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Determining Factors That Affect Location Planning of Wind Farms: An Analysis with DEMATEL Method

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Abstract

Generating electricity from wind energy is now amongst the cheapest forms of renewable kind and less expensive than that produced by new coal and nuclear power plants. As wind energy investments have increased, capacity has continued to grow more and more. The numbers for wind power for the future are expected to be astounding. This paper presents a model in order to identify factors that are significant for the wind farms installment which can have important support for the planners and the managers in the area of wind energy projects. The suggested model is based on a multi-criteria decision-making method, which is DEMATEL. The implementation of DEMATEL method has shown that wind direction condition is the most important factor for the wind farm in the area. Therefore, analyzing wind direction conditions in detail and keeping in touch with meteorologists in building process are suggested in order to successfully identify the potential suitable sites for the wind farms.

Keywords: *Wind Energy; Location Selection; DEMATEL; Renewable Energy; Investments*

Rüzgar Santrallerinin Yerleşim Planlamasını Etkileyen Faktörlerin Belirlenmesi: DEMATEL Yöntemi ile Bir Analiz

Özet

Rüzgar enerjisinden elektrik üretmek, şimdi en ucuz yenilenebilir enerji türleri arasındadır ve yeni kömür ve nükleer enerji santrallerinden üretilenlere kıyasla daha ucuzdur. Rüzgar enerjisi yatırımları arttıkça kapasite gittikçe artmaya devam etmektedir. Gelecek için rüzgar enerjisi sayılarının şaşırtıcı olması beklenmektedir. Bu makale, rüzgar enerjisi projeleri alanındaki planlamacılara ve yöneticilere önemli destek verebilecek rüzgar santrallerinin kurulum lokasyonunun belirlenebilmesi adına önemli olan faktörleri tanımlamak için bir model sunmaktadır. Önerilen model çok kriterli bir karar verme yöntemi olan DEMATEL yaklaşımına dayanmaktadır. DEMATEL yönteminin uygulanması sonucunda rüzgar yönü koşulunun bölgedeki rüzgar santrallerine yer belirlemek için en önemli faktör olduğu belirlenmiştir. Bu nedenle, rüzgar santralleri için potansiyel uygun alanların başarılı bir şekilde tanımlanması amacıyla rüzgar yönü koşullarının ayrıntılı bir şekilde analiz edilmesi ve meteorologlarla iletişim halinde kalması önerilmektedir.

Anahtar Kelimeler: *Rüzgar Enerjisi; Yer Seçimi; DEMATEL; Yenilenebilir Enerji; Yatırımlar*

1. Introduction

The need for energy production increases day by day in the world. The periods in which energy use increases so much requires the discovery of new energy sources (Yu et al., 2019:2). Although fossil

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fuels are frequently preferred sources for electricity production from past to present, fossil fuels are both a resource to be consumed and the fact that they have many negative effects on the environment such as carbon emission reveals that these resources cannot be used for a long time (Yüksel et al., 2019:3). In this case, it highlights environmentally friendly and inexhaustible energy sources, which are renewable ones (Qiu et al., 2020:2). Especially with the development of technology, many countries have started to make investments in this direction and have started to work for the expansion of renewable energy sources. The enormous need for energy brings renewable energy sources to the agenda constantly.

Wind energy, which is one of the renewable energy sources, is clean and does not pollute the environment, it is the cheapest energy source that can renew itself, and it can be produced cheaper compared to thermal and nuclear power plants, which makes wind energy stand out from other renewable energies (Kumar et al., 2016:209). Wind energy is a renewable energy source that has sufficient potential in many regions of the world and gives hope for the future. Wind energy, which is one of the renewable energy sources, is frequently preferred by countries to meet this increasing energy need. Wind energy is obtained by converting the speed of the wind turbines located at certain points into usable energy (Yüksel and Ubay, 2020:2). Wind energy is converted into mechanical energy in the past as windmills and today, thanks to wind turbines. Apart from obtaining energy, wind turbines have benefits such as preventing air pollution, saving fossil fuels, providing new job positions and regional development. Contrary to fossil or nuclear fuels, wind cannot be transported or stored.

