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A Wind Power Plant Feasibility Study for Bursa,Gemlik Region,Turkey

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Abstract

Increasing energy demand on a global scale and with the emerging constraint of conventional energy resources has forced the developing countries to improve alternative energy sources. Especially in last decades, many studies and researches have been done in order to benefit more efficiently from renewable energy sources. Wind energy as a renewable energy source has showed a greater improvement since it is sustainable, efficient and clean energy. As a natural consequence of this development, the number of wind power plants (WPP) investments has been increasing expeditiously all around the world. Correspondingly, Turkey promotes the incentives and investments to the wind power conversion systems. Thus, the external dependence on energy of Turkey will decrease with these incentives and investments. In addition to that, competitive power of Turkey in the energy sector will increase dramatically. In this study, a WPP feasibility study is released for Gemlik Bay connected with Bursa Province in which has remarkable wind potential but has not any WPP. Wind data of Gemlik applied to Windsim software; annual energy production (AEP) and capacity factor are calculated. The study shows that through 5 Vestas V90 turbines with 2-MW capacity in Gemlik Ata region, establishment of an economic WPP which has over 40 GWh/y AEP capacity is feasible.

Key words

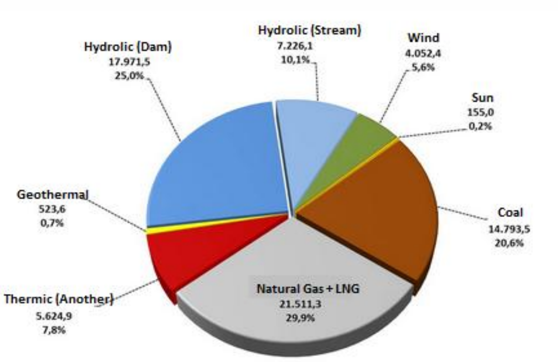
Gemlik Region, Renewable Energy Sources, Wind Energy, Wind Power Plant, Windsim

1. INTRODUCTION

Energy is the most important source for economic sustainability. Rapidly increase of population and industrialization resulted in an enormous energy demand all around the world. In order to meet this huge energy demand, investments in renewable energy sources have increased across the world. Nowadays, new energy investments are directed towards to clean energy. Renewable energy sources enable countries to meet energy requirements and protect environment with almost zero emission [1-3]. In addition, renewable energy sources are seen as a hope for economy of the developing countries.

Industrialization in Turkey is developing which respect to the developed countries. Turkey's main energy demand is increasing with a rate of 4-5% per year and this amount is causing 8% electrical energy demand [3].Turkey's electricity generation by primary sources in 2015 is shown in Figure 1. According to Figure 1, Turkey meets its nearly 60% of energy demands from fossil fuel resources. Turkey is a foreign-dependent country in terms of energy. Turkey imports 72% of current energy sources to meet energy demand [3]. This issue brings along a current deficit problem and Turkey's economy sustains a serious loss and, also it causes negative effect on competitive power of Turkey on a global scale. The main reason of this situation is not used from domestic energy resources efficiently. If this problem is addressed, it can be said that investment in renewable energy sources is inevitable for Turkey's future.

Turkey has a prosperous geographical position and thanks to this feature, Turkey is a rich country in terms of renewable energy sources. Wind power as a renewable energy source, is one of the cleanest and the most environment-friendly energy source. All forms of energy production methods have negative environmental effect, but effects of wind power generation are very low. These effects of wind power are quite a little when compared with conventional energy sources. It is predicted that Turkey's technical and economic wind power potential are 83,000 MW and 10,000 MW respectively [4]. However, Turkey cannot benefit from this remarkable potential adequately. In this study, a wind power feasibility study is released for Gemlik region connected with Bursa Province where wind potential is currently high. The aim of this study is providing inputs to investors and policy makers for exploiting the wind potential of the region.



