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PERFORMANCE ANALYSIS FOR THE MOST CONVENIENT WIND TURBINE SELECTION IN WIND ENERGY FACILITY

Abstract. *As governments seek renewable and more sustainable energy resources, wind energy has emerged as one of the most rapidly developing renewable power resources. The relevance of wind energy turbines has grown as more nations turn to renewable energy. A significant criterion that conduces to wind energy's efficient production is the proper wind turbine's utilize. Due to the fact that a lot of wind turbine manufacturers have built a global presence, it is critical for project administrators to do informed selections about which wind energy turbines to establish in every specific design. Therefore the problem of wind energy turbine choice is critical for nations experiencing global warming and climate change. This study proposes a new hybrid MCDM model including CCSD and MULTIMOOSRAL methods. In this study, 11 100kW wind turbines (T) are evaluated based on 14 criteria. According to the results of the proposed model, T7 coded wind turbine alternative was determined as the best one. The results of the proposed method were compared with other MCDM methods and it was confirmed that the proposed method reached accurate results. In addition, it was determined that the changes in the criteria weights changed the ranking of the alternatives.*

Keywords*: Renewable Energy, Wind Turbine, CCSD, MULTIMOOSRA.*

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1. Introduction

Population increase and financial development need the use of electricity energy. Despite the fact that it is primarily obtained from traditional resources like natural gas, oil, and coal, the ecological effects of these resources are far worse than those caused through the renewable energy resources' usage (Kumar et al., 2016). The majority of regions and countries have made optimal use of energy resources a priority. Given the fact that many nations have abandoned the use of raw fossil resources, renewable energy production will continue to rise in importance. In this reason, climate change and global warming have raised human consciousness of the importance of environmental preservation and altered the industrial development focus to less-C renewable energy (ECA, 2019). Solar radiation, wind, biomass, marine tides, precipitation, geothermal energy, and sea waves are all examples of renewable energy resources. Water's gravitational energy is the most often utilized renewable energy resource. It amounted to 62.80 percent of power from renewable resources in 2018. Other resources contain wind energy accounts for 19.00 percent, geothermal energy for 6.30 percent, biofuels for 6.30 percent, and solar energy for 8.80 percent (BP Statistical Review, 2019).

Wind energy has seen the most resource consumption growth in the recent two decades. It also has a high rate of return on investment. Wind energy's global popularity is due to the energy resource's widespread availability, which is wind. There is a possible impact on the environment. Nonetheless, wind farm lands, on the other hand, can still be used for agricultural and other uses. Currently, wind facilities are operational in about eighty nations, and there are numerous advantages to building wind facilities in both developing and established countries. Stable electricity costs, energy security increased, financial improvement to generate jobs and attract investment, less reliance on foreign fuels, CO2 emissions declines, and air quality improved are just a few of the advantages (GWEC, 2011). That is, wind power is generated without emitting dangerous contaminants into the sky, and hence has a limited influence on ecosystems (Ehrlich et al., 2018). It's also critical that the wind farm can function both as part of a power system and independently. The entire investment process takes around two years and allows the investor to choose the farm output that best suits his or her demands and financial resources.

