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Beyhan Öztürk and Hıdır Serkendiz

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RESEARCH ARTICLE

Location Selection forWind Turbines in Balıkesir, NW Turkey, Using GIS

Beyhan Öztürk*, Hıdır Serkendiz

Çanakkale Onsekiz Mart University Faculty of Arts and Sciences Department of Geography TR 17100 Çanakkale, Turkey.

*Corresponding author
Tel : +90 286 2180018
E-mail :bozturk@comu.edu.tr

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Abstract

In comparison to traditional production of energy by using fossil fuels, the demand for renewable energy is increasing constantly due to the negative effects of fossil fuels on the environment, increased public awareness and the fact that fossil resources will be exhausted someday. As a renewable energy source, wind energy is an economically feasible, environmentally clean, popular and reliable way of energy production. This study determined twelve geographical factors, the effects and weights of these factors were determined by considering the relevant literature and field conditions, and various analyses were conducted on these factors with the help of geographical information systems (GIS). As a result of the analyses, the most suitable establishment locations for wind energy stations were determined for the province of Balıkesir. The resulting map was divided into four classes based on their suitability (somehow suitable, moderately suitable, suitable and highly suitable). The classes were distributed as highly suitable by 12%, suitable by 29%, moderately suitable by 36% and somehow suitable by 23%.

Keywords: Wind, wind energy, wind power plant (WPP), Geographical Information Systems (GIS), Balıkesir

Introduction

Energy is one of the most important inputs for the economic and social development of countries. Increased population, industrialization, urbanization and higher living standards are increasing the energy needs in the world and in Turkey daily (Narin, 2008). Reasons such as increased demand for energy, higher living standards and those fossil fuels may be exhausted have turned the attention towards renewable energy (Haaren and Fthenakis, 2011). The development of renewable energy sources (RES), together with measures aimed at more efficient use of energy, are priorities at a national and European level, as both the basis of environmental protection and of energy policy (Pamučar, et al., 2017). Usage of clean energy has increased especially in recent years in place of fossil-based energy production which pollutes the environment and the atmosphere (Şen, 2002). Wind energy is the most technologically advanced one among clean energy resources which has a relatively lower first construction cost in comparison to other renewable energy resources (Yerebakan, 2001). Electrical energy is essential for economic growth and well-being of human populations. The growing concern with pollution resulting from the use of fossil fuels increases the pressure to use renewable energy sources to produce electricity. One of such resources is the energy obtained from wind. Location of wind farms producing electricity requires careful and combined analysis of numerous criteria such as technical requirements, as well as environmental, social and spatial constraints (Szurek, et al. 2014).

Energy consumption in Turkey is foreign-dependent and based on natural gas and oil (Greenpeace, Energy Revolution Report 2015). In this case, Turkey, which is a developing country, allocates a considerable budget to import fossil fuels from abroad. Reducing its increased foreign-dependency and utilizing its own resources more by incentivizing and investing more on wind energy, which is not foreign-dependent, has increased technology and potential for employment, is clean, cheap,

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safe, reliable and promising, is highly important for Turkey's economy (Oksay, 2014).

In order to determine the wind energy potential and its geographical distribution in Turkey, the Directorate of Electrical Power Resources Research and Development published the Wind Energy Potential Atlas for Turkey (REPA) in 2007 (Map 1). REPA provides wind resource data produced by using medium-scaleweather production and micro-scale wind flow models (Çalışkan, 2011). This study shows that Turkey has a high potential for wind energy. REPA (Fig 1) shows that especially the Northern Aegean and Southern Marmara regions are highly rick in terms of their wind potential. Considering all these, the province of Balıkesir, which is seen to have a high potential in terms of wind energy, was included in this study for analysis of optimal location selection to establish wind power plants (WPP).

