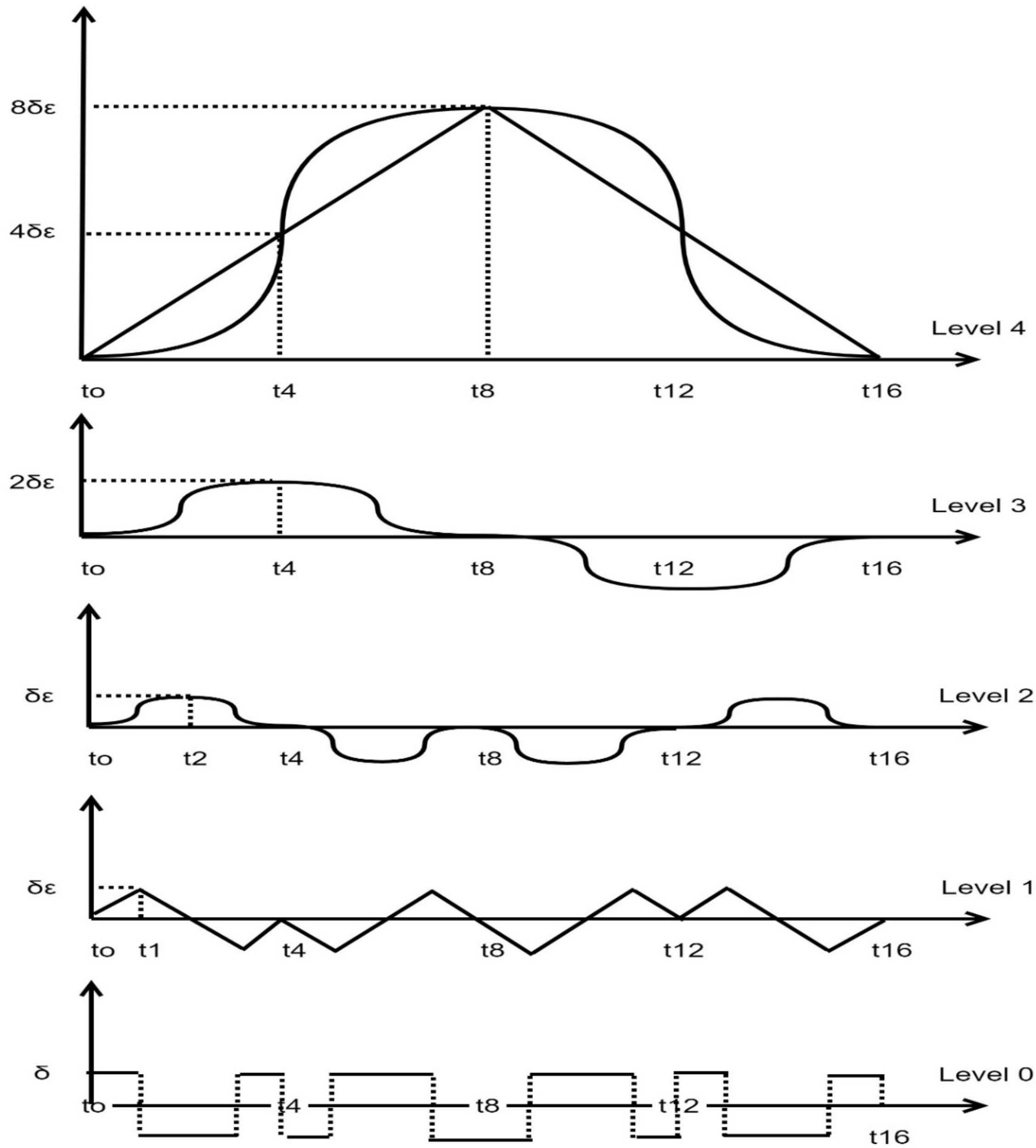

FIGURE 1. Geometrical patterns with integer code series.

equation (2) [29].

