Financial Innovation

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Pattern recognition of financial innovation life cycle for renewable energy investments with integer code series and multiple technology S-curves based on Q-ROF DEMATEL

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Abstract

The current study evaluates the financial innovation life cycle for renewable energy investments. A novel model is proposed that has two stages. First, the financial innovation life cycle is weighted by the two-generation technology S-curve (TTSC) for renewable energy investments. Second, the TTSC is ranked with integer patterns for renewable energy investments. For this purpose, the decision-making trial and evaluation laboratory (DEMATEL) is considered with q-rung orthopair fuzzy sets (q-ROFSs). A comparative examination is then performed using intuitionistic and Pythagorean fuzzy sets, and we find similar results for all fuzzy sets. Hence, the suggested model is reliable and coherent. Maturity phase 1 is the most significant phase of the financial innovation life cycle for these projects. Aging is the most important period for financial innovation in renewable energy investment projects—renewable energy companies should make strategic decisions after that point. In this situation, decisions should relate to either radical or incremental innovation. If companies do not make decisions during these phases, innovative financial products cannot be improved. As a result, renewable energy companies will not prefer financing products.

Keywords: Renewable energy investments, Q-ROF sets, DEMATEL, Financial innovation

Introduction

Expanded investment in renewable energy projects contributes crucially to the sustainable development of countries. Environmentally friendly energy projects are expected to minimize the carbon emission problem. Doing so will make it possible to address important problems worldwide, such as global warming. Conversely, renewable energy will help countries reduce their energy dependence. In other words, these projects will help solve problems faced by energy-importing countries (Khan et al. 2020). However, renewable energy projects have high installation costs that discourage investors from turning to these projects. Therefore, this problem must be managed through an effective financing system.

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Innovative financing instruments should be offered to solve the financing problem presented by these projects. Companies offering these products should pay attention to certain issues. These companies should first clearly analyze the expectations of renewable energy investors so they can offer financing products in line with those expectations. Moreover, the products offered should not be expensive. Otherwise, these financing products will not be preferred by renewable energy investors (Kou et al. 2021). Furthermore, for these financing products to be successful, an effective platform must be established. In this context, companies should stay current in their knowledge of emerging technologies.

Companies that offer financing products to renewable energy investors should provide financial innovations to address the fact that investor expectations and market conditions are both quite volatile. Therefore, companies that cannot achieve product innovation will find it difficult to survive. Financial innovation for renewable energy projects also has a life cycle with various stages such as emerging, growth, maturity, and aging. In the emerging phase, the expectations of renewable energy investors are evaluated. Within this framework, innovative ideas can be provided by various parties, including customers, suppliers, and employees. These inputs help in achieving objectives more effectively.

Moreover, during the growth phase, renewable energy investors begin to use these financial products (Alshubiri et al. 2020). In other words, the performance of these innovative financial products can be tested. In the maturity phase, sales exhibit a decreasing trend. Thus, companies strive to increase the performance of innovative financial products. To meet the needs of clean energy investors, innovative financial products must be sustainable. Otherwise, they will not be used in the long run, and the cost problem of renewable energy projects will again arise. It is thus necessary to ensure product continuity by taking necessary actions during this stage. The final phase of the financial innovation life cycle is decline.

In this context, companies should make radical or incremental innovations, especially in the maturity and decline phases. Companies should not develop products through radical innovation but instead generate new financial products for renewable energy investors. Alternatively, companies can use incremental innovation to improve the performance of financial products currently in use. Within this framework, companies make investments to improve innovative financial products. Appropriate methodologies should be considered for optimal decision-making—for example, multicriteria decision-making methods (Xie et al. 2021). These approaches can find solutions that are appropriate for a range of issues (Jun et al. 2021).

Because the decision-making process can become quite complex, the literature has employed fuzzy sets with these methods. In a significant number of studies, the analysis has been performed with triangular fuzzy sets. Furthermore, various fuzzy numbers have been considered to minimize uncertainties in decision-making. For example, uncertainty in decision-making can be more effectively overcome by incorporating trapezoidal fuzzy sets. Conversely, a variety of numbers have been proposed to reach appropriate solutions, such as intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs) (Ren et al. 2021; Molla et al. 2021). In addition, q-rung orthopair fuzzy sets (q-ROFSs) have been generated by extending IFSs and PFSs.

Because more space is considered in the analysis process, q-ROFSs achieve more precious results (Farhadinia et al. 2021).

To increase investment in renewable energy projects, developing innovative financial products is critical. However, these products have life spans. Therefore, making the necessary innovations for these financial products on time will maximize the efficiency of these products. If these issues are not implemented, it will be very difficult for these products to be sustainable. On the other hand, it should be determined at which stage of these financial products have been developed, and action should be taken. Otherwise, these actions will be taken at the wrong time, which will cause the products to fail. Financial products have different stages, such as emerging, growth, maturity, and aging. To improve the performance of these products, new studies are needed to determine which of these stages is the most important. As can be seen, this problem related to innovative financial products can become quite complex. In this context, q-ROFSs are the most suitable fuzzy sets for innovative financial products in renewable energy investments because they consider more areas in the analysis process and better manage uncertainty.