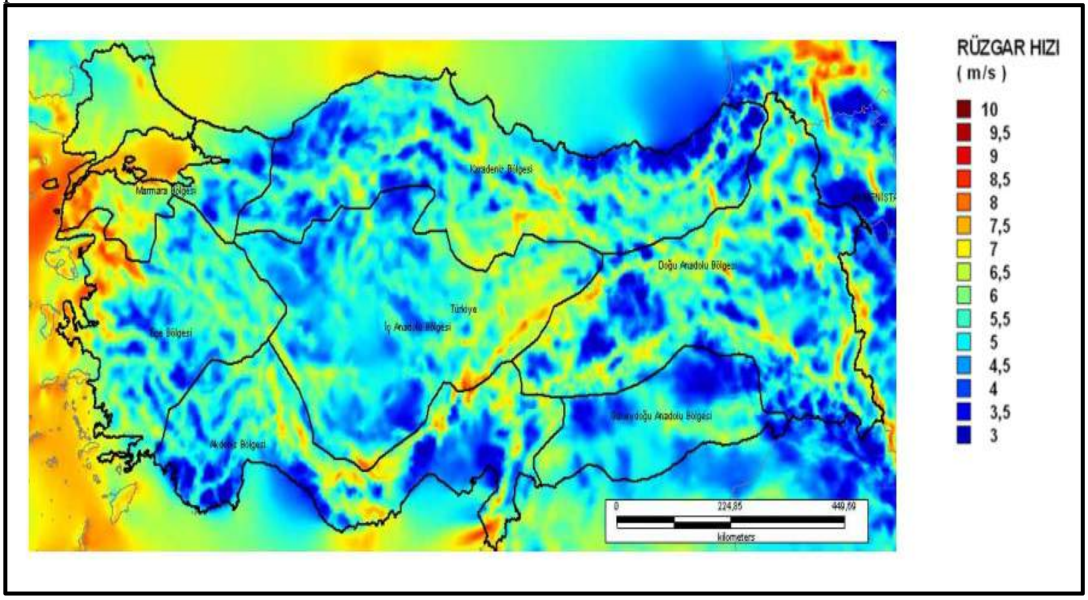

Fig 1. Distribution of average annual wind speeds at 50 m altitude for Turkey (Çalışkan, 2011).

Analyzing optimal WPP construction location for Balıkesir will provide information on better utilization of wind energy, which is renewable, has negligible levels of negative effects on life, is not foreign-dependent in terms of raw material, does not need much space, and is a clean energy resource. By investigation of all these issues, foreign-dependency in energy, which has a strategic importance, may be reduced and more loss of foreign currency may be prevented (Aydın, 2009; Gazioğlu et al., 2014; 2016).

This study aimed to analyze optimal location selection for WPP construction with the use of GIS along with various geographical factors. Location selection for WPP construction is not only a technical issue, but it is a complex process influenced by various physical, social, economic and environmental factors (Bennui et al., 2007). Accordingly, it was aimed to determine the must suitable location for WPP construction for the province of Balıkesir.

The studied region has an area of 14,299 km² and it is located at 39.20° – 40.30° N and 26.30° – 28.30° E. It has coasts on Marmara Sea in the north and Aegean Sea in the west. It is surrounded by Çanakkale in the west, İzmir and Manisa in the south, and Kütahya and bursa in the east (Fig 2).

Data and Methodology

Firstly, previous studies related to the subject were reviewed. Then, the maps of factors that were determined for analyses were created. For factors of distances to streams, roads, residential areas, lakes and coasts, maps were created by utilizing the maps (joint operation maps) with scales of 1/25000 prepared by the General Command of Cartography.

Topography maps and DEM data were utilized to obtain maps for the factors of altitude, exposure and slope. Coordination of Information on the Environment (CORINE) 2012 data were utilized to obtain a land usage map. The map with a scale of 1/250000 prepared by the General Directorate of Mineral Research and Exploration (MTA: URL 2) was utilized for the factor of distance to fault lines. A map of distances to energy transfer lines was obtained by utilizing the energy transfer line map prepared by the Directorate of Energy, Ministry of Energy and Natural Resources. For the factor of power density, average daily wind data of the period of 1970-2015 were used. Weibull probability density functions were applied on the average daily wind values for the years. The reason for using this function was that it is one of the most frequently preferred statistical distributions in calculating wind energy potential. In estimation of wind speed, average wind power density, and therefore, wind energy; usually the potential wind energy is calculated by the help of two-parameter Weibull probability density function (Çelik, 2004).