Wind is caused through the earth surface's uneven heating by sun. Turbines transform wind kinetic energy into mechanic energy, which drives a power unit to generate neat electrical energy. Wind turbines are today's modular, versatile producers of electricity. Their wings are planned to gain the maximal amount of power from the wind energy. Wind energy rotates the wings, which rotate a mile attached to a power unit or the rotor of the generator, which generates power (Tenghiri, 2018). When picking a site for a wind farm, it's critical to look for one with the most wind energy capacity. Where the yearly mean wind speed exceeds 5 m/s is the most favorable site (Wais, 2017). The diagnostics of solid barriers and land roughness, topographic maps, suppositions on wind circumstances, and choice of efficient wind turbines are all taken into account while determining on the development of next wind facilities. Installing the most productive wind turbine is critical for increasing the wind farm's production. Varied wind turbines have different manufacturing processes and installation technologies, each with its own benefits in terms of production cost, failure ratio, and power generation. The required wind turbine's size is determined on the implementation. The small wind turbines are available in sizes ranging between 100 and 20 kilowatts. Depending on the quantity of electricity it wishes to generate, wind turbines utilized in residential implementations can vary in size between 100 kW and 40 W (100 kW for too heavy loads). This information will assist in determining the turbine's size will require. Since efficiency of energy is generally cheaper than power generation, making home more powerful will likely save money and allow to minimize the wind turbine's size require. Manufacturers, dealers, and installers of wind turbines can assist in sizing system depending on energy needs as well as the characteristics of local micro-siting and wind source. The wind turbine's planned annual power production as a function of annual mean wind velocity can be derived from the installer, supplier, or manufacturer. The producer will also disclose any maximal wind velocities at which the wind turbine is planned to safely function. To protect the rotor from control's spinning out in exceptionally strong gusts, most turbines incorporate automatic over speed controlling mechanisms. A wind facility incurs 3 sorts of expenses to generate electricity: capital, operating, and finance costs. The capital expenses are the expenses of establishing and connecting the power plant to the grid; the operating and maintenance costs are the costs of operating and maintaining the wind facility: and the finance costs are the costs of obtaining the essential funding for developing and operating a wind facility. Nonetheless, because the expenses of wind turbines account for the bulk of the whole expense of a wind facility planning, selecting adequate wind turbines is critical. Furthermore, the adaptability of wind turbines for a specific area may have an impact on their capacity factor.

The renewable energy options' selection and evaluation is a MCDM issue. Multi-criteria, some of which may be in conflict, must be considered therewithal. MCDM methodologies, like ÉLECTRE, ANP, MAUT, TOPSIS, PROMETHEE, VIKOR, MODM, and AHP, have been utilized in the renewable power design assessment (San Cristóbal, 2013). Renewable energy facility designing, geothermal planning, solar energy planning, wind farm planning, and hydro site choosing, among other things, have all used MCDM in the past (Kahraman et al., 2009). Although the renewable energy assessment topic is gaining more carefulness these years, the utilization of MCDM techniques to address the complicated challenge of fuzzy and imprecise data remains limited. Here is a look at some recent energy decision-making research.

The optimal locations for wind power plants were found using an MCDM approach with equal weights. For a biomass energy facility, Ioannou et al. (2018) created an areal decision-support mechanism for determining the best location. Fuzzy logic and AHP were used to create the decision system. The 6 criteria were chosen, and the significance of each was allocated depend on the opinions of professionals. In Spain, San Cristóbal (2013) offered a case research in which the VIKOR approach, a strategy of compromise, was used as an MCDM to pick a renewable energy project established by the Spanish government. An analytical hierarchy procedure was used to determine the weight, and followed a biomass design through wind energy facilities was found to be the most suitable alternative. The TOPSIS and the AHP, along with GIS, were used by Konstantinos et al. (2019) to establish an approach for choosing wind facility sites. Thrace and Eastern Macedonia in Greece were the areas under investigation. Three qualitative factors were chosen from 7 attributive criteria (height/elevation, wind speed, slope, space from provinces, space from shore, and the like). The most essential criterion turned out to be wind speed. A decision support approach was used to assign 34 sites, which were then narrowed to 17 and ranked by TOPSIS. For identifying the optimal sustainable power option in Turkey, Kahraman et al. (2009) utilized two MCDM methods, which are fuzzy axiomatic design and AHP. A case comparison revealed that both techniques produced the same result. Tagle et al. (2017) looked into the possibilities of Saudi Arabia's wind energy resources. The influence of an alter in interior climatic on the periodical wind energy intensity was investigated using a computer system. Important carefulness has been dediced to wind energy turbine choice topic in over the twenty-year lifetime. Because the wind facility's construction is a difficult process, and the most proper wind turbines' choosing is critical for the wind farm's next functioning, a systematical MCDM modeling for wind turbine's analyzing alternative systems is requisite for fulfillment the right choice option. Wind turbine choice strategy depend on SCADA information analysis was proposed by Du et al. (2017). Lee et al. (2012) suggested a MCDM that took into account economic considerations, environmental concerns, technical challenges, and machine features. Four turbines were evaluated, each with almost the same rated power.

In recent years, many studies have been carried out on the selection of wind turbines. These studies are listed in Table 1.

