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An integrated expert recommender system approach to environmental service priorities in renewable energy

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Serhat Yüksel[1,2,*], **Hasan Dinçer**[1,2,3], **Ümit Hacıoğlu**[3], **Jaehyung An**[4] **and Alexey Mikhaylov**[5,*]

[1] The School of Business, İstanbul Medipol University, İstanbul, Turkey
[2] Department of Economics and Management, Khazar University, Baku, Azerbaijan
[3] School of Business, Ibn Haldun University, Istanbul, Turkey
[4] College of Business, Hankuk University of Foreign Studies, Seoul, Republic of Korea
[5] Financial University under the Government of the Russian Federation, Moscow, Russia
[*] Authors to whom any correspondence should be addressed.

E-mail: serhatyuksel@medipol.edu.tr, hdincer@medipol.edu.tr, umit.hacioglu@ihu.edu.tr, jaehyung.an@hufs.ac.kr and mikhayloff0@gmail.com

Keywords: clean energy, energy project, service design, fuzzy logic

Abstract

The purpose of this study is to analyze the investment success of renewable energy generation projects design. A novel model has been constructed for this purpose. At the first stage, collaborative filtering methodology is taken into consideration to complete missing evaluations. After that, M-SWARA based on QUSFSs with golden cut is used to compute the weights of these factors. Finally, the components of the service design are ranked by TOPSIS approach. The main contribution of the paper is that a new methodology (M-SWARA) has been created in this study by making improvements to SWARA. With the help of this new model, causal directions between the indicators can also be examined. Similarly, collaborative filtering methodology is taken into consideration to complete missing evaluations. In this process, the decision makers are allowed to leave the questions they wanted blank. This situation is considered as the superiority of the proposed model compared to many previous models in the literature. The findings indicate that cost is the most significant factor for the success of renewable energy investments because it gets the highest weight (.261). The ranking results also demonstrate that product is the most essential component of the service design of renewable energy investments. Therefore, solving the high-cost problem is of vital importance to increase these investments. First, renewable energy companies can reduce costs with more effective financial management. To carry out this process effectively, a finance department consisting of qualified personnel is needed. Thanks to this team, current situations in the financial markets will be better followed and this will play an important role in reducing costs.

1. Introduction

Renewable energy projects contribute to the development of the country in many ways. First, thanks to these types of energy, countries can be independent in terms of energy. This situation can help countries to increase both their economic and political power. Furthermore, thanks to renewable energy projects, the carbon emission problem can be reduced to minimum levels. In this way, it will be possible to reduce environmental pollution. Due to these vital benefits, countries are trying to increase their renewable energy investments (Bastian-Pinto *et al* 2021, Tugcu and Menegaki 2024). On the other hand, some problems hinder the increase of these investments. In this process, the high cost of investments is one of the most prominent disadvantages. As the high cost negatively affects the profit margin of the projects, the interest of the investors in these investments decreases. On the other hand, the amount of electricity generation in renewable energy projects may experience imbalances due to climatic conditions (Cohen *et al* 2021). Therefore, the need for energy storage arises, which leads to an increase in already high costs.

For the purpose of minimizing these problems, renewable energy generation projects need to be designed effectively. To achieve success in this process, it is important to pay attention to some different issues. Energy companies should determine the priorities in their investment targets. For example, if these companies aim to serve micro-scale companies, they can focus on small-scale solar panels and wind turbines (Wang *et al* 2023). In this way, it will be possible to serve a large number of small-scale companies with this energy produced. Additionally, the risk tolerance levels and appropriate ass*et al*location should be diversified effectively (Menyeh 2021). In this framework, the balance between liquidity and profitability should be provided by the energy companies. Otherwise, the risk of bankruptcy arises for companies that cannot effectively manage their liquidity risk.

Cost effectiveness is another issue that should be taken into consideration for the effectiveness of the renewable energy generation projects design. The high cost of renewable energy projects is considered one of the biggest disadvantages. Therefore, reducing the costs in these projects to reasonable levels is important for the sustainability of the projects (Kozlova and Lohrmann 2021). In this context, the financial resources needed for the investments to be made should be provided at the lowest possible cost. Otherwise, the long-term success of these projects will not be very possible. In addition, the budgeting of projects needs to be done comprehensively. In this way, imbalances that may occur in cash flows can be detected early. In this way, necessary measures can be taken before the negative effects of the problems become too great.

In summary, many different factors can affect the success of renewable energy generation projects design. On the other hand, all measures to improve these factors lead to an increase in the costs of energy companies. Therefore, it is not financially reasonable for companies to apply all of these measures in the same sense (Ofori *et al* 2021). Therefore, it is vital to determine the more important factors among the factors that affect the success of the service design. Energy companies can use their budgets to improve more important factors. In this way, the success of renewable energy generation projects design will be ensured without incurring very high costs (Tsao *et al* 2021). In other words, there is a serious need to make a priority analysis among these factors.

In this study, it is aimed to analyze the investment success of renewable energy generation projects design. In other words, the main research question is to define key indicators to improve the service design for renewable energy projects so that clean energy consumption can be increased. A novel model has been constructed for this purpose. First, collaborative filtering methodology is taken into consideration to complete missing evaluations. Secondly, M-SWARA based on QUSFSs with golden cut is used to compute the weights of these factors. Finally, the components of the service design are ranked by TOPSIS approach. The main motivation of this study is the necessity for a detailed evaluation to create appropriate strategies for the effectiveness of the renewable energy generation projects design. Decision-making models can be considered to satisfy this issue. However, there are some criticisms regarding the existing models (Jebadurai *et al* 2024, Lestari *et al* 2024). In this new model, these criticisms should be overcome so that uncertainties can be minimized.

The main theoretical contribution of the paper to the literature is that prior investment strategies can be identified to improve the performance of renewable energy generation projects design. The most critical factors for renewable energy generation projects design are identified in this study. A priority analysis can be conducted with the help of this analysis. This situation helps to present specific investment strategies to renewable energy companies. In other words, the results obtained in this study have guidelines for both policy makers and investors. Hence, it can be more possible to increase clean energy investments. This situation is applied while establishing a novel model. The main superiorities of this proposed model are detailed below. (i) An original decision-making model has been constructed in this study. A new methodology (M-SWARA) has been created in this study by making improvements to SWARA so that causal directions between the indicators can also be examined. This situation is accepted as the main superiority of this model over classical SWARA technique (Pandey and Khurana 2024, Seikh and Chatterjee 2024). There may also be a causal relationship between the factors affecting the success of renewable energy generation projects design. For example, budgeting can be done more successfully thanks to the effective management of costs. Therefore, it is essential to consider the causality relationship to create effective strategies. Therefore, it is understood that the M-SWARA technique is an optimal approach for the subject of this study. (ii) Another important issue in the creation of fuzzy logic-based decision-making models is how the degrees are calculated. In this study, the golden ratio is taken into consideration in the calculation of the degrees. Firstly, this contributes strongly to the originality of the developed model. In addition, by considering the golden ratio, uncertainties in the decision-making processes can be overcome more successfully. This situation provides a significant advantage to this model over the previously generated ones (Bose *et al* 2024, Ma *et al* 2024) (iii) Integration of quantum theory and Spherical fuzzy sets is another factor that increases the originality of the model. Thanks to quantum theory, conditions within different possibilities can be taken into consideration. This allows the reliability of the obtained results to be tested. In addition, hesitancy condition can be examined by means of Spherical fuzzy sets. Thus, it is possible for the obtained results to be more consistent by comparing with other sets (Hussain *et al* 2024, Thakur *et al* 2024). (iv) Collaborative filtering methodology is taken into consideration to complete missing evaluations. One of the most important problems in decision-making analysis is the risk that the knowledge of experts to evaluate all questions is not sufficient. On the other hand, in most of the decision-making models created, experts are expected to give their opinions on all questions. In this situation, experts have to give an answer even if they do not have full knowledge of some issues. This situation harms the accuracy of the analysis results. In the model created in this study, the decision makers were allowed to leave the questions they wanted blank. This situation is considered to be the superiority of the proposed model compared to many previous models in the literature.

