International Journal of Pioneering Technology and Engineering

Research Article

The Site Selection of Wind Energy Plants Using the MOORA Method

Engin Ufuk Ergül [a*], **Mustafa Genç** [b]

[a] Department of Electrical and Electronics Engineering, Faculty of Engineering, Amasya University, Amasya, Turkey

[b] Department of Technology and Innovation Management, Institute of Science, Amasya University, Amasya, Turkey

Article Info

Article history
Received: 02.05.2022
Revised: 27.05.2022
Accepted: 05.06.2022

Keywords:
Renewable Energy
Wind Energy
Multi-Criteria Decision Making
MOORA

ABSTRACT

An important part of Turkey's energy needs is met with fossil fuel energy resources. The lack of fossil fuels to be sustainable and lead to pollution of the renewable energy resources, wind energy has led to be a very important energy resource for Turkey. Wind energy potential of Turkey is high. The initial installation costs of wind energy plants are high. For this reason, it is very important to select the wind energy plant installation sites correctly to ensure high efficiency from the plants. There are many criteria that affect the decision-making process in selecting an installation site of a wind energy plant. Therefore, installation site selection of a wind energy plant is a complex decision-making process. In this study, considering the wind speeds over the wind energy potential atlas, three plant sites are determined in the southeast (RES_1), north (RES_2) and southwest (RES_3) of Amasya. MOORA method (Multi-Objective Optimization on basis of Ratio Analysis), which is one of the Multi-Criteria Decision Making methods, has been used in the selection of the most appropriate installation site. Determined criteria values and benchmark weights are used in MOORA method. Using the MOORA method, the plant installation sites are ranked. After that, the most suitable wind energy plant installation site (RES_2) is determined for Amasya.

1. Introduction

The rapid development of technology, rapidly continuing migrations from rural areas to cities, more employment efforts and industrialization moves have increased the need for energy [1]. The rapid increase in the world's population and technology is indispensable in daily life causing high energy consumption, the high efficiency uses of resources, and focused the renewable energy resources that are less harmful to the ecological system [2].

Turkey has a significant potential to produce electricity from wind energy due to its location. In developing countries such as Turkey, the use and planning of energy resources are critical. Having only fossil fuels for power generation is becoming a major concern for the future due to its limitation and monopoly. Turkey, which does not have rich underground resources, meets its constantly increasing energy needs by importing, therefore it becomes dependent on foreign sources.

In order to eliminate all these negative situations and to obtain its energy needs from local sources, our country needs to turn to renewable energy sources. One of the most important and potential of these resources is wind energy. Therefore, the number of wind power plants should be increased. For this reason, it is critical to choose the settlements of wind power plants appropriately and to increase their efficiency. One of these resources and one of the highest potentials is wind energy. Therefore, the number of wind energy plants should be increased. Therefore, it is very important to select the settlements of the wind energy plants properly and to increase their efficiency.

Haaren and Fthenakis [3] have carried out a selection of installation sites of wind farms using the spatial multi-criteria analysis technique in New York. In that study; the appropriate areas for wind farms were determined, and economically evaluated the effects of wind turbines on bird habitats were examined. Gass et al. made an economic evaluation of Austria's wind energy potential [4]. The general purpose of their study was the economical evaluation of places where wind energy plants according to the infrastructure, natural environment, protected regions, and existing electricity tariffs. Tegou, Polatidis and Haralambopoulos have an application for the most suitable siting for a wind farm on the island of Lesvos in Greece [5]. They used the AHP (Analytical Hierarchy Process) method to weight the criteria. Bennui and others [6] have made GIS (Geographical Information Systems) -based site selection for large wind turbines in Thailand. The main purpose of the study was to create a model of the site selection by integrating the GIS and multi-criteria decision-making methods..

***Corresponding author:** Engin Ufuk Ergül
*E-mail address: engin.ergul@amasya.edu.tr
https://doi.org/10.56158/jpte.2022.18.1.01

Tasri and Susilawati used fuzzy AHP to identify the renewable energy alternatives in Indonesia [7]. Şengül et al. used fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) for ranking the renewable energy supply systems in Turkey [8]

Zhang et al. proposed a new MCDM (multi-criteria decision-making) method and applied this method to evaluate clean energy alternatives for Jiangsu/China [9]. Kabak and Dağdeviren proposed a hybrid model using BOCR (Benefit, Opportunity, Cost and Risk) and ANP (Analytical Network Process) to evaluate the energy production of Turkey and rank the alternative resources [10]. Al-Yahyai et al., used Analytical Hierarchy Process with Ordered Weigh Averaging (AHP-OWA) aggregation function method to derive wind farm land suitability index and classification under the GIS environment for wind energy plants in Oman [11].

Turkey has a high potential for wind energy while the potential wind energy of Turkey cannot be fully utilized. To produce the highest rate of electrical energy from the existing wind potential, it is very important to determine the sites where power plants will be installed. In this study; the importance of determining the best site for wind energy plants is emphasized, the criteria for the selection of the best wind energy plant are determined and a study is made for Amasya province. The MOORA method is used to determine the best site for a wind energy plant.

Section 2, it is given some information about the production of electrical energy in Turkey and Turkey's situation in wind energy production. Explanations about the methods used are given in Section 3. The obtained results are given and evaluated in Section 4. In the last chapter, the results and suggestions of the study were evaluated.

2. The Production of Electrical Energy in Turkey and the Status of Wind Energy

As of the end of 2018, the installed capacity of the electrical power of Turkey was 83 198.6 MW licensed and 5 352.4 MW unlicensed. 26.97 % of the total installed electrical power is provided by natural gas-based power plants. The installed power of renewable energy resources is 44.86%. Almost half of the existing installed power consists of renewable energy induced power plants. Installed renewable energy capacity consists of 24.68% hydraulic (dam) energy plants, hydraulic (stream) energy plants with 9.31%, wind energy plants with 8.34%, geothermal energy plants with 1.54%, biomass energy plants with 0.89%, and solar energy plants with 0.1% [12] (shown in Fig.1).

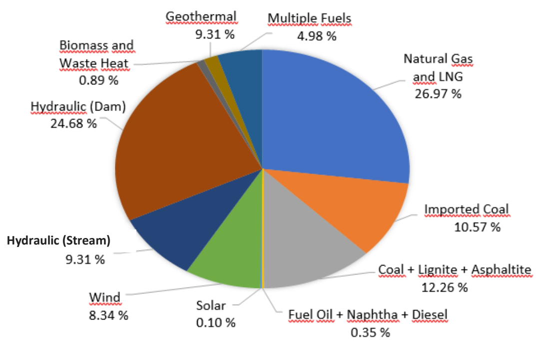

Fig.1. Distribution of installed electrical power by primary resources (december 2018) [12]

The primary resource in electrical energy production in Turkey is still natural gas and coal. Investment in renewable energy resources is increasing day by day in Turkey. Despite the investments made, Turkey continues to depend on outside energy. For this reason, more comprehensive feasibility studies should be carried out to obtain the highest efficiency from renewable energy resources except for seasonal effects. Especially, it should be more careful when selecting the installation site of the power plants.