Accordingly, the current study evaluates the financial innovation life cycle for renewable energy investments. First, the financial innovation life cycle is weighted for renewable energy investments. On the other hand, in the second stage, the two-generation technology S-curve (TTSC) is ranked with integer patterns (IPTs) for renewable energy investments by decision-making trial and evaluation laboratory (DEMATEL) based on q-ROFSs. Additionally, an examination has also been conducted with IFSs and PFSs. The main research question of this study is to define the appropriate phase in the financial innovation life cycle to make critical decisions about the future of innovation for green energy investments.

The main contributions of this study are as follows:

(i) A priority analysis is performed to provide appropriate strategies for improving financial innovations regarding renewable energy investments. This situation has a positive influence on the increase in clean energy projects that contribute to the sustainable development of countries. Innovative financial product development is essential for the effective development of clean energy projects. However, these financial products also have life spans. Thus, this period should be extended to increase the effectiveness of these products. However, determining which stage of the life span is most important is a remaining task. Doing so will make it possible to take the right actions at the most appropriate times. This study seeks to determine the most important stage through a priority analysis of the stages.

(ii) The DEMATEL method is superior to similar approaches in some respects, and an impact-relation map can be generated using this approach (Kalkavan et al. 2021). It is quite difficult to determine which stages are most important in the life cycles of innovative financial products, and this task becomes more complex because the phases can influence each other. For example, effectively passing through the growth process contributes to greater success in the maturity process. To achieve this goal, the interrelated effects of these periods should be considered. Within this framework, decision-making methods that do not model a cause–effect relationship between criteria are not suitable for analyzing the life cycles of innovative financial products. In other words, the DEMATEL technique, which analyzes the effect relationships of factors, is the most optimal method for this study.

(iii) Various fuzzy numbers are used in the decision-making methods in the literature. Each number has distinct properties. Within this framework, q-ROFSs consider the larger data set in the analysis process, which minimizes uncertainty during the decision-making process. Analyzing the life expectancy of innovative financial products for clean energy projects involves complex processes. This situation increases analysis process uncertainty. Therefore, q-ROFSs are the optimal fuzzy sets for this framework. In addition, it is possible to perform a comparative analysis using IFSs and PFSs. This allows the findings to be tested for consistency. Furthermore, q-ROFSs provide other advantages as well, and with the help of IPTs, pattern answers can be tested for suitability (Meng et al. 2021a, b).

Section "Literature review" examines the literature. Section three explains the approaches considered in this study. Section "Analysis" describes the analysis results. Section five discusses highlights and conclusions.

Literature review

Many scholars have focused on financial innovation in clean energy investments. A comprehensive examination should be conducted to understand the needs of renewable energy investors (Yun et al. 2021; Song et al. 2023). Therefore, appropriate financial products can be created specific to the needs of these investors. Because they provide customer satisfaction, these financial products will be preferred by renewable energy investors (Xu and Wang 2021; Shibano and Mogi 2022). Hence, this situation contributes to the success of financial innovation (Chao et al. 2022). Liu et al. (2021a, b) evaluated the financial innovation effectiveness of green energy projects. They highlighted the significance of customer satisfaction for the success of financial innovation. Additionally, Meng et al. (2021a, b) focused on the pathways of fintech-based clean energy investment projects using fuzzy group decision modeling. They concluded that customer satisfaction plays a key role in improving financial innovation performance. Hsu et al. (2021) also highlighted the significance of this issue for clean energy projects.

The importance of cost analysis was also stated as a success factor. The high initial cost is an essential obstacle to improving renewable energy projects. Therefore, the costs of financial products for these investors should not be too high (Chishti and Sinha 2022; Kou et al. 2022). Because renewable energy investors must overcome the problem of high initial costs, they will disfavor financial products with high costs (Kauffman and Roston 2021; Lorente et al. 2023). Therefore, innovative financial products must be created that contribute to solving the problem of high costs faced by renewable energy investors (Xu et al. 2021). Khan et al. (2020) focused on the relationship between economic development and energy consumption. They indicated that clean energy should be preferred for sustainable economic development. In this case, financial products should be designed to solve the high-cost problem of renewable energy investors. Yüksel and Ubay (2021) also identified the need for low-cost financial innovation to expand clean energy investments. Jiang (2022) also concluded that for success, new financial instruments should contribute to cost minimization for these investors.

Conversely, some researchers have highlighted the importance of technological improvement to provide effective financial innovation for renewable energy investors. It is very difficult to offer original financial products to renewable energy investors (Xu et al. 2019; Singh et al. 2023). This is because renewable energies have a scope and include very detailed technical issues. Therefore, companies that want to make financial innovations should have significant technical competence (Ulucak 2021; Xu et al. 2022). Thus, it will be possible to produce financial products that can meet the expectations of renewable energy investors and include technical details (Pham 2019; Li et al. 2022). Otherwise, there is a risk that financial innovations developed by companies that do not have technological competence will not meet the needs of renewable energy investors (Shi et al. 2022). Yüksel et al. (2020) evaluated the relationship between technological development and renewable energy usage. They stated that priority should be given to technological development for the success of clean energy projects. Wang et al. (2020) and Dinçer and Yüksel (2019) also highlighted the significance of this situation in their evaluations.

According to the results of the literature review, financial innovation is crucial to improving renewable energy investments. However, financial innovation has a life cycle with emerging, growth, maturity, and decline phases. In other words, if companies do not update their financial innovations based on the needs of the market, these financial products will become unusable after a certain point. Hence, there is a need for a new examination that considers the important phases in the life cycle of financial innovation. With the help of this analysis, it is possible to understand when companies should decide to make either incremental or radical financial innovations. By considering this need in the literature, a new evaluation has been performed with respect to the financial innovation life cycle for renewable energy investments.

