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Research Article

DETERMINATION OF THE INSTALLATION SITES OF WIND POWER PLANTS WITH SPATIAL ANALYSIS: A MODEL PROPOSAL

Mehmet KABAK*[1], Gözde TAŞKINÖZ[2]

[1]*Gazi University, Department of Industrial Engineering, ANKARA;* ORCID: 0000-0002-8576-5349
[2]*Gazi University, Department of Industrial Engineering, ANKARA;* ORCID: 0000-0002-1242-6557

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ABSTRACT

Energy is an indispensable element in the continuity of life. The rapidly growing world population and increasing demand for energy have led people to seek new sources of energy other than scarce fossil resources. As the need for energy increases, energy production studies are increasing. Energy production is not only made for purposes of profit, but also for the continuity of the energy, the conditions of acquisition, the impact on the environment, etc. Therefore, the trend towards sustainable energy resources is increasing day by day. Wind energy, which is one of the most important renewable energy sources, is considered as a sustainable source that is open to development and development in the field of energy production with an increasing rate. Wind energy is a type of energy suitable for investing in electrical energy production. This study focuses on the selection of the power plant site in the establishment phase, which is one of the most important cost issues in obtaining energy from the wind. The choice of location was made by the use of ArcGIS and an integer programming model. For the wind farm site selection, 11 criteria were determined and alternative four regions which are in Konya province were determined with ArcGIS. The site selection was made by using an integer programming model based on cost minimization within appropriate alternative regions that provide the criteria. According to the model solution the total number of turbines to be installed is sixty-five. Twenty-six of these turbines will be installed in the 1 st region and thirty-nine of these turbines will be installed in the 2nd region.
Keywords: Wind, renewable energy, facility location, geographic information system, integer programming.

1. INTRODUCTION

Energy is necessary for people to maintain their daily lives. The evolution of societies has remained dependent on the energy resources they have developed and used throughout history. Future developments will also be based on the adequacy of energy resources. Knowing that energy cannot be found in increasing amounts over time or even in the long term causes serious concerns about the future of energy [1]. With high-speed population growth and the development of industry, energy needs cannot be met with limited resources, and the gap between energy production and consumption is widening more and more every day. By 2035, global energy consumption is estimated to be twice the consumption in 1998 and three times in 2055 [2]. As the

* Corresponding Author: e-mail: mkabak@gazi.edu.tr, tel: (312) 582 38 58

world population increases, the need for energy increases, and this shows that work for energy production has increased and will increase in the future.

Energy needs, which are the most important input of economic and social life, increase with the development of the world and technological developments [3]. The negative effects of fossil fuels such as coal, oil and natural gas and the negative impacts of the world against the increasing in the need affect the whole world. The amount of carbon dioxide (CO_2), which is caused by the burning of fossil fuels, increases with the forest decline and therefore prevents the reflection of the sun rays with other gases in the atmosphere. Another combustion of fossil fuels from gases evolved carbon monoxide (CO) while causing death by decreasing the percentage of oxygen in the body, sulfur dioxide (SO_2) is considered one of the causes of cancer. Nitrogen oxide (NO) caused by burning of natural gas interacts with other gases in the atmosphere and damages the body's immune system [2].

The negative effects of human on the environment causes environmental pollution and ecological crises such as global warming. One of the most important reasons for the negative effects of these ecological crises is the use of fossil fuels in energy production. Although the need for energy has to be met, the high rate of fossil fuel in energy production and consumption affects human health and nature negatively [4]. Despite the need for more energy, reducing the use of fossil resources that are harmful to nature and living beings has led to new and different resources such as wind, solar, hydro, biomass, geothermal, etc., which are called renewable energy sources. As a result, countries increase their investments in renewable energy. According to the Global Trends in Renewable Energy Investments 2016 report prepared annually by the United Nations Environment Program (UNEP), investments in renewable energy sources in 2015 amounted to USD 266 billion. In 2015, the investments made to generate energy from coal and oil were around 130 billion dollars. Accordingly, for 2015, investments in renewable energy in the world were more than twice as much as investments aimed at generating energy with fossil fuels. This indicates a structural change in energy production. As a result of these investments in renewable energy in the world, 134 gigawatts of new energy production was provided in 2015. Investments in solar and wind energies lead the way in this new energy production. In 2015, a new generation of 56 gigawatts of solar energy was provided from 62 gigawatts of wind [5].

