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A suitable wind turbine selection for achieving maximum efficiency from wind energy by an adaptive hybrid multi-criteria decision-making approach

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Keywords:
Wind energy,
Wind turbine,
Multi-criteria decision-making,
Wind energy efficiency,
Entropy

Abstract — Wind energy is rapidly developing and gaining great importance among renewable energy sources. Moreover, wind energy is an important renewable energy option that is clean and environmentally friendly but has comparatively high costs. Wind turbines especially play an essential role in increasing wind energy conversion systems costs. For this reason, choosing the most suitable turbine in planning wind energy systems is very valuable for investors. The approaches used in literature studies have a limited perspective. Therefore, this study presented an adaptive hybrid multi-criteria decision-making approach for the first time in the appropriate wind turbine selection. Expert interviews and literature reviews were considered in the application phase of the model. Four mains (technical, economic, environmental, and customer service criteria) and seventeen sub-criteria were applied for the thirty-five wind turbine brands selected in the suggested adaptive hybrid assessment model. Additionally, the consistency analysis performed to test the consistency of comparisons shows that the analyses and choices have high consistency. The adaptive hybrid model suggested in this study can also be easily used to select a suitable wind turbine for onshore and offshore wind farm planning.

Subject Classification (2020): 28D20, 62C99.

1. Introduction

Energy has critical importance for the economic growth and development of world states. However, there is no energy component among the millennium development goals of the United Nations. Recently, Ban-Ki-Moon [1], Secretary General of the United Nations, has highlighted that development is not possible without energy, and sustainable development is not possible without sustainable energy. In the last decade, energy has become one of the sustainable development goals because of its impact on sustainable development. Nonetheless, many countries still provide their energy needs from fossil fuels [2]. Fossil fuels, such as coal, oil, natural gas and nuclear, are environmentally unfriendly to harvest, become exhausted, diminish faster, draw on limited resources and are non-renewable. The utility of fossil fuels in meeting energy demand is considered the most important cause of climate change and global warming. This situation threatens the sustainability and security of the global.

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Renewable energy sources are the only viable energy option for environmentally friendly, clean energy. Thus, the greenhouse gas effect and climate change can be reduced by using renewable energy sources. Among renewable resources, such as wind, solar, water (hydro) and mini-hydro, geothermal heat, biomass and tides, wind energy has significant importance due to its economic attributes, the potential for energy generation and wide application range [3]. Wind energy showed the biggest annual capacity increase in 2020 after the peak in 2015. In 2020, the new capacity (93 GW) was added to the world's electric grids, and the global wind power market grew by 14%. Thus, the global installed wind power capacity increased to around 743 GW overall (Fig. 1) [4].

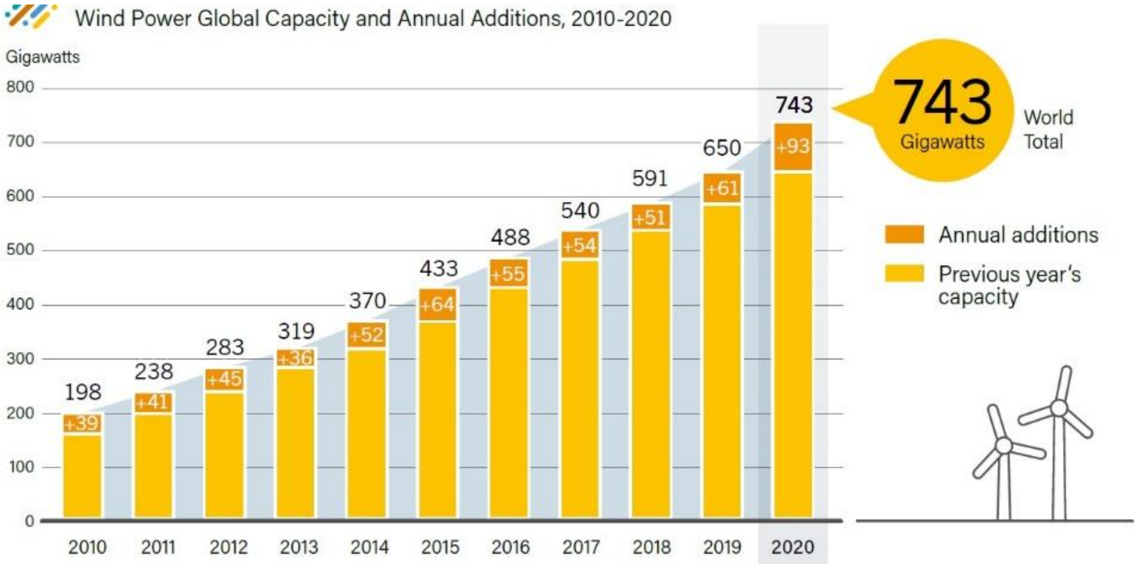

Figure 1. Wind power global capacity and annual additions

At the end of 2020, China maintained its leadership with additional capacities. The United States, Brazil, Netherlands, Germany and Spain followed. Other countries in the top 10 for total capacity additions were Norway, France, Turkiye and India (Fig 2) [4].

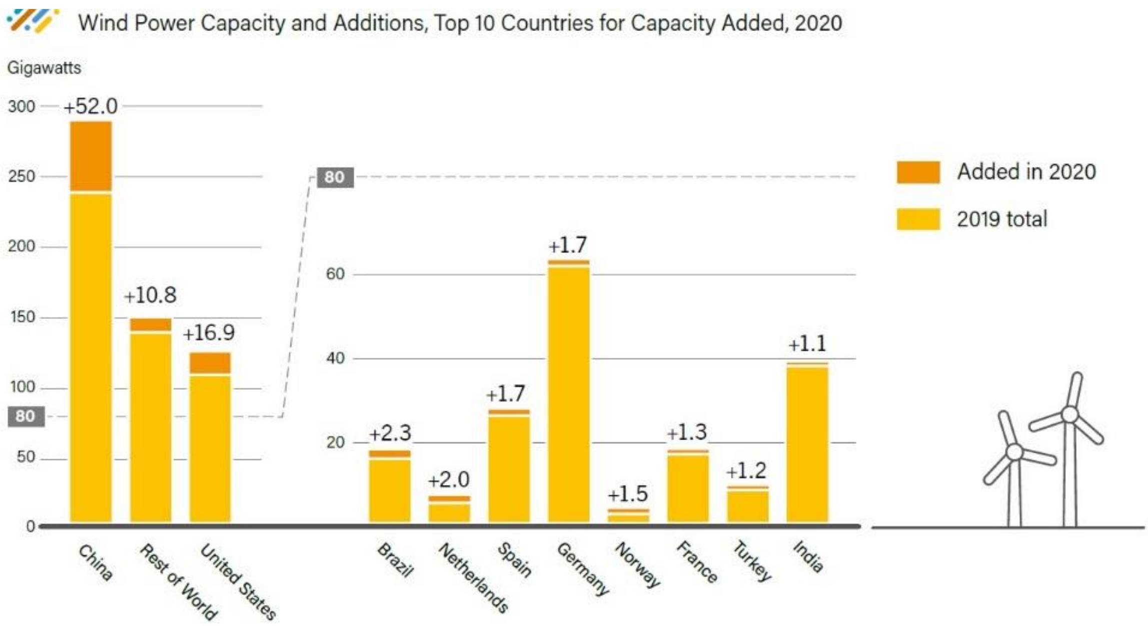

Figure 2. Wind power capacity and additions, top 10 countries

To utilise wind power generation, a better understanding of the wind characteristics of a wind field and the performance of the wind turbines will be installed crucial because the wind turbines used in the wind energy conversion system are essential to evaluate the wind source correctly. For every wind turbine model, the turbine power curve created by the manufacturer is used in power calculation [5,6]. This way, different wind turbines can be evaluated for regions with varying wind regimes. According to the market share in 2019, the leading wind turbine suppliers on a global scale are shown in Figure 3 [7].