For this reason, determining where the wind farms will be located is a very important problem. Wind energy, like most renewable energy sources, requires extensive capital. However, if the technological developments in the wind energy sector continue, the costs of wind power plants are expected to decrease significantly in the coming years. The fact that the installation costs of wind power plants have decreased considerably in the last 15 years has increased the demand for wind turbines worldwide. At this point, many factors that can determine the locations of wind farms can be considered. As Nematollahi et al. (2016) research in Middle East stated that RE eliminate problems thanks to the solar and wind energy generate electricity supply. With regard of these, Izquierdo et al. (2020) denoted that wind energy is one of the most important energy powers and its component should be reliable and operated well. So, ease of access to field, electrical energy demand of the region, ease of connecting to the national grid, size of the field and the wind direction condition of the land have a role in order to determine accurate location for wind energy power. The most important of these can be the size of the area where the wind farm will be installed (Dinçer and Yüksel, 2019:1775). Wind power plants are structures that cover quite a large area with turbines and other equipment they contain. therefore, the area where the wind farm will be installed should be large enough in terms of width (Dinçer et al., 2019:152). Besides that, wind power plants need to be installed in areas that receive regular and continuous wind. Average wind and hourly wind speeds required for the places where wind power plants will be installed are generally taken from meteorological stations.

In this paper, the main factors that affect the functionality of wind farms in terms of are discussed. In this context, as a first, 5 different factors that affect selecting a location for wind farms are determined by scanning literature on this subject. Later on, an analyze is made by using DEMATEL method to give a weight to every criterion that are taken into account. This article can contribute a lot to the literature. Firstly, the analysis results can be very beneficial for countries that want to adapt wind energy. According to results, countries can decide where to locate the wind farms, so these investments can be more efficient. In addition to this, this study can offer both investors and managers the opportunity to analyze the geographical areas in a short time in terms of suitability for plant installation. In this case, it will help determine the areas where they can focus the feasibility studies. The methods that are used in that article are also bring novelty. DEMATEL which is used in the analysis process, facilities to remove the uncertainty and vague information issue in decision-making process. It also provides the interrelationships between criteria (Zhang and Deng, 2019).

The article includes 5 different sections. In the first section of the study, a brief introduction to wind energy was given. Later on, related studies on determinants of the efficiency of wind farms was examined. In the third part, a theoretical background on the DEMATEL is given. After that, the results of the analysis are examined and expressed. In the final section, information about conclusion part was given.

2. Literature Review

Usage of renewable energy (RE) is rapidly increasing with rising energy demand and global warming. At this point, wind energy can be used in order to handle increased energy demand. However, there are some factors that affect efficiency of wind energy. Location of wind farms is one of them. In this context, there are many studies in literature that explain what important factors that are needed to take into account when build a wind farm. The first factor is ease of access to field. The literature related to measurement experiment for actual field and angle of attack (associated with length of wind blades) has included limited study. Angle of attack measurement is important for accessing actual field in order to evaluate power loss and fatigue loads. Any changes in the wind turbine blades can cause huge damages. So, measurement, design of wind turbines and setting up correctly angle of attack to the actual field is important and difficult for wind speed and control mechanism (Wu et al., 2020:4). Moreover, Rehman et al. (2018) remarked that wind turbines blades design, speed of environment and other equipment are effective on performance, converting energy efficiency and reducing cost. On the other hand, Hart et al. (2019) denoted that type of wind turbines should be setup appropriate characteristics of wind field in order to prevent failures, maintain its operations and control energy load efficiently. Also, Bucksteeg (2019) studied that geographical diversification is determinant of wind turbines in order to secure electricity supply, balance peak loads and cost savings.

Secondly, electrical energy demand of the region is also an important factor when deciding the wind farms where to locate. Global warming, CO2 emissions and energy consumption is increasing day by day. For example, electricity demand and environmental pollution are rising strictly in China. Thus, RE energy-based electricity generation has come into question and also, Chinese government encourage electricity producers so they would use RE. Wind power is completely more efficient than biomass energy generation in order to meet electricity demand and wind power has fewer environmental impacts. In addition to that, wind power in desert is converted to electricity energy easier than steppe and woodland (Gao et al., 2019:308). On the other hand, Duman and Güler (2018) study stated that people move to seasonal vacation homes/second homes for summer months in Turkey. In these seasons, electricity demand is high in coastal regions. For example, Çeşme, İzmir is the one of the most place in Turkey where has relatively high solar and wind energy potential. Thus, storage technology of electricity power concerted by solar and wind energy is economically important for the regions during seasonal and regular times. So, PV/Wind/Battery, PV/Battery and Wind/Battery systems are more economical. However, wind-based systems are costlier than PV based systems in İzmir. Otherwise, Bentouba and Bourouis examined for remote are from Algeria where live more than 200 families. In that place, PV/Wind/Diesel/Battery hybrid system is processing to electricity power in order to meet demand because of decreasing CO2 and COE (cost of electricity). Also, Devrim and Bilir (2016) studied on İncek region of Ankara in Turkey and they said that hybrid systems based on PV, wind and fuel cell electricity generation is above the electricity demand of the region except November while wind energy is satisfying a part of these demand.