Methodology

This section covers IPTs, q-ROF sets, and DEMATEL.

Integer patterns and geometrical recognition

An important issue in decision-making processes is the quality of expert opinions. In this context, the experts who make assessments must possess sufficient knowledge about and work experience with the subject. Even then, expert opinions must be tested for consistency. The primary reason for doing this is that all analysis results depend on these expert evaluations. Accordingly, integer formations provide optimal solutions to complex problems. The main advantage of using IPTs is that evaluations can be evaluated for pattern suitability. The hierarchical situation of this process is considered in Eq. (1), where I represents the integer letter (Nikravesh and Zadeh 2004):

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

Integer code series are detailed in Eqs. (2)–(6). The value of f in Eq. (2) is a constant that can also take values as in Eq. (3). Note that the values for δ in Eqs. (4) and (5) and ε in Eq. (6) should be greater than zero:

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

$$(t_{i-1}, t_i] \tag{3}$$

$$f(t_m) = s_1\delta \tag{4}$$

$$f(t) = s_i\delta \tag{5}$$

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

These series provide the kth integral of a function, as shown in Eq. (7):

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

Moreover, the condition in Eq. (8) should be satisfied:

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

This condition is presented with the code $c(f) = s_1 \ldots s_n$ and integer powers in Eqs. (9)–(11):

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

$$\alpha_{kmi} = \binom{k}{i}\Big((-1)^{k-i-1}(m+1)^{k-i} + (-1)^{k-i} m^{k-i}\Big)/k! \tag{10}$$

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

The function is given by Eq. (12):

$$f^{[0]}(t), t_{j-1} \le t \le t_j \tag{12}$$

q-Rung orthopair fuzzy sets

To increase the efficiency of decision-making models, the methods are integrated with fuzzy numbers. Determining which fuzzy numbers to use is critical. IFSs are considered to achieve more appropriate results in the decision-making process. Here, we aim to reach more accurate results using different parameters. Equation (13) provides information about these sets. In this context, $\mu_I(\vartheta)$ and $n_I(\vartheta)$ are the degrees of membership and nonmembership, respectively. Furthermore, the condition of $0 \le \mu_I(\vartheta) + n_I(\vartheta) \le 1$ should be met (Atanassov 1986):

$$I = \{\vartheta, \mu_I(\vartheta), n_I(\vartheta)/\vartheta \epsilon U\} \tag{13}$$

PFSs are nonstandard fuzzy membership grades that aim for better solutions in the decision-making process. In this process, the evaluations of the experts are converted into Pythagorean numbers, which allows a wider area to be considered. These sets are detailed in Eq. (14), with μ_P and n_P representing degrees (Yager 2013):

$$P = \{\vartheta, \mu_P(\vartheta), n_P(\vartheta)/\vartheta \epsilon U\} \tag{14}$$

Equation (15) indicates the condition to be satisfied:

$$0 \leq (\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{15}$$

As a further iteration, q-ROFSs demonstrate an extension of IFS and PFS. In other words, these two fuzzy numbers are integrated into this process to achieve more appropriate results. In this framework, the first q-level fuzzy sets are considered by IFS. The second q-level fuzzy sets are then defined by PFS. Equation (16) shows the details of these sets. In this equation, the degrees are illustrated by μ_Q and n_Q (Yager 2016):

$$Q = \left\{\vartheta, \mu_Q(\vartheta), n_Q(\vartheta)/\vartheta \epsilon U\right\} \tag{16}$$

Equation (17) indicates the condition to be met:

$$0 \leq \left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q \leq 1, q \geq 1 \tag{17}$$

Equation (18) represents the degree of indeterminacy:

$$\pi_Q(\vartheta) = \left(\left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q - \left(\mu_Q(\vartheta)\right)^q \left(n_Q(\vartheta)\right)^q\right)^{1/q} \tag{18}$$

The mathematical details of these sets are stated in Eqs. (19)–(23):

$$Q_1 = \left\{\vartheta, Q_1(\mu_{Q_1}(\vartheta), n_{Q_1}(\vartheta))/\vartheta \epsilon U\right\} \text{ and } Q_2 = \left\{\vartheta, Q_2(\mu_{Q_2}(\vartheta), n_{Q_2}(\vartheta))/\vartheta \epsilon U\right\} \tag{19}$$

$$Q_1 \oplus Q_2 = \left(\left(\mu_{Q_1}^q + \mu_{Q_2}^q - \mu_{Q_1}^q \mu_{Q_2}^q\right)^{1/q}, n_{Q_1} n_{Q_2}\right) \tag{20}$$

$$Q_1 \otimes Q_2 = \left(\mu_{Q_1} \mu_{Q_2}, \left(n_{Q_1}^q + n_{Q_2}^q - n_{Q_1}^q n_{Q_2}^q\right)^{1/q}\right) \tag{21}$$

$$\lambda Q = \left(\left(1 - \left(1 - \mu_Q^q\right)^\lambda\right)^{1/q}, \left(n_Q\right)^\lambda\right), \lambda > 0 \tag{22}$$

$$Q^\lambda = \left(\left(\mu_Q\right)^\lambda, \left(1 - \left(1 - n_Q^q\right)^\lambda\right)^{1/q}\right), \lambda > 0 \tag{23}$$

