International Journal of
Sustainable Energy Planning and Management

Determination of the most appropriate site selection of wind power plants based Geographic Information System and Multi-Criteria Decision-Making approach in Develi, Turkey

Fatih Karipoğlu[a], Mustafa Serdar Genç[*b,c,d] and Kemal Koca[b]

[a] *Department of Energy Systems Engineering, Izmir Institute of Technology, 35430, Izmir, Turkey*
[b] *Wind Engineering and Aerodynamic Research Laboratory, Department of Energy Systems Engineering, Erciyes University, 38039, Kayseri, Turkey*
[c] *Energy Conversions Research and Application Center, Erciyes University, 38039, Kayseri, Turkey*
[d] *Multi Science Gate (MSG) Technology Ltd.Şti., Erciyes Teknopark, 38039 Kayseri, Turkey*

ABSTRACT

Wind power has major benefits including providing for an increasing energy demand while tackling climate change problems. Detailed planning processes such as technical, social, environmental, various agents, and political concerns are essential for the development of wind energy projects. The objective of the present study is to develop a visualization that combines Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) and implementation for Kayseri, Develi in Turkey as a case study. For the analyzes, CORINE CLC 2000 and other data sources were employed for data acquisition to unlock fragmented and hidden onshore data resources and to facilitate investment in sustainable coastal and inland activities. Several factors were determined in the wind power plant installations such as wind potential, roads, water sources, and these factors were analyzed based on their buffer zones. After detailed analyses, sites near the Havadan (7.87 MW) and Kulpak (9.22 MW) villages were found to be the most suitable locations for the installation of a potential onshore wind farm. The method suggested in this study can be used to analyze the suitability of any region at the regional level for onshore wind power plant and the results of the study can be used to develop based on public perception, renewable energy policies, energy political rules.

Keywords

Wind power;
GIS;
MCDM;
Suitable site selection;
Environment;

URL: https://doi.org/10.5278/ijsepm.6242

1. Introduction

Energy has become the basic input in many areas such as factories, workshops, electronic devices in homes, street lighting, railway transportation even electric vehicles. Inherently, energy consumption is inevitably increasing because of the rising world population and the development of technological devices rapidly. Hence, many concerns such as increasing energy demand, fossil fuel depletion, and environmental issues have led countries to search for ways to develop Renewable Energy capacities [1]. These caused the Renewable Energy Sources (RES) to gain more reputation [2]. It can be said that RES consists of wind, solar, geothermal, ocean, and bioenergy. Of these resources, wind energy plays a crucial role due to its potential in energy generation, its market value, its wide application range, and its economic attributes [3–6]. Therefore, it has become more competitive among other RES with conventional energy sources in recent years [7].

Regarding the information of Turkey, it is located 36°–42° northern parallel with 26°–45° eastern meridians, and it is surrounded by seas including the

*Corresponding author - e-mail: musgenc@erciyes.edu.tr

Mediterranean Sea in the south, the Aegean Sea in the west, the Marmara Sea in the northwest and the Black Sea in the north, resulting in an appearance of a peninsula. It has many natural resources such as geothermal energy, water sources, and boron. Therefore, the Turkish Government determined the aims for 2023. Specifically, inside of aims, Turkey will meet 30% of energy demand from RES. In this respect, Turkey is executing an innovative energy policy for the future so that RES plays an important role [8]. Due to geographical location, onshore and offshore wind energy potential were identified 48000 MW and 17393.2 MW, respectively [9].

The first wind power plant was established in 1988 with an installed capacity of 7.2 MW [10]. Then, information was obtained from the wind speed measurements, a wind farm was evaluated and it helped to form a potential atlas. The potential atlas of Turkey for an altitude of 50 m was performed and it was given as seen in Fig. 1. According to the atlas, the high potential regions were the Marmara and Aegean divisions. In Turkey, 21.75% of the onshore wind power plants were installed in Balıkesir. Then, İzmir and Manisa followed Balıkesir with 18.2% and 12.89% installed capacity, respectively [11]. The wind speed was also higher in the parts of Anatolia, including southeast of Kayseri [12–13], south of Sivas [14–15], and northwest of Kahramanmaraş.

Concerning the most suitable regions for wind farm installation, it was important to determine of criteria that had to be taken into consideration how these criteria would affect the site selection regions. Geographic Information Systems (GIS) technologies enable the identification of factors, affecting the installation of energy power plants and their collection in a spatial database along with the effective evaluations of relevant analyses [16]. GIS can determine the most suitable regions for energy power plants after the determination of crucial factors for the selected area. In addition to GIS, Multi-Criteria Decision Makers (MCDM) was conducted at a suitable region selection process for energy power plants [17]. Many researchers were interested in studying suitable site selection examined by utilizing these two methods [18–23]. Within the scope of Turkey's 2023 targets, it is aimed that the most suitable regions for electricity production from wind energy are determined and suitable wind energy conversion systems are installed. With the reach of these targets, the dependence on external sources and fossil fuels of Turkey will be gradually decreased.

In the last decade, Turkey has shown great interest in renewables energy systems. Therefore, the questions and concerns that arise relate to determining the most suitable investment regions [8]. Determined regions should be suitable in terms of all restrictions of environmental, technical, and social impacts. This study will provide a lot of important information to solve the questions and concerns as a case study in Turkey.

This study aimed to determine the most appropriate regions for the installations of onshore wind power plants to show selected region can benefit from high wind potential. Therefore, in the scope of the Turkey Government's renewable energy support policies, the aim was to determine the most preferable regions for investors and to contribute to the implementation of the wind power plants for energy planners. Furthermore, the criteria were determined for the construction of wind

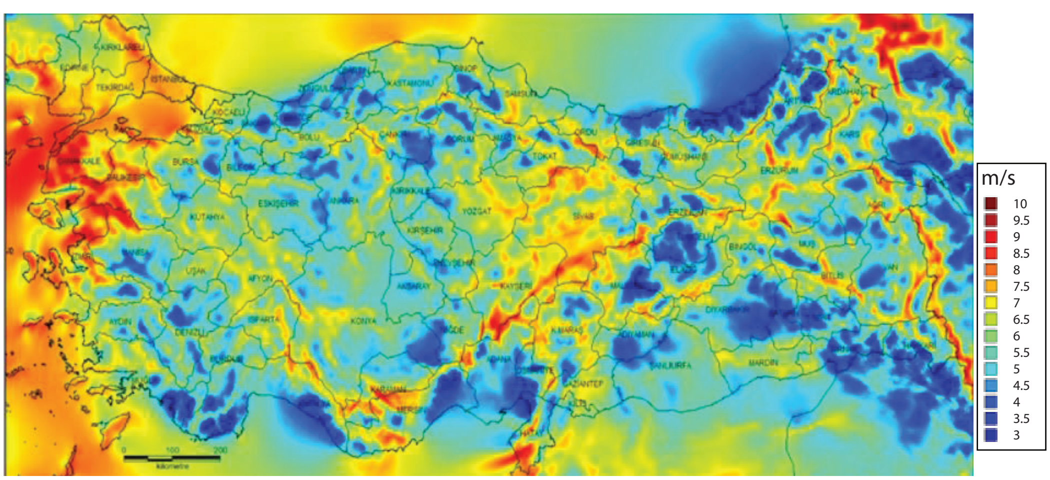

Figure 1: Turkey wind potential atlas at 100 m elevation [27]

power plants at the most suitable areas and the process steps and required analyses were conducted using databases from different sources such as Global Wind Atlas, Copernicus, Emodnet, Wind Energy Atlas [24–27].

Develi was selected as a study area in Turkey. The average wind speed and capacity of Develi are above 7 m/s and 40% during the year and the installation of a wind power plant is suitable in terms of techno-economical assessment of wind speed [5, 27, 28]. In the study, the necessary criteria and process steps were determined. Multiple data sources were newly utilized for accurate analysis results.

Databases from different sources, processed in GIS, and important MCDM methods, spatial analysis queries were performed for the most appropriate site selection. Using GIS and MCDM, all necessary technical, social, environmental, and political details were considered at a suitable region selection process for wind power conversion system installation. Consequently, this study determined the most appropriate regions in Develi for wind power plants with detailed analysis and to examine their suitability and efficiency for all of Turkey. This detailed paper was the first study for Develi for the installation of the wind power plant. Hereby, it helped policymakers in evaluating and a suitable and ideal place for a wind power plant.

