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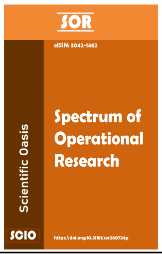

Multi-Criteria Evaluation of Wind Turbines using Entropy-based-TOPSIS and CoCoSo Methods: Insights from a Turkish Case Study

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ABSTRACT

This study evaluated different alternatives using entropy-based TOPSIS and CoCoSo techniques, which are multi-criteria decision-making (MCDM) methods, to optimise the decision-making process in wind turbine selection. The study considered six criteria: price, rated power, rotor diameter, turbine size, noise emission value, and annual energy production. As a result of the analyses, Wind turbine-3 and Wind turbine-4 were the most suitable options. The findings revealed that criteria such as energy efficiency, sizeable nominal power, and minimisation of sound emission play a critical role in wind turbine selection. The findings of this study provide a more objective and analytical approach for decision-makers in wind energy projects. The Entropy-based TOPSIS and CoCoSo methodologies used in this study provide consistent and reliable results in evaluating alternatives. In particular, the fact that the CoCoSo method obtains similar rankings with TOPSIS shows that the methods can complement each other in multi-criteria decision-making problems.

1. Introduction

Renewable energy sources are becoming increasingly important with increased energy demand and environmental concerns worldwide. In this context, wind energy is an environmentally friendly and unlimited energy source. Wind energy is among the strategies developed to reduce global warming and support the Kyoto Protocol. Many countries have invested in this renewable energy source, and wind energy has gradually increased its importance by meeting 4% of the world's electricity demand today. Wind energy is generated by pressure differences caused by the sun heating the land and

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sea at different rates. This technology, which has progressed rapidly in recent years, offers a strong alternative to traditional energy systems. Wind turbines are the most critical components of systems that convert the kinetic energy of the wind into electrical energy. Therefore, wind turbines should be selected more meticulously for long-term use [1].

Traditional decision-making methods are often insufficient to capture the multifacetedness of the problem of evaluating renewable energy resources. Multi-Criteria Decision Making (MCDM) methods have emerged as effective tools to deal with these complexities where multiple conflicting criteria need to be evaluated simultaneously [2]. Many MCDM methods have been used in the problem of selecting renewable energy sources, each with its own strengths and limitations. Özdamar [3] stated that wind energy generation provides economic advantages according to regions by comparing different wind turbines according to various criteria. Çolak and Kaya [4] examined seven alternative energy sources—solar, wind, hydraulic, geothermal, biomass, hydrogen, and wave—to determine the most suitable renewable energy source for Türkiye. The study stated that wind energy was determined as the best option, and solar energy was the second best option. Wave and hydrogen energy were found to be remarkable in terms of their future potential with low proximity index values. Taraf and Yazgan [5] evaluated the renewable energy potential of Türkiye, emphasising the importance of energy for economic development and social welfare. In the analysis conducted by the Analytic Network Process (ANP) method, Manisa for geothermal energy and Marmara Region for wind energy were determined as the most suitable regions. The study states that geological factors in geothermal and weather conditions in wind energy are decisive and that these findings can guide the site selection and feasibility studies of the facilities. Büyükikiz [6] compared seven renewable energy sources in Türkiye (solar, hydroelectric, geothermal, wind, biomass, hydrogen, wave) with AHP (Analytic Hierarchy Process) and Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods. According to the results of both methods, hydroelectric energy was found to be the most suitable option. The study revealed that fewer criteria provide more reliable results in energy selection. Derse and Yontar [7] evaluated the renewable energy resources in Türkiye with Step-wise Weight Assessment Ratio Analysis (SWARA) and TOPSIS methods in terms of criteria such as cost, efficiency, employment and accessibility. The results show that hydroelectric energy is the most suitable option, followed by biomass, geothermal, hydrogen, solar, wind and wave energy. Karaaslan and Aydın [8], in their study, determined hydroelectric energy as the most suitable source according to the evaluation made with Complex Proportional Assessment (COPRAS) and MULTIMOORA (Multiple Objective Optimisation based on Ratio Analysis) methods and then revealed that solar, wind, geothermal and biomass energies are the most suitable energy sources respectively. They found that economic criteria, especially maintenance cost, electricity production cost, risk and production amount, are the most important factors. Urfalı and Eylem [9] examined the site selection of wind power plants for Kayseri province with AHP and GIS methods. The study divided the suitability map created by considering environmental, socio-cultural and economic criteria into four classes. The analyses showed that most of the existing power plants are located in the most suitable areas, and the method is applicable. Yiğit and Akpınar [10] used the fuzzy AHP method to determine the safest alternative by evaluating the cost and structural strength of wind turbine towers. The analyses showed that hybrid towers are the most suitable option. It is stated that future studies with methods such as PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations), TOPSIS, VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) and mathematical models can provide new findings. Bilgiç et al. [11] evaluated renewable energy resources with the Best-Worst Method (BWM) to ensure Türkiye's energy supply security and reduce foreign dependency. In the analysis made in line with 13 criteria for an energy company in Central Anatolia Region, it was determined that the most suitable alternative was energy. Aslay [12] states in his study that users consider factors such as cost, temperature coefficient and energy efficiency when choosing between solar energy panels. In order to help users choose the most suitable panel, the TOPSIS method was applied, and monocrystalline, perc monocrystalline, polycrystalline, thin film and semi-flexible panel types were evaluated. Karaaslan and Aydın [8] evaluated different renewable energy alternatives to meet Türkiye's energy needs. As a result of the analyses made using multi-criteria decision-making methods such as PROMETHEE, MULTIMOORA, and PSI (Preference Selection Index), "Hydraulic Energy" was determined as the most suitable option for Türkiye. Hydraulic energy stands out with advantages such as high production capacity and storage, but there are also challenges, such as large area requirements. In the existing literature, there are many review studies on evaluating renewable energy with MCDM methods [13–15].