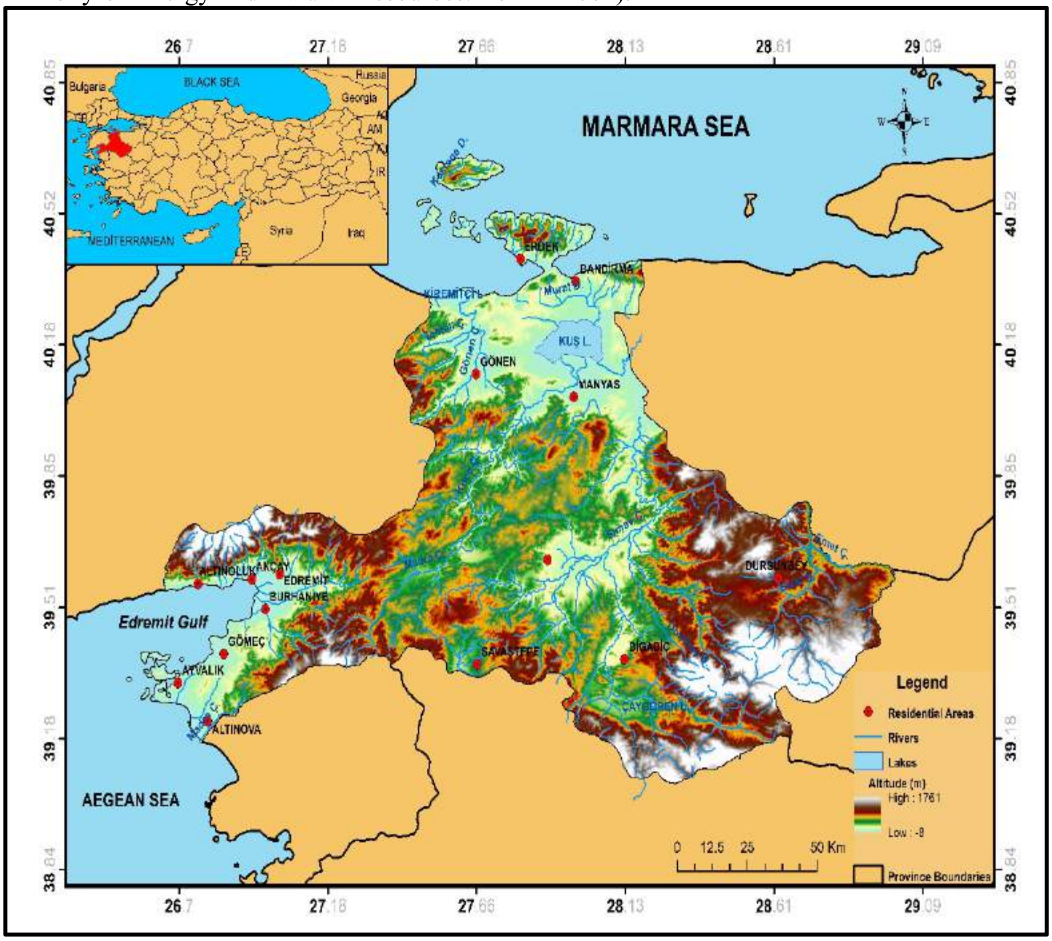

Fig 2. Location of Balıkesir.

After the factors that are considered to be effective in selection of WPP construction sites were determined and the necessary factor maps were obtained by taking into account the literature review and regional conditions, analyses were conducted by using the ArcGIS 10 package software. Buffer analysis was conducted on the vector data which were in the form of dots and lines at the beginning. The Buffer analysis was applied in terms of distances (meters) to streams, roads, electricity transfer lines, residential areas, wetlands and coasts. After this analysis, the raster maps created for all factors were assigned with values based on their effect values determined based on the literature reviews and field conditions.

Table 1. Effect class, effect value and weight values of the factors based on their priority

Priority Rank	Faktor	Effect Class	Effect Value	Weight Value
1	**Power Density (W/m²)**	5 - 17	1	**0.31**
		17 - 30	2	
		30 - 50	3	
		50 - 75	4	
		75 - 106	5	
2	**Altitude (m)**	< - 150	1	**0.15**
		150 - 300	1	
		300 - 450	2	
		450 - 600	3	
		600 - 750	4	
		750 - 900	5	
		900 - 1050	5	
		1050 - >	3	
3	**Exposure (Degrees)**	Flat	5	**0.14**
		North	5	
		Northeast	3	
		East	1	
		Southeast	1	
		Southeast	1	
		Southwest	3	
		West	1	
		Northwest	4	
4	**Land Usage**	Forest	1	**0.068**
		Agriculture	2	
		Bushes - Shrubbery	2	
		Meadow - Pasture	3	
		Bond - Garden	2	
		Residential Area	1	
		Open Areas	5	
5	**Slope (Degrees)**	0 - 1	5	**0.06**
		1 - 8	4	
		8 - 16	3	
		16 - 32	2	
		32 - 89	1	
6	**Distance to Energy Transfer Lines (m)**	0 - 100	5	**0.052**
		100 - 500	4	
		500 - >	3	
		1000 - 5000	2	
7	**Distance to Residential Areas (m)**	0 - 2500	1	**0.08**
		2500 - 3500	2	
		3500 - 4500	3	
		4500 - 5500	4	
		5500 - >	5	
8	**Distance to Roads (m)**	0 - 500	5	**0.05**
		500 - 1000	4	
		1000 - 1500	3	
		1500 - 2000	2	
		2000 - >	1	
9	**Distance to Wetlands (m)**	0 - 2500	1	**0.03**
		2500 - 3000	2	
		3000 - 3500	3	
		3500 - 4000	4	
		4000 - >	5	
10	**Distance to Coasts (m)**	0 - 2500	1	**0.025**
		2500 - 3000	2	
		3000 - 3500	3	
		3500 - 4000	4	
		4000 - >	5	

Table 2. Effect class, effect value and weight values of the factors based on their priority (Cont.)

