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Wind Energy and Assessment of Wind Energy Potential in Turkey: A Case of Study from Sinop Province

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ABSTRACT

Due to the emerging needs in parallel with the developing technology and industrialization, the importance of renewable energy sources is increasing with the decrease of usable fossil resources and the ever-increasing need for energy. For this reason, solutions are sought to provide the energy needed in a timely, sufficient, and reliable manner. Wind energy has the greatest potential and usage area among renewable energy sources. The wind, which has advantages such as clean, fast commissioning, reliability, and being independent of fuel, is considered a good example of a clean energy source with these features. In this study, the production potential of electrical energy from wind energy was investigated by using wind data for Sinop province. Wind energy potential on the availability of wind energy systems suitable for its natural structure for Sinop province; Visual Basic 6.0 was determined using the computer package program. In the study, hourly wind data were used and analyzes were made for suitable wind energy systems. In addition, for a possible WPPs, analysis has been made and evaluated considering the current data; The availability of wind energy in Sinop province has been tried to be revealed.

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Introduction

Increasing population, industrialization, and urbanization are increasing the demand for energy (Mann and Teilmann, 2013). In recent years, industrialized countries that are in the position of importers in the provision of energy resources, especially petroleum, and developing countries, that want to change their energy policies are getting help from energy services for their energy management. On the other hand, another issue that should not be ignored is energy production in the context of sustainability. This matter emphasizes the concept of "clean energy" in energy production (Akdağ and Güler, 2010). Energy sources are diverse as is known. However, it cannot be said that every energy source is used at the same rate. Usage or preference of different energy sources can be linked to different reasons. Among these reasons; geographic, economic, technological, and environmental ones can be mentioned. All positive developments created by humanity's efforts to reach advanced civilizations have been achieved through the generous use of natural resources (lkin and Atkin,1991). The use of natural resources in the degree of extinction causes the phenomenon of environmental pollution to be experienced at an intensity leading to disruption of the human-nature balance. This situation threatens the future of human beings, which is a part of nature (Uçar, 1991). Today, the following options can be mentioned as alternatives for the use of clean energy. Energy Saving is like improving energy efficiency, applying technologies to reduce CO_2 emissions, developing and using new fuels, and increasing the use of renewable energy sources (Yelmen and Öztekin, 2010).

Wind energy is caused by the uneven warming of all parts of the earth and the interaction of low and high-pressure centers that occur accordingly (Doganay, 1998). Wind energy results from solar radiation heating the ground surfaces differently (İlkilic, 2012). Different heating of the ground surfaces causes different temperatures, humidity, and pressure of the air, and this

different pressure causes the movement of the air. As long as there are sun rays, there will be wind. The wind is an indirect product of solar energy. Approximately 2% of the solar energy reaching the world is converted to wind energy. The earth's surface heats and cools irregularly, resulting in atmospheric pressure zones. Thus, air flows from high-pressure areas to low-pressure areas. There are many different changes in wind speed, from calm air to a storm. Since the use of electrical energy depends on time; daily and seasonal changes in the wind are an important indicator (MENR, 2019).

Wind energy is more economical when compared to other energy types, it is also very important in terms of easy installation and operation of power plants (Güler, 2009). In addition, only 10% of the electricity needed worldwide is supplied by wind energy until 2025; CO_2 emissions released into the atmosphere will decrease by 1.41 Gton per year (Özgener, 2002). According to the data of the World Energy Agency, the investment in renewable energy sources is expected to reach $ 10 trillion by 2030. Turkey in 2025; It will be able to produce approximately 200 billion kWh of the projected energy needed from its resources. However, although it has significant potential in solar, geothermal and wind energy; Adequate steps are still not taken in this regard and dependence on fossil fuels remains to a large extent.

In terms of renewable energy sources; Turkey has important potential. Turkey Electricity Transmission Company (TEIAS) According to a report prepared; Turkey's current electricity generation, is about 140 billion kWh annually, while the annual electricity consumption of 2 thousand kWh per person. The EU average is 8 thousand per person and 5 thousand kWh in the OECD. According to TEIAS projections, Turkey's energy requirements will be a minimum of 400-500 billion kWh in 2025 and a large part of it will be produced from local sources. Therefore, the use of alternative energy sources in Turkey is important. However, since the energy policies implemented in recent years are directed towards natural gas; it prevents the supports for renewable energy sources from reaching the desired level (MENR, 2017; Gorgun, 2008). With the increase of renewable energy support in Turkey; new WPPs are being installed, whose capacities are not very large. While the annual wind energy production amount was 11652 GWh at the beginning of 2016; At the end of the year, this figure decreased to 11308 GWh. As of the beginning of 2016, the total power of the WPPs in operation was 4503 MW, while it was 5190.9 MW at the end of 2016 (TCME, 2016). The share of total electricity consumption in Turkey is projected to be 3.55% from the wind until 2025 (Acaroglu, 2013). Fossil fuels are consumable energy sources. However, wind energy is an inexhaustible, renewable energy source (Dereli, 2001). The energy consumption rate in the world is 300 thousand times the rate of the formation of fossil fuels (İlker, 2003). Regarding the history of wind turbines, it is estimated that the oldest wind power machine, the windmill, was built near Alexandria 3000 years ago (Özgener, 2002). Wind energy is the most advanced type of energy among renewable energies (Özgener, 2010). In this work a is study conducted to determine the potential of wind energy depending on wind speed in Kahramanmaraş, it was found that wind energy can be used economically in this region in June, July and August. It is estimated that 4 times more energy is gained compared to the mechanical energy obtained from the wind turbine (Aybek et al., 2000).