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

Within this framework, $i = m+1, \ldots, m+n$. The equations (3)-(5) are also considered in this respect.

$$f\ (t_m) = s_1\delta \tag{3}$$

$$f\ (t) = s_i\delta \tag{4}$$

$$t \in (t_{i-1}, t_i] \quad \text{and } t_i = i\varepsilon \tag{5}$$

In this context, m indicates an integer whereas s_i, $i = 1, \ldots, n$ represent real numbers. Furthermore, $f^{[k]}$ indicates the kth integral. Moreover, the kth derivative is equal to f and $f^{[0]} = f$ and $k \geq 1$. Additionally, equation (6) demonstrates the integer code series [30].

$$f \in W_{\delta\varepsilon}\ ([t_m, t_{m+n}]) \tag{6}$$

Also, kth integral should satisfy the equation (7).

$$f^{[k]}\ (t_m) = 0 \tag{7}$$

Additionally, the equations (8)-(10) are also used [31].

$$f^{[k]}\ (t_{m+l+1}) = \sum_{i=0}^{k-1} \alpha_{kmi} \Big((m+l+1)^i\, s_1 + \ldots + (m+1)^i s_{l+1} \Big) \delta\varepsilon^k + \sum_{i=0}^{k} \beta_{k,l+1,i} f^{[i]}\ (t_m) \varepsilon^{k-i} \tag{8}$$

$$\alpha_{kmi} = \frac{\binom{k}{i}\left((-1)^{k-i-1}(m+1)^{k-i} + (-1)^{k-i} m^{k-i}\right)}{k!} \tag{9}$$

$$\beta_{k,l+1,i} = \frac{(l+1)^{k-i}}{(k-i)!}, i = 1, \ldots, k \tag{10}$$

Figure 1 demonstrates geometrical patterns.

These patterns are obtained by the integration of the function $f^{[k]}(t), t_0 \leq t \leq t_{16}$. Hence, equation (11) shows the condition where k is equal to "0".

$$f^{[0]}(t), \; t_{j-1} \leq t \leq t_j \quad \text{where } t_j = j\varepsilon, \; \text{j} = 1, 2, \ldots, 16 \tag{11}$$

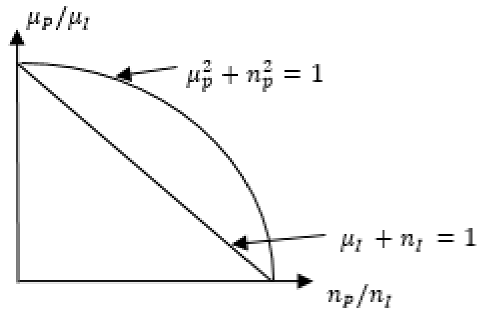

FIGURE 2. Differences between IFS and P.

B. PYTHAGOREAN FUZZY SETS (P)

P identifies extended fuzzy sets. It is detailed in the equation (12) [32].

$$P = \left\{ \langle \vartheta, \mu_p(\vartheta), n_p(\vartheta) \rangle / \vartheta \epsilon U \right\} \tag{12}$$

Within this context, μ_P and n_P: $U \rightarrow [0, 1]$ give information about the membership and non-membership functions. Additionally, equation (13) should be satisfied.

$$(\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{13}$$

Moreover, the equation (14) indicates the degree of indeterminacy [33].

$$\pi_P(\vartheta) = \sqrt{1 - (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2} \tag{14}$$

On the other side, the equations (15)-(19) show the details of these sets [6].

$$P_1 = \left\{ \langle \vartheta, P_1(\mu_{P1}(\vartheta), n_{p1}(\vartheta)) \rangle / \vartheta \epsilon U \right\} \text{ and}$$
$$P_2 = \left\{ \langle \vartheta, P_2(\mu_{P2}(\vartheta), n_{p2}(\vartheta)) \rangle / \vartheta \epsilon U \right\} \tag{15}$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^1 + \mu_{P_2}^2 - \mu_{P_1}^1 \mu_2^2}, n_{P_1} n_{P_1} \right) \tag{16}$$

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

$$\lambda P = P\left(\sqrt{1 - \left(1 - \mu_p^2\right)^{\lambda}}, (n_p)^{\lambda} \right), \; \lambda > 0 \tag{18}$$

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

Also, the difference of P from the intuitionistic fuzzy sets (IFS) is emphasized in Figure 2 [7].

Finally, score function helps to identify the defuzzified values as in the equation (20).

$$S(\vartheta) = \left| (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2 \right| \tag{20}$$

C. DEMATEL

This approach evaluates different factors to define the most important ones. In this framework, the evaluations from the different experts are collected. By using them, direct relation matrix (A) is developed as in equation (21) [34].

