e-ISSN: 2458-8091

Journal Homepage: http://dergipark.gov.tr/ejsdr

EJSDR

European Journal of Sustainable Development Research

DergiPark AKADEMİK

CODEN: EJSDR

A Case Study of Installation of a Wind Power Plant in the Sinop Province, Turkey

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Publication Info

Paperreceived:
01June2016

Revisedreceived:
19-23October2016

Accepted:
01 March2017

Abstract

World energy demand has been increasing very rapidly, resulting in environmental issues such as the greenhouse effect and air pollution. This situation stimulates the developing countries to benefit more efficiently from alternative energy sources. In parallel to this policy, Turkey as a developing country has been increasing incentives and investments to wind power conversion systems. Thanks to these investments, the numbers of the wind power plants (WPP) have been increasing in the country each passing day. In this study, the Sinop Province where wind potential is high, is analyzed in terms of establishment of a WPP. Four years of hourly average wind speed data of the selected region are applied to the Windsim software: annual energy production, capacity factor and also power and energy curves of selected wind turbines are obtained as output. The study shows that a WPP that has approximately 29 GWh/y annual energy production and 33% capacity factor can be operated with five Vestas V90 commercial wind turbines.

Keywords

Renewable Energy Sources,The Sinop Province, Wind Energy, Wind Power Plant(WPP)

1. INTRODUCTION

Renewable energy technologies including solar, wind, biomass, geothermal, etc., have become more important since they are clean, sustainable and efficient energy sources. In addition, renewable energy sources are seen as a hope todecreasethe use of global fossil fuel. Wind energy as a renewable energy source has shown a remarkable growth all around the world [1]. Turkey as a developing country, has been investing in wind energy by increasing incentives and investments. As it can be seen from Figure 1, Turkey's installed wind power capacity has been increasing consistently. According to the wind statistic report published by the Turkish Wind Energy Association, installed wind capacity of Turkey has reached 4,718 MW by January of 2016 [2]. It is predicted that Turkey's technical and economical wind energy potential are 83,000 MW and 10,000 MW respectively [3]. However, Turkey is a foreign dependent country in terms of the energy sector and it imports almost 70% of current energy resources to meet the current energy demand [4]. Also, this issue causes severaleconomic problems such as current deficit, soaring inflation etc. Moreover, it leads to a decrease of the competitive power of Turkey. When considered from this aspect, investment in renewable energy technologies is inevitable for Turkey's future.

In this study, the Sinop Province which is located in the most northern edge of Turkey is studied for WPP investment. The wind atlases developed by the Turkish Electric Affairs Etude Administration are used to evaluate the wind power potential of the Sinop Province. Wind data of the selected region areobtained through the met mast ofthe Turkish State Meteorological Service. In addition to that, four years of hourly average wind speed data of the selected region are applied to the Windsim software; annual energy production, capacity factor and power curves of selected wind turbines are obtained as output.

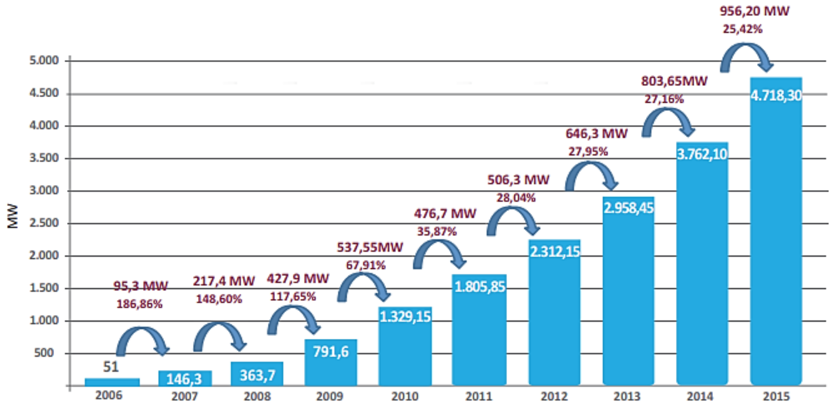

Figure 1.Cumulative installations for wind power plants in Turkey by years (MW) [5].