The International Energy Agency (IEA) defines renewable energy as energy derived from natural processes that can be renewed faster than its consumption. Solar energy, wind energy, geothermal energy, hydraulic energy, and biomass energy are some of the renewable energy sources [2]. Renewable energy sources have an important role in helping countries to meet their energy needs without being dependent on foreign sources, and to reduce the damage to the environment and people in energy production. Today, 20% of world energy consumption is met by renewable energy sources [6]. Although the dependence on fossil fuels is currently high, renewable energy usage rates are increasing gradually over the years. According to the forecast of the IEA 2018 renewable energy report, renewable energy power will continue to grow in the next 5 years, and renewable energy-based energy production worldwide will increase by more than 1000 GW. According to the IEA estimate, by 2023, 40% of the world electricity consumption will be covered by renewable energy sources. In the 5 years period, the largest increase in the field of renewable energy will be in the solar energy, and the second most likely increase in the report will be wind energy [7]. Figure 1.1. shows annual and cumulative installed wind capacity in the world announced by Global Wind Energy Council. According to Figure 1.1., in 2001, 6,5 GW of wind capacity was newly installed and bringing the total up to approximately 24 GW of installed wind capacity. Until 2010, although the number of installations according to the globally established wind power capacity has increased cumulatively in Figure 1.1, the acceleration of this increase has decreased in recent years and the annual installed power capacity has decreased. The maximum new wind installations were conducted in 2015, about 64 GW.

Wind energy is actually an indirect form of solar energy. The fact that solar energy does not heat the land, the sea, and the atmosphere uniformly gives rise to differences in temperature and pressure, which in turn causes the wind. Due to the growing supply of wind energy and increasing wind power plants, regions suitable for wind energy installation are decreasing each year. In Turkey, especially in Aegean Region, residential wind power plants are mostly located in the coastal areas because of the favorable conditions.

In Turkey, the theoretical power potential of wind power is projected to be about 115,000 MW. The total potential of turbine installable land areas is expressed as 48 000 MW [8, 9]. Today, 12% of this potential is used and can be said to be an important area of investment. At the same time, the total capacity of existing investments in construction is 2,214 MW [10]. As seen in Figure 1.2, it is increasing according to Turkey's wind generated electricity amount of years.

Figure 1.1. World annual installed wind capacity [7]

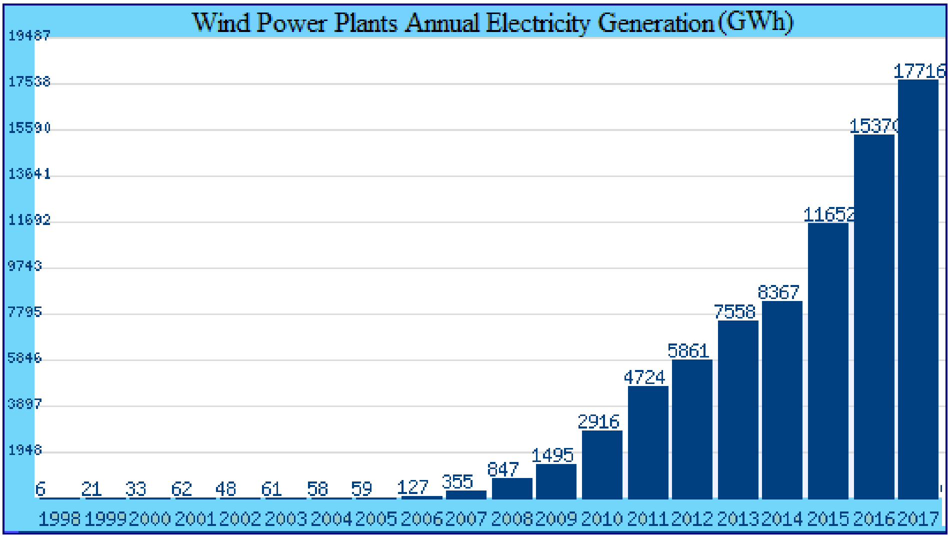

Figure 1.2. Annual electricity production from wind power plants in Turkey [8]

Electricity generation from wind energy in Turkey started in 1998 has continued to increase every year. In the first year, the wind produced 6 million kilowatts of electricity. The next year, the amount of production increased by 250% to 21 million kilowatts. Despite the rapid growth in the first years, the sector, which closed 2014 with 11.5 billion kilowatt hours of production, managed to increase its production by 38% in 2015 compared to 2014. In 2017, the amount of electricity generated from wind farms reached 17 716 gigawatts.

Although the number of wind power plants established in Turkey increase each year, as shown in Figure 1.3.. According to Figure 1.3. new wind power plants with a capacity of 428 MW were installed in 2008 thus bringing annual totals to 364, 792, 1329, 1806, 2312, 2958, 3762, 4718, 6106, 6872, 7369, 7615 MW respectively for each year from 2008 to 2019. Figure 1.4. shows that the acceleration of annual wind power plant installation slows down. According to Figure 1.4. each year from 2008 to 2019 wind power plants with capaticies of 217, 428, 538, 477, 506, 646, 804, 956, 1388, 766, 497, 246 MW were installed.

In the evaluation of the potential areas, the allocation of priority to similar regions, such as coastal zones, has led to a reduction in installation areas. In this study, a model has been proposed for the evaluation of the inner parts of the country.

