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Strategic feasibility outlook for blue energy investments using an integrated decision-making approach

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ABSTRACT

Conducting feasibility analysis in blue energy investments is very critical to provide performance analysis of the projects. However, a significant portion of the studies in the literature focus on general energy projects. Nevertheless, there are not enough studies for a more specific area such as blue energy. This situation significantly increases the need for this type of priority analysis. Accordingly, the purpose of this study is to identify the most appropriate strategies to increase the effectiveness of the feasibility analysis of blue energy investments via a novel decision-making model. In the first stage of the model, the importance levels of experts are computed using machine learning technique. The second stage includes weighting the feasibility criteria set for blue energy project investment by Fermatean fuzzy entropy. After that, the strategic alternatives for increasing the capacity of blue energy projects are ranked with Fermatean fuzzy CoCoSo. The main contribution of this study to the literature is making a detailed evaluation to generate appropriate strategies for the feasibility analysis of the blue energy investments via a novel decision-making model. The integration of AI system provides some advantages to the proposed model. In this way, the decision matrix is obtained by calculating the importance weights of each expert. This situation allows to have more accurate analysis results. It is defined that the technological infrastructure of the company plays the most critical role (weight: 0.173) when conducting feasibility analysis for blue energy investments. Similarly, it is also identified that the financial performance of the business (weight: 0.172) is also important to conduct a more successful feasibility analysis for blue energy investments. On the other side, the ranking results demonstrate that collaborating with the investment-ready companies for increasing the innovative technologies is the most appropriate strategy to increase the capacity of blue energy projects.

1. Introduction

Blue energy is the name given to energy production methods at the points where oceans and rivers meet. For example, wave energy and tidal energy can be taken into account in this context. It is possible to talk about some advantages of blue energy projects. First, blue energy is considered renewable energy because it is obtained from the combination of river and sea water. In other words, the source of blue energy does not run out, and this supports increasing energy security. Similarly, low carbon emissions are another important advantage of blue energy [29]. This makes it possible to significantly reduce environmental pollution caused by energy production. In addition to them, it is possible to produce high amounts of energy with blue energy projects. Energy production resources in the oceans and seas are quite high. In this way, these projects have a large amount of energy production potential. Moreover, it is possible to develop renewable energy projects thanks to the development of blue energy projects [18]. In this way, countries can obtain the energy they need with their own means. In other words, blue energy investments significantly contribute to the energy independence of countries.

Ensuring the feasibility of blue energy investments is essential for these projects to be sustainable and economically feasible. The initial costs of blue energy projects can be quite high. Therefore, it is important to carry out the feasibility studies correctly to ensure the long-term continuity of these projects. On the other hand, conducting the feasibility study correctly is also necessary to access financial supports such as government incentives [32]. Moreover, blue energy technologies involve quite complex processes. Therefore, for these processes to be

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implemented successfully, this technology must be used correctly. In this context, a comprehensive feasibility study should be carried out to ensure this accuracy. There are various issues that need to be taken into consideration to ensure the feasibility of blue energy investments [23]. In this context, a comprehensive economic analysis should be made. During this process, the total investment cost of the project should be calculated in detail. Conducting a detailed technical evaluation is also effective on the success of the feasibility of blue energy investments. In this context, it is important to choose the most suitable technology for projects.

It is extremely important and necessary to determine the most important strategies for the success of the feasibility of blue energy investments. First, it is possible to ensure the cost effectiveness of projects by determining the correct strategies. This situation enables the economic sustainability of the projects as it will support increasing financial profitability. Similarly, determining the most appropriate strategies allows innovative solutions to be offered [37]. This significantly increases the efficiency of projects. If the most important strategies for the successful feasibility of blue energy investments are not determined, some problems arise. In cases where the most accurate strategies are not determined, the costs of the project may be higher than expected. This situation causes businesses to experience financial problems. Similarly, if the right strategies are not determined for the success of the feasibility of projects, businesses cannot use their financial and human resources effectively. However, there are few studies in the literature on determining the most important factors. This situation significantly increases the need for this type of analysis.