Ease of connecting to the national grid is also important for location of wind farms. Energy should be accessible for every consumer in the world and it is possible with grids. Many of rural area (e.g. sub-Saharan Africa countries, in rural areas in Iran and Jordan) is still supplying their electricity demand far away from national grids and they are satisfying their demands more expensive and their energy generation methods are harmful for environment because of hard to connection of national grid problem (Feilat et al., 2018:257; Bashir et al., 2018:1217; Alayi et al., 2019:4). Therefore, RE based production and distribution these energy with national grids are feasible against to cost of traditional methods. As cited in Jahangiri et al. (2019) research, electricity generation by wind turbine and distribution with national grid is are economically recommended and also, national grid/wind turbine/solar cell scenario is stated as the most cost-effective electricity producing in Iran. In addition to that areas which are far away and no connection of national grids with Iran should use wind energy.

Moreover, Bennaceur et al. (2019) expressed that wind power location to the geography and connection grid for distribution play a key role for energy cost and efficiency in Algeria.

In this context, size of the field is a factor that is needed to take into account. Size of field and wind turbine measurement should be appropriate for each other. Otherwise, there might be damages for wind turbine blades, labours, wiring systems, speed of wind turbines and its other equipment such as its sensors. So, 3D DIC system and a multi-camera 3DPT system is less costly to measure field and gather all data to the wind turbine blades as Poozesh et al. (2017) experienced. Furthermore, observing the field and real-time foundation monitoring is help to wind turbine monitoring, sensor design, construction and field installation activities, operation, reducing fixed cost and environmental impact on wind turbines and policy makers (Rubert et al., 2018:97). Besides, Pagnini et al. (2015) specified that small wind turbines should be established in small urban environment in order to gain efficiency from converted energy.

The wind direction condition of the land can be a leading factor on locating wind farms. Wind data, wind speed and wind direction condition of the land are factors for wind power-based energy generation efficiency. Bagavathsingh et al. (2016) denoted that wind direction and wind shear value is changing in summer and winter terms (seasonal) and it shows difference turbulence between near coastal and urban coastal. For example, Milanese et al. (2017) found by looking using meteorological software, historical data and technical feasibility analysis that the most feasible wind fields/ wind farms establishments for turbines and above ground heights in specific geographical area, south of Italy. Also, Li et al. (2018) remarked by looking wind speed, direction records and geographical conditions that North China, Northeast China, Central China, coastal regions in East China and Southeast China regions were the most optimal land for wind power in China. On the other hand, extreme wind direction causes extreme energy load and damages on lifetime of wind turbines (HAWT) components such as its blades.

3. Methodology

This part of the study includes the analysis regarding the relationship between factors that affect selecting a location for wind farms. For this purpose, DEMATEL analysis is taken into account. The DEMATEL analysis is one of the multi-criteria decision-making methods that helped make decisions under uncertain and vague situations. For numerical data sets, DEMATEL can be used alone. In the context of the DEMATEL analysis; it is possible to explain relationships between criteria (Han and Deng, 2018:5073). The DEMATEL analysis is considered to express which are the most important criteria that affect our purpose. The most important benefit of this analysis is that, in the DEMATEL method, it can be understood which variables affect others. In DEMATEL analysis, the steps are as follows:

Firstly, an expert team is formed, and the evaluations about direct affect between each pair of elements are acquired. (Dinçer et al., 2017). Later on, these linguistic evaluations are converted into crisp values, as a result, the direct-relation matrix ($\tilde{Z}$) can be formed as in the equation (1).

$$\tilde{Z}=\begin{bmatrix} 0 & \tilde{z}_{12} & \cdots & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & 0 & \cdots & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \cdots & 0 \end{bmatrix} \quad (1)$$

After the direct-relation matrix, average values of these assessments are considered, as the details are shown in the equation (2) (Yüksel et al., 2017).

$$\tilde{Z} = \frac{\tilde{Z}^1 + \tilde{Z}^2 + \tilde{Z}^3 + \cdots \tilde{Z}^n}{n} \quad (2)$$

Later on, normalized direct-relation matrix X is generated by considering the equations (3)-(5).