For defuzzification, Eq. (24) is used:

$$S(\vartheta) = \left(\mu_Q(\vartheta)\right)^q - \left(n_Q(\vartheta)\right)^q \tag{24}$$

DEMATEL

Goal achievement may be affected by several variables. However, it is not financially feasible to make improvements to each variable. Therefore, it is necessary to determine the importance weights of these variables. Many decision-making methods are used for this purpose in the literature. DEMATEL attempts to find the significant items among factors. The difference between this method and others is that the causality relationship between variables is considered in the analysis process. The DEMATEL technique is especially appropriate for subjects with factors sharing cause–effect relationships. In this process, the direct relation matrix is constructed, as in Eq. (25) (Ding et al. 2021):

$$A = \begin{bmatrix} 0 & a_{12} & a_{13} & & \cdots & a_{1n} \\ a_{21} & 0 & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & 0 & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & 0 \end{bmatrix} \tag{25}$$

Next, this matrix is normalized using Eqs. (26) and (27) (Kou et al. 2021):

$$B = \frac{A}{max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}} \tag{26}$$

$$0 \leq b_{ij} \leq 1 \tag{27}$$

The total relation matrix is created by Eq. (28):

$$\lim_{k \to \infty} \left(B + B^2 + \ldots + B^k \right) = B(I - B)^{-1} \tag{28}$$

Next, the sums of rows (D) and columns (E) are computed using Eqs. (29) and (30) (Liu et al. 2021a, b):

$$D = \left[\sum_{j=1}^{n} e_{ij} \right]_{nx1} \tag{29}$$

$$E = \left[\sum_{i=1}^{n} e_{ij} \right]_{1xn} \tag{30}$$

A threshold value (α) is also used, as in Eq. (31):

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij} \right]}{N} \tag{31}$$

Analysis

This study examines the financial innovation life cycle for renewable energy investments. First, the financial innovation life cycle is weighted with TTSC for renewable energy investments. In this process, the problem is first defined. Next, linguistic evaluations are collected. Average fuzzy preferences are then computed, and degrees are calculated. Later, score function values are determined, and the relation matrix is normalized. The total relation matrix is then created, and weights are defined. In the second stage, TTSC is ranked with IPTs for renewable energy investments. First, linguistic evaluations are obtained. Second, decision combinations are constructed. Finally, the financial innovation life cycle is evaluated for renewable energy investments. The details of this model are presented in Fig. 1.

In this study, an evaluation is performed using fuzzy decision-making methodology. This technique has some advantages over other methodologies in the literature. For instance, fuzzy decision-making analysis has significant advantages over econometric modeling. In this context, fuzzy decision-making analysis makes it possible to deal with uncertainty in the data set (Moradi et al. 2021). However, econometric modeling considers deterministic data (Suganthi et al. 2015). Additionally, it may not be possible to obtain data for each variable. Furthermore, with fuzzy decision-making analysis, nonlinear relationships between factors can be evaluated more appropriately than in econometric modeling (Al-Fattah and Aramco 2021). Fuzzy decision-making analysis is also better than survey analysis under certain circumstances. Within this scope, subjective data can be handled more appropriately by fuzzy decision-making analysis. However,

