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Quantum fuzzy decision-making for analyzing the service progress life cycle of renewable energy innovation investments

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HIGHLIGHTS

- A novel soft computing model evaluates renewable energy innovation investments' service progress life cycle.
- The model incorporates facial action coding system (FACS) to enhance originality and effectiveness of decision-making.
- The model develops a new technique, M-SWARA.
- The model applies quantum spherical fuzzy TOPSIS and VIKOR to rank renewable innovation investment alternatives .
- The model offers coherent and reliable findings for efficient investment strategies .

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ABSTRACT

Innovative and effective solutions can be produced by using advanced technologies to increase renewable energy innovation investments. However, many actions taken to increase these investments may cause the costs of enterprises to reach an unmanageable level. As a result, a priority analysis is needed to identify the most critical issues, but in literature, there are limited studies in the literature regarding this issue. Accordingly, the purpose of this study is to evaluate the service progress life cycle of renewable energy innovation investments. A novel model is presented in this process while integrating different approaches. First, the service progress life cycle of renewable innovation investments is weighted. In this scope, two-generation technology S-curve and facial action coding system-based Quantum Spherical fuzzy M-SWARA are considered. Secondly, the renewable innovation investment alternatives are ranked. In this framework, the integer patterns and facial action coding system-based Quantum Spherical fuzzy TOPSIS are taken into consideration. Additionally, these investment alternatives are also ranked by using VIKOR technique to test the validity of the proposed model results. Moreover, a sensitivity analysis is conducted by considering 8 different cases so that coherency of the results can be tested. The main contribution of this manuscript is the consideration of the FACS system to increase both the originality and effectiveness of the proposed model and the development of new technique named M-SWARA. Additionally, conducting a priority evaluation helps to identify the efficient investment strategies to increase renewable energy innovation. It is defined that the same findings can be achieved by both TOPSIS and VIKOR techniques. Furthermore, sensitivity analysis also indicates the same rankings as well. It is understood that the proposed model provides coherent and reliable findings. The findings denote that maturity is the most critical

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stage of the service progress life cycle of the renewable energy investments. Moreover, advanced technologies are found as the best alternative of the renewable innovation investments for the service progress life cycle. Hence, it is recommended that R&D activities should be prioritized for the provision of advanced technologies in the renewable energy sector. For this purpose, research centers, universities, private sector companies and government institutions can work for the development of innovative and advanced technologies.

1. Introduction

Renewable energy innovation investments mean the development of technological innovations for renewable energy sources and investing in this field [1]. Renewable energy innovation investments include studies for the development of innovative technologies and the optimization of the production, distribution and use processes of these technologies [2]. Renewable energy innovation investments provide many advantages both economically and environmentally. These investments contribute to the fight against climate change by accelerating technological developments towards more efficient, economical, and environmentally friendly renewable energy sources. On the other hand, investments in these resources help to reduce production costs by reducing energy costs. These investments also help to ensure energy independence by increasing the use of domestic energy resources [3]. Moreover, these projects help protect the environment and ensure sustainability, as they provide less greenhouse gas emissions compared to the use of fossil fuels.

Analyzing the service progress life cycle of renewable energy innovation investments is crucial to increase the effectiveness of these projects. In this process, evaluating the service progress life cycle has a powerful contribution on renewable energy innovation performance [4]. With the help of these assessments, it can be understood how well current technologies meet the objectives. In addition to this issue, understanding the life cycle helps to make a comprehensive risk assessment. Owing to this situation, potential risks in different stages can be identified [5]. This issue has a positive influence to reduce uncertainties. Moreover, evaluation of the life cycle is also significant for effective resource allocations. While making life cycle analysis, more critical steps can be identified. This condition helps to make more efficient resource allocations. On the other hand, analyzing the service progress life cycle gives information about the need for a new technology in this process [6]. With the help of this issue, companies can take necessary actions to make technological improvements. Moreover, life cycle analysis helps to generate opportunities for innovation.

To increase the performance of the service progress life cycle of renewable energy innovation investments, businesses should pay attention to some issues. With the help of these actions, the development of these investments and thus the development of the economy by considering environmental issues should be ensured. The biggest obstacle in this process is that all these actions lead to an increase in the costs of the enterprises. In other words, many actions taken to increase renewable energy innovation investments may cause the costs of enterprises to reach an unmanageable level. Therefore, while taking these actions, businesses should also pay attention to the fact that the costs are not too high. Thus, it would be financially correct for businesses to prioritize issues that are more important instead of making many improvements. To achieve this goal, businesses need to determine the more critical factors. In this context, studies are needed to determine these criteria.

For satisfying this need, this study aims to analyze the service progress life cycle of renewable energy innovation investments. While integrating different approaches, a novel model is presented in this process. In the first stage, the service progress life cycle of renewable innovation investments is weighted. Within this scope, two-generation technology S-Curve and facial action coding system-based Quantum Spherical fuzzy M-SWARA are considered. Secondly, the renewable innovation investment alternatives are ranked. In this framework, the integer patterns and facial action coding system-based Quantum Spherical fuzzy TOPSIS are taken into consideration. The main motivation of this study is that a novel model should be generated to evaluate the service progress life cycle of renewable energy innovation investments. Existing models in the literature for this subject are criticized due to some reasons. For instance, the performance indicators of these projects can have a causal impact on each other. However, the models in which AHP and ANP were considered cannot create an impact relation map for the determinants [7,8]. Thus, for satisfying this issue, a novel model is constructed in this study by proposing a new methodology (M-SWARA). Similarly, facial expressions of the decision-makers are also considered in this novel model. With the help of this issue, more effective findings can be reached.

The main contributions of this manuscript are explained below.

(i) Consideration of the FACS system increases both the originality and effectiveness of the proposed model. Multi-criteria decision-making problems are complex decision-making processes that require decision makers to make the right decisions by considering multiple criteria. It is very important for decision makers to have sufficient information to increase the effectiveness of the model to be created. Decision makers need to consider many factors while solving these problems. However, there is a possibility that these people may have hesitations about some issues. Ignoring these hesitations leads to a decrease in the efficiency of the process. Owing to the FACS system, facial expressions of decision makers are also included in the analysis process, thus minimizing this problem [9–11]. Finding the most critical steps in the service progress life cycle of renewable innovation investments is a very complex issue. In this context, a comprehensive evaluation should be conducted. For this purpose, considering facial expressions of the decision makers while making evaluations helps to find more appropriate process in the service progress life cycle of renewable innovation investments.

(ii) The development of the M-SWARA technique also increases the superiority of the proposed model. Although the classical SWARA technique has many advantages, the lack of causality between the variables is considered one of the most important weaknesses of this approach [12]. Renewable energy innovation investments and technology development processes can also affect each other. In other words, for defining the most critical indicators of the performance of these projects, causal directions between the items should be considered. Hence, it is understood that decision-making models currently in literature may not be sufficient to solve this problem. In this study, some improvements have been made on SWARA method [13]. As a result, a new approach named M-SWARA has been developed so that the causality relationship between the factors can be taken into consideration [14]. Owing to these issues, M-SWARA methodology has some superiorities over other methods, such as fuzzy compromise programming (FUCOM), life-based weight assignment (LBWA), or ordered weighted averaging (OPA). Therefore, it is understood that the M-SWARA method is very suitable for research on this subject [15]. The steps in the service progress life cycle of renewable innovation investments may have an impact on each other. Because of this issue, for the purpose of finding appropriate steps, this causal direction should be taken into consideration. Thus, using M-SWARA methodology in the analysis process provides an opportunity to make more effective evaluation.

(iii) The sensitivity of the proposed model increases by using both Spherical fuzzy sets and quantum logic. To ensure the success of renewable energy innovation investments, many different issues need to be taken into consideration. In other words, to determine the most accurate strategy in this process, a complex decision-making process must be analyzed correctly. For this situation, different conditions should be taken into consideration to achieve an effective solution. Quantum theory allows different possibilities to be considered in the analysis process [16,17]. On the other hand, Spherical fuzzy numbers also allow working with a larger data set in the analysis process [18]. Because of this issue, it can be possible to make a comprehensive evaluation in the analysis process. As a result, M-SWARA, TOPSIS and VIKOR techniques are extended with Quantum Spherical fuzzy sets. Therefore, by integrating these approaches, this complex problem can be solved in a better way [19]. Similarly, considering the TOPSIS technique provides some benefits. This technique uses the distances to both positive and negative optimal values in the analysis process. This situation helps to reach more appropriate and effective results. Due to this issue, it is seen that TOPSIS has some superiorities over the similar models, such as multi-attributive border approximation area comparison (MABAC), multi-attributive ideal-real comparative analysis (MAIRCA), rough AHP fuzzy similarity measure (RAFSI), or multi-attribute comparison based on ratio and compromisel solution (MARCOS).

(iv) Considering the technology S-curve in the evaluation of the renewable energy innovation process also provides some advantages [20]. The technology S-curve is an important tool for understanding the adoption trends of a technology and the marketing strategies of businesses [21]. This curve helps businesses predict how quickly they can adopt a new technology. These forecasts can help businesses refine their marketing strategies and decide what actions they need to take to roll out a technology [22]. In summary, thanks to this curve, it is possible to determine more accurate strategies for the development of clean energy innovation investments.

(v) Conducting a priority evaluation helps to identify the efficient investment strategies to increase renewable energy innovation. Various factors can affect the performance of this process, but these actions increase the cost of the companies. Due to this aspect, it would be financially correct for businesses to prioritize issues that are more important instead of making many improvements. Because of this situation, this priority analysis has a powerful contribution to reach this objective.

Literature is reviewed in the second part. The methods are explained in the following part. The next part consists of results of the proposed model. The final sections give information about the discussions and conclusions.

2. Literature review on influencing factors of renewable energy innovation

Advanced technology is of great importance in increasing renewable energy innovation investments. The use of advanced technologies can also increase the reliability of renewable energy sources [23]. On the other hand, thanks to the robust technological infrastructure, it is possible to use energy resources in a longer and sustainable way [24]. Almulhim [25] identified that a new generation of photovoltaic cells developed for solar panels can convert sunlight into electricity more efficiently. This contributes to making solar energy resources more efficient and economical. Similarly, Khan et al. [26] claimed that next-generation designs for wind turbines can enable more efficient use of wind energy resources. Kebede et al. [27] and Li et al. [28] defined that innovative and effective solutions can be produced by using advanced technologies to increase renewable energy innovation investments. This, in turn, enables more widespread use of renewable energy sources [29].