Figure 1.3. The cumulative installation for wind power plants in Turkey [11]

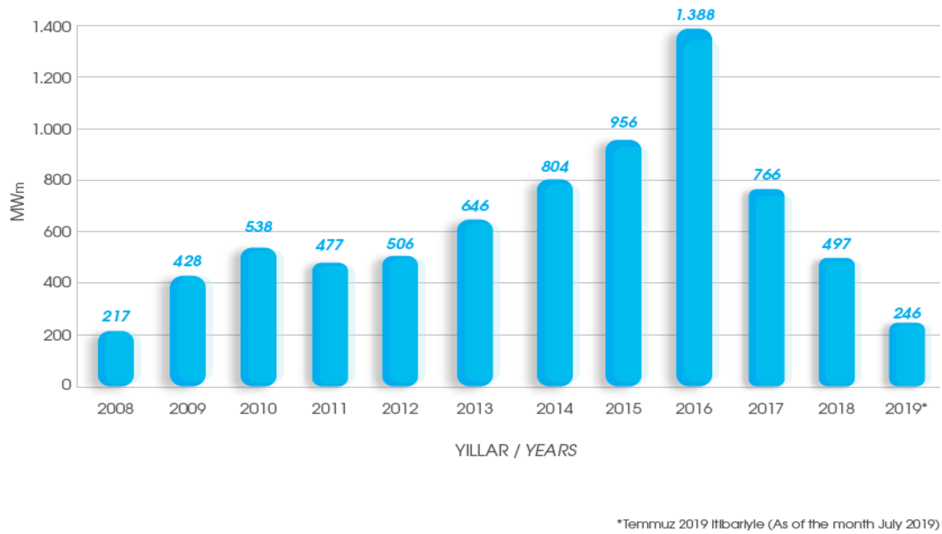

Figure 1.4. Annual installation for wind power plants in Turkey [11]

This paper contributes to the literature and renewable energy studies in several ways;

- Wind power installation criteria for the inner area was determined, as opposed to coastal areas,
- GIS was used to identify alternative sites,
- Cost minimization model was proposed to determine the number of wind power plants to be installed in alternative zones.

The paper is organized as follows. Next section provides a review of the literature on wind energy site selection that used GIS and MCDM, while Section 3 describes determination of area and investment model for wind turbines. The last section sums up conclusions and sets future study directions.

2. LITERATURE REVIEW

Knowing that fossil energy sources will be exhausted in the long term causes serious concerns about the future of energy. The inadequacy and the negative effects of the fossil resources against the increasing need have led to the emergence of research on renewable energy sources in the literature.

In June 1887, Scottish academician Professor James Blyth began his wind power experiments and patented a wind power-powered battery charger in 1891, UK [12]. Shortly after this experiment, American inventor Charles Brush built the first automatic wind turbine [13]. In the 1890s, Danish scientist and inventor Paul La Cour built wind turbines to produce electricity. By the year 1900, the electricity supply of the house and laboratory was provided by the wind power machine [12]. One of the first examples of modern wind generators was founded in 1931 in Yalta, formerly Soviet Union. The turbine with a tower height of 30 meters has a power output of 100 kW per hour [14]. In 1939, Smith Putnam wind turbine with a diameter of 53 meters and power of 1.25 MW was installed in Granpa's Knob, Vermont, USA. The next milestone at wind turbine development was the Gedser wind turbine. With the financial help of post-war Marshall Plan, a wind turbine with a diameter of 24 meters and power of 200 kW was established in 1956 – 1957 in Gedser Island which is located in the south east of Denmark. This machine worked with a capacity of 20% between 1958 and 1967 [5].

The first megawatt-class wind turbine was connected to the grid in Vermont in 1941. The so-called Smith-Putnam turbine was only able to work for 1100 hours, due to some technical problems and could not be repaired due to war conditions [14]. The first grid-operated wind turbine was installed and operated in 1951 by Scottish shipbuilding and shipping company John Brown & Pompan on the northern coast of Scotland's Okey Islands [15]. In the early 1960s, Ulrich Hütter developed the Hütter Allgaier wind turbine, a 100 kW 34-meter, 2-wing, high-wind, fast unstable impeller. The modern wind power industry began in 1979 with the production of wind turbines by Danish Kuriant, Vestas, Nordtank and Bonus companies [12].

At the beginning of 2000s, Baban and Parry (2000) and Rodman and Meentemeyer (2006) determined the criteria according to which the wind turbines sites were chosen. They weighted these criteria with regard to their importance and assessed the area to establish the wind turbines by using Geographic Information Systems (GIS) in their studies [16, 17]. Simao et al. (2009), In Norfolk, the UK, conducted multi-criteria decision making and web-based GIS utilization for wind farm site selection. In addition to the other studies, the collaborative participation of the people was added to the process, and the surveys affected the selection criteria [18]. Janke (2010) made a site selection study with GIS by weighting the turbine site selection criteria for Colorado. There are various solar potential and state land criteria in the study [10]. Tegou et al. (2010), unlike the site selection study conducted in Lesvos (Greece), determined the criteria with AHP. Appropriate location was determined by using GIS according to the determined criteria weight [19]. Aydın et al. (2010), in their study including cities of Uşak, Aydın, Denizli, Muğla and Burdur, while selecting wind turbine sites with GIS, environmental constraints and criteria were represented by fuzzy sets and these set values were entered into GIS and appropriate site selection was determined [12].