Wind energy plants are priority in energy investments for Turkey. Turkey's wind energy capacity calculated at a height of 100 m is 48 000 MW. As of the end of 2018, the total installed power of wind energy in Turkey is 7 143.8 MW. This rate corresponds to 15 % of the total wind energy potential of Turkey.

The regions where wind energy plants are installed in Turkey are shown in Fig.2. Since Fig.2 is examined, the places where wind energy plants are the most installed are in the Aegean and Marmara regions.

Fig.2. Map of wind energy plants in turkey [13]

When the regions of Turkey are examined, the region with the highest wind energy potential, where is the Aegean Region, is shown in Fig.3.

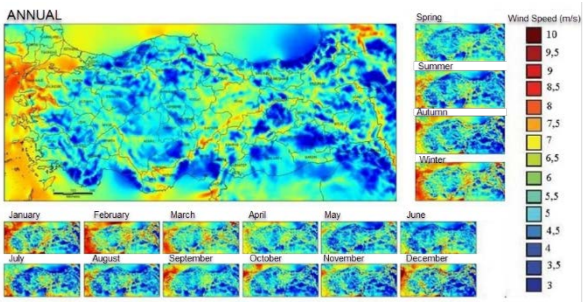

Fig.3. Wind energy potential atlas of turkey according to seasons and months [14]

Due to the geopolitical location and geographical structure of Turkey, wind energy potential is high in coastal regions. Many of the wind energy plants established in Turkey are located in these regions. Turkey's wind energy potential was calculated as 5 MW on an area of 1 km^2 at a wind speed of 7.5 km/h at a height of 100 m. Turkey's total wind energy potential is 48 000 MW [15]. 1.3% of Turkey's surface area has this potential.

Wind Energy Potential Atlas (WEPA) in 50 m height, which is prepared by EIGM (Enerji Isleri Genel Mudurlugu), is shown in Fig.4.

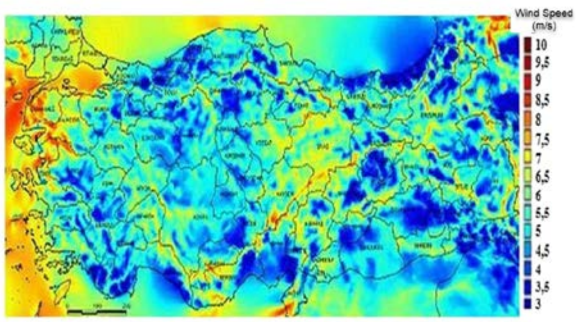

Fig.4. Wind energy potential atlas of turkey (50 m) [14]

While Turkey's average wind speed is high in winter, it is at low levels in the spring season. When it is compared the averages of wind speed on a monthly basis, the highest average is reached in February and the lowest average is reached in June. In the same way, the same situations are observed when WEPA given in Fig.5 is examined for a height of 100 m.

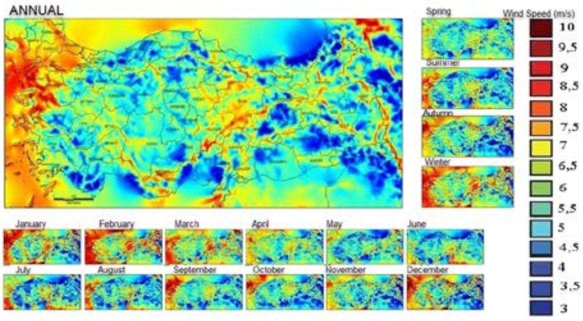

Fig.5. Wind energy potential atlas of turkey (100 m) [14]

Compared to Europe and Turkey, Turkey ranks third in the wind energy potential. While the working time of Turkey's wind turbines is 3000 hours annually, this value is around 2000-2500 hours in Europe [16].

3. Material and Method

3.1. MCDM and MOORA Method

MCDM is the process of selecting the best alternative from among alternatives according to conflicting criteria [17]. Decision makers decide according to the criteria, decision variables, and alternatives in MCDM problems. Many methods have been proposed in the literature for the solution of MCDM problems [18, 19].

Considering the methods followed in this study and the results to be achieved, it was determined that the most appropriate method would be the MOORA method in the determination of the installation site of the wind energy plant. The determination of the installation site of the wind energy plants requires a complex decision-making mechanism as it has independent criteria. MOORA method is the best method that can offer us the solutions close to the right result, where many independent criteria are evaluated. One of the most important advantages of the MOORA method is that it does not require special software because it does not require many mathematical processes.

The MOORA method was proposed in 2006 by Brauers and Zavadskas [20]. The main benefits of this method are; considering and evaluating all criteria and alternatives together, not one by one [19]. MOORA method begins with the generation of a decision matrix that shows the performance of various alternatives and criteria [20]. This decision matrix is given in Eq.1:

$$D = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ . \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & x_{13} & . & x_{1n} \\ x_{21} & x_{22} & x_{23} & . & x_{2n} \\ x_{31} & x_{32} & x_{33} & . & x_{3n} \\ . & . & . & . & . \\ x_{m1} & x_{m2} & x_{m3} & . & x_{mn} \end{bmatrix} \quad (1)$$

Here A_i is the alternatives (i= 1,2,…,m) and x_{ij} is the performance measure of *i*-th alternative with respect to *j*-th criterion, *m* is the number of alternatives and *n* is the number of criteria.

3.1.1. Ratio System Method

Normalization matrix is obtained by dividing the criterion values by the sum of the squares of the alternative values [17].

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

Here, i = 1.2 ,…,m is the number of alternatives, j = 1.2, ...,n is the number of criteria. x_{ij}^* is the normalized value of alternative *i* with criteria *j* $x_{ij}^* \in [0,1]$ [21]. In the table obtained after these procedures, the criteria are summed after they are determined according to being maximum or minimum. After that, the sum of maximum values is subtracted from the sum of minimum values:

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^* \quad (3)$$

written as [20]. Where g is the number of criteria to be maximized, *(n−g)* is the number of criteria to be minimized, and y_i^* is the normalized assessment value of i th alternative with respect to all the criteria. The process is completed by ranking the y_i^*.

3.1.2. Reference Point Theory

In addition to the ratio system method, for each criterion; maximum reference points for maximization and the minimum reference points for minimization are determined. These points (r_j) have distances to each x_{ij}^* criterion value and the values obtained are written as a matrix. [22]. This matrix is applied to the 'Tchebycheff Min-Max Metric' process [20]. In this way, the ranking is done:

$$min_i \{max_j(|r_j - x_{ij}^*|)\} \quad (4)$$

In some cases, it is often observed that some criteria are more important than others. In order to give more importance to a criterion, it could be multiplied by its corresponding weight (significance coefficient) [23].

$$\ddot{y}_i^* = \sum_{j=1}^{g} s_j x_{ij}^* - \sum_{j=g+1}^{n} s_j x_{ij}^* \quad (5)$$

$\ddot{y}_i^*$ is the assessment value (composite score) of the i-th alternative with respect to all considered criteria. s_j is the weight of j th criterion.