The efficiency of service processes is very important in increasing renewable energy innovation investments. Renewable energy projects are generally large-scale and long-term investments. Therefore, service processes are critical to the success of projects [30]. Service processes include the design, construction, maintenance, and operation of renewable energy projects [31]. According to Wang [31], the efficiency of these processes ensures that projects are completed on time and budgets are protected. Hassan et al. [32] defined that service processes allow efficient use of renewable energy sources and increase energy efficiency. This helps us move towards a more sustainable energy future. In addition to technological innovations, Amin et al. [33] highlighted that good management and organization are also critical for efficient service processes. Chakravarty et al. [34] stated that a well-planned and effective management ensures that service processes proceed in an orderly and efficient manner. In addition, employee training and competencies can increase the efficiency of service processes [35].

Innovative business models are of great importance in increasing renewable energy innovation investments. Innovative business models can be effective in all processes such as financing, design, construction, operation and maintenance of these investments. Costa et al. [36] defined that innovative business models can include various elements such as new financing models, innovations in products and services, innovation, and the use of digital technologies. According to Mukoro et al. [37], innovative financing models can increase investment returns and reduce investment risks. These models include green financing instruments such as green bonds, green bonds, and green funds. Mihailova et al. [38] determined that these instruments offer investors low-risk and long-term investment opportunities. This facilitates the financing of renewable energy projects. Wright et al. [39] mentioned that innovative business models can also enable customers to access renewable energy sources more easily and cost-effectively. Thus, it both reduces the costs of customers and contributes to the growth of the renewable energy sector [40]. Iazzolino et al. [41] identified that innovative business models can facilitate the financing of renewable energy projects, provide customers with more affordable energy, and contribute to the growth of the sustainable energy sector.

Dynamic service management is another issue that needs to be taken into consideration in increasing these innovation projects. Marinescu et al. [42] explained that dynamic service management improves the performance of them and resolves issues faster. This contributes to renewable energy projects operating with higher efficiency and making them more sustainable. According to Li et al. [43], dynamic service management can also reduce the operating costs of renewable energy projects. This could help renewable energy projects become more competitive and attract more investors. Raihan and Tuspekova [44] determined that dynamic service management helps minimize fluctuations in energy production. Wind turbines must be adjusted for changing wind conditions. In this way, it is possible to obtain more efficiency from these turbines. Rostirolla et al. [45] mentioned that dynamic service management can also optimize the maintenance of them. Hassan et al. [46] and Peng et al. [47] identified that dynamic service management can better understand the maintenance needs of renewable energy projects, enabling them to be done at lower costs and with less time wasted.

Multi-criteria decision-making models are also considered to evaluate the effectiveness of the service progress life cycle of renewable energy innovation investments. For instance, SWARA is a method that helps users to choose objectively and systematically in complex and multi-criteria decision-making processes [12]. However, one of the most important shortcomings of this technique is that causality between factors is not used in the analysis process [13]. To complete this deficiency, a new model named M-SWARA was developed by making some improvements. This new approach considers the cause-effect relationship while determining the order of importance of the criteria [14]. This new methodology was also taken into consideration in the literature for different purpose. Dinçer et al. [48] generated a hybrid model by integrating M-SWARA and TOPSIS to evaluate the investment alternatives of microgeneration energy technologies. Wu et al. [49] focused on the crowdfunding platforms for microgrid project investors by using this approach. Li et al. [50] analyzed the levelized cost of renewable energy alternatives via M-SWARA. Kafka et al. [51] and Yüksel and Dinçer [52] used this new technique for sustainability analysis in the emerging economies.

The main issues of the literature evaluation are summarized below. Renewable energy innovation is very necessary to provide environmental sensitivity in economic development. Necessary implementations should be performed to improve this innovation. However, these actions increase the cost of the companies. Due to this aspect, it would be financially correct for businesses to prioritize issues that are more important instead of making many improvements. As a result, a priority analysis is needed to identify the most critical issues, but in literature, there are limited studies in the literature regarding this issue. To satisfy this situation, this study aims to determine the service progress life cycle of renewable energy innovation investments. A novel model is presented in this process by integrating different approaches.

3. Methodology

The proposed methodology includes two different stages. Firstly, the service progress life cycle of renewable innovation investments is weighted. Secondly, the renewable innovation investments with the two-generation service progress life cycle are ranked. Fig. 1 explains the flowchart of the proposed model.

This section explains the techniques used in the analysis process.

3.1. FACS

The first stage of the proposed model includes weighting the service progress life cycle of renewable innovation investments. For this purpose, quantum Spherical fuzzy M-SWARA method based on facial expression is taken into consideration. *Step 1* of the proposed model is related to the definition of the service progress life cycle with two-generation technology S-curve for the renewable innovation investments. The competence of experts who make evaluations is very important in the effective solution of decision-making problems. In the decision-making process, experts provide critical knowledge and expertise. Having in-depth knowledge of the subject enables them to correctly evaluate alternatives and criteria. A competent specialist can be more effective at understanding and analyzing the problem and identifying appropriate solution options. The decision-making process can be complex and require an analytical approach that considers multiple factors. Competent experts, with their analytical abilities, can analyze data, use the right methods, and interpret the results. This enables healthier and more informed decisions to be made.

On the other hand, experts who make evaluations in the decision-making process may be hesitant about the answers to some questions. Experts may not always have complete or complete information. The decision-making process is often filled with uncertainty and uncertainty. Experts may not fully know the answers to questions based on insufficient or conflicting data. Moreover, experts may encounter uncertainties in predicting or determining the consequences of future events. These uncertainties can make it difficult to determine definitive answers to

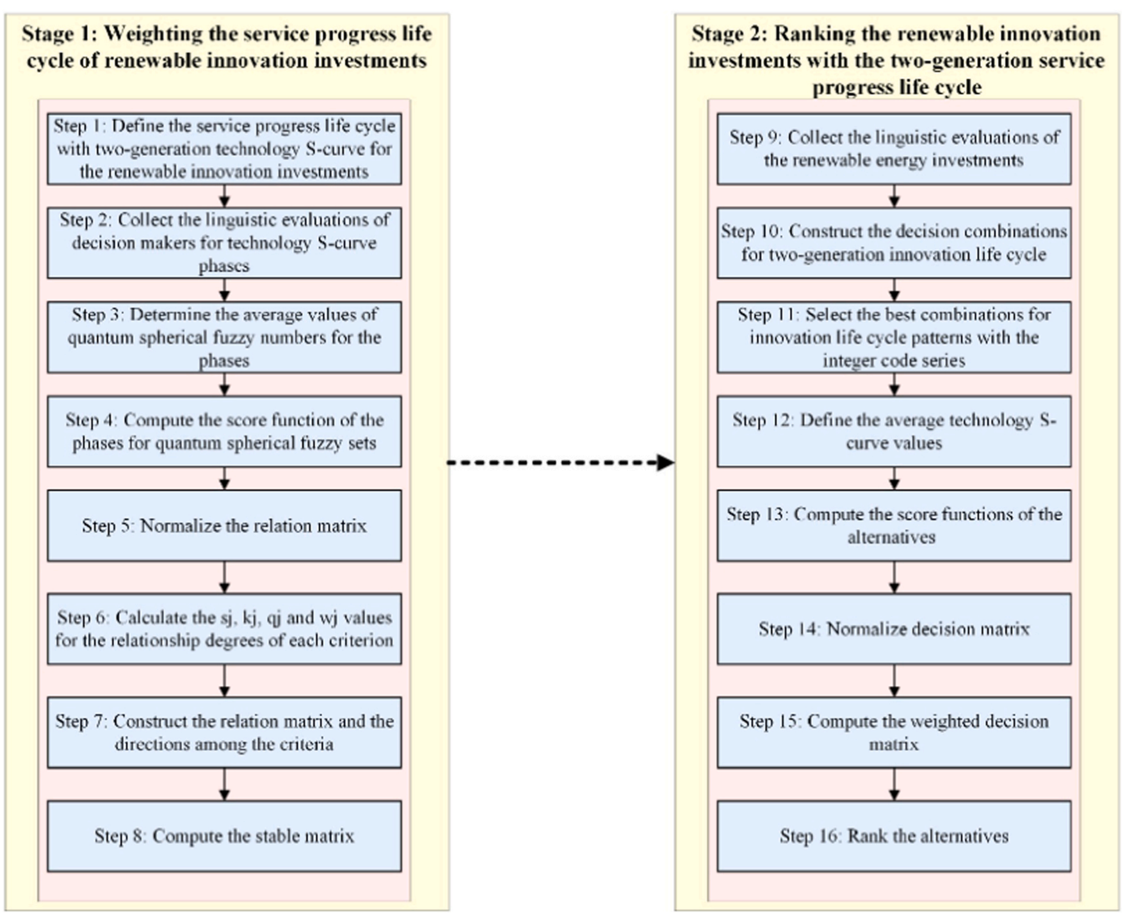

Fig. 1. Flowchart.

some questions and cause hesitation. On the other hand, the decision-making process can sometimes be complex. Among the many variables, influences, and relationships, questions may arise that require understanding. Experts may feel the need to do more analysis and evaluation to deal with this complexity. In addition, experts may not be fully satisfied with the solution options available. The effort to find a better or more suitable solution may increase the hesitation about the answers to some questions.

As can be understood from all these issues, experts may be hesitant in answering some questions, even though they have a high level of knowledge. For the decision-making problems to be solved correctly, these issues should also be taken into consideration in the relevant process. Facial Action Coding System (FACS) is a method used to systematically analyze and code facial expressions [9]. FACS is a system that describes the movements of facial muscles by using action units (AUs) [10]. Its main purpose is to describe and analyze people's emotional expressions and emotional states. FACS identifies the different muscle groups that make up facial expressions [11]. Facial muscle movements and combinations of these movements create different emotional expressions. FACS uses a numbering system to analyze and encode facial expressions. In this system, the movements and intensity of each facial muscle are represented by a specific code. These codes facilitate the identification and analysis of facial expressions.

3.2. Integer patterns and geometrical recognition

Integer patterns refer to mathematical operations or situations where numbers in sequences have a particular order or pattern [53]. These patterns can occur because of mathematical operations such as the sum, difference, multiplication, or division of numbers [54]. Integer patterns can occur in different mathematical contexts. These patterns play an important role in mathematical analysis, problem solving, and working with numbers. In this study, they are considered with decision-making models with the aim of finding better solutions for complex problems. In this framework, I refers to the integer alphabet while $\delta > 0 and \varepsilon > 0$ define spacings of a spacetime lattice (δ, ε). Integer alphabet is detailed in Eq. (1) [55].

$$I_n = \{s = s_1 \ldots s_n, \quad s_i \in I, \quad i = 1, \ldots, n\} \text{where} n \geq 2 \tag{1}$$

Integer code series denote the geometrical patterns given into each other as detailed in Eq. (2)-(5). In this process, $W_{\delta\varepsilon}([t_m, t_{m+n}])$ gives information about the set of piecewise constant functions. On the other side, f is constant as $(t_{i-1}, t_i)]$ and m indicates the integer.