One of the most popular renewable energy sources is wind energy. Wind turbine selection is a critical decision in the development of wind energy projects because it has a direct impact on operational efficiency, economic viability and environmental sustainability. In addition, the issue of wind turbine selection is of particular importance as it affects the energy quality and economic benefits of the wind farm. Wind turbine selection requires balancing various criteria such as cost, efficiency, environmental impact and technical performance [16]. Wind turbine selection criteria vary depending on the nature of the project. Criteria such as capacity, efficiency and durability [17], initial investment, maintenance costs and payback period [18, 19], noise level, carbon footprint and land use [20], and wind speed, turbulence and grid connection significantly affect turbine performance [21] are commonly used in wind turbine selection.

This study aims to provide a guideline for decision-makers, researchers, and industry representatives in the wind energy industry. It also aims to provide a basis for understanding the role of multi-criteria decision-making methods in wind turbine selection. In the study, wind turbines from renewable energy sources are evaluated using TOPSIS and CoCoSo (COmbined COmpromise SOlution) by considering the specified criteria and the results are compared.

The remainder of the paper is divided as follows: Section 2 provides theoretical information about TOPSIS and CoCoSo, while Section 3 describes the case study, criteria, and alternatives. It also presents the methodology's application to the problem and the empirical results. Finally, Section 4 presents this study's conclusions.

2. Methodology

2.1 Determination of criteria weights by entropy weighting technique

Entropy is a concept that originated in thermodynamics and was added to information theory by Shannon [22] as entropy weight. The entropy weighting method determines objective weights by calculating the information entropy of the criteria. It is used to analyse the differences between criteria and criteria with the same value in all alternatives are excluded from the evaluation [23]. It is widely used in fields such as engineering, technology and social sciences [24]. The steps of the technique applied for the criteria weights used in this study are as follows:

Step 1: *Creating the decision matrix*: Let *D* be a decision matrix consisting of *n* criteria and *m* alternatives. Here, it is the initial matrix that the decision maker (DM) will first create. In the decision matrix, d_{ij} shows the score of alternative a_i with respect to criterion c_j.

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix}, \ \forall \ i,j \tag{1}$$

Step 2: *Normalisation of the actual performance data in the decision metric*:

$$r_{ij} = \frac{d_{ij}}{\sum_{i=1}^{m} d_{ij}}, \; \forall \; i, j \tag{2}$$

Step 3: *Calculating the entropy value of each criterion*: Using the calculated normalised values, the entropy value of each criterion is calculated using Eq. (3).

$$z_j = -k \sum_{i=1}^{m} r_{ij} \ln\left(r_{ij}\right) = -\frac{1}{\ln\left(m\right)} \sum_{i=1}^{m} r_{ij} \ln\left(r_{ij}\right) \tag{3}$$

Here $\ln\left(-\right)$ is the logarithm based on e and z_j is $[0, 1]$.