3.1.3. Full Multiplicative Form Method

The formula of this method developed by Brauers and Zavadskas in 2010 is as follows [20]:

$$u_i = \frac{A_i}{B_i} \quad (6)$$

Here $A_i = \prod_{j=1}^{g} x_{ij}^*$ ve $B_i = \prod_{j=g+1}^{n} x_{ij}^*$.

j=1, 2, ..., m; m the number of alternatives; i=the number of objectives to be maximized; n–i=the number of objectives to be minimized. ui: the utility of alternative j with objectives to be maximized and objectives to be minimized. In Eq.6, the values to be maximized are written to the nominator, the values to be minimized are written to the denominator and the formula is applied.

3.1.4. MULTIMOORA Method

With this method, the results obtained from three different MOORA methods (ratio system, reference point theory, and full multiplicative form) are tried to obtain a more accurate order by evaluating the results between the dominance theorem developed by Brauer and Zavadskas [23, 24]. An alternative in all three methods rank *i*, it is stated that it is dominant on other alternatives. If there is an alternative with rank *i* in two methods, it will provide a general dominance on the alternatives with rank *i* in other methods. In addition, if the A alternative is dominant to the B alternative, the B alternative is dominant to C; it is accepted that the A alternative is dominant to the C alternative.

3.1.5. Site Selection Criteria of Wind Energy Plants

The decisions to be made during the selected sites of wind energy plants are at the micro and macro level. Decisions to be made at the micro level are that the direction of the turbine, blade pitch angles, and blade lengths according to the wind profile after the site of the wind energy plant is determined. Decisions to be made at the macro level are the economic, technical, and environmental-social criteria of the determination of the site.

3.1.5.1. Economical Criteria

Land Cost: It is directly proportional to the size of the wind energy plant. Larger lands are required for big wind energy plants. The land cost may vary according to the socio-economic situation of the installation region of the plant and the distance of the residential districts. Another point to be considered is whether surrounding lands are suitable for purchasing or leasing for enlargement in the future power increase

Incentives: Considerable incentive programs are applied due to the low damage to the environment while electrical energy is produced from wind energy plants. Provided incentives are tax reduction, insurance premium support, land allocation, fixed price guarantee, electric purchase guarantee, etc.

Distance to Roads: Since wind turbines are formed by combining large and heavy parts, the transportation of these parts to the plant area is significant in the installation phase. The distance of the power plant to the roads is directly proportional to the installation costs. In addition, the distance to the roads leads to an increase in the staff expenses to carry out operations, maintenance, and repair operations.

Ground Structure: Wind turbines are physically heavy and large structures. The foundation of such a structure should be strong enough to carry the turbine. When selecting the turbine field, hard and rocky floors should be preferred, not swamp and slippery floors. Swamp and slippery floors bring additional costs for basic strengthening.

Distance to Electrical Transmission Lines: Electrical energy is transferred to the end user by transmission lines. As the distance in transmission lines increases, the losses also increase. The energy produced in wind energy plants is measured by the electric meters at the point where it is connected to the grid. The losses that occur at a distance from the plant to the grid ports are added to the costs. When the first installation costs of the transmission lines between the turbine field and the electrical grid and the maintenance and repair expenses in the operation process increase, the costs as the distance increases.

3.1.5.2. Technical Criteria

Wind Speed: Kinetic energy of wind is directly proportional to wind speed. In order to produce high amounts of energy from wind turbines, the wind speed should be high. The average annual wind speeds should be examined when determining the wind energy plant site. The most important criterion when selecting the site is the wind speed.

Wind Capacity Factor: The capacity factor is one of the data showing how efficient the wind energy plant is in electrical energy production. It is used to explain the relationship between the nominal power of the wind energy plant and the annual electrical energy produced from this plant. Turkey's wind capacity factor map is shown in Fig.6. The values under 35 % of the wind capacity factor in Turkey are not evaluated economically.

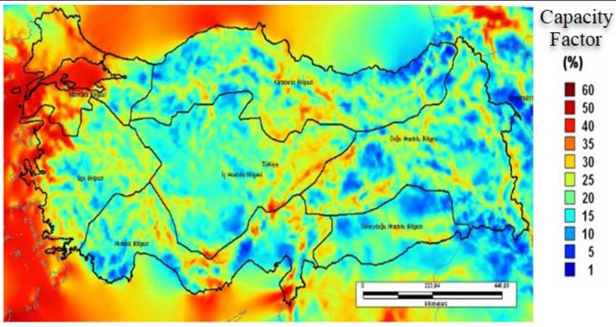

Fig.6. Average wind capacity factor distribution throughout turkey (50 m) [14]

Slope: For the wind turbine to work for many years and to carry parts such as blades and body, the foundation must be solid. Additional procedures are required for the solid foundation of the turbine in sloping lands. In addition, since the turbine parts are transported by road during the construction phase, it is impossible for the heavy tonnage vehicles used to perform this process on sloping lands. Air transportation is also expensive. In the literature, it is seen that the installation of a wind energy plant above a 20% slope value will not be economical.

Altitude: The temperature decreases by 1 °C at every 100 m above sea level. The mechanical parts of the wind turbines are produced suitable for operation at certain temperatures. The fact that the air temperature falls below zero rather than sea level causes freezing on turbine surfaces and mechanical parts. This causes faults and increases maintenance costs. Studies have shown that a wind turbine should be built below 1500 m high in order to operate economically.

3.1.5.3. Environmental and Social Criteria

Noise: As a result of the friction of the blades of wind turbines with air, sound waves occur. After 300m away, the sound in the wind turbines is heard at 43 dB (A) levels. This sound level is at the same level as the household items (air conditioner, refrigerator etc.) which we use in daily life. At distances of 500 m and above, the sound that can be heard decreases to 38 dB(A). The sounds at these levels have no negative impact on human life [25].

Distance to Bird Habitat: According to the observations and studies, some migrant bird species were negatively affected by wind turbines. Observation should be made for two years, before the installation and during the operation of wind turbines [26]. It has been observed that the turbines do not affect so much the bird habitats in the observations and studies carried out in the world and Turkey. In the observations, it is seen that birds are protected from impacts and do not fly toward the turbines [26]. The map of bird migration through Turkey prepared by official institutions and researchers is shown in Fig.7.

Fig.7. Migrant bird routes in Turkey [26].

Distance to the Airport: Since the bodies of the wind turbines are fixed and their turbine blades are moving, they send signals of constantly varying amplitude to the airport radar systems. In radar systems following this area, blindness occurs due to signals from the turbines [27]. Image irregularity adversely affects flights in civil and military airports. Turbine blade manufacturers use fiberglass material to reduce the effect on radar systems. However, the metal cables used in the blades to protect from lightning reflect microwave signals. In order to protect airport radar systems and aircraft from these effects, wind turbines should be established at a minimum of 5000 m and beyond airports.

Distance to the Residental District: Wind turbines are physically large structures. Noise and shadow flicker effect occurs during blade movements. These effects cause sleep disorders, headaches, and blurred vision in people who live close to wind turbines. In order to prevent such negative effects, it is stated in the literature that the turbines should be 2500 m or further away from the residential districts.

Distance to conservation areas and cultural heritage sites: Historical areas and antiquities are protected by the government. The wind turbine is not allowed to be established in these areas [28].

Distance to the Military Zones: Since military zones and military airport radar systems are negatively affected by wind turbines; what is said under the section of distance to the airport also applies to this situation.