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

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

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

$$t \in (t_{i-1}, t_i)] \text{and} t_i = i\varepsilon \text{Where} i = m+1, \ldots, m+n \tag{5}$$

Moreover, $f^{[k]}$ shows the kth integral of a function as stated in Eq. (6).

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

Similarly, kth integral should satisfy Eq. (7).

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

The mathematical details are given in Eq. (8)-(10).

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

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

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

Eq. (11) demonstrates the constant function regarding the level.

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

3.3. Quantum spherical fuzzy M-SWARA

For weighting the service progress life cycle of renewable innovation investments, Quantum Spherical Fuzzy M-SWARA methodology is taken into consideration. In this process, quantum theory, Spherical fuzzy sets and M-SWARA technique are integrated. Quantum theory plays a fundamental role in many technological developments today. Quantum theory is a theory in which the concepts of randomness, uncertainty and probability are important. This theory also examines how uncertainties can be handled [16]. Because of these advantages, this theory is considered together with decision making techniques and fuzzy numbers in the study [17]. Within this context, φ^2 denotes the amplitude, ς represents the set of collective events, θ^2 is the phase angle and u demonstrates the events. Eqs. (12)-(14) identify this condition.

$$Q(|u>) = \varphi e^{j\theta} \tag{12}$$

$$|\varsigma> = \{|u_1>, |u_2>, \ldots, |u_n>\} \tag{13}$$

$$\sum_{|u> \subseteq |\varsigma>} |Q(|u>)| = 1 \tag{14}$$

This theory is integrated into the Spherical fuzzy sets (A) in this proposed model. Neutrosophic and Pythagorean fuzzy numbers are generated to create these fuzzy sets. The membership, non-membership, and hesitancy degrees (μ, ν and π) are taken into consideration in these sets [18]. Eqs. (15) and (16) indicate the details of them.

$$\widetilde{A}_S = \left\{ \langle u, (\mu_{\tilde{A}_S}(u), \nu_{\tilde{A}_S}(u), h_{\tilde{A}_S}(u)) \,|u \in U \right\} \tag{15}$$

$$0 \leq \mu^2_{\tilde{A}_S}(u) + \nu^2_{\tilde{A}_S}(u) + h^2_{\tilde{A}_S}(u) \leq 1 \quad , \quad \forall_u \in U \tag{16}$$

In Eq. (17), these sets are shown with Quantum theory in which $\varsigma_{\mu_{\tilde{A}_S}}$, $\varsigma_{\nu_{\tilde{A}_S}}$, and $\varsigma_{h_{\tilde{A}_S}}$ refer to the degrees.

$$\left|\varsigma_{\tilde{A}_S}\right> = \left\{ \langle u, (\varsigma_{\mu_{\tilde{A}_S}}(u), \varsigma_{\nu_{\tilde{A}_S}}(u), \varsigma_{h_{\tilde{A}_S}}(u)) \,|u \in 2^{\left|\varsigma_{\tilde{A}_S}\right>} \right\} \tag{17}$$

Eqs. (18) and (19) indicate the formulization of these sets with phase angles and amplitude.

$$\varsigma = \left[\varsigma_\mu . e^{j2\pi.\alpha}, \varsigma_\nu . e^{j2\pi.\gamma}, \varsigma_h . e^{j2\pi.\beta}\right] \tag{18}$$

$$\varphi^2 = |\varsigma_\mu(|u_i>)| \tag{19}$$

Furthermore, in this model, these degrees are defined with golden ratio (G) [19]. In this framework, a and b refers to the large and small quantities in the straight line. Eqs. (20) and (21) define this condition.

$$G = \frac{a}{b} \tag{20}$$

$$G = \frac{1+\sqrt{5}}{2} = 1.618 \tag{21}$$

The amplitude of non-membership and hesitancy degrees with golden cut are given in Eqs. (22) and (23).

$$\varsigma_v = \frac{\varsigma_\mu}{G} \tag{22}$$

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_v \tag{23}$$

Eq. (24) denotes the phase angle of these sets.

$$\alpha = \left| \varsigma_\mu (|u_i >) \right| \tag{24}$$

The phase angle of non-member and hesitancy degrees are given in Eqs. (25) and (26).

$$\gamma = \frac{\alpha}{G} \tag{25}$$

$$\beta = 1 - \alpha - \gamma \tag{26}$$

The operations are detailed in Eqs. (27)-(30).

$$\lambda * \widetilde{A}_\varsigma = \left\{ \left(1-\left(1-\varsigma_{\mu_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(1-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}},\ \varsigma_{v_{\tilde{A}}}{}^\lambda e^{j2\pi\cdot\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^\lambda},\ \left(\left(1-\varsigma_{h_{\tilde{A}}}{}^2\right)^\lambda-\left(1-\varsigma_{\mu_{\tilde{A}}}{}^2-\varsigma_{h_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(1-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \right\}, \lambda > 0 \tag{27}$$

$$\widetilde{A}_\varsigma{}^\lambda = \left\{ \varsigma_{\mu_{\tilde{A}}}{}^\lambda e^{j2\pi\cdot\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^\lambda},\ \left(1-\left(1-\varsigma_{v_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(1-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}},\ \left(\left(1-\varsigma_{v_{\tilde{A}}}{}^2\right)^\lambda-\left(1-\varsigma_{v_{\tilde{A}}}{}^2-\varsigma_{h_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \right\}, \lambda > 0 \tag{28}$$

$$\widetilde{A}_\varsigma \oplus \widetilde{B}_\varsigma = \left\{ \left(\varsigma_{\mu_{\tilde{A}}}{}^2+\varsigma_{\mu_{\tilde{B}}}{}^2-\varsigma_{\mu_{\tilde{A}}}{}^2\varsigma_{\mu_{\tilde{B}}}{}^2\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2+\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}},\ \varsigma_{v_{\tilde{A}}}\varsigma_{v_{\tilde{B}}} e^{j2\pi\cdot\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)\right)},\ \left(\left(1-\varsigma_{\mu_{\tilde{B}}}{}^2\right)\varsigma_{h_{\tilde{A}}}{}^2+\left(1-\varsigma_{\mu_{\tilde{A}}}{}^2\right)\varsigma_{h_{\tilde{B}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2\varsigma_{h_{\tilde{B}}}{}^2\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(1-\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2+\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}} \right\} \tag{29}$$

$$\widetilde{A}_\varsigma \otimes \widetilde{B}_\varsigma = \left\{ \varsigma_{\mu_{\tilde{A}}}\varsigma_{\mu_{\tilde{B}}} e^{j2\pi\cdot\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)},\ \left(\varsigma_{v_{\tilde{A}}}{}^2+\varsigma_{v_{\tilde{B}}}{}^2-\varsigma_{v_{\tilde{A}}}{}^2\varsigma_{v_{\tilde{B}}}{}^2\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2+\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}},\ \left(\left(1-\varsigma_{v_{\tilde{B}}}{}^2\right)\varsigma_{h_{\tilde{A}}}{}^2+\left(1-\varsigma_{v_{\tilde{A}}}{}^2\right)\varsigma_{h_{\tilde{B}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2\varsigma_{h_{\tilde{B}}}{}^2\right)^{\frac{1}{2}} e^{j2\pi\cdot\left(\left(1-\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2+\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}} \right\} \tag{30}$$

Quantum spherical fuzzy sets are adopted to the M-SWARA methodology. SWARA is used to determine weights and evaluate when choosing between alternatives. First, criteria are determined for the use of this technique. A decision matrix is then created. The next step is to create a relationship matrix in which the relationships between the criteria are evaluated. Weights are calculated using the relations between the criteria and the decision matrix.

Step 2 of the proposed model includes the collection of the linguistic evaluations of decision makers for technology S-curve phases. Relation matrix is developed while using the evaluations of the experts as in Eq. (31).

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{31}$$

Step 3 determines the average values of quantum spherical fuzzy numbers for the phases Eq. (32) are used to compute aggregated values [15].

$$\varsigma = \left\{ \left[1-\prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi\cdot\left[1-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}, \prod_{i=1}^{k}\varsigma_{v_i}{}^{\frac{1}{k}} e^{2\pi\cdot\prod_{i=1}^{k}\left(\frac{\gamma_i}{2\pi}\right)^{\frac{1}{k}}}, \left[\prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}-\prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2-\varsigma_{h_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi\cdot\left[\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2-\left(\frac{\beta_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}} \right\} \tag{32}$$

Step 4 computes the score function of the phases for quantum spherical fuzzy sets. Defuzzification of the values are made with Eq. (33).

$$Def\varsigma_i = \varsigma_{\mu_i} + \left(\frac{\varsigma_{\mu_i}}{\varsigma_{\mu_i}+\varsigma_{h_i}+\varsigma_{v_i}}\right) + \left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\left(\frac{\alpha_i}{2\pi}\right)}{\left(\frac{\alpha_i}{2\pi}\right)+\left(\frac{\gamma_i}{2\pi}\right)+\left(\frac{\beta_i}{2\pi}\right)}\right) \tag{33}$$

Step 5 consists of normalization of the relation matrix. In *Step 6*, the values of s_j (importance ratio), k_j (coefficient), q_j (recalculated weight), and w_j (weight) are identified by Eqs. (34)-(36).

$$k_j = \begin{cases} 1 & j=1 \\ s_j+1 & j>1 \end{cases} \tag{34}$$

$$q_j = \begin{cases} 1 & j=1 \\ \frac{q_{j-1}}{k_j} & j>1 \end{cases} \tag{35}$$

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

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{36}$$

Step 7 is related to the construction of the relation matrix and the directions among the criteria by considering these values.

In *Step 8*, the stable matrix is created. Stable values are identified in the following stage by transposing and limiting the matrix to the power of 2 t+1. These values are used to calculate the impact-relation degrees.

3.4. The extension of TOPSIS

In the second stage of the proposed model, the renewable innovation investments with the two-generation service progress life cycle are ranked. In this process, TOPSIS technique is integrated to the quantum spherical fuzzy numbers. The TOPSIS method is used to rank the alternatives. This method ranks alternatives based on their similarity to ideal solutions [56]. TOPSIS technique is extended in this study by integrating with Quantum spherical fuzzy numbers [57].