Previous Studies About the Use of Wind Energy

Despite the completion of the European Wind Atlas (Troen and Petersen, 1989), studies for determining wind potential for stations that are not included in this study are ongoing. Wind potential determination studies are also conducted in countries other than developed countries. It is stated that wind energy can be used in Nigeria, Morocco, India, Greece and Cyprus according to the studies conducted by researchers (Adekoya and Adewale, 1992; Darwish and Sayigh, 199; Panda, 1990; Pneumatikos, 1991; Pashardes and Christofides, 1995). In the studies carried out by EIE (Electrical Works Survey Administration), Bandırma, Antakya, Kumköy, Mardin, Sinop, Gökçeada, Çorlu and Çanakkale were identified as rich regions in terms of wind energy (MENR, 2016). In addition, local wind potential determination studies have been carried out in places such as Bandırma, Bozcaada, Çeşme, Gökçeada, Çanakkale, Karadeniz Ereğlisi, Florya and Siverek (Dündar and İnan, 1996, 1997,1999; Tolun, 1994). In our country, Wind Energy investment was first made in 1998 in Çeşme (8.7 MW). In the year 2000; only an investment of 10.2 MW was made in Bozcaada (Kulunk, 1993).

Wind Energy Importance and Use of Wind Energy

The use of renewable energy sources is increasing day by day due to the decrease in fossil fuels and their negative effects on the environment. Wind energy is a natural and renewable energy source and can be converted into electrical energy through wind turbines. The energy needs per capita increases in proportion to the increasing world population. the use of renewable and environmentally-friendly wind, solar and hydraulic energy sources is increasing day by day in order to meet the increasing energy needs. Wind energy systems are systems that convert the wind at various speeds into electricity, depending on their regional wind potentials. Various criteria must be known in order to determine the potential of the energy to be obtained by wind turbine. The most important of these criteria are regional monthly average air velocity values at various heights, turbine rotor diameters and air density values. The use of wind energy in electricity generation has been started as an alternative energy after the oil crisis in 1970s. Between 1980-1985, wind farms with a total power of 1580 MW were established in America. The installed power value has reached 1946 MW as of the end of 1998. The establisament of wind farms in European countries such as Denmark, Netherlands and Germany, have been increased rapidly with the energy law reorganized in 1991, Germany has ranked first in wind energy. 60% of the installed power in the world is in Europe and 20% of it is in America. With the capacity of 2100 MW added in 1998, the installed wind power capacity in the world has reached 9600 MW (TUBİTAK, 2016). One of the benefits of using wind energy is that the social cost is very low compared to other energy sources. In other words, wind energy is the cheapest in terms of social cost among all energy types we will spend for each economic value we produce. Within this cost; establishment costs, operating costs, disposal costs of produced waste,

economic life, dismantling costs, replacement costs etc. are the most important. Another benefit that will occur with the use of renewable energy sources is the decreases in energy cut costs in production processes (Canpolat, 2000).

Wind Energy and Use of Wind Energy Potential in Türkiye

In Turkey, the increase in energy demand, could not envisaged until now. Therefore, production planning could not be made.

Energy types that production does not meet the demand are provided through imports. Petroleum and natural gas have the biggest share in imported energy resources (Kapluhan, 2013). Compared to other developed countries, in Turkey, more payments are made on energy imports (Mac, 2006). At the end of 2006, in the production of electrical energy, it is seen that natural gas has the highest share with 51% at the share of resources. This is followed by hydroelectricity (dam) with 15% and imported coal with 13%, respectively (MENR, 2013).

In Turkey, the first scientific studies on wind energy were conducted by Ankara University in the 1960s, Ege University in the 1970s, Middle East Technical University and TÜBİTAK Marmara Research Center (MRC), and after 1981 the Electrical Affairs Survey Administration (EASA). In 1989, the Wind Energy Branch Directorate was established within this organization. In 1992, the European Wind Energy Association (EWEA) Turkey Branch was opened. Turkey has initiated studies to develope the Wind Atlas with the use of topographic data obtained from the wind values of 43 meteorology stations by the General Directorate of State Meteorology Affairs (GDSMA) since 1993 (Kapluhan, 2017).