2. MATERIALS ANDMETHODS

In this section, firstly wind potential of Turkey is evaluated by using wind atlases. Secondly, wind power potential of the Sinop Province is analyzed for aWPP investment. Finally, terrain selection for the WPP is performed by considering wind power potential, accessibility and distance to energy transmission lines (ETL).

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. Turkey has a significant wind energy potential when compared with most European countriesthanks to its unique geographical position [3]. Turkey has realized this remarkable wind potential in recent years. According to Turkey's 2023 vision, Turkey is planning to supply 30% of its total energy demand from renewable energy sources [6]. Thus,wind energy comes into prominence for Turkey's future. The wind energy investments in Turkey are generally made in the western and southern regions [7]. Wind atlases as shown in Figure 1 and Figure 2 were developed by the Turkish Electric Affairs Etude Administration in order to determine the wind power potential of Turkey.

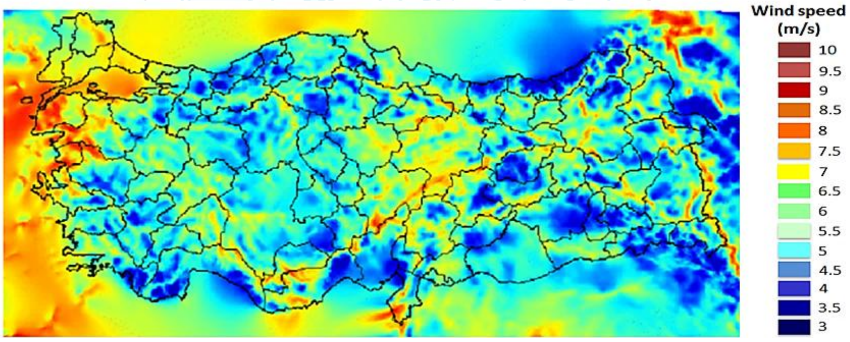

Figure 2.Yearly average wind speed distribution map of Turkey (50m) [8].

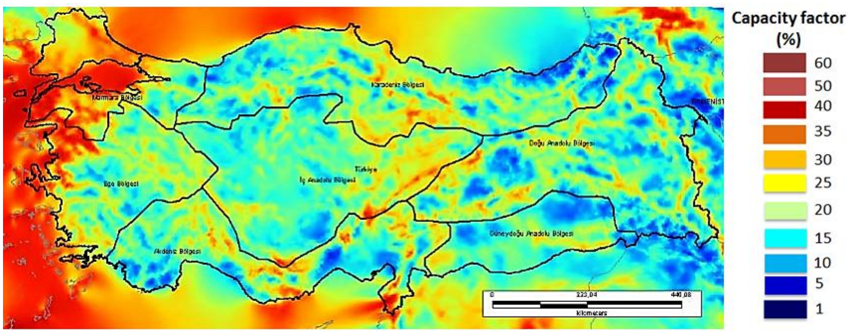

Figure 3.Average wind capacity factor in Turkey (50m) [8].

According to Figure 2, the annual average wind speed at 50 m elevation is approximately 7.0m/s throughout the country. Also, average wind capacity factor is almost 35% for most northern parts of Turkey including the Sinop Province. It can be concluded that Turkey is a rich country in terms of wind power potential.

2.2 Assessment of Wind Power Potential in the Sinop Province, Turkey

Sinop is a province of Turkey and it is located the most northern edge of the Turkish side of the Black Sea. The surface area of the city is 5,862 m^2, equivalent to 0.8% of Turkey's surface area. The borders of the city are 475 km and it consists of 300 km of land and 175 km of seaside borders [9].

Figure 4.Location of the Sinop Province in Turkey [10].

The wind atlas of Sinop is analyzedto evaluate the wind power potential of the SinopProvince. Yearly average wind speed and capacity factor distribution at 50 m elevation for the Sinop Province are given in Figure 4 and Figure 5. When the wind atlases oftheSinop Province are evaluated, it can be said that the northern part of the city is more convenient for WPP investment. In the northern part of Sinop, hourly average wind speed changes between 6.5 and 7.0 m/s. Besides, average wind capacity of northern part of the province is approximately 35%. For economical WPP investments, 35% or more capacity factor is required for the selected site [11]. When considered from this point of view, the northern part of the Sinop Province is rather suitable for a WPP establishment.

