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Software-based wind energy potential assessment: a case study from western Turkey

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Software-Based Wind Energy Potential Assessment: A Case Study from Western Turkey

Highlights

- *Weibull distribution has been utilized in the wind energy potential assessment.*
- *Average wind speed values and prevailing wind directions have been calculated for the selected locations in the analyzed region.*
- *Estimated electrical energy generation values for Enercon E-101/3000 and Nordex N117/3000 turbines were obtained between 10177-11925 MWh/year and 9283-10954 MWh/year, respectively.*

Graphical Abstract

In this research, wind energy potential of a specific region in Western Turkey has been analyzed by using WindPRO software. The analyzed site is located in Ayvacık district of Çanakkale province of Turkey.

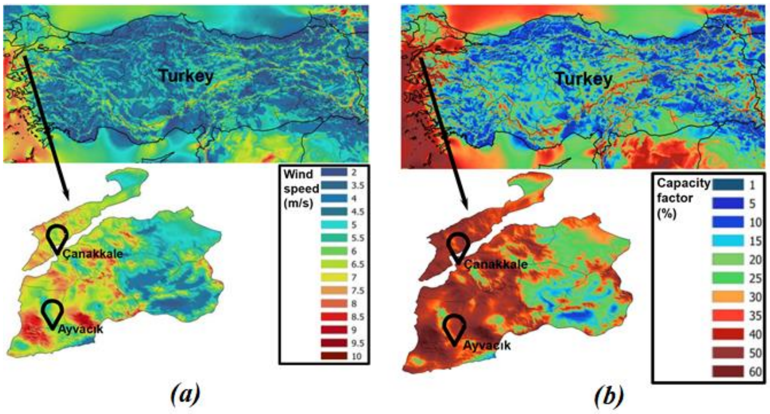

Figure. (a) Wind speed distribution and (b) capacity factor distribution of Çanakkale province and Turkey (at 100 m height)

Aim

Wind energy potential of a specific region in western Turkey, shape and scale parameters for each wind directions and annual energy generation values of each location have been calculated within the scope of this work.

Design & Methodology

Two types of wind energy turbines with 3 MW power including Enercon E-101/3000 and Nordex N117/3000 have been selected for the analyses.

Originality

Weibull distribution has been utilized in the wind energy potential assessment. Also, average wind speed values and prevailing wind directions have been calculated for the selected locations in the analyzed region.

Findings

Estimated electrical energy generation values for Enercon E-101/3000 and Nordex N117/3000 turbines were obtained between 10177-11925 MWh/year and 9283-10954 MWh/year, respectively.

Conclusion

The maximum power density was found as 3 for Enercon E-101/3000 and Nordex N117/3000 wind turbines. For Nordex N117/3000 turbine, October gets maximum wind speed while February gets minimum wind speed.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Software-Based Wind Energy Potential Assessment: A Case Study from Western Turkey

Araştırma Makalesi / Research Article

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ABSTRACT

In this research, wind energy potential of a specific region in Western Turkey has been analyzed by using WindPRO software. The analyzed site is located in Ayvacık district of Çanakkale province of Turkey. Two types of wind energy turbines with 3 MW power including Enercon E-101/3000 and Nordex N117/3000 have been selected for the analyses. Weibull distribution has been utilized in the wind energy potential assessment. Also, average wind speed values and prevailing wind directions have been calculated for the selected locations in the analyzed region. The prevailing wind direction was determined for Enercon E-101/3000 and Nordex N117/3000 turbines as NNW and SSE, respectively. Estimated electrical energy generation values for Enercon E-101/3000 and Nordex N117/3000 turbines were obtained between 10177-11925 MWh/year and 9283-10954 MWh/year, respectively. Moreover, shape and scale parameters for each wind directions and annual energy generation values of each location have been calculated within the scope of this work.

Keywords: Wind energy, potential assesment, software, windPRO, western Turkey.

1. INTRODUCTION

Due to the rapid advancement of technological developments, increased population effects, and current emissions problems, supplying continuous energy is becoming the world's common problem. This is where most of the energy needs are met, both because of the rapid depletion of fossil fuels, and because of the emissions problems that are secreting them, alternative energy sources are increasing. Renewable energy sources such as solar, wind, and hydrogen energy are becoming quite popular. Both clean and sustainable aspects of renewables provide a positive perspective.