Turkey Wind Energy Potential Atlas (WEPA) has been prepared by the General Directorate of Renewable Energy dependent on the Ministry of Energy and Natural Resources (SEL, 2012).

Turkey is a very rich country in terms of wind energy. The potential of wind energy in Türkiye is 7, 5 and 2 times higher than Germany, Denmark, and Spain respectively. This will show that great gains can be obtained in every sense if the wind is turned into energy. Wind turbines, as shown in Figure 1, are used to convert wind energy into electrical energy. This energy is used in many fields (Civi and Köksal, 2011).

According to Turkey's wind atlas, Turkey's wind areas with high potential; Marmara is the Southeastern Anatolia and Aegean region (Table 1) (MENR, 1986). Turkey's wind energy potential atlas (REPA) is given in Figure 2.

The wind atlas of Turkey; with colors is explained as follows (Bektaş, 2013). Dark blue zone shows the average wind speed larger than 7.5 m s^{-1}. These regions are not visible on the Atlas at this scale because it is low in Turkey. Red zone shows the regions with an average wind speed of 5.0-7.5 m. s^{-1} in open areas. These are regions with high wind energy potential. For example, Bandırma, Gökçeada, Bozcaada, Çanakkale, and Amasra are located in this region. Yellow zone shows the places whose wind speed average is 5.5-6.5 m. s^{-1} in open areas. There are many places in our country from the yellow region. For example, Antakya, Bergama, Şile, Sinop, Edirne, and Mersin are from these regions. Green zone shows areas with a wind speed average of 5.0-5.5 m s^{-1} at an altitude of 50 m. This region which has a widespread distribution in Turkey, covers many cities. Light blue zone shows areas whose wind speed average is less than 4.5 m s^{-1}. This region also covers some parts of Eastern Anatolia, the Eastern Black Sea, and Central Anatolia. This region is considered to be inefficient in terms of installing wind turbines (Onurbasavcioğlu, 2017).

In 2007, according to Turkey's Wind Energy Potential Atlas; In Turkey, the annual wind speed of 8.5 m s^{-1}, and in the regions above, at least 5000 MW; It has been determined that there is a wind energy potential of at least 48000 MW in regions above 7.0 m s^{-1} (Yılmaz and Dombayci, 2018). Turkey's wind energy potential varies according to time and seasonal factors. The best wind resource areas of Turkey are located near the coastlines, high slopes, the top of the mountains, or open spaces. The highest annual average wind speeds along the west coast of Turkey are formed in a region near the Sea of Marmara and around Antakya. According to the data of the Ministry of Energy and Natural Resources, the total wind power potential is 131756.40 MW (Table 2). As can be seen from the Table, Turkey has major wind energy potential (İlkilic, 2012).

The "Wind Energy Observation Station Project" was initiated by the General Directorate of Electrical Works Survey Administration within the scope of determining the wind energy potential for energy production. The stations established as part of the project and studies are conducted for collecting wind data. In the meantime, Karabiga, Nurdağı, Şenköy, Karaburun, and Bandırma stations, whose measurement period was completed and they were dismantled. New stations were established in Söke, Yalıkavak (Bodrum), Sinop, Eğirdir (Isparta) and Foça, which were determined as a result of the regional studies. The average wind power density and wind speeds in some provinces of Turkey are given in Table 3.

Table 1. Wind energy potential in various regions of Turkey

Regions	Average Wind speed (m. s^{-1})	Annual Average Wind Density (W. m^{-2})
Marmara Region	3.29	51.91
Aegean Region	2.65	23.47
Mediterranean region	2.45	21.36
Central Anatolia Region	2.46	20.14
Black Sea region	2.38	21.31
Eastern Anatolia Region	2.12	13.19
Southeastern Anatolia	2.69	29.33
Region Average	2.58	25.82

Table 2. Total wind power potential Turkey (50 m)

Wind Class	Wind power (W. m^{-2})	Wind Speed (m. s^{-1})	Total Potential (MW)
3	300-400	6.5-7.0	83906.96
4	400-500	7.0-7.5	29259.36
5	500-600	7.5-8.0	12994.32
6	600-800	8.0-9.0	5399.92
7	>800	>9.0	195.84
Total			131756.40

Table 3. Average wind energy density and wind speeds (Basaran, 2008)

Location	Average Power Density (W. m^{-2})	Average Wind Speed (m. s^{-1})
Bandırma	152.6	5.0
Antakya	108.9	4.4
Kumköy	82.0	4.0
Mardin	81.4	4.0
Sinop	77.9	3.9
Gökçeada	74.5	3.9
Çorlu	72.3	3.8
Çanakkale	71.2	3.8

Table 4. Wind power plant power capacity which can be installed in Sinop province (REPA, 2013)