11	**Distance to Streams (m)**	0 - 500	1	**0.02**
		500 - 600	2	
		600 - 700	3	
		700 - 800	4	
		800 - >	5	
12	**Distance to Fault Lines (m)**	0 - 500	1	**0.015**
		500 - 1000	2	
		1000 - 1500	3	
		1500 - 2000	4	
		2000 - >	5	

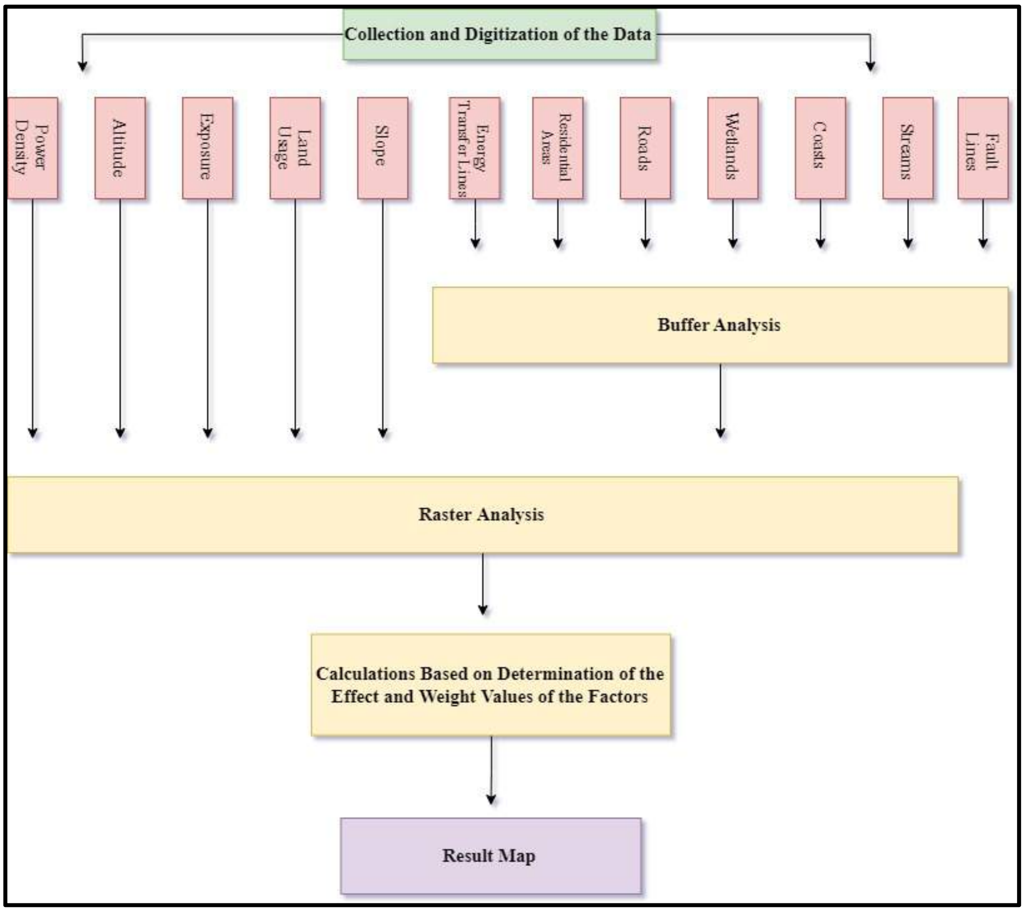

Fig 3. Flow Chart of the Study

using the Spatial Analyst Tools. A 5-point scale was used to assign effect values. Here, 5 represented the most suitable, and 1 represented the least suitable value. After assigning effect values, again, Spatial Analyst Tools were used to make calculations by utilizing the literature (Bennui et al., 2007, Azizi 2014, Baban and Parry 2000, and Özşahin and Kaymaz, 2013) and determining weight values based on priority (Table 1 and Fig 3) and the result map was obtained

Findings

Location selection for wind power plants (WPP) is a complex issue which involves various factors such as physical, economic, environmental effects, visually and planning (Baban & Parry, 2000). In order to determine a comprehensive set of criteria, the "Regional Wind Resource Information Report" published by the Directorate of Renewable Energy and relevant previous studies (Bennui et al., 2007,

Baban & Parry, 2000, Özşahin & Kaymaz 2013, Menduhoğlu et al., 2014, Aydın, 2009, Azizi et al., 2014, Moiloa, 2009, Asadi & Karami, 2017, Crill et al., 2010, Gazioğlu et al., 1997, Haaren and Fthenakis, 2011, Haralambopoulos and Polatidis, 2003; Farajzadeh , et al., 2013; Nobre, A., et al. 2009, Memduhoğlu, et al., 2014). were reviewed, factors influential for WPP (power density, altitude, exposure, land usage, slope, electricity lines, residential centers, roads, wetlands, coasts, streams, fault lines) were determined, they were subjected to analysis, and spatially the best WPP locations for the province of Balıkesir were found.
Among the twelve determined criteria, the factor with the highest weight was power density. This is because the most important criterion for measuring the wind energy potential in a geographical region is calculation of power density (Azizi et al., 2014, Asedi and Karami, 2017). This is why its weight value was held higher than all the others (Fig 4a).
Altitude is also a highly important factor for WPP location selection. Wind speed may have a tendency to increase or decrease based on altitude (Özşahin & Kaymaz 2013). According to Aydın (2013), a WPP should be located at an altitude of higher than 1500 meters. Excessive increase in altitude also makes WPP construction more difficult and increases investment costs. Based on relevant studies (Moiloa, 2009, Bennui et al., 2007), altitude intervals in the range of 150-1050 meters were assumed to be advantageous for constructing WPP in Balıkesir (Fig 4b).