Accordingly, this study tries to identify the most appropriate strategies to increase the effectiveness of the feasibility analysis of blue energy investments. A new decision-making model is established to reach this goal. In the first stage of the model, the importance levels of experts are computed using machine learning technique. In this process, standardized values, covariance matrix and importance levels are identified. The second stage includes weighting the feasibility criteria set for blue energy project investment using Fermatean fuzzy entropy. Within this framework, decision matrix and entropy values are computed. After that, the strategic alternatives for increasing the capacity of blue energy projects are ranked using Fermatean fuzzy CoCoSo. Additionally, these strategies are also ranked via SAW method to measure the reliability of the findings. By considering these issues, the main research questions of the manuscript can be determined as follows.

(1) Which feasibility indicators of blue energy investments have the highest significance weights?
(2) Which strategies to increase the effectiveness of the feasibility analysis of blue energy investments should be prioritized?

The main motivation of this study is the need for comprehensive feasibility analysis in blue energy investments. Blue energy has a rising importance among renewable energy sources. However, to increase the performance of these investments, an effective feasibility analysis must be conducted. Failure to conduct these feasibility analyses effectively may result in the failure of projects. Therefore, determining strategies that will improve feasibility analysis is of vital importance. Similar to this issue, there is no consensus in the literature on which strategies are most appropriate for feasibility analysis of blue energy investments. This deficiency may cause projects to be inadequate in terms of applicability and efficiency. In summary, there is a strong need for a comprehensive evaluation with respect to strategy generation for the feasibility analysis of the blue energy investments. Decision-making models can be taken into consideration in this framework [12,13]. However, existing models are criticized by the scholars due to some reasons. Failure to manage uncertainty is one of the most essential criticisms for existing decision-making models. Therefore, to satisfy the need in the literature, a new model is needed that can overcome these criticisms.

The main contribution of this study to the literature is making a detailed evaluation to generate appropriate strategies for the feasibility analysis of the blue energy investments via a novel decision-making model. This proposed model has some superiorities by comparing with the previously created ones. The main advantages of this proposed model are detailed below.

(1) The integration of AI system provides some advantages to the proposed model. In most of the fuzzy multi-criteria decision-making models, the importance weights of experts are generally considered equal. In other words, the decision matrix is created by calculating the average of each expert's evaluation. However, experts may have different education and work experience. As can be understood from this situation, accepting the importance of experts as equal is not a correct approach. To solve this problem, AI technique is integrated into the model in this study. In this way, the decision matrix is obtained by calculating the importance weights of each expert. This allows more accurate analysis results to be obtained. The use of AI techniques in calculating expert weights has significant advantages over other techniques in the literature. Techniques such as analytic hierarchy process and DEMATEL are also classical multi-criteria decision-making methods used in weighting expert opinions. Since these methods are directly based on expert opinions, subjectivity problems may arise. AI techniques such as machine learning reduce this subjectivity by producing more objective results by learning from data.

(2) Considering Fermatean fuzzy numbers is another advantage of the model. Fermatean fuzzy numbers use a more comprehensive data set. This helps reduce uncertainty in the analysis process [27]. Fermatean fuzzy sets are an extended version of the classical fuzzy set theory. Fermatean fuzzy numbers have a wider range of uncertainty when expressing membership and non-membership degrees [26]. Fermatean fuzzy numbers use a more comprehensive data set. This helps reduce uncertainty in the analysis process. Due to some features, Fermatean fuzzy sets have some advantages over other similar numbers. Classical fuzzy sets use only the membership degree. Therefore, they cannot model uncertainty in real-world problems like Fermatean fuzzy sets. Type-2 fuzzy sets define membership degrees as a fuzzy interval by expanding the uncertainty range. However, they cannot perform precise analysis mathematically like Fermatean fuzzy sets. Moreover, Pythagorean fuzzy sets are also an extension of classical fuzzy sets. However, Fermatean fuzzy sets have a wider range of uncertainty than Pythagorean fuzzy numbers.

(3) Using entropy and CoCoSo techniques is another superiority of the proposed model. By choosing the entropy method, criterion weights can be determined according to alternatives. There is a strong relationship between the criteria affecting the performance of the feasibility analysis of blue energy investments and the strategy alternatives for increasing the capacity of these projects. Therefore, these alternatives should be taken into consideration when determining the importance weights of this criterion set. In summary, entropy is one of the most suitable techniques to obtain the most accurate results for this study. The entropy method has some advantages over other similar methods. The analytic network process (ANP) technique is also a method that considers the interdependence between the criteria in the decision-making process. In the entropy method, the amount of information in the real data is evaluated. In contrast, ANP is based only on subjective evaluations. Moreover, the CRITIC method is a method that calculates weights by evaluating the level of variability of the criteria and their relationships with each other. The CRITIC method is based on the relationship between the criteria. However, the entropy method has a wider application area with the assumption of criterion independence. Similarly, three different strategies are used in the analysis process carried out with the CoCoSo technique. In other words, this technique performs a much more sensitive analysis compared to other similar ones.