Wind Power (50m) (W. m^{-2})	Wind Speed (50m) (m. s^{-1})	Total Area (km^2)	Total Power Capacity (MW)
300-400	6.8-7.5	289.63	1448.16
400-500	7.5-8.1	8.59	42.96
500-600	8.1-8.6	0.00	0.00
600-800	8.6-9.5	0.00	0.00
>800	>9.5	0.00	0.00
Total		298.22	1491.12

Table 5. Average monthly wind speed of Sinop city (MENR, 2019)]

Months	Wind Speed (m. s^{-1})
January	4.3
February	4.5
March	4.7
April	4.9
May	5.0
June	5.4
July	4.5
August	4.1
September	4.2
October	4.4
November	4.6
December	4.4
Average annual	4.4

In this study, a program has been developed for the calculation of wind energy potential by considering the monthly average wind speeds in the province of Sinop. Using the program written in VisualBasic 6.0, electrical energy values that can be obtained from wind turbines at various monthly wind speeds were calculated.

Materials and Methods

The wind data used in this study was measured and recorded hourly at a height of 10 m above ground level from the Turkish State Meteorological Service Sinop Province station between 2013-2020. Sinop is located between 41° 12' and 42° 06' north latitudes and 34° 14' and 35° 26' east longitudes in the middle of the Black Sea region. Sinop city location is given in Figure 3,

The annual average temperature of the districts on the coastal part of Sinop is 13-15°C; the temperature in the inner part varies between 12-14°C The seasonal temperature difference is not much. On the coastline, the dominant wind direction is northwest and the annual average wind speed is 3.5 m s^{-1}. In places far from the coastline; The dominant wind is west oriented and it is blowing at an average of 1.0 m s^{-1} and 2.0 m s^{-1} lighter than the coastline. The population of Sinop province is 218408 (Sinop Governorate Culture Directorate, 2021). Power capacities based on wind speeds of 50 m height in Sinop province are given in Table 4. The speed of the prevailing wind must be at least 7 m s^{-1} or more for the economic Wind Power Plant investment (WPP) that is planned to be established in a place. As can be seen in Figure 4, it can be said that the Wind Power Plant is an economic investment since the dominant wind speed in Sinop is between 6.8 and 7.5 m s^{-1}.

Figure 1. Wind turbines

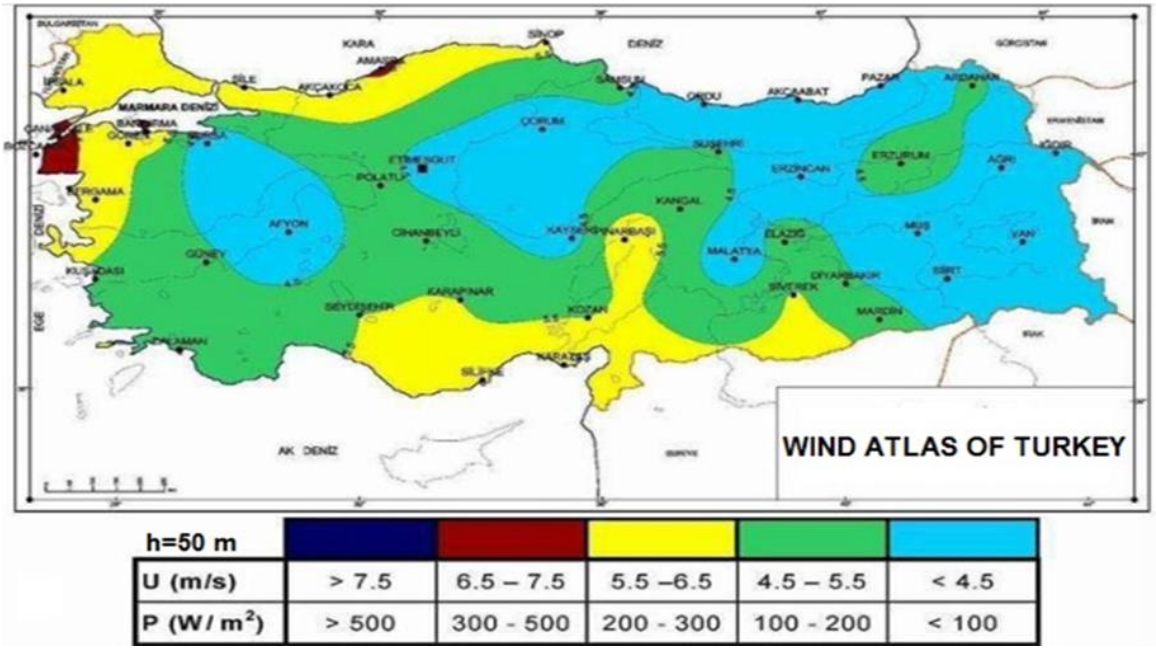

Figure 2. Turkey wind energy potential atlas (REPA)