Step 9 collects the linguistic evaluations of the renewable energy investments.

Step 10 constructs the decision combinations for two-generation innovation life cycle. Decision matrix is generated with the help of expert evaluations by Eq. (37).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{37}$$

Step 11 includes the selection of the best combinations for innovation life cycle patterns with the integer code series. *Step 12* defines the average technology S-curve values. *Step 13* is related to the computation of the score functions of the alternatives. The values are defuzzified in the following step. *Step 14* normalizes decision matrix. Then, the values are normalized by Eq. (38) [58].

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{38}$$

Step 15 focuses on the computation of the weighted decision matrix. Eq. (39) is considered to identify the weighted values.

$$v_{ij} = w_{ij} \times r_{ij} \tag{39}$$

Step 16 is related to the ranking of the alternatives. Eqs. (40) and (41) reefer to the calculations of the positive (A^+) and negative (A^-) ideal solutions.

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j} for \forall \quad j \in n\} \tag{40}$$

$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min v_{1j} for \forall \quad j \in n\} \tag{41}$$

The distances to the best (D_i^+) and worst alternatives (D_i^-) are determined with Eqs. (42) and (43).

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij}-A_j^+\right)^2} \tag{42}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij}-A_j^-\right)^2} \tag{43}$$

Eq. (44) shows the relative closeness to the ideal solutions (RC_i) that is used for ranking.

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{44}$$

3.5. The extension of VIKOR

In this study, a comparative ranking is also made with VIKOR technique. VIKOR is a method used to rank alternatives. This method makes a ranking by taking into consideration the preferences and sensitivities of the decision makers [59]. The fourth step includes the calculation of the best $\widetilde{f}_J^*$ and worst $\widetilde{f}_j^-$ values with Eq. (45) [60].

$$\widetilde{f}_J^* = \max_i \widetilde{x}_{ij}, \text{and} \widetilde{f}_j^- = \min_i \widetilde{x}_{ij} \tag{45}$$

Step 5: The mean group utility and maximal regret are identified by Eqs. (46) and (47) [61].

$$\widetilde{S}_i = \sum_{i=1}^{n} \widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)} \tag{46}$$

$$\widetilde{R}_i = \max_j \left[\widetilde{w}_j \frac{\left(\left|\widetilde{f}_j^* - \widetilde{x}_{ij}\right|\right)}{\left(\left|\widetilde{f}_j^* - \widetilde{f}_j^-\right|\right)}\right] \tag{47}$$

The alternatives are ranked while calculating $\widetilde{Q}_i$ values as given in Eq. (48).

$$\widetilde{Q}_i = v\left(\widetilde{S}_i - \widetilde{S}^*\right) / \left(\widetilde{S}^- - \widetilde{S}^*\right) + (1-v)\left(\widetilde{R}_i - \widetilde{R}^*\right) / \left(\widetilde{R}^- - \widetilde{R}^*\right) \tag{48}$$

3.6. Advantages of the proposed methodology

The methodology is structured in two distinct stages, providing a clear separation of processes. The first stage employs the FACS method for facial expression analysis, Integer patterns for mathematical operations, and Quantum Spherical Fuzzy M-SWARA for weighting the service progress life cycle. The second stage integrates TOPSIS and VIKOR techniques for ranking renewable innovation investments.

The criteria for selecting methods are driven by the need to comprehensively analyze the service progress life cycle. FACS is employed to account for the uncertainty and complexity introduced by expert hesitancy. Integer patterns bring a mathematical rigor to decision-making models. Quantum Spherical Fuzzy M-SWARA is chosen for its ability to handle uncertainties using quantum theory.

Advantages of the proposed methodology can be listed as

- The proposed methodology integrates facial expression analysis, mathematical patterns, and quantum fuzzy logic, providing a comprehensive approach to decision-making.
- Quantum Spherical Fuzzy M-SWARA is adept at handling uncertainties, crucial in decision-making processes where incomplete or conflicting information may exist.
- FACS addresses the hesitancy of experts in decision-making, ensuring a more nuanced and realistic evaluation.
- The methodology is relevant because it not only addresses the technical aspects of renewable innovation investments but also considers the human element through facial expression analysis. It acknowledges the uncertainties and hesitancies that often accompany decision-making processes.

However, the main advantages of comparative analysis using TOPSIS and VIKOR can be illustrated as follows

- TOPSIS excels in scenarios with multiple criteria, efficiently handling diverse factors that contribute to decision-making.
- TOPSIS also has the sensitivity to both positive (ideal) and negative (non-ideal) solutions, ensuring a comprehensive analysis of alternatives.
- Its straightforward nature enhances accessibility, making it an attractive choice for decision-makers seeking an interpretable and implementable method.
- The normalization step in TOPSIS ensures that criteria with different scales contribute proportionately.
- VIKOR allows for a flexible approach, considering not only the best-case scenario but also the worst-case scenario and the compromise solution.
- VIKOR strikes a balance between mean group utility and maximal regret, offering a sophisticated approach to decision analysis.
- The Q-Ratio in VIKOR provides a comprehensive measure, balancing the trade-offs between the best and worst-case scenarios.
- VIKOR is well-suited for group decision-making situations, where preferences may vary among decision makers.

The selection of TOPSIS and VIKOR for ranking alternatives is driven by their unique strengths and applicability to specific decision-making contexts. The robustness of TOPSIS in handling multiple criteria and the nuanced consideration of decision maker preferences in VIKOR contribute to their effectiveness in providing comprehensive and tailored rankings for decision-makers.

4. Analysis results

For analyzing the service progress life cycle of renewable energy innovation investments, a novel model is presented while integrating different approaches. Firstly, the service progress life cycle of renewable innovation investments is weighted. For this purpose, two-generation

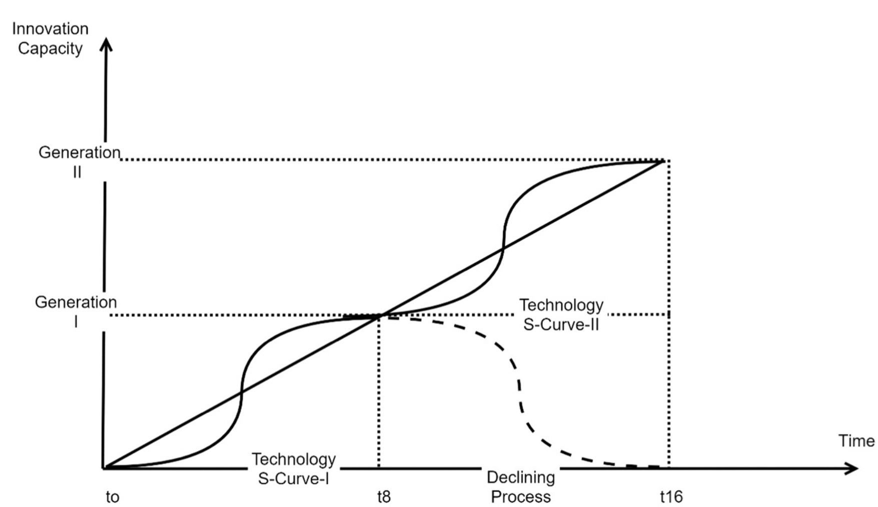

Fig. 2. Two-generation technology S-Curve with integer patterns.

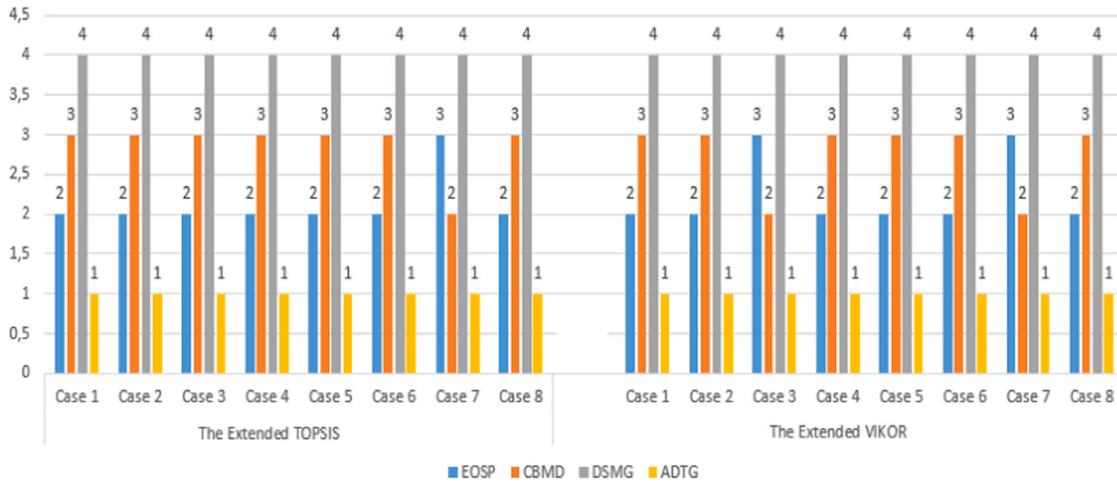

Fig. 3. Comparative ranking results with sensitivity analysis.

Table 1
Impact directions.

	EMP1	EMP2	GRP1	GRP2	MTP1	MTP2	AGP1	AGP2	Impact directions
EMP1		.134	.134	.151	.151	.134	.119	.176	EMP1→GRP2,MTP1,AGP2
EMP2	.197		.146	.115	.129	.170	.115	.129	EMP2→EMP1,GRP1,MTP2,
GRP1	.162	.186		.121	.099	.186	.138	.108	GRP1→EMP1,EMP2,MTP2
GRP2	.109	.185	.161		.123	.140	.097	.185	GRP2→EMP2,GRP1,AGP2
MTP1	.130	.116	.116	.116		.200	.148	.172	MTP1→MTP2,AGP1,AGP2
MTP2	.157	.181	.157	.122	.122		.122	.138	MTP2→EMP1,EMP2,GRP1
AGP1	.156	.123	.156	.138	.181	.110		.138	AGP1→EMP1,GRP1,MTP1
AGP2	.153	.135	.153	.153	.153	.135	.120		AGP2→EMP1,GRP1,GRP2,MTP1

Table 2
Stable Matrix.

	EMP1	EMP2	GRP1	GRP2	MTP1	MTP2	AGP1	AGP2
EMP1	.133	.133	.133	.133	.133	.133	.133	.133
EMP2	.132	.132	.132	.132	.132	.132	.132	.132
GRP1	.127	.127	.127	.127	.127	.127	.127	.127
GRP2	.116	.116	.116	.116	.116	.116	.116	.116
MTP1	.120	.120	.120	.120	.120	.120	.120	.120
MTP2	.134	.134	.134	.134	.134	.134	.134	.134
AGP1	.110	.110	.110	.110	.110	.110	.110	.110
AGP2	.130	.130	.130	.130	.130	.130	.130	.130

Table 3
Alternatives of the renewable innovation investments for the service progress life cycle.