The paper is organized as follows. Section 2 explains the details of the literature review. Methodology is demonstrated in section 3. Analysis results are denoted in section 4. Discussions and conclusions are detailed in sections 5 and 6.

2. Literature review

There are many studies in the literature on the factors affecting the renewable energy generation projects design. As a result of the literature review, it is understood that some of these factors come to the fore. In some of the studies, it is emphasized that cost-effectiveness is very important to increase the performance of renewable energy generation projects design. Pastore *et al* (2022) stated that high investment costs are one of the most important problems of renewable energy projects. Sharmila *et al* (2022) emphasized that this situation increases the anxiety of investors towards these projects. Therefore, the costs of renewable energy generation projects to be developed should be reasonable. Otherwise, it is not possible for these investments to be successful in the long term (Blázquez *et al* 2022). According to Yap *et al* (2022) and Fikru and Kilinc-Ata (2024), a financial analysis department consisting of qualified personnel should be established in renewable energy companies. Thanks to this department, it will be possible to obtain the financial resources required for investments at the lowest possible cost. Fan *et al* (2022) and Laimon and Yusaf (2024) determined that innovative financial products also need to be considered for the cost effectiveness of renewable energy investments. He *et al* (2022) concluded that thanks to innovative financial products such as crowdfunding, it becomes possible for renewable energy companies to reach a large number of investors in different geographies. This contributes significantly to bringing the costs to a reasonable level.

Some researchers emphasize that technological development is necessary for the success of renewable energy generation projects design investments. Haldar and Sethi (2022) identified that for these projects to be sustainable, it is vital that their profitability is high. Otherwise, these projects will not attract the attention of investors and it will be very difficult to develop clean energy projects. Krupnik *et al* (2022) stated that technological developments contribute significantly to the cost-effectiveness of these projects. According to Lee *et al* (2022), thanks to new applications, it is possible to produce the same amount of electricity at a lower cost. This helps to increase the profitability of the projects. Suki *et al* (2022) and Belyak *et al* (2024) claimed that a comprehensive research and development department should be established in renewable energy companies. This department should both conduct research on new technologies and follow up-to-date practices on these issues around the world. According to Ibrahim *et al* (2022) and Elahi *et al* (2022), it is also important to quickly implement some new applications for renewable energy technologies. Thirunavukkarasu *et al* (2022) and Lawal *et al* (2024) identified that thanks to microgrid energy management systems, the costs in renewable energy projects are shared by many different segments. This situation helps to increase clean energy projects as it increases the cost effectiveness of these investments. Liu *et al* (2022) and Bojnec *et al* (2024) concluded that owing to distributed energy applications, it is possible to reduce renewable energy logistics costs.

Ensuring customer satisfaction also plays a very important role in the success of the design investment of renewable energy generation projects. Therefore, this issue should be taken into consideration in new products and services to be developed. Otherwise, customer expectations will not be met, and it will be very difficult for projects to be successful in the long run (Khan *et al* 2022). Tempesta *et al* (2022), Islam *et al* (2024) and Van Quyen and Duc (2022) concluded that organic solar panels can be considered for customers who are very phase sensitive to environmental issues. Although these products produce less electricity, they will help satisfy customers who care more about environmental impact (Zahid *et al* 2022). Appadurai and Raj (2022) claimed that renewable energy companies that want to appeal to smaller customers can also manufacture small-scale wind turbines or solar panels. In this way, it will be possible to meet the expectations of many customers. This will contribute significantly to the success of the developed renewable energy generation projects.

Staff quality also plays a key role in the success of the renewable energy generation projects. Eti (2022) explained that significant engineering knowledge is needed to create renewable energy projects effectively. Yi-Chia *et al* (2022) identified that it is very important for these companies to employ qualified personnel. Otherwise, it will be very difficult for the new product to be developed to attract the attention of customers. This will lead to a decrease in the long-term performance of investments. Xin *et al* (2022) concluded that renewable energy companies should contribute to their development by providing certain training to their personnel. It is especially important that the personnel who use technology and perform financial analysis complete the necessary training for the development of their knowledge. Sun and Xu (2021) and Khurshid *et al* (2024) stated that renewable energy companies need to provide high income opportunities for their personnel working in critical departments. Otherwise, qualified personnel will leave the company, which will lead to a decrease in the success of their investments.

Based on the literature evaluations, it is possible to reach some important points. The details of these conclusions are demonstrated below. The popularity of the renewable energy generation projects design has increased especially in the last years. Most of the studies in the literature focused on the key indicators that affect the success of renewable energy generation projects investments. There is a necessity of a priority analysis for these indicators because it is not financially reasonable for companies to apply all these measures in the same sense. However, there are limited studies in the literature which focused on the more significant indicators of the success of these investments. As a result, there is a need for a new study that makes evaluation with the aim of finding the most critical indicators of the success of renewable energy generation projects investments. By considering these points, in this study, a priority analysis is made for the indicators that have an influence on the investment success of renewable energy generation projects design with a new model. Hence, it is aimed to satisfy this missing part in the literature.

3. Methodology

Quantum theory considers different probabilities in the analysis process so that it gives an opportunity to solve the problems more effectively. The amplitude (φ^2) and the phase angle items (θ) are used in this theory. This situation helps to handle uncertainties more successfully (Zadeh and Shahbazian 2011). Additionally, the set of collective events is represented by ς. Equations (1)–(3) in the appendix part indicate the details of this theory. On the other hand, different fuzzy sets were introduced in the literature to reach better solutions for the problems. *Spherical fuzzy sets* $(\tilde{A}_S)$ are generated for this purpose. The main superiority of these sets is considering hesitancy situation in the analysis process. The main requirement is that the squared sum of membership, non-membership, and hesitancy parameters (μ, ν, π) can get values between '0' and '1' (Kutlu Gündoğdu and Kahraman 2019). Equations (4) and (5) demonstrate these sets. In this study, quantum theory is integrated with spherical fuzzy sets by equations (6)–(8). Another critical issue in these sets is the way of calculating the degrees. Golden ratio (G) is taken into consideration in this proposed model where small and large quantities are given by a and b. The operations of G are stated in equation (9)–(19) in which γ and β refer to the non-member and hesitancy degrees.

SWARA was introduced for the aim of weighting different factors. In the examination process, hierarchical priorities of the expert team are taken into consideration. In this proposed model, SWARA is extended so that both weights of the factors and causal directions can be identified. This new technique is named by *M-SWARA*.

Step 1: In the first stage, evaluations are obtained from the experts.