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \cdots & \tilde{x}_{nn} \end{bmatrix} \tag{3}$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{Z_{a'_{ij}}}{r}, \frac{Z_{b'_{ij}}}{r}, \frac{Z_{c'_{ij}}}{r}, \frac{Z_{d'_{ij}}}{r}; H_1(z_{ij}^U), H_2(z_{ij}^U)\right), \left(\frac{Z_{e'_{ij}}}{r}, \frac{Z_{f'_{ij}}}{r}, \frac{Z_{g'_{ij}}}{r}, \frac{Z_{h'_{ij}}}{r}; H_1(z_{ij}^L), H_2(z_{ij}^L)\right) \tag{4}$$

$$r = max\left(max_{1 \le i \le n} \sum_{j=1}^{n} Z_{d'_{ij}}, max_{1 \le i \le n} \sum_{j=1}^{n} Z_{d'_{ij}}\right) \tag{5}$$

After creating normalized direct-relation X, the total-relation matrix T can be formed as in the equations (6)-(10).

$$X_{a'} = \begin{bmatrix} 0 & a'_{12} & \cdots & \cdots & a'_{1n} \\ a'_{21} & 0 & \cdots & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & \cdots & 0 \end{bmatrix}$$

$$X_{h'} = \begin{bmatrix} 0 & h'_{12} & \cdots & \cdots & h'_{1n} \\ h'_{21} & 0 & \cdots & \cdots & h'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h'_{n1} & h'_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{6}$$

$$\tilde{T} = \lim_{k \to \infty} \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^k \tag{7}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \cdots & \tilde{t}_{nn} \end{bmatrix} \tag{8}$$

$$\tilde{t}_{ij} = \left(a''_{ij}, b''_{ij}, c''_{ij}, d''_{ij}; H_1(\tilde{t}_{ij}{}^U), H_2(\tilde{t}_{ij}{}^U)\right), \left(e''_{ij}, f''_{ij}, g''_{ij}, h''_{ij}; H_1(\tilde{t}_{ij}{}^L), H_2(\right. \tag{9}$$

$$[a''_{ij}] = X_{a'} \times (I - X_{a'})^{-1}, \ldots, [h''_{ij}] = X_{h'} \times (I - X_{h'})^{-1} \tag{10}$$

Subsequently to these steps, the sum of rows and the sum of columns are denoted as vector $(\widetilde{D_i})$ and vector $(\tilde{R}_i)$ respectively. The horizontal axis vector $(\tilde{D}_i + \tilde{R}_i)$ is formed by adding $(\widetilde{D_i})$ to $(\tilde{R}_i)$, which expresses how much the criterion important is. When $(\tilde{D}_i + \tilde{R}_i)$ is higher, it means that the factor is closer to the central point by considering the equations (11)-(12).

$$\widetilde{D}_i = \left[\sum_{j=1}^{n} \tilde{t}_{ij}\right]_{n\times 1} \tag{11}$$

$$\tilde{R}_i = \left[\sum_{i=1}^{n} \tilde{t}_{ij}\right]'_{1\times n} \tag{12}$$

4. Analysis Results

In the analysis process of this study, as a first, factors that need to be taken into account when locate a wind farm are determined. In this regard, recent studies on this topic in the literature are scanned. As a result of the analysis, 5 different criteria were determined as can be seen in Table 1.

Table 1. List of Criteria

Criteria Set	Literature
Ease of Access To The Field (C1)	Wu et al. (2020); Rehman et al. (2018)
Size of the Field (C2)	Poozesh et al. (2017); Rubert et al. (2018)
Electricity Demand of the Region (C3)	Gao et al. (2019); Duman and Güler (2018)
The Wind Direction Condition (C4)	Bagavathsingh et al. (2016); Milanese et al. (2017)
Ease of Connection to the National Grid (C5)	Feliat et al. (2018); Bashir et al. (2018)

Firstly, assessments from three different experts that are academicians or high-level managers are collected. These experts have at least 15-year experience in the area of this study. They made their evaluations by considering 5 different criteria and these evaluations are analyzed in regard of DEMATEL. These analysis steps are made on Microsoft Excel program.