Established Power (2015): 71,858.5 MW

Figure 1.Turkey's electricity generation statistics [5]

2. MATERIALS and METHODS

Wind power plants are established and operated by considering some parameters. These parameters are wind power potential, accessibility and distance to energy transmission lines (ETL) and transformer stations. In this section, wind power potential in Bursa is evaluated by using Turkey wind atlases which have been developed by the Turkish Electric Affairs Etude Administration. Yearly average wind speed distribution and average wind capacity factor are given for the region. Also, the convenience of the region for WPP investment is analyzed in terms of roughness formation, distance to energy transmission lines (ETL) and transformer stations. Finally, site selection is performed for the WPP.

2.1. Assessment of Turkey's Wind Power Potential

Turkey is located in the northern hemisphere between the 36°-42° northern parallels and the 26°-45° eastern meridians. Thanks to its geographical position, Turkey has remarkable wind energy potential. In order to determine the wind power potential of Turkey, the wind atlases have been developed as shown in Figure 2 and Figure 3, below.

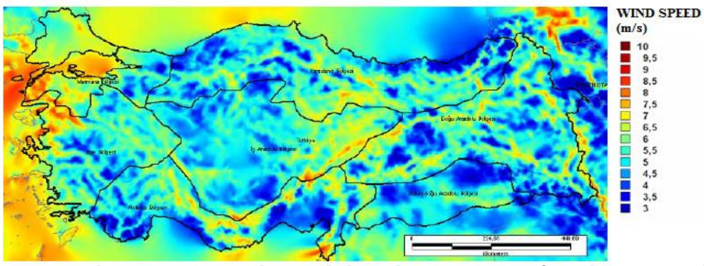


Figure 2. Yearly average wind speed distribution map of Turkey (50m) [6]

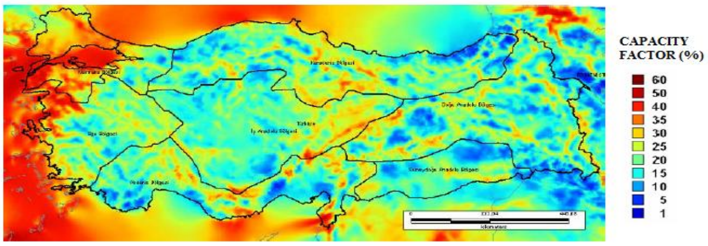


Figure 3. Average wind capacity factor in Turkey (50m) [6]

According to Turkey wind atlases given in Figure 2 and Figure 3, the average wind speed at 50 meters elevation is approximately 7.0 m/s throughout of Turkey. In addition, Marmara region has the highest wind potential with the value of 7.0-9.0 m/s. For economical wind power plant investment, capacity factor must be 35% or more [7]. As shown in Figure 3, a great majority of Marmara, Aegean and East Mediterranean regions have more than %35 capacity factors. According to power density distribution as shown in Figure 4, the power density is in Marmara region changes between 600 W/m^2 and 800 W/m^2 at 50 meters elevation. Table 1 shows the wind power classes at 50 meters height above ground. According to Table 1, Marmara region is included in class 5 and class 6. If these parameters are considered, it can be said that Marmara region is the most suitable region in Turkey for WPP investment.

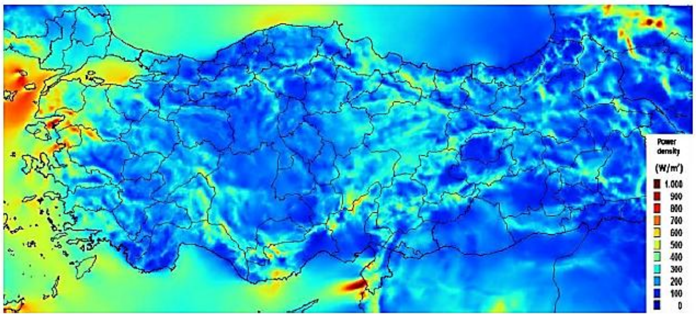


Figure 4. Yearly average wind power density at 50m [8]

Table 1.Wind Power Classification [9]

Wind Power Class	**Wind Power Density(W/m^2)**	**Wind Speed (m/s)**
1	≤200	≤5.6
2	≤300	≤6.4
3	≤400	≤7.0
4	≤500	≤7.5
5	≤600	≤8.0
6	≤800	≤8.8
7	≤ 2000	≤ 11.9

2.2. Assessment of Wind Power Potential in Bursa, Turkey

Bursa is a large city in Turkey, located in northwestern Anatolia within the Marmara Region. It is the fourth most populous city in Turkey and one of the most industrialized metropolitan centers in the country [10]. In addition to these features, Bursa is a coastal city where connects to Marmara Sea. The coastal regions of Bursa are Mudanya and Gemlik respectively as shown in Figure 5.