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

Normalized direct relation matrix (B) is created in equation (22) [35].

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

Total relation matrix (C) is generated by considering equation (23).

$$\lim_{k \to \infty} \left(B + B^2 + \ldots + B^k \right) = B(I - B)^{-1} \tag{23}$$

Later, the sums of rows and columns (D and E) are defined by equations (24) and (25) [8].

$$D = \left[\sum_{j=1}^{n} e_{ij} \right]_{nx1} \tag{24}$$

$$E = \left[\sum_{i=1}^{n} e_{ij} \right]_{1xn} \tag{25}$$

The weights are computed by considering the value of (D+E). Threshold value (α) is used in equation (26) [9].

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij} \right]}{N} \tag{26}$$

D. TOPSIS

TOPSIS ranks the factors based on the performance. Primarily, the evaluations are normalized as in the equation (27) [36].

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \text{i} = 1, 2, 3, \ldots m \quad \text{and j} = 1, 2, 3, \ldots n \tag{27}$$

The weights of these values are computed by considering equation (28) [11].

$$v_{ij} = w_{ij} \times r_{ij} \tag{28}$$

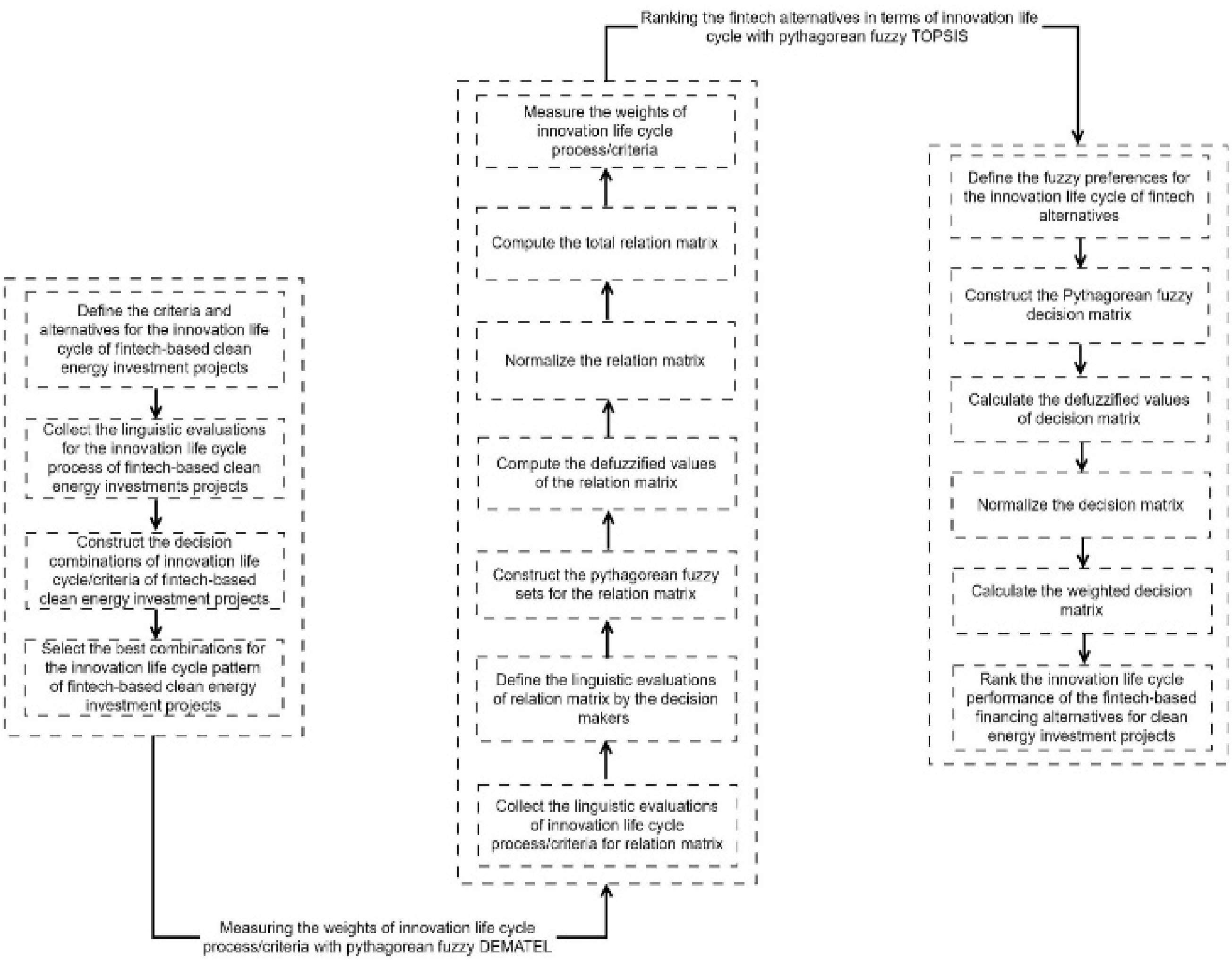

FIGURE 3. The details of the suggested model.

After that, the positive (A^+) and negative (A^-) ideal solutions are calculated as in equations (29) and (30).

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max\ v_{1j}\, for \forall\, j \in n\} \quad (29)$$
$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min\ v_{1j}\, for\ \forall\, j \in n\} \quad (30)$$

Later, the distances to the worst and best alternatives (D_i^-, D_i^+) are calculated by equations (31) and (32) [10].

$$D_i^+ = \sqrt{\sum\nolimits_{j=1}^{n} \left(v_{ij} - A_j^+\right)^2} \quad (31)$$
$$D_i^- = \sqrt{\sum\nolimits_{j=1}^{n} \left(v_{ij} - A_j^-\right)^2} \quad (32)$$

Relative closeness (RC_i) is computed in equation (33) [37].

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-}\ 0 \leq RC_i \leq 1 \quad (33)$$

E. PROPOSED MODEL

A new model is developed to analyze the fintech innovation life cycle of clean energy investment projects. Figure 3 explains the details of the suggested model.

IV. ANALYSIS RESULTS

The proposed model includes three different stages that are detailed as following.

A. CALCULATING OPTIMAL COMBINATIONS OF FINTECH-BASED FINANCING ALTERNATIVES (PHASE 1)

The innovation life cycle process and criteria for the fintech-based financing of clean energy investment projects are shown in Table 1.