Mari et al. (2011) established a GIS-based interactive web decision support system for wind turbines site selection in Tuscany, Italy. MapServer and java script were used to create the decision support system [20]. In their study for Oman, Yahyai et al. (2012) weighted the criteria with AHP-OWA and evaluated the alternatives with GIS [21]. Aziz et al. (2014) determined the relationship between the criteria by using DEMATEL for wind power plant location in Erdebil province of Iran. The criteria weight were determined by ANP, and depending on these weights, the appropriate location was determined with GIS [22]. Sağbaş and Mazmanoğlu (2014) determined the benchmark weights with the Fuzzy AHP for the wind power plant for the

Marmara Region in Turkey. Unlike other studies, investment costs, operating costs, production quantity, capacity, and service life criteria were also taken into consideration [23].

Sanchez-Lozano et al. (2014) used ELECTRE-TRI and CBS for Murcia [24]. Kallioras et al. (2015) used the harmonic research method based on batch variants with stochastic data in order to reflect the truth more strongly. Two different calculations were made, taking the wind direction into account. The first objective function was the maximum profit, the other objective function was formed to minimize the number of turbines [25]. Noorollahi et al. (2015) evaluated the country with GIS and equal important constraints and determined that 28% of Western Iran was favorable to the wind power plant [26]. Höfer et al. (2016) used AHP based GIS to evaluated Aachen region and determined that the 9.4% of the region was suitable for wind energy, and 1.74% of the area was found to be high suitability [27].

Sánchez-Lozano et al. (2016) determined criteria weights with fuzzy AHP and evaluated the alternatives with fuzzy TOPSIS. They formed a fuzzy decision matrix in GIS with the obtained data and selected the appropriate location for Southeastern Spain [28]. Elibüyük et al. (2016) calculated wind speed and wind energy potential for the facility to be installed at Süleyman Demirel University and calculated the cost and depreciation values of the power plant [29]. In his master thesis, Aitzhanov (2016) used GIS and AHP together and a wind power plant site selection study was conducted for Kazakhstan. The results were compared and evaluated by using ELECTRE III, ELECTRE-TRI, SMAA-TRI decision making techniques [30].

Ritter and Deckert (2017) determined the wind energy indices supported by the related people according to MERRA data, and the expected wind energy generation for each turbine type was presented with an example. Site options and turbine alternatives were evaluated and compared with cost analysis [31]. Chamanepour and others (2017) evaluated the regions by criteria such as wind speed, temperature, slope, town, villages, airport, protected areas, rivers etc. These criteria are using AHP and Fuzzy multi-criteria decision making methods in GIS [32]. Ayodele et al. (2018) used GIS with type-2 fuzzy AHP together, weighted criteria based on expert opinions, and identified the most suitable region for wind farm installation site in Nigeria [33]. Pambudi and Nananukul (2019) proposed a hierarchical dual data envelopment analysis model to identify the suitable location for building wind farm [34].

The criteria for wind power plant site selection used in these studies are summarised in Table 2.1. and their definitions are explained in Table 2.2. In this study, 11 criteria were used depending on the inner site selection and study's differentiation. Th criterion C2, C3 and C17 were not used in the study since the turbine settlement plan was not made for the selected area. C7 and C9 are similiar and C9 was not used. C12 was also not used due to road use in transportation and C5 was not preferred due to the fact that C15 criterion was considered in REPA. In addition, the C14 criterion was not used as the cost of using energy was not taken into consideration in the study. Finally, C6 criterion was covered by altitude and inclination criteria in REPA, and C17 and C18 were not used because the capacity factor was directly used in calculations. In the study, the remaining 11 criteria were evaluated with GIS and then a cost-based site selection study was conducted with mathematical model.

Table 2.1. Criteria for wind farm site selection in the literature

Ref	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
[16]	✓	✓		✓	✓	✓	✓	✓	✓	✓										
[17]	✓			✓			✓	✓	✓						✓					
[10]	✓				✓	✓	✓			✓			✓		✓					
[19]	✓			✓			✓	✓		✓	✓				✓					
[21]	✓		✓	✓						✓					✓		✓	✓		
[22]	✓			✓		✓	✓	✓		✓	✓				✓	✓				
[24]	✓			✓			✓			✓	✓		✓		✓					
[25]	✓	✓	✓																	
[26]	✓			✓			✓	✓		✓	✓	✓	✓		✓	✓				
[27]	✓			✓		✓	✓			✓			✓		✓					
[35]	✓			✓			✓	✓		✓			✓		✓	✓				
[28]	✓			✓			✓	✓		✓			✓	✓	✓	✓				
[32]	✓			✓	✓	✓	✓	✓		✓	✓				✓	✓				
[34]	✓				✓	✓									✓	✓			✓	
*	✓			✓			✓	✓		✓	✓		✓		✓	✓			✓	✓