Step 2: Next, relation matrix (ς_k), aggregated values (ς) and defuzzified values $(Def\varsigma)$ are computed by equations (20)–(22).

Step 3: In the following stage, s_j (significance rate), k_j (coefficient value), q_j (recalculated weight) and w_j (weights) are identified with equations (23)–(25).

Step 4: In addition, with the help of limiting and transposing the matrix by the power of 2t+1, stable values are defined.

Step 5: Finally, weights are calculated, and impact directions are identified.

Yoon and Hwang (1981) introduced *TOPSIS* for the aim of ranking alternatives. Negative and positive ideal solutions are considered at the same time which is accepted as the main superiority of this technique. This methodology is extended with QUSFSs in this proposed model (Candila *et al* 2021, An *et al* 2020, Mikhaylov 2023).

Step 1: Evaluations are taken for the expert team in the first stage.

Step 2: Decision matrix (X) is constructed by equation (26).

Step 3: Next, defuzzification and normalization steps are applied with equation (27).

Step 4: Weighted values (v), positive and negative $(A^+,\ A^-)$ best solutions, distances $(D_i^+,\ D_i^-)$ and relative closeness (RC_i) are computed with equations (28)–(33).

Step 5: These values are considered to identify both weights and causal relations.

One of the biggest difficulties encountered in decision-making processes is the issues that are not evaluated by experts. Although the expert team has the necessary knowledge on this subject, these people may lack knowledge of some issues. In this context, experts may not have a clear idea about the questions in which some

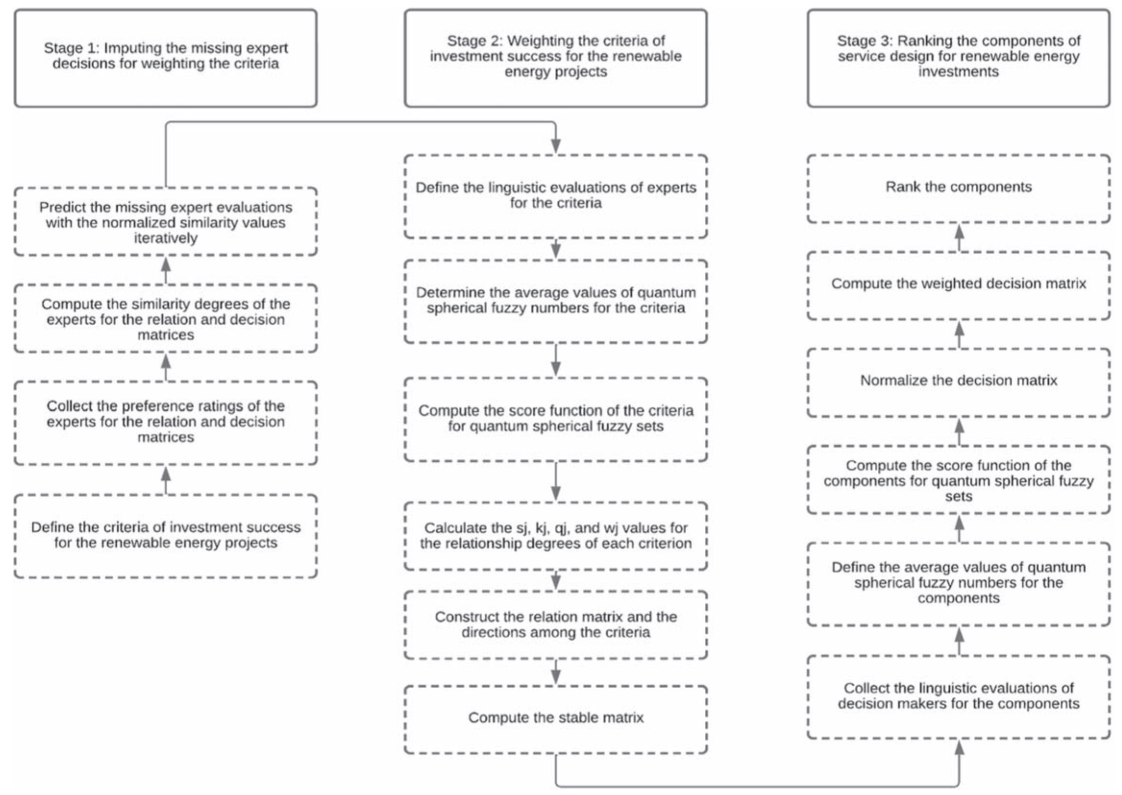

Figure 1. Algorithm of proposed model.

criteria are compared with each other. In this case, some evaluations will be missing. *Collaborative filtering* technique helps to predict this missing information. In this framework, similarity ($sim(u,\ v)$) and prediction indices ($p_{u,i}$) are taken into consideration as in equations (34) and (35).

In this study, it is aimed to analyze the investment success of renewable energy generation projects design. A novel model has been constructed for this issue. Figure 1 demonstrates the stages of this model.

The proposed model has three different stages. Firstly, missing evaluations are defined. In this process, the following steps are considered (Yu *et al* 2024, Zhang *et al* 2024a, Zhang *et al* 2024b, Zhang *et al* 2024c, Zheng *et al* 2024).

Step 1: Criteria are defined.

Step 2: Evaluations are taken.

Step 3: Similarity degrees are computed.

Step 4: Missing evaluations are predicted.

The second stage is related to the criteria weighting. Steps 5–10 are implemented in this stage and are detailed below.

Step 5: Evaluations are obtained.

Step 6: Average values are determined.

Step 7: Score values are identified.

Step 8: Significant values are computed.

Step 9: Relation matrix is created.

Step 10: Stable matrix is computed.

The final stage includes the ranking of the components of the service design. In this scope, steps 11–16 are considered.

Step 11: Evaluations are taken for the components.

Step 12: Average values are determined.

Step 13: Score values are identified.

Step 14: Normalization is applied.

Step 15: Weighted matrix is constructed.

Step 16: Components are ranked.

Table 1. Selected criteria of investment success.

Criteria	Supported literature
Goals (GAS)	Assi *et al* (2021), Wang *et al* (2020)
Diversification (DFC)	Khan *et al* (2021), Liu *et al* (2022)
Cost (CST)	Suki *et al* (2022), Krupnik *et al* (2022)
Monitoring (MNR)	He *et al* (2022), Blázquez *et al* (2022)

Table 2. Selected components of service design for renewable energy investments.

Components	Supported literature
People (PEE)	Elahi *et al* (2022)
Product (POU)	Thirunavukkarasu *et al* (2022), Pastore *et al* (2022)
Process (POE)	Sharmila *et al* (2022), Yap *et al* (2022)
Partners (PTN)	Koohi-Fayegh and Rosen (2020), Yap *et al* (2022)

4. Results

The results are indicated based on each stage of the proposed model.

4.1. Imputing the missing expert decisions for weighting the criteria (Stage 1)

In *Step 1*, the criteria of investment success for the renewable energy projects are defined by considering similar studies in the literature. Table 1 gives information about these indicators.