Step 4: *Calculation of the priority weight of each criterion*: Using the entropy values, the weight of each criterion is calculated using Eq. (4).

$$w_j = \frac{1 - z_j}{\sum_{j=1}^{n} \left(1 - z_j\right)} \tag{4}$$

2.2 *Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)*

TOPSIS is a method proposed by Hwang et al. [25] and widely used to solve MCDM problems. Its basic principle is that the best alternative is closest to the positive ideal solution and farthest from the negative ideal solution [26]. The positive ideal solution represents the highest benefit and lowest cost, while the negative ideal solution represents the lowest benefit and highest cost. The basic steps of the TOPSIS method are explained below [27]:

Step 1: *Creating the decision matrix*: An initial matrix consisting of the criteria values of the alternatives is created. This matrix structure is given in Step 1 in Section 2.1.

Step 2: *Constructing the normalised decision matrix*: After creating the decision matrix *D*, the following equation is used for vector normalisation:

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}}, \; \forall \; i, j \tag{5}$$

The normalised decision matrix calculated by Eq. (5) is given in Eq. (6).

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{6}$$

Step 3: *Weighting the normalised matrix*: The normalised values are multiplied by the weights w_j calculated using the entropy technique and obtained from Eq. (7). The final weighted normalised decision matrix is as follows.

$$V = \begin{bmatrix} w_1 \cdot r_{11} & w_2 \cdot r_{12} & \cdots & w_n \cdot r_{1n} \\ w_1 \cdot r_{21} & w_2 \cdot r_{22} & \cdots & w_n \cdot r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 \cdot r_{m1} & w_2 \cdot r_{m2} & \cdots & w_n \cdot r_{mn} \end{bmatrix} \tag{7}$$

Step 4: *Determination of positive and negative ideal solutions*: In this step, the positive ideal solution V^+ and the negative ideal solution V^- are calculated with the help of the following equations.

$$V^+ = \left\{ \left(\max V_{ij} / J^+ \right), \left(\min V_{ij} / J^- \right) \right\} \tag{8}$$

$$V^- = \left\{ \left(\min V_{ij} / J^+ \right), \left(\max V_{ij} / J^- \right) \right\} \tag{9}$$

Here, J^+ refers to the benefit criteria and J^- refers to the cost criteria.

Step 5: *Calculation of distances*: The distance of the decision or solution to both options is calculated with the help of Eqs. (10)-(11).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_i^+ \right)^2}, \ \forall\, i \tag{10}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_i^- \right)^2}, \ \forall\, i \tag{11}$$

Step 6: *Calculation of the relative closeness to the ideal solution*: The relative closeness to the ideal solution is calculated as follows.

$$C_i^+ = \frac{S_i^-}{S_i^+ - S_i^-}, \ \forall\, i \tag{12}$$

Step 7: *Ranking*: At this step, the alternatives are ranked according to their proximity to the ideal solution.

2.3 Combined Compromise Solution (CoCoSo)

Yazdani et al. [28] developed a CRM technique called CoCoSo by combining the exponentially weighted product model with a simple additive weighting method. The CoCoSo approach in this study is used to determine the ranking of alternatives. Five steps in a typical CoCoSo model with alternatives and n criteria are given below.

Step 1: *Creating the decision matrix*: An initial matrix consisting of the criteria values of the alternatives is created. This matrix structure is given in Step 1 in Section 2.1.

Step 2: *Normalisation*: In order to eliminate the effect of measuring the criteria with different units of measurement, the criteria values (decision matrix) showing the performance of each alternative on the basis of criteria should be normalised. With the help of Eqs. (13)-(14), the criteria are normalised according to the type of benefit or cost.

$$r_{ij} = \frac{d_{ij} - \min_i d_{ij}}{\max_i d_{ij} - \min_i d_{ij}}, \quad \text{for benefit criteria} \tag{13}$$

$$r_{ij} = \frac{\max_i d_{ij} - d_{ij}}{\max_i d_{ij} - \min_i d_{ij}}, \quad \text{for cost criteria} \tag{14}$$

Step 3: *Calculation of the weighted comparability sequence*: Based on the WSM (Weighted Sum Model) and WPM (Weighted Product Model) methods, the performance indices S_i and P_i are estimated for each alternative. These calculations are shown in Eqs. (15)-(16). Criterion weights are expressed by w_j, which indicates the level of importance of each criterion. S_i represents the weighted sum of the performances of the *i*th alternative, i.e. the weighted total performance of the *i*th alternative, while P_i represents the sum of the weighted product of the performances of the *i*th alternative.