Another important factor for WPP location selection is exposure. The effect of the exposure factor of a topography is felt on the hills exposed to the direction of the dominant wind in the region (Özşahin & Kaymaz 2013). Directions were ranked from the most efficient to the least efficient by accounting for the dominant winds in the province of Balıkesir. As the dominant directions of wind in Balıkesir are directions of north and northeast, the effect values of these directions were determined to be the highest (Fig 4c).

Another important factor is land usage. Land usage was categorized within itself as forests, agriculture, bushes-moors, vineyards-orchards, residential areas and open areas. As dense plant coverage may affect the speed and direction of wind, the value of the effect class of forests was accepted to be low. Due to concerns like noise pollution, safety and aesthetics, WPP should be located at a certain distance from residential areas (Baban & Parry, 2000). Additionally, agricultural lands were also not seen suitable for WPP construction. Open areas (with little or no vegetation) were selected as the most suitable class for WPP establishment. Residential areas, agricultural areas and forest were seen to be the least suitable areas, and their effect values were assigned accordingly (Fig 4d). Water bodies (internal swamps, lakes, waterways, lagoons, etc.) were not included in the calculations.

The factor of slope is also an important factor for location selection for WPP. For Balıkesir, the slope of the area was divided into five classes (Fig 4e), and the most suitable slope interval was found to be 0° to 10°. This is because increased slope of a land makes it difficult to establish WPP and increases the costs. This is why lands with slopes of higher than 10° are also not economically advantageous (Haaren & Fthenakis, 2011).

Another significant parameter is the distance from energy transfer lines. Being close to transfer lines was found to be advantageous. This is because energy lines are needed to transfer the produced wind energy to centers of consumption (Moiloa, 2009). So, the effect value increases by getting closer to energy transfer lines (Fig 4f).