Alternatives	Supported Literature
Efficiency of service process (EOSP)	[27]; [31]
Creative business models (CBMD)	[24]; [36]
Dynamic service management (DSMG)	[22]; [39]
Advanced technologies (ADTG)	[25]; [42]

technology S-Curve and facial action coding system-based Quantum Spherical fuzzy M-SWARA are considered. Secondly, the renewable innovation investment alternatives are ranked. During this process, the integer patterns and facial action coding system-based Quantum Spherical fuzzy TOPSIS are considered. The analysis results are presented based on each section.

4.1. Weighting the service progress life cycle of renewable innovation investments (Stage 1)

In *Step 1*, the service progress life cycle with two-generation technology S-curve for the renewable innovation investments is defined. First, the problem of service progress life cycle is defined for the renewable innovation investments. The patterns are illustrated in Fig. 2.

Two-generation technology S-Curve is a graphical representation of a technology that tracks its evolution over time, showing its diffusion rate and acceptance [20]. This concept refers to the evolution of technology in that it initially grows slowly, then spreads rapidly and eventually reaches saturation point. Two-generation refers to the spread of technology in two different generations [21]. The first generation emerges in the early stages of the technology's development process and has limited use and acceptance. The second generation, on the other hand, is widely adopted and disseminated at a more mature stage of the technology's development [22].

Two-generation technology S-Curve indicates that the rate of diffusion of technology changes over time. Initially, the rate of diffusion may be slow as the technology is new and unknown. However, as technology improves and users gain experience, the rate of spread accelerates. In the first-generation stage, the adoption and adoption of the technology may be limited. But in the second-generation phase, the technology is accepted and adopted by more users. In this period, the rate of spread increases and the technology is used by a wider user base. In Fig. 3, this situation is divided into 16 different time processes.

In *Step 2*, evaluations from three experts are obtained by using the values in Table A.1 in the Appendix part. These experts are the top managers in international renewable energy companies. They have worked on many different projects regarding the service progress life cycle of renewable energy innovation investments. Table A.2 gives information about the facial evaluations of these experts.

Step 3 includes the determination of the average values of quantum spherical fuzzy numbers for the phases. Average values are identified in Table A.3. In *Step 4*, score values are also defined in Table A.4. In *Step 5*, the values are normalized, and the results are presented in Table A.5. *Step 6* consists of the calculation of the significant values as in Table A.6. The relation matrix is created in *Step 7*, and the directions among the criteria are identified as in Table 1.

The threshold is computed as.143 and the directions are determined based on this assumption. It is determined that "Aging-Phase 2" is the most influencing stage in the service progress life cycle of renewable energy innovation investments. In *Step 8*, the weights of the service progress life cycle are calculated in Table 2.

Table 2 indicates that "Maturity-Phase 2" is the most critical stage of the service progress life cycle of the renewable energy investments. Two-generation technology S-Curve's maturity stage represents an important point in the development process of a technology. This stage refers to the period when the technology reaches the saturation point and the rate of diffusion slows down. At this stage, large-scale innovations or changes to technology usually occur less frequently. During the maturity phase, the development and optimization of technology becomes an important focus. Increased competition encourages technology providers to improve their existing products, increase their performance and reduce their costs. Customer feedback and market demands provide important guidance for improvements and innovations.

Emerging phases also play an important role in this respect. Two-generation technology S-Curve's emerging phase refers to the period in which a technology begins to evolve rapidly, and new markets are formed. This stage represents the potential and growth opportunities of a technology. In the emerging phase, new markets and application areas of technology are discovered. As technology is not yet widely adopted, many new opportunities and gaps may exist. During this period, technology providers can increase their growth potential by focusing on new customer segments and industries.

4.2. Ranking the renewable innovation investments with the two-generation service progress life cycle (Stage 2)

Step 9 is the collection of the evaluations for the alternatives. In this context, four different alternatives are selected. The details of them are denoted in Table 3.

Creative business models play an important role for effective service development in renewable energy investments. Business models define how businesses create value, generate revenue, and interact with their stakeholders. Creative business models create new sources of income in renewable energy investments. In addition to traditional sales models and energy production, income is diversified with different business models such as energy storage, energy management services, energy trading, energy data analytics. This increases the profitability of businesses and ensures sustainable growth.

In the development of effective services in renewable energy investments, service management should also be dynamic. Dynamic service management enables services to be managed effectively in an ever-changing and complex environment. The renewable energy industry is a rapidly changing industry. Dynamic service management adapts quickly to changing conditions and increases flexibility. Factors such as technological developments, regulatory changes or changes in market conditions may require reorganization or conversion of services. Dynamic service management reacts to these changes quickly and effectively.

On the other hand, the use of advanced technology in renewable energy investments is very important. Advanced technology can increase the efficiency of renewable energy systems. High efficiency increases the return on investment by providing more energy production and lower costs. The efficiency of the service process is very important for effective service development in renewable energy investments. Renewable energy projects are generally long-term investments and the return on investment can be substantial. Effective service processes ensure that the project is carried out on time and on budget. Efficient management of the service process accelerates project completion and reduces costs, thereby increasing return on investment. The scales and integer alphabet are given in Table A.7. The evaluations for the first generation are shown in Table A.8. Table A.9 states the evaluations for the second generation. Decision combinations are constructed in *Step 10* and presented in Tables A.10 and A.11. The best combinations are selected as follows in *Step 11*.

Combination 1:

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

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

$f^{[1]}(t_9,t_{12}) \neq 0$ for combination 1. It is identified that this combination is not suitable.

Combination 2:

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

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

$f^{[1]}(t_1,t_4)$ and $f^{[1]}(t_9,t_{12}) \neq 0$ at the level 2, the combinations cannot be calculated.

Combination 3:

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

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

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

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

Combination 3 is found convenient.

Combination 4:

At the level 1, $f^{[0]}(t_1,t_2) = (1)^0 - (2)^0 = 0$, $f^{[0]}(t_3,t_4) = (1)^0 -$

Table 4
Ranking the alternatives.

	D+	D+	RCi	Ranking
EOSP	.0070	.0085	.5492	2
CBMD	.0068	.0079	.5358	3
DSMG	.0077	.0079	.5048	4
ADTG	.0051	.0081	.6137	1

Table 5
Comparative results with sensitivity analysis.

The Extended TOPSIS								
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
EOSP	2	2	2	2	2	2	3	2
CBMD	3	3	3	3	3	3	2	3
DSMG	4	4	4	4	4	4	4	4
ADTG	1	1	1	1	1	1	1	1
The Extended VIKOR								
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
EOSP	2	2	3	2	2	2	3	2
CBMD	3	3	2	3	3	3	2	3
DSMG	4	4	4	4	4	4	4	4
ADTG	1	1	1	1	1	1	1	1

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

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

$f^{[1]}(t_1,t_4) \neq 0$. It is concluded that this combination is not suitable.

Necessary calculations are also made for the second generation of alternative 1. The details are indicated below.

Combination 1:

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

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

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

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

Combination 2:

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

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

$f^{[1]}(t_1,t_4) \neq 0$. This combination is not convenient.

Step 12 defines the average technology S-curve values. The computations are also employed for the first and the second-generation technology S-curves of other alternatives as detailed in Table A.12. Average technology S-curve values are calculated and given in Table A.13. *Step 13* computes the score functions of the alternatives. Table A.14 gives information about the score values. In *Step 14*, these values are normalized as in Table A.15. In *Step 15*, Weighted matrix is constructed in Table A.16. Alternatives are ranked in *Step 16* and the results are demonstrated in Table 4.

Advanced technologies are found as the best alternative of the renewable innovation investments for the service progress life cycle. Similarly, efficiency of the service process also plays a crucial role in this regard. Nonetheless, creative business models and dynamic service management have lower significance for this situation.

The proposed methodology integrates two-generation technology S-Curve and Quantum Spherical fuzzy M-SWARA for weighting, and Quantum Spherical fuzzy TOPSIS for ranking renewable innovation investments, involving a comprehensive evaluation process with expert input. Sensitivity analysis aims to assess the robustness and reliability of your proposed model by varying the weights of the criteria. The investigation involves altering the weighting scheme and observing its impact on the ranking of renewable innovation investment alternatives. Eight different cases are considered for sensitivity analysis, involving adjustments to the weights of criteria. This analysis is performed by iteratively changing the weights of the criteria and recalculating the rankings for each case. Similarly, the results are also presented using the Extended VIKOR method, providing rankings for each alternative across the eight sensitivity analysis cases. Comparative evaluation results are indicated in Table 5.

These results are also illustrated in Fig. 3.

The results of the sensitivity analysis are presented through the Extended TOPSIS method. The rankings for each alternative (EOSP, CBMD, DSMG, ADTG) are shown for eight different cases. Comparative evaluations are presented in Table 5, showcasing that both TOPSIS and VIKOR techniques yield similar results. Furthermore, the sensitivity analysis reaffirms the stability of the rankings across different weighting scenarios. The results of the sensitivity analysis are found to be consistent with the rankings obtained from the proposed model. This consistency reinforces the reliability and coherency of your model in providing robust findings. The sensitivity analysis conducted in this study provides a thorough investigation into the impact of varying criteria weights on the rankings of renewable innovation investment alternatives. The consistent findings across different cases strengthen the credibility of your proposed model and contribute to its reliability in decision-making for renewable energy investments.

5. Discussions

Maturity stage refers to the period when the technology reaches the saturation point, and the rate of diffusion slows down. A technology that has reached the maturity stage is generally considered a stable and mature stage. A broad understanding and experience have been gained about the basic operation and use of technology. At this stage, large-scale innovations or changes to technology usually occur less frequently. By the maturity stage, technology is generally widely accepted and used. Users recognize the benefits of technology and use it routinely in their daily lives. Technology saturation often means that a large portion of a market is adopting and using the technology. The maturity stage is a period when a technology takes place in a competitive market. Multiple players compete by offering similar or alternative solutions. At this stage, factors such as competitive pricing, service quality and customer satisfaction gain importance. Technology providers focus on innovation and value creation to meet customer needs and gain competitive advantage in the marketplace.