Distance to the Forests: Since forests are under protection, the installation of wind energy plants is not allowed there. In addition, high-length trees prevent winds from the turbines, wind energy plants do not work efficiently in such areas [28].

Distance to the Lakes: Wind energy plants can be installed on the sea and the lakes. Wind energy plants are built in a very small area of the specified plant area. The area covered by the turbine is 1% of the plant area. There is no harm to fishes and other creatures. Fishing and tourist activities can be carried out in those regions [29].

Distance to the Mining Zones: It is impossible to build wind turbines on open mining sites. In non-dangerous areas of underground mining sites, there is no harm in the establishment of wind energy plants.

Distance to the Agricultural Fields: In the sites where wind turbines are established, agriculture and forestry activities can be done.

3.1.6. Determination of the Site Alternatives of Wind Energy Plants

This study, it is aimed that determining the best site alternative for wind energy plants within the borders of Amasya province. Alternative plant installation sites were determined by using the maps of the wind speed and capacity factor in Amasya given in Fig.8 and Fig.9 and areas where plants cannot be established given in Fig.10. Three regions were determined as the site options of wind energy plants in the southeast, north (RES_2) and southwest (Res_3) of Amasya given in Fig.11.

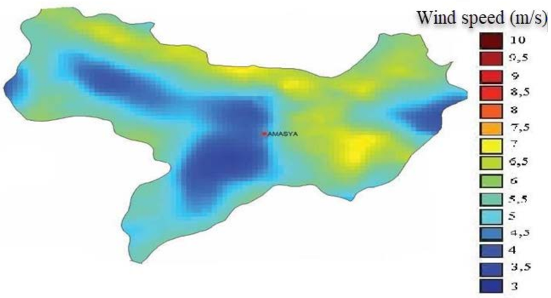

Fig.8. Wind speed distribution of amasya (50 m) [14]

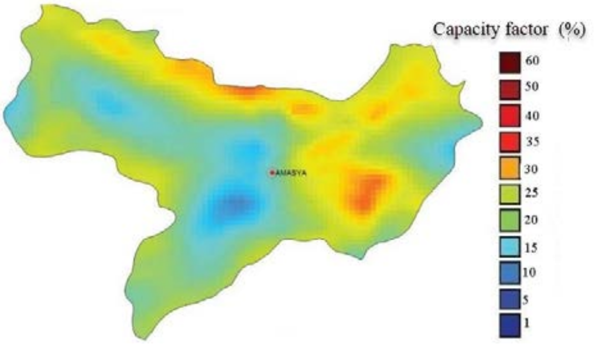

Fig.9. Capacity factor distribution of Amasya (50 m) [14]

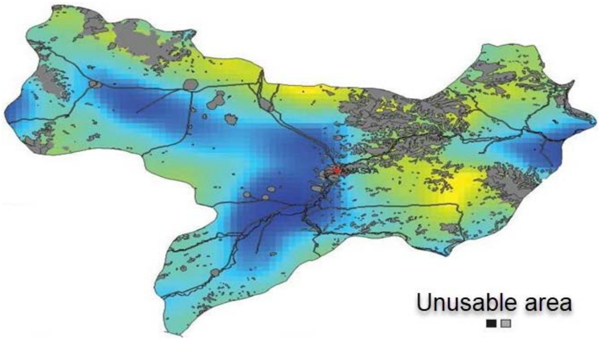

Fig.10. Sites where wind turbine cannot be installed in amasya [14]

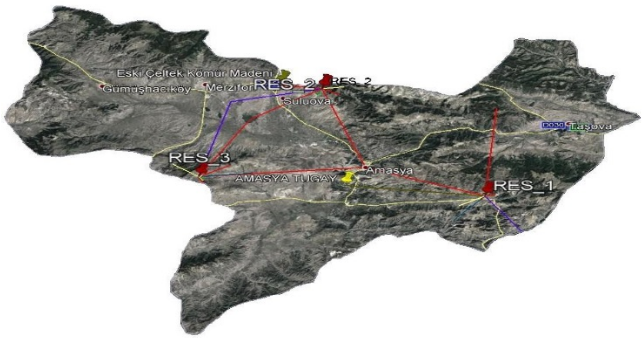

Fig.11. Alternative installation sites of wind energy plant in Amasya

3.1.7. Determination of Criteria Values

The existing wind speeds and wind capacities in the alternative plant installation sites obtained by examining Amasya wind speed atlas given in Fig.8 are shown in Table 1. Fig.9 was used to determine wind capacity factors.

Table 1. Mean wind speed and wind capacity factor values of alternative sites

Criteria	Alternatives		
	RES_1	RES_2	RES_3
Wind Speed (km/h)	7	7.5	6.5
Wind Capacity Factor (%)	35	40	30

The slope and altitude information of alternative plant installation sites in Amasya is shown in Table 2. The slopes of alternative sites were found by using the digital elevation model (DEM). Fig.12 shows the height isohips map of Amasya. Each curve range is 50 meters on this map.

Table 2. Slope and altitude values of alternative sites

Criteria	Alternatives		
	RES_1	RES_2	RES_3
Slope (^{0})	16	15	13
Altitude (m)	720	1000	978

Fig.12. Height isohips map of Amasya

The slope map of Amasya is shown in Fig.13. ArcMap 10.3 software was used in the calculations of the slopes and heights of the alternative regions.

Fig.13. The slope map of Amasya

The ground structure of the alternative sites is determined by using the soil types distribution map of Turkey given in Fig.14.

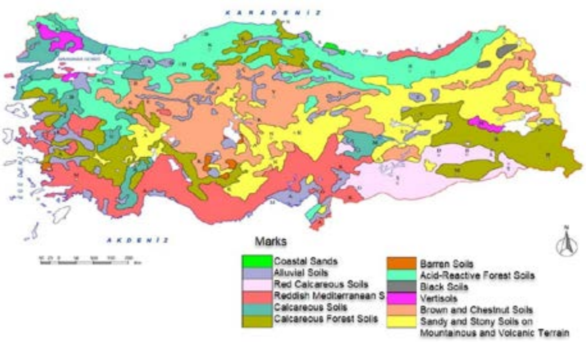

Fig.14. Soil types distribution map of Turkey [30]

The ground structure of the RES_1 is acid-reaction forest soils (brown forest soils), the ground structure of the RES_2 is calcareous forest soil and the ground structure of the RES_3 is barren soil. Since the ground structures of the fields have qualitative characteristics, these criteria should be quantitative to be evaluated. While the ground structure of the alternative sites was quantitative, the following method was applied. The most appropriate and inappropriate ground structure for the installation site of the wind energy plant is determined from the literature. Accordingly, the most suitable ground structure is hard and rock floors (value of 1), and inappropriate floors are slippery and swamp floors (value of 0). In the range of 0 and 1 values, the area with the most suitable ground structure for alternative sites is the RES-3 area with a barren soil structure and a 0.65 value is given. For RES_1 region, which has the least appropriate brown forest soils compared to others, is given 0.40.

The land costs of alternative sites were found by taking the averages of the square meter prices in the sales announcements of fields and lands in the region and the surrounding area. The average square meter prices of three lands that were sold for sale in and around the same region were determined as land cost value for the alternative sites.