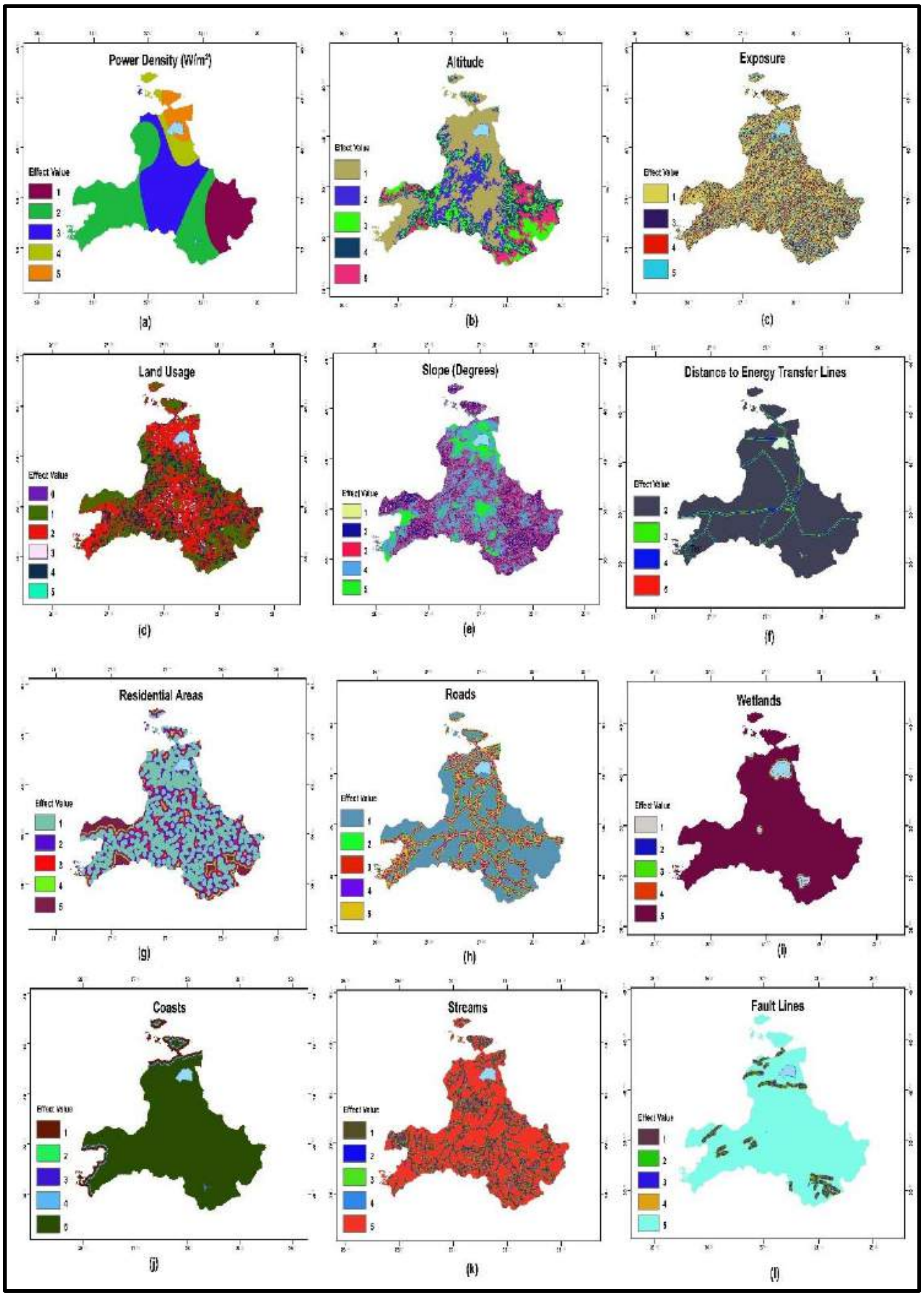

Fig 4. Effect value maps of thefactor.

Distance to residential areas is also an important factor for WPP location selection. This distance was divided into five classes. The effect value decreases by getting closer to residential areas. In WPP location selection, the most important reasons for the disadvantages of proximity to residential areas include concerns of aesthetics and noise (Moiloa, 2009). Another significant disadvantage is that residential areas are dynamic. They may expand in time and WPP sites may stay in residential zones (Azizi et al., 2009). The effect values of residential areas were assigned accordingly (Fig 4g).

Distance to roads is another factor for WPP location selection. It is seen as an effective parameter. Being close to roads was found to be an advantage. This is because proximity to roads provides significant easiness both during construction and in the process of maintenance and repairs (Baban and Parry, 2000). Therefore, the effect value increases by getting closer to roads (Fig 4h).

Wetlands are another factor. Manyas Bird Lake, which is the largest wetland within the study area, is a living space for first which has international significance with the Ramsar Convention (especially in terms of preservation of internationally important wetlands as living spaces for water birds) (Provincial Environmental Status Report for Balıkesir, 2015). It was seen that wetlands host wildlife, and WPP pose a threat especially for migrant birds (Moiloa, 2009). This is why the effect value increases by getting further away from wetlands (Fig 4i).

Another factor, distance from coasts, is also seen as an important factor. Constructing WPP close to coastal areas was not found to be suitable, because coastal areas are areas where urban and rural areas are dense, and touristic activities are effective (Bennui et al., 2007). Considering field conditions, the effect value decreases by getting closer to the coasts (Fig 4j).

Another important parameter is distance from streams. Generally due to terrain unevenness and the dynamic structure of streams, the effect values of streams in WPP location selection were assigned by considering the danger of floods. In addition to this, as streams are in the position of areas of special habitat and recreational activities, WPP is seen as a threat for such areas (Aydın, 2009). The effect values were determined accordingly (Fig 4k).

Finally, another important factor for WPP location selection was seen as the distance to fault lines. As it is known, as the proximity to the epicenter of an earthquake increases, the destructive effect of the earthquake increases (Chamanehpour et al., 2017). Therefore, because being close to fault lines will increase the destructive effects of a possible earthquake, the effect values of being far from fault lines increased accordingly (Fig 4l).

Conclusion and Recommendations

The result map (Fig 5) was obtained as a result of the analysis of and calculations on all the factors. According to the map, the factors of power density, altitude and exposure had the strongest effects. Accordingly, the WPP sensitivity areas for Balıkesir were determined as four classes. These were, in order, somehow suitable, moderately suitable, suitable and highly suitable.

The highly suitable areas were usually in the northern parts of Balıkesir. They were homogenously distributed especially on the line of Erdek, Bandırma, Manyas, Göbel and Susurluk. Highly suitable, suitable and moderately suitable areas were found in the Marmara Island. These areas were believed to be the most suitable locations for WPP construction.

The central and southern parts of Balıkesir containing the district of Savaştepe were here the suitable and moderately suitable classes were seen.

The areas that were not suitable for WPP establishment were generally in Dursunbey, and most of the southern districts of Bigadiç and Sındırgı. The district of Gönen, and the greater part of the area of the Gulf of Edremit, which contains the districts of Ayvalık and Edremit, were seen to be among areas not suitable for WPP construction. A significant part between the Gulf of Edremit and the district of Savaştepe containing the districts of Havran and İvrindi were also not found to be suitable for establishing WPP.