Table 1 shows five different stages in the innovation life cycle process which are emerging, growth, maturity, aging and declining. On the other side, the declining process is divided into four different stages. Hence, there are totally

TABLE 1. Innovation life cycle process and criteria for the fintech-based financing of clean energy investment projects.

Process	Phase (P)	Time (T)
Emerging	P1	T1
	P2	T2
Growth	P1	T3
	P2	T4
Maturity	P1	T5
	P2	T6
Aging	P1	T7
	P2	T8
Declining-I	P1	T9
	P2	T10
Declining-II	P1	T11
	P2	T12
Declining-III	P1	T13
	P2	T14
Declining-IV	P1	T15
	P2	T16

TABLE 2. Preference numbers and integer alphabet for decision matrix.

Scales	PN	IA
Worst	.10	-2
Bad	.25	-1
Normal	.50	0
Well	.75	+1
Perfect	1	+2

eight different stages and 16 different phases. Additionally, 4 different fintech-based financing alternatives are also defined which are royalty payments (A1), shareholders (A2), lending (A3), and pre-order pricing (A4). With respect to the royalty payment, the payment is made to the party who owns the asset. Furthermore, necessary funding can also be obtained from the shareholders. Moreover, lending includes borrowing something, such as money or assets. Finally, with the help of the pre-order pricing, the company can have guaranteed income before giving the products/services. Table 2 demonstrates integer alphabet (IA) and preference numbers (PN).

With respect to the royalty payments (A1), the details of the calculations for different combinations are given below. Additionally, only the analysis results for other alternatives are shared. The combination (CBN) 1 is detailed below.

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

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

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

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

It is concluded that CBN 1 is appropriate. Also, the details of CBN 2 are given below.

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

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

It is identified that CBN 2 is not usable. Additionally, CBN 3 is explained as following.

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

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

As a result, it is understood that CBN 3 is not appropriate. Moreover, the details of CBN 4 are indicated below.

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

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

The results give also information that the CBN 4 is not suitable. Furthermore, the calculation details for the combination 5 are explained below.