Firstly, for the success of green energy projects, the investment goals should be defined with clear and measurable tools. It is possible to talk about different investment targets for renewable energy projects. For example, solar energy investments can be implemented on a large or small scale. Similarly, wind energy investments can be made on land or on the sea. In this context, for these projects to be successful, businesses need to determine the priorities in their investment targets. In addition, diversification refers to the constructing the risk tolerance levels and appropriate asset allocation. In this context, businesses need to balance between liquidity and profitability. Among the risk diversification strategies in renewable energy projects, counterparty credit risks have an important place. This risk is the risk of the counterparty not being able to fulfill its financial obligations in the agreement. Energy purchase agreements constitute a significant portion of the revenues of renewable energy projects. Therefore, the risk of the counterparty not being able to fulfill its financial obligations directly affects the financial stability of the project. In this context, Markowitz Portfolio Theory is a very important and effective tool for risk diversification in renewable energy projects. This theory basically considers the correlations between the assets in the portfolio. It expresses how the risk can be minimized and how the return can be optimized based on this correlation. In renewable energy projects, diversification can be made between different energy sources. This situation contributes significantly to the reduction of the total portfolio risk. Companies that unconsciously direct all their assets to business investments for the sole purpose of profitability may face a liquidity problem. Likewise, the profitability of companies that do not allocate any resources to investments to minimize the liquidity risk may decrease. In summary, it is vital for companies to strike a balance between these two issues (Jiang *et al* 2024; Kang *et al* 2024; Li *et al* 2024a, 2024b; Liao *et al* 2023).

Minimizing the initial and operational expenses at an optimal cost level is another key issue for the success of these investments. The high investment costs are considered to be the most important disadvantage of renewable energy projects. Therefore, businesses need to take actions to minimize their investment costs. In this framework, all existing alternatives should be evaluated comprehensively to effectively provide the funds that businesses need for investment. In addition, current technological developments should be followed actively. Finally, monitoring also plays a significant role in the performance improvements of these projects. For this purpose, periodical reports should be provided for the feedback of capital budgeting. Regular inspections are also required during this process. In this way, it is possible to detect a potential problem related to investments early. This contributes significantly to increasing the performance of investments. On the other hand, selected components of service design for renewable energy investments are also demonstrated in table 2 (Shi *et al* 2023, Wang *et al* 2023, Liu *et al* 2024, Lu 2024, Xinyu *et al* 2024).

The first component of service design is people in which the customer expectations are considered for service improvement of renewables. Customers' expectations from these investments can take many different forms.

Table 3. Weights and the impact directions.

	GAS	DFC	CST	MNR	Impact directions
GAS	.235	.235	.235	.235	GAS → MNR
DFC	.246	.246	.246	.246	DFC → CST
CST	.261	.261	.261	.261	CST → DFC
MNR	.258	.258	.258	.258	MNR → GAS

Table 4. Ranking results of the components.

Components	D+	D-	RCi	Ranking
PEE	.005	.005	.513	2
POU	.005	.006	.582	1
POE	.007	.003	.304	3
PTN	.006	.002	.250	4

While uninterrupted electricity supply is important for some customers, other customers may consider the importance given to the environment more. In this context, the basic expectations of the main target audience should be determined first. In this way, it is much more possible to produce the right investment strategies. Moreover, with respect to the product component, it is very significant to design renewable technologies with smart equipment and systems. For example, it is possible to use efficient energy sources thanks to smart grids. Smart meters are used in these networks. This allows the electrical power to be regulated, controlled, and distributed more successfully. Furthermore, the applicable service development process of new renewable tools should be presented. In this context, it is necessary to provide creative ideas for new service development. In this process, the views of employees, suppliers and customers should be used. After that, the efficiency of the investment project should be evaluated with an effective cost-benefit analysis. Then, a final check should be made before the developed product is put on the market. In the last process, criticisms of the service launched on the market should be obtained and improvements should be made in the design of the service. Finally, regarding the component of partner, the technical requirements of the suppliers and other third parties for the sustainable service presentations in energy industry should be taken into consideration.

In *Step 2*, evaluations are taken from the expert team that consists of six decision makers (PSRs) who hold senior management positions in the product management department of international energy companies. These people have educational backgrounds at least at master's level. Experts have 27–36 years of work experience. Thanks to this extensive experience in energy investments, it has been concluded that they can make effective evaluations regarding the criteria. Questions are derived from the criteria and alternatives selected as a result of the literature review. Each of these questions is asked to experts. During this process, online interviews last at least 2 h with each expert. The expert team takes into consideration the values in table A1 in their evaluations. Preference ratings for the factors and components are given in tables A2 and A3. Similarity degrees are computed in *Step 3* (tables A4 and A5) and missing evaluations are predicted in *Step 4* (tables A6 and A7) (Guo *et al* 2023, He *et al* 2023, Bao *et al* 2024, Chen *et al* 2024, Cheng *et al* 2024).

4.2. Weighting the criteria of investment success (Stage 2)

In *Step 5*, evaluations are obtained as in table A8. *Step 6* is related to the identification of average values (table A9) whereas *Step 7* includes the creation of score values (table A10). In *Step 8*, significant values are computed (table A11) and relation matrix is created in *Step 9* (table A12). The normalized values of the score function for the relation matrix are considered to construct the Sj values. Stable matrix is computed in *Step 10*. Impact directions and weighing results are indicated in table 3.

The average value of the relation matrix is considered as a threshold value and the higher value than the threshold is assumed that the criterion at the row has an impact on the criterion at the column of the relation matrix. Accordingly, the threshold is computed as .33 and the directions are determined based on this assumption. It is seen that there is a mutual relationship between cost and diversification. Similarly, this relationship has also occurred between goals and monitoring. Additionally, based on the stable matrix values, it is understood that cost is the most significant factor for the success of renewable energy investments because it gets the highest weight (.261). Moreover, monitoring is the second key issue in this regard with the weight of .258. In spite of many different significant advantages, renewable energy projects have some drawbacks, such as high initial investment costs. Weighting results of this study indicate that companies should mainly focus on the actions to minimize the costs. In this scope, while companies aim to find funds for the investments in an effective manner, all existing alternatives should be evaluated comprehensively. Similarly, current technological developments should be adopted directly to the companies that can have a powerful contribution to the cost minimization. For this purpose, a new department can be generated in the renewable energy companies that makes both research and development activities and follow current technologies in the world.

4.3. Ranking the components of service design (Stage 3)

In *Step 11*, evaluations are taken for the components (table A13). *Step 12* gives information about the average values (table A14) while Score values are identified in *Step 13* (table A15). Normalization is applied in *Step 14* (table A16) and weighted matrix is constructed regarding *Step 15* (table A17). Components are ranked in *Step 16*. The details of the ranking results are demonstrated in table 4.

It is concluded that product is the most essential component of the service design of renewable energy investments. Process and people are also other important components for this situation. However, patterns are less significant than other components. The results indicate that it is very significant to design renewable technologies with smart equipment and systems. Within this framework, smart grids help to use energy in a more efficient way. In these networks, smart meters are taken into consideration. With the help of this situation, regulations can be adopted more effectively to the electricity generation. Similarly, the generated energy can be distributed to the necessary regions more successfully. All these issues have a positive influence on the success of the renewable energy investment projects.

5. Discussion

Although renewable energy projects provide benefits to countries in many respects, the high-cost problem is an obstacle to the development of these projects. The low profit margin of these projects compared to fossil fuels causes investors not to turn to these investments. Therefore, solving the high-cost problem is of vital importance to increase these investments. Countries are also looking for solutions to manage this problem. In this process, two different solutions come to the fore. First, renewable energy companies can reduce costs with more effective financial management. In this context, it is necessary to conduct extensive research to obtain the funds that companies need at the lowest possible cost. In this process, innovative financial products should also be considered. In this way, it will be possible to obtain the funds needed for investment both at lower cost and in a fast and safe manner. To carry out this process effectively, a finance department consisting of qualified personnel is needed. Thanks to this team, current situations in the financial markets will be better followed and this will play an important role in reducing costs.