Table 1. The recent studies

Authors	Methods
Uzunlar et al. (2020)	ANP and Cost-Benefit Analysis
Beskese et al. (2020)	Hesitant fuzzy AHP and TOPSIS
Supçiller and Toprak (2020)	SWARA, Single Valued Neutrosophic TOPSIS, EDAS
Yörükoğlu and Aydın	MULTIMOORA

(2021)	
Xue et al. (2021)	Fuzzy Bayesian Network based MADM
Ma et al. (2022)	ANP and Entropy
Eryilmaz and Navarro (2021)	Decision Theoretic Framework
Wang et al. (2022)	Dempster Shafer, SWARA and TOPSIS

Unlike other studies, this study will select a wind turbine with a new hybrid MCDM model consisting of CCSD and MULTIMOOSRAL methods. The rest of the study is organized as follows. Section 2 indicates the methodology of CCSD and MULTIMOOSRAL. Section 3 presents the results of CCSD and MULTIMOOSRAL. Section 4 presents a discussion section. The last section presents a brief conclusion.

2. Materials and Methods

In this study, the wind turbine selection will be made by the CCSD method and the MULTIMOOSRAL method. The methodology of the methods used in the study is presented below.

2.1. CCSD Method

CCSD (developed by Wang and Luo, 2010) is a weighting method. The steps of this method are presented as follows (Wang and Luo, 2010; Dahooie et al., 2019).

Step 1: Decision matrix (F) including m alternatives, $U_1, \dots, U_m$ based on the n criteria, $K_1, \dots, K_n$ is organized.

$$F = \left[f_{ij}\right]_{m\times n} \tag{1}$$

In equation 1, f_{ij} shows the performance of ith alternative for jth criterion.

Step 2: Equation 2 (for B(beneficial criteria)) and 3 (for NB(non-beneficial criteria)) are used to normalize this matrix.

$$g_{ij} = \frac{f_{ij}-\min(f_{ij})}{\max(f_{ij})-\min(f_{ij})} \tag{2}$$

$$g_{ij} = \frac{\max(f_{ij})-f_{ij}}{\max(f_{ij})-\min(f_{ij})} \tag{3}$$

Step 3: To consider its impact on decision-making, the criterion K_j is removed. Equation 4 is used to calculate the performance value (Hwang and Yoon, 1981).

$$e_{ij} = \sum_{k=1,k\neq j}^{n} g_{ik} w_k \tag{4}$$

Step 4: Equation 5 is utilized to calculate the correlation coefficient (B_j) between e_{ij} and K_j criterion's value.

$$B_j = \frac{\sum_{i=1}^{m}(g_{ij}-\bar{g}_j)(e_{ij}-\bar{e}_j)}{\sqrt{\sum_{i=1}^{m}(g_{ij}-\bar{g}_j)^2 \sum_{i=1}^{m}(e_{ij}-\bar{e}_j)^2}} \tag{5}$$

Where

$$\bar{g}_j = \frac{\sum_{i=1}^{m} g_{ij}}{m} \tag{6}$$

$$\bar{e}_j = \frac{\sum_{i=1}^{m} e_{ij}}{m} \tag{7}$$

Step 5: To identify weights (w_j) of criteria, a non-linear optimization model is written as.

$$Minimize\ J = \sum_{j=1}^{n}\left(w_j - \frac{\sigma_j\sqrt{1-B_j}}{\sum_{k=1}^{n}\sigma_k\sqrt{1-B_k}}\right)^2 \tag{8}$$

$$s.t. \sum_{j=1}^{n} w_j = 1$$

In equation 8, σ_j shows the standard deviation of K_j criterion. Equation 9 is used to compute this value.

$$\sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(g_{ij}-\bar{g}_j)^2} \tag{9}$$

2.2. MULTIMOOSRAL Method

The steps of MULTIMOOSRAL are explained as follows (Ulutaş et al., 2021).

Step 1. A decision matrix, which is indicated in Equation 1, is shown.