Resources: [16] Baban and Parry (2000); [17] Rodman and Meentemeyer (2006); [10] Janke (2010); [19] Tegou, Polatidis and Haralambopoulos (2010); [21] Al-Yahyai, Charabi, Gastli and Al-Badi (2012); [22] Azizi, Malekmohammadi, Jafari, Nasiri and Parsa (2014); [24] Sanchez-Lozano, García-Cascales and Lamata (2014); [25] Kallioras, Lagaros, Karlaftis and Pachy (2015); [26] Noorollahi, Yousefi and Mohammadi (2015); [27] Höfer, Sunak, Siddique and Madlener (2016); [35] Rezaian and Jozi (2016); [28] Sánchez-Lozano, García-Cascales and Lamata (2016); [32] E. Chamanepour, Ahmadizadeh and Akbarpour (2017); [34] Galih Pambudi and Narameth Nananukul (2019); * The proposed study.

Table 2.2. Wind turbine site selection criteria

No	Definition	Explanation
C1	Wind Speed / Potential	The wind speed must be between cut in and cut out
C2	Wind direction	The wind direction should be parallel to the turbine and perpendicular to the wings.
C3	Wind Density	Wind density should be higher.
C4	Tilt / Upgrade	The area to be selected must be at minimum inclination (max 10%)
C5	Population	Distance to residences outside the city center
C6	Topography / Terrain	It should be suitable for turbine installation.
C7	Protected Areas	Agricultural area, forest area, ecological regions, historical places, cultural heritage, archaeological sites, natural habitats are given as protected areas.
C8	Distance to water resources	Maximum distance to water resources is preferred.
C9	Ecology	It should be constructed in such a way as to give minimum damage to nature and living beings (bird, habitat, etc.).
C10	Transportation (Distance to Highway)	It should be close to the highway.
C11	Distance to Airport	It should be away from the airport.
C12	Distance to Railway	It must be close to the railway.
C13	Distance to Power Lines / Substation	It must be close to the substation and power lines.
C14	Distance to Electric Poles	It should be close to the electric poles.
C15	Distance to Settlement	The settlement should be away from the place.
C16	Distance to Fault Lines	It should be away from fault lines.
C17	Turbulence Intensity	The turbulence density should be lower than the load on the wings.
C18	Peak Clock Matching	The efficiency at the top point should be high (capacity factor)
C19	Investment Cost	The investment cost should be low.
C20	Productivity	Productivity should be high.

3. METHODOLOGY

Geographic Information Systems (GIS) is a modern technology product that enables the display of geographic proximity, distance, relationship, similarities and differences that cannot be provided by graphics, tables and text reports. GIS is a system that helps users in location-based decision making processes for the solution of social, economical, environmental etc., that performs to provides evaluate together all kinds of graphical and non-graphical spatial informations. The purpose of the GIS is to provide professional information system technology that all people can share the production, management, analysis and geographical data from distributed databases on the network. Earth information can be stored independently in vector and raster formats in different layers with GIS. The data of the location is stored with vector data format which is x, y coordinate values. The data that is raster data format of the location is represented depending on the cells. Depending on the literature review, 11 criteria for wind turbine site selection and constraint intervals for these criteria were determined and basic factor maps were created with ArcGIS. These maps were combined to examine the simultaneous application of all criteria. The completed and constructed power plants in the province of Konya were marked on the map. An integer programming model was proposed for the cost-based assessment of the remaining eligible regions.

3.1. Determination of Constraints and Parameters

Factors affecting wind farm site selection studies can be grouped under three main headings: environmental, geographical, and technical. Factors such as airport, fault line, distance to the settlement, protected areas, water resources, distance to highway, distance to electricity lines, agricultural areas, bird habitats are environmental; factors such as slope, elevation, forest area are geographical; factors such as investment cost, productivity and wind speed can be classified as technical.

Exclusion parameters (Constraints) (Given buffer zone in 0, outside 1)

According to the exclusion parameters in Table 3.1. the inside of the buffer zones is marked as zero, which is marked as unusable. According to the exclusion parameters, the 3000 meters area around the airport and its surrounding area, the 400 meters area around the fault line and the surrounding areas, the 100m vicinity of the water resources, the 5000 meters of water resources, and the 1000 meters close to the transformer centers were supposed as restricted area for wind turbine installation because of their effects on the environment.

Table 3.1. Wind turbine location selection constraints

	Constraint	Min (meter)
1	Distance to Airport	>3000
2	Distance to Fault Line	>400
3	Distance to Highway	>100
4	Distance to Water Resources	>5000
5	Distance to Transformer Center	>1000

Forests, agricultural areas, bird habitats, protected areas, and places within the noise boundaries are considered as environmental constraints as shown at Fig.3.1. Wind turbines are not allowed to be installed in forest areas and agricultural areas as they make the soil ineffective. Similarly, there is no risk of damaging the historical and cultural heritage areas. In addition, bird habitats and migration paths should be taken into consideration in installation as turbines are on birds' migration paths, leading to deaths.