The organization of the manuscript is demonstrated as follows. Similar studies in the literature are evaluated in the next part. The steps of the proposed model are defined in the third section. Analysis results, discussion and conclusion are shared in the final parts.

2. Literature review

Determining market demand plays a critical role in the success of the feasibility of blue energy investments. Market demand is also of key importance in determining energy prices. This allows energy price strategies to be determined correctly [25]. This supports the satisfaction of both producers and consumers. Otherwise, energy prices will be determined incorrectly, causing financial losses to the parties [33]. In addition to this issue, accurate determination of market demand is also necessary to determine the amount of investment to be made. In this context, Aziz et al. [4] defined that high market demand makes projects more financially attractive. Therefore, higher financial demand is effective in making the decision to increase the amount of investments. On the other hand, Yu and Ren [35] concluded that market demand helps determine future energy demand projections. These projections are also very necessary for the feasibility of blue energy investments to be successful [20]. In this way, it is possible to implement more effective long-term investment strategies.

The development of technological infrastructure is also necessary for the feasibility of blue energy investments to be successful. The use of advanced technology is important to increase the efficiency of these projects [34]. This helps to significantly reduce the costs of investments. Thus, it will be possible to increase the profitability of the projects. This contributes to the long-term sustainability of these projects [31]. In this process, the important issue is the need to increase research studies. These studies enable the development of innovative solutions and technologies in the field of blue energy. Kirkels and Pernot [16] mentioned that this condition helps to implement feasibility studies for these projects more successfully. In addition to them, technological advances help overcome the technical and operational challenges faced by blue energy systems. In this way, van der Loos et al., [30] identified that feasibility studies can be carried out more successfully. New technologies also reduce the difficulties encountered during the installation and operation of blue energy systems. By effectively managing these difficulties, the feasibility study can be carried out more appropriately.

Financial performance is of great importance in the success of the feasibility of blue energy investments. For these projects to be economically sustainable, the costs must be analyzed in detail. This situation allows the feasibility analysis to be carried out more successfully [24]. Conducting cost analysis determines the degree of financial

Fig. 1. Proposed model.

Table 1
The pseudo-code of dimension reduction algorithm.

Input: Demographic information $f_{ik}, i \in [1, k], j \in [1, m]$; where k equals number of experts, and m equals number of features

Output: Important Levels of Experts $ew_i, i \in [1, m]$

Begin

(1) Define a features matrix

$$F = [f_{ij}]_{k \times m}$$

(2) Compute the standardized values with the average of the jth column ($\bar{f}_j$)

$$c_{ij} \leftarrow f_{ij} - \bar{f}_j$$

$$n_{ij} \leftarrow \frac{c_{ij}}{\sqrt{\sum_{i=1}^{k} c_{ij}^2}}\ ; \forall i \in [1,2,\ldots,k];\ \forall j \in [1,2,\ldots,m]$$

(3) Found the covariance matrix (CM)

(4) Calculate the eigenvalue (λ) of covariance matrix. (I is identity matrix)

$$Det(CM - \lambda I) = 0$$

(5) Compute the eigenvector (v) for the largest eigenvalue (λ_{max})

$$(CM - \lambda_{max} I) * v = 0$$

(6) Convert matrix to the new space (H)

$$H \leftarrow \mathrm{FxV}$$

(7) Determine the weights of experts

$$ew_j \leftarrow \frac{h_j}{\sum_{j=1}^{k} h_j}, \forall j \in [1,2,\ldots,k]$$

End

fragility of businesses. Thanks to this situation, more accurate results can be achieved in the feasibility analysis [17]. On the other hand, Ojelade and Jolaoso [22] underlined that fragility decreases in businesses with good financial performance. This issue enables more successful predictions about future events. The financial performance of the project depends on effective control of operational efficiency. Akdağ [1] denoted that this condition supports businesses in making long-term decisions regarding financial matters more easily. Similarly, as a result of increasing incomes, it also supports the effective evaluation of market demand. Furthermore, according to Kabir et al. [15], by increasing the financial performance of projects, risks such as exchange rate volatility can be managed more successfully.