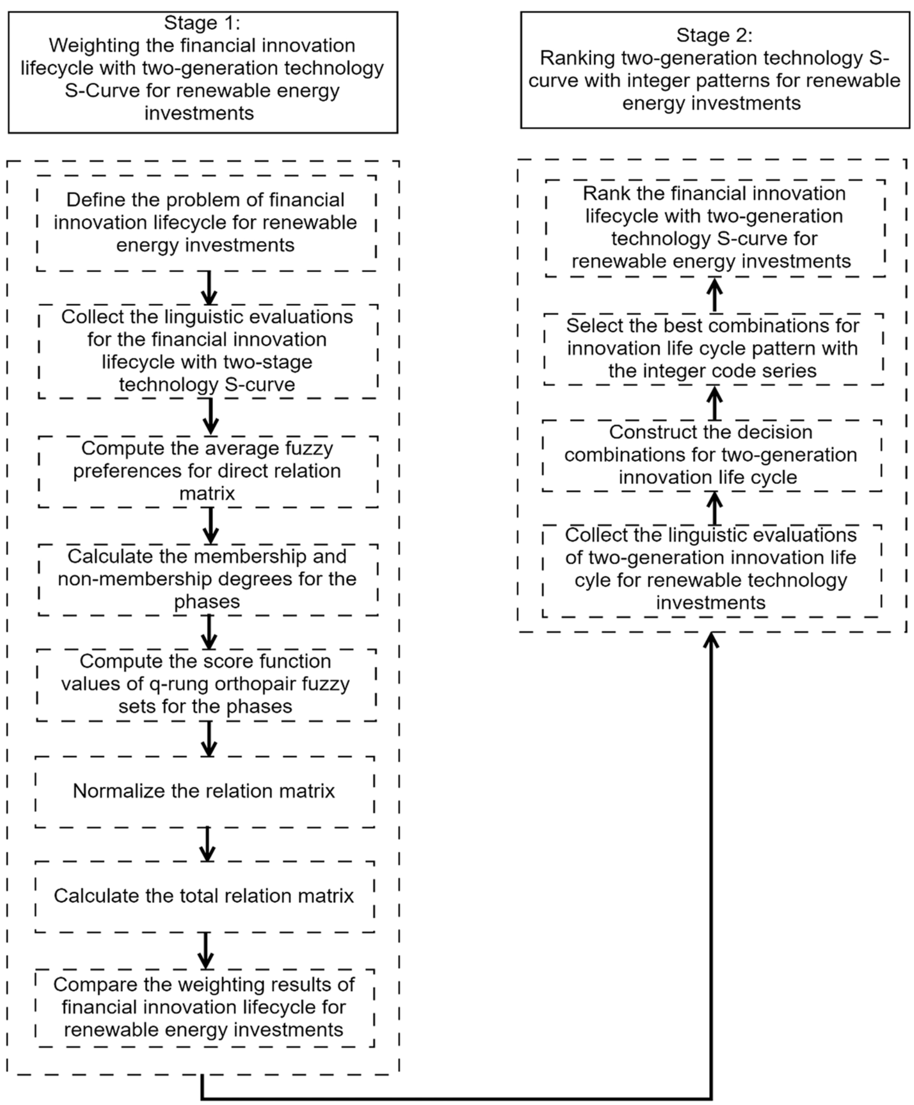

Fig. 1 Algorithm of the proposed model

survey analysis relies on responses that cannot effectively capture human perceptions (Hajek and Novotny 2022). The problem is defined in the first stage. Table 1 provides the scales and degrees considered in this process.

This study considers the evaluations of three experts (Ds). These people have sufficient experience in renewable energy technology investments. They have a minimum of 24 years of experience and at least a master's degree. Table 2 includes the expert evaluations. The phases are demonstrated for emerging (P1, P2), growth (P3, P4), maturity (P5, P6), and aging (P7, P8). In the evaluation process, Table 1 presents the five scales that were considered.

Average fuzzy preferences are shown in Table 3. For this purpose, these evaluations are converted into the fuzzy sets defined in Table 1.

Degrees are also indicated in Table 4. In Table 1, both membership and nonmembership degrees are identified according to each scale.

In the following step, score values are computed by considering Eq. (24). Table 5 demonstrates the score function values.

A normalized matrix is created as in Table 6. For this purpose, Eqs. (26) and (27) are considered. The main purpose of normalization is to make it possible to work with a lower-scale data set. This also contributes to increasing the efficiency of the analysis results.

The relationship matrix is constructed in Table 7. Within this framework, Eq. (28) is considered. The values are defuzzified using Eq. (24). The values in the total relation matrix help identify both the weights of the items and the causal directions between them.

In the final stage, the weights of the items are defined. This analysis can also be performed with IFSs and PFSs. Table 8 includes the details of the analysis results. The sums of rows (D) and columns (E) are computed with Eqs. (29) and (30). Their sums are used to calculate the item weights. The differences between these values are used to define causal relationships among these determinants. For this purpose, the results are compared with the threshold values emphasized in Eq. (31). If the results are greater than this value, the criterion is accepted as an influencing factor. The opposite result indicates an influence factor.

Table 8 indicates similar results for all fuzzy sets. Hence, the proposed model is reliable and coherent. Maturity phase 1 is identified as the most significant phase in the financial innovation life cycle for renewable energy investments. Maturity phase 2 is also important in this regard. The suggested model then ranks TTSC with IPTs for renewable energy

Table 1 Scales and degrees

Linguistic Scales	Membership Degrees	Non-membership Degrees	Evaluation numbers
No (q)	0.10	0.90	0
some (r)	0.30	0.70	1
normal (t)	0.60	0.40	2
great (u)	0.80	0.20	3
perfect (w)	0.90	0.10	4

Table 2 Evaluations

	P1			P2			P3			P4			P5			P6			P7			P8		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
P1				W	W	T	R	T	U	R	R	T	R	T	T	R	T	T	U	U	U	T	T	U
P2	R	T	U				T	T	T	Q	Q	Q	R	R	R	W	W	W	W	T	T	R	T	T
P3	U	T	T	R	R	R				R	R	R	W	W	W	T	T	T	R	R	R	W	W	W
P4	U	U	U	U	T	T	U	U	U				T	T	T	W	W	W	R	R	U	R	R	U
P5	T	T	T	T	T	T	R	R	R	T	T	T				U	U	U	U	U	U	U	U	U
P6	T	T	T	T	T	T	U	T	T	W	W	W	U	U	U				T	T	T	T	T	T
P7	R	T	T	U	U	T	T	T	T	U	U	U	W	W	W	R	R	R				R	T	T
P8	R	R	R	R	R	U	U	U	U	T	T	T	U	U	U	T	T	T	U	U	U			

Table 3 Average fuzzy preferences

	P1	P2	P3	P4	P5	P6	P7	P8
P1		0.80	0.57	0.40	0.50	0.50	0.80	0.67
P2	0.57		0.60	0.10	0.30	0.90	0.70	0.50
P3	0.67	0.30		0.30	0.90	0.60	0.30	0.90
P4	0.80	0.67	0.80		0.60	0.90	0.47	0.47
P5	0.60	0.60	0.30	0.60		0.80	0.80	0.80
P6	0.60	0.60	0.67	0.90	0.80		0.60	0.60
P7	0.50	0.73	0.60	0.80	0.90	0.30		0.50
P8	0.30	0.47	0.80	0.60	0.80	0.60	0.80	