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

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

This situation also demonstrates that CBN 5 is not appropriate. In addition, the calculations of the CBN 6 are also shown below.

TABLE 3. Best combinations for the innovation life cycle of fintech alternatives in clean energy investments projects with the integer patterns.

Time	Process	Phase (PS)	Royalty payments (Combination 1)	Shareholders (Combination 2)	Lending (Combination 2)	Pre-order pricing (Combination 1)
T-1	Emerging	PS 1	G	G	G	B
T-2		PS 2	P	W	W	W
T-3	Growth	PS 1	G	B	B	B
T-4		PS 2	P	P	P	W
T-5	Maturity	PS 1	B	G	B	B
T-6		PS 2	W	P	W	W
T-7	Aging	PS 1	G	B	B	G
T-8		PS 2	P	W	W	P
T-9	Declining-I	PS 1	G	G	G	G
T-10		PS 2	P	P	P	P
T-11	Declining-II	PS 1	G	G	G	G
T-12		PS 2	P	P	P	P
T-13	Declining-III	PS 1	G	B	G	G
T-14		PS 2	P	W	P	P
T-15	Declining-IV	PS 1	G	G	G	G
T-16		PS 2	P	P	P	P

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

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

The findings demonstrate that CBN 6 cannot be taken into consideration in this regard. Moreover, the details of CBN 7 are underlined as following.

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

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

It is obvious CBN 7 cannot be used in this analysis. CBN 8 is also calculated as below.

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

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

TABLE 4. Weights of innovation life cycle process/criteria for the fintech-financing alternatives in clean energy investments.

Time	D-E	D+E	Weights
T1	-1.777	7.564	.054
T2	-.585	7.578	.054
T3	-2.229	9.041	.065
T4	1.738	7.446	.053
T5	1.483	8.717	.063
T6	-.343	9.568	.069
T7	.249	8.977	.064
T8	-.508	11.184	.080
T9	-.101	1.931	.078
T10	.165	1.661	.076
T11	.438	8.070	.058
T12	-.618	6.391	.046
T13	-.386	8.255	.059
T14	.581	7.411	.053
T15	1.911	7.882	.057
T16	-.017	9.686	.070

It is concluded that CBN 8 is not appropriate for this purpose. Similarly, the best combinations of other alternatives are also computed with the integer patterns at the level 4, the results are given respectively as below. Regarding the shareholders (A2), the calculation results are demonstrated below.

CBN 2:

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

TABLE 5. Fuzzy preferences regarding alternatives.

Time	Process	Phase (PS)	Royalty payments	Shareholders	Lending	Pre-order pricing
T1	Emerging	PS 1	.75	.75	.75	1
T2		PS 2	.25	.10	.10	.10
T3	Growth	PS 1	.75	1	1	1
T4		PS 2	.25	.25	.25	.10
T5	Maturity	PS 1	1	.75	1	1
T6		PS 2	.10	.25	.10	.10
T7	Aging	PS 1	.75	1	1	.75
T8		PS 2	.25	.10	.10	.25
T9	Declining-I	PS 1	.75	.75	.75	.75
T10		PS 2	.25	.25	.25	.25
T11	Declining-II	PS 1	.75	.75	.75	.75
T12		PS 2	.25	.25	.25	.25
T13	Declining-III	PS 1	.75	1	.75	.75
T14		PS 2	.25	.10	.25	.25
T15	Declining-IV	PS 1	.75	.75	.75	.75
T16		PS 2	.25	.25	.25	.25

TABLE 6. Pythagorean fuzzy DM.