A socio-economic evaluation is also necessary to ensure the feasibility of blue energy investments is successful. With this evaluation, it is possible to examine projects not only in economic terms but also in terms of their social and environmental impacts [38]. Thanks to this comprehensive analysis, the potential impacts of projects on local communities can be understood. This enables more successful predictions for the future to be made [5]. Thus, it is possible to carry out the feasibility analysis of these investments more accurately. Similarly, Aquino et al. [3] showed that blue energy projects make significant contributions to the local economy. This is very necessary for the long-term sustainability of the projects. De Leo et al. [7] reached a conclusion that thanks to socio-economic evaluation, the extent of the impact of these projects on the local economy can be determined more clearly. On the other hand, Ismail et al. [10] identified that socio-economic evaluation determines environmental sustainability strategies. In this way, it is possible to consume much fewer natural resources in the energy production process.

The results of the literature review highlight some important issues. The popularity of blue energy projects is increasing because they are environmentally friendly and contribute to energy independence. Therefore, the feasibility of these investments must be carried out effectively. There are some factors that affect the performance of the feasibility analysis to be carried out for these projects. The development of technological infrastructure, the financial performance of the project,

Table 2
The pseudo-code of Entropy.

Input: Values $d_{ij}, i \in [1, m], j \in [1, n]$; where n equals number of criteria; m equals number of alternatives

Output: Weights of criteria $w_i, i \in [1, n]$

Begin

(1) Create a expert weighted decision matrix

$$\widetilde{D} = [\tilde{d}_{ij}]_{m \times n}$$

(2) Obtain the normalize values

(3) Calculate the Entropy values (E)

$$E_j \leftarrow 1 - \frac{1}{n} \sum_{i=1}^{n} [({\mu_i}^3 - {v_i}^3)({\mu_i}^3 + {v_i}^3)]^2$$

(4) Compute the weights of criteria (w)

$$w \leftarrow \frac{E}{\sum E}$$

End

a clear understanding of market demand and socio-economic evaluation are determined as important variables in this process. Improvements to be made regarding these variables contribute to the success of the feasibility study. However, the disadvantage of these improvements is that they increase costs. Therefore, it is not financially feasible to implement too many improvements. In this context, a small number of improvements should be made to the most important variables to ensure efficiency. Therefore, it is necessary to determine the factors that most affect the performance of the feasibility analysis. Nevertheless, there are not enough studies on this subject in the literature. This situation emerges as an important missing part for the literature on feasibility analysis of blue energy investments. To eliminate this deficiency in the literature, priority analysis is carried out with a new model in this study.

3. Model

The strategic feasibility outlook of blue energy projects, one of the current research areas, is gaining importance day by day. In this article, an integrated decision-making approach is applied to determine the most sustainable strategic feasibility outlook for the investments of blue energy projects. In the integrated decision-making approach, firstly, the feasibility criteria determined for blue energy project investments are objectively weighted by the Entropy method. In the second stage, strategic alternatives for increasing the capacity of blue energy projects are ranked using the CoCoSo method and the most sustainable/suitable alternative is selected. Finally, the SAW method is used for the consistency of the results.

Since the integrated decision-making approach includes MCDM models, the data of the study is obtained from experts. Some of the criticisms of obtaining data from experts include making calculations with linguistic expressions and giving equal importance to expert opinions. Considering these criticisms, Fermatean fuzzy numbers and machine learning techniques are added to the integrated decision-making approach. Thus, an approach that processes linguistic terms with the help of Fermatean fuzzy numbers and determines the importance weights of experts through demographic information using machine learning is constructed. The details of the proposed model are given in Fig. 1.

The models of the proposed integrated decision-making approach are introduced under this section.

3.1. Dimension reduction

Dimension reduction is a machine learning technique. Dimension reduction is the process of obtaining fewer variables from a larger number of variables. While reducing the number of variables and trying to preserve the total variance in the data set, projections of the data set are created in the new vector space. In other words, in dimension reduction, which is a machine learning technique, complex and numerous variables are expressed with a smaller number of more meaningful and understandable variables. Although the demographic information of experts varies, it can contain many variables. A data set containing such data is reduced to a one-dimensional space representing experts by dimension reduction, and this dimension is used to determine the importance levels of experts. The stepwise pseudocodes of dimensionality reduction are shared in Table 1 [19].