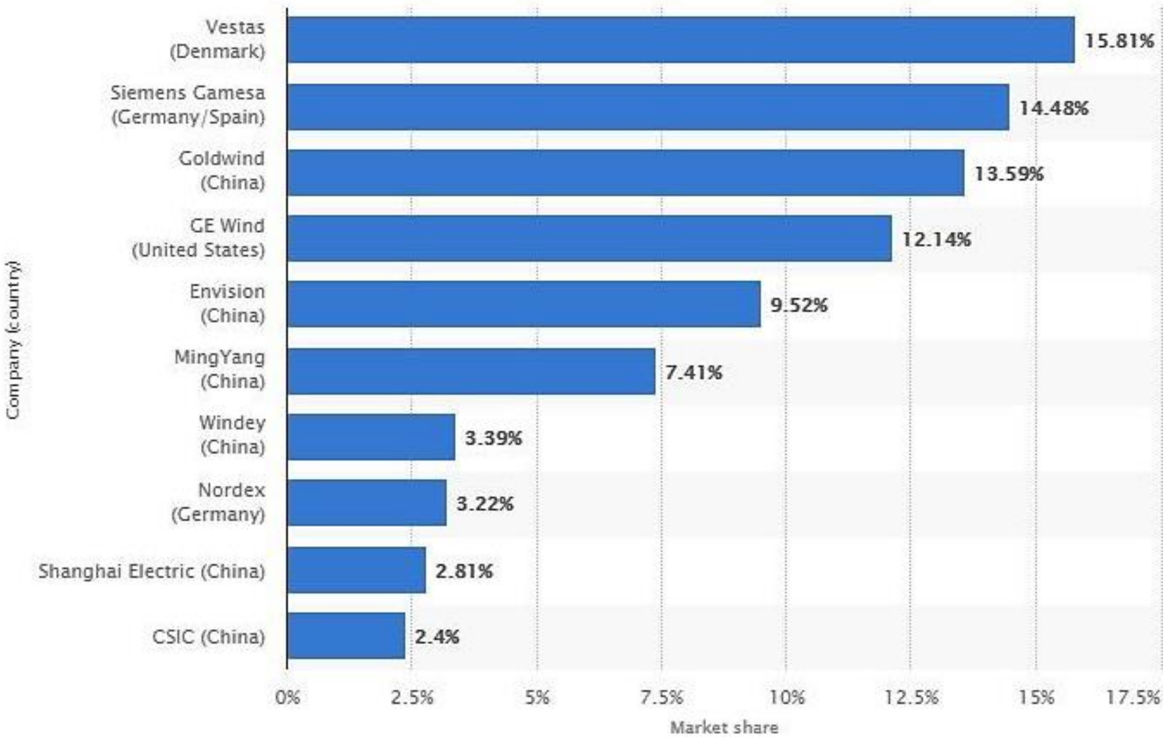

Figure 3. Leading wind turbine suppliers globally based on market share in 2019

Nowadays, the best wind turbine selection problem for specific wind regimes has been the subject of many studies in the literature. Five wind turbines at 60 m height (Nordex N80, Gamesa G80, Nordex 70, Nordex N60 and Gamesa G58) were compared using a classical method by Jowder. It was determined that Gamesa G58 is the most suitable turbine [8]. Alimi et al. [9] examined the wind energy production on the central coast of Tunis by using eight different commercial wind turbines at different hub-heights (Repower (2000 kW) MM 70-65, Dewind 1250 kW, GE 1500 kW, V39-35, V82-0.9, Anbonus MK III-30, Vestas V80, Nordex (2300 kW) N90-100). De Araujo Lima and Filho [10] examined wind energy of São João do Cariri (SJC) in Paraiba (PB) state using 3 different types of wind turbine (Vestas V27, Bonus Mk III and Bonus Mk III). A multi-criteria decision-making method was used to choose a suitable wind turbine for the wind energy station project by Lee et al. [11]. The concepts of the costs, benefits, opportunities and risks came to the fore in the Analytical Hierarchy Process (AHP) method. The wind power generation of Ghana's coastal region was assessed using four different wind turbines (Garbi150/ 28, Polaris 15–50, CF-100 and WES30) [12].

Four wind turbine models (ZEUS 500, WES-30, P19-100 and G-3120) were examined by Adaramola et.al. [13]. The performance of turbines was compared for the Niger Delta region, and it was determined that the highest energy output was obtained from G-3120 wind turbine. A systematical methodology was presented using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) by Kolios et al. [14]. They proposed this methodology for classifying and evaluating wind turbine support structures. Montoya et al. [15] used a multi-objective optimisation algorithm for the best wind turbine selection. This algorithm was applied to the energy outputs of twenty-six different wind turbines.

Nahi and Nabavi [16] characterised the new network using the Monte Carlo method to select the best wind turbine used in the Manjil region. Wind speed data were simulated using MATLAB and EXCEL software. The performances of parametric and nonparametric methods were analysed by Shokrzadeh [17]. Four wind turbines were selected for the study, and simulated data sets were used in the analysis. The results of studies realised by Somma et al. [18] and Yan et al. [19] demonstrated that exergy efficiency could be developed while the energy cost is reduced. Different ecological and economic criteria were applied in the study of Haaren and Vasilis [20]. One of these criteria is preventing economic costs in wind energy production.

This study presents an adaptive assessment model with a wide range of criteria. Although many literature studies using various decision-making techniques were summarised above, the approaches used in these studies have a limited perspective. The proposed adaptive approach was used for the first time for turbine selection, especially in wind energy planning. This situation also constitutes the original and innovative side of the study. Therefore, the idea of overcoming this gap in the literature with the adaptive model we presented in the study excited us. The proposed adaptive assessment model evaluated 35 wind turbine brands using four main and 17 sub-criteria. In addition, experts and stakeholders in the field of wind energy management were interviewed and included in the process. The power of the wind turbines used in the case study was selected as 3 MW. No market research has been conducted on the selected turbines; conversely, it was focused on the model that will make the most appropriate choice among the wind turbines that have the same power to be used in wind farms. The consistency of the proposed model was achieved by consistency analysis, and the consistency ratio was calculated as 0.0956. This value shows that the analysis and selections are quite consistent. In addition, the results obtained are commercially viable and applicable.