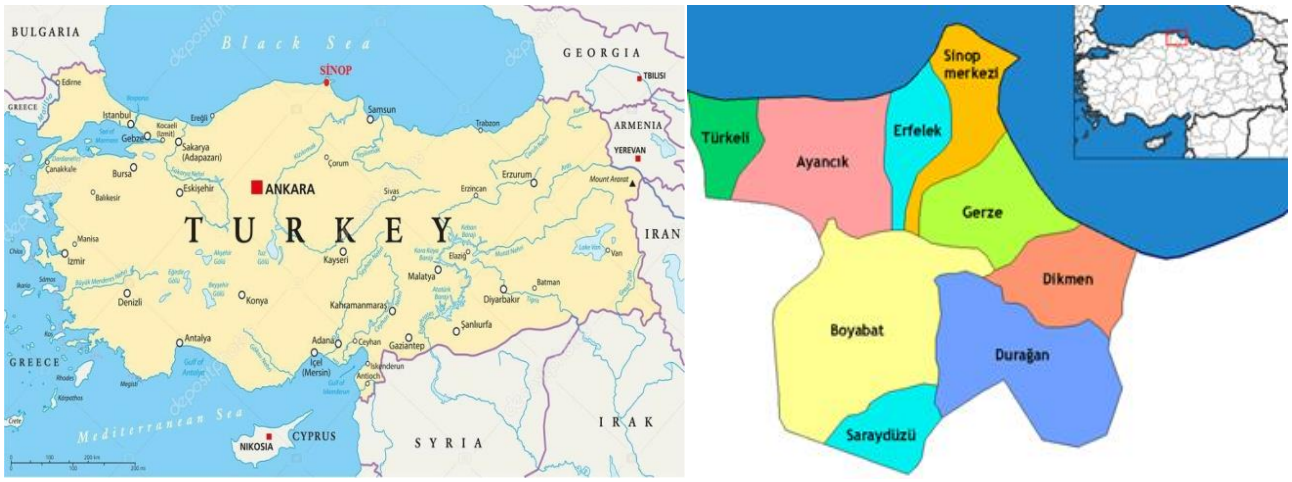

Figure 3. Location of Sinop on Turkey map (Sinop Province Map, 2020)