3.2. Entropy with Fermatean fuzzy numbers

According to information theory, Entropy is defined as the amount of information contained in a message. Additionally, Entropy is used as a measure of average uncertainty. In other words, data is calculated in science to measure the information in a random variable [2]. In multi-criteria decision making, Entropy is an objective weighting

Table 3
The pseudo-code of CoCoSo method.

Input: Values $d_{ij}, i \in [1, m], j \in [1, n]$; where n equals number of criteria; m equals number of alternatives; Weights of criteria $w_i, i \in [1, n]$

Output: Ranking of alternatives $A_i, i \in [1, m]$

Begin

(1) Create a matrix

$$\widetilde{D} = [\tilde{d}_{ij}]_{m \times n}$$

(2) Compute the normalized matrix $(\widetilde{N})$

(3) Calculate the weighted sum $(\widetilde{W})$ and weighted power $(\widetilde{P})$ values.

$$\widetilde{W_i} \leftarrow \sum w_j \widetilde{N}_{ij}$$

$$\widetilde{P_i} \leftarrow \prod \widetilde{N}_{ij}{}^{w_j}$$

(4) Determine the defuzzified values

(5) Obtain Ka, Kb and Kc values

$$K_a \leftarrow \frac{W+P}{\sum W+P}$$

$$K_b \leftarrow \frac{W}{\min W} + \frac{P}{\min P}$$

$$K_c \leftarrow \frac{\lambda W+(1-\lambda)P}{\lambda \max W+(1-\lambda) \max P} \qquad 0 \leq \lambda \leq 1$$

(6) Found performance of alternatives (K)

$$K \leftarrow (K_a * K_b * K_c)^{\frac{1}{3}} + \frac{1}{3}(K_a + K_b + K_c)$$

End

Table 4
The information about three experts.

	Age	Experience	Salary	Education
Expert1	36	10	2200	Master
Expert2	48	11	2500	PhD
Expert3	49	17	2650	Master

Table 5
The standardized values.

	Age	Experience	Salary	Education
Expert1	−.815	−.498	−.772	−.408
Expert2	.358	−.311	.154	.816
Expert3	.456	.809	.617	−.408

method used to weight criteria according to their amount of information. The stepwise pseudocodes of Entropy method are summarized in Table 2 [6].

Table 6
The Covariance Matrix.

	Age	Experience	Salary	Education
Age	.333	.221	.322	.146
Experience	.221	.333	.279	−.127
Salary	.322	.279	.333	.063
Education	.146	−.127	.063	.333

Table 7
The importance levels of experts.

	Imp. Lev.
Expert1	.299
Expert2	.34
Expert3	.361

Table 8
The feasibility criteria set.

Criteria	Codes
Environmental Monitoring	ENVMON
Market Demand	MARDEM
Technological Infrastructure	TECHINF
Expected Return Rate	EXPRERA
Project Lifetime	PROLIF
Socio-Economic Assessment	SOCECOASS

Table 9
The strategic alternatives.

Alternatives	Codes
Focusing on the geographical diversifications for expending the market growth	FOCGEO
Collaborating with the investment-ready companies for increasing the innovative technologies	COLINV
Monitoring the investment opportunities for emerging the energy alternatives	MONINV
Investing in blue economy for attracting the sustainable practices of climate change	INVSUS

3.3. *CoCoSo with Fermatean fuzzy numbers*

The CoCoSo method is an improved version of the weighted sum and weighted product models. The CoCoSo method, used to rank alternatives, is a consensus-based multi-criteria decision-making method that examines sum and multiplication operators from different perspectives. The stepwise pseudocodes of CoCoSo method are shown in Table 3 [8].

4. Analysis results

The findings of the analyzes conducted to determine the most appropriate strategic alternative to increase the strategic feasibility outlook for blue energy projects are presented. Findings regarding the steps of the integrated decision-making approach are reported under subheadings.

Table 12
The weights of the criteria.

Criteria	Values	Weights
ENVMON	.913	.160
MARDEM	.940	.165
TECHINF	.987	.173
EXPRERA	.981	.172
PROLIF	.951	.166
SOCECOASS	.945	.165

Table 13
The Fermatean fuzzy and defuzzfied values of results.

	$\widetilde{W}$		$\widetilde{P}$		W	P
FOCGEO	.562	.355	.503	.424	.566	.525
COLINV	.847	.105	.839	.107	.804	.795
MONINV	.611	.294	.597	.315	.601	.591
INVSUS	.672	.241	.646	.275	.645	.624

Table 14
Ka, Kb and Kc values of strategic alternatives.