The importance of this issue has been emphasized by many different researchers in literature. Khan *et al* (2021), Assi *et al* (2021) and Wang *et al* (2020) also focused on the ways to increase the effectiveness of the clean energy investments. It is identified that innovative financial products should be generated for this purpose. With the help of these products, it can be much easier to minimize costs.

Another way to minimize the cost is focusing on research and development activities. Thanks to new technologies, it is possible to obtain clean energy at a lower cost. For example, thanks to the new solar panel modules to be developed, it is possible to obtain more electricity from the sun's rays. This will increase efficiency and allow the costs to be reduced. In addition, energy storage processes are also issues that create additional costs for renewable energy investments. However, it is possible that this process can be carried out more effectively thanks to developing technologies. Therefore, energy investment companies need to follow up-to-date technologies. In this context, it is very important to establish a competent research and development department within the company. Thanks to this department, up-to-date technologies will be monitored instantly, and these applications will be implemented in the company in a timely manner. Thus, it will be possible to minimize the investment costs.

The necessity of this issue has been underlined in many studies. Adedoyin *et al* (2020) tried to define the critical issues to transit from non-renewable to renewable energy. In this study, European Union countries were examined. It is identified that technological improvements play a crucial role in this condition. Tabrizian (2019) also defined that technological innovation is quite necessary to achieve sustainable development. It is emphasized that thanks to technological innovation, investment costs of the renewable energy projects can be decreased. Koohi-Fayegh and Rosen (2020) also stated that effective energy storage applications have a positive influence on the cost effectiveness.

In this study, it is also found that renewable technologies should be designed with smart equipment and systems. For this purpose, it is quite important to implement smart grid technologies. With respect to these technologies, smart meters are taken into consideration. This technology helps to regulate energy production in a more effective way. In addition to this issue, this energy can also be distributed to the related regions more successfully. Hence, the performance of the energy investment projects can be improved. Muzumdar *et al*

(2021), Calise *et al* (2021) and Baza *et al* (2019) also underlined the significance of smart grid energy systems for the cost minimization of clean energy investments.

6. Conclusion

In this study, it is aimed to analyze the investment success of renewable energy generation projects design with a novel model. By considering similar studies in the literature, the criteria of investment success for renewable energy projects are selected. It is understood that cost is the most significant factor for the success of renewable energy investments. Moreover, monitoring is the second key issue in this regard. Having high initial investment costs is accepted as one of the most significant disadvantages of the renewable energy projects. The analysis results denote that companies should mainly focus on the actions to handle this problem. On the other hand, four different components of service design for renewable energy investments are selected. Regarding the ranking results, it is identified that that product is the most essential component of the service design of renewable energy investments. Process and people are also other important components for this situation. It is concluded that renewable technologies should be designed with smart equipment and systems. This situation has a positive impact on the success of the renewable energy investment projects.

It is possible to implement some policies and strategies to manage and combat the high-cost problem in renewable energy projects more effectively. Tax reductions offered for renewable energy investments can be implemented to achieve this goal. On the other hand, financial support to be provided by the state to these projects also contributes significantly to reducing costs. Moreover, joint financing methods also support the solution of the cost problem of these projects. In this context, public and private sector collaborations can provide more effective financing for renewable energy projects. In addition to them, increasing research and development projects is also necessary for more effective cost management in these projects. Technological developments can be made possible thanks to these research projects. This also helps to reduce operational costs. Furthermore, collaborations between universities and the private sector should be increased. This also contributes significantly to the development of innovative solutions.

With the help of this analysis, a priority analysis can be conducted, and this situation helps to present specific investment strategies to renewable energy companies. Hence, it can be more possible to increase clean energy investments. On the other hand, renewable energy investments are discussed in general in this study. This is considered as one of the most important limitations of the study. In this framework, it would be appropriate to conduct specific analyzes for renewable energy types in new studies. It is possible that the degree of importance of the criteria for clean energy types such as solar energy or wind energy may differ. Thanks to the new analysis, it is possible to detect the existence of these differences. There are also some limitations about the proposed model. For example, it will be possible to compare the results obtained thanks to the analyzes with different techniques. This situation will help test the consistency of the results. Moreover, in this model, decision matrix is established by taking the average of all expert assessments. However, these experts can have different qualifications. Hence, for the following models, the weights of these experts can be calculated.

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Data availability statement

The data cannot be made publicly available upon publication because they are not available in a format that is sufficiently accessible or reusable by other researchers. The data that support the findings of this study are available upon reasonable request from the authors.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of supporting data

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Appendix

$$Q(|u\rangle) = \varphi e^{j\theta} \tag{1}$$

$$|\varsigma\rangle = \{|u_1\rangle, |u_2\rangle, \ldots, |u_n\rangle\} \tag{2}$$

$$\sum_{|u\rangle \subseteq |\varsigma\rangle} |Q(|u\rangle)| = 1 \tag{3}$$

$$\tilde{A}_S = \{\langle u, (\mu_{\tilde{A}_S}(u), v_{\tilde{A}_S}(u), h_{\tilde{A}_S}(u)) |\, u \in U\} \tag{4}$$

$$0 \leqslant \mu^2_{\tilde{A}_S}(u) + v^2_{\tilde{A}_S}(u) + h^2_{\tilde{A}_S}(u) \leqslant 1, \forall_u \in U \tag{5}$$

$$|\varsigma_{\tilde{A}_S}> = \{\langle u, (\varsigma_{\mu_{\tilde{A}_S}}(u), \varsigma_{v_{\tilde{A}_S}}(u), \varsigma_{h_{\tilde{A}_S}}(u)) |\, u \in 2^{|\varsigma_{\tilde{A}_S}>}\} \tag{6}$$

$$\varsigma = [\varsigma_\mu . e^{j2\pi.\alpha}, \varsigma_v . e^{j2\pi.\gamma}, \varsigma_h . e^{j2\pi.\beta}] \tag{7}$$

$$\varphi^2 = |\varsigma_\mu(|u_i\rangle)| \tag{8}$$

$$G = \frac{a}{b} \tag{9}$$

$$G = \frac{1 + \sqrt{5}}{2} = 1.618\ldots \tag{10}$$

Table A1. Linguistic scales and golden cut-based QUSFSs.