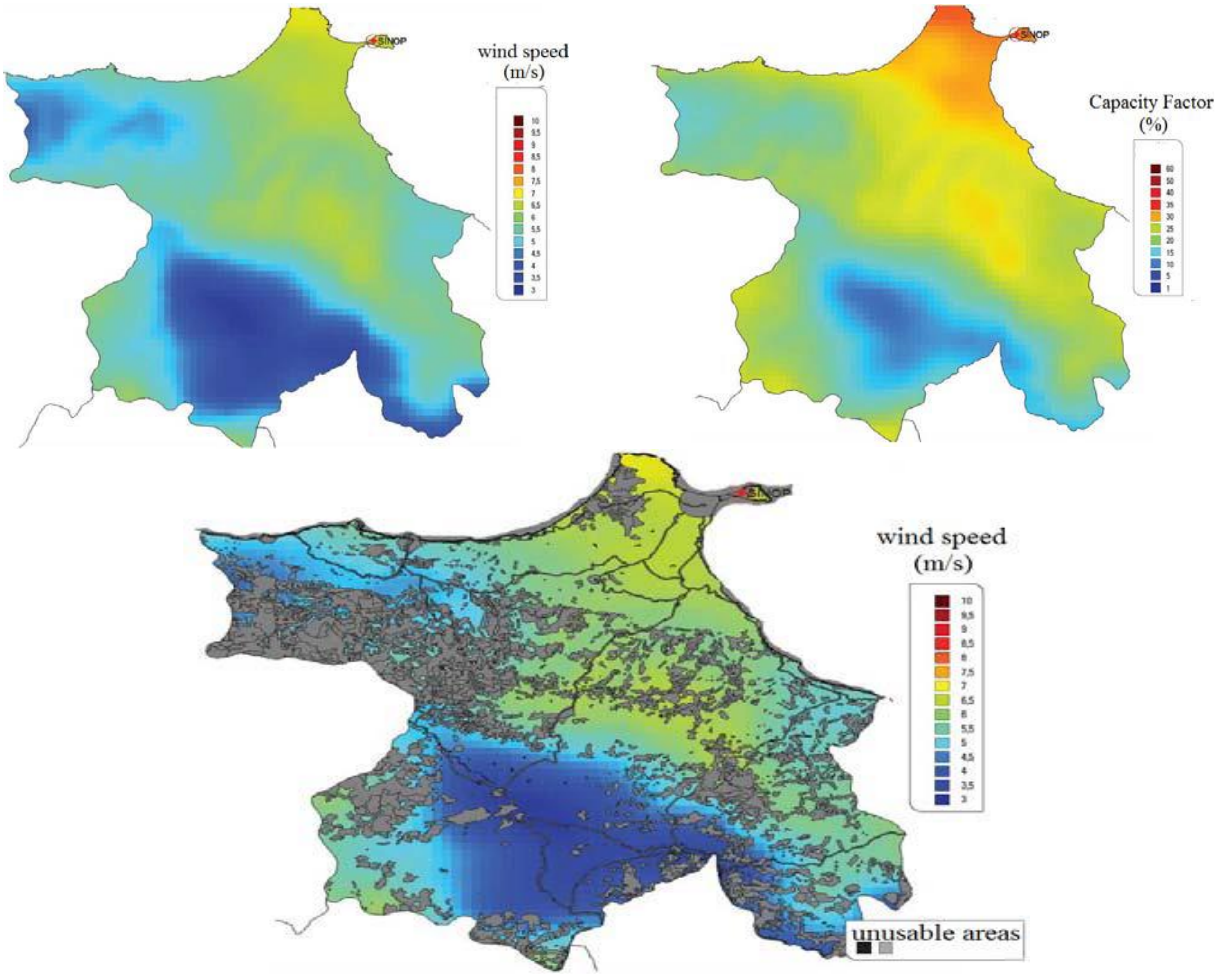

Figure 4. Sinop province wind speed distribution (50m) (MENR, 2017)

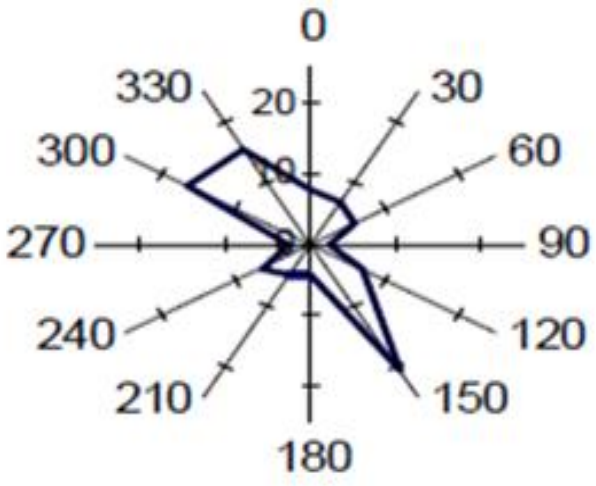

Figure 5. The dominant wind direction in Sinop (Tagil, 2000)

Coordinates whose wind data are taken into consideration in the study; 42.0025513345238 north latitude, 35.0127371674451 east longitude, a point located in Dibekli village of Sinop province, central district was determined. This point is 78 m high from the sea level and is in the north west direction. The priority process in the selection of wind power plant turbines is the determination of the dominant wind direction belonging to that place. The dominant wind direction in Sinop is 150° 300° in June and August; In July, it is 330° (Figure 5). The east of Sinop is limited to the high plains of the Boztepe peninsula. The west of Sinop; is surrounded by the foothills of the Küre Mountains.

In this study, a program has been written for the calculation of wind energy potential in the province by considering the monthly average wind speeds of Sinop. Electrical energy values that can be obtained from wind turbines at various monthly wind speeds were calculated using the program written in VisualBasic 6.0. At various rotor radii and wind speeds, the amount of energy that can be obtained has been determined by entering the rotor radii at different values in the program dialog menu.

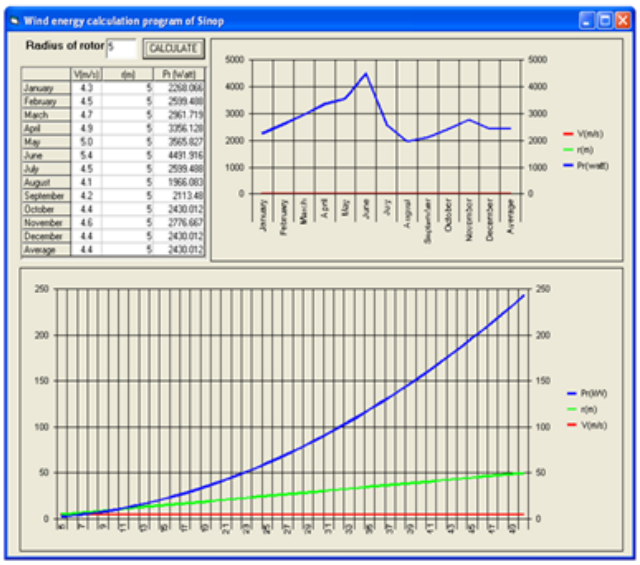

Figure 6. Wind energy amount that can be obtained in Sinop province with a 5 m rotor radius