Step 2. Equation 10 is utilized to the normalized matrix.

$$t_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{n}(f_{ij})^2}} \tag{10}$$

Step 3. Each alternative's utility (c_i) based on Ratio System is calculated as follows.

$$c_i = \begin{cases} h_i, & max_i(h_i) > 0, \\ h_i + 1, & max_i(h_i) = 0, \\ -\frac{1}{h_i}, & max_i(h_i) < 0, \end{cases} \tag{11}$$

where

$$h_i = \sum_{j\in B} w_j t_{ij} - \sum_{j\in \mathrm{N}B} w_j t_{ij} \tag{12}$$

Step 4. Equation 13 is used to calculate the maximal distance (o_i) based on Reference Point.

$$o_i = \max_j(w_j\left|t_j^* - t_{ij}\right|) \tag{13}$$

In Equation 13, t_j^* value presents the reference point.

Step 5. Equation 14 is used to compute each alternative's utility (p_i) based on Full Multiplicative Form.

$$p_i = \frac{\prod_{j\in B} w_j t_{ij}}{\prod_{j\in \mathrm{N}B} w_j t_{ij}} \tag{14}$$

Step 6. Each alternative's utility (r_i) based on Addition Form is calculated as follows.

$$r_i = \frac{\sum_{j\in B} w_j t_{ij}}{\sum_{j\in \mathrm{N}B} w_j t_{ij}} \tag{15}$$

Step 7. Each alternative's utility (s_i) based on Logarithmic Approximation is obtained as follows.

$$s_i = \sum_{j\in B} \ln(1 + w_j t_{ij}) + \frac{1}{\sum_{j\in \mathrm{N}B} \ln(1+w_j t_{ij})} \tag{16}$$

Step 8. Equations 17-21 are used to normalize maximal distance (o_i) and the utility values (c_i, p_i, r_i, s_i).

$$c_i' = \frac{c_i - \min(c_i)}{\max(c_i) - \min(c_i)} \tag{17}$$

$$p_i' = \frac{p_i - \min(p_i)}{\max(p_i) - \min(p_i)} \tag{18}$$

$$r_i' = \frac{r_i - \min(r_i)}{\max(r_i) - \min(r_i)} \tag{19}$$

$$s_i' = \frac{s_i - \min(s_i)}{\max(s_i) - \min(s_i)} \tag{20}$$

$$o_i' = \frac{\max(o_i) - o_i}{\max(o_i) - \min(o_i)} \tag{21}$$

Step 9. By using Equation 22, the total utility value (V_i) is calculated.

$$V_i = c_i' + p_i' + r_i' + s_i' + o_i' \tag{22}$$

The alternative, which have the highest total utility value (V_i), is determined as the best one.

3. Results

In this study, 11 100kW wind turbines (T) are evaluated based on 14 criteria. The criteria taken into account in the study are listed below.

- Annual Output (AO)
- Capacity Factor (CF)
- Normal Rotor Diameter (NRD)
- Hub Height (HH)
- Cut-out Wind Speed (CWS)
- Nominal Wind Speed (NWS)
- Power Density (PD)
- Total Cost (TC)
- Support of Government (SG)
- Max. sound power (dB) (MSP)
- Electromagnetic effects (EEF)
- Service support (SSU)
- Spare part (SP)
- Reliability (R)

Only three (TC, MS and EEF) of the mentioned criteria were determined as non-beneficial criteria, and the other criteria were determined as beneficial criteria. The decision matrix showing the wind turbine alternatives and criteria is presented in Table 2.

Table 2. Wind Turbine Alternatives and Criteria

Criteria / Alternatives	AO	CF	NRD	HH	CWS	NWS	PD
T1	270	30.8	24	23/38 (30.5)	20.0	10.0	4.53
T2	255	29.0	19	20/35 (27.5)	20.0	10.0	2.84
T3	252	28.8	17.9	18/30 (24)	24.0	16.0	2.52
T4	265	30.2	21	23/38 (30.5)	25.0	14.5	3.47
T5	273	31.1	26	40	26.5	11.5	5.31
T6	277	31.6	29	30/50 (40)	25.0	10	6.61
T7	254	29.0	18	18/24 (21)	20.0	14.5	2.55
T8	259	29.5	21	23/40 (31.5)	25	12	3.47
T9	262	30.0	24	25/36 (30.5)	20	9.5	4.53
T10	265	30.0	20.7	29/37 (33)	25	15	3.37
T11	258	29.5	18	20/30 (25)	26	12	2.55