	Ka	Kb	Kc
FOCGEO	.212	2.000	.683
COLINV	.310	2.931	1.00
MONINV	.231	2.185	.746
INVSUS	.246	2.326	.794

Table 10
The evaluations from three experts.

Expert1						
	ENVMON	**MARDEM**	**TECHINF**	**EXPRERA**	**PROLIF**	**SOCECOASS**
FOCGEO	7	7	4	3	4	6
COLINV	9	9	8	8	9	8
MONINV	6	7	6	7	6	5
INVSUS	9	6	6	6	5	7
Expert2						
	ENVMON	**MARDEM**	**TECHINF**	**EXPRERA**	**PROLIF**	**SOCECOASS**
FOCGEO	8	7	4	4	3	5
COLINV	9	8	8	8	9	9
MONINV	5	6	5	5	5	6
INVSUS	8	7	7	7	6	6
Expert3						
	ENVMON	**MARDEM**	**TECHINF**	**EXPRERA**	**PROLIF**	**SOCECOASS**
FOCGEO	7	7	6	4	5	5
COLINV	8	9	7	8	8	9
MONINV	7	8	5	7	6	5
INVSUS	8	6	7	5	5	7

Table 11
The Fermatean fuzzy decision matrix.

	ENVMON		MARDEM		TECHINF		EXPRERA		PROLIF		SOCECOASS	
FOCGEO	.741	.158	.700	.200	.496	.416	.368	.528	.414	.491	.535	.367
COLINV	.873	.100	.875	.100	.770	.128	.800	.100	.873	.100	.878	.100
MONINV	.618	.286	.720	.179	.535	.367	.651	.253	.571	.331	.540	.363
INVSUS	.839	.100	.640	.261	.675	.226	.614	.290	.540	.363	.671	.230

Table 15
The performance of strategic alternatives.

	K
FOCGEO	1.627
COLINV	2.383
MONINV	1.776
INVSUS	1.891

4.1. Calculating the importance levels of experts using machine learning technique

Contact is made via e-mail to obtain opinions from experts experienced in blue energy projects. Among the experts contacted, it is determined that there are three experts with at least 10 years of experience, and the demographic information of these experts is given in Table 4.

When the information of the experts in Table 4 is examined, it is seen that the age range varies between 36 and 49 and the lowest education level is master's degree. Income levels are in dollars. By using this information of the experts, the importance levels of the experts are determined with the help of machine learning technique. For this, firstly, the values are standardized. Standardized values are shared in Table 5.

Then, the covariance values between the experts' information are calculated. The covariance matrix created with standardized values is displayed in Table 6.

Covariance has polynomial roots, that is, eigenvalues. The largest of the four eigenvalues is 0.889. The eigenvector corresponding to this eigenvalue is determined and finally, the importance levels of the experts are computed by multiplying the eigenvector and the feature matrix. The importance levels of experts are illustrated in Table 7.

According to Table 7, the third of the experts has the highest importance. In other words, the third expert's evaluations are evaluated by multiplying with.361. The opinions of other experts are similarly multiplied by their own importance levels and included in the analysis.

4.2. Weighting the feasibility criteria set for blue energy project investment using FF-entopy

Six criteria effective in blue energy project investments and four strategic alternatives are determined by considering the results of the literature. Feasibility criteria for blue energy project investments are shown with codes in Table 8.

Environmental situations are effective in the feasibility of blue energy projects. Environmental assessment allows these projects to be designed to protect wildlife and ecosystems. This supports the sustainability of the projects. Similarly, the feasibility assessment of projects may vary depending on market demand. Market demand is a factor that directly affects the long-term success of projects. Similarly, market demand also plays an important role in determining energy prices. Additionally, the strength of the technological infrastructure can increase the feasibility of the project. Technological advances increase the efficiency of blue energy systems. More efficient systems also enable projects to be more economically successful. This value is important in terms of feasibility, as projects with a high expected return rate receive more demand. High return on investment increases investors' interest in the project. This situation allows more investors to focus on projects. The lifespan of the project is another factor that should be taken into consideration in the feasibility of the project. In addition, socio-economic factors are another issue that investors take into consideration. Strategic alternatives determined to increase the capacity of blue energy projects are displayed with code in Table 9.