Factors	Components	Possibility degrees	Preference numbers	QUSFSs
no (N)	lowest (OE)	.40	1	$[\sqrt{.16}\, e^{j2\pi..4}, \sqrt{.10}\, e^{j2\pi..25}, \sqrt{.74}\, e^{j2\pi..35}]$
low (LW)	bad (BD)	.45	2	$[\sqrt{.20}\, e^{j2\pi..45}, \sqrt{.13}\, e^{j2\pi..28}, \sqrt{.67}\, e^{j2\pi..27}]$
standard (ST)	normal (RL)	.50	3	$[\sqrt{.25}\, e^{j2\pi..50}, \sqrt{.15}\, e^{j2\pi..31}, \sqrt{.60}\, e^{j2\pi..19}]$
powerful (PL)	successful (SF)	.55	4	$[\sqrt{.30}\, e^{j2\pi..55}, \sqrt{.19}\, e^{j2\pi..34}, \sqrt{.51}\, e^{j2\pi..11}]$
perfect (PF)	wonderful (DF)	.60	5	$[\sqrt{.36}\, e^{j2\pi..6}, \sqrt{.22}\, e^{j2\pi..37}, \sqrt{.42}\, e^{j2\pi..03}]$

Table A2. The preference ratings for factors.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
GAS- DFC	4	4	n/a	3	4	n/a
GAS- CST	n/a	3	4	4	n/a	n/a
GAS- MNR	3	n/a	n/a	3	n/a	2
DFC- GAS	5	n/a	5	n/a	5	5
DFC- CST	n/a	3	n/a	3	5	n/a
DFC- MNR	3	n/a	3	2	n/a	4
CST- GAS	n/a	3	n/a	4	3	n/a
CST- DFC	2	n/a	4	n/a	4	n/a
CST- MNR	n/a	3	5	n/a	4	4
MNR- GAS	n/a	5	2	4	n/a	n/a
MNR- DFC	4	n/a	n/a	4	4	5
MNR- CST	5	4	n/a	n/a	2	5

Table A3. The preference ratings of the components.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
GAS-PEE	5	n/a	n/a	4	2	5
GAS- POU	3	4	n/a	2	3	n/a
GAS- POE	n/a	4	3	n/a	4	3
GAS- PTN	n/a	n/a	4	3	5	n/a
DFC- PEE	3	4	n/a	4	n/a	2
DFC- POU	n/a	n/a	4	3	n/a	4
DFC- POE	3	3	n/a	5	n/a	4
DFC- PTN	2	4	3	n/a	3	n/a
CST- PEE	4	n/a	n/a	4	2	3
CST- POU	n/a	4	2	n/a	5	5
CST- POE	n/a	n/a	n/a	2	5	5
CST- PTN	n/a	2	3	4	n/a	4
MNR- PEE	5	n/a	4	n/a	3	4
MNR- POU	n/a	n/a	n/a	4	5	2
MNR- POE	3	4	3	n/a	n/a	3
MNR- PTN	3	n/a	n/a	3	4	5

Table A4. Similarity matrix of factors.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
PSR 1	1.00	.13	.25	.25	−.15	.59
PSR 2	.13	1.00	−.67	.06	−.19	.08
PSR 3	.25	−.67	1.00	.02	.22	.17
PSR 4	.25	.06	.02	1.00	−.18	.26
PSR 5	−.15	−.19	.22	−.18	1.00	−.09
PSR 6	.59	.08	.17	.26	−.09	1.00

Table A5. Similarity matrix of components.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
PSR 1	1.00	−.14	.31	.13	−.33	.21
PSR 2	−.14	1.00	−.09	−.38	.00	−.17
PSR 3	.31	−.09	1.00	−.15	−.15	−.12
PSR 4	.13	−.38	−.15	1.00	−.24	−.33
PSR 5	−.33	.00	−.15	−.24	1.00	.00
PSR 6	.21	−.17	−.12	−.33	.00	1.00

$$\varsigma_\nu = \frac{\varsigma_\mu}{G} \tag{11}$$

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_\nu \tag{12}$$

$$\alpha = |\varsigma_\mu(|u_i\rangle)| \tag{13}$$

$$\gamma = \frac{\alpha}{G} \tag{14}$$

$$\beta = 1 - \alpha - \gamma \tag{15}$$

$$\lambda^*\tilde{A}_\varsigma = \left\{ (1 - (1 - {\varsigma_{\mu_{\tilde{A}}}}^2)^\lambda)^{\frac{1}{2}} e^{j2\pi.\left(1-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}}, \quad {\varsigma_{\nu_{\tilde{A}}}}^\lambda e^{j2\pi.\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^\lambda}, \right.$$

$$\left. ((1 - {\varsigma_{h_{\tilde{A}}}}^2)^\lambda - (1 - {\varsigma_{\mu_{\tilde{A}}}}^2 - {\varsigma_{h_{\tilde{A}}}}^2)^\lambda)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda - \left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \right\}, \lambda > 0 \tag{16}$$

Table A6. Completed evaluations for the criteria.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
GAS- DFC	4	4	4 (NAE 1)	3	4	4 (NAE 1)
GAS- CST	4 (NAE 2)	3	4	4	4 (NAE 1)	4 (NAE 2)
GAS- MNR	3	3 (NAE 1)	3 (NAE 1)	3	2 (NAE 2)	2
DFC- GAS	5	5 (NAE 1)	5	5 (NAE 1)	5	5
DFC- CST	3 (NAE 4)	3	5 (NAE 2)	3	5	3 (NAE 2)
DFC- MNR	3	3 (NAE 1)	3	2	3 (NAE 1)	4
CST- GAS	4 (NAE 4)	3	3 (NAE 2)	4	3	4 (NAE 2)
CST- DFC	2	2 (NAE 1)	4	2 (NAE 2)	4	2 (NAE 1)
CST- MNR	4 (NAE 1)	3	5	4 (NAE 1)	4	4
MNR- GAS	2 (NAE 2)	5	2	4	2 (NAE 1)	4 (NAE 2)
MNR- DFC	4	4 (NAE 1)	4 (NAE 1)	4	4	5
MNR- CST	5	4	5 (NAE 1)	5 (NAE 1)	2	5
			Iteration: NAE			

Table A7. Completed evaluations for the components.

	PSR 1	PSR 2	PSR 3	PSR 4	PSR 5	PSR 6
GAS-PEE	5	2 (NAE 1)	5 (NAE 1)	4	2	5
GAS- POU	3	4	3 (NAE 1)	2	3	3 (NAE 1)
GAS- POE	3 (NAE 1)	4	3	3 (NAE 2)	4	3
GAS- PTN	4 (NAE 1)	5 (NAE 1)	4	3	5	5 (NAE 2)
DFC- PEE	3	4	3 (NAE 1)	4	4 (NAE 1)	2
DFC- POU	4 (NAE 1)	4 (NAE 2)	4	3	4 (NAE 2)	4
DFC- POE	3	3	3 (NAE 1)	5	3 (NAE 1)	4
DFC- PTN	2	4	3	2 (NAE 1)	3	2 (NAE 1)
CST- PEE	4	2 (NAE 1)	4	4	2	3
CST- POU	2 (NAE 1)	4	2	2 (NAE 2)	5	5
CST- POE	5 (NAE 2)	5 (NAE 1)	5 (NAE 3)	2	5	5
CST- PTN	3 (NAE 1)	2	3	4	2 (NAE 1)	4
MNR- PEE	5	3 (NAE 1)	4	5 (NAE 1)	3	4
MNR- POU	2 (NAE 2)	5 (NAE 1)	2 (NAE 3)	4	5	2
MNR- POE	3	4	3	3 (NAE 1)	4 (NAE 1)	3
MNR- PTN	3	4 (NAE 1)	3 (NAE 1)	3	4	5
			Iteration: NAE			

Table A8. Linguistic evaluations for the factors.