Consequently, the amount of land that was in the highly suitable class within the studied 1397899 hectares (ha) of area, covers 12% of the area by 169156 ha. The suitable class covered an area of 407059 ha by 29% within the general area, the moderately suitable class had an area of 498525 ha and a share of 36%, and the somehow suitable class covered an area of 323159 ha by a 23% share in the total area (Table 2, Fig 6).

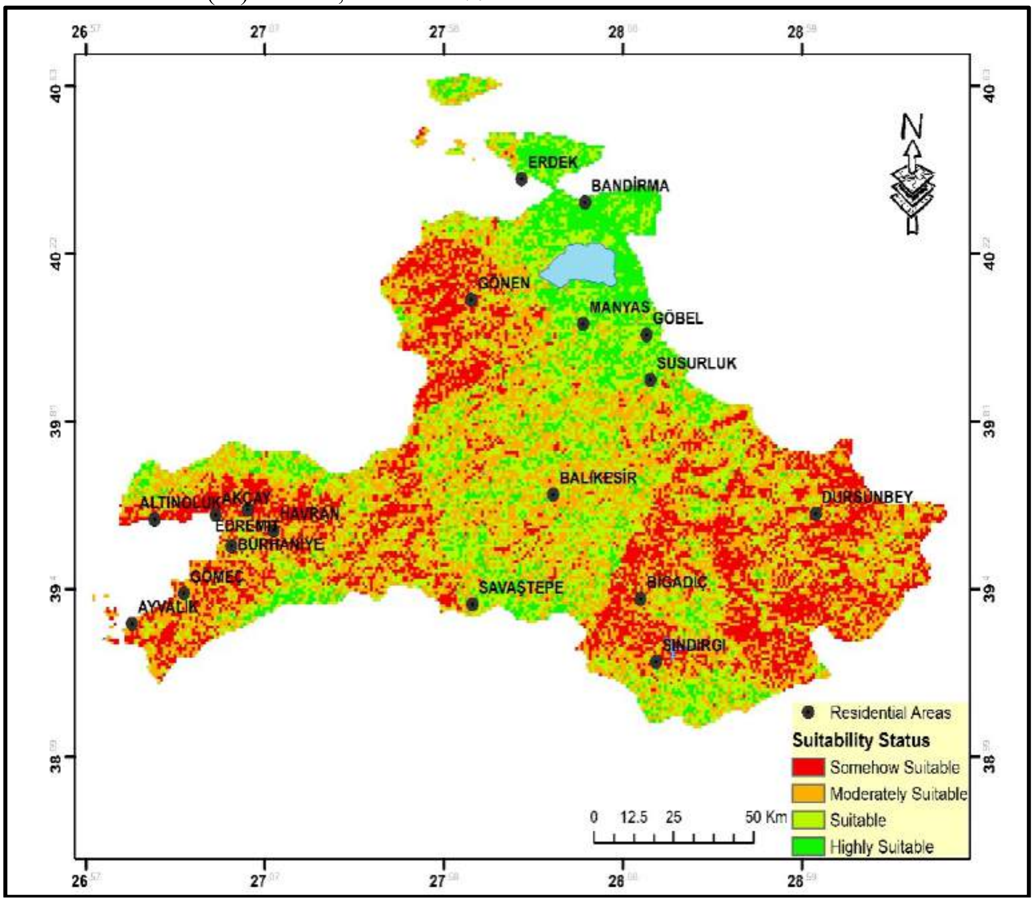

Fig 5. Result Map

When the map of areas where wind power plants may be established (Fig 7) provided in the Balıkesir report of the “Wind Energy Atlas for Turkey” published by the Directorate of Renewable Energy of the Ministry of Energy and Natural Resources and the result map here (Fig 5) are compared, the distribution of areas where WPP may be built usually overlap.

Table 3. Distribution of suitability classes for WPP construction location

Suitability	**Area (ha)**	**Area(%)**
Somehow Suitable	323159	23%
Moderately Suitable	498525	36%
Suitable	407059	29%
Suitable	169156	12%
Total	1397899	100%