2. Methodology

The proposed adaptive assessment model, classification of main and sub-criteria and consistency analysis are presented in detail in the following sections.

2.1. The Adaptive Assessment Model That Is Entropy-Based Multi-Attribute Utility Theory (MAUT)

MAUT [21] is a systematic method that analyses and identifies multiple variables to provide a common decision. MAUT is a much more precise methodology [22,23], an extension of Multi-Attribute Value Theory (MAVT), in which both uncertainties and risk preferences are included in decision support methods. MAUT aims to maximise the utility function ($U(a_i)$), defined in the set of alternatives in decision problems. The MAUT method is based on several key ideas. These are listed as follows [24]:

- ✓ As much as possible, evaluations should be comparative.
- ✓ Usually, the program has multiple regions of service.
- ✓ The program should focus on many goals.
- ✓ Trials must be part of the evaluation.
- ✓ It should be necessary to criticise numerically great values.
- ✓ Evaluations should typically be about decisions or at least covered.

This method's most useful alternative is based on qualitative and quantitative criteria. During the decision-making phase, quantitative criteria determined are countable and easily evaluated. 5, 10 or 100-point scoring system can be used for comprehensibility by everyone in evaluating qualitative criteria. This helps to facilitate the evaluation. (For example: Very bad: 1, bad: 2, medium: 3, good: 4, very good: 5, Very bad: 0 bad: 25, medium: 50, good: 75, very good: 100) [25]. While making these evaluations, paired comparisons are used by utilising expert opinions. In other words, how good or bad one alternative is compared to another is considered. Therefore, an expert group of 7 people was formed to determine the criteria and in determining the relationships between the criteria. This group consists of 2 electrical-electronic engineers, two energy systems engineers, one economist and two statistics experts. In particular, open-ended questions were asked to 7 experts to determine the criteria, and in line with the answers given to these questions, four main and 17 sub-criteria criteria, which are thought to be important in the selection of wind turbines, were determined. In evaluating the qualitative criteria used in our study, a 5-point scoring system was preferred. The application steps of the MAUT method are shown as follows [26]:

Step 1. The criteria (a_n) and qualities/alternatives (x_m) that are the subject of the decision problem should be determined.

Step 2. To evaluate the qualities correctly, the weight values (w_j) where the priorities are determined must be provided. The sum of the weight values must be equal to 1, as shown in Equation (2.1).

$$\sum_{j}^{n} w_j = 1 \tag{2.1}$$

Step 3. The value measurements of the criteria are assigned. This assignation is made by considering the paired comparisons for qualitative criteria while having quantitative values for quantitative criteria. Thus, the decision matrix is created.

Step 4. The assigned values are placed in the decision matrix, and the normalisation process is started. In the normalisation process, the best and the worst values are determined for each feature. For best and worst values, 1 and 0 are assigned, respectively. Equation (2.2) is used to calculate other values.

$$f_j(a_i) = \frac{f_i(a_i) - \min(f_i)}{\max(f_i) - \min(f_i)} \tag{2.2}$$

Step 5. After the normalisation process, utility values are determined. The utility function is calculated by Equation (2.3).

$$U(a_i) = \sum_{j=1}^{n} f_j(a_i) w_j \tag{2.3}$$

$U(a_i)$: Utility value of the alternative

$f_j(a_i)$: Normalised utility values for each criterion and alternative

w_j : Weight values

Step 6. The utility value calculated with Equation (2.3) is obtained by preference ranking by descending sort. The alternative, which takes the first place at the end of the ranking, represents the alternative that provides the most benefit.

The weight values (w_j) were calculated using the entropy method. The entropy method can be applied if the decision matrix data is known to calculate the objective weights. Entropy is defined as a measure of uncertainty and disorder in a system [27]. It is the most essential decisive of the accuracy and reliability of the decision to be made in a decision-making problem. Entropy is used to measure the amount of helpful information from which the available data are provided [28]. The application steps of the entropy method are shown as follows [29]:

Step 1. A decision matrix is created to evaluate the original data in a multiple decision-making problem with 'm' alternatives and 'n' criteria.

$$P = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2j} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \dots & a_{ij} & \dots & a_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mj} & \dots & a_{mn} \end{bmatrix}$$

According to the j^{th} criteria, the a_{ij} ; i^{th} *the* alternative is the utility value. $i = 1, 2, ..., m$ and $j = 1, 2, ..., n$.

Step 2. The entropy-based normalised decision matrix: To eliminate the discrepancies in different units of measurement, P_{ij} is calculated using Equation (2.4) by normalisation.

$$P_{ij} = \frac{a_{ij}}{\sum_i^m a_{ij}}, \qquad i = 1, 2, \dots m \text{ and } j = 1, 2, \dots, n \tag{2.4}$$

Step 3. Entropy values are calculated as below:

$$E_j = \frac{-1}{\ln(m)} \sum_{i=1}^{m} [P_{ij} \ln(P_{ij})], \qquad j = 1, 2, \dots, n \tag{2.5}$$

Here, P_{ij} denotes entropy-based normalised decision matrix and E_j denotes entropy value.

Step 4. Calculation of uncertainty as a degree of diversity

$$d_j = 1 - E_j, \qquad j = 1, 2, \dots, n \tag{2.6}$$

Step 5. Weights of each criterion are calculated.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \qquad j = 1, 2, \dots, n \tag{2.7}$$

Many methods are used to determine whether the comparisons performed are consistent. One of them is the calculation of the coefficient called the "Consistency Index (CI)". Hence, the consistency index (CI) put forth is defined by Equation (2.8) put forth by [30]:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2.8}$$

n and λ_{max} represents the number of criteria and the maximum eigenvalue of the comparison matrix, respectively [31]. Moreover, λ_{max} acts as a reference index during the consistency. λ_{max} is calculated by using Equation (2.9):

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{n} a_{ij} w_j}{w_i} \right) \tag{2.9}$$

To evaluate the consistency, the value of the "Random Index (RI)" should be known. RI values defined for n-dimensional comparison matrices are given in Table 1 [32,33].

Table 1. Random index (RI) values

n	1	2	3	4	5	6	7	8	9	10
RI	0.01	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
RI	1.51	1.48	1.56	1.57	1.58	1.59	1.60	1.61	1.62	1.63

After determining the CI and RI values, the "Consistency Ratio (CR)" is calculated as follows:

$$CR = \frac{CI}{RI} \quad (2.10)$$

If the CR defined by Equation (2.10) is less than 0.10, it is decided that the comparison is consistent [34].

2.2. Determination of Criteria in Turbine Selection

Many factors influence the choice of turbines to be used in a wind turbine power plant. Among these factors, technical, economic, environmental and customer service criteria are presented in the literature as the main criteria [35]. In addition, these criteria are generally divided into several sub-criteria. Therefore, the basic criteria in this study were examined in four main groups technical, economic, environmental and customer service. Technical criteria were created from sub-criteria: cut-in wind speed (WS), rated wind speed, cut-out wind speed, rotor diameter, swept area, power density, hub height, and capacity factor (CF). The economic criteria are subdivided into government support and total cost. The environmental criteria include noise, shadow vibration and glare, impact on living things and electromagnetic effect. Finally, service support, spare parts and reliability created the sub-criteria of the customer service criteria. The hierarchy created from these criteria is shown in Figure 4.