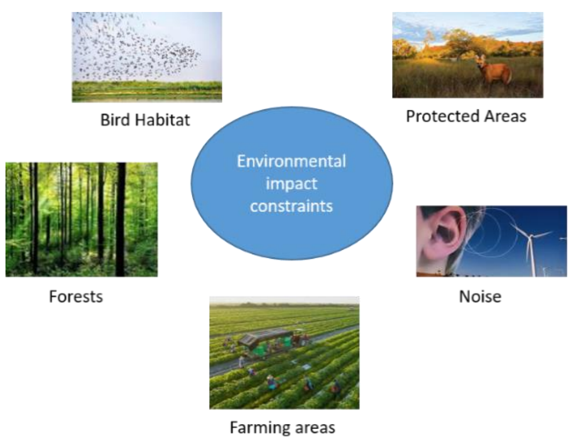

Figure 3.1. Environmental impact constraints

According to potential atlas of wind energy, areas with a slope greater than 20%, regions with altitudes greater than 1500 meters, residential areas; protected areas such as National Parks, Natural Reserve Areas, Natural monuments, nature parks, Wildlife Conservation and Development Areas, Special Protection Areas; Prohibited areas such as forests, agricultural areas, bird migration routes are designated as unavailable areas. In addition to these, the constraints in Table 3.1. are included in the study.

3.2. Evaluation of Criteria and Identification of Appropriate Areas

The maps, which were examined separately by ArcGIS and are shown as airport, highway, disaster area, water resources, transformer centers and potential atlas of wind energy respectively (Fig.3.2). In Figure 3.3, potential atlas of wind energy map of Konya province and existing wind energy plants identified as four alternative investment zones are shown.