Criteria / Alternatives	TC	SG	MSP	EEF	SSU	SP	R
T1	653	0.31	93.2	7-12 (9.5)	4	3	4
T2	645	0.30	87.8	7-13 (10)	7	7	8
T3	640	0.28	88.0	6-16 (11)	9	10	9
T4	655	0.29	95.2	6-19 (12.5)	3	4	5
T5	700	0.32	96.6	7-13 (10)	2	1	1
T6	750	0.32	95.7	6-15 (10.5)	1	2	2
T7	632	0.28	89	6-12 (9)	11	11	10

T8	667	0.30	90.5	6-16 (11)	6	6	6
T9	724	0.30	95.2	7-15 (11)	5	5	3
T10	645	0.29	89.1	6-16 (11)	8	8	7
T11	620	0.29	88.0	7-14 (10.5)	10	9	11

The values of the HH and EEF criteria shown in Table 2 are interval values. The arithmetic mean of these values was taken and written in parentheses in the same table. If the CCSD method is applied to the decision matrix shown in Table 2, the weights of the criteria are found. Table 3 presents the results of CCSD method.

Table 3. The results of CCSD method

Weights \ Criteria	AO	CF	NRD	HH	CWS	NWS	PD
w_j	0.0663	0.0682	0.0745	0.0641	0.0711	0.0754	0.0716
Weights \ Criteria	**TC**	**SG**	**MSP**	**EEF**	**SSU**	**SP**	**R**
w_j	0.0672	0.0792	0.0905	0.0529	0.0728	0.0742	0.0719

According to Table 3, the weights of the criteria are listed as follows; MSP, SG, NWS, NRD, SP, SSU, R, PD, CWS, CF, TC, AO, HH, and EEF. After the weights of the criteria are found, the MULTIMOOSRAL method is used. Equation 10 is applied to Table 2 so that the values are normalized. Table 4 shows the normalized matrix.

Table 4. The normalized matrix

Alternatives \ Criteria	AO	CF	NRD	HH	CWS	NWS	PD
T1	0.3097	0.3099	0.3294	0.2981	0.2570	0.2417	0.3417
T2	0.2925	0.2918	0.2608	0.2688	0.2570	0.2417	0.2142
T3	0.2891	0.2898	0.2457	0.2345	0.3084	0.3867	0.1901
T4	0.3040	0.3039	0.2882	0.2981	0.3213	0.3504	0.2617
T5	0.3132	0.3129	0.3568	0.3909	0.3406	0.2779	0.4005
T6	0.3178	0.3179	0.3980	0.3909	0.3213	0.2417	0.4985
T7	0.2914	0.2918	0.2470	0.2052	0.2570	0.3504	0.1923
T8	0.2971	0.2968	0.2882	0.3078	0.3213	0.2900	0.2617

Criteria / Alternatives	TC	SG	MSP	EEF	SSU	SP	R
T9	0.3005	0.3018	0.3294	0.2981	0.2570	0.2296	0.3417
T10	0.3040	0.3018	0.2841	0.3225	0.3213	0.3625	0.2542
T11	0.2960	0.2968	0.2470	0.2443	0.3342	0.2900	0.1923

Criteria / Alternatives	TC	SG	MSP	EEF	SSU	SP	R
T1	0.2949	0.3131	0.3064	0.2707	0.1778	0.1334	0.1778
T2	0.2913	0.3030	0.2886	0.2849	0.3112	0.3112	0.3556
T3	0.2890	0.2828	0.2893	0.3134	0.4001	0.4446	0.4001
T4	0.2958	0.2929	0.3129	0.3561	0.1334	0.1778	0.2223
T5	0.3161	0.3232	0.3175	0.2849	0.0889	0.0445	0.0445
T6	0.3387	0.3232	0.3146	0.2991	0.0445	0.0889	0.0889
T7	0.2854	0.2828	0.2926	0.2564	0.4890	0.4890	0.4446
T8	0.3012	0.3030	0.2975	0.3134	0.2667	0.2667	0.2667
T9	0.3270	0.3030	0.3129	0.3134	0.2223	0.2223	0.1334
T10	0.2913	0.2929	0.2929	0.3134	0.3556	0.3556	0.3112
T11	0.2800	0.2929	0.2893	0.2991	0.4446	0.4001	0.4890

The utility values and maximal distances of the alternatives are found by applying Equations 12-16 to the normalized matrix. Table 5 presents utilities and maximal distances of the wind turbine alternatives.