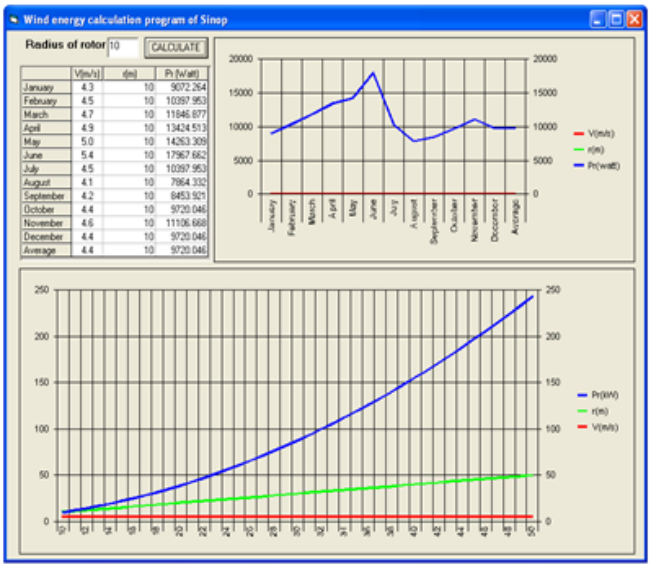

Figure 7. Wind energy amount that can be obtained in Sinop province with 10 m rotor radius

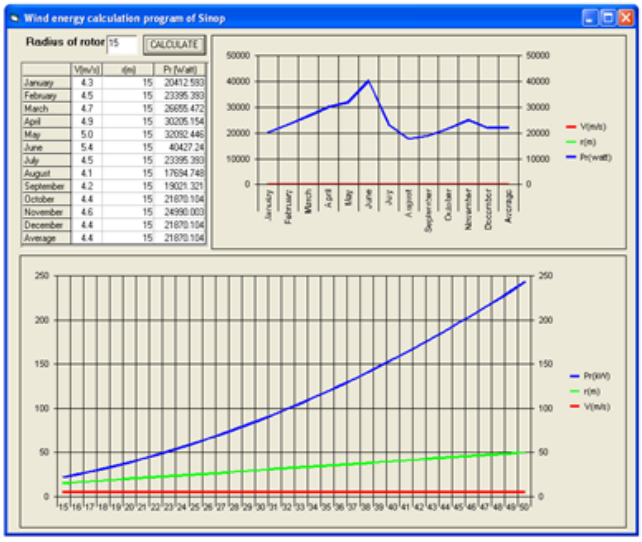

Figure 8. Wind energy amount that can be obtained in Sinop province with 15 m rotor radius

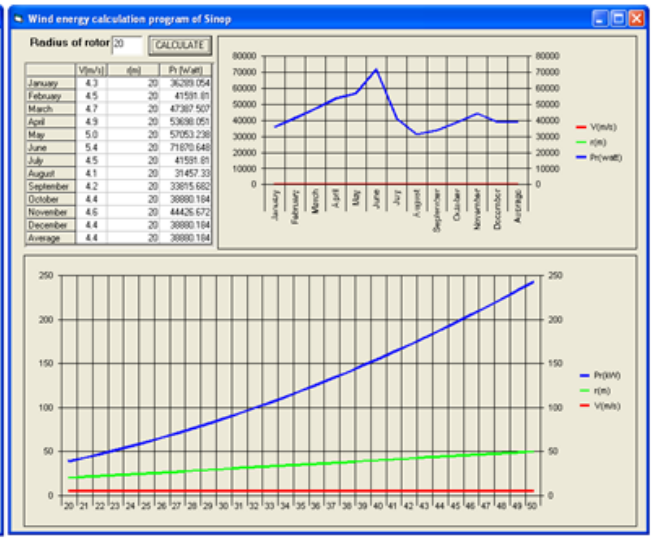

Figure 9. Wind energy amount that can be obtained in Sinop province with 20 m rotor radius

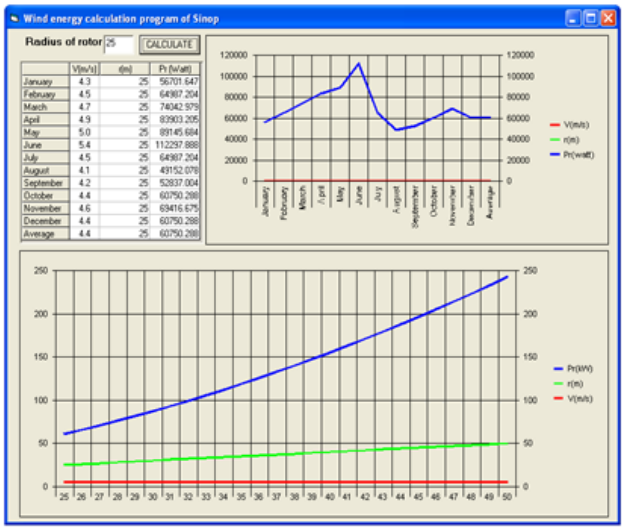

Figure 10. Wind energy amount that can be obtained in Sinop province with 25 m rotor radius

In the study, it is emphasized that wind energy systems can be used in the region instead of planned nuclear and thermal power plants in Sinop province.