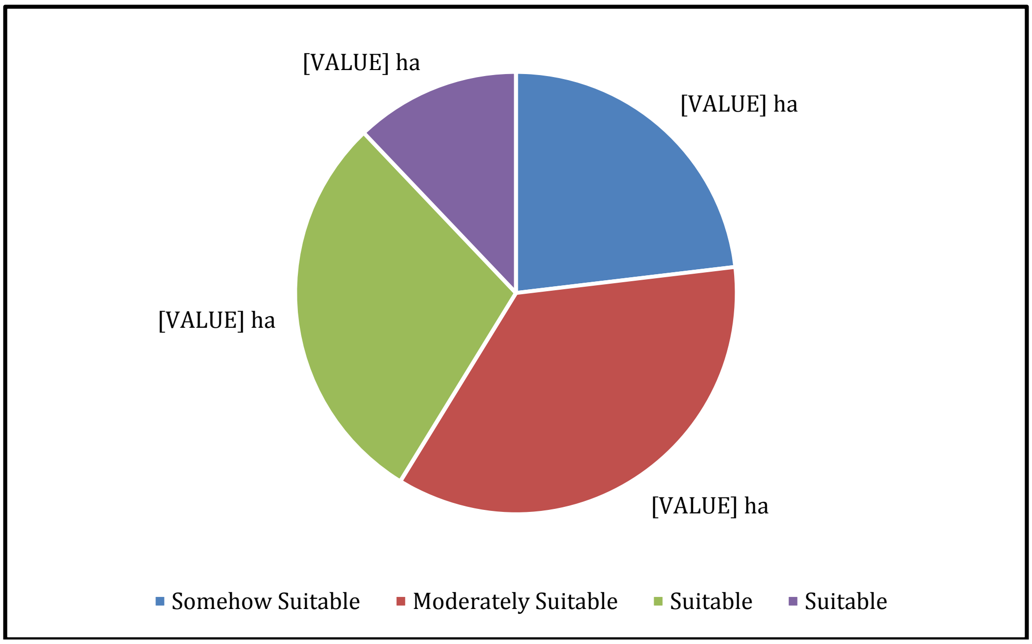

Fig 6. Rate of distribution (ha) of suitability classes for WPP construction locations.

In conclusion, Balıkesir appears to be highly rich in terms of areas where WPP may be established. These areas may be utilized more and more benefits may be derived from the potential of wind energy in the region. It may be more useful for further studies to also investigate the factors of migration paths for birds, and national and historical archeological sites.

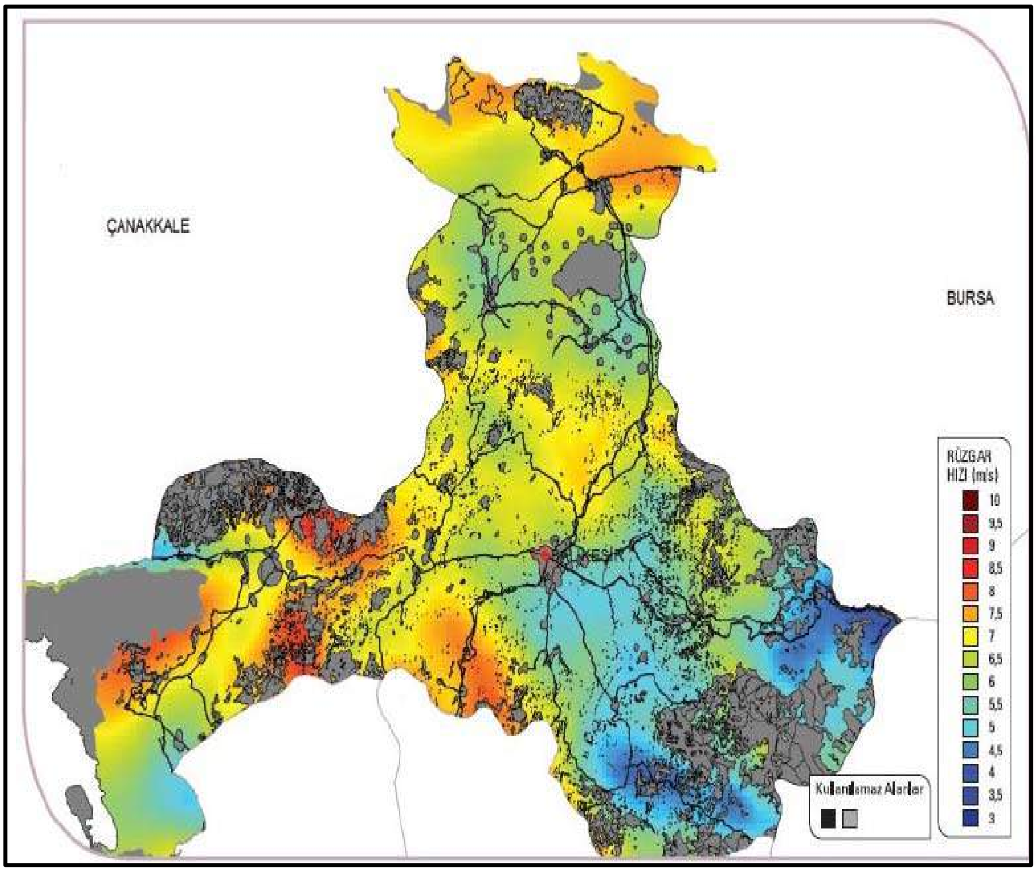

Fig7. Balıkesir, areas where WPP may be built URL 1).

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