Table 5. The utilities and maximal distances of the alternatives

Utilities / Alternatives	c_i	o_i	p_i	r_i	s_i
T1	0.1448	0.0264	0.0000000000000090	3.3411	16.54622
T2	0.1623	0.0204	0.0000000000000270	3.6715	16.85200
T3	0.1881	0.0221	0.0000000000000670	4.0244	16.50151
T4	0.1445	0.0259	0.0000000000000090	3.1559	15.29941
T5	0.1411	0.0330	0.0000000000000010	3.1694	15.75424
T6	0.1490	0.0324	0.0000000000000020	3.2219	15.30151
T7	0.1963	0.0219	0.0000000000000830	4.3140	17.31550
T8	0.1632	0.0170	0.0000000000000310	3.5606	16.08529
T9	0.1436	0.0256	0.0000000000000090	3.1474	15.33623
T10	0.1861	0.0175	0.0000000000000850	3.9705	16.37726
T11	0.1929	0.0219	0.0000000000000820	4.1719	16.86622

Finally, using Equations 17-22, the total utility value of each alternative and the ranking of the alternatives are determined. Table 6 presents the results.

Table 6. The results

Alternatives \ Results	c'_i	o'_i	p'_i	r'_i	s'_i	V_i	Rankings
T1	0.067029	0.41250	0.095238	0.166038059	0.618432	1.359238	7
T2	0.384058	0.78750	0.309524	0.449254243	0.770097	2.700433	5
T3	0.851449	0.68125	0.785714	0.751757243	0.596252	3.666423	4
T4	0.061594	0.44375	0.095238	0.007286131	0	0.607868	9
T5	0	0	0	0.018858220	0.225599	0.244458	11
T6	0.143116	0.03750	0.011905	0.063860792	0.001045	0.257426	10
T7	1	0.69375	0.97619	1	1	4.669940	1
T8	0.400362	1	0.357143	0.354191668	0.389805	2.501501	6
T9	0.045290	0.46250	0.095238	0	0.018264	0.621292	8
T10	0.815217	0.96875	1	0.705554603	0.534627	4.024149	3
T11	0.938406	0.69375	0.964286	0.878193040	0.777151	4.251785	2

According to the results shown in Table 6, the alternatives are listed as follows; T7, T11, T10, T3, T2, T8, T1, T9, T4, T6 and T5. Thus, the T7 coded alternative is determined as the best wind turbine.

4. Discussion

The COPRAS, MARCOS, and WASPAS methods were used in this study to determine that the results of the MULTIMOOSRAL method were correct. Table 7 shows the ranking of wind turbines according to the results of the methods.

Table 7. The results of methods

Alternatives \ Methods	COPRAS	MARCOS	WASPAS	MULTIMOOSRAL
T1	9	10	8	7
T2	5	6	6	5
T3	3	4	4	4
T4	8	9	7	9
T5	11	8	11	11
T6	7	7	10	10
T7	1	1	1	1

T8	6	5	5	6
T9	10	11	9	8
T10	4	3	3	3
T11	2	2	2	2

Alternative rankings according to the methods were evaluated with the Pearson correlation method. According to the results of the Pearson correlation method, the Pearson correlation coefficients between the methods are as follows; 0.909 (COPRAS-MULTIMOOSRAL), 0.827 (MARCOS-MULTIMOOSRAL), and 0.964 (WASPAS-MULTIMOOSRAL). According to these results, it can be said that the MULTIMOOSRAL method has achieved correct results.

By changing the weights of the criteria, it will be checked whether the order of wind turbine alternatives has changed. For this, 4 scenarios were arranged. The scenarios are shown in Table 8.