	PSR 1				PSR 2			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
GAS		PL	PL	ST		PL	ST	ST
DFC	PF		ST	ST	PF		ST	ST
CST	PL	LW		PL	ST	LW		ST
MNR	LW	PL	PF		PF	PL	PL	
	PSR 3				PSR 4			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
GAS		PL	PL	ST		ST	PL	ST
DFC	PF		PF	ST	PF		ST	LW
CST	ST	PL		PF	PL	LW		PL
MNR	LW	PL	PF		PL	PL	PF	
	PSR 5				PSR 6			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
GAS		PL	PL	LW		PL	PL	LW
DFC	PF		PF	ST	PF		ST	PL
CST	ST	PL		PL	PL	LW		PL
MNR	LW	PL	LW		PL	PF	PF	

Table A9. Average values for the factors.

	GAS	DFC
GAS		$[\sqrt{.29}\,e^{j2\pi..54},\ \sqrt{.18}\,e^{j2\pi..33},\ \sqrt{.53}\,e^{j2\pi..13}]$
DFC	$[\sqrt{.36}\,e^{j2\pi..60},\ \sqrt{.22}\,e^{j2\pi..37},\ \sqrt{.42}\,e^{j2\pi..03}]$	
CST	$[\sqrt{.28}\,e^{j2\pi..53},\ \sqrt{.17}\,e^{j2\pi..32},\ \sqrt{.56}\,e^{j2\pi..15}]$	$[\sqrt{.24}\,e^{j2\pi..48},\ \sqrt{.14}\,e^{j2\pi..30},\ \sqrt{.62}\,e^{j2\pi..22}]$
MNR	$[\sqrt{.27}\,e^{j2\pi..51},\ \sqrt{.16}\,e^{j2\pi..31},\ \sqrt{.59}\,e^{j2\pi..20}]$	$[\sqrt{.31}\,e^{j2\pi..56},\ \sqrt{.19}\,e^{j2\pi..34},\ \sqrt{.50}\,e^{j2\pi..10}]$
	CST	MNR
GAS	$[\sqrt{.29}\,e^{j2\pi..54},\ \sqrt{.18}\,e^{j2\pi..33},\ \sqrt{.53}\,e^{j2\pi..13}]$	$[\sqrt{.24}\,e^{j2\pi..48},\ \sqrt{.14}\,e^{j2\pi..30},\ \sqrt{.62}\,e^{j2\pi..22}]$
DFC	$[\sqrt{.29}\,e^{j2\pi..54},\ \sqrt{.18}\,e^{j2\pi..33},\ \sqrt{.53}\,e^{j2\pi..13}]$	$[\sqrt{.25}\,e^{j2\pi..50},\ \sqrt{.15}\,e^{j2\pi..31},\ \sqrt{.60}\,e^{j2\pi..19}]$
CST		$[\sqrt{.31}\,e^{j2\pi..56},\ \sqrt{.19}\,e^{j2\pi..34},\ \sqrt{.50}\,e^{j2\pi..10}]$
MNR	$[\sqrt{.33}\,e^{j2\pi..57},\ \sqrt{.20}\,e^{j2\pi..35},\ \sqrt{.49}\,e^{j2\pi..12}]$	

Table A10. Score values for the factors.

	GAS	DFC	CST	MNR
GAS	.000	1.241	1.241	1.243
DFC	1.236	.000	1.266	1.246
CST	1.244	1.263	.000	1.248
MNR	1.281	1.242	1.280	.000

Table A11. Critical values.

GAS	Sj	kj	qj	wj	DFC	Sj	Kj	qj	Wj
MNR	.334	1.000	1.000	.400	CST	.338	1.000	1.000	.432
DFC	.333	1.333	.750	.300	MNR	.333	1.333	.750	.324
CST	.333	1.333	.750	.300	GAS	.330	1.330	.564	.244
CST	Sj	kj	qj	wj	MNR	Sj	Kj	qj	Wj
DFC	.336	1.000	1.000	.432	GAS	.337	1.000	1.000	.432
MNR	.332	1.332	.751	.324	CST	.337	1.337	.748	.324
GAS	.331	1.331	.564	.244	DFC	.327	1.327	.564	.244

Table A12. Relation matrix.

	GAS	DFC	CST	MNR
GAS		.300	.300	.400
DFC	.244		.432	.324
CST	.244	.432		.324
MNR	.432	.244	.324	

$$\tilde{A}_{\varsigma}{}^{\lambda} = \left\{ \begin{array}{l} \varsigma_{\mu_{\tilde{A}}}{}^{\lambda} e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{\lambda}},\ (1-(1-\varsigma_{\nu_{\tilde{A}}}{}^{2})^{\lambda})^{\frac{1}{2}} e^{j2\pi.\left(1-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}\right)^{\lambda}\right)^{\frac{1}{2}}}, \\ ((1-\varsigma_{\nu_{\tilde{A}}}{}^{2})^{\lambda}-(1-\varsigma_{\nu_{\tilde{A}}}{}^{2}-\varsigma_{h_{\tilde{A}}}{}^{2})^{\lambda})^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}\right)^{\lambda}-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^{2}-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}\right)^{\lambda}\right)^{\frac{1}{2}}} \end{array} \right\},\ \lambda > 0 \tag{17}$$

$$\tilde{A}_{\varsigma} \oplus \tilde{B}_{\varsigma} = \left\{ \begin{array}{l} (\varsigma_{\mu_{\tilde{A}}}{}^{2}+\varsigma_{\mu_{\tilde{B}}}{}^{2}-\varsigma_{\mu_{\tilde{A}}}{}^{2}\varsigma_{\mu_{\tilde{B}}}{}^{2})^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}+\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}}, \\ \varsigma_{\nu_{\tilde{A}}}\varsigma_{\nu_{\tilde{B}}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)\right)},\quad ((1-\varsigma_{\mu_{\tilde{B}}}{}^{2})\varsigma_{h_{\tilde{A}}}{}^{2}+(1-\varsigma_{\mu_{\tilde{A}}}{}^{2})\varsigma_{h_{\tilde{B}}}{}^{2}-\varsigma_{h_{\tilde{A}}}{}^{2}\varsigma_{h_{\tilde{B}}}{}^{2})^{\frac{1}{2}} \\ e^{j2\pi.\left(\left(1-\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}+\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^{2}\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^{2}\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^{2}\right)^{\frac{1}{2}}} \end{array} \right\} \tag{18}$$

$$\tilde{A}_{\varsigma} \otimes \tilde{B}_{\varsigma} = \left\{ \varsigma_{\mu_{\tilde{A}}} \varsigma_{\mu_{\tilde{B}}} e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)}, ({\varsigma_{\nu_{\tilde{A}}}}^2 + {\varsigma_{\nu_{\tilde{B}}}}^2 - {\varsigma_{\nu_{\tilde{A}}}}^2 {\varsigma_{\nu_{\tilde{B}}}}^2)^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2 + \left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2 - \left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2 \left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}}, \right.$$
$$\left. ((1 - {\varsigma_{\nu_{\tilde{B}}}}^2){\varsigma_{h_{\tilde{A}}}}^2 + (1 - {\varsigma_{\nu_{\tilde{A}}}}^2){\varsigma_{h_{\tilde{B}}}}^2 - {\varsigma_{h_{\tilde{A}}}}^2 {\varsigma_{h_{\tilde{B}}}}^2)^{\frac{1}{2}} e^{j2\pi.\left(\left(1 - \left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2 + \left(1 - \left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2 - \left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2 \left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}} \right\} \tag{19}$$