Time	Royalty payments	Shareholders	Lending	Pre-order pricing
T1	[.675,.1625]	[.675,.1625]	[.675,.1625]	[.9,.05]
T2	[.225,.3875]	[.09,.455]	[.09,.455]	[.09,.455]
T3	[.675,.1625]	[.9,.05]	[.9,.05]	[.9,.05]
T4	[.225,.3875]	[.225,.3875]	[.225,.3875]	[.09,.455]
T5	[.9,.05]	[.675,.1625]	[.9,.05]	[.9,.05]
T6	[.09,.455]	[.225,.3875]	[.09,.455]	[.09,.455]
T7	[.675,.1625]	[.9,.05]	[.9,.05]	[.675,.1625]
T8	[.225,.3875]	[.09,.455]	[.09,.455]	[.225,.3875]
T9	[.675,.1625]	[.675,.1625]	[.675,.1625]	[.675,.1625]
T10	[.225,.3875]	[.225,.3875]	[.225,.3875]	[.225,.3875]
T11	[.675,.1625]	[.675,.1625]	[.675,.1625]	[.675,.1625]
T12	[.225,.3875]	[.225,.3875]	[.225,.3875]	[.225,.3875]
T13	[.675,.1625]	[.9,.05]	[.675,.1625]	[.675,.1625]
T14	[.225,.3875]	[.09,.455]	[.225,.3875]	[.225,.3875]
T15	[.675,.1625]	[.675,.1625]	[.675,.1625]	[.675,.1625]
T16	[.225,.3875]	[.225,.3875]	[.225,.3875]	[.225,.3875]

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

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

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

Additionally, as for the lending (A3), the results of the calculation are shown.

CBN 2:

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

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

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

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

Finally, the calculations are indicated regarding the pre-order pricing (A4).

TABLE 7. DDM.

Time	Royalty payments	Shareholders	Lending	Pre-order pricing
T1	.429	.429	.429	.808
T2	.100	.199	.199	.199
T3	.429	.808	.808	.808
T4	.100	.100	.100	.199
T5	.808	.429	.808	.808
T6	.199	.100	.199	.199
T7	.429	.808	.808	.429
T8	.100	.199	.199	.100
T9	.429	.429	.429	.429
T10	.100	.100	.100	.100
T11	.429	.429	.429	.429
T12	.100	.100	.100	.100
T13	.429	.808	.429	.429
T14	.100	.199	.100	.100
T15	.429	.429	.429	.429
T16	.100	.100	.100	.100

TABLE 8. Normalized DM.

Time	Royalty payments	Shareholders	Lending	Pre-order pricing
T1	.391	.391	.391	.736
T2	.278	.555	.555	.555
T3	.293	.552	.552	.552
T4	.378	.378	.378	.756
T5	.552	.293	.552	.552
T6	.555	.278	.555	.555
T7	.332	.624	.624	.332
T8	.316	.632	.632	.316
T9	.500	.500	.500	.500
T10	.500	.500	.500	.500
T11	.500	.500	.500	.500
T12	.500	.500	.500	.500
T13	.391	.736	.391	.391
T14	.378	.756	.378	.378
T15	.500	.500	.500	.500
T16	.500	.500	.500	.500

CBN 1:

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

Table 3 also gives information about the best combinations for different fintech alternatives.

B. MEASURING THE WEIGHTS OF INNOVATION LIFE CYCLE PROCESS/CRITERIA WITH PYTHAGOREAN FUZZY DEMATEL (PHASE 2)

Five linguistic scales and fuzzy preferences are used that are "1", ".75", ".50", ".25" and "0". The next point includes the computation of the defuzzified values. After that, the normalization is implemented and TRM is generated. Later,

TABLE 9. Weighted DM.

Time	Royalty payments	Shareholders	Lending	Pre-order pricing
T1	.021	.021	.021	.040
T2	.015	.030	.030	.030
T3	.019	.036	.036	.036
T4	.020	.020	.020	.040
T5	.035	.018	.035	.035
T6	.038	.019	.038	.038
T7	.021	.040	.040	.021
T8	.025	.051	.051	.025
T9	.039	.039	.039	.039
T10	.038	.038	.038	.038
T11	.029	.029	.029	.029
T12	.023	.023	.023	.023
T13	.023	.044	.023	.023
T14	.020	.040	.020	.020
T15	.028	.028	.028	.028
T16	.035	.035	.035	.035

weights of innovation life cycle process/criteria are defined. Also, Table 4 shows the weights.

Table 4 demonstrates that aging is the most important phase with respect to the innovation life cycle process for the fintech-financing alternatives in clean energy investments. Similarly, the first times of the declining phase play also key roles in this respect. It is understood that the terminal stage is very crucial for these investments. In other words, when the sales volume and the profitability reduce, the clean energy investors should give a strategic decision. In this framework, they may focus on implementing new technology or stop the investments. The results indicate that these companies should not wait too much for this decision. Otherwise, it can be very difficult to adopt new technologies to the existing projects.