Table 8. The scenarios

Scenarios / Criteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AO	0.071	0.350	0.100	0.070
CF	0.071	0.050	0.010	0.050
NRD	0.071	0.050	0.200	0.100
HH	0.071	0.050	0.050	0.150
CWS	0.071	0.150	0.150	0.100
NWS	0.071	0.050	0.050	0.050
PD	0.071	0.050	0.050	0.200
TC	0.071	0.050	0.050	0.010
SG	0.071	0.010	0.150	0.150
MS	0.071	0.050	0.050	0.010
EEF	0.071	0.050	0.050	0.030
SSU	0.071	0.050	0.050	0.060
SP	0.071	0.010	0.010	0.010
R	0.071	0.030	0.030	0.010

Figure 4 presents the results of the scenarios.

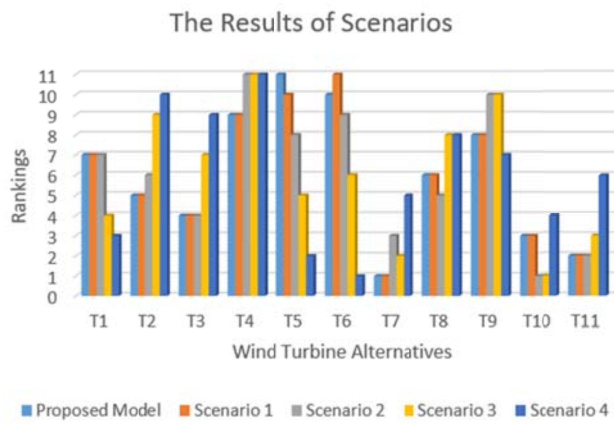

Figure 4. The results of scenarios

According to Figure 4, T1 coded alternative ranks 7th in the proposed model, scenario 1 and scenario 2, while it ranks 4th in scenario 3 and 3rd in scenario 4. T2 coded alternative ranks 5th in the proposed model and scenario 1, while it ranks 6th in scenario 2, 9th in scenario 3, and 10th in scenario 4. T3 coded alternative ranks 4th in the proposed model, scenario 1 and scenario 2, while it ranks 7th in scenario 3 and 9th in scenario 4. T4 coded alternative ranks 9th in the proposed model and scenario 1, while it ranks 11th in scenario 2, scenario 3, and scenario 4. T5 coded alternative ranks 11th in the proposed model, while it ranks 10th in scenario 1, 8th in scenario 2, 5th in scenario 3, and 2nd in scenario 4. T6 coded alternative ranks 10th in the proposed model, while it ranks 11th in scenario 1, 9th in scenario 2, 6th in scenario 3, and 1st in scenario 4. T7 coded alternative ranks 1st in the proposed model and scenario 1, while it ranks 3rd in scenario 2, 2nd in scenario 3, and 5th in scenario 4. T8 coded alternative ranks 6th in the proposed model and scenario 1, while it ranks 5th in scenario 2, 8th in scenario 3, and scenario 4. T9 coded alternative ranks 8th in the proposed model and scenario 1, while it ranks 10th in scenario 2 and scenario 3, 7th in scenario 4. T10 coded alternative ranks 3rd in the proposed model and scenario 1, while it ranks 1st in scenario 2 and scenario 3, 4th in scenario 4. T11 coded alternative ranks 2nd in the proposed model, scenario 1 and scenario 2, while it ranks 3rd in scenario 3 and 6th in scenario 4. As can be seen from the results, the changes in the criteria weights have changed the ranking of the wind turbine alternatives.

5. Conclusions

The wind turbine selection problem can be solved by MCDM methods as it includes multiple alternatives and criteria. Many studies in the literature have performed wind turbine selection using MCDM methods. This study proposes a new hybrid MCDM model consisting of CCSD and MULTIMOOSRAL methods for wind turbine selection. According to the results of the CCSD method, the most important criterion was determined as MSP. According to the results of the MULTIMOOSRAL method, the best alternative was determined as the T7 coded wind turbine. In addition, in this study, the results of the MULTIMOOSRAL method were compared with the results of other MCDM (COPRAS, MARCOS and WASPAS) methods. According to the Pearson correlation results, it was concluded that the MULTIMOOSRAL method obtained correct results. In addition, by changing the weights of the criteria, it was checked whether the rankings of the wind turbines changed. It was concluded that the change of criterion weights changed the rankings of wind turbines.

This study has some limitations. First of all, subjective data were not used in this study. In addition, only 11 wind turbines were evaluated in this study. Future studies may do a more detailed study with subjective data. Also, future studies may evaluate more wind turbines.

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