The first strategy is to reduce risk and expand the market through geographical diversification. Another strategy is to cooperate with companies that are ready for investment. Thus, the capacity of energy projects can be increased with both technology and capital. Exploring investment opportunities for energy alternatives could be another strategic move. Finally, engaging in sustainable practices while taking climate change into consideration is another preferable strategy alternative. After the criteria and alternatives are determined, each strategic alternative is evaluated by three different experts at the criterion level. The evaluation results of the three experts are summarized in Table 10.

The Fermatean fuzzy number equivalents of expert evaluations are multiplied by the experts' importance levels and summed. The aggregate and multiplication operations are operators defined in Fermatean Fuzzy sets. The calculation of the first element of the Fermatean fuzzy decision matrix is as follows.

For 7, Fermatean fuzzy number is (0.7,0.2) and for 8, Fermatean fuzzy number is (0.8,0.1). Then, for Expert 1, the weighted value is computed by $\left(\left(1-\left(1-0.7^3\right)^{0.299}\right)^{\frac{1}{3}} = 0.491, \quad 0.1^{0.299} = 0.618\right)$. Similarly, for Expert 2, the weighted value is (0.600,0.457). For Expert

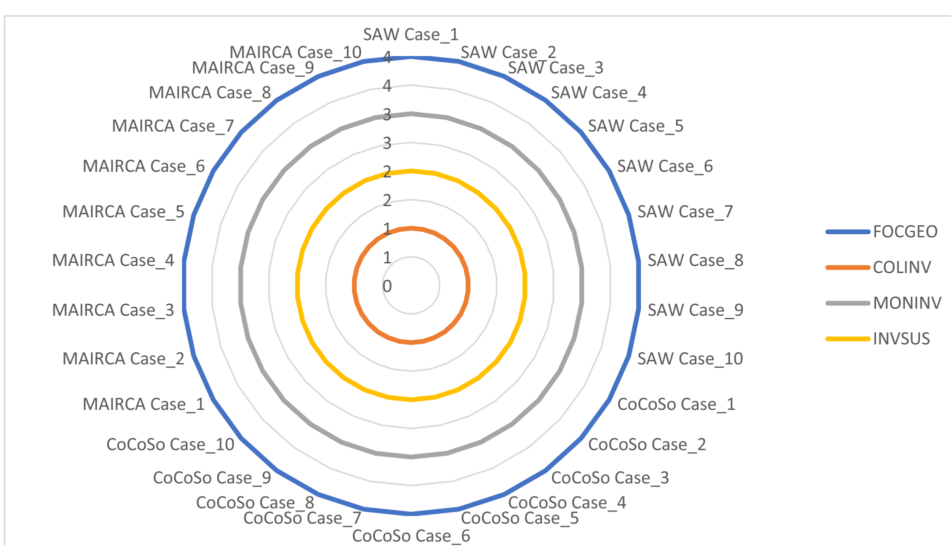

Fig. 2. The result of comparative analysis.

3, the weighted value is (0.520,0.559). Afterwards, these values are summed. Firstly, these values of Expert 1 and Expert 2 are computed by $\left(\left((0.491^3) + (0.600^3) - (\ \ 0.491^3) * (\ \ 0.600^3)\right)^{\frac{1}{3}} = 0.676, \; 0.618 * 0.457 = 0.282\right)$. Similarly, the total value and the value of Expert 3 are summed. The result is $(0.741, 0.158)$. At the end of the processes, the Fermatean fuzzy decision matrix is obtained and is expressed in Table 11.

The Fermatean fuzzy decision matrix is normalized. Afterwards, the entropy value of each criterion is calculated. Finally, the weights of the criteria are computed with the Entropy values. Diversity and weight values of feasibility criteria for blue energy projects are summarized in Table 12.

According to the order of magnitude of the values in Table 12, the most important criterion for blue energy projects is Technological Infrastructure. As can be seen from the result, technological infrastructure is extremely important for blue energy projects. In other words, projects with a strong technological infrastructure are more successful. Another important criterion is the expected return rate of the project. In the feasibility of blue energy projects, projects with high return rates come to the fore.

4.3. Ranking the strategic alternatives for increasing the capacity of blue energy projects using FF-CoCoSo

The Fermatean fuzzy decision matrix in Table 11 and the Criterion weights in Table 12 are used to rank the alternatives. After the Fermatean fuzzy decision matrix in Table 11 is normalized, the weighted sum and weighted product models are calculated. Afterwards, the results of the models are defuzzified. Fermatean fuzzy and defuzzified results of the two models are exhibited in Table 13.