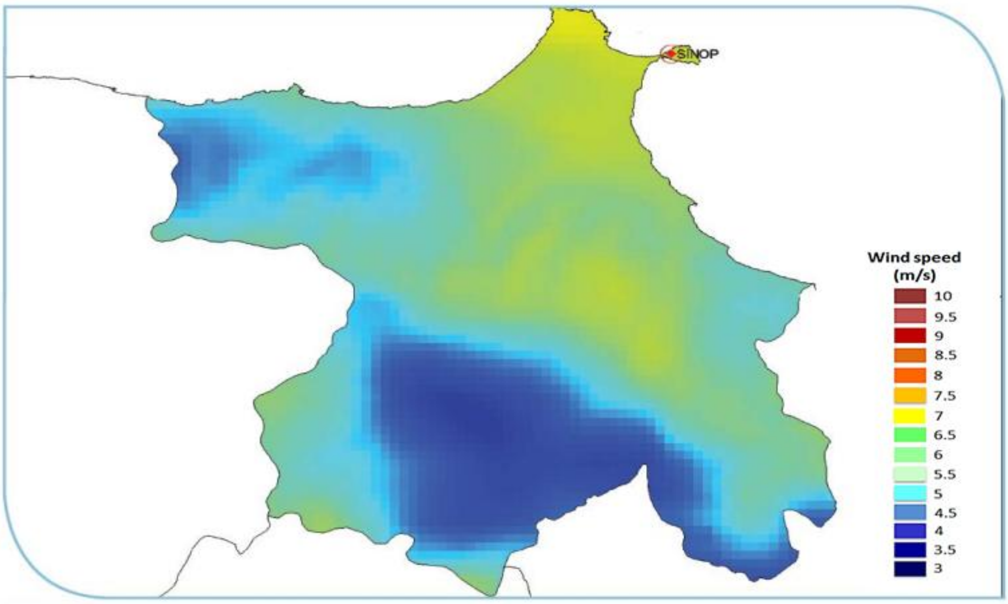

Figure 5.Average wind speed distribution map of the Sinop Province (50m) [12].

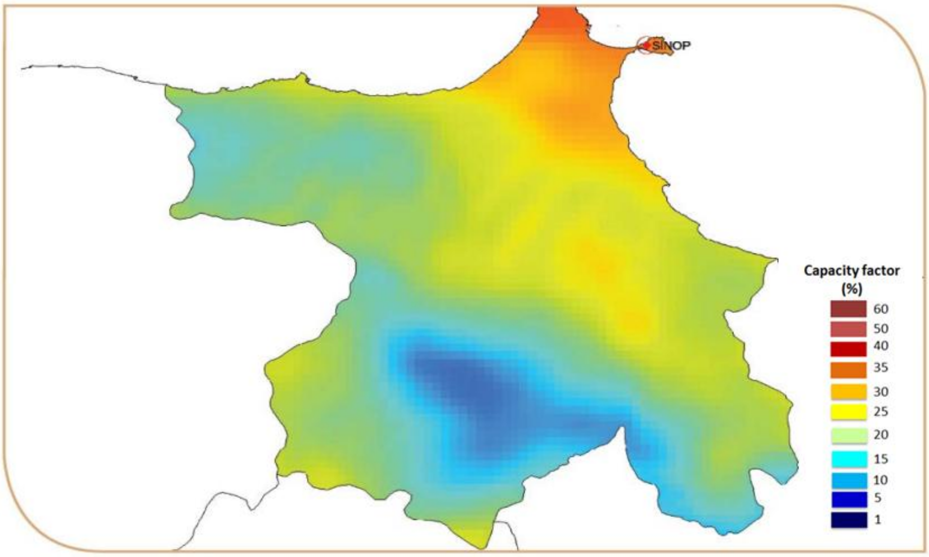

Figure 6.Average wind capacity factor in theSinop Province (50m) [12].