2.1. The description of generic methodology

In this study, the proposed methodology for suitable site selection of wind energy power plant in Develi County was illustrated in Fig. 2. The diagram was handled in four steps. According to the information obtained in the literature review [1, 2, 7, 17, 18, 19, 21], the data sources and databases required for the potential, environmental, and social analyses were found in the first step. On the next step, according to received wind speed data from the Global Wind Atlas, regions with a wind speed of less than 3 m/s were excluded since the wind turbine cut-in speed was generally 3 m/s. In the third step, environmental and social analyzes for the remaining regions were performed according to the 12 different restrictions. The environmental and social analyzes should be formed according to the condition of the study area and the type of energy power plants. It was aimed to prevent the non-objective decisions in the present study. As seen in Fig. 2, the red-colored restrictions were very important for the wind energy plant investment. Buffer zones of red restrictions were closer, and the weights of effect were higher than other restrictions. Also, some red-colored restrictions were, more importantly, restricted because of existing policy, regulations, and legislation. After the environmental and social analysis, it was obtained required map layers and final suitability map

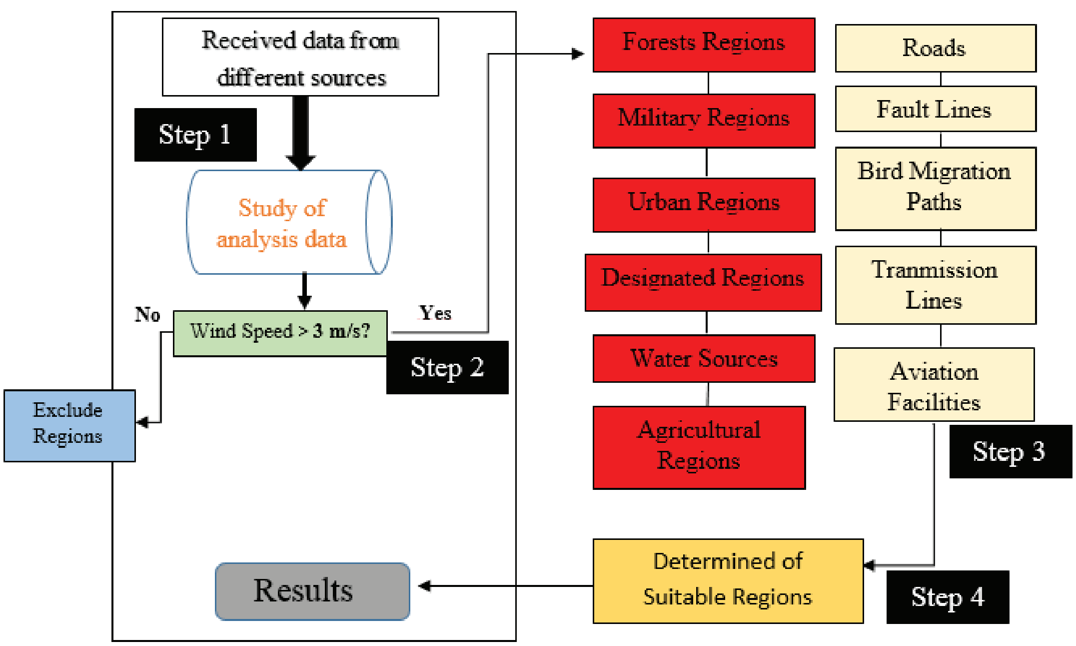

Figure 2: Methodology diagram of the study

layer of the studied area. Under technical, environmental, and social impacts, it was determined the suitable regions and wind potential in the study area.

2.1.1 Multi-criteria Decision-Making Methods (MCDM)

As mentioned before, this method is very important for suitable site selection for energy power plants. The application of MCDM techniques supplies renewable energy management [28]. A method is a tool that allowed the best choice to be made from multiple and concurrent criteria. As the energy management problems are getting more complex, economic considerations are complemented with environmental and social considerations, leading to multiple-criteria decision making being used to deal with conflicting decision problems [19]. The international studies in the field of solar energy evaluating the criteria effective in the installation of solar PV power plants using GIS have often preferred MCDM to determine the weights of the parameters [29–31]. Hence, MCDM was performed in this study. It was examined the two steps of the multi-criteria. In the first step, it was examined the wind energy potential. Environmental and social restrictions were investigated in the next step.

2.1.2 Studied area

This studied area was conducted in Develi, located southwest of the Kayseri. Develi is located at the latitude of 38.4° and longitude of 35.5°. The face measurement is 1887 m^2 and its height above sea level is 1150 m. Develi is at the foot of the high mountain (Erciyes Mountain). The dominant wind direction was northwest [12]. According to the wind energy potential atlas [27], Develi, Yahyalı, and Pınarbaşı are the places with the highest wind potential in Kayseri. There are wind farms in Yahyalı but there were not any wind farms in Develi and Pınarbaşı. Due to geographical location and air density, Pınarbaşı was not suitable for wind farm investments, thus Develi is a correct selection [12-15]. Because the average wind speed of the study area above 7 m/s according to data sources [27]. Moreover, Develi has not any fault lines in its underground. For these reasons, Develi was selected as a study area due to either a suitable geographical situation or high wind potential. Therefore, the installation of a wind power plant in the study area can be a beneficial and useful region in terms of economy and the development of renewable energy system installations. Also, the Develi Municipality gives importance to renewable energy systems, and Develi has 3 solar energy power plants. This study will shed light on the Develi Municipality's wind energy investments. The study area is shown in Fig. 3.

2.1.3 The affecting factors for suitable regions and obtained data

Data are among the most basic requirements of site selection for wind energy power plants. Therefore, it was used

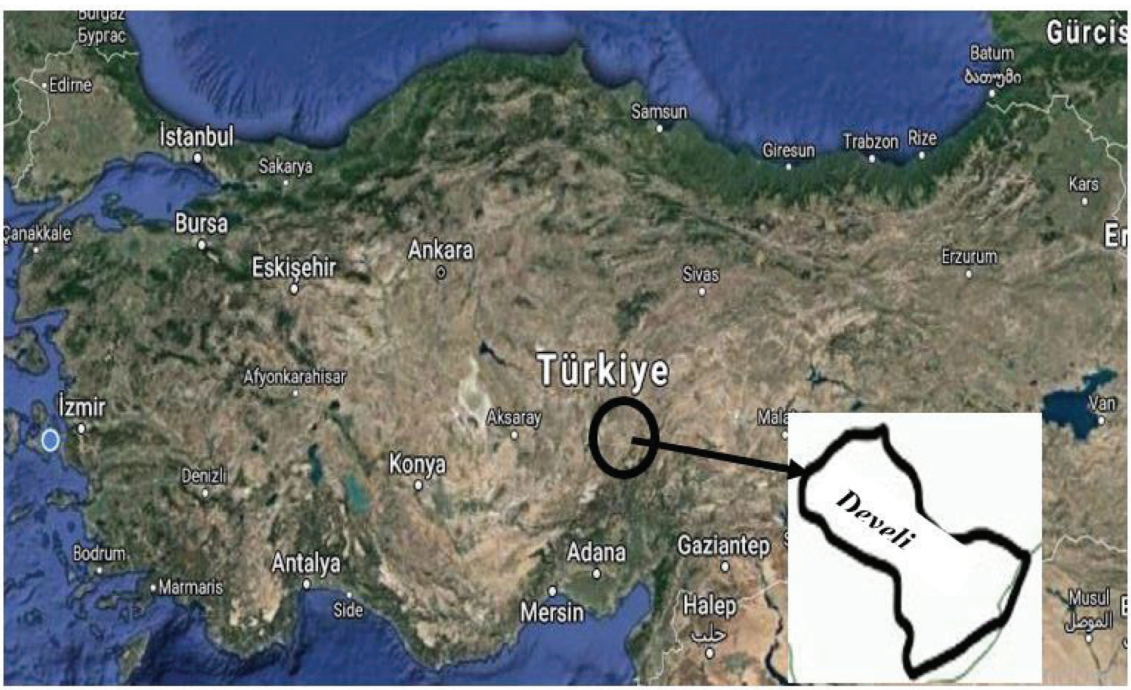

Figure 3: The study area

Table 1: Map layers for restrictions and data sources [24–27, 29, 37–39, 44]

Layer	Source of data
Wind speed and	Global wind atlas 2020
power	Corine Clc 2000 (311, 312, 313)
Forests	Turkish army forces
Military regions	Corine Clc 2000 (124), Flight radar 24
Airports and aviation	Corine Clc 2000 (111, 112)
Urban regions	Emodnet 2018, Unesco 2020
Designated regions	
Agricultural regions	Corine Clc 2000 (212, 213, 222, 223)
Water sources	Corine Clc 2000 (511, 512, 132)
Roads	Corine Clc 2000 (122), Openstreet map 2020
Fault lines	General directorate of mineral research and Exploration
Bird migration paths	2013, Kandilli Observatory and
Energy transmission	Earthquake Research Institute (Koeri 2020) *Decision making based on environmental impacts* (Degirmenci 2018) Teiaş (Teias 2020), Repa 2020

in many different data sources in this study. Firstly, the restrictions and demands were determined. The factors affecting selection for the installation of wind energy power plants within the borders of Develi were determined as a result of literature research and expert opinions [8, 18, 19, 21, 27, 32, 33, 39]. In Table 1, the criteria of the restrictions and data sources were given. For this study, it was determined 12 different criteria by using GIS. These criteria consisted of wind speed, forests, military regions, civil and military aviation, designated regions, agricultural, water sources, roads and ports, fault lines, bird's migration paths, energy transmission lines, which are important for wind energy installation. In addition to the criteria, it was determined the buffer zones for 9 restrictions.

In Table 2, buffer zone distances and sources of these distances were ensured for the determined restrictions. According to Table 2, buffer zones analysis studies were carried out in GIS and were determined unsuitable regions for wind power plants. For example, the suitable wind farm regions must be 150 and 3000 meters away from fault lines and urban areas, respectively. The buffer zone distances for the 9 restrictions were described in the section 2.3.

2.2. The description of analytical methodology

2.2.1 Wind power and potential in Develi

Wind speed was generally below 10 m/s for most of the year in the studied area [12]. In the winter, stronger

Table 2. Buffer zones and their sources [8, 15, 32, 38–40, 43]

Spatial constraints	Buffers
Agricultural regions	outside
Military regions	5 km
Roads	0,1 km
Designated regions	5 km
Urban regions	3 km
Fault lines	150 m
Energy transmission lines	0-5 km
Airports and aviation	3 km
Bird migration paths	3 km

winds exceeding 20 m/s and the summer winds were much weaker than the winter winds, rarely exceeds 10 m/s [27]. To obtain the updated wind power data, the long-term data was taken from Global Wind Atlas (GWA). GWA has wind power data which are measured during 10 years (2008–2017) by European Centre for Medium-Range Weather Forecast (ECMWF) [24]. These measurement results are visualized by using the location grid method and shown for five heights: 10 m; 50 m; 100 m; 150 m; 200 m. The mean wind speed and wind roses for the studied area at 100 m elevation were shown in Figure 4 [24]. Moreover, the wind frequency and dominant direction were analyzed for the study area [12, 27]. The frequency deviation is assumed maximum the shape factor (k) is 1.88 in Weibull Distribution for Develi [6]. The average wind speed of the studied area at 100 m was between 7-9.5 m/s [24]. Genç [6] calculated the annual wind speed of Develi was 8.11 at 100 m elevation for Develi. For the accurate wind power plant investment, the wind speed should exceed 7 m/s for a high level of power generation and should indicate good potentiality for feasible wind farms [34]. Moreover, wind turbines can be selected easily according to wind power and potential level via energy planners and investors.