During the maturity stage, new technology-based innovation opportunities may arise. At this stage, new products and services can be developed, such as technology-based ancillary services, add-ons, or advanced versions. Two-generation technology S-Curve is a model that defines the development of renewable energy technologies. This model represents a curve in which renewable energy technologies progress slowly at first, then gain momentum and eventually reach saturation point. S-Curve's maturity stage marks the maturation period of the technology. Razzaq et al. [62] and Kukharets et al. [63] concluded that technologies increase in performance, decrease in costs, and become more widely adopted. This maturation period is important for effective service development because it enables more advanced and efficient services to be delivered. Oad et al. [64] and Cheng et al. [65] identified that the maturity phase increases growth opportunities in the renewable energy sector. Maturing technologies have the potential to gain more market share. This provides opportunities for effective service development and competitive advantage. Renewable energy investors can evaluate the growth potential in the market and expand their services at this stage.

Advanced technology is very important in the development of effective services in renewable energy investments. Advanced technology can increase the efficiency of renewable energy systems. High efficiency increases the return on investment by providing more energy production and lower costs. On the other hand, advanced technology increases the reliability and traceability of renewable energy systems. Especially in systems that generate electricity from variable energy sources such as wind and sun, the use of advanced technology makes energy production more predictable and manageable. This ensures that energy systems operate more reliably and stably. In renewable energy investments, advanced technology plays an important role in critical areas such as energy storage and integration of energy systems.

The development of energy storage technologies ensures the continued use of renewable energy and helps balance energy demand and supply. It also increases the flexibility of energy systems by enabling the integration of renewable energy systems with other energy sources. In addition to the points mentioned, the use of advanced technology can reduce the operating and maintenance costs of renewable energy systems [66]. Advanced technology supports continuous innovation in the renewable energy sector [67]. New materials, energy conversion technologies, energy management systems and other advanced technologies create new opportunities in the renewable energy sector and enable achieving sustainability goals. This significantly contributes to reducing operating costs and increasing system efficiency [68].

According to many researchers, it is important to provide advanced technologies to develop effective services in renewable energy investments. Sowby [69] stated that R&D activities are of great importance for the provision of advanced technologies in the renewable energy sector. Research centers, universities, private sector companies and government institutions can work for the development of innovative and advanced technologies. Yu et al. [70] determined that R&D activities contribute to the development of more efficient energy generation, storage, and distribution technologies. Pata et al. [71] concluded that collaborations and partnerships can be established to provide advanced technologies. Nemmour et al. [72] mentioned that it facilitates collaborations, technology transfer and knowledge sharing between renewable energy companies, technology providers, research institutions and other stakeholders. In this way, more advanced technologies can be used, and services can be improved. According to Kolte et al. [73], data analytics and artificial intelligence play a big role in providing advanced technologies. Teh and Rana [74] defined that big data analysis enables the development of more efficient and effective services by analyzing data on renewable energy production and consumption. Olabi et al. [75] explained that artificial intelligence and machine learning algorithms can be used in areas such as energy demand forecasting, energy efficiency optimization and automated management of energy systems.

6. Conclusions

This study aims to examine the service progress life cycle of renewable energy innovation investments. First, the service progress life cycle of renewable innovation investments is evaluated. Within this scope, two-generation technology S-curve and facial action coding system-based Quantum Spherical fuzzy M-SWARA are taken into consideration. In the second stage, the renewable innovation investment alternatives are ranked. Within this scope, the integer patterns and facial action coding system-based Quantum Spherical fuzzy TOPSIS are considered. Moreover, these investment alternatives are also ranked by using VIKOR technique to test the validity of the proposed model results. Additionally, a sensitivity analysis is conducted by considering 8 different cases so that coherency of the results can be tested. It is concluded that the same findings can be achieved by both TOPSIS and VIKOR techniques. Furthermore, sensitivity analysis also demonstrates the same rankings as well. It is understood that the proposed model provides coherent and reliable findings. The findings show that maturity is the most critical stage of the service progress life cycle of the renewable energy investments. Also, advanced technologies are found as the best alternative of the renewable innovation investments for the service progress life cycle.

By considering the analysis, it is strongly recommended that companies should priorly take action to increase the effectiveness of the maturity stage. During a product's maturity phase, revenues often slow down. At this stage, there is also a period in which competition becomes more intense. At this stage, businesses must maintain the competitive advantage of their products. In this context, it is of critical importance that the pricing strategy is effective. In this process, determining competitive prices contributes to increasing customer loyalty. On the other hand, at this stage, continuous improvements to the product are required. In this way, it is possible to attract customers' interest in the products. More effective advertising strategies also provide businesses with a significant competitive advantage. Moreover, providing quick responses to customer complaints is another issue that will increase customer satisfaction. Solving problems quickly helps products become more preferred. On the other hand, increasing technological investments in order to develop renewable energy innovations requires various strategies and policies. Research and development incentives significantly support especially innovative businesses. Similarly, the development of new financing models also contributes to the development of renewable energy projects.

The main contribution of this manuscript is the consideration of the FACS system to increase both the originality and effectiveness of the proposed model and the development of a new technique named M-SWARA. Additionally, conducting a priority evaluation helps to identify the efficient investment strategies to increase renewable energy innovation. In this study, renewable energy types are not discussed separately. On the contrary, the analysis was carried out by considering them in general. This issue can be considered as an important limitation of the study. Therefore, more specific projects such as wind and solar energy investments may be considered in future studies. In the analysis process of this study, the importance weights of the technology S-curve processes are determined. An examination can be made on the factors affecting the service quality of these projects. In this process, a comprehensive new model can be developed to make an effective analysis. The main limitation of the proposed model is that the evaluations of all experts are considered with equal weights. However, the quality of the experts can be different according to different demographic factors. Therefore, in the future studies, a novel model can be constructed in which the weights of the experts can be identified based on their qualifications.

CRediT authorship contribution statement

Hasan Dinçer: Methodology, Supervision, Writing – original draft, Writing – review & editing. **Serhat Yüksel:** Methodology, Supervision, Writing – original draft, Writing – review & editing. **Gang Kou:** Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Dragan Pamucar:** Supervision.

Declaration of Competing Interest

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

Data Availability

Data will be made available on request.

Appendix

See Tables A.1 and A.16.

Table A.1
Linguistic scales, facial action units, and golden cut-based quantum spherical fuzzy numbers

Emotions	AUs	Combinations of AUs	Scales for Criteria	Scales for Alternatives	Possibility Degrees	QASH
Contempt (Disdain)	7, 10, 14, 15	(7, 10), (7, 14), (7, 15), (10, 14), (10, 15), (14, 15)	No (n)	Weakest (w)	.40	$\begin{bmatrix} \sqrt{.16}\, e^{j2\pi..4}, \\ \sqrt{.10}\, e^{j2\pi..25}, \\ \sqrt{.74}\, e^{j2\pi..35} \end{bmatrix}$
Intermediate Emotion	1 AU of Contempt +1 AU of Surprise	(7, 1), (7, 2), (7, 5), (7, 27), (10, 1), (10, 2), (10, 5), (10, 27), (14, 1), (14, 2), (14, 5), (14, 27), (15, 1), (15, 2), (15, 5), (15, 27)	some (s)	Poor (p)	.45	$\begin{bmatrix} \sqrt{.20}\, e^{j2\pi..45}, \\ \sqrt{.13}\, e^{j2\pi..28}, \\ \sqrt{.67}\, e^{j2\pi..27} \end{bmatrix}$
Surprise	1, 2, 5, 27 1 AU of Contempt +1 AU of Happy	(1, 2), (1, 5), (1, 27), (2, 5), (2, 27), (5, 27) (7, 6), (7, 12), (7, 25), (7, 26), (10, 6), (10, 12), (10, 25), (10, 26), (14, 6), (14, 12), (14, 25), (14, 26), (15, 6), (15, 12), (15, 25), (15, 26)	medium (m)	Fair (f)	.50	$\begin{bmatrix} \sqrt{.25}\, e^{j2\pi..50}, \\ \sqrt{.15}\, e^{j2\pi..31}, \\ \sqrt{.60}\, e^{j2\pi..19} \end{bmatrix}$
Intermediate Emotion	1 AU of Surprise +1 AU of Happy	(1, 6), (1, 12), (1, 25), (1, 26), (2, 6), (2, 12), (2, 25), (2, 26), (5, 6), (5, 12), (5, 25), (5, 26), (27, 6), (27, 12), (27, 25), (27, 26)	high (h)	Good (g)	.55	$\begin{bmatrix} \sqrt{.30}\, e^{j2\pi..55}, \\ \sqrt{.19}\, e^{j2\pi..34}, \\ \sqrt{.51}\, e^{j2\pi..11} \end{bmatrix}$
Happiness	6, 12, 25, 26	(6, 12), (6, 25), (6, 26), (12, 25), (12, 26), (25, 26)	very high (vh)	Best (b)	.60	$\begin{bmatrix} \sqrt{.36}\, e^{j2\pi..6}, \\ \sqrt{.22}\, e^{j2\pi..37}, \\ \sqrt{.42}\, e^{j2\pi..03} \end{bmatrix}$