2.2. Site Selection for the Wind Power Plant

Modern wind turbines are installed near the coasts, on the hills, and the open valleys through the sea to obtain maximum efficiency [13]. Sinop is a coastal city on the Black Sea and thanks to this characteristic feature; the coastal terrains of the province are pretty convenient for WPP investment. Unusable lands for WPP investment are shown in Figure 7. According to Figure 7, most areas of the Sinop Province are inconvenient for WPP investment since there is asignificant amount of forestland in the northern part of the province. When ETL parameter is evaluated for WPP investments, it can be seenfrom Figure 8, there is a transformer station close to the city and it can reduce the initial investment cost of the WPP.

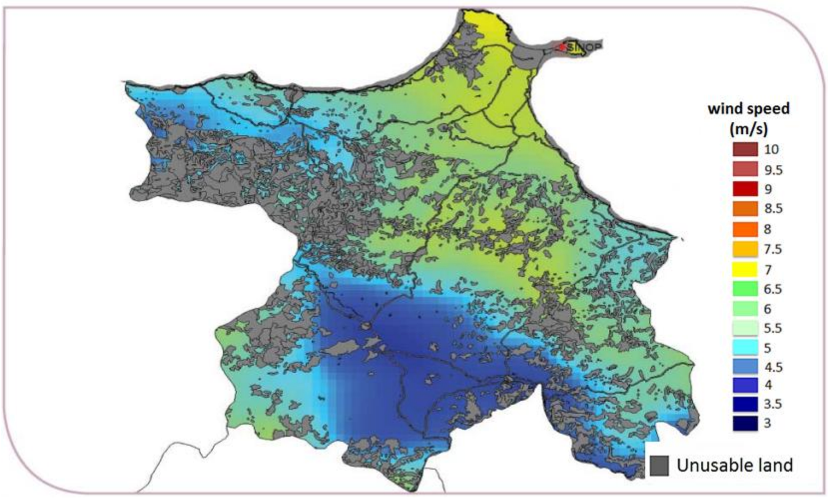

Figure 7.Unusable fields for the WPP in the *Sinop Province [12].*

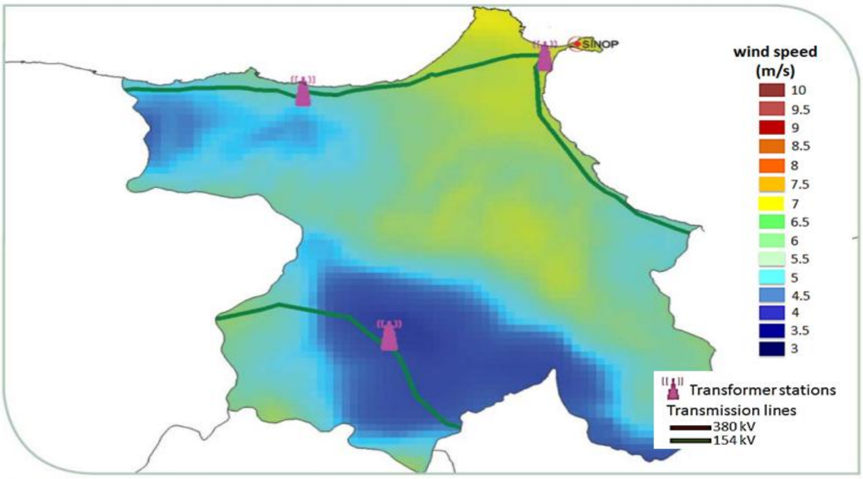

Figure 8.ETL and transformer stations in the *Sinop Province [12].*

When these parameters are considered, the wind farm site selection is carried out in theSinop Cape as shown in Figure 9. As can be seen in Figure 9, there is no settlement in the selected site and it is a big advantage for the operational security of transmission grids. In addition to that, the commercial wind turbines have a serious noise problem during operation. This noise problem is caused from mechanical and aerodynamic effects [14]. In this context, it can be concluded that the selected site is feasible in terms of noise and environmental issues.

3. DESIGNOF THE WIND FARM LAYOUT

In this section, wind farm layout design is carried out for the Sinop Cape using Windsim software. Five number of commercial Vestas V90 wind turbines are installed in the region by considering wake affect. In addition, Weibull distribution is obtained for the region, its parameters are calculated for all sectors and calculated values are compared with the wind atlas.