These data were processed in GIS and were obtained from the wind speed distribution map as seen in Figure 5. According to this map, a huge part of Develi could be suitable regions for wind farms. It was also clearly seen that there was a small excluded region for wind speed data in Figure 5.

2.2.2 Forests regions

The total area of Turkey was 78 million hectares and 21.7 million hectares were designated as forest areas. Kayseri has a few forest areas. In general, the number of forest areas in the districts is low. Southeast of Develi is forested areas for natural sources and facilities areas.

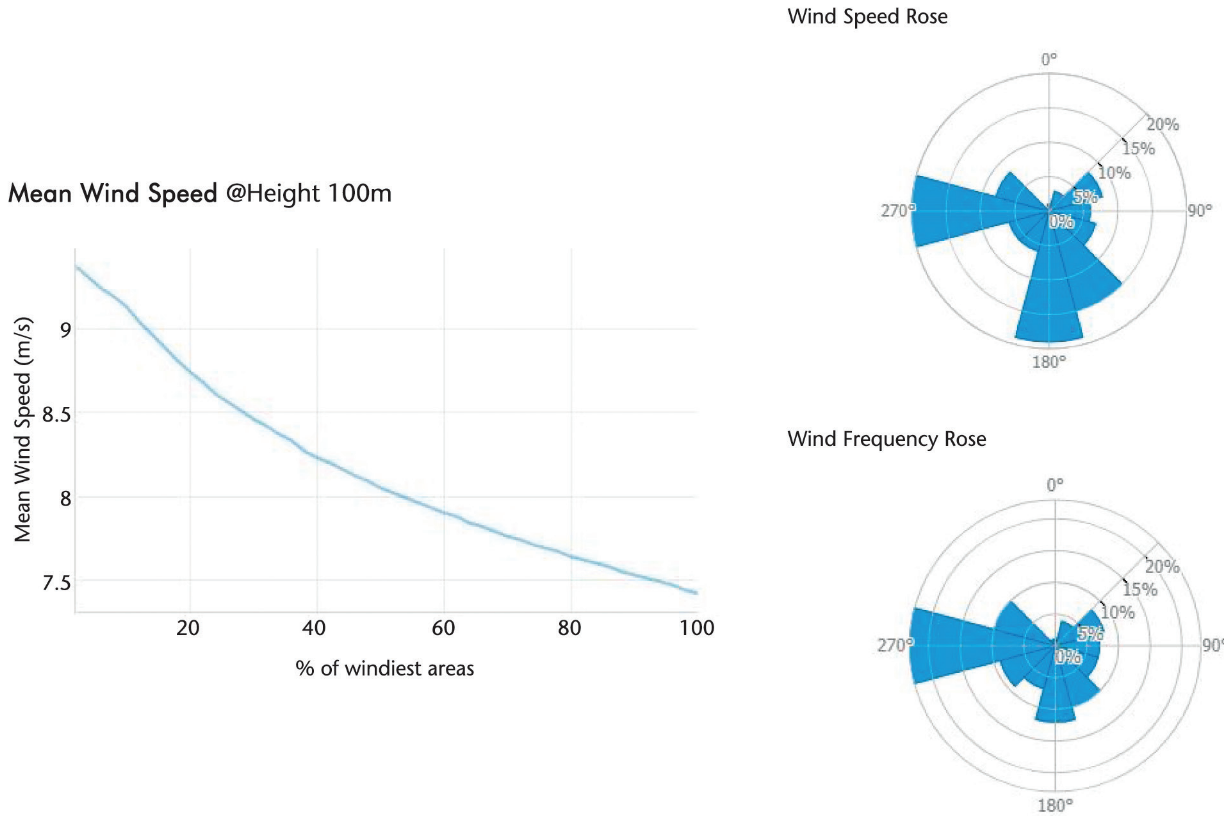

Figure 4: a) The mean wind speed b) wind rose of speed and frequency of the study area [24]

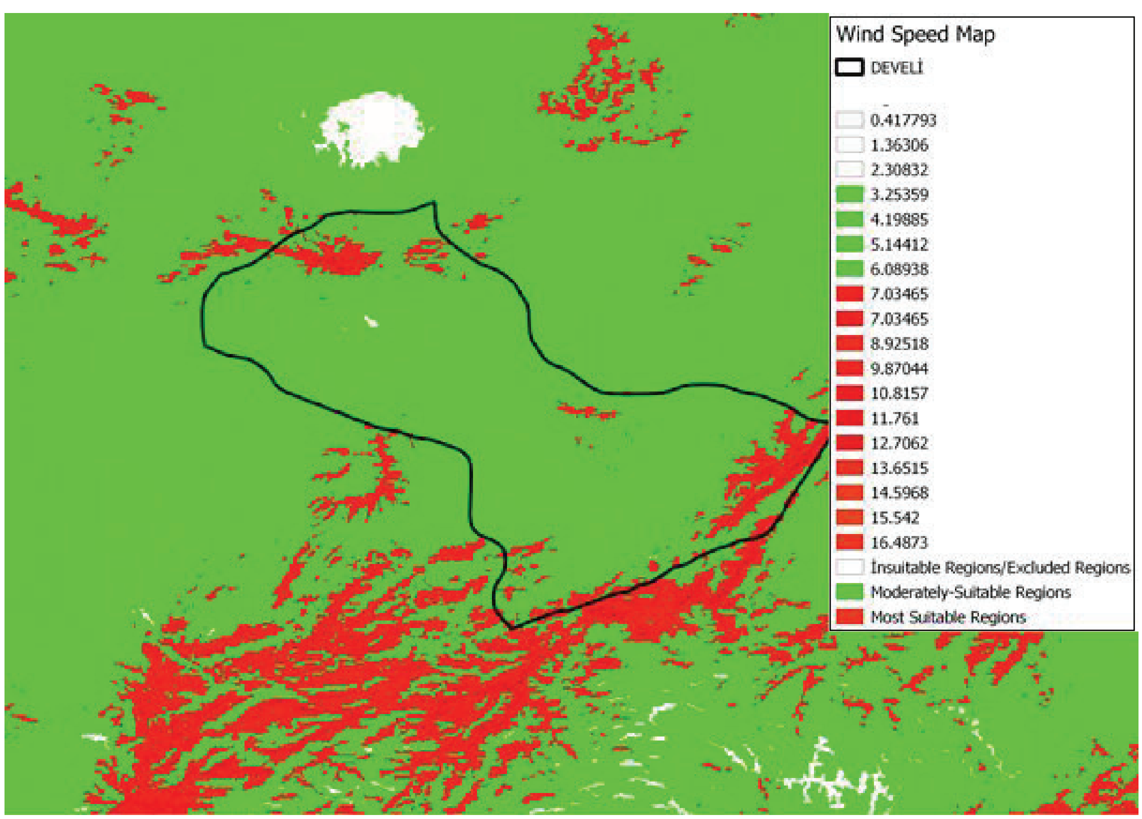

Figure 5: The wind energy map for the studied area

According to Forest Law in Turkey, some areas in the forest were rent as renewable energy power plants such as solar and wind energy systems. Also, to minimize forest loss, the forest areas don't use for different purposes. In this study, forest areas in Develi were illustrated in Figure 6 as a red color point.

2.2.3 Military regions

Some lands can be used by the army as military exercise and settlement areas. The military regions are very important for every country. Therefore, these regions are closed off to use for different purposes. The army can use these regions as military prohibited, exercises regions, and security zones. On the other hand, the wind industry thinks that many economically feasible projects are limited due to military reasons [35]. There is one military region within Develi borders. This region is located in Develi province. Therefore, installation of the wind power plants is not prohibited in regions.

2.2.4 Civil and military aviation

Wind farms may sometimes be dangerous for civil or military planes, helicopters. Since the wind tower and hill heights are approximately 100 and 400 m respectively, the total height from the ground is 500 meters. This height is dangerous when the planes or helicopters taken-in or taken-off. Therefore, wind farms must not install near civil or military airport regions. Kayseri Province has one airport and this airport is far away 50 km from Develi as seen in Figure 7. This airport was used for civil and military purposes.

2.2.5 Urban regions

The population has migrated from village to city for 10 years. Therefore, cities are being crowded day by day, and the land area is used for the installation of houses, factories, and shopping centers in the agricultural lands. This causes irregular urbanization to occur especially in big cities. As considering economically, the land prices are very high level in urban regions. Because of the reasons, energy plants are located outer part of urban regions [36]. Kayseri urbanization is very regular, but the districts are not traditional for urbanization. So, a high amount of the Develi population lives in the center. Villages and outside of the central city are very suitable for energy plant investments. Turkey and Develi urbanization are shown in Figure 8 as a green color.

2.2.6 Designated regions

The designated regions are very important to determine the suitable regions for energy power plants. Around the world, the designated and the wonder of natural regions are determined by the European Council (UNESCO). These regions are protected by this council and they are not used. Therefore, these regions are the excluded regions in any feasible site selection study.