Table A.2
Facial evaluations

DM 1								
	Emerging- 1 (EMP1)	**Emerging- 2 (EMP2)**	**Growth- 1 (GRP1)**	**Growth- 2 (GRP2)**	**Maturity- 1 (MTP1)**	**Maturity- 2 (MTP2)**	**Aging- 1 (AGP1)**	**Aging- 2 (AGP2)**
EMP1		(7, 2)	(7, 5)	(5, 26)	(27, 26)	(15, 2)	(15, 2)	(25, 26)
EMP2	(25, 26)		(27, 26)	(7, 5)	(15, 25)	(6, 12)	(7, 2)	(15, 12)
GRP1	(27, 26)	(25, 26)		(27, 26)	(10, 14)	(25, 26)	(27, 26)	(14, 1)
GRP2	(10, 14)	(5, 26)	(5, 26)		(15, 12)	(6, 25)	(14, 1)	(5, 26)
MTP1	(15, 12)	(7, 5)	(7, 5)	(7, 2)		(6, 12)	(27, 26)	(6, 25)
MTP2	(15, 25)	(27, 26)	(15, 25)	(7, 2)	(7, 2)		(14, 1)	(7, 2)
AGP1	(27, 26)	(7, 5)	(27, 26)	(15, 12)	(25, 26)	(10, 14)		(15, 25)
AGP2	(5, 26)	(15, 12)	(5, 26)	(5, 26)	(27, 26)	(15, 12)	(15, 25)	
DM 2								
	EMP1	**EMP2**	**GRP1**	**GRP2**	**MTP1**	**MTP2**	**AGP1**	**AGP2**
EMP1		(15, 12)	(15, 25)	(5, 26)	(5, 26)	(15, 12)	(7, 2)	(15, 12)
EMP2	(15, 12)		(27, 26)	(7, 2)	(15, 25)	(25, 26)	(14, 1)	(15, 25)
GRP1	(27, 26)	(25, 26)		(5, 26)	(10, 15)	(6, 12)	(27, 26)	(10, 5)
GRP2	(15, 25)	(27, 26)	(5, 26)		(15, 12)	(15, 25)	(10, 5)	(27, 26)
MTP1	(15, 12)	(7, 2)	(7, 2)	(7, 2)		(25, 26)	(27, 26)	(15, 25)
MTP2	(15, 6)	(5, 26)	(15, 25)	(10, 5)	(10, 5)		(10, 5)	(15, 25)
AGP1	(27, 26)	(14, 1)	(27, 26)	(10, 5)	(25, 26)	(15, 12)		(15, 25)
AGP2	(5, 26)	(15, 25)	(5, 26)	(27, 26)	(27, 26)	(15, 25)	(7, 2)	
DM 3								
	EMP1	**EMP2**	**GRP1**	**GRP2**	**MTP1**	**MTP2**	**AGP1**	**AGP2**
EMP1		(14, 1)	(7, 2)	(27, 26)	(27, 26)	(14, 1)	(14, 1)	(25, 26)
EMP2	(25, 26)		(27, 26)	(10, 5)	(10, 5)	(10, 5)	(7, 2)	(7, 2)
GRP1	(27, 26)	(6, 12)		(15, 6)	(10, 15)	(6, 12)	(27, 26)	(14, 1)
GRP2	(15, 25)	(27, 26)	(15, 25)		(15, 25)	(14, 1)	(14, 1)	(5, 26)
MTP1	(15, 25)	(7, 2)	(14, 1)	(7, 2)		(6, 25)	(5, 26)	(25, 26)
MTP2	(15, 12)	(27, 26)	(15, 12)	(7, 2)	(14, 1)		(7, 2)	(7, 2)

(continued on next page)

Table A.2 (*continued*)

DM 1	Emerging- 1 (EMP1)	Emerging- 2 (EMP2)	Growth- 1 (GRP1)	Growth- 2 (GRP2)	Maturity- 1 (MTP1)	Maturity- 2 (MTP2)	Aging- 1 (AGP1)	Aging- 2 (AGP2)
AGP1	(27, 26)	(10, 5)	(27, 26)	(15, 25)	(25, 26)	(10, 15)		(10, 5)
AGP2	(5, 26)	(15, 25)	(5, 26)	(5, 26)	(27, 26)	(15, 25)	(10, 5)	

Table A.3
Average values

	EMP1	EMP2	GRP1	GRP2
EMP1		$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$	$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$
EMP2	$\left[\sqrt{.33}e^{j2\pi..57},\sqrt{.20}e^{j2\pi..35},\sqrt{.49}e^{j2\pi..11}\right]$		$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$
GRP1	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.36}e^{j2\pi..60},\sqrt{.22}e^{j2\pi..37},\sqrt{.42}e^{j2\pi..03}\right]$		$\left[\sqrt{.29}e^{j2\pi..53},\sqrt{.18}e^{j2\pi..33},\sqrt{.54}e^{j2\pi..14}\right]$
GRP2	$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.29}e^{j2\pi..53},\sqrt{.18}e^{j2\pi..33},\sqrt{.54}e^{j2\pi..14}\right]$	
MTP1	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$
MTP2	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$
AGP1	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.24}e^{j2\pi..48},\sqrt{.14}e^{j2\pi..30},\sqrt{.62}e^{j2\pi..22}\right]$
AGP2	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$

	MTP1	MTP2	AGP1	AGP2
EMP1	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.33}e^{j2\pi..57},\sqrt{.20}e^{j2\pi..35},\sqrt{.49}e^{j2\pi..11}\right]$
EMP2	$\left[\sqrt{.24}e^{j2\pi..48},\sqrt{.14}e^{j2\pi..30},\sqrt{.62}e^{j2\pi..22}\right]$	$\left[\sqrt{.32}e^{j2\pi..56},\sqrt{.18}e^{j2\pi..34},\sqrt{.52}e^{j2\pi..15}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.24}e^{j2\pi..48},\sqrt{.14}e^{j2\pi..30},\sqrt{.62}e^{j2\pi..22}\right]$
GRP1	$\left[\sqrt{.16}e^{j2\pi..40},\sqrt{.10}e^{j2\pi..25},\sqrt{.74}e^{j2\pi..35}\right]$	$\left[\sqrt{.36}e^{j2\pi..60},\sqrt{.22}e^{j2\pi..37},\sqrt{.42}e^{j2\pi..03}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$
GRP2	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.28}e^{j2\pi..52},\sqrt{.16}e^{j2\pi..32},\sqrt{.58}e^{j2\pi..19}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$
MTP1		$\left[\sqrt{.36}e^{j2\pi..60},\sqrt{.22}e^{j2\pi..37},\sqrt{.42}e^{j2\pi..03}\right]$	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.33}e^{j2\pi..57},\sqrt{.20}e^{j2\pi..35},\sqrt{.49}e^{j2\pi..11}\right]$
MTP2	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$		$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$	$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$
AGP1	$\left[\sqrt{.36}e^{j2\pi..60},\sqrt{.22}e^{j2\pi..37},\sqrt{.42}e^{j2\pi..03}\right]$	$\left[\sqrt{.20}e^{j2\pi..45},\sqrt{.13}e^{j2\pi..28},\sqrt{.67}e^{j2\pi..27}\right]$		$\left[\sqrt{.24}e^{j2\pi..48},\sqrt{.14}e^{j2\pi..30},\sqrt{.62}e^{j2\pi..22}\right]$
AGP2	$\left[\sqrt{.30}e^{j2\pi..55},\sqrt{.19}e^{j2\pi..34},\sqrt{.51}e^{j2\pi..11}\right]$	$\left[\sqrt{.25}e^{j2\pi..50},\sqrt{.15}e^{j2\pi..31},\sqrt{.60}e^{j2\pi..19}\right]$	$\left[\sqrt{.22}e^{j2\pi..47},\sqrt{.13}e^{j2\pi..29},\sqrt{.65}e^{j2\pi..25}\right]$	

Table A.4
Score values

	EMP1	EMP2	GRP1	GRP2	MTP1	MTP2	AGP1	AGP2
EMP1	.000	1.373	1.373	1.705	1.705	1.373	1.305	1.778
EMP2	1.778	.000	1.705	1.305	1.437	1.720	1.305	1.437
GRP1	1.705	1.920	.000	1.638	1.120	1.920	1.705	1.305
GRP2	1.382	1.705	1.638	.000	1.500	1.588	1.305	1.705
MTP1	1.500	1.305	1.305	1.305	.000	1.920	1.705	1.778
MTP2	1.500	1.705	1.500	1.305	1.305	.000	1.305	1.373
AGP1	1.705	1.305	1.705	1.437	1.920	1.258	.000	1.437
AGP2	1.705	1.500	1.705	1.705	1.705	1.500	1.373	.000

Table A.5
Normalized matrix

	EMP1	EMP2	GRP1	GRP2	MTP1	MTP2	AGP1	AGP2
EMP1	.000	.129	.129	.161	.161	.129	.123	.168
EMP2	.166	.000	.160	.122	.134	.161	.122	.134
GRP1	.151	.170	.000	.145	.099	.170	.151	.115
GRP2	.128	.158	.151	.000	.139	.147	.121	.158
MTP1	.139	.121	.121	.121	.000	.177	.158	.164
MTP2	.150	.171	.150	.131	.131	.000	.131	.137
AGP1	.158	.121	.158	.133	.178	.117	.000	.133
AGP2	.152	.134	.152	.152	.152	.134	.123	.000

Table A.6
Sj, kj, qj, and wj values

EMP1	Sj	Kj	qj	wj	EMP2	Sj	Kj	qj	Wj
AGP2	.168	1.000	1.000	.176	EMP1	.166	1.000	1.000	.197
GRP2	.161	1.161	.862	.151	MTP2	.161	1.161	.861	.170
MTP1	.161	1.161	.862	.151	GRP1	.160	1.160	.743	.146
EMP2	.129	1.129	.763	.134	MTP1	.134	1.134	.655	.129
GRP1	.129	1.129	.763	.134	AGP2	.134	1.134	.655	.129
MTP2	.129	1.129	.763	.134	GRP2	.122	1.122	.584	.115
AGP1	.123	1.123	.679	.119	AGP1	.122	1.122	.584	.115
GRP1	**Sj**	**kj**	**qj**	**wj**	**GRP2**	**Sj**	**Kj**	**qj**	**Wj**
EMP2	.170	1.000	1.000	.186	EMP2	.158	1.000	1.000	.185
MTP2	.170	1.000	1.000	.186	AGP2	.158	1.158	1.000	.185
EMP1	.151	1.151	.869	.162	GRP1	.151	1.151	.869	.161
AGP1	.151	1.151	.743	.138	MTP2	.147	1.147	.757	.140
GRP2	.145	1.145	.649	.121	MTP1	.139	1.139	.665	.123
AGP2	.115	1.115	.582	.108	EMP1	.128	1.128	.590	.109
MTP1	.099	1.099	.529	.099	AGP1	.121	1.121	.526	.097
MTP1	**Sj**	**kj**	**qj**	**wj**	**MTP2**	**Sj**	**Kj**	**qj**	**Wj**
MTP2	.177	1.000	1.000	.200	EMP2	.171	1.000	1.000	.181
AGP2	.164	1.164	.859	.172	EMP1	.150	1.150	.869	.157
AGP1	.158	1.158	.742	.148	GRP1	.150	1.150	.869	.157
EMP1	.139	1.139	.652	.130	AGP2	.137	1.137	.764	.138
EMP2	.121	1.121	.581	.116	GRP2	.131	1.131	.676	.122
GRP1	.121	1.121	.581	.116	MTP1	.131	1.131	.676	.122
GRP2	.121	1.121	.581	.116	AGP1	.131	1.131	.676	.122
AGP1	**Sj**	**kj**	**qj**	**wj**	**AGP2**	**Sj**	**Kj**	**qj**	**Wj**
MTP1	.178	1.000	1.000	.181	EMP1	.152	1.000	1.000	.153
EMP1	.158	1.158	.863	.156	GRP1	.152	1.152	1.000	.153
GRP1	.158	1.158	.863	.156	GRP2	.152	1.152	1.000	.153
GRP2	.133	1.133	.762	.138	MTP1	.152	1.152	1.000	.153
AGP2	.133	1.133	.762	.138	EMP2	.134	1.134	.882	.135
EMP2	.121	1.121	.679	.123	MTP2	.134	1.134	.882	.135
MTP2	.117	1.117	.608	.110	AGP1	.123	1.123	.785	.120