The distance of alternative sites to the transmission lines was calculated by using the map of transmission lines and transformer centres of Amasya published by the Enerji İsleri Genel Mudurlugu given in Fig.15 and Google Earth software. The distances of alternative sites to roads were calculated using Google Earth software.

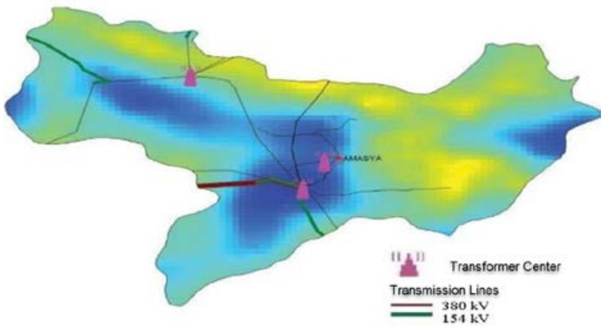

Fig.15. Transmission lines and transformer centers of Amasya [14]

Renewable energy resources are encouraged in Turkey. There are some incentive programs in Turkey. According to the Regulation on the Certification and Supporting Renewable Energy Sources, which was published on 21.07.2011, the government gives purchasing guarantees for the electricity produced by wind energy plants. Currently, in Turkey, the government has been buying electricity produced for 7.3 cents per kWh for 20 years. The sub-criteria values of the economical criteria of the alternative sites are given in Table 3.

Table 3. Sub-criteria Values of Economical Criteria of Alternative Sites

Criteria	Alternatives		
	RES_1	**RES_2**	**RES_3**
Land Cost (TL/m^2)	25	20	15
Incentives (kWh/cent)	7.3	7.3	7.3
Distance to Roads (m)	279	672	883
Ground Structure	0.4	0.55	0.65
Distance to Electrical Transmission Lines (m)	1568	3920	2752

The data of the sub-criteria of the environmental and social criteria for alternative sites are given in Table 4. When determining the noise criterion of the installation sites, the distance to the nearest residential district with a human population is based on the distance. Alternative sites are generally in rural and residential districts. In addition, since there is no existing plant in the specified regions, a real measurement could not be made. The noise criterion values of the alternative sites were determined by using the literature studies and the measurement data of the plants in operation. As a result, the sound intensity measured and calculated 500 m away from a wind energy plant was found to be 43.3 dB. This data is referenced, and the noise made at alternative sites in the closest residential districts is calculated as 40,9 dB (659 m) for RES_1, 30.4 dB (2194 m) for RES_2, and 35.3 dB (1249 m) for RES_3. The formula used in the calculations is given in Eq.7.

$$L_r = L - 20.\log\left(\frac{r}{100}\right) \qquad (dB) \tag{7}$$

Here, L_r refers to the sound intensity (dB), L refers reference sound source intensity (dB) and r refers the distance of the sound source (m).

Turkey is located on important bird migration routes. For alternative sites, there is no data given on any bird observation in the literature. Therefore, to evaluate this criterion, the distance of these sites to the dams and lakes preferred by birds as a region of life was taken into consideration.

Table 4. Sub-criteria values of environmental and social criteria of alternative sites

Criteria	Alternatives		
	RES_1	RES_2	RES_3
Noise (dB)	40.9	30.4	35.3
Distance to Bird Habitat (m)	25140	16797	19310
Distance to Airport (m)	31900	19675	22200
Distance to Residential District (m)	1412	2194	1249
Distance to conservation areas and cultural heritage sites (m)	5875	4391	6225
Distance to Military Zones (m)	28347	18675	22200
Distance to Forests (m)	416	498	1557
Distance to Lakes (m)	9314	600	10770
Distance to Mining Zones (m)	2281	8583	7096
Distance to Agricultural Fields (m)	15.2	219	10

The distance of alternative sites to airport, residential districts, conservation ares and cultural heritage sites, military zones, forests, lakes, mining zones given in Fig.16 and agricultural fields were calculated using Google Earth software.

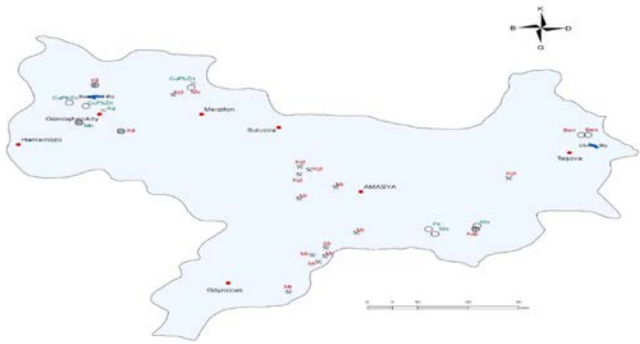

Fig.16. Mine map of Amasya [31]

The model generated for the selection of the best wind energy plant installation site is shown in Fig.17.