In the region, which has touristic features and international wetlands in the province, the establishment of wind power plants instead of nuclear and thermal power plants has great importance in terms of natural energy production.

The following equations are used to calculate the monthly and annual energy amounts that can be obtained according to the average wind speeds in the region (Johnson, 2001).

$$P_m = C_P\left(\frac{1}{2}.p.A.V^3\right)\ (watt) \quad (1)$$

$$A = \pi.r^2\ (\mathrm{m}^2) \quad (2)$$

Here, the turbine performance coefficient (Betz coefficient) is used as 0.593 for wind power and electricity generation systems. ρ is the air density and is used as 1.225

kg m^{-3}. A rotor rotation surface area, r wind turbine rotor radius, V is the regional average air velocity value. The monthly average wind speeds of Sinop Province are shown in the Table 5.

Screen photos of the program prepared to calculate the wind energy amounts that can be obtained according to monthly average wind data of Sinop province and the monthly, annual average energy amount values varying according to various rotor radius are shown in Figure 6-10. In the software, monthly and annual average wind speed values of the province are entered.

Based on equations 1 and 2, the amount of energy that can be obtained from the system for various rotor radii is calculated according to the rotor, radius value entered; The amount of wind energy that can be obtained monthly is calculated and transferred to the tables and graphics.

In addition, after the rotor radius value is entered based on the annual average wind speed value, the amount of energy that can be obtained up to a radius of 50 m is calculated and the output is obtained graphically at the bottom of the screen.

The output obtained by testing the program in various rotor radii is shown in the figures below.

Here, the turbine performance coefficient (Betz coefficient) is used as 0.593 for wind power and electricity generation systems. ρ is the air density and is used as 1.225 kg m^{-3} A rotor rotation surface area, r wind turbine rotor radius, V is the regional average air.

Conclusion

Turkey's current energy sources cannot meet the energy requirements of a growing population and booming industry. Therefore, the gap between energy production and consumption is growing rapidly. Regarding the rapid depletion of energy resources, the use of renewable energy sources should be encouraged. Wind energy is a renewable alternative energy source to meet the increasing energy need in the world and our country. The fact that it does not emit CO_2 to the atmosphere, and is an environmentally friendly and infinite energy source has made it inevitable to focus on these sources. This study includes assessments of wind and electricity generation potential and environmental impacts for Sinop province. In developed world countries, where the utilization rate of renewable energy resources is increasing, awareness-raising studies on environmentally friendly energy use have gained importance. To minimize the negative effects of fossil fuels on nature and living things, several protocols and cooperation agreements have been made between countries, and penal sanctions have been imposed on countries that do not comply with these agreements. In fossil-based fuels are used in Turkey as well; Although filter application is mandatory, many thermal power plants, factories, and workplaces do not follow the rules; therefore, they harm the environment and living things. The wind atlas prepared for Sinop province shows that a wind speed of 7 m s^{-1} or higher is needed for the economic Wind power plant investment. It can be said that, the dominant wind speed in Sinop is at these values and the wind power plant is an economic investment. In this study, which emphasizes the need to use wind energy systems that will not harm the nature of the region in the touristic Sinop province, where nuclear and thermal power plants are planned to be established recently. The wind energy amounts that can be obtained from a wind turbine system from 5 m rotor radius to 50 m rotor radius are analysed by computer support. The results are presented in graphs. The amount of energy that can be obtained by increasing the number of wind turbines can also be increased. According to the results obtained from the energy calculations of the study, 60.75 kW/turbine power can be obtained from the wind turbine system with a radius of 25 m in annual average wind speed values and 243 kW turbine values were obtained from the 50 m radius system. As can be seen from the results, the wind energy potential in Sinop province is at a level that can be evaluated, and depending on the number of wind turbines, a certain part or all of the energy needed in the province can be provided through these systems. Considering the wind data for Sinop province, it is calculated that the 1.5 MW wind power plant, which is likely to be built using a wind turbine, will contribute to the production of 4.2 GWh of electricity per year. Besides, approximately 3000 tons of CO_2 emission that can be released into the atmosphere will be prevented by the wind power plant being established. Energy production based on fossil fuels, environmental pollution, and the greenhouse effect are causing. As a result, it has negative effects on natural vegetation and human health. Current wind farm applications show that the wind potential in the region is sufficient. These systems can be used primarily in energy production due to their advantages such as having positive contributions to the environment and not harming agricultural areas and changing according to the purpose of use. In today's conditions where the ecological balance is disturbed, the importance of wind energy increases. In this respect, the share of wind turbines in electricity generation should be increased more. If these systems are operated in connection with the electricity distribution network, additional income can be obtained through the sale of the excess of consumption of electricity produced by establishing the necessary legal basis.

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Conflict of İnterest

M Dağtekin and B Yelmen declare that they have no competing interests.

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