Figure 9.Selected wind farm site in the Sinop Province [12].

3.1 Wind speed assessment by Computational Fluid Dynamics (CFD) method

CFD approach is a numerical method used generally tosolve the problems that include fluid flow. Awind resource assessment by CFD models is performed by solving the RANS (Reynolds Averaged Navier-Stokes) equations with a turbulence closure. In this study, the Windsim software is used to solve the RANS equations and the k-ε turbulence model is used as a turbulence closure since it is common in CFD application.In the first analysis, the siteis divided into 172,800 cells as shown in Figure 10. Then, the model is solved under the fixed pressure boundary condition.

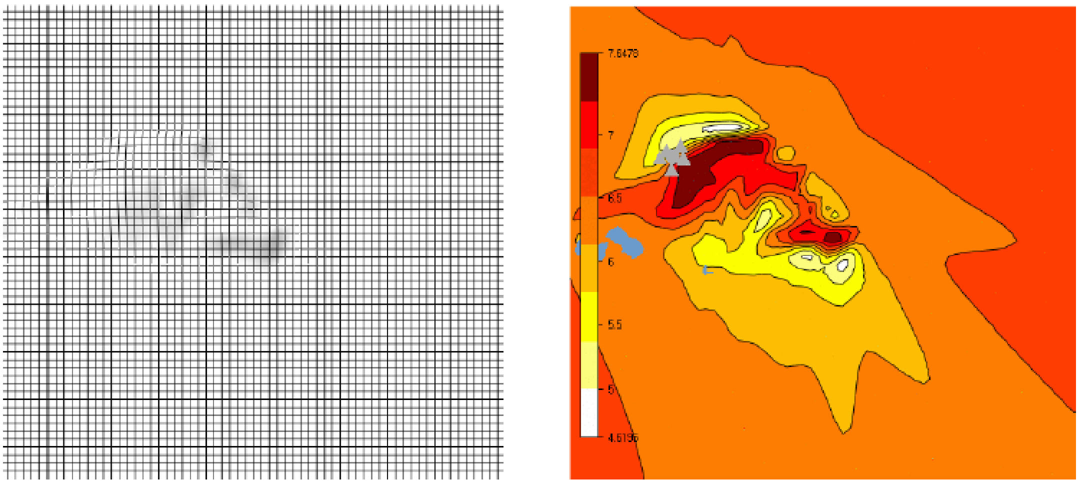

Figure 10.Cell structure of the region and wind resource map at the hub height of 80 meters (m/s).

According to CFD results presented in Figure 10, average wind speed in the wind farm site is almost 6.5-7 m/s. When the CFD result is compared with the wind atlas of the Sinop Province, it can be seen that the results are quite similar.

3.2 Assessment of Wind Power Potential by Weibull Distribution

Weibull distribution is one of the most popular statistical methods used in engineering and it also is widely used for modeling wind speed data [15]. The Weibull probability density function is given by Equation 1 where k and c are the Weibull parameters and v is wind speed [16]. Weibull distribution of the wind farm site is also obtained as shown in Figure 11.

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

According to the Weibull distribution, average wind speed is 6.49 m/s for 80 m elevation. Also, Weibull parameters shape factor and scale factor were calculated as 1.37 and 6.97 respectively. When these calculated values are compared with the CFD analysis and wind atlas, it can be said that the results match pretty well.

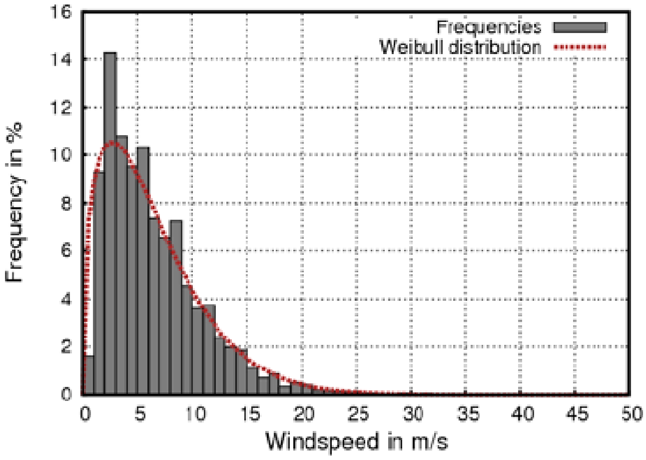

Figure 11.Weibull Distribution for all sectors.