Due to its geographical location and the old volcano mountain Erciyes, Kayseri has a lot of natural wonders. As seen in Figure 9, in Develi borders, Sultan Sazlığı is protected by UNESCO, and Soysallı Lake is a designated region. The data related to designated regions

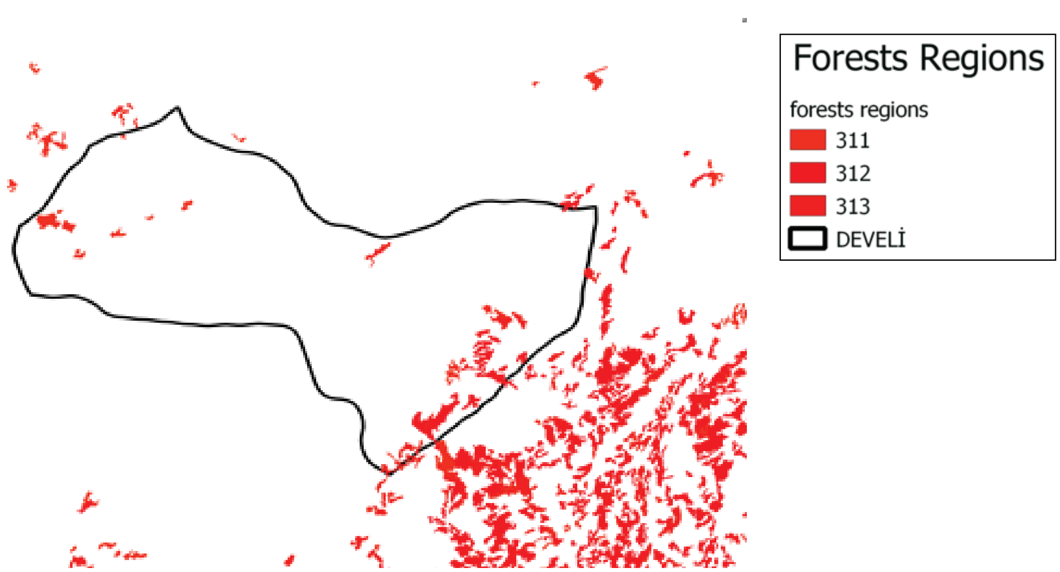

Figure 6: The forests areas for the study area

Figure 7: The airport in Kayseri

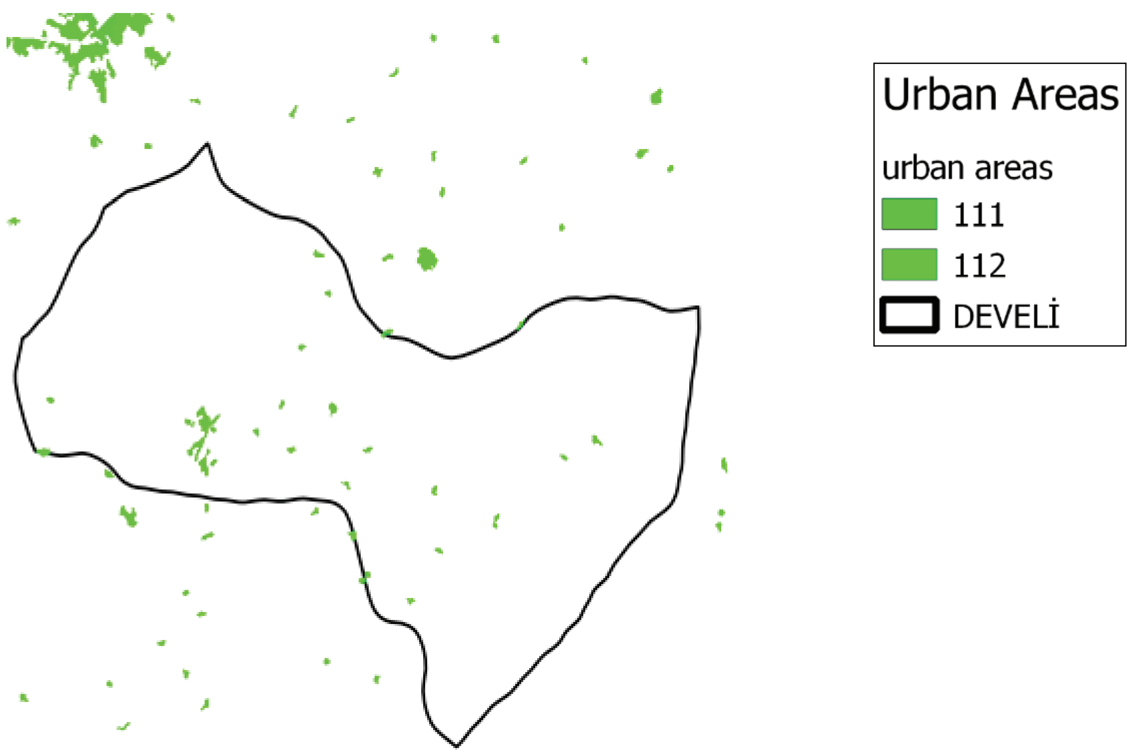

Figure 8: The urban areas of the study area

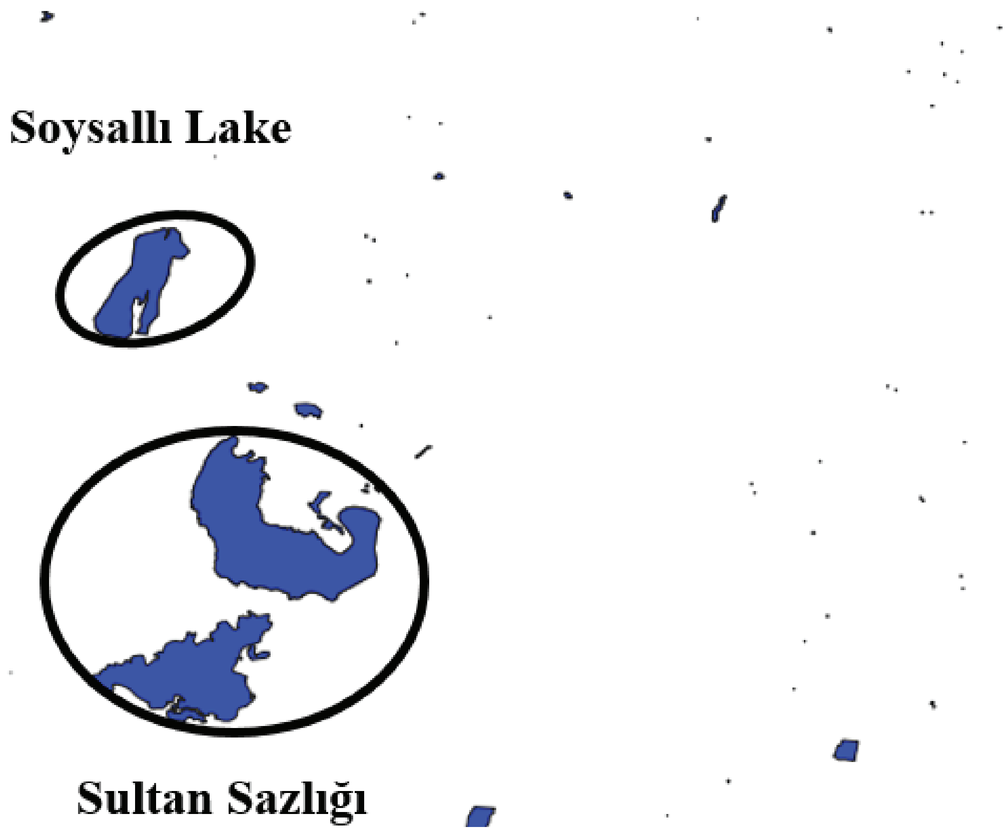

Figure 9: The designated regions in Develi

were received from CLC 2000 and Emodnet [25, 26]. These data were proceeded to determine the designated regions in the study area by using GIS.

2.2.7 Agricultural regions

Turkey has been a marvelous agricultural country for a long time. Because Turkey has a lot of efficient lands. Located in the middle of Turkey, the soil is better than in other regions. Although Kayseri is expressed as a trade center in Turkey, there are many agricultural areas in Kayseri. Also, Develi has a lot of regions related to agriculture such as honey pumpkin. Due to the increasing industrialization, agricultural works have decreased in the last years in Turkey. But the agricultural regions are acceptable as protected regions such as forest and urban areas for renewable energy plants.

In the study, the data with regards to agricultural regions were received from CLC 2000 [25] and were then proceeded in GIS as illustrated in Figure 10. According to data from CLC 2000 data sources, 211, 212, 222, 223 factors are rice fields, fruit trees, and honey pumpkin, olive groves, pastures, respectively. All agricultural regions are related to the same color. As seen in Figure 10, almost half of Develi is used as agricultural regions. Finally, the excluded regions were determined related to agricultural regions.

2.2.8 Water sources and water paths

Water is the basic element of life. Therefore, the use of water sources is very important correctly and carefully. Develi is in a rich position with regards to water sources because the snow on the Erciyes mountain is melting on sunny days and accumulates to water sources in Develi. While the water sources and paths are very important, these regions should not be used for any other purpose. So, these water regions are not suitable for wind energy plants. Figure 11 showed water sources and paths in Develi and Turkey. Waterways and water sources are located in the southeast and southwest of Develi, respectively. There are also agricultural lands in these regions. In Figure 11, the water sources were shown in blue shapes, and waterways were shown in blue lines.