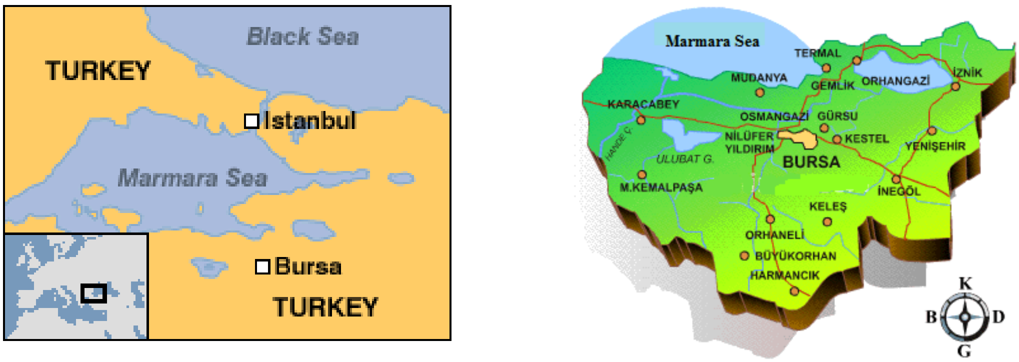


Figure 5. Location of Bursa Province in Turkey and city map of Bursa [11-12]

In order to determine the field for WPP installation, wind potential of Bursa should be evaluated. In this context, it can be benefited from the wind atlases designed for Bursa region as shown in Figure 6 and Figure 7.

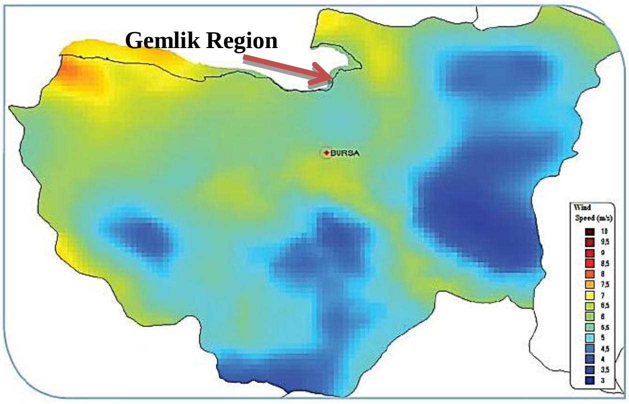


Figure 6. Average wind speed distribution map of Bursa (50m) [13]

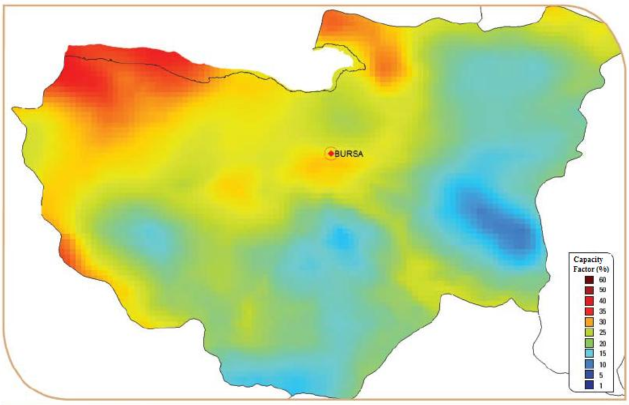


Figure 7. Average wind capacity factor in Bursa (50m) [13]

As shown in Figure 6, yearly average wind speed distribution in Gemlik region is 6.5-7.5 m/s. Also, average wind capacity factor is 35-40% as shown in Figure 7. If these two parameters are considered, it can be deduced that Gemlik is a suitable region for the WPP investment.

2.3. Assessment of ETL and Accessibility Parameters for Bursa Province

In order to provide an economical WPP establishment, accessibility and distance to (ETL) and transformer stations of the region should be analyzed.