Table 4 Degrees

	P1		P2		P3		P4		P5		P6		P7		P8	
	μ	v	μ	v	μ	v	μ	v	μ	v	μ	v	μ	v	μ	v
P1			0.80	0.20	0.57	0.43	0.40	0.60	0.50	0.50	0.50	0.50	0.80	0.20	0.67	0.33
P2	0.57	0.43			0.60	0.40	0.10	0.90	0.30	0.70	0.90	0.10	0.70	0.30	0.50	0.50
P3	0.67	0.33	0.30	0.70			0.30	0.70	0.90	0.10	0.60	0.40	0.30	0.70	0.90	0.10
P4	0.80	0.20	0.67	0.33	0.80	0.20			0.60	0.40	0.90	0.10	0.47	0.53	0.47	0.53
P5	0.60	0.40	0.60	0.40	0.30	0.70	0.60	0.40			0.80	0.20	0.80	0.20	0.80	0.20
P6	0.60	0.40	0.60	0.40	0.67	0.33	0.90	0.10	0.80	0.20			0.60	0.40	0.60	0.40
P7	0.50	0.50	0.73	0.27	0.60	0.40	0.80	0.20	0.90	0.10	0.30	0.70			0.50	0.50
P8	0.30	0.70	0.47	0.53	0.80	0.20	0.60	0.40	0.80	0.20	0.60	0.40	0.80	0.20		

Table 5 Score function values

	P1	P2	P3	P4	P5	P6	P7	P8
P1	0.000	0.504	0.101	− 0.152	0.000	0.000	0.504	0.259
P2	0.101	0.000	0.152	− 0.728	− 0.316	0.728	0.316	0.000
P3	0.259	− 0.316	0.000	− 0.316	0.728	0.152	− 0.316	0.728
P4	0.504	0.259	0.504	0.000	0.152	0.728	− 0.050	− 0.050
P5	0.152	0.152	− 0.316	0.152	0.000	0.504	0.504	0.504
P6	0.152	0.152	0.259	0.728	0.504	0.000	0.152	0.152
P7	0.000	0.375	0.152	0.504	0.728	− 0.316	0.000	0.000
P8	− 0.316	− 0.050	0.504	0.152	0.504	0.152	0.504	0.000

Table 6 Normalized matrix

	P1	P2	P3	P4	P5	P6	P7	P8
P1	0.000	0.235	0.047	0.000	0.000	0.000	0.235	0.121
P2	0.047	0.000	0.071	0.000	0.000	0.339	0.147	0.000
P3	0.121	0.000	0.000	0.000	0.339	0.071	0.000	0.339
P4	0.235	0.121	0.235	0.000	0.071	0.339	0.000	0.000
P5	0.071	0.071	0.000	0.071	0.000	0.235	0.235	0.235
P6	0.071	0.071	0.121	0.339	0.235	0.000	0.071	0.071
P7	0.000	0.175	0.071	0.235	0.339	0.000	0.000	0.000
P8	0.000	0.000	0.235	0.071	0.235	0.071	0.235	0.000

Table 7 Total relation matrix

	P1	P2	P3	P4	P5	P6	P7	P8
P1	0.264	0.553	0.429	0.429	0.653	0.551	0.685	0.490
P2	0.361	0.371	0.492	0.528	0.726	0.881	0.624	0.443
P3	0.514	0.484	0.591	0.632	1.275	0.858	0.777	0.961
P4	0.698	0.669	0.848	0.713	1.118	1.181	0.777	0.718
P5	0.508	0.600	0.640	0.784	1.038	1.052	0.956	0.831
P6	0.595	0.642	0.794	1.016	1.278	0.974	0.857	0.781
P7	0.436	0.634	0.615	0.805	1.171	0.848	0.670	0.596
P8	0.434	0.496	0.784	0.714	1.222	0.871	0.914	0.667

Table 8 Weights of the items

Phases	q-ROF DEMATEL	DEMATEL	IF DEMATEL	PF DEMATEL
Emerging-Phase 1	0.085	0.115	0.087	0.087
Emerging-Phase 2	0.095	0.113	0.098	0.098
Growth-Phase 1	0.121	0.121	0.121	0.121
Growth-Phase 2	0.133	0.124	0.130	0.130
Maturity-Phase 1	0.160	0.137	0.159	0.159
Maturity-Phase 2	0.152	0.137	0.150	0.150
Aging-Phase 1	0.129	0.128	0.130	0.130
Aging-Phase 2	0.125	0.127	0.125	0.125

Table 9 Scales, preference numbers, and letters

Scales	Numbers	Alphabet
Poorest (J)	0	−2
Poor (K)	0.25	−1
Fair (L)	0.50	0
Good (M)	0.75	+1
Best (N)	1	+2

investments. Linguistic evaluations are first obtained from experts. This process considers the scales in Table 9.

Table 10 summarizes the evaluations. In this evaluation process, three experts state their opinions on the phases by considering the scales provided in Table 9.

Evaluations for the second generation are provided in Table 11.

Table 12 presents the first-generation decision combinations.

Table 13 includes the second-generation combinations.