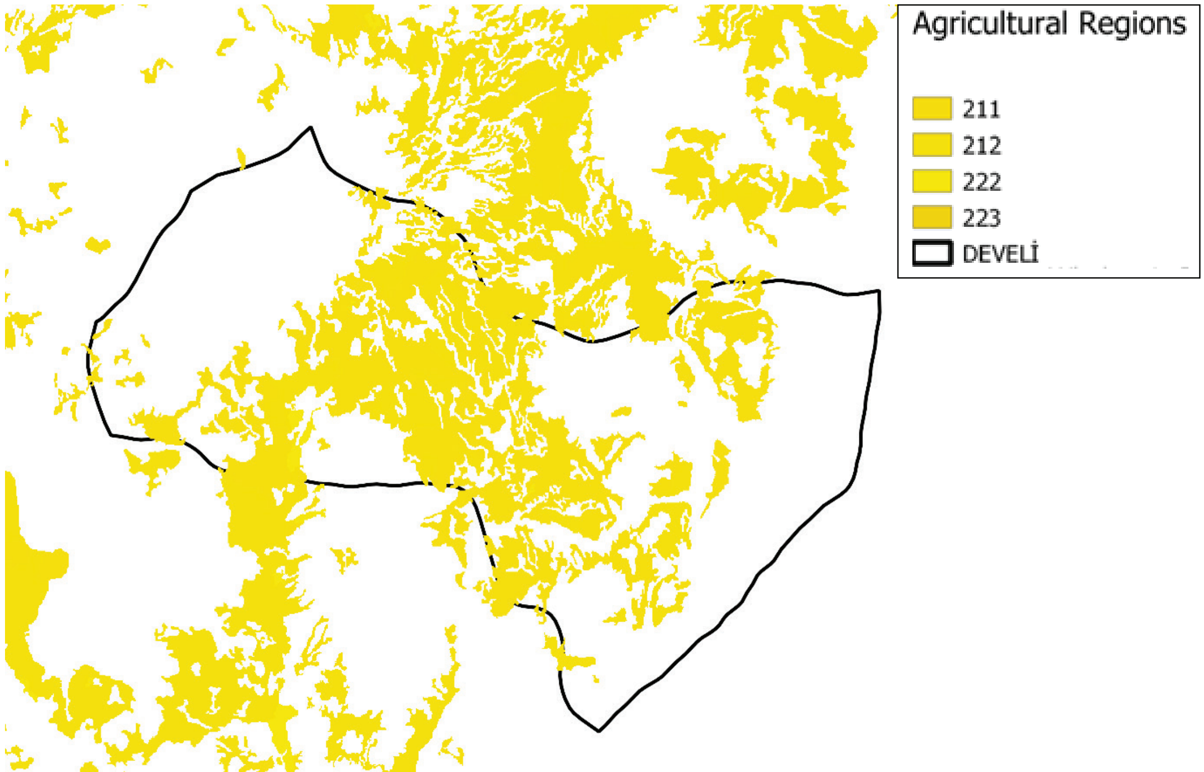

Figure 10: The agricultural regions in the study area

Figure 11: The water sources and waterways in the study area

2.2.9 Roads and railways

Transportation is very important for the big energy power plant investments. Generally, the wind energy power plant investment prefers easily accessible regions. Therefore, for wind energy conversion system transportation, the main roads are preferred. New roads will bring new costs in areas where there are no existing transportation systems. The road map layers data were obtained from CLC 2000 data sources [25]. The roads and railways map layers were shown in Figure 12. Develi is seen as a transport bridge between districts due to geographical locations. Thus, there are a lot of roads in Develi. According to Table 2, the suitable wind energy power plants must be 100 meters far away from roads. Roads with buffer zone distances were shown as an orange color line in Figure 12.

2.2.10 Fault lines

There are a lot of active and passive fault lines in Turkey because of its geographical position. The complex wind turbine systems in Turkey are either very tall or heavy. Hence, the static balance of wind turbines must be calculated carefully for weather conditions and soil topology. In selecting the location of the installation of a wind energy power plant, areas with low earthquake risk should be selected [8]. Therefore, another factor for selecting wind energy power plant sites is the presence of earthquake fault lines. For the fault line, spatial data were received from the Kandilli observatory and earthquake research institute [42]. It was prepared fault lines map layers related to these two sources in GIS as illustrated in Figure 13. For the determination of suitable wind energy power plant regions, fault lines must be 150 meters far away [40]. All of the fault lines with buffer zone distances were shown with black lines in Turkey by using GIS. According to the fault lines map layer, there are no active fault lines, but there are a few fault lines around Develi. Therefore, all regions of Develi are suitable due to fault lines restriction.

2.2.11 Bird migration paths

Generally, people say that the wind turbines kill the birds or changed their migration paths. According to Figure 14, the wind turbine and planes caused the rate of %0.003 percent of all the bird death [29]. Besides, different issues could also emerge such as loss of physical habitat due to location changes coupled with the breakup in the ecological habitat network [37]. Also, Figure 14

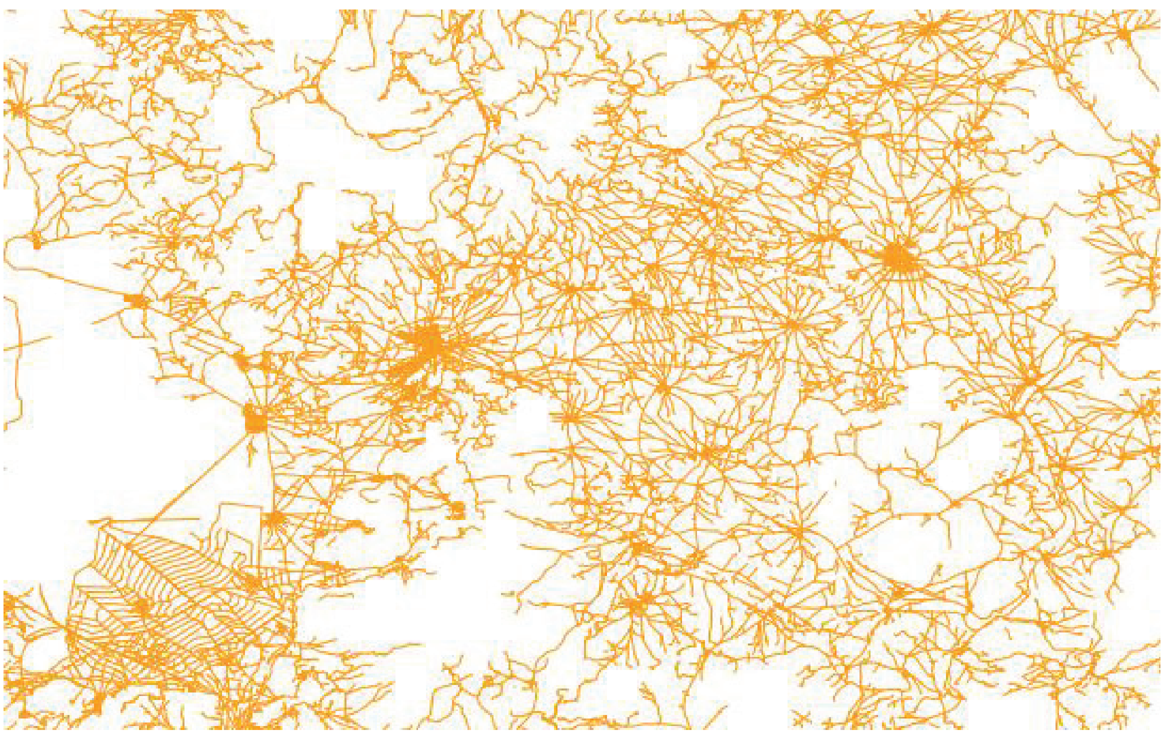

Figure 12: The roads in the study area

Figure 13: The fault lines map [42]

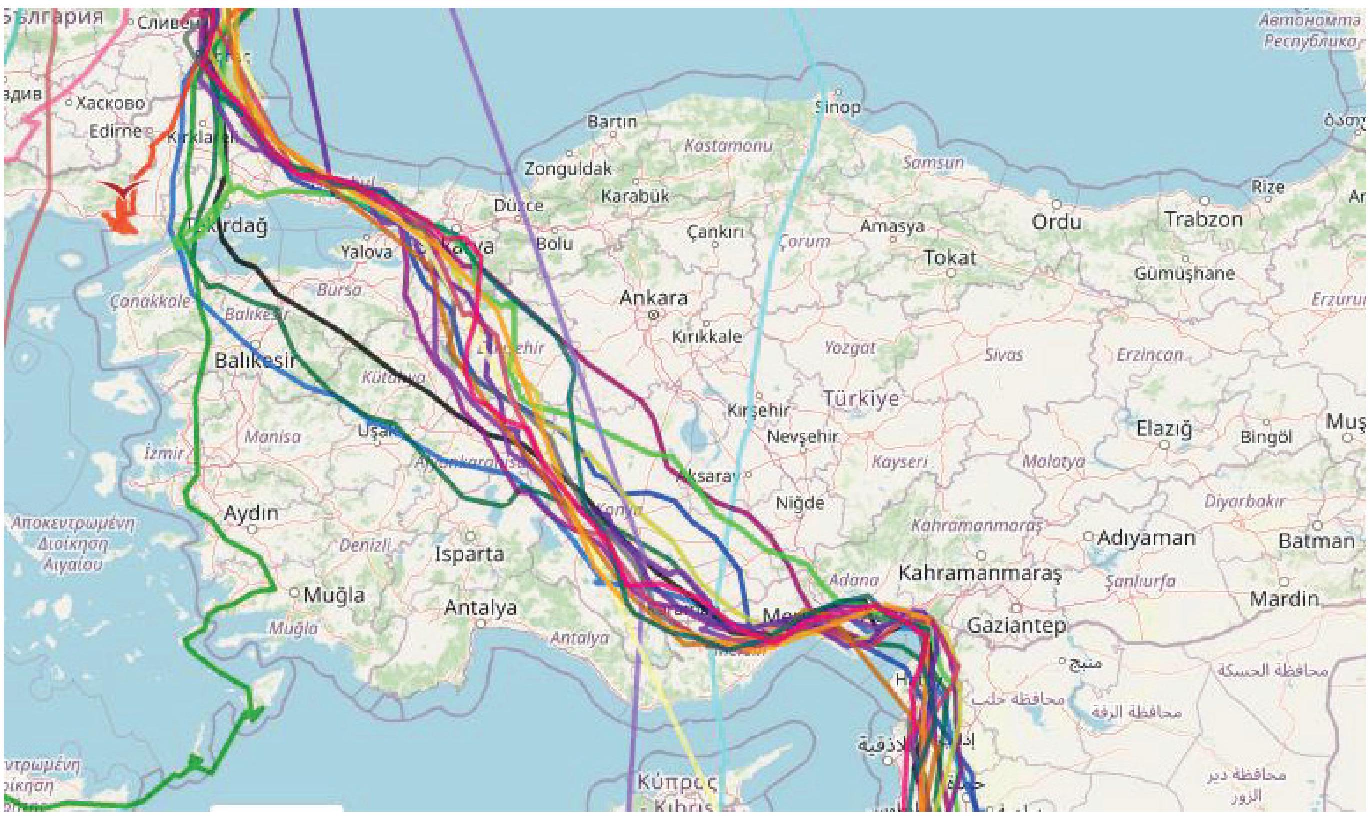

Figure 14: The bird migration paths in Turkey [43]