Then, using W and P values, Ka, Kb and Kc values are computed respectively. The results of these values are shared in Table 14. Where, the lambda value for Kc is calculated as 0.5.

Finally, the performance value of the alternatives is calculated. K values of strategic alternatives to increase the capacity of blue energy projects are illustrated in Table 15.

According to Table 15, the most suitable strategy for increasing the capacities of blue energy investments is COLINV. As can be seen from this result, in order to increase the capacity of blue energy projects, it is necessary to increase innovative technologies and cooperate with companies ready for investment.

4.4. Comparative results

The ranking of strategies created to increase the capacity of blue energy projects is compared with the results of the SAW and MAIRCA methods with the help of different weights. The results of the two methods are calculated for ten different scenarios created using four different weights. The comparison of the results is visualized in Fig. 2.

Since both methods give similar results in different weight scenarios, it can be seen that the results are consistent, and the ranking is valid.

5. Discussion

When conducting feasibility analysis for blue energy investments, the technological infrastructure of the company plays a critical role in many aspects. Thanks to advanced technologies, it is possible to collect more comprehensive data. These data are necessary to perform feasibility analyzes correctly. On the other hand, thanks to the development of technology, advanced data analysis techniques can be used. This allows more effective analysis results to be achieved. Similarly, Isloor and Kumar [9] discussed that thanks to these comprehensive analyses, it is possible to determine the risks in the process more accurately. Thus, more accurate strategies can be implemented. On the other hand, Zagonari [36] demonstrated that advanced technology offers innovative solutions in energy production and operational processes. Thus, it is possible to increase the efficiency in operational processes. Thanks to this efficiency, feasibility analysis for blue energy investments can be carried out more accurately. Jiao et al. [14] indicated that financial sustainability of businesses can be ensured by effectively managing costs. This also contributes to the feasibility analysis being more successful.

It is of great importance that the financial performance of the business is good to conduct a more successful feasibility analysis for blue energy investments. As the financial performance of the business increases, the planning process can be implemented more effectively. Thus, it is possible to carry out the feasibility analysis more successfully. On the other hand, Trivedi et al. [28] showed that investors want to invest in businesses with high financial performance. Since the initial investment costs of blue energy projects are high, it may be difficult to find sufficient financing sources. In this context, Novotny [21] demonstrated that businesses with high financial performance can access these resources more easily. It is possible for businesses that can easily access sufficient funding sources to carry out feasibility analysis more successfully. In addition to them, Jiang et al. [11] concluded that if the financial performance is high, it is possible to reduce some risks faced by the business. This allows the feasibility analysis to be carried out more successfully.

6. Conclusion

This study aims to find the most appropriate strategies to increase the effectiveness of the feasibility analysis of blue energy investments with the help of a novel decision-making model. First, the importance levels of experts are computed using machine learning technique. The second stage consists of weighting the feasibility criteria set for blue energy project investment using Fermatean fuzzy entropy. In the final stage, the strategic alternatives for increasing the capacity of blue energy projects are ranked using Fermatean fuzzy CoCoSo. It is defined that the technological infrastructure of the company plays the most critical role when conducting feasibility analysis for blue energy investments. Similarly, it is also identified that the financial performance of the business is also important to conduct a more successful feasibility analysis for blue energy investments. On the other side, the ranking results demonstrate that collaborating with the investment-ready companies for increasing the innovative technologies is the most appropriate strategy to increase the capacity of blue energy projects.

The main limitation of this study is that only blue energy projects are taken into consideration. However, other renewable energy types also play a crucial role for the social and economic development of the countries. Thus, a similar evaluation can also be conducted for wind solar energy projects. On the other hand, the proposed model includes some limitations. For example, CoCoSo and SAW techniques are used for ranking the strategic alternatives for increasing the capacity of blue energy projects. Some scholars criticized these methods due to the calculation process. Thus, a new methodology can be proposed in the following studies to rank different alternatives. Similar to this issue, while computing the weights of the decision makers, a limited number of indicators are taken into consideration. However, some additional variables can have an influence on this situation. In the next studies, a more comprehensive examination can be performed by considering more determinants. With the help of this issue, more sensitive calculations can be conducted.

CRediT authorship contribution statement

Hasan Dinçer: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Serhat Yüksel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Serkan Eti:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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

No data was used for the research described in the article.

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