$$S_i = \sum_{j=1}^{n} w_j \cdot r_{ij}, \ \ \forall i \tag{15}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j}, \ \ \forall i \tag{16}$$

Step 4: *Aggregation evaluation strategies*: Three different scoring strategies are applied to determine the importance of the alternatives.

$$k_{ia} = \frac{(S_i + P_i)}{\sum_{i=1}^{m} (S_i + P_i)} \tag{17}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{18}$$

$$k_{ic} = \frac{\lambda S_i + (1-\lambda)\, P_i}{\lambda \max_i S_i + (1-\lambda) \max_i P_i} \tag{19}$$

Here, Eq. (17) is the average of the WSM and WPM scores, and Eq. (18) is the sum of the scores relative to the best alternative. Eq. (19) provides a balanced compromise between these scores. In Eq. (19), the threshold value λ (lambda) set by the decision maker varies between 0 and 1, and 0.5 is assumed by default. This value affects the flexibility and stability of the method [29].

Step 5: *Final ranking*: The ranking of the alternatives is done with the help of the following formula using the calculated evaluation values (k_i):

$$k_i = (k_{ia} \cdot k_{ib} \cdot k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{20}$$

3. Real-case study of wind turbine

Renewable energy sources play a critical role in sustainable development and environmental protection. Wind energy, in particular, reduces greenhouse gas emissions and increases energy security by reducing dependence on fossil fuels [30]. The Marmara Region in northwestern Türkiye, especially Çanakkale and Balıkesir provinces, offers significant opportunities in terms of wind energy potential. Due to their geographical location and climate characteristics, Çanakkale and Balıkesir are among the regions with the most efficient wind energy resources in Türkiye. The area around the Dardanelles, especially the Lapseki, Gelibolu, and Biga districts, attracts attention due to high wind speeds. The wind speed in the region varies between 7-8 m/s per year on average, and these values are pretty suitable for the efficient operation of commercial wind turbines [31]. Similarly, Bandırma, Gönen and Susurluk districts of Balıkesir offer favourable areas for wind energy investments thanks to their vast and open land structures. Figure 1 shows the wind energy potential in the Marmara Region.

Both Çanakkale and Balıkesir have a significant potential for onshore wind turbines. Especially the inland regions of Çanakkale and the districts of Balıkesir, such as Bandırma, Manyas and Susurluk, have favourable wind conditions for wind turbines. Within the scope of Türkiye's renewable energy projects, large-scale wind power plants are planned to be built in these regions IRENA [32]. Considering the high wind energy potential and energy demand in the region, this study was determined as an application area for wind turbine selection.

Based on the literature review and consultations with the management of the joint-stock company, a hierarchical structural model was developed, as illustrated in Figure 2. This hierarchical structure determined six criteria for wind turbine selection: monthly cost, nominal power, rotor diameter, wind turbine size, emission value and annual energy consumption. To maintain anonymity, the four wind turbines evaluated are identified as A$_1$, A$_2$, A$_3$ and A$_4$ and the characteristics of the alternatives for each criterion are listed in Table 1.

In this case study, the group decision-making process, such as identifying criteria and alternatives and determining the criteria values for each alternative, was carried out with the support of 5 decision makers (DMs) with expertise and experience in a wind turbine. The CVs were asked to discuss various decisions and considerations for selecting the most appropriate wind turbine. In this study, the first expert (KV$_1$) is an electrical and electronic engineer with 10 years of experience in renewable energy systems and project management. The second expert (KV$_2$) is a mechanical engineer with 8 years of expertise in wind energy system design and aerodynamic analysis. The third expert (KV$_3$) is a technician in the field of mechanical technologies with 7 years of expertise in mechanical maintenance and