Table A.7
Scales and alphabets

Emotion Scales	Integer Alphabet
Contempt	-2
Intermediate Emotion (Contempt-Surprise)	-1
Surprise	0
Intermediate Emotion (Surprise-Happiness)	+1
Happiness	+2

Table A.8
Evaluations with the facial expressions of decision makers for alternative 1 (First Generation)

Periods	Phases (P)	Time (T)	DM1	DM2	DM3
Emerging	P1	T1	(27, 25)	(6, 12)	(5, 26)
	P2	T2	(14, 15)	(10, 14)	(10, 14)
Growth	P1	T3	(27, 25)	(27, 25)	(27, 12)
	P2	T4	(14, 15)	(10, 15)	(10, 14)
Maturity	P1	T5	(6, 12)	(6, 12)	(6, 25)

(*continued on next page*)

Table A.8 (*continued*)

Periods	Phases (P)	Time (T)	DM1	DM2	DM3
	P2	T6	(15, 5)	(15, 2)	(15, 5)
Aging	P1	T7	(5, 26)	(27, 25)	(27, 25)
	P2	T8	(10, 15)	(14, 15)	(10, 14)
Declining-I	P1	T9	(27, 25)	(27, 12)	(27, 12)
	P2	T10	(14, 27)	(15, 5)	(15, 2)
Declining-II	P1	T11	(6, 12)	(27, 12)	(6, 12)
	P2	T12	(15, 5)	(15, 5)	(15, 5)
Declining-III	P1	T13	(6, 25)	(6, 12)	(6, 25)
	P2	T14	(10, 15)	(14, 15)	(10, 14)
Declining-IV	P1	T15	(25, 26)	(25, 26)	(6, 12)
	P2	T16	(14, 15)	(14, 15)	(14, 15)

Table A.9
Evaluations with the facial expressions of decision makers for alternative 1 (Second Generation)

Periods	Phases (P)	Time (T)	DM1	DM2	DM3
Emerging	P1	T1	(27, 12)	(6, 12)	(6, 25)
	P2	T2	(14, 15)	(10, 15)	(10, 14)
Growth	P1	T3	(5, 26)	(27, 12)	(5, 26)
	P2	T4	(15, 5)	(15, 5)	(15, 5)
Maturity	P1	T5	(6, 12)	(6, 12)	(6, 12)
	P2	T6	(15, 2)	(15, 5)	(14, 27)
Aging	P1	T7	(5, 26)	(27, 25)	(27, 12)
	P2	T8	(10, 15)	(14, 15)	(14, 15)
Declining-I	P1	T9	(27, 25)	(27, 25)	(5, 26)
	P2	T10	(15, 5)	(15, 2)	(15, 2)
Declining-II	P1	T11	(27, 12)	(27, 25)	(5, 26)
	P2	T12	(15, 5)	(15, 5)	(15, 2)
Declining-III	P1	T13	(6, 25)	(6, 12)	(6, 25)
	P2	T14	(14, 15)	(10, 15)	(14, 15)
Declining-IV	P1	T15	(6, 12)	(6, 12)	(6, 12)
	P2	T16	(10, 15)	(14, 15)	(10, 14)

Table A.10
Decision Combinations of Alternative 1 for First Generation Technology S-Curve

	T1	T2	T3	T4	T5	T6	T7	T8
CMBT 1	Happiness	Contempt	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
CMBT 2	Intermediate Emotion (Surprise-Happiness)	Contempt	Intermediate Emotion (Surprise-Happiness)	Contempt	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
CMBT 3	Happiness	Contempt	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
CMBT 4	Intermediate Emotion (Surprise-Happiness)	Contempt	Intermediate Emotion (Surprise-Happiness)	Contempt	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
	T9	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**
CMBT 1	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt
CMBT 2	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt
CMBT 3	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt
CMBT 4	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt

Table A.11
Decision Combinations of alternative 1 for Second Generation Technology S-Curve

	T1	T2	T3	T4	T5	T6	T7	T8
CMBT 1	Happiness	Contempt	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
CMBT 2	Intermediate Emotion (Surprise-Happiness)	Contempt	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Contempt
	T9	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**	**T16**
CMBT 3	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt
CMBT 4	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Contempt-Surprise)	Happiness	Contempt	Happiness	Contempt

Table A.12
Combinations

Items				Combination Set	Alternatives			
Generation	Periods	P	T		EOSP	CBMD	DSMG	ADTG
First Generation	Emerging	P1	T1	CMBT 1	Happiness	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)
		P2	T2		Contempt	Contempt	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)
	Growth	P1	T3		Intermediate Emotion (Surprise-Happiness)	Happiness	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)
		P2	T4		Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)
	Maturity	P1	T5		Happiness	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)
		P2	T6		Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)
	Aging	P1	T7		Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)
		P2	T8		Contempt	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)
Second Generation	Emerging	P1	T9	CMBT 2	Happiness	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Happiness
		P2	T10		Contempt	Intermediate Emotion (Contempt-Surprise)	Contempt	Contempt
	Growth	P1	T11		Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Happiness	Happiness
		P2	T12		Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Contempt
	Maturity	P1	T13		Happiness	Happiness	Intermediate Emotion (Surprise-Happiness)	Happiness
		P2	T14		Intermediate Emotion (Contempt-Surprise)	Contempt	Intermediate Emotion (Contempt-Surprise)	Contempt
	Aging	P1	T15		Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)	Intermediate Emotion (Surprise-Happiness)
		P2	T16		Contempt	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)	Intermediate Emotion (Contempt-Surprise)

Table A.13
Average technology S-curve values of the alternatives

	EOSP	CBMD	DSMG	ADTG
T1	$\begin{bmatrix} \sqrt{.36}\, e^{j2\pi..60}, \\ \sqrt{.22}\, e^{j2\pi..37}, \\ \sqrt{.04}\, e^{j2\pi..16} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.30}\, e^{j2\pi..55}, \\ \sqrt{.19}\, e^{j2\pi..34}, \\ \sqrt{.10}\, e^{j2\pi..13} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.30}\, e^{j2\pi..55}, \\ \sqrt{.19}\, e^{j2\pi..34}, \\ \sqrt{.10}\, e^{j2\pi..13} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.33}\, e^{j2\pi..58}, \\ \sqrt{.20}\, e^{j2\pi..36}, \\ \sqrt{.07}\, e^{j2\pi..15} \end{bmatrix}$
T2	$\begin{bmatrix} \sqrt{.16}\, e^{j2\pi..40}, \\ \sqrt{.10}\, e^{j2\pi..25}, \\ \sqrt{.32}\, e^{j2\pi..01} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.18}\, e^{j2\pi..43}, \\ \sqrt{.11}\, e^{j2\pi..26}, \\ \sqrt{.29}\, e^{j2\pi..03} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.18}\, e^{j2\pi..43}, \\ \sqrt{.11}\, e^{j2\pi..26}, \\ \sqrt{.29}\, e^{j2\pi..03} \end{bmatrix}$	$\begin{bmatrix} \sqrt{.18}\, e^{j2\pi..43}, \\ \sqrt{.11}\, e^{j2\pi..26}, \\ \sqrt{.29}\, e^{j2\pi..03} \end{bmatrix}$

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Table A.13 (*continued*)

	EOSP	CBMD	DSMG	ADTG
T3	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$	$\left[\sqrt{.33}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..36}, \sqrt{.07}\,e^{j2\pi..15}\right]$	$\left[\sqrt{.33}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..36}, \sqrt{.07}\,e^{j2\pi..15}\right]$	$\left[\sqrt{.33}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..36}, \sqrt{.07}\,e^{j2\pi..15}\right]$
T4	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.18}\,e^{j2\pi..43}, \sqrt{.11}\,e^{j2\pi..26}, \sqrt{.29}\,e^{j2\pi..03}\right]$
T5	$\left[\sqrt{.36}\,e^{j2\pi..60}, \sqrt{.22}\,e^{j2\pi..37}, \sqrt{.04}\,e^{j2\pi..16}\right]$	$\left[\sqrt{.33}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..36}, \sqrt{.07}\,e^{j2\pi..15}\right]$	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$	$\left[\sqrt{.33}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..36}, \sqrt{.07}\,e^{j2\pi..15}\right]$
T6	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.18}\,e^{j2\pi..43}, \sqrt{.11}\,e^{j2\pi..26}, \sqrt{.29}\,e^{j2\pi..03}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.18}\,e^{j2\pi..43}, \sqrt{.11}\,e^{j2\pi..26}, \sqrt{.29}\,e^{j2\pi..03}\right]$
T7	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$	$\left[\sqrt{.30}\,e^{j2\pi..55}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.10}\,e^{j2\pi..13}\right]$
T8	$\left[\sqrt{.16}\,e^{j2\pi..40}, \sqrt{.10}\,e^{j2\pi..25}, \sqrt{.32}\,e^{j2\pi..01}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$	$\left[\sqrt{.20}\,e^{j2\pi..45}, \sqrt{.13}\,e^{j2\pi..28}, \sqrt{.25}\,e^{j2\pi..05}\right]$

Table A.14
Score function of the alternatives

	T1	T2	T3	T4	T5	T6	T7	T8
EOSP	2.073	1.448	1.902	1.581	2.073	1.581	1.902	1.448
CBMD	1.902	1.517	1.993	1.581	1.993	1.517	1.902	1.581
DSMG	1.902	1.517	1.993	1.581	1.902	1.581	1.902	1.581
ADTG	1.993	1.517	1.993	1.517	1.993	1.517	1.902	1.581

Table A.15
Normalized matrix

	T1	T2	T3	T4	T5	T6	T7	T8
EOSP	.527	.483	.483	.505	.521	.510	.500	.467
CBMD	.483	.506	.506	.505	.500	.490	.500	.510
DSMG	.483	.506	.506	.505	.478	.510	.500	.510
ADTG	.506	.506	.506	.485	.500	.490	.500	.510

Table A.16
Weighted matrix

	T1	T2	T3	T4	T5	T6	T7	T8
EOSP	.070	.064	.061	.058	.062	.068	.055	.061
CBMD	.064	.067	.064	.058	.060	.065	.055	.066
DSMG	.064	.067	.064	.058	.057	.068	.055	.066
ADTG	.067	.067	.064	.056	.060	.065	.055	.066

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