Figure 4. The hierarchical structure of the criteria

35 pieces of 3 MW wind turbines selected in the study are coded as T1, T2, T3, …, and T35. Selected turbines and turbine codes (TC) are shown in Table 2.

Table 2. Selected turbines and turbine codes

Wind Turbines	TC	Wind Turbines	TC
Alstom ECO 122/3000	T1	MBB Messerschmitt Aeolus II	T19
Amperax A3000	T2	Nordex N131/3000 Delta	T20
AMSC wt3000fc TC IIIB	T3	PROKON P3000/116	T21
CATUM CA-3.0 MW-WD R120	T4	Repower 3.0M122	T22
CCWE CCWE-3000D/D103	T5	Senvion 3.0M122	T23
CSIC H146-3.0	T6	GFF GF121-3.0	T24
Doosan WinDS3000/134	T7	Swiss Electric YZ121/3.0	T25
Enercon E-115 3.000	T8	Siemens SWT-3.0-133	T26
Fuhrlander LLC WTU3.0-132	T9	Sinovel SL3000/121	T27
FWT 120/3000	T10	TYHI - Taiyuan TZ3000/140	T28
MingYang MySE3.0-135	T11	Vensys 136/3000	T29
United Power UP3000-120	T12	Vestas V126-3.0	T30
Jacobs PowerTec JPT 3-120	T13	W2E Wind to Energy W2E-145/3.0fc	T31
Karlskronavarvet WTS-3 Maglarp	T14	WEG Wind EnergyGroup LS1	T32
Kvaerner Turbin AB Nasudden II	T15	WinWinD WWD-3 D120	T33
Lagerwey L100 3.0 MW	T16	Goldwind GW 150/3000	T34
Leitwind LTW101 3000	T17	Windey WD156-3000	T35
MAN GROWIAN	T18		

The technical, economic, environmental and customer service criteria of the selected 3 MW wind turbines are summarised in Tables 3-6 [36].

2.3. The Sub-Criteria of Technical Criterion

The minimum wind speed at which the turbine blades start rotating is called “cut-in wind speed”. To increase the turbine’s operating time, choosing turbines with a low cut-in wind speed is reasonable. The wind speed that the rotation of the turbine blades will create danger and therefore automatically turn off itself is called the ‘cut-out wind speed’. The wind speed at which energy is produced from the wind turbine with maximum capacity is called “rated wind speed”. That is, it is the lowest speed at which maximum power can be obtained. Having the nominal speed as low as possible will increase the efficiency of the wind turbines. The rotor diameter is related to the area where the blades of the wind turbine sweep. The rotor diameter changes according to the height of the wind turbine from the ground. Turbines with a rotor diameter of 10 to 90 meters are widely used. Energy production is high in turbines with large rotor diameters. The swept area refers to the area of the circle created by the blades as they sweep through the air.

Power density is a measure of power output per unit volume. If a system has a high-power density, then it can output large amounts of energy based on its volume. As altitude increases, turbulence decreases and wind speed increases. Therefore, tower height is essential. Rotor rotation speed also increases with tower height. The capacity factor is the ratio that the turbine can provide its rated power in a percentage of the time. The values of these sub-criteria of technical criteria are shown in Table 3.

Table 3. The values of the sub-criteria of technical criterion

Turbine Code	Cut-In WS (m/s)	Rated WS (m/s)	Cut-Out WS (m/s)	Rotor Diameter (m)	Swept Area (m²)	Power Density (W/m²)	Hub Height (m)	CF
T1	3	10.5	25	122	11683	256.7	139	36.197
T2	3	11.3	23	116	105623	283.9	142	32.121
T3	3	11	20	120	11304	265.3	110	32.538
T4	5	11	25	118.2	10967	273.4	140	33.536
T5	3	11.5	25	103	8328	360.2	85	38.671
T6	3	9.1	22	146	16733	179.2	120	38.824
T7	3	10	20	134	14095	212.8	90	34.737
T8	2	11.5	25	115.7	10508	285.3	149	30.626
T9	3	12	25	132	13677	219.2	160	20.712
T10	3	12	25	120.6	11417	262.6	140	24.814
T11	3	9.3	20	135	14306	209.6	140	42.541
T12	3.5	10.2	25	120	11304	265.3	90	40.809
T13	3	10.1	25	120	11304	265.3	126	42.033
T14	6	14	21	78	4775	627.9	80	37.358
T15	6	14.5	25	80.5	5087	589	78	31.543
T16	2.1	16	28	100	7850	382	135	15.225
T17	3	15	25	101	8008	374.4	143	18.113
T18	5.4	12	24	100.4	7913	382	100	36.089
T19	3.5	14	20	80.5	5087	589	92	35.045
T20	3	11.9	20	131	13471	222.6	134	21.565
T21	3	11.3	23	116	10563	283.9	142	32.121
T22	3	11.5	22	122	11684	256.6	139	27.549
T23	3	11.5	22	122	11684	256.6	139	27.549
T24	3	10.4	22	121.4	11569	260.9	90	37.863
T25	1.8	9.7	20	121	11493	261	140	46.695
T26	4	12.5	25	113	10023	300	142	25.078
T27	3	10.5	10.5	121	11493	261	110	36.814
T28	3	9.1	22	140	15386	194.9	100	42.222
T29	3	11	22	136	14519	206.5	136	25.332
T30	3	12	22.5	126	12462	240.6	119	22.732
T31	3	10.5	22	145	16504	181.7	100	25.622
T32	7	17	27	60	2826	1061.2	45	35.265
T33	3	11	25	120	11304	263.9	120	32.376
T34	2.5	9	18	150	17662	169.8	140	38.019
T35	2.5	8.8	25	156	19103	157	160	37.604

2.4. The Sub-Criteria of Economic Criterion

Costs per unit turbine were calculated according to the determined turbine cost, maintenance and repair costs and installation costs. Total costs were determined with these data. The dollar ($) was used as the currency in total cost calculations. In addition, the government support rates to be given are determined according to the turbine capacities and presented in Table 4.

Table 4. The values of the sub-criteria of economic criterion

Turbine Code	Total Cost (million $)	Government support	Turbine Code	Total Cost (million $)	Government support
T1	1.75	36.19	T19	1.8	35.04
T2	1.75	32.12	T20	1.85	21.56
T3	1.75	32.53	T21	1.8	32.12
T4	1.8	33.53	T22	1.95	27.54
T5	1.8	38.67	T23	1.8	27.54
T6	1.75	38.82	T24	1.75	37.86
T7	1.8	34.73	T25	1.85	46.69
T8	1.8	30.62	T26	1.95	25.07
T9	1.85	20.71	T27	1.8	36.81
T10	1.75	24.81	T28	1.75	42.22
T11	1.7	42.54	T29	1.75	25.33
T12	2	40.80	T30	2	22.73
T13	2	42.03	T31	1.8	25.62
T14	1.95	37.35	T32	1.75	35.26
T15	1.9	31.54	T33	1.8	32.37
T16	1.85	15.22	T34	1.85	38.01
T17	1.75	18.11	T35	1.8	37.60
T18	1.95	36.08			

2.5. The Sub-Criteria of Environmental Criterion

The turbines were evaluated according to noise, shadow vibration and glare, impact on living things and electromagnetic effect. The impact level of the turbines on living things was taken equally. Shadow vibration and glare effects were evaluated according to the shadow size that occurred depending on the rotor diameters and heights of the turbines. Point scoring was given to the wind turbine brands from 1 to 5. In the electromagnetic effect, the blade rotation speeds of the turbines were utilised. The values of the sub-criteria of environmental criteria are shown in Table 5.