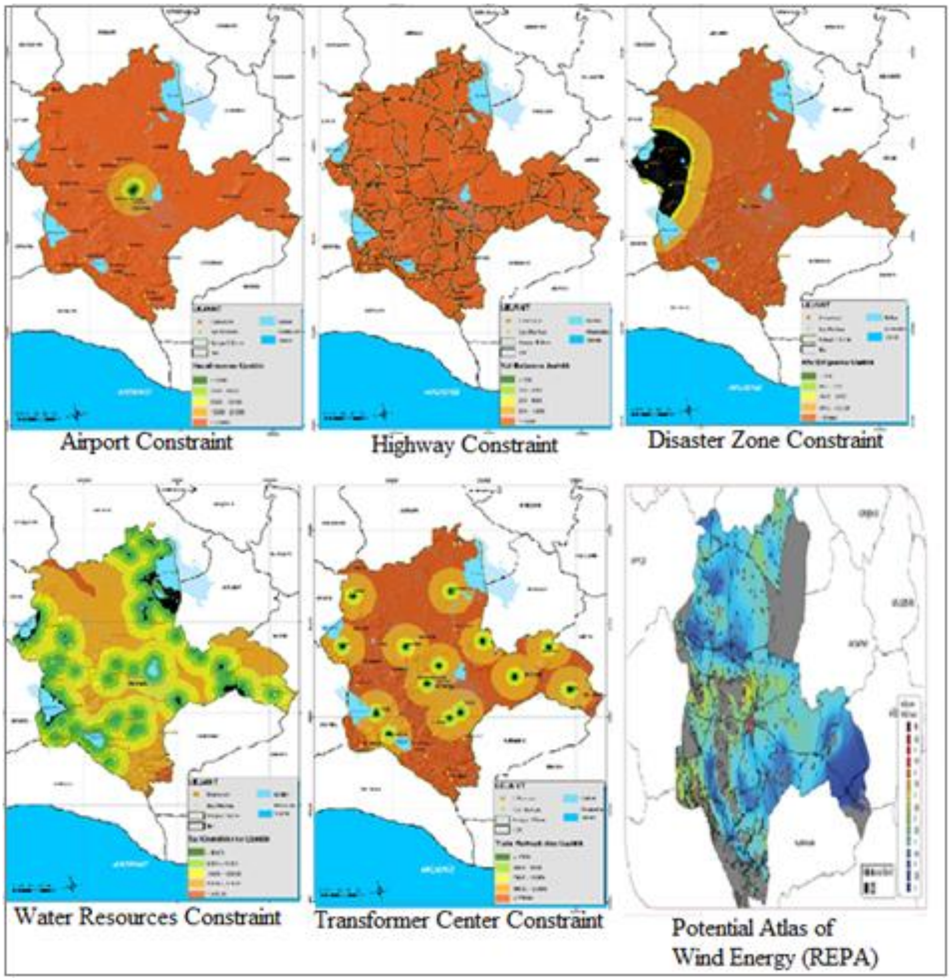

Figure. 3.2. Wind turbine location selection constraints

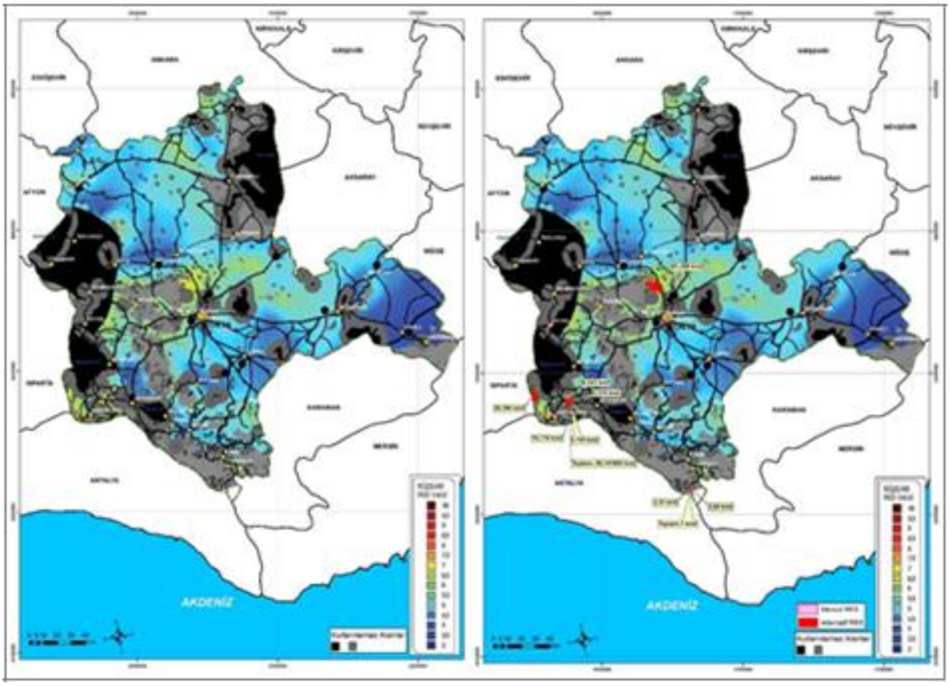

Figure 3.3. All constraints, existing wind energy plants, and alternative zones

A mathematical model has been proposed in order to determine the number of wind turbines to be installed in four alternative regions in accordance with the environmental and geographical criteria evaluated by ArcGIS. In the model, the minimization of investment, maintenance, and operating costs were aimed at while the appropriate region and number of wind turbines were determined by operating the model in GAMS. The model is given below and the parameters are defined in Table 3.2.

Z_{min} =Investment Cost + Operating Cost

$Z_{min} = Y_k*L*n_k + A_k + C_k + (P+B)*n_k$ (1)

$A_k = Y_k*S_k*3*10^6$ (2)

$C_k = 3*Y_k*l_k*n_k$ (3)

$Y_k = \begin{cases} 1\,; if\ k\ region\ is\ selected \\ 0\,; else \end{cases}$ (4)

k=1 for; $n_k \le 40$, $l_k = 34\ km$, $S_k = 26.394\ km^2$ (5)

k=2 for; $n_k \le 39$, $l_k = 18\ km$, $S_k = 26.1416\ km^2$ (6)

k=3 for; $n_k \le 11$, $l_k = 77\ km$, $S_k = 5.009 km^2$ (7)

k=4 for; $n_k \le 93$, $l_k = 9\ km$, $S_k = 61.26\ km^2$ (8)

$n_1 \le 40$;
$n_2 \le 39$;
$n_3 \le 11$;
$n_4 \le 93$;
$n_k \ge 65$; k=1,2,3,4

Table 3.2. Parameters

Z_{min}	Annual energy cost
k	Area; k = 1,2,3,4
S_k	Area of k region
A_k	rental price for region k
n_k	Number of turbines to be installed in zone k
L	Annual turbine cost
B	Turbine maintenance cost
P	Turbine operation cost (System use, electrical quality expense, system operating expense, other operating expenses)
l_k	Distance of zone k to transformer
C_k	The annual energy transportation cost of the region k

Here, the objective function (1) consists of investment and operating costs. Investment cost consists of turbine cost, rental cost and transportation cost. Assuming that the life cycle of the turbine is 20 years and the total cost is considered as 3 742 200 USD, which is a total turbine cost according to the use of single type 3.3 MW turbine, and annual cost is calculated as 187 110 USD. In case of inequalities (2), (3), (4), (5), the upper limit of the turbine for each region is calculated as 5 MW per square kilometer. (6) A minimum of 65 turbines must be installed for electricity consumption that is targeted to be met according to its inequality. In the equation (7), the rental value for each region of k is expressed by the variable K, and the rental rate for K is calculated by multiplying the area of the region by $(3 * 10^6)$ USD per square kilometer. (8) equation carrying cost Ck, 3 USD is accepted for carrying 1 MW of energy for 1 kilometer, the closest transformer capacity is accepted and calculated according to the distance of the regions to the nearest transformer. Operating cost consists of maintenance cost (B) and operating costs (P) such as system usage, electrical quality expense, system operating expense, and other operating expense. Maintenance cost (B) is accepted as 37 800 USD per year for each turbine. Operating cost (P) is taken as 38 950 USD per turbine annually.