shows a map indicating the bird migration pathways in Turkey [43]. According to Figure 14, the bird migration paths mostly occurred from Tekirdağ to Hatay in Turkey. No bird migration path affects Develi. All regions of Develi can be said to be suitable due to bird migration paths restriction.

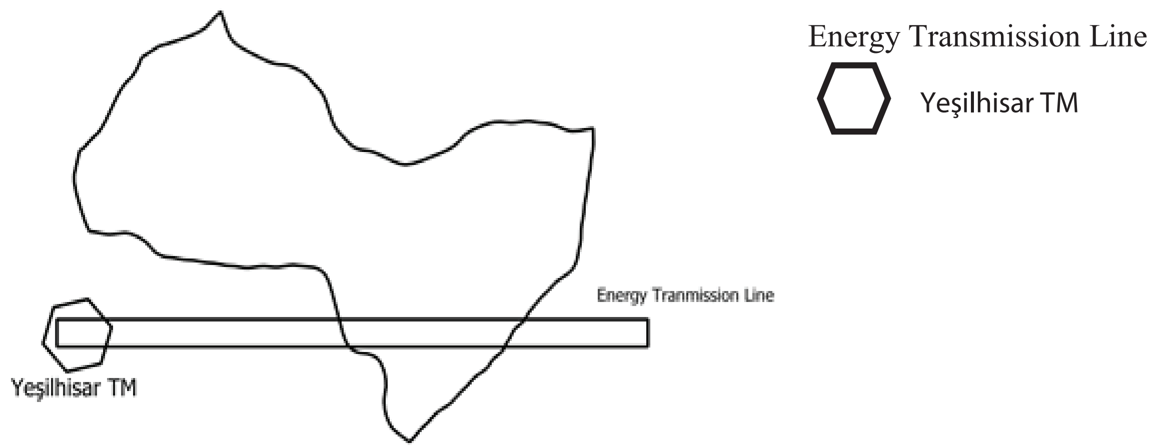

Figure 15: The energy transmission line in the study area

2.2.12 Energy transmission line

The energy should be consumed where it is produced for the minimum energy losses. Turkey has an interconnected system for energy lines from production plants to energy demand points. Considering the distance to substations and power transmission lines in the selection of locations will provide an advantage in reducing energy loss. In this study, necessary information and data were received from TEİAŞ Directorate [44]. Develi has a transformer center (Sızırlı) and energy collection. The Yeşilhisar transformer center and energy transmission line are close to Develi as shown in Figure 15.

3. Results

Regarding the suitable site selection of onshore wind power plants for Develi city, it was received that much data was related to potential, environmental and social impacts from different sources and proceed in GIS. Table 1 shows that effective impacts are 12 for onshore wind farm installation. These determined impacts have to assess before wind power plant installations. For the comprehensive analysis, necessary data was received from data sources where shown in Table 1. These data are analyzed as 12 different map layers in GIS. Finally, suitable site map layers were obtained by using all of the map layers. For determined the suitable site selection in Develi, it was prepared in Figure 16 and it was obtained final analysis map layer. Firstly, according to the environmental and potential impacts, five suitable regions for wind power plants were determined. To obtain the updated and accurate results, the constraints buffers was determined in Table 2. According to Table 2, the suitable region must be outside of the agricultural region, far away 5 km from designated and military region, and so on. Determined 12 restrictions were analyzed in the map layers with the constraints buffer distance. Although, as indicated in Table 2, only 2 regions were the most appropriate for wind power plants because of the energy transmission line constraints buffers. Because other regions were much far than 5 km to the Develi energy transmission line. In Figure 17, two suitable regions for wind farms' investment could be seen. These regions were two different villages. It was examined from Google Maps to determine the suitable region; these regions were not used as a human activity. And these regions had many mountains, hills and near the main roads. The first determined regions were near Havadan village and the suitable region was nearly 7500 m^2. The second region was near the Kulpak village and a suitable region was 12300 m^2.

Determined suitable regions for wind energy power plants are shown in Figure 18. These regions are important for wind energy power plant installations. When only wind speed is evaluated, almost all of Develi is suitable according to Figure 5. Also, unsuitable regions with