In this study, wind farm design is carried out by considering wake affect. As shown in Figure 12, wake effect occurs when the wind turbines embower themselves and it causes a negativeeffect on wind farm efficiency. In this study, the Jensen wake model is selected due to the fact that it is widely used, quitesimple and effective [18].

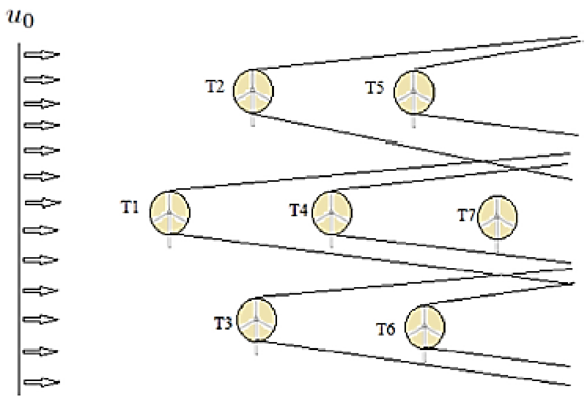

Figure 12.Multiple wake effect in the wind farm [17].

Adequate separation distance at the dominant wind direction must be ensured among the wind turbines in order to prevent wake affect, As shown in Figure 13, all turbines are installed horizontally and the distance between two adjacent wind turbines is set as 400 m. Thus, wake loss is calculated as 0.2% of the total energy production and this value is rather satisfactory in terms of wake effect.

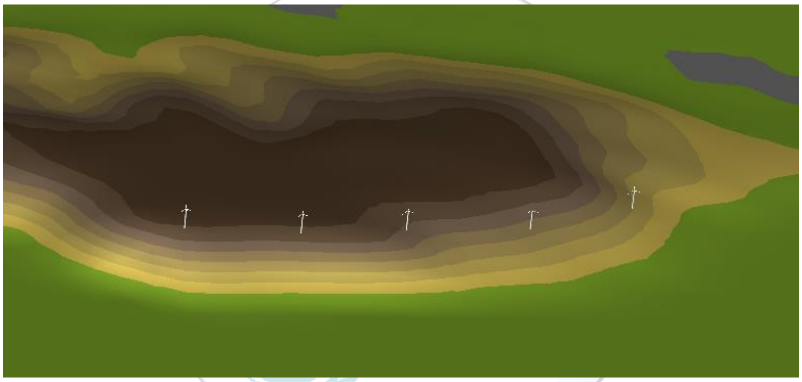

Figure 13.Wind farm layout.

4. ENERGY ANALYSIS

In this section, wind farm energy analysis is performed considering wake affect and air density change. In this study, the US Standard Atmosphere Model is used to calculate the air density change with elevation. The US Standard Atmosphere Model is given in Equation 2 where ρ and z are density and elevation respectively [19].

$$\rho = 1.225 - (1.194 \times 10 - 4) \times z \quad (2)$$

After this step, the model is applied to the Windsim software and then it issolved.According to the first analysis, AEP and capacity factor are calculated 28.7 GWh/y and 32.8% respectively. Also, wake loss is obtained as 0.4%. Hereupon, a new analysis is run by 239,800 cellsin order to ensure the mesh independent result.In second analysis, AEP, capacity factor and wake loss are calculated as given in Table 1.When the analysis results are evaluated, AEP value is same for all analysis. Also, when the first and second analyses are compared, it can be seen that relative error for capacity factor is 0.6%. Finally, it can be concluded that, establishment of a WPP that has 28.7 GWh/y AEP, 33% capacity factor and 0.2% wake loss is feasible in the Sinop Cape.Furthermore, energy curves of the selected wind turbines are obtained as given in Figure14.