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{20}$$

$$\varsigma = \left\{ \left[1 - \prod_{i=1}^{k} (1 - {\varsigma_{\mu_i}}^2)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[1 - \prod_{i=1}^{k}\left(1 - \left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}, \prod_{i=1}^{k} \varsigma_{\nu_i}{}^{\frac{1}{k}} e^{2\pi.\prod_{i=1}^{k}\left(\frac{\gamma_i}{2\pi}\right)^{\frac{1}{k}}}, \right.$$
$$\left. \left[\prod_{i=1}^{k} (1 - {\varsigma_{\mu_i}}^2)^{\frac{1}{k}} - \prod_{i=1}^{k} (1 - {\varsigma_{\mu_i}}^2 - {\varsigma_{h_i}}^2)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[\prod_{i=1}^{k}\left(1 - \left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}} - \prod_{i=1}^{k}\left(1 - \left(\frac{\alpha_i}{2\pi}\right)^2 - \left(\frac{\beta_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}} \right\} \tag{21}$$

$$Def\varsigma_i = \varsigma_{\mu_i} + \varsigma_{h_i}\left(\frac{\varsigma_{\mu_i}}{\varsigma_{\mu_i} + \varsigma_{\nu_i}}\right) + \left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\gamma_i}{2\pi}\right)\left(\frac{\left(\frac{\alpha_i}{2\pi}\right)}{\left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\beta_i}{2\pi}\right)}\right) \tag{22}$$

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{23}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{24}$$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{25}$$

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{26}$$

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{27}$$

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

$$A^+ = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\max v_{1j}\ for\ \forall\ j \in n\}, \tag{29}$$

$$A^- = \{v_{1j}, v_{2j}, \ldots, v_{mj}\} = \{\min v_{1j}\ for\ \forall\ j \in n\}. \tag{30}$$

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^+)^2}, \tag{31}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^-)^2}. \tag{32}$$

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-}. \tag{33}$$

$$sim(u, v) = \frac{\sum_{i \in I} (r_{u,i} - \overline{r_u})(r_{v,i} - \overline{r_v})}{\sqrt{\sum_{i \in I} (r_{u,i} - \overline{r_u})^2} \sqrt{\sum_{i \in I} (r_{v,i} - \overline{r_v})^2}} \tag{34}$$

Table A13. Linguistic evaluations for the components.

	PSR 1				PSR 2			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
PEE	DF	RL	SF	DF	BD	SF	BD	RL
POU	RL	SF	BD	BD	SF	SF	SF	DF
POE	RL	RL	DF	RL	SF	RL	DF	SF
PTN	SF	BD	RL	RL	DF	SF	BD	SF
	PSR 3				PSR 4			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
PEE	DF	RL	SF	SF	SF	SF	SF	DF
POU	RL	SF	BD	BD	BD	RL	BD	SF
POE	RL	RL	DF	RL	RL	DF	BD	RL
PTN	SF	RL	RL	RL	RL	BD	SF	RL
	PSR 5				PSR 6			
	GAS	DFC	CST	MNR	GAS	DFC	CST	MNR
PEE	BD	SF	BD	RL	DF	BD	RL	SF
POU	RL	SF	DF	DF	RL	SF	DF	BD
POE	SF	RL	DF	SF	RL	SF	DF	RL
PTN	DF	RL	BD	SF	DF	BD	SF	DF

Table A14. Average values for the components.

	GAS	DFC
PEE	$[\sqrt{.31}\,e^{j2\pi..56}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.50}\,e^{j2\pi..10}]$	$[\sqrt{.27}\,e^{j2\pi..51}, \sqrt{.16}\,e^{j2\pi..31}, \sqrt{.59}\,e^{j2\pi..20}]$
POU	$[\sqrt{.25}\,e^{j2\pi..50}, \sqrt{.15}\,e^{j2\pi..31}, \sqrt{.60}\,e^{j2\pi..19}]$	$[\sqrt{.29}\,e^{j2\pi..53}, \sqrt{.18}\,e^{j2\pi..33}, \sqrt{.54}\,e^{j2\pi..14}]$
POE	$[\sqrt{.27}\,e^{j2\pi..51}, \sqrt{.16}\,e^{j2\pi..31}, \sqrt{.59}\,e^{j2\pi..20}]$	$[\sqrt{.28}\,e^{j2\pi..53}, \sqrt{.17}\,e^{j2\pi..32}, \sqrt{.56}\,e^{j2\pi..16}]$
PTN	$[\sqrt{.33}\,e^{j2\pi..57}, \sqrt{.20}\,e^{j2\pi..35}, \sqrt{.49}\,e^{j2\pi..11}]$	$[\sqrt{.24}\,e^{j2\pi..48}, \sqrt{.14}\,e^{j2\pi..30}, \sqrt{.62}\,e^{j2\pi..22}]$
	CST	MNR
PEE	$[\sqrt{.26}\,e^{j2\pi..51}, \sqrt{.16}\,e^{j2\pi..31}, \sqrt{.59}\,e^{j2\pi..19}]$	$[\sqrt{.31}\,e^{j2\pi..56}, \sqrt{.19}\,e^{j2\pi..34}, \sqrt{.50}\,e^{j2\pi..10}]$
POU	$[\sqrt{.28}\,e^{j2\pi..53}, \sqrt{.17}\,e^{j2\pi..32}, \sqrt{.56}\,e^{j2\pi..16}]$	$[\sqrt{.28}\,e^{j2\pi..53}, \sqrt{.17}\,e^{j2\pi..32}, \sqrt{.56}\,e^{j2\pi..16}]$
POE	$[\sqrt{.34}\,e^{j2\pi..58}, \sqrt{.20}\,e^{j2\pi..35}, \sqrt{.47}\,e^{j2\pi..11}]$	$[\sqrt{.27}\,e^{j2\pi..51}, \sqrt{.16}\,e^{j2\pi..31}, \sqrt{.59}\,e^{j2\pi..20}]$
PTN	$[\sqrt{.26}\,e^{j2\pi..51}, \sqrt{.16}\,e^{j2\pi..31}, \sqrt{.59}\,e^{j2\pi..19}]$	$[\sqrt{.29}\,e^{j2\pi..53}, \sqrt{.18}\,e^{j2\pi..33}, \sqrt{.54}\,e^{j2\pi..14}]$

Table A15. Score values of the components.

	GAS	DFC	CST	MNR
PEE	1.293	1.253	1.260	1.259
POU	1.246	1.241	1.294	1.294
POE	1.243	1.255	1.283	1.243
PTN	1.258	1.253	1.256	1.255

Table A16. Normalized matrix.

	GAS	DFC	CST	MNR
PEE	.513	.501	.495	.499
POU	.494	.496	.508	.512
POE	.493	.502	.504	.492
PTN	.499	.501	.493	.497

$$p_{u,i} = \frac{\sum_{j\in S} sim(u,\ v) r_{u,j}}{\sum_{j\in S} |sim(u,\ v)|} \tag{35}$$

Table A17. Weighted matrix.

	GAS	DFC	CST	MNR
PEE	.121	.123	.129	.129
POU	.116	.122	.132	.132
POE	.116	.123	.131	.127
PTN	.117	.123	.129	.128

ORCID iDs

Jaehyung An https://orcid.org/0000-0001-5410-7506
Alexey Mikhaylov https://orcid.org/0000-0003-2478-0307

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