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--- DICOPT: Best integer solution found: 174773401.400000

                      LOWER     LEVEL     UPPER    MARGINAL

---- EQU amac           .         .         .        1.000
---- EQU kisit1       65.000    65.000     +INF       .
---- EQU kisit2        -INF     26.000    40.000      .
---- EQU kisit3        -INF     39.000    39.000      .
---- EQU kisit4        -INF       .       11.000      .
---- EQU kisit5        -INF       .       93.000      .
---- EQU kisit6        1.000     2.000     +INF       .
---- EQU kisit7        -INF      2.000     4.000      .
---- EQU kisit8         .       14.000     +INF       .
---- EQU kisit9         .         .        +INF       .
---- EQU kisit10        .         .        +INF       .
---- EQU kisit11        .         .        +INF       .

---- VAR Y  karar degiskeni

     LOWER     LEVEL     UPPER    MARGINAL

1      .        1.000     1.000 8.6051E+7
2      .        1.000     1.000 8.8722E+7
3      .          .       1.000 2.1000E+7
4      .          .       1.000 1.8378E+8

---- VAR n  turbin sayisi

     LOWER     LEVEL     UPPER    MARGINAL

1      .       26.000   100.000 2.6420E+5
2      .       39.000   100.000 2.6404E+5
3      .          .     100.000       EPS
4      .          .     100.000       EPS
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Figure 3.4. Optimal solution of the model

The total number of turbines to be installed according to the solution is 65 (Fig. 3.4). Twenty-six of these turbines will be installed in the 1st region and 39 in the 2nd region. Total Y (k) value was determined as two. This indicates that two zones have been selected for installation. According to the constraint 8, 26 turbines were installed in the first zone with a capacity of 40 turbines. In the event that all these conditions are met, the cost is determined as 174 773 401.4 USD.

While the 4th region alone would be sufficient for the total number of turbines to be installed, the model selected the 1st and 2nd regions where the total rental price was low, but the unit energy transportation cost was higher than the 4th region. Although they are more remote areas of the transformer, the low rental value leads to the emergence of the cost-based model.

According to the model, with the establishment of 65 wind turbines, it is foreseen that 375 804 MW electricity will be obtained with 20% capacity factor. In the EPDK 2017 Electricity

Market Development Report, the electricity consumption of Konya in 2017 was determined as 5 986 996.38 MWh. The investment to be made in this case covers 6.28% of the electricity consumption in Konya. According to 2018 General Directorate of Renewable Energy, the cost of YEKDEM for 1 KW energy produced from RES was 7.3 cents. Based on the assumptions that the turbines operate at a capacity factor of 24 hours and 365 days at 20%, payback period is calculated as 6.37 years.

4. CONCLUSIONS AND FUTURE STUDIES

The wind energy used to solve the energy problem caused by the consumption of scarce resources will be one of the most important energy sources in the future as it is today. Investments made for the use of wind in electricity generation are increasing in both public and private sectors. Since the investments are made up of high cost items, investors want to choose the places where maximum benefit will be provided. In order to achieve maximum efficiency, the data should be accurate and realistic, and the calculations should be applied on the basis of the evaluation of the regions.

Studies and reports analyses declare that investors in Turkey primarily preferred locations in the northwest of the country and continued towards south. The high wind potential in these regions led to the priority evaluation of these regions. However, studies carried out in the coastal regions have ignored the evaluation of the potential of the interior sectors. In this study, a mathematical model has been proposed in order to evaluate the inner regions. In the study, the problem of location selection, which is one of the most important factors for wind power plant installations, was developed to generate electricity from wind energy for an investor.

In the study, the provinces with high capability for wind power plant installation were firstly examined and Konya was selected as the working province of the region with the consideration of the previous WPP investments. The Ministry of Energy and Natural Resources and the established General Directorate of Renewable Energy publishes annual Renewable Energy Potential Atlas (REPA) specifying the areas of wind power plants and wind potential in Turkey. For Konya province, the Ministry of Energy and Natural Resources, General Directorate of Renewable Energy has established areas of wind energy potential. Konya province was evaluated according to the previously stated constraints which are distance to city airport, highway infrastructure, disaster zone, water resources and transformer center. The appropriate areas determined by REPA were re-evaluated with ArcGIS according to the constraints and parameters added, and four suitable regions were determined. These regions were analyzed with the mathematical model established in terms of investment and operating costs.

It is considered that the proposed model can be used in all wind turbine location selection problems with data update. In future studies, wind turbine types can be included in the mathematical model and the study can be carried out for the installation coordinates of the turbines. With the appropriate placement of different wind turbines, the maximum amount of energy can be produced and the initial installation cost can be reimbursed in a shorter time.

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