Table 5. The values of the sub-criteria of environmental criterion

Turbine Code	Noise	Shadow vibration and glare	Impact on living things	Electromag. effect	Turbine Code	Noise	Shadow vibration and glare	Impact on living things	Electromag. effect
T1	3	2	1	3	T19	3	2	1	3
T2	3	2	1	3	T20	5	5	1	5
T3	3	2	1	3	T21	3	2	1	3
T4	3	2	1	3	T22	3	2	1	3
T5	3	2	1	3	T23	4	3	1	4
T6	3	2	1	3	T24	3	2	1	3
T7	3	2	1	3	T25	3	3	1	3
T8	5	5	1	5	T26	4	4	1	4
T9	4	4	1	4	T27	4	3	1	4
T10	3	3	1	3	T28	3	2	1	3
T11	4	3	1	4	T29	4	3	1	4
T12	3	4	1	3	T30	5	5	1	5
T13	4	4	1	4	T31	3	2	1	3
T14	3	3	1	3	T32	3	2	1	3
T15	3	4	1	3	T33	3	3	1	3
T16	3	2	1	3	T34	3	2	1	3
T17	4	3	1	4	T35	3	3	1	3
T18	3	2	1	3					

2.6. The Sub-Criteria of Custom Service Criterion

Under the heading of customer service, turbine brands were compared according to the service support, spare parts and brand reliability they provide to their customers. While making these comparisons, the necessary information provided by using web addresses of turbine brands, the guarantees, and the number of wind power plants and turbines they have built were used. The values of the sub-criteria of customer service criteria are shown in Table 6.

Table 6. The values of the sub-criteria of the customer service criterion

Turbine Code	Service support	Spare parts	Reliability	Turbine Code	Service support	Spare parts	Reliability
T1	3	2	3	T19	3	2	3
T2	3	2	3	T20	5	5	5
T3	3	2	3	T21	3	2	3
T4	3	2	3	T22	3	2	3
T5	3	2	3	T23	4	3	4
T6	3	2	3	T24	3	2	3
T7	3	2	3	T25	3	3	3
T8	5	5	5	T26	4	4	4
T9	4	4	4	T27	4	3	4
T10	3	3	3	T28	3	2	3
T11	4	3	4	T29	4	3	4
T12	3	4	3	T30	5	5	5
T13	4	4	4	T31	3	2	3
T14	3	3	3	T32	3	2	3
T15	3	4	3	T33	3	3	3
T16	3	2	3	T34	3	2	3
T17	4	3	4	T35	3	3	3
T18	3	2	3				

3. Results

The novelty assessment model was applied to 3 MW wind turbines selected for the case study. The Entropy-based Novelty Multi-Attribute Utility Theory used in the novelty assessment model is explained in detail in Section 2.1. In addition, the criteria are coded as shown in Table 7 so that the tables containing the results can be evaluated easily.

Table 7. Criteria codes

Criteria	Criteria Code
Cut-In WS (m/s)	C1
Rated WS (m/s)	C2
Cut-Out WS (m/s)	C3
Rotor Diameter (m)	C4
Swept Area (m^2)	C5
Power Density (W/m^2)	C6
Hub height (m)	C7
CF	C8
Total cost (million $)	C9
Government support	C10
Noise	C11
Shadow vibration and glare	C12
Impact on living things	C13
Electromagnetic effect	C14
Service support	C15
Spare parts	C16
Reliability	C17

35 × 17 decision matrix, which includes wind turbines and selection criteria, was created. The decision matrix is shown in Table 8. The decision matrix is also the matrix in which all criteria are combined with their values. Each criterion is evaluated in the decision matrix, and the best and worst values are determined.

Table 8. The decision matrix

Turbines & Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
T1	3	10.5	25	122	11683	256.7	139	36.19	1.75	36.197	3	2	1	3	3	2	3
T2	3	11.3	23	116	105623	283.9	142	32.12	1.75	32.121	3	2	1	3	3	2	3
T3	3	11	20	120	11304	265.3	110	32.53	1.75	32.538	3	2	1	3	3	2	3
T4	5	11	25	118.2	10967	273.4	140	33.53	1.80	33.536	3	2	1	3	3	2	3
T5	3	11.5	25	103	8328	360.2	85	38.67	1.80	38.671	3	2	1	3	3	2	3
T6	3	9.1	22	146	16733	179.2	120	38.82	1.75	38.824	3	2	1	3	3	2	3
T7	3	10	20	134	14095	212.8	90	34.73	1.80	34.737	3	2	1	3	3	2	3
T8	2	11.5	25	115.7	10508	285.3	149	30.62	1.80	30.626	5	5	1	5	5	5	5
T9	3	12	25	132	13677	219.2	160	20.71	1.85	20.712	4	4	1	4	4	4	4
T10	3	12	25	120.6	11417	262.6	140	24.81	1.75	24.814	3	3	1	3	3	3	3
T11	3	9.3	20	135	14306	209.6	140	42.54	1.70	42.541	4	3	1	4	4	3	4
T12	3.5	10.2	25	120	11304	265.3	90	40.80	2.00	40.809	3	4	1	3	3	4	3
T13	3	10.1	25	120	11304	265.3	126	42.03	2.00	42.033	4	4	1	4	4	4	4
T14	6	14	21	78	4775	627.9	80	37.35	1.95	37.358	3	3	1	3	3	3	3
T15	6	14.5	25	80.5	5087	589	78	31.54	1.90	31.543	3	4	1	3	3	4	3
T16	2.1	16	28	100	7850	382	135	15.22	1.85	15.225	3	2	1	3	3	2	3
T17	3	15	25	101	8008	374.4	143	18.11	1.75	18.113	4	3	1	4	4	3	4
T18	5.4	12	24	100.4	7913	382	100	36.08	1.95	36.089	3	2	1	3	3	2	3
T19	3.5	14	20	80.5	5087	589	92	35.04	1.80	35.045	3	2	1	3	3	2	3
T20	3	11.9	20	131	13471	222.6	134	21.56	1.85	21.565	5	5	1	5	5	5	5
T21	3	11.3	23	116	10563	283.9	142	32.12	1.80	32.121	3	2	1	3	3	2	3
T22	3	11.5	22	122	11684	256.6	139	27.54	1.95	27.549	3	2	1	3	3	2	3
T23	3	11.5	22	122	11684	256.6	139	27.54	1.80	27.549	4	3	1	4	4	3	4
T24	3	10.4	22	121.4	11569	260.9	90	37.86	1.75	37.863	3	2	1	3	3	2	3
T25	1.8	9.7	20	121	11493	261	140	46.69	1.85	46.695	3	3	1	3	3	3	3
T26	4	12.5	25	113	10023	300	142	25.07	1.95	25.078	4	4	1	4	4	4	4
T27	3	10.5	10.5	121	11493	261	110	36.81	1.80	36.814	4	3	1	4	4	3	4
T28	3	9.1	22	140	15386	194.9	100	42.22	1.75	42.222	3	2	1	3	3	2	3
T29	3	11	22	136	14519	206.5	136	25.33	1.75	25.332	4	3	1	4	4	3	4
T30	3	12	22.5	126	12462	240.6	119	22.73	2.00	22.732	5	5	1	5	5	5	5
T31	3	10.5	22	145	16504	181.7	100	25.62	1.80	25.622	3	2	1	3	3	2	3
T32	7	17	27	60	2826	1061.2	45	35.26	1.75	35.265	3	2	1	3	3	2	3
T33	3	11	25	120	11304	263.9	120	32.376	1.80	32.376	3	3	1	3	3	3	3
T34	2.5	9	18	150	17662	169.8	140	38.019	1.85	38.019	3	2	1	3	3	2	3
T35	2.5	8.8	25	156	19103	157	160	37.604	1.80	37.604	3	3	1	3	3	3	3