Fig. 1. Potential locations map for the Marmara Region

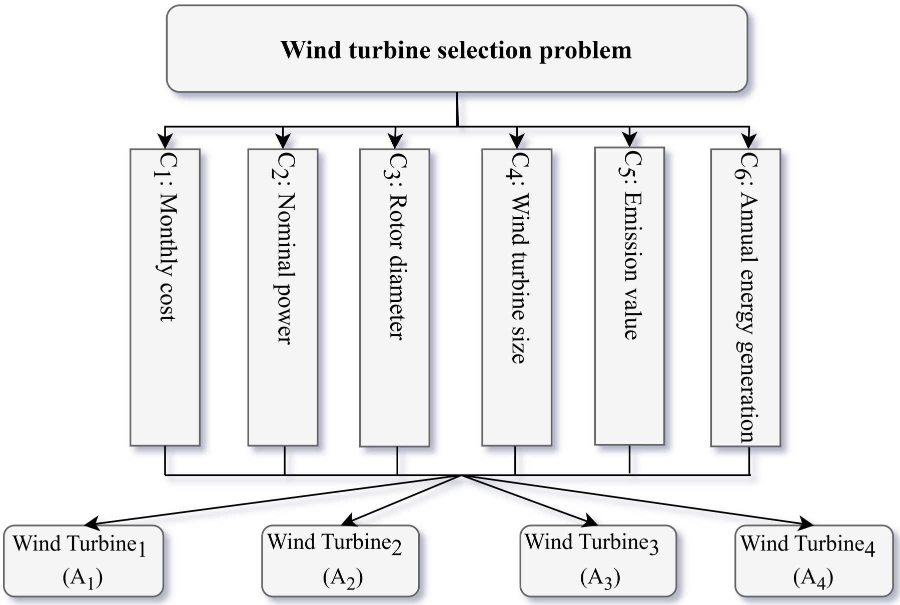

Fig. 2. The hierarchical structure of the wind turbine evaluation problem

repair of wind turbines. The fourth expert (KV_4) is a technician in electrical and electronic technologies with 5 years of expertise in electrical and power systems. The fifth expert (KV_5) is a technician in electrical and electronic technologies with 6 years of expertise in the field operation and installation processes of wind turbines.

Table 1
Specifications of each wind turbine

	Wind Turbine$_1$	Wind Turbine$_2$	Wind Turbine$_3$	Wind Turbine$_4$	Criteria Type
C$_1$: Monthly cost (₺)	34500	32500	37500	39000	Cost
C$_2$: Nominal power (kW)	1750	1800	2000	2100	Benefit
C$_3$: Rotor diameter (m)	66	64	68	67	Benefit
C$_4$: Wind turbine size (m)	67	68	72	70	Benefit
C$_5$: Emission value (db)	104	103	103	102	Cost
C$_6$: Annual energy generation (mwH)	5	4	6	7	Benefit

3.1 *Determining the weights of the criteria with the entropy weighting technique*

After the decision matrix (*D*) was created in Table 1 with 5 decision-makers, the weight of each criterion was calculated with the help of the formulae in Eqs. (1)-(4), as shown in Table 2.

Table 2
Comprehensive weight value for each criterion

Criteria	C$_1$	C$_2$	C$_3$	C$_4$	C$_5$	C$_6$
w_j	0.0932	0.1040	0.0093	0.0143	0.0009	0.7783

3.2 *Evaluation of wind turbine with TOPSIS method*

After the decision matrix was formed, the normalised decision matrix given in Table 3 was obtained with the help of Eq. (5).

Table 3
Normalised values

	Wind Turbine$_1$	Wind Turbine$_2$	Wind Turbine$_3$	Wind Turbine$_4$
C$_1$	0.4796	0.4518	0.5213	0.5422
C$_2$	0.4562	0.4693	0.5214	0.5475
C$_3$	0.4980	0.4829	0.5131	0.5055
C$_4$	0.4836	0.4908	0.5197	0.5052
C$_5$	0.5048	0.5000	0.5000	0.4951
C$_6$	0.4454	0.3563	0.5345	0.6236

Using the weight values of each criterion obtained in Table 2, a weighted normalised decision matrix is obtained as shown in Table 4. Then, the negative and positive ideal solutions obtained by using Eqs. (8)-(11) are also presented in Table 4.

Using Eqs. (10)-(12), distance calculations were made and scores of closeness to the ideal solution were obtained. Accordingly, a ranking in Table 5 was obtained. Wind turbine$_4$ ranked first with the highest score of 0.9611, followed by Wind turbine$_2$ and Wind turbine$_3$. Wind turbine$_2$ was ranked last with the lowest score of 0.0394.