Table 1.Energy Analysis Results

Cell Number	AEP(GWh/y)	Capacity Factor (%)	Wake Loss (%)
172,800	28.7	32.8	0.4
239,800	28.7	33.0	0.2

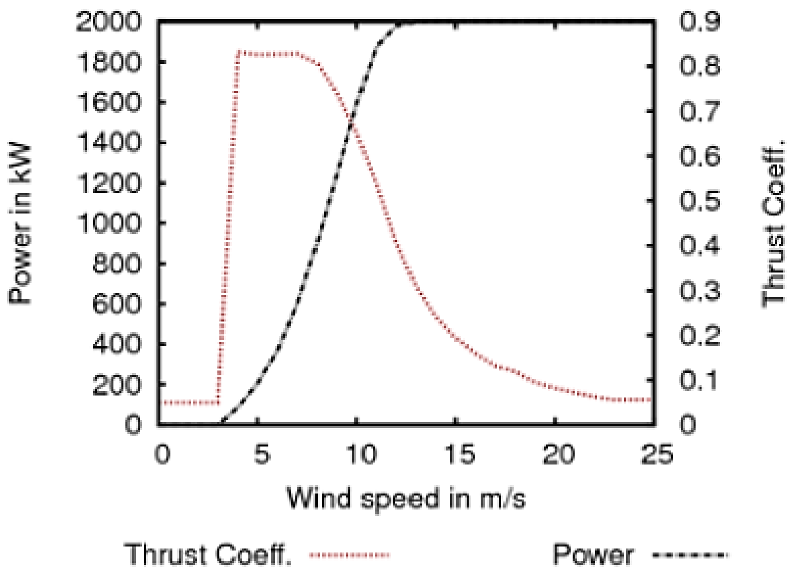

Figure 14.Turbine characteristics with power and thrust coefficient.

5. RESULTS AND DISCUSSIONS

Turkey's economy has been growing significantly and this development brings serious energy challenges for Turkey's future. According to Turkey's 2023 vision, the main target is to increase the share of renewable energy sources to at least 30% [20]. In the current situation, Turkey's installed wind power plant capacity is 4,718 MW [2]. When viewed from this perspective, investment in renewable energy sources should be increased to accomplish this objective. In this context,theSinop Province becomes important since it has remarkable wind power potential. Currently, there is a licensed WPP named Fener WPP in Sinop. The Fener Wind Energy Plant project will have a 5 MW installed power with 2 Enercon turbines, each 1,000 kW. It is expected that, 17.2 million kWh of electricity will be produced in a year [21]. However, this investment is not enough for harnessing the wind power potential oftheSinop Province. The number of the WPP should be increased to benefit the wind potential of the province.

In this case study, capacity factor and AEP of the designed WPP were calculated by Windsim using software considering wake affect.The wind data were obtained from the Turkish State Meteorological Service mast in Sinop. However, height of this measurement mast is only 10 meters and it is required to extrapolate the data to the hub height of wind turbine. In this context, the Wind Power Law was used for this aim.However, this approach caused some errors in the results. If a special measurement mast whose elevation is the same with the hub height of the turbines d installed in the wind farm site, more reliable data could be acquired. Although the data were extrapolated for 80 m elevation, a good convergence was handled. Thus, CFD result, Weibull distribution results and the wind atlas values were obtained fairly similar. Moreover, AEP and capacity factor were calculated as 28.7 GWh/y and 33.0% respectively. On the other hand, cost analysis such as the cost of turbine acquisition, installation and running cost, along with grid connection,were not taken into account in this study. If these parameters were considered, more reliable results could be obtained.

6. CONCLUSIONS

In this work, a case study of installation of a WPP was revealed for theSinop Province, Turkey. The study shows that hourly average wind speed is 6.5-7.0 m/s at 80 meters elevation in Sinop and this wind speed is satisfactory for a WPP investment in the region. In addition, the regions located near the coast side of the Sinop Cape are pretty convenient in terms of roughness formation and distance to ETL. The study also indicates that establishment of a WPP which has 28.7 GWh/y energy production capacity is feasible by five Vestas V90 commercial wind turbines. Also, the capacity factor of the designed wind farm was calculated as 33% and this value is convenient for an economic investment. The main objective of this study is providing inputs to the investors and the policy makers for harnessing the wind potential of the region.

ACKNOWLEDGEMENT

The authors would like to thank the Turkish State Meteorological Service for their support given to this work.

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