The best and worst values determined based on the decision matrix are shown in Table 9.

Table 9. Best and worst values of decision matrix according to the criteria

Values	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
Best Value	1.8	8.8	28	156	19103	1061.2	160	46.69	1.7	46.695	5	5	1	5	5	5	5
Worst Value	7	17	10.5	60	2826	157	45	15.22	2.0	15.225	3	2	1	3	3	2	3

After determining the best and worst values, the calculated normalised decision matrix is presented in Table 10.

Table 10. Normalised decision matrix

Turbines & Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
T1	0.769	0.793	0.829	0.646	0.544	0.110	0.817	0.666	0.833	0.666	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T2	0.769	0.695	0.714	0.583	0.475	0.140	0.843	0.537	0.833	0.537	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T3	0.769	0.732	0.543	0.625	0.521	0.120	0.565	0.550	0.833	0.550	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T4	0.385	0.732	0.829	0.606	0.500	0.129	0.826	0.582	0.667	0.582	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T5	0.769	0.671	0.829	0.448	0.338	0.225	0.348	0.745	0.667	0.745	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T6	0.769	0.963	0.657	0.896	0.854	0.025	0.652	0.750	0.833	0.750	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T7	0.769	0.854	0.543	0.771	0.692	0.062	0.391	0.620	0.667	0.620	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T8	0.962	0.671	0.829	0.580	0.472	0.142	0.904	0.489	0.667	0.489	1.000	1.000	0.000	1.000	1.000	1.000	1.000
T9	0.769	0.610	0.829	0.750	0.667	0.069	1.000	0.174	0.500	0.174	0.500	0.667	0.000	0.500	0.500	0.667	0.500
T10	0.769	0.610	0.829	0.631	0.528	0.117	0.826	0.305	0.833	0.305	0.000	0.333	0.000	0.000	0.000	0.333	0.000
T11	0.769	0.939	0.543	0.781	0.705	0.058	0.826	0.868	1.000	0.868	0.500	0.333	0.000	0.500	0.500	0.333	0.500
T12	0.673	0.829	0.829	0.625	0.521	0.120	0.391	0.813	0.000	0.813	0.000	0.667	0.000	0.000	0.000	0.667	0.000
T13	0.769	0.841	0.829	0.625	0.521	0.120	0.704	0.852	0.000	0.852	0.500	0.667	0.000	0.500	0.500	0.667	0.500
T14	0.192	0.366	0.600	0.188	0.120	0.521	0.304	0.703	0.167	0.703	0.000	0.333	0.000	0.000	0.000	0.333	0.000
T15	0.192	0.305	0.829	0.214	0.139	0.478	0.287	0.519	0.333	0.519	0.000	0.667	0.000	0.000	0.000	0.667	0.000
T16	0.942	0.122	1.000	0.417	0.309	0.249	0.783	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T17	0.769	0.244	0.829	0.427	0.318	0.240	0.852	0.092	0.833	0.092	0.500	0.333	0.000	0.500	0.500	0.333	0.500
T18	0.308	0.610	0.771	0.421	0.309	0.249	0.478	0.663	0.167	0.663	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T19	0.673	0.366	0.543	0.214	0.139	0.478	0.409	0.630	0.667	0.630	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T20	0.769	0.622	0.543	0.740	0.654	0.073	0.774	0.201	0.500	0.201	1.000	1.000	0.000	1.000	1.000	1.000	1.000
T21	0.769	0.695	0.714	0.583	0.475	0.140	0.843	0.537	0.667	0.537	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T22	0.769	0.671	0.657	0.646	0.544	0.110	0.817	0.392	0.167	0.392	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T23	0.769	0.671	0.657	0.646	0.544	0.110	0.817	0.392	0.667	0.392	0.500	0.333	0.000	0.500	0.500	0.333	0.500
T24	0.769	0.805	0.657	0.640	0.533	0.115	0.391	0.719	0.833	0.719	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T25	1.000	0.890	0.543	0.635	0.532	0.115	0.826	1.000	0.500	1.000	0.000	0.333	0.000	0.000	0.000	0.333	0.000
T26	0.577	0.549	0.829	0.552	0.440	0.158	0.843	0.313	0.167	0.313	0.500	0.667	0.000	0.500	0.500	0.667	0.500
T27	0.769	0.793	0.000	0.635	0.532	0.115	0.565	0.686	0.667	0.686	0.500	0.333	0.000	0.500	0.500	0.333	0.500
T28	0.769	0.963	0.657	0.833	0.772	0.042	0.478	0.858	0.833	0.858	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T29	0.769	0.732	0.657	0.792	0.718	0.055	0.791	0.321	0.833	0.321	0.500	0.333	0.000	0.500	0.500	0.333	0.500
T30	0.769	0.610	0.686	0.688	0.592	0.092	0.643	0.239	0.000	0.239	1.000	1.000	0.000	1.000	1.000	1.000	1.000
T31	0.769	0.793	0.657	0.885	0.840	0.027	0.478	0.330	0.667	0.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T32	0.000	0.000	0.943	0.000	0.000	1.000	0.000	0.637	0.833	0.637	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T33	0.769	0.732	0.829	0.625	0.524	0.118	0.652	0.545	0.667	0.545	0.000	0.333	0.000	0.000	0.000	0.333	0.000
T34	0.865	0.976	0.429	0.938	0.912	0.014	0.826	0.724	0.500	0.724	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T35	0.865	1.000	0.829	1.000	1.000	0.000	1.000	0.711	0.667	0.711	0.000	0.333	0.000	0.000	0.000	0.333	0.000

It is necessary to find the criteria weights to find the total utility values. Therefore, at this stage of the study, the entropy method was used, and entropy values were calculated using Equation (2.5). The entropy-based normalised decision matrix and calculated entropy values are presented in Tables 11 and 12.