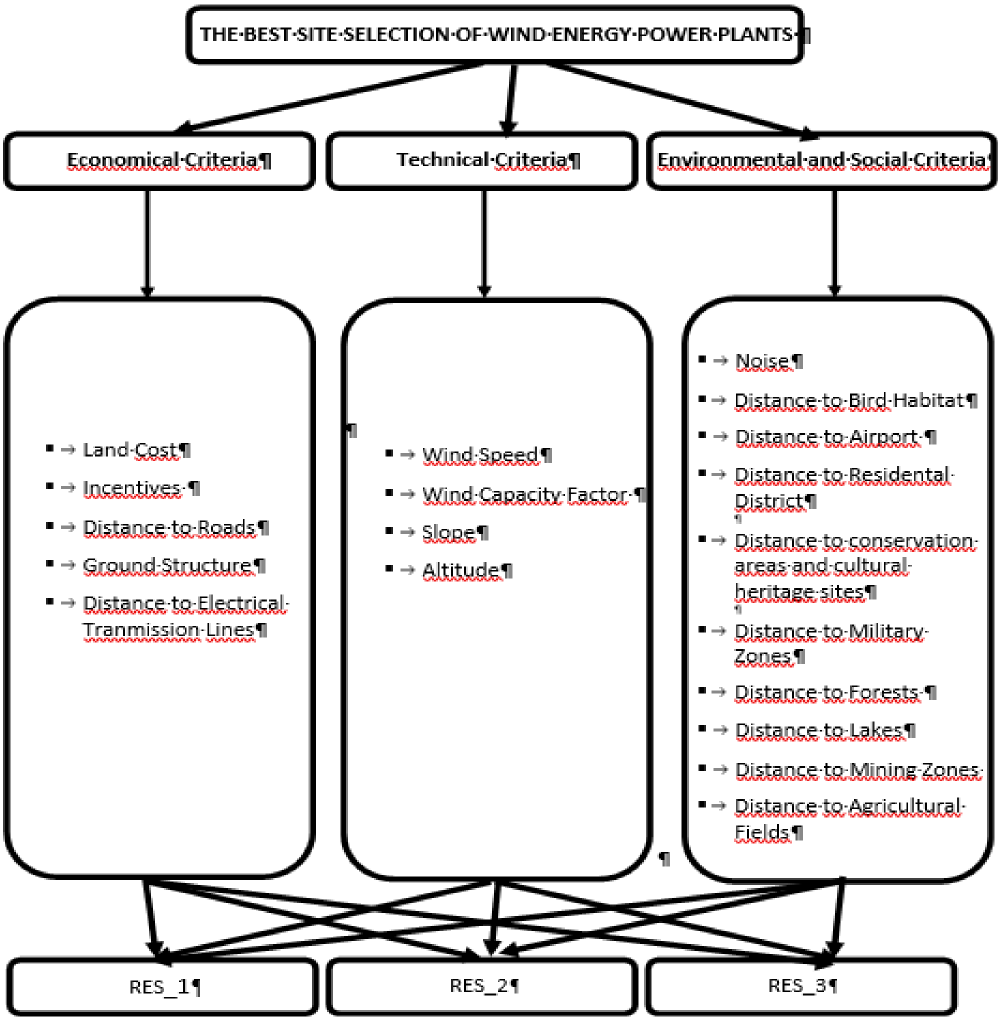

Fig.17. The model of the selection of the best wind energy plant installation site

All the criterion values determined and calculated in the model of wind energy plant installation site model shown in Fig.17 are given in Table 5. Using these values, the best installation site alternative will be determined by the MOORA method.

Table 5, which is formed with the criteria values of the best wind energy plant site, is also the decision matrix. In order to determine the weights of the wind energy plant site criteria, the evaluations of three experts in this field were taken and Table 6 was formed.

Table 5. Criteria values of alternative sites

Criteria		RES_1	RES_2	RES_3
		Alternatives		
ECONOMICAL	Land Cost (TL/m^2)	25	20	15
	Incentives (kWh/cent)	7.3	7.3	7.3
	Distance to Roads (m)	279	672	883
	Ground Structure	0.40	0.55	0.65
	Distance to Electrical Transmission Lines (m)	1568	3920	2752
TECHNICAL	Wind Speed (km/h)	7	7.5	6.5
	Wind Capacity Factor (%)	35	40	30
	Slope (^{0})	16	15	13
	Altitude (m)	720	1000	978
ENVIRONMENTAL and SOCIAL	Noise (dB)	40.9	30.4	35.3
	Distance to Bird Habitat (m)	25140	16797	19310
	Distance to Airport (m)	31900	19675	22200
	Distance to Residential District (m)	1412	2194	1249
	Distance to conservation areas and cultural heritage sites (m)	5875	4391	6225
	Distance to Military Zones (m)	28347	18675	22200
	Distance to Forests (m)	416	498	1557
	Distance to Lakes (m)	9314	600	10770
	Distance to Mining Zones(m)	2281	8583	7096
	Distance to Agricultural Fields (m)	15.2	219	10

Table 6. Criteria weights

Criteria		Criteria Weights
ECONOMICAL	Land Cost	0.07
	Incentives	0.06
	Distance to Roads	0.04
	Ground Structure	0.04
	Distance to Electrical Transmission Lines	0.05
TECHNICAL	Wind Speed	0.16
	Wind Capacity Factor	0.14
	Slope	0.07
	Altitude	0.05
ENVIRONMENTAL and SOCIAL	Noise	0.02
	Distance to Bird Habitat	0.04
	Distance to Airport	0.04
	Distance to Residential District	0.05
	Distance to conservation areas and cultural heritage sites	0.05
	Distance to Military Zones	0.05
	Distance to Forests	0.01
	Distance to Lakes	0.01
	Distance to Mining Zones	0.02
	Distance to Agricultural Fields	0.03

4. Findings

In this study, the MOORA method, one of the multi - criteria decision -making methods, was used in determining the best site for wind energy plants. The main advantages of the MOORA method are that it takes into account and evaluates all the criteria and evaluates the alternatives and criteria at the same time.

Three alternative wind energy plant sites were determined from the boundaries of Amasya: in the southeast (RES_1), in the north (RES_2), and the southwest (RES_3) of the Amasya province.

4.1. Ratio system method

The decision matrix formed from alternatives and criteria values is given in Table 5. Normalized matrices are obtained using the decision matrix.

After the decision matrix is created, the normalized matrix is obtained by applying the formula in Eq.2 to the criterion values of all alternatives given in Table 7.

Table 7. Normalized matrix for ratio system method

Criteria		RES_1	RES_2	RES_3
		Alternatives		
ECONOMICAL	Land Cost	0.7071	0.5657	0.4243
	Incentives	0.5774	0.5774	0.5774
	Distance to Roads	0.2438	0.5873	0.7717
	Ground Structure	0.4252	0.5846	0.6909
	Distance to Electrical Transmission Lines	0.3111	0.7778	0.5461
TECHNICAL	Wind Speed	0.5764	0.6175	0.5352
	Wind Capacity Factor	0.5735	0.6554	0.4915
	Slope	0.6276	0.5883	0.5099
	Altitude	0.4577	0.6357	0.6217
ENVIRONMENTAL and SOCIAL	Noise	0.6598	0.4904	0.5694
	Distance to Bird Habitat	0.7008	0.4682	0.5383
	Distance to Airport	0.7323	0.4517	0.5096
	Distance to Residential District	0.4881	0.7585	0.4318
	Distance to conservation areas and cultural heritage sites	0.6107	0.4564	0.6471
	Distance to Military Zones	0.6989	0.4604	0.5473
	Distance to Forests	0.2466	0.2952	0.9230
	Distance to Lakes	0.6535	0.0421	0.7557
	Distance to Mining Zones	0.2007	0.7550	0.6242
	Distance to Agricultural Fields	0.0692	0.9966	0.0455

After the normalized matrix is formed, the criterion value of each alternative is multiplied by criteria weights respectively and the weighted normalized matrix is obtained. Maximum or minimum situations are determined by considering the benefit status of the criteria. Land cost, road distance, distance to electrical transmission lines, slope, altitude, and noise criteria are required to be minimum as they have cost-increasing and challenging effects on plant installation. Other criteria are required to be maximum. Therefore, the weighted normalized matrix is given in Table 8.

Table 8. Weighted normalized matrix for ratio system method

Criteria			Alternatives		
			RES_1	RES_2	RES_3
ECONOMICAL	min	Land Cost	0.0495	0.0396	0.0297
	max	Incentives	0.0346	0.0346	0.0346
	min	Distance to Roads	0.0098	0.0235	0.0309
	max	Ground Structure	0.0170	0.0234	0.0276
	min	Distance to Electrical Transmission Lines	0.0156	0.0389	0.0273
TECHNICAL	max	Wind Speed	0.0922	0.0988	0.0856
	max	Wind Capacity Factor	0.0803	0.0918	0.0688
	min	Slope	0.0439	0.0412	0.0357
	min	Altitude	0.0229	0.0318	0.0311
ENVIRONMENTAL and SOCIAL	min	Noise	0.0132	0.0098	0.0114
	max	Distance to Bird Habitat	0.0280	0.0187	0.0215
	max	Distance to Airport	0.0293	0.0181	0.0204
	max	Distance to Residential District	0.0244	0.0379	0.0216
	max	Distance to conservation areas and cultural heritage sites	0.0305	0.0228	0.0324
	max	Distance to Military Zones	0.0349	0.0230	0.0274
	max	Distance to Forests	0.0025	0.0030	0.0092
	max	Distance to Lakes	0.0065	0.0004	0.0076
	max	Distance to Mining Zones	0.0040	0.0151	0.0125
	max	Distance to Agricultural Fields	0.0021	0.0299	0.0014

After obtaining the normalized matrix, the $\mathbf{y_i^*}$ values are calculated with Eq.3 and the ranking is as shown in Table 9.