The best combinations (CNTS) are selected as follows. The first-generation details are below:

Table 10 Evaluations

Periods	Phases	Time	D1	D2	D3
Emerging	P 1	Q 1	M	M	M
	P 2	Q 2	J	J	J
Growth	P 1	Q 3	M	N	N
	P 2	Q 4	K	K	K
Maturity	P 1	Q 5	M	M	M
	P 2	Q 6	K	K	K
Aging	P 1	Q 7	N	N	N
	P 2	Q 8	K	K	K
Declining-I	P 1	Q 9	M	M	M
	P 2	Q 10	K	K	K
Declining-II	P 1	Q 11	M	N	N
	P 2	Q 12	K	K	K
Declining-III	P 1	Q 13	M	M	M
	P 2	Q 14	K	K	K
Declining-IV	P 1	Q 15	N	N	N
	P 2	Q 16	J	J	J

Table 11 Evaluations of the second generation

Periods	Phases	Time	D1	D2	D3
Emerging	P 1	Q 1	M	M	M
	P 2	Q 2	K	K	K
Growth	P 1	Q 3	N	N	N
	P 2	Q 4	J	J	J
Maturity	P 1	Q 5	M	M	M
	P 2	Q 6	K	K	K
Aging	P 1	Q 7	M	M	M
	P 2	Q 8	K	K	K
Declining-I	P 1	Q 9	M	M	N
	P 2	Q 10	J	J	J
Declining-II	P 1	Q 11	M	M	M
	P 2	Q 12	K	K	K
Declining-III	P 1	Q 13	M	M	M
	P 2	Q 14	K	K	K
Declining-IV	P 1	Q 15	N	N	N
	P 2	Q 16	K	K	K

Table 12 Combinations (first generation)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Combination 1	M	J	M	K	M	K	N	K	M	K	M	K	M	K	N	J
Combination 2	M	J	N	K	M	K	N	K	M	K	M	K	M	K	N	J
Combination 3	M	J	M	K	M	K	N	K	M	K	N	K	M	K	N	J
Combination 4	M	J	N	K	M	K	N	K	M	K	N	K	M	K	N	J

Table 13 Combinations (second generation)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Combination 1	M	K	N	J	M	K	M	K	N	J	M	K	M	K	N	K
Combination 2	M	K	N	J	M	K	M	K	M	J	M	K	M	K	N	K

CNTS 1:

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

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

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

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

Hierarchical forms are provided.

CNTS 2:

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

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

$f^{[1]}(t_5,t_8)\neq 0$ for combination 2. The requirements are not satisfied for CNTS 2.

CNTS 3:

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

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

$f^{[1]}(t_5,t_8)$ and $f^{[1]}(t_9,t_{12})\neq 0$. The requirements are not satisfied for CNTS 3.

CNTS 4:

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

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

$f^{[1]}(t_5,t_8)\neq 0$ and $f^{[1]}(t_9,t_{12})\neq$. The requirements are not satisfied for CNTS 4.

The second-generation details are as follows.

CNTS 1:

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

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

$f^{[1]}(t_{13},t_{16}) \neq 0$ for combination 1. The requirements are not satisfied for combination 1.

CNTS 2:

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

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

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

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

Hierarchical forms are provided for all levels. Table 14 shows the combination set.

Finally, the financial innovation life cycle is ranked for renewable energy investments, as shown in Table 15.

Table 15 shows a ranking of the financial innovation life cycle performed using q-ROF DEMATEL. In addition, DEMATEL, IF DEMATEL, and PF DEMATEL are considered to check the consistency of analytical results. The results of all sets are the same. Thus, the findings are reliable. Aging is the most important period for financial innovation in renewable energy investment projects, with maturity also playing a key role.

Table 14 Combination set

Generation	Periods	Phases	Time	Combinations	Scales
First Generation	Emerging	P 1	Q 1	Combination 1	M
		P 2	Q 2		J
	Growth	P 1	Q 3		M
		P 2	Q 4		K
	Maturity	P 1	Q 5		M
		P 2	Q 6		K
	Aging	P 1	Q 7		N
		P 2	Q 8		K
Second Generation	Emerging	P 1	Q 9	Combination 2	M
		P 2	Q 10		K
	Growth	P 1	Q 11		N
		P 2	Q 12		J
	Maturity	P 1	Q 13		M
		P 2	Q 14		K
	Aging	P 1	Q 15		M
		P 2	Q 16		K

Table 15 Ranking results

Time and pattern preferences			q-ROF DEMATEL				DEMATEL			
Generation	**Time**	**Fuzzy Pref.**	**Weighted Pref.**	**Periods**	**Period Pref.**	**Period ranking**	**Weighted Pref.**	**Periods**	**Period Pref.**	**Period ranking**
First Generation	Q 1	0.75	0.063	Emerging	0.032	8	0.086	Emerging	0.043	8
	Q 2	0	0.000				0.000			
	Q 3	0.75	0.091	Growth	0.062	5	0.091	Growth	0.061	5
	Q 4	0.25	0.033				0.031			
	Q 5	0.75	0.120	Maturity	0.079	2	0.102	Maturity	0.068	2
	Q 6	0.25	0.038				0.034			
	Q 7	1	0.129	Aging	0.080	1	0.128	Aging	0.080	1
	Q 8	0.25	0.031				0.032			
Second Generation	Q 9	0.75	0.063	Emerging	0.044	7	0.086	Emerging	0.057	7
	Q 10	0.25	0.024				0.028			
	Q 11	1	0.121	Growth	0.061	6	0.121	Growth	0.060	6
	Q 12	0	0.000				0.000			
	Q 13	0.75	0.120	Maturity	0.079	2	0.102	Maturity	0.068	2
	Q 14	0.25	0.038				0.034			
	Q 15	0.75	0.097	Aging	0.064	4	0.096	Aging	0.064	4
	Q 16	0.25	0.031				0.032			