Table 11. The entropy-based normalised decision matrix

Turbines & Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
T1	0.026	0.026	0.031	0.029	0.029	0.024	0.033	0.032	0.027	0.032	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T2	0.026	0.028	0.029	0.028	0.027	0.026	0.034	0.028	0.027	0.028	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T3	0.026	0.027	0.025	0.029	0.029	0.024	0.026	0.029	0.027	0.029	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T4	0.043	0.027	0.031	0.029	0.028	0.025	0.033	0.030	0.028	0.030	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T5	0.026	0.029	0.031	0.025	0.021	0.033	0.020	0.034	0.028	0.034	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T6	0.026	0.023	0.028	0.035	0.042	0.016	0.028	0.034	0.027	0.034	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T7	0.026	0.025	0.025	0.032	0.036	0.020	0.021	0.031	0.028	0.031	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T8	0.017	0.029	0.031	0.028	0.027	0.026	0.035	0.027	0.028	0.027	0.042	0.051	0.029	0.042	0.042	0.051	0.042
T9	0.026	0.030	0.031	0.032	0.034	0.020	0.038	0.018	0.029	0.018	0.034	0.040	0.029	0.034	0.034	0.040	0.034
T10	0.026	0.030	0.031	0.029	0.029	0.024	0.033	0.022	0.027	0.022	0.025	0.030	0.029	0.025	0.025	0.030	0.025
T11	0.026	0.023	0.025	0.033	0.036	0.019	0.033	0.037	0.027	0.037	0.034	0.030	0.029	0.034	0.034	0.030	0.034
T12	0.030	0.025	0.031	0.029	0.029	0.024	0.021	0.036	0.031	0.036	0.025	0.040	0.029	0.025	0.025	0.040	0.025
T13	0.026	0.025	0.031	0.029	0.029	0.024	0.030	0.037	0.031	0.037	0.034	0.040	0.029	0.034	0.034	0.040	0.034
T14	0.051	0.035	0.026	0.019	0.012	0.058	0.019	0.033	0.030	0.033	0.025	0.030	0.029	0.025	0.025	0.030	0.025
T15	0.051	0.036	0.031	0.019	0.013	0.054	0.019	0.028	0.030	0.028	0.025	0.040	0.029	0.025	0.025	0.040	0.025
T16	0.018	0.040	0.035	0.024	0.020	0.035	0.032	0.013	0.029	0.013	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T17	0.026	0.037	0.031	0.024	0.020	0.034	0.034	0.016	0.027	0.016	0.034	0.030	0.029	0.034	0.034	0.030	0.034
T18	0.046	0.030	0.030	0.024	0.020	0.035	0.024	0.032	0.030	0.032	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T19	0.030	0.035	0.025	0.019	0.013	0.054	0.022	0.031	0.028	0.031	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T20	0.026	0.030	0.025	0.032	0.034	0.020	0.032	0.019	0.029	0.019	0.042	0.051	0.029	0.042	0.042	0.051	0.042
T21	0.026	0.028	0.029	0.028	0.027	0.026	0.034	0.028	0.028	0.028	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T22	0.026	0.029	0.028	0.029	0.029	0.024	0.033	0.024	0.030	0.024	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T23	0.026	0.029	0.028	0.029	0.029	0.024	0.033	0.024	0.028	0.024	0.034	0.030	0.029	0.034	0.034	0.030	0.034
T24	0.026	0.026	0.028	0.029	0.029	0.024	0.021	0.033	0.027	0.033	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T25	0.015	0.024	0.025	0.029	0.029	0.024	0.033	0.041	0.029	0.041	0.025	0.030	0.029	0.025	0.025	0.030	0.025
T26	0.034	0.031	0.031	0.027	0.025	0.028	0.034	0.022	0.030	0.022	0.034	0.040	0.029	0.034	0.034	0.040	0.034
T27	0.026	0.026	0.013	0.029	0.029	0.024	0.026	0.032	0.028	0.032	0.034	0.030	0.029	0.034	0.034	0.030	0.034
T28	0.026	0.023	0.028	0.034	0.039	0.018	0.024	0.037	0.027	0.037	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T29	0.026	0.027	0.028	0.033	0.037	0.019	0.032	0.022	0.027	0.022	0.034	0.030	0.029	0.034	0.034	0.030	0.034
T30	0.026	0.030	0.028	0.030	0.031	0.022	0.028	0.020	0.031	0.020	0.042	0.051	0.029	0.042	0.042	0.051	0.042
T31	0.026	0.026	0.028	0.035	0.042	0.017	0.024	0.023	0.028	0.023	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T32	0.060	0.042	0.034	0.014	0.007	0.098	0.011	0.031	0.027	0.031	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T33	0.026	0.027	0.031	0.029	0.029	0.024	0.028	0.029	0.028	0.029	0.025	0.030	0.029	0.025	0.025	0.030	0.025
T34	0.021	0.022	0.023	0.036	0.045	0.016	0.033	0.033	0.029	0.033	0.025	0.020	0.029	0.025	0.025	0.020	0.025
T35	0.021	0.022	0.031	0.038	0.048	0.014	0.038	0.033	0.028	0.033	0.025	0.030	0.029	0.025	0.025	0.030	0.025

Table 12. Entropy values

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
E_j	0.986	0.996	0.997	0.995	0.985	0.968	0.992	0.992	1.000	0.992	0.995	0.985	1.000	0.995	0.995	0.985	0.995

After determining the entropy values, the weight values were determined using Equations (2.6) and (2.7). Calculated weight values are shown in Table 13.

Table 13. Weight values

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
w_j	0.096	0.026	0.020	0.031	0.106	0.217	0.052	0.054	0.002	0.054	0.032	0.107	0.000	0.032	0.032	0.107	0.032

The total utility values obtained using the required parameters calculated above are presented in Table 14. In addition, when Table 14 is examined, it is seen that the selection of turbines with codes T8, T20 and T30 will be more appropriate. Moreover, in the consistency analysis, the consistency index and consistency ratio were determined for 17 criteria as 0.1538 and 0.0956, respectively.