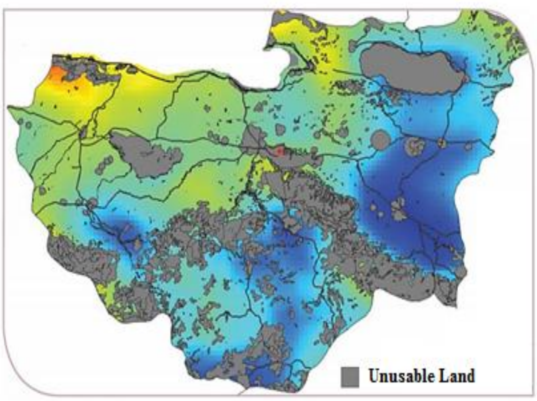


Figure 8. Unusable fields for the WPP in Bursa [13]

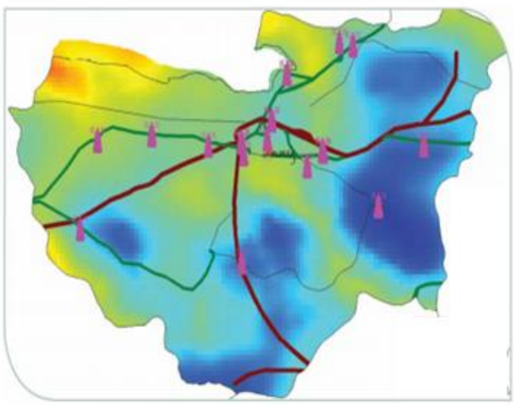


Figure 9. ETL and transformer stations in Bursa[13]

Unusable fields for WPP investment is shown in Figure 8. According to Figure 8, Gemlik is a favorable region in terms of accessibility. ETL and transformer stations in Bursa are given in Figure 9. As seen in Figure 9, the most suitable region is Gemlik in Bursa in terms of distance to ETL and transformer stations. In order to determine the roughness formation of Gemlik region, it can be benefited from CORINE (Coordination of Information on the Environment) database with 100 meters resolution. The terrain roughness formation is given in Figure 10 by using CORINE database. If the roughness formation of Gemlik is analyzed, it can be said that the most favorable field is Ata region which given in Figure 11.

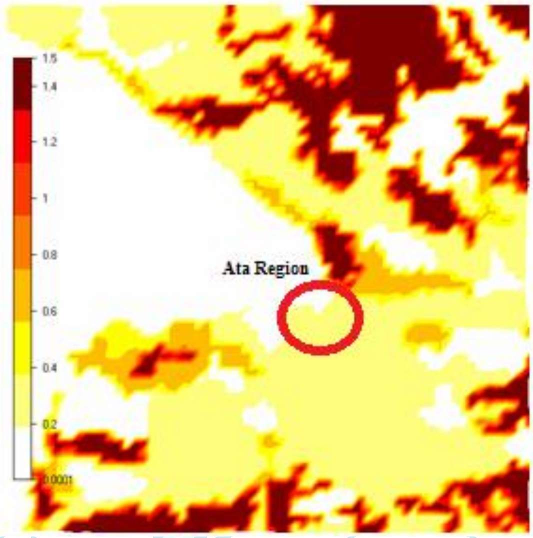


Figure 10. Roughness formation in Gemlik (m)

Figure 11. Ata Region in Gemlik

3. WIND FARM LAYOUT

In this section, a wind farm layout is designed for Ata region by using Windsim software. In order to gain 40 GWh/y or more AEP capacity, 5 Vestas V90 wind turbines are installed in the region by considering wake affect and air density changing. In addition to that, wind potential of the region is calculated by Windsim. Weibull distribution and its parameters are calculated for all sectors. Also calculated values are compared with the wind atlases.

3.1. Windsim Software

Windsim is wind energy software that uses computational fluid dynamics (CFD) to design and optimize wind turbine placement in onshore and offshore wind farms. Considering terrain conditions, the AEP amount of onshore and offshore wind farms can be calculated by Windsim. Windsim is powerful, world-class software based on CFD that combines advanced numeric processing with compelling 3D visualization. Through Windsim software, more accurate results can be obtained by taking turbulence, density changing, and topography-vegetation effects into account [14].