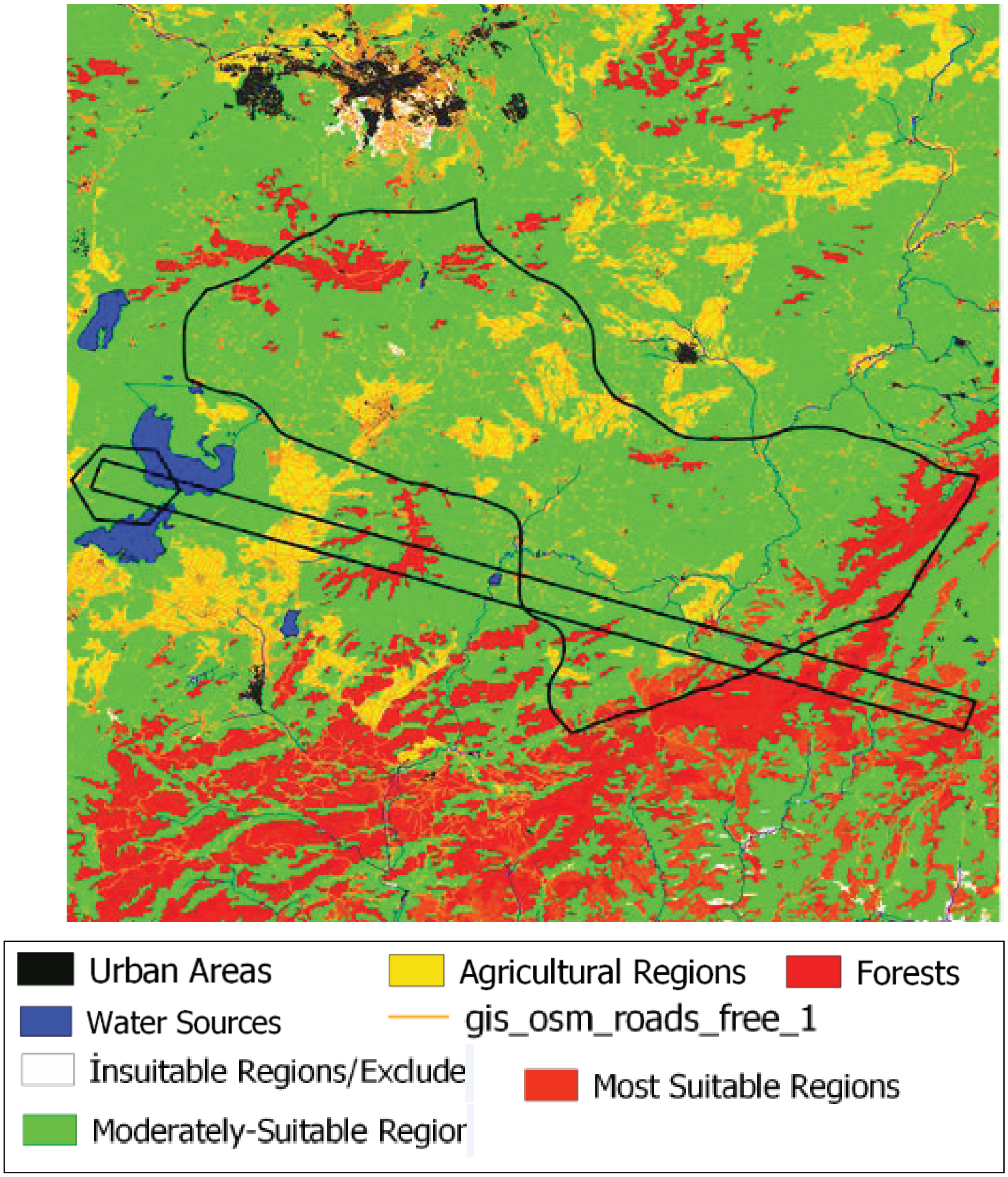

Figure 16: The final analysis of the select suitable regions

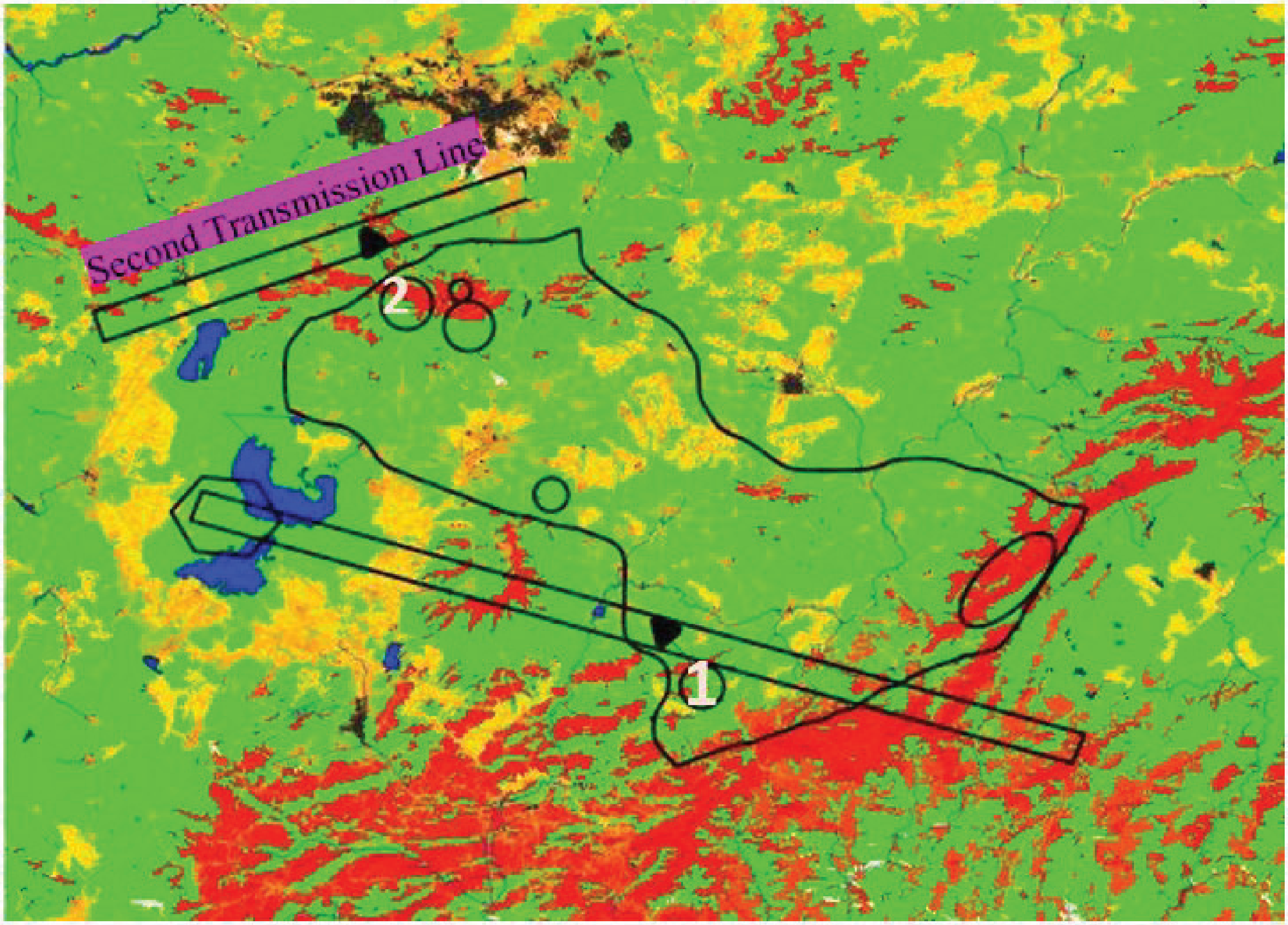

Figure 17: Determined two suitable regions in the study area

below 3 m/s are shown in two small regions in Figure 5. However, when environmental and social impacts are included, only two are determined as suitable regions in Figure 18. So, a detailed and versatile analysis is very important for the determination of suitable site selection. This comprehensive detailed analysis study, it was analyzed technical, environmental, and social impacts. After the analysis studies, it was obtained two regions with a total of 19800 m^2 suitable regions. If the restrictions set with buffer zone distances change over time, the determination of suitable site selection and total suitable regions may change.

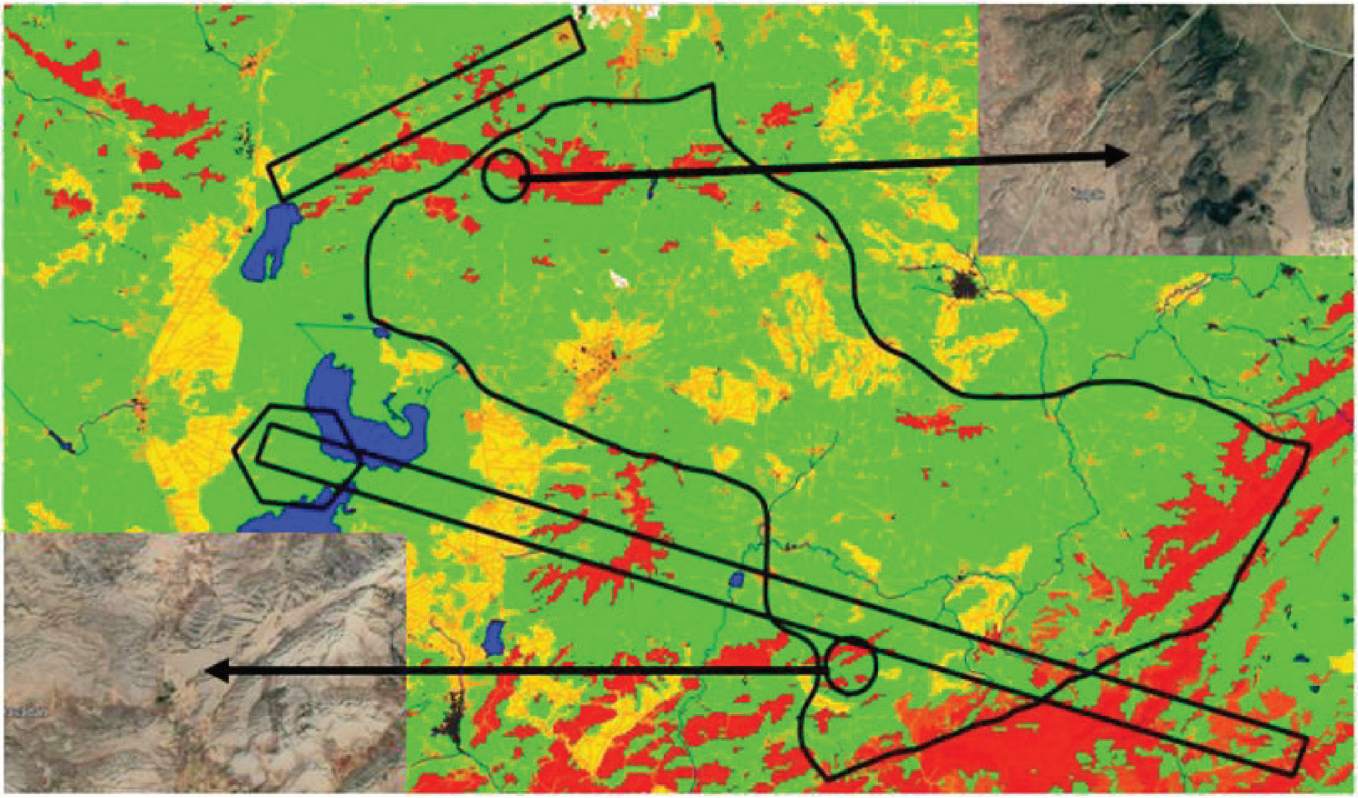

Figure 18: Google maps review for determining regions

4. Conclusions

In this study, the suitable site selection of wind power plants was investigated for Develi city in Turkey. For the suitable site selection, employing 12 criteria of Develi borders were assessed in this comprehensive study. These criteria consisted of technical, environmental, social impacts. The received data were processed in GIS using the MCDM method. There were two unsuitable regions in terms of wind power analysis where the wind speed was below 3 m/s in the study area. The third step consisted of 12 criteria for a suitable site selection process. This data was analyzed and two regions were determined for wind power plant installation according to wind potential, technical, environmental, and social impacts.

After determined these suitable regions, selected areas were examined in Google Maps. The first suitable sector was near Havadan village. According to Global Wind Atlas Mean Power Density [24], the first region's wind power density was determined 1050 W/m^2 and the suitable area was 7500 m^2. The first region's wind energy potential was 7.875 MW level and this wind power level was the low rate for any wind energy plant. The second suitable sector was near Kulpak village. According to mean power density, for the second region's wind power density was determined 750 W/m^2, and the suitable area was 12300 m^2. Therefore, the second region's wind energy potential was 9.225 MW level and this potential value was better than the first region. The total suitable land's wind energy potential was determined at a 17.1 MW level.

The GIS and MCDM combination method provides to create a lot of map layers for the analysis of the suitability of areas according to environmental and social impacts. For the determination of suitable site selection in Develi, it was created with 12 map layers by using GIS and MCDM. In this study, the specific conclusion of this study is to prepare a detailed and versatile analysis study for the suitable site selection. Thanks to this comprehensive research, fast, virtual, and detailed results were obtained for wind energy potential evaluation studies in Turkey. With this study, investors, decision-makers, authorities, and planners can easily get information and this project can easily adapt to changing updates.