C. RANKING THE FINTECH ALTERNATIVES IN TERMS OF INNOVATION LIFE CYCLE WITH PYTHAGOREAN FUZZY TOPSIS (PHASE 3)

The fuzzy preferences are details are indicated in Table 5.

DM and normalized matrix are created by using the equality of $\mu_p^2 + n_p^2 = 1$ as in Table 6.

Table 7 shows defuzzified decision matrix (DDM).

Later, Table 8 represents normalized DM.

Moreover, the weights of time are employed by using the criteria weight results with PF DEMATEL are presented in Table 9.

Finally, the fintech-based financing alternatives are examined. The findings are summarized in Table 10.

Table 10 states that the finding funds from the shareholders (A2) is the most appropriate fintech-based financing alternative. Additionally, the lending (A3) is another essential alternative for this situation. However, royalty payments (A1) and pre-order pricing (A4) are less suitable to obtain funds.

TABLE 10. Ranking results.

Principles	D+	D-	CCi	Ranking
Royalty payments (A1)	.056	.025	.310	4
Shareholders (A2)	.037	.048	.565	1
Lending (A3)	.040	.046	.538	2
Pre-order pricing (A4)	.043	.043	.505	3

V. CONCLUSION AND DISCUSSION

This study evaluates the fintech innovation life cycle of clean energy investments by proposing a new model. Firstly, the best decision combinations of fintech-based financing alternatives with integer code series are determined. In order to define the decision combinations, integer patterns and geometrical recognition methodology has been used. Secondly, criteria are evaluated by Pythagorean fuzzy DEMATEL approach. Finally, these 4 different fintech alternatives are ranked with Pythagorean fuzzy TOPSIS. Aging is the most essential phase for the innovation life cycle process for the fintech-financing alternatives in clean energy investments. Similarly, the first times of the declining phase play also significant roles for this situation. In addition, it is also identified that the finding funds from the shareholders is the most appropriate fintech-based financing alternative. Moreover, the lending is another important alternative in this regard.

According to the analysis results obtained, two different issues come to the fore. First, the last stages in the life cycle of innovation for clean energy investments are very important. In this process, clean energy investors must make a strategic decision. In this framework, either this investment should be terminated, or new technological developments should be adapted to the investments. Otherwise, a significant competitive advantage will be lost as a result of continuing investments with existing technology. In this case, there is a risk that the project will cause serious damage. If the company prefers the continuation of the investments, it is important that it can easily apply the new technology to its project. In this context, the company should follow the technological developments closely regarding the subject. In addition, the company needs competent staff so that these new applications can be easily adapted to the project. The results are quite parallel to the similar studies in the literature [38], [39]. For instance, Gielen *et al.* [40] focused on the role of renewable energy in the global energy transformation. They also highlighted the significance of staff quality to catch technological developments regarding this subject. Similarly, Du *et al.* [41] evaluated the importance of green energy technologies. They defined that with the help of the competent staff, new technologies can be adopted to the green energy projects easily. This situation has a positive contribution to increase the efficiency of these projects.

Another result of the study is that equity financing is the most suitable alternative for clean energy investments. Due to the high costs, it becomes very difficult to obtain continuous funding. In addition, due to the high cost and the long duration of the project, it may take some time for the project to become profitable. The most suitable alternative is financing with equity. Thanks to equity financing, the company will not have to pay investors unless it is making a profit. This will contribute to the company's ability to manage its costs more effectively. In the literature, Mazzucato and Semieniuk [24], Lam and Law [42] and Schwerhoff and Sy [43] also claimed that equity financing should be preferred for clean energy investment projects. Similarly, Elie *et al.* [44] and Ziaei [45] also identified that with the help of equity-based financing, it can be much easier to provide sustainability in green energy investment projects.

The main contribution is defining the appropriate fintech-based financial alternative regarding the innovation life cycle performance regarding clean energy projects. Nonetheless, the main limitation in this study is making evaluation for the clean energy investments in a more general manner. More specific innovative strategies can be generated for different clean energy types. Hence, in the future studies, a new model can be generated for the solar or wind energy investment projects. Additionally, there is no industrial implementation in this evaluation. However, the analysis results of this study are not tested in the industry. Therefore, in the next studies, a case study can be conducted with the aim of measuring the effectiveness of the clean energy investment projects.

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