3.2. Assessment of Wind Power Potential for Bursa Province by CFD Analysis

In CFD analysis, the fluid is divided into finite volumes and the links which connects the volumes are represented by the nodes. For each element, mass conservation law and momentum conservation law are written. By combining these equations, Navier-Stokes equations are derived. Finally, Navier-Stokes Equations are solved by CFD method. As shown in Figure 12, Gemlik region is divided into 85,800 cells for the CFD analysis. According to CFD analysis, the average wind speed at 80 meters elevation is calculated as 9-12 m/s in Ata region as shown in Figure 13.

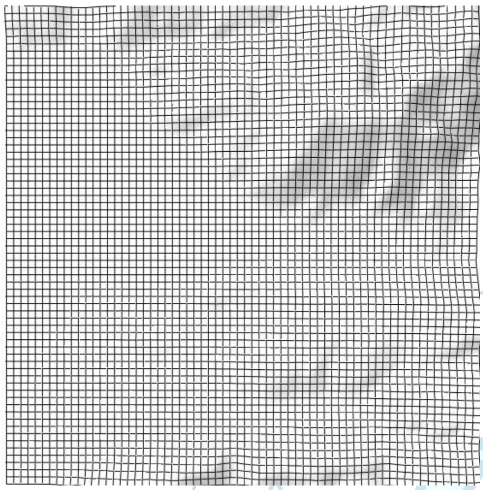


Figure 12. Grid structure of the region for CFD analysis

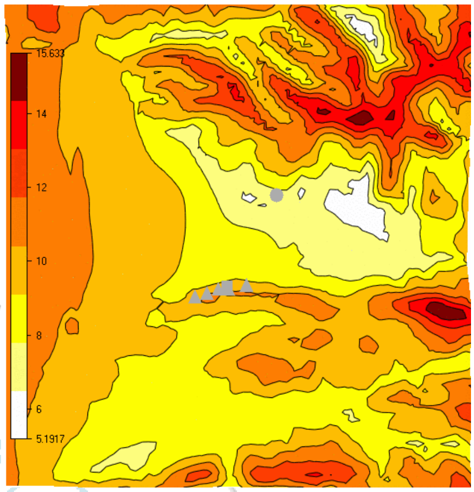


Figure 13. CDF analysis results at 80 meters.

3.2.1 Prospecting of Wind Energy Potential by Weibull Distribution Method

Weibull distribution method is one of the widely used statistical methods in wind data analysis [15]. Weibull distribution can be defined as a probability function f(v) and a cumulative distribution function f(v) represented by the following equations[16]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

$$f(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (2)$$

where k and c are the Weibull parameters and v is the wind speed. In these equations, k is the dimensionless shape factor and c (*m/s*) is the scale factor. According to wind resource analysis, Weibull distribution for the region is obtained as shown in Figure 14, below.

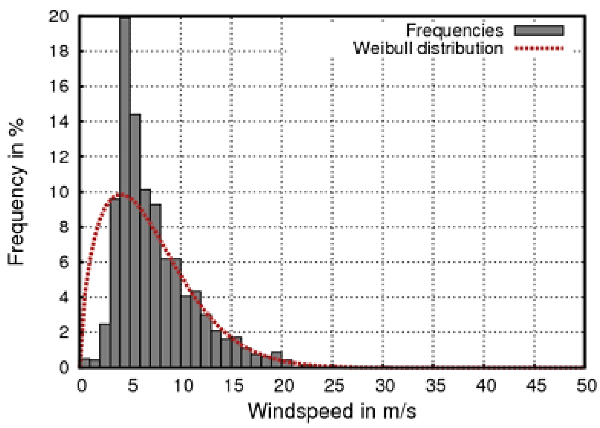


Figure 14. Wind speed frequency distribution with Weibull distribution for all sector

According to Weibull distribution given in Figure 14, average wind speed is found as 7.41 m/s for 80 meters elevation. Also, Weibull parameters, shape factor and scale factor are calculated 1.57 and 7.67 respectively. Through CFD analysis, this value was found as approximately 10 m/s. It can be deduced that CFD analysis results and Weibull distribution results match well.