Table 9. rankings of ratio-system method

	Alternatives		
	RES_1	RES_2	RES_3
y_i^*	0.2316	0.2328	0.2046
Ranking	2	1	3

When Table 9 is examined, RES_2, which has the highest y_i^* value, is determined as the most suitable site.

4.2. Reference point theory method

In the reference point theory, the maximum and minimum values of the criterion values provided by using the weighted normalized matrix obtained from the ratio system method given in Table 8 are determined as a reference point. In Table 10, the reference points were determined by considering the maximum and minimum of each criterion according to three alternatives.

Table 10. References of criteria values

Criteria			Alternatives			Reference Point
			RES_1	RES_2	RES_3	
ECONOMICAL	min	Land Cost	0.0495	0.0396	0.0297	0,0297
	max	Incentives	0.0346	0.0346	0.0346	0,0346
	min	Distance to Roads	0.0098	0.0235	0.0309	0,0098
	max	Ground Structure	0.0170	0.0234	0.0276	0,0276
	min	Distance to Electrical Transmission Lines	0.0156	0.0389	0.0273	0,0156
TECHNICAL	max	Wind Speed	0.0922	0.0988	0.0856	0,0988
	max	Wind Capacity Factor	0.0803	0.0918	0.0688	0,0918
	min	Slope	0.0439	0.0412	0.0357	0,0357
	min	Altitude	0.0229	0.0318	0.0311	0,0229
ENVIRONMENTAL-SOCIAL	min	Noise	0.0132	0.0098	0.0114	0,0098
	max	Distance to Bird Habitat	0.0280	0.0187	0.0215	0,0280
	max	Distance to Airport	0.0293	0.0181	0.0204	0,0293
	max	Distance to Residential District	0.0244	0.0379	0.0216	0,0379
	max	Distance to conservation areas and cultural heritage sites	0.0305	0.0228	0.0324	0,0324
	max	Distance to Military Zones	0.0349	0.0230	0.0274	0,0349
	max	Distance to Forests	0.0025	0.0030	0.0092	0,0092
	max	Distance to Lakes	0.0065	0.0004	0.0076	0,0076
	max	Distance to Mining Zones	0.0040	0.0151	0.0125	0,0151
	max	Distance to Agricultural Fields	0.0021	0.0299	0.0014	0,0299

The distances of each criterion to the reference points are found as given in Table 11.

The ranking is done by applying Eq.4 to the matrix formed in Table 11. The ranking obtained is given in Table 12. According to the reference point theory, RES_2, which has the lowest value, is determined as the best installation site.

Table 11. The distances of each criterion to the reference points

Criteria			Alternatives		
			RES_1	RES_2	RES_3
ECONOMICAL	min	Land Cost	0.0198	0.0099	0.0000
	max	Incentives	0.0000	0.0000	0.0000
	min	Distance to Roads	0.0000	0.0137	0.0211
	max	Ground Structure	0.0106	0.0043	0.0000
	min	Distance to Electrical Transmission Lines	0.0000	0.0233	0.0117
TECHNICAL	max	Wind Speed	0.0066	0.0000	0.0132
	max	Wind Capacity Factor	0.0115	0.0000	0.0229
	min	Slope	0.0082	0.0055	0.0000
	min	Altitude	0.0000	0.0089	0.0082
ENVIRONMENTAL and OCIAL	min	Noise	0.0034	0.0000	0.0016
	max	Distance to Bird Habitat	0.0000	0.0093	0.0065
	max	Distance to Airport	0.0000	0.0112	0.0089
	max	Distance to Residential District	0.0135	0.0000	0.0163
	max	Distance to conservation areas and cultural heritage sites	0.0018	0.0095	0.0000
	max	Distance to Military Zones	0.0000	0.0119	0.0076
	max	Distance to Forests	0.0068	0.0063	0.0000
	max	Distance to Lakes	0.0010	0.0071	0.0000
	max	Distance to Mining Zones	0.0111	0.0000	0.0026
	max	Distance to Agricultural Fields	0.0278	0.0000	0.0285

Table 12. Rankings of the alternatives according to the reference point theory

	Alternatives		
	RES_1	RES_2	RES_3
Maximum Values	0.278	0.0233	0.0285
Ranking	2	1	3

4.3. Full multiplicative form method

In the full multiplication method, the normalization process is not performed as in the ratio system method and reference point theory method. The standard decision matrix is used. The criteria values of the alternatives are multiplied in the form of an array according to maximum or minimum objectives. Multiplication values of each alternative are calculated according to their maximum and minimum objectives. With the help of Eq.5, the utility degree of each alternative is calculated. The results are sorted from the maximum to the minimum and the ranks are determined.

In Table 13, according to the rankings of utilities, the best site is determined as RES_3.

Table 13. Alternative usage degrees for full multiplicative form method

	Alternatives		
	RES_1	RES_2	RES_3
A_i (max)	1.81240E+34	4.02233E+34	8.14664E+34
B_i (min)	5.15307E+12	2.40243E+13	1.63590E+13
$U_i=A_i/B_i$	3.51712E+21	1.67428E+21	4.97991E+21
Ranking	2	3	1

4.4. MULTIMOORA method

MULTIMOORA method is not a method applied alone. It is aimed to reach the final result by examining the rankings as a result of the ratio system method, reference point theory method, and full multiplicative form method. MULTIMOORA is a method of interpretation according to the result of other methods. Table 14 shows the final ranking reached as a result of the dominance examination.

Because RES_1 has the second rank in the ratio system method, reference point theory method, and full multiplicative form method, it has also the second rank in the MULTIMOORA method Although RES_2 is the third rank in the full multiplicative form method, it is the first rank in the MULTIMOORA method because it has the first rank in the ratio system and reference point theory methods. Although RES_3 has the first rank in the full multiplicative form method, it has the third rank in the MULTIMOORA method because it comes third in the other two methods given in Table 14.

Table 14. Dominance ranking of multi MOORA method

Methods	Alternatives		
	RES_1	RES_2	RES_3
Ratio System	2	1	3
Reference Point Theory	2	1	3
Full Multiplicative Form	2	3	1
MULTIMOORA	2	1	3

As a result of the MULTIMOORA method, the most suitable site for wind energy plant installation is determined as RES_2. e the last region to be considered as an alternative. The second most appropriate alternative is RES_1, while the last alternative is RES_3.

5. Conclusions

Underground resources in Turkey and the world are decreasing day by day and the damages caused by the environment are incompatible. Fossil fuels used in energy production cause greenhouse gas releases and climate changes. Countries have oriented to alternative energy resources to make the world liveable, to leave a clean world for future generations, and to meet the energy it needs.