Table 2. Direct-Relation Matrix (A)

	C1	C2	C3	C4	C5
C1	0,00	1,33	3,00	0,00	0,67
C2	3,00	0,00	2,33	0,33	1,00
C3	1,33	1,33	0,00	0,33	1,00
C4	4,00	4,00	4,00	0,00	3,67
C5	3,33	3,33	3,00	1,00	0,00

The analysis results acquired from the experts are defined in the direct-relation matrix as seen in Table 2. After direct-relation matrix, this matrix is normalized, and new matrix is given on Table 3.

Table 3. Normalizing Matrix (X)

	C1	C2	C3	C4	C5
C1	0,00	0,09	0,19	0,00	0,04
C2	0,19	0,00	0,15	0,02	0,06
C3	0,09	0,09	0,00	0,02	0,06
C4	0,26	0,26	0,26	0,00	0,23
C5	0,21	0,21	0,19	0,06	0,00

Then as seen in Table 4, total relation matrix is formed.

Table 4. Total-Relation Matrix

	C1	C2	C3	C4	C5
C1	0,06	0,13	0,24	0,01	0,07
C2	0,26	0,07	0,24	0,03	0,10
C3	0,14	0,13	0,07	0,03	0,09
C4	0,45	0,41	0,47	0,04	0,32
C5	0,34	0,31	0,34	0,08	0,07

In the next step, the weights of the criteria have been determined. The details are given on Table 5.

Table 5. Effect-relationship Degree Results and Weight Values

Criteria	D	R	D-R	D+R	Weights
Ease of Access to The Field (C1)	0,52	1,25	-0,74	1,77	0,195635012
Size of the Field (C2)	0,70	1,05	-0,35	1,75	0,193957466
Electricity Demand of the Region (C3)	0,47	1,36	-0,89	1,83	0,202134632
The Wind Direction Condition (C4)	1,70	0,20	1,50	1,90	0,209686761
Ease of Connection to the National Grid (C5)	1,14	0,66	0,48	1,80	0,198586129

According to the results of Table 5, the wind direction condition and electricity demand of the region are the most influencing criterion. Additionally, size of the field turns out to have a relatively low weight.

5. Discussion and Conclusion

In this study, it is aimed to determine important factors for locating wind farms. As a first, the criteria that affect the effectiveness of wind farms locations are determined. Later that step, these criteria are analyzed by using DEMATEL method. The findings indicate that the wind direction condition (C4) is the most important criterion that needed to be taken into account when build a wind farm. Using existing icing and wind maps, predictive models, and onsite measurements can be helpful at that point. On the other hand, a high-skilled analyzing team can be created in order to monitor wind speed before installation process. Bagavathsingh et al. (2016) also emphasized the importance of this situation. In their research, they determined that the wind direction condition of the land can be a leading factor on locating wind farms. Wind speed and its direction condition of the land are factors for wind power-based energy generation efficiency. The efficiency of wind farms can be affected even by changing wind directions and intensity as the seasons change. It shows that, investor that want to make wind energy investors should take into account seasonal changes also. In this context, working with an expert team on geography can be beneficial. Otherwise, the efficiency of investments in the area can be volatilized. Also, Milanese et al. (2017) and Li et al. (2018) remarked the importance of wind direction by analyzing Italy and China respectively.

In the other hand, electricity demand of the region (C3) is also determined as an important factor. It indicates that a place with high demand for renewable energy sources will be efficient when selecting a place in wind energy, such investments will be inefficient in a place where there is little demand for renewable energy sources. In this case, it is of utmost importance to establish the demographic structure of the places where the stations will be installed before the wind power plants are located. At this point, the authorities should work with the experts to examine the population structure of the place in detail and see if the people in this place are open to green energy. As Devrim and Bilir (2016) and Duman and Güler (2018) also identified this situation for different cities and they concluded that when there is a high demand for wind energy in an area, the efficiency of wind energy installments is increase since this energy cannot be stored.

In this study, it is aimed to determine factors that are needed to take into account when locate a wind farm. In this framework, the perspectives of the DEMATEL method were taken into consideration in the process of the development of both criteria and novel strategies. Using DEMATEL is considered as the most important constraint of the study. Thus, in future studies, it will be appropriate to determine the criteria by implying another method whose accepted in the literature. On the other hand, wind energy investments could differ among countries even cities. So that, it is important to conduct an analysis for different country groups or cities.

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