3.3. Turbine Layout

Turbine layout is performed by considering wake affect. Wake effect occurs when the wind turbines embower themselves. This phenomena affects the wind farm performance substantially. In order to prevent this situation, adequate separation distance at the dominant wind direction must be ensured between the wind turbines. As shown in Figure 15, wind turbines in the prevailing wind direction need a minimum distance of eight times the rotor diameter. At the vertical direction, the space in the prevailing wind direction should be three times of the rotor diameter to avoid each other's mutual interference.

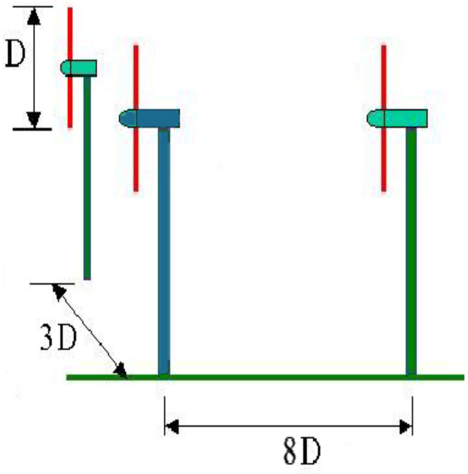


Figure 15. Wind turbine layout [16]

In this study, Jensen's wake affect is used since it is effective in terms of converging [17]. By considering this layout proposal, the wind farm layout is designed by using 5 Vestas V90 wind turbines as shown in Figure 16.

Figure 16. Wind farm layout

4. ENERGY ANALYSIS

Wind farm energy analysis is calculated by Windsim software. According to energy analysis performed with 85,800 cells, AEP and capacity factor are calculated 45.0 (GWh/y) and 49.8% respectively. In order to verify the analysis, the results must be obtained independent of the cell number. The next phase of the study, cell number is increased until finding the cell independent results. The results of the new analyses are obtained as given in Table 2.

Table 2.Analyses Results

Cell Number	AEP(GWh/y)	Capacity Factor (%)	Wake Loss (%)
85,800	45.0	49.8	3.1
239,800	44.0	50.2	3.0
541,200	43.6	49.8	3.1

5. RESULTS and DISCUSSIONS

According to Table 2, if the second analysis is compared with the last analysis; relative error at the capacity factor is found as 0.917% and relative error at the wake losses is 3.21%. If these values are evaluated, it can be said that the last analysis is pretty reliable. Apart from this, the WPP provides of being an economical WPP condition with 49.8% capacity factor.

In this study, the energy analysis of the WPP is performed by using the data which obtained from the measurement mast of Turkish State Meteorological Service. The height of this mast is 10 meters; on the other hand the hub height of the wind turbines is 80 meters. In order to extrapolate the wind speed to the hub height, Wind Power Law is used. However, this situation causes an error on the results. In addition to that, there is a significant distance between the measurement mast location and Ata region, Gemlik. In order to prevent this problem, a climate transferred mast was added into the region by using Windsim software. Also, in this study the cost analysis such as cost of turbine acquisition, installation and running cost along with grid connection is not considered. If these parameters are considered, truer results can be obtained.

6. CONCLUSIONS

Turkey's energy demand is increasing rapidly and Turkey imports the 72% of current energy which required for maintaining the production. This issue brings along a serious current deficit problem. Investment in renewable energy sources is inevitable for reducing the foreign dependence of Turkey. According to Turkey Wind Atlases which have been developed by the Turkish Electric Affairs Etude Administration, Turkey has 10,000 MW economical wind power potential. However, it cannot be efficiently benefited from this remarkable amount of energy. Through the investment of the wind energy conversion systems, Turkey's economy will develop in the long term and Turkey will have a big potential to compete with developed countries.

In this work, a WPP feasibility study is released for Gemlik region connected with Bursa Province where wind potential is very high but has not any wind power plant. The study shows that establishment of an economic WPP which has 43.6 GWh/y AEP capacity is feasible by using 5 number of Vestas V90 turbines with 2-MW capacity in Ata region, Gemlik. The main objective of this study is providing inputs to investors and policy makers for exploiting the wind potential of the region.

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