Table 14. Total utility values

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	Total
T1	0.074	0.021	0.017	0.020	0.058	0.024	0.042	0.036	0.002	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.329
T2	0.074	0.018	0.014	0.018	0.051	0.030	0.044	0.029	0.002	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.309
T3	0.074	0.019	0.011	0.020	0.055	0.026	0.029	0.030	0.002	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.295
T4	0.037	0.019	0.017	0.019	0.053	0.028	0.043	0.031	0.001	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.279
T5	0.074	0.018	0.017	0.014	0.036	0.049	0.018	0.040	0.001	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.306
T6	0.074	0.025	0.013	0.028	0.091	0.005	0.034	0.040	0.002	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.352
T7	0.074	0.022	0.011	0.024	0.074	0.013	0.020	0.033	0.001	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.306
T8	0.092	0.018	0.017	0.018	0.050	0.031	0.047	0.026	0.001	0.026	0.032	0.107	0.000	0.032	0.032	0.107	0.032	0.668
T9	0.074	0.016	0.017	0.023	0.071	0.015	0.052	0.009	0.001	0.009	0.016	0.071	0.000	0.016	0.016	0.071	0.016	0.494
T10	0.074	0.016	0.017	0.020	0.056	0.025	0.043	0.016	0.002	0.016	0.000	0.036	0.000	0.000	0.000	0.036	0.000	0.356
T11	0.074	0.025	0.011	0.024	0.075	0.013	0.043	0.047	0.002	0.047	0.016	0.036	0.000	0.016	0.016	0.036	0.016	0.495
T12	0.065	0.022	0.017	0.020	0.055	0.026	0.020	0.044	0.000	0.044	0.000	0.071	0.000	0.000	0.000	0.071	0.000	0.454
T13	0.074	0.022	0.017	0.020	0.055	0.026	0.036	0.046	0.000	0.046	0.016	0.071	0.000	0.016	0.016	0.071	0.016	0.548
T14	0.018	0.010	0.012	0.006	0.013	0.113	0.016	0.038	0.000	0.038	0.000	0.036	0.000	0.000	0.000	0.036	0.000	0.335
T15	0.018	0.008	0.017	0.007	0.015	0.104	0.015	0.028	0.001	0.028	0.000	0.071	0.000	0.000	0.000	0.071	0.000	0.382
T16	0.091	0.003	0.020	0.013	0.033	0.054	0.040	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.255
T17	0.074	0.006	0.017	0.013	0.034	0.052	0.044	0.005	0.002	0.005	0.016	0.036	0.000	0.016	0.016	0.036	0.016	0.387
T18	0.030	0.016	0.015	0.013	0.033	0.054	0.025	0.036	0.000	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.257
T19	0.065	0.010	0.011	0.007	0.015	0.104	0.021	0.034	0.001	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.301
T20	0.074	0.016	0.011	0.023	0.070	0.016	0.040	0.011	0.001	0.011	0.032	0.107	0.000	0.032	0.032	0.107	0.032	0.614
T21	0.074	0.018	0.014	0.018	0.051	0.030	0.044	0.029	0.001	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.308
T22	0.074	0.018	0.013	0.020	0.058	0.024	0.042	0.021	0.000	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.291
T23	0.074	0.018	0.013	0.020	0.058	0.024	0.042	0.021	0.001	0.021	0.016	0.036	0.000	0.016	0.016	0.036	0.016	0.428
T24	0.074	0.021	0.013	0.020	0.057	0.025	0.020	0.039	0.002	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.309
T25	0.096	0.023	0.011	0.020	0.057	0.025	0.043	0.054	0.001	0.054	0.000	0.036	0.000	0.000	0.000	0.036	0.000	0.454
T26	0.055	0.014	0.017	0.017	0.047	0.034	0.044	0.017	0.000	0.017	0.016	0.071	0.000	0.016	0.016	0.071	0.016	0.469
T27	0.074	0.021	0.000	0.020	0.057	0.025	0.029	0.037	0.001	0.037	0.016	0.036	0.000	0.016	0.016	0.036	0.016	0.436
T28	0.074	0.025	0.013	0.026	0.082	0.009	0.025	0.046	0.002	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.348
T29	0.074	0.019	0.013	0.025	0.076	0.012	0.041	0.017	0.002	0.017	0.016	0.036	0.000	0.016	0.016	0.036	0.016	0.432
T30	0.074	0.016	0.014	0.022	0.063	0.020	0.033	0.013	0.000	0.013	0.032	0.107	0.000	0.032	0.032	0.107	0.032	0.609
T31	0.074	0.021	0.013	0.028	0.089	0.006	0.025	0.018	0.001	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.292
T32	0.000	0.000	0.019	0.000	0.000	0.217	0.000	0.034	0.002	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.306
T33	0.074	0.019	0.017	0.020	0.056	0.026	0.034	0.029	0.001	0.029	0.000	0.036	0.000	0.000	0.000	0.036	0.000	0.375
T34	0.083	0.025	0.009	0.029	0.097	0.003	0.043	0.039	0.001	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.368
T35	0.083	0.026	0.017	0.031	0.106	0.000	0.052	0.038	0.001	0.038	0.000	0.036	0.000	0.000	0.000	0.036	0.000	0.464

4. Discussion and Conclusion

Nowadays, wind energy systems are commercialised by many countries around the world to generate energy because many advantages have been proven over other renewable energy sources. Wind turbines are also the most important part of this energy conversion system. In this study, an adaptive assessment model is presented to select the best wind turbine to fill the gap in the literature studies where turbine selections are made with qualitative evaluation using limited criteria. This is the most important focus of the study. In addition, although the MAUT used in the proposed adaptive model is encountered in some of the literature studies, the studies in which it was used with the entropy method are limited. It was especially preferred in determining the weights using the entropy method's advantages.

Selection problems involve various evaluation criteria and the different stakeholders who set these criteria. For this reason, experts and stakeholders in the field of wind energy management were included in the process through interviews. The proposed model's consistency rate (0.0956) indicates that the results are also quite consistent. When the study results were evaluated, it was seen that choosing solely turbine power was not the right approach. The necessity of examining the effect of all criteria was clearly understood in the study's outcome, and a more consistent selection targeted with the proposed model was achieved. The evaluations of the analysis results are presented below:

1. 35 different turbine brands were examined using four main and 17 sub-criteria. These criteria were applied to the innovative evaluation model developed for use in turbine selection.
2. When the total benefit values obtained by the innovative evaluation model are examined, it is seen that the turbines with codes T8, T20 and T30 are more suitable, respectively.
3. The average total utility value was determined as 0.389. When an evaluation is made on this value, it is seen that 13 turbine models are above the average benefit value.
4. When the criteria are evaluated independently, the advantages of each turbine differ from the others. However, evaluating the effectiveness of all criteria leads to more consistent and realistic results. The results obtained from the consistency analysis support this.

Unlike the studies in the literature, an entropy-based approach is preferred in the method used in the proposed study. Thus, the consistency rate is increased by utilising the benefits of entropy. In addition, classical multi-criteria decision-making methods are preferred in the studies in the literature, but not as many criteria as the number of criteria used in this study. This provides the opportunity to evaluate the results in multiple ways. Although 3 MW turbines are used in this study, the developed model can be easily applied to all turbines with different powers. Evaluating with many criteria strengthens the model and adds significant value to the study. The proposed model has the property that can be applied both commercially and practically. Therefore, the results are significant and precious in engineering and economics.

Additionally, it was emphasised that this study's correct selection of wind turbines for wind energy production facilities is critical. Thus, it is possible to present different approaches for the optimal selection of wind turbines for future work. It is also planned to determine the valid features for optimal selection.

Author Contributions

They all read and approved the final version of the manuscript.
Cem Emeksiz: Analysis, Investigation, Software, Writing- Original Draft, Writing – Review, Methodology.
Abdullah Yüksel: Writing – Review & Editing, Formal Analysis, Validation, Supervision.

Conflicts of Interest

The authors declare no conflict of interest.

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