Table 15 (continued)

Time and Pattern Preferences			IF DEMATEL				PF-DEMATEL			
Generation	**Time**	**Fuzzy Pref.**	**Weighted Pref.**	**Periods**	**Period Pref.**	**Period ranking**	**Weighted Pref.**	**Periods**	**Period Pref.**	**Period ranking**
First Generation	Q 1	0.75	0.066	Emerging	0.033	8	0.066	Emerging	0.033	8
	Q 2	0	0.000				0.000			
	Q 3	0.75	0.091	Growth	0.062	5	0.091	Growth	0.062	5
	Q 4	0.25	0.033				0.033			
	Q 5	0.75	0.119	Maturity	0.078	2	0.119	Maturity	0.078	2
	Q 6	0.25	0.038				0.038			
	Q 7	1	0.130	Aging	0.080	1	0.130	Aging	0.080	1
	Q 8	0.25	0.031				0.031			
Second Generation	Q 9	0.75	0.066	Emerging	0.045	7	0.066	Emerging	0.045	7
	Q 10	0.25	0.024				0.024			
	Q 11	1	0.121	Growth	0.061	6	0.121	Growth	0.061	6
	Q 12	0	0.000				0.000			
	Q 13	0.75	0.119	Maturity	0.078	2	0.119	Maturity	0.078	2
	Q 14	0.25	0.038				0.038			
	Q 15	0.75	0.097	Aging	0.064	4	0.097	Aging	0.064	4
	Q 16	0.25	0.031				0.031			

Discussion and conclusions

This study examines the financial innovation life cycle for renewable energy investments. First, the financial innovation life cycle is weighted with the TTSC for renewable energy investments. Next, the TTSC is ranked with IPTs for renewable energy investments. Within this context, the DEMATEL methodology is considered based on q-ROFSs. Furthermore, a comparative examination has been performed using IFSs and PFSs. We conclude that the results with all fuzzy sets are similar. Therefore, the proposed model is determined to be reliable and coherent. Maturity phase 1 is the most significant phase of the financial innovation life cycle for renewable energy investments. Maturity phase 2 is also important in this regard. Meanwhile, aging is the most important period for financial innovation in renewable energy investment projects. Furthermore, maturity plays a key role in this regard.

Renewable energy companies should make strategic decisions after this point. In this situation, the decision should be related to either radical or incremental innovation. In terms of radical innovation, renewable energy companies complete their innovation and start to implement new innovations. With respect to incremental innovation, renewable energy companies can decide to update a currently used innovation. If companies do not make decisions during these phases, innovative financial products cannot be improved. Because of this, financing products will find disfavor with renewable energy companies. However, financial innovation has a life cycle with emerging, growth, maturity, and decline phases. In other words, if companies do not update their financial innovations based on the needs of the market, financial products will become unusable after a certain point.

The literature contains differing views about what innovations are needed for financial products generated for renewable energy investors. Some researchers claim that incremental innovation is necessary for financial products to satisfy the needs of renewable energy investors. Assi et al. (2021) focused on the relationship between financial innovation and renewable energy development. They determined that existing financial information should be improved according to the expectations of renewable energy investors. Moreover, Hamelink and Opdenakker (2019) determined that after a certain point, companies should make incremental innovations to financial products created for renewable energy projects. Lacerda and van den Bergh (2020) noted a similar conclusion in their examination. On the other hand, Kerr et al. (2021) and Mendonça and Fonseca (2018) stated that radical innovation is necessary to improve the performance of financial instruments generated for renewable energy investors.

Cost-effectiveness plays a crucial role in improving clean energy projects, and renewable energy investors should find sufficient financial sources to achieve this objective (Xu et al. 2023). Otherwise, it will be quite difficult to ensure project sustainability (Martínez et al. 2023). In the short run, this problem can be solved with government support. Under this framework, financial incentives, such as tax decreases, can contribute to the effectiveness of the cost management process of renewable energy investors (Yüksel and Dinçer 2023). However, over the long term, innovative financial products are necessary. With the help of these products, it is possible to increase clean energy project investment (Wan et al. 2023). In this context, the design of innovative financial products should be effective and appropriate (Moiseev et al. 2023; Mikhaylov et al. 2023).

The main contribution of this study is providing appropriate strategies for improving financial innovations for renewable energy investment. This situation has a positive influence on the growth of clean energy projects. The main limitation is highlighting only the important phases in the financial innovation life cycle for renewable energy investments. Other subjects for renewable energy projects can be considered in future studies, such as risk management, cost evaluation, and performance examination. Other multicriteria decision-making approaches can also be used in the analysis process. For instance, the analytic hierarchy process helps identify hierarchical relationships among criteria. Another limitation of this study is that the analysis is based primarily on the subjective evaluations of three experts. By considering this situation in future studies, an objective analysis can be conducted for a comparative evaluation.

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Author contributions
GK participated in the design of the study, performed the statistical analysis and helped to draft the manuscript. HD participated in the design of the study and performed the statistical analysis. SY conceived of the study and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
No data is used in the analysis.

Declarations

Competing interests
The authors declare that they have no competing interests.

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