68% of the electricity produced in Turkey is provided from fossil fuels. Turkey does not have enough fossil fuels. It provides these resources in need from other countries. In order to reduce external dependence and leave a clean and liveable Turkey, a great breakthrough has been made in renewable energy resources since 2006. Turkey is a country with a high wind energy potential due to its geographical and climatic characteristics. In this study, wind energy plant installation site selection was carried out in Amasya. Three alternatives were determined Three main criteria were determined to select the best alternative installation site These are economical, technical and environmental, and social criteria. The sub-criteria of these criteria were formed by taking the opinions of three experts and literature studies. The sub-criteria values were obtained from a wide variety of resources considering alternative sites. After determining alternatives and criteria values, a multi-criteria decision-making structure was established. MOORA methods were applied to this structure and the most appropriate alternative was obtained as RES_2.

Turkey is developing day by day and energy needs are increasing in parallel with this situation. To meet this need, investments in wind energy plants are encouraged by the government. In order to ensure maximum efficiency from wind energy plants and reduce the high installation costs, the plants should be established in the most appropriate sites. In this study, the criteria for the selection of wind energy plants installation site were determined and an exemplary study was made for Amasya. The method used in this study will benefit the wind energy plants planned to be established in other regions. While investment costs are minimized by these methods, maximum efficiency will be provided by electrical energy generated by wind.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

References

[1] Miremadi, I., Saboohi, Y., and Jacobsson, S., *Assessing the performance of energy innovation systems: Towards an established set of indicators,* Energy Research & Social Science, 40: 159-176, 2018.

[2] Kumar, I., Tyner, W.E., and Sinha, K.C., *Input–output life cycle environmental assessment of greenhouse gas emissions from utility scale wind energy in the United States,* Energy Policy, 89: 294-301, 2016.

[3] Van Haaren, R. and Fthenakis, V., *GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State,* Renewable and sustainable energy reviews, 15(7): 3332-3340, 2011.

[4] Gass, V., Schmidt, J., Strauss, F., and Schmid, E., *Assessing the economic wind power potential in Austria,* Energy policy, 53: 323-330, 2013.

[5] Tegou, L.-I., Polatidis, H., and Haralambopoulos, D.A., *Environmental management framework for wind farm siting: Methodology and case study,* Journal of environmental management, 91(11): 2134-2147, 2010.

[6] Bennui, A., Rattanamanee, P., Puetpaiboon, U., Phukpattaranont, P., and Chetpattananondh, K. *Site selection for large wind turbine using GIS*. PSU-UNS international conference on engineering and environment, 2007.

[7] Tasri, A. and Susilawati, A., *Selection among renewable energy alternatives based on a fuzzy analytic hierarchy process in Indonesia,* Sustainable energy technologies and assessments, 7: 34-44, 2014.

[8] Şengül, Ü., Eren, M., Shiraz, S.E., Gezder, V., and Şengül, A.B., *Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey,* Renewable energy, 75: 617-625, 2015.

[9] Zhang, L., Zhou, P., Newton, S., Fang, J.-x., Zhou, D.-q., and Zhang, L.-p., *Evaluating clean energy alternatives for Jiangsu, China: An improved multi-criteria decision making method,* Energy, 90: 953-964, 2015.

[10] Kabak, M. and Dağdeviren, M., *Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology,* Energy conversion and management, 79: 25-33, 2014.

[11] Al-Yahyai, S., Charabi, Y., Gastli, A., and Al-Badi, A., *Wind farm land suitability indexing using multi-criteria analysis,* Renewable Energy, 44: 80-87, 2012.

[12] Web Page: *Yenilenebilir Enerji Kaynakları ve Önemi*, http://direnc.blog/elektrik-istatistikleri-nisan-2019/ Last access date: 12.04.2019.

[13] Web Page, http://cografyaharita.com/haritalarim/4eturkiye-ruzgar-santralleri-haritasi.png Last access date: 2022-04-01.

[14] Web Page, https://www.yegm.gov.tr/yenilenebilir.aspx Last access date.

[15] Web Page, https://www.enerji.gov.tr/tr-TR/Sayfalar/Ruzgar& Last access date: 2019-05-02.

[16] Başaran, K., *Bulanık Mantık Kontrollü Otonom ve Şebeke Bağlantılı Rüzgar-Güneş Hibrid Güç Sisteminin Optimizasyonu ve Adnan Menderes Üniversitesi Kampüs Alanında Uygulanması*, Doktora Tezi, 2013.

[17] Brauers, W.K.M., Zavadskas, E.K., Peldschus, F., and Turskis, Z., *Multi-objective decision-making for road design,* Transport, 23(3): 183-193, 2008.

[18] Kumar, A., Sah, B., Singh, A.R., Deng, Y., He, X., Kumar, P., and Bansal, R., *A review of multi criteria decision making (MCDM) towards sustainable renewable energy development,* Renewable and Sustainable Energy Reviews, 69: 596-609, 2017.

[19] Ishizaka, A. and Nemery, P., *Multi-criteria decision analysis: methods and software*: John Wiley & Sons, 2013.

[20] Brauers, W.K. and Zavadskas, E.K., *Robustness of the multi-objective MOORA method with a test for the facilities sector,* Technological and economic development of economy, 15(2): 352-375, 2009.

[21] Önay, O. and Çetin, E., *Turistik yerlerin popülaritesinin belirlenmesi: Istanbul örnegi,* Isletme Iktisadi Enstitüsü Yönetim Dergisi, (72): 90, 2012.

[22] Brauers, W.K. and Zavadskas, E.K., *The MOORA method and its application to privatization in a transition economy,* Control and cybernetics, 35(2): 445-469, 2006.

[23] Brauers, W.K.M. and Zavadskas, E.K., *Robustness of MULTIMOORA: a method for multi-objective optimization,* Informatica, 23(1): 1-25, 2012.

[24] Brauers, W.K. and Zavadskas, E.K., *Multi-objective decision making with a large number of objectives. An application for Europe 2020,* International Journal of Operations Research, 10(2): 67-79, 2013.

[25] Web Page: *Bir rüzgar türbini ne kadar sessiz olabilir?*, https://geturkiyeblog.com/bir-ruzgar-turbini-ne-kadar-sessiz-olabilir/ Last access date: 2019-05-02.

[26] Web Page, https://www.tureb.com.tr/turek2017/files/2017_sunumlar/mehmet_ali_tabur_revize_edilen.pdf Last access date: 2019.04.04.

[27] Web Page, http://seyrusefergunce.blogspot.com/2012/06/ruzgar-turbini-ve-radarlara-etkileri.html Last access date: 2019.04.04.

[28] Aydin, Y., *Bulanık topsis ve vikor yöntemi kullanılarak rüzgâr enerjisi santral yer seçimi*, 2013.

[29] Web Page, https://www.ekoyapidergisi.org/1791-ruzgar-enerjisi-hakkinda-dogru-bilinen-yanlislar.html Last access date: 2019.05.02.

[30] Web Page, http://cografyaharita.com/turkiye_toprak_haritalari1.html Last access date: 2019.05.02.

[31] Web Page, http://yerbilimleri.mta.gov.tr/anasayfa.aspx Last access date: 2019.04.09.