References

[1] Satir M, Murphy F, McDonnel K, Feasibility study of an offshore wind farm in the Aegean Sea, Turkey, Renewable and Sustainable Reviews (2018) pages 2552–2562. https://doi.org/10.1016/j.rser.2017.06.063

[2] Emeksiz C, Demirci B, The determination of offshore wind energy potential of Turkey by using novelty hybrid site selection method, Sustainable Energy Technologies and Assessments (36) (2019) pages 1–21. https://doi.org/10.1016/j.seta.2019.100562

[3] Adelaja A, McKeown C, Calnin B, Hailu Y. Assessing offshore wind potential, Energy Policy (42) (2012) pages 191–200. https://doi.org/10.1016/j.enpol.2011.11.072

[4] Coskun AA, Türker YÖ, Wind energy and Turkey, Environmental Monitoring Assessments (184) (2012) pages 1265–1273. https://doi.org/10.1007/s10661-011-2038-2

[5] Genç M.S., Economic viability of water pumping systems supplied by wind energy conversion and diesel generator systems in North Central Anatolia, Turkey, Hournal of Energy Engineering-ASCE (137) (2011) pages 21–35. https://doi.org/10.1061/(asce)ey.1943-7897.0000033

[6] Genç M.S., Economic analysis of large scale wind energy conversion systems in Central Anatolian Turkey, Clean Energy Systems and Experiences, Intech-Sciyo Publishing, Rijeka (2010) pages (131–154).

[7] Chandel S, Ramasamy P, Murthy K, Wind power potential assessment of 12 locations in western Himalayan region of India, Renewable and Sustainable Energy Reviews (39) (2014) pages 530–545. https://doi.org/10.1016/j.rser.2014.07.050

[8] Çolak E, Memişoğlu T, Gercek Y, Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey, Renewable Energy (2020) pages 565–576. https://doi.org/10.1016/j.renene.2019.12.078

[9] Altuntaşoğlu Z T, Wind Energy in Turkey, Current Status, Problems, Journal of Engineer and Machine 52(617) (2014) pages (6–63).

[10] Ilkilic C, Aydın H, Wind power potential and usage in the coastal regions of Turkey, Renewable and Sustainable Energy Reviews (44) (2015) pages 78–86. https://doi.org/10.1016/j.rser.2010.03.033

[11] Argin M, Yerci V, The assessment of offshore wind power potential of Turkey, 9Th International Conference on Electrical and Electronics Engineering (ELECO) (2015).

[12] Genç M.S. and Gökçek M., Evaluation of wind characteristics and energy potential in Kayseri, Turkey. Journal of Energy Engineering 135(2) (2009) pages 33–43. https://doi.org/10.1061/(ASCE)0733-9402(2009)135:2(33)

[13] Genç M.S., Çelik M, Karasu İ., A review on wind energy and wind-hydrogen production in Turkey: A case study of hydrogen production via electrolysis system supplied by wind energy conversion system in Central Anatolian Turkey, Renewable & Sustainable Energy Reviews 16 (2012) pages 6631–6646. https://doi.org/10.1016/j.rser.2012.08.011

[14] Gökçek M. and Genç M.S., Evaluation of electricity generation and energy cost of wind energy conversion systems (WECSs) in Central Turkey, Applied Energy 86(12) (2009) pages 2731–2739. https://doi.org/10.1016/j.apenergy.2009.03.025

[15] Genç G., Çelik M., Genç M.S., Cost analysis of wind-electrolyzer-fuel cell system for energy demand in Pınarbaşı-Kayseri, International journal of hydrogen energy 37(17) (2012) pages 12158–12166. https://doi.org/10.1016/j.ijhydene.2012.05.058

[16] Jahangiri M, Ghaderi R, Haghani A, Nematollahi O, Finding the best locations for establishment of solar-wind power stations in Middle-East using GIS, a review, Renewable Sustainable Energy Rev. 66 (2016) pages 38–52. https://doi.org/10.1016/j.rser.2016.07.069

[17] Brewer J, Ames D P, Solan D, Lee R, Carlisle J, Using GIS analytics and social preference data to evaluate utility-scale solar power site suitability, Renewable Energy 81 (2015) pages 825–836. https://doi.org/10.1016/j.renene.2015.04.017

[18] Siyal S, Mörtberg U, Mentis D, Welsch M, Babelon L, Howells M, Wind energy assessment considering geographic and environmental restrictions in Sweden: A GIS-based approach, Energy (2015) pages 447–461. https://doi.org/10.1016/j.energy.2015.02.044

[19] Değirmenci S, Bingöl F, Sofuoğlu C, MCDM analysis of wind energy in Turkey: decision making based on environmental impacts, Environmental Science and Pollution Research (2018) pages 19753–19766. https://doi.org/10.1007/s11356-018-2004-4

[20] Szurek M, Blachowski J, Nowacka A, GIS-based method for wind farm location multi-criteria analysis, Mining Science (2014) pages 65–81. https://doi.org/10.5277/ms142106

[21] Mahdy M, Bahaj A, Multi-criteria decision analysis for offshore wind energy potential in Egypt, Renewable Energy (2018) pages 278–289. https://doi.org/10.1016/j.renene.2017.11.021

[22] Saleous N, Issa S, Mazrouei J, GIS-based wind farm site selection model offshore ABU DHABİ EMİRATE, UAE, Remote Sensing and Spatial İnformation Sciences, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.

[23] Cavazzi S, Dutton A G, An offshore wind energy Geographical Information System (OWE-GIS) for assessment of the UK's offshore wind energy potential, Renewable Energy (2016) pages 212–228. https://doi.org/10.1016/j.renene.2015.09.021

[24] Denmark Technical University, Global Wind Atlas GWA, 2020. (https://globalwindatlas.info/) (accessed date: 06.10.2020)

[25] Copernicus and Land Monitoring Service, CLC 2000 Database, 2020. (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2000) (accessed date: 06.10.202)

[26] Emodnet (European Marine Observation Data Network), Human Activities, Environmental and Social Impacts Database, 2020. (https://www.emodnet-humanactivities.eu/view-data.php) (accessed date: 10.10.2020)

[27] Energy Atlas, Turkey Wind Potential Atlas, 2020. (https://www.enerjiatlasi.com/ruzgar-enerjisi-haritasi/turkiye) (accessed date: 02.10.2020)

[28] Akdağ S A, Güler Ö, Evaluation of wind energy investment interest and electricity generation cost analysis for Turkey, Applied Energy (2010) pages 2574–2580. https://doi.org/10.1016/j.apenergy.2010.03.015

[29] Zimmerling JR, Pomeroy AC, d'Entremont MV, Francis CM (2013) Canadian estimate of bird mortality due to collisions and direct habitat loss associated with wind turbine developments estimation de la mortalité aviaire canadienne attribuable aux collisions et aux pertes directes d'habitat associées à l'éolien, Avian Conservation and Ecology 8(2) (2013) pages 10–24. http://dx.doi.org/10.5751/ACE-00609-080210

[30] Pohekar S, Ramachandran M, Application of multi-criteria decisionmaking to sustainable energy planning - a review., Renewable Sustainable Energy Reviews 8(4) (2004) pages 365–381. https://doi.org/10.1016/j.rser.2003.12.007

[31] Uyan M., Optimal site selection for solar power plants using multi-criteria evaluation: a case study from the Ayranci region in Karaman, Turkey, Clean Technology Environment 19 (9) (2017) pages 2231–2244. https://doi.org/10.1007/s10098-017-1405-2

[32] Fang J, Song W Y, Sustainable site selection for photovoltaic power plant: an integrated approach based on prospect theory, Energy Conversation Management 174 (2018) pages 755–768. https://doi.org/10.1016/j.enconman.2018.08.092

[33] Doorga JRS, Rughooputh SDDV, Boojhawon R., Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: a case study in Mauritius, Renewable Energy 133 (2019) pages 1201–1219. https://doi.org/10.1016/j.renene.2018.08.105

[34] Akın S, Kara YA, An assessment of wind power potential along the coast of Bursa, Turkey: A wind power plant feasibility study for Gemlik Region, Journal of Clean Energy Technologies 5(2) (2017) pages 101–105. https://doi.org/10.18178/JOCET.2017.5.2.352

[35] Ladenburg J, Visual impacts assessment of offshore wind farms and prior experience, Applied Energy (2009) pages 380–387. https://doi.org/10.1016/j.apenergy.2008.05.005

[36] Baban, S, Parry T, Developing and applying a GIS assisted approach to locating wind farms in the UK, Renewable Energy (2001) pages 59–71. https://doi.org/10.1016/S0960-1481(00)00169-5

[37] Lindgren F, Johansson B, Malmlöf T, Lindvall F, Siting conflicts between wind power and military aviation – problems and potential solutions, Land Use Policy (34) (2013) pages (104–111). https://doi.org/10.1016/j.landusepol.2013.02.006

[38] Watson JJ, Hudson MD, Regional scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation. Landscape Urban Plan 138 (2015) pages 20–31. https://doi.org/10.1016/j.landurbplan.2015.02.001

[39] Baisner AJ, Andersen JL, Findsen A, Granath SW, Madsen KØ, Minimizing collision risk between migrating raptors and marine wind farms: development of a spatial planning tool, Environmental Management 46 (2010) pages 801–808. https://doi.org/10.1007/s00267-010-9541-z

[40] Malczewski J, Multiple criteria decision analysis and geographic information systems. In: Ehrgott M, Figueira RJ, Greco S (eds) Trends in multiple criteria decision analysis, Springer (2010), Boston, pages 369–395.

[41] Demirtaş R (2005) Principles of Creating a Buffer Zone Around Active Faults in Urban Planning. Ankara University Press, Ankara.

[42] Boğaziçi University, Kandilli Observatory Earqutake Research Institution, Fault Lines Map, 2020. (http://www.koeri.boun.edu.tr/sismo/zeqmap/osmapen.asp) (accessed date: 12.10.2020)

[43] Bird Fund, Bird Migration Paths Map, 2020. (http://birdmap.5dvision.ee/EN/) (accessed date: 15.10.2020)

[44] TEİAŞ, Turkey Energy Transmission Company, Energy Transmission Lines, 2020. (https://www.teias.gov.tr/) (accessed date: 16.10.2020)