3.3 *Evaluation of wind turbine with CoCoSo method*

In this subsection. wind turbines are evaluated using the entropy-based CoCoso method. The aim here is to determine the most suitable wind turbine. For this reason. CoCoSo steps are applied to the

Table 4
Weighted normalised decision matrix

	Wind Turbine$_1$	Wind Turbine$_2$	Wind Turbine$_3$	Wind Turbine$_4$	V^+	V^-
C$_1$	0.0447	0.0421	0.0486	0.0505	0.0421	0.0505
C$_2$	0.0474	0.0488	0.0542	0.0569	0.0569	0.0474
C$_3$	0.0046	0.0045	0.0048	0.0047	0.0048	0.0045
C$_4$	0.0069	0.0070	0.0074	0.0072	0.0074	0.0069
C$_5$	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
C$_6$	0.3467	0.2774	0.4160	0.4854	0.4854	0.2774

Table 5
Sequencing of each wind turbine

Alternatives	S_i^+	S_i^-	C_i	Final rank
A$_1$	0.1390	0.0696	0.3336	3
A$_2$	0.2082	0.0085	0.0394	4
A$_3$	0.0697	0.1389	0.6658	2
A$_4$	0.0084	0.2082	0.9611	1

real-life problem respectively. Using Eqs. (13)-(14), the decision matrix, which was previously used for the TOPSIS method, was normalised. Afterwards, the third step of the CoCoSo method, which involves the integration of *S* and *P* values using Eqs (15)-(16), was applied. Normalised decision matrix and *S* and *P* values. It is presented in Table 6.

Table 6
The normalised decision matrix and the aggregation strategies for CoCoSo

	Wind Turbine$_1$	Wind Turbine$_2$	Wind Turbine$_3$	Wind Turbine$_4$
C$_1$	0.6923	1	0.2308	0
C$_2$	0	0.1429	0.7143	1
C$_3$	0.5	0	1	0.75
C$_4$	0	0.2	1	0.6
C$_5$	0	0.5	0.5	1
C$_6$	0.3333	0	0.6667	1
S_i	0.3286	0.1114	0.6387	0.8987
P_i	23.851	37.935	55.666	49.901

As a result of the integration of *S* and *P* values, k_{ia}, k_{ib} and k_{ic} values are obtained. As a result, k_i is determined to show the final ranking of the wind turbines. According to this final ranking, Wind turbine$_4$ is determined as the most preferable alternative by CoCoSo method, while Wind turbine$_2$ is determined as the worst alternative.

Table 7
Final aggregation of alternatives and CoCoSo ranking

Alternatives	k_{ia}	Rank	k_{ib}	Rank	k_{ic}	Rank	k_i	Final rank
A$_1$	0.1450	4	39.508	3	0.4197	4	21.271	3
A$_2$	0.2087	3	25.905	4	0.6040	3	18.230	4
A$_3$	0.3316	1	80.687	2	0.9598	1	44.894	2
A$_4$	0.3147	2	101.617	1	0.9108	2	52.239	1

4. Conclusion and discussion

In order to optimise the decision-making process in wind turbine selection, this study evaluated different alternatives using Entropy-based TOPSIS and CoCoSo techniques from multi-criteria decision-making (MCDM) methods. As a result of the analyses, it was found that Wind turbine$_3$ and Wind turbine$_4$ turbines were superior to the other alternatives in important criteria. The findings revealed that criteria such as energy efficiency, large-rated power and minimisation of noise emissions play a critical role in wind turbine selection.

The findings of this study provide a more objective and analytical approach for decision-makers in wind energy projects. The Entropy-based TOPSIS and CoCoSo methodologies used in this study provide consistent and reliable results in evaluating alternatives. In particular, the CoCoSo method obtains similar rankings with TOPSIS, indicating that the methods can complement each other in multi-criteria decision-making problems.

The results obtained in the study are largely consistent with similar studies in the literature. Previous studies [1, 7] also emphasised that energy efficiency is one of the most critical factors in wind energy projects by using similar multi-criteria decision-making methods. However, the different contribution of this study is that it makes the decision-making process more reliable by using Entropy-based CoCoSo and TOPSIS methods together.

The limitations of the study include the fact that only six criteria were considered, and the number of expert opinions was limited to a certain number. Future studies can increase the generalisability of the model by including more criteria and different decision-makers. Furthermore, comparative analyses with other multi-criteria decision-making methods, such as PROMETHEE, and VIKOR, can be conducted to provide a broader perspective on the most appropriate decision-making methods.

In conclusion, this study has demonstrated that MCDM methods can effectively support decision-making in wind energy. It is recommended that this approach be adopted to make more informed and efficient decisions in wind energy projects. Future studies can provide more comprehensive findings by applying the methodology to different energy types and environmental conditions.

Conflicts of Interest

The authors declare no conflicts of interest.

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