Wind power plants have a system that basically converts mechanical energy into electric energy. Many studies have been conducted on this specific field of research. Astolfi et al. (2022) studied wind turbine performance in the long term with SCADA data analysis. This study examined and analyzed the operational values of 7 wind turbines from 2011 to 2020. In this study, 4 of the wind turbines found positive long-term results, 2 of them negative for literature, and 1 showed high levels of loss of yield, and suggested more work should be done [1]. Similarly, Pellegrini et al. (2021) conducted a study on the performance of micro wind turbines. In the study, they concluded that micro wind turbines had a cost-cutting rate of up to 75% in operating performance over 20 hours per day at 6 m/s and indicated the potential to compete other renewable applications [2].

In order to establish wind energy farm in a specific region/area, the wind energy potential of the region should be analyzed in detail. There are some studies are available on wind potential of designated areas. Zahedi et al. (2022) studied wind energy potential of western region of Iran by using computational techniques. According to the findings, wind energy capacity of the specific region has been determined as 1900 MW [3]. Kose et al. (2004) investigated the region's wind energy potential using CALLaLOG and ALWIn softwares linked to the Weibull and Rayleigh distribution using 20 months of wind speed data from 10 m and 30 m [4]. Ozerdem and Turkeli (2005) studied on predicting wind energy content calculations. They stated that micro-settled turbines with nominal power of 600 and 1500 kW can produce 100.3 GWh and 122.4 GWh of energy per year, respectively [5]. Similarly, Rogers et al. (2019) studied the wind energy potential of small island states and studied the wind potential of Barbados. As of 2003, the region's wind speed data was taken hourly and with the use of Weibull distribution, wind speed was obtained at 9.81 m/s [6]. Akpinar and Akpinar (2004) studied on utilization of Weibull and Rayleigh distributions to determine wind energy potential of a specific region of Elazig province, Turkey. The average wind speed of the region was found between 5 and 6 m/s, and the average power density was 244.65 W/m^2 [7]. Argin et al. (2019) conducted a research on the offshore wind power potential in Turkey. In this study, they performed statistical investigation using WAsP software and determined the most appropriate regions. They stated that the overall potential was 1629 MW [8]. Özerdem et al. (2006) conducted a feasibility study of a wind power

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plant in Izmir, Turkey, and took advantage of the Weibull distributions. In the structed scenario, they put the unit energy cost at 2.68 UScent/kWh [9]. Dabar et al. (2019) analyzed the wind supply from NCEP-CFSR and ERA5 models to generate electricity from wind power in three regions of the Republic of Djibouti [10].

The production of electrical energy from wind energy has reached a crucial point due to increased energy demand. There are some studies available in the scientific literature that focused on examining wind turbine performance and improving efficiency. Akkaya et al. (2020) analyzed the wind speed data of the Mersin region of the Turkey via Artificial Neural Network approach [11]. Guo et al. (2022) conducted a study that contains future trends and performance of offshore wind turbines and analyzed more than 280 relevant studies [12]. Heragy et al. (2022) analyzed the performance of a cross-flow wind turbine by employing computational fluid dynamics to improve its performance with wind concentrator. As a result of the study, they observed an increase in wind power density from 0.12 to 0.25 [13]. Jahani et al. (2022) performed a review study on offshore wind turbines. The most significant factors related to structural dynamics such as offshore wind turbines model alignment, aeroelasticity, hydroelasticity and ground-stake interaction have been analyzed within the scope of this work [14]. Pichandi et al. (2022) worked on the performance of wind turbines with horizontal and vertical axes combined using computational fluid dynamics technique. Obtained data has been optimized using Taguchi method. The optimized wind turbine configuration was applied in a specific terrain and the outcomes has been evaluated and performance improvement of the new configuration has been presented [15]. Muheisen et al. (2021) analyzed the wing structure of an horizontal-axis wind turbine to improve its performance. Studies show a 16% increase in the number of power coefficients with the designed wing structure [16].

In this work, software-based wind energy potential investigation of a specific region in Turkey has been done. Selected region is located in Ayvacık, Çanakkale province. It should be stated that the region studied is located in one of the provinces with the highest wind energy potential in Turkey. Main aim of this study is to show the applicability of computational methods in determining wind energy potential of a specific region, selecting appropriate wind turbine installation location and wind turbine type. WindPRO software which works with the Weibull distribution has been utilized within the scope of this investigation. Power values for two different heights have been calculated and the region's wind energy potential has been analyzed.

2. METHODOLOGY

2.1. Investigated Region and Utilized Software for the Potential Assessment

Specific softwares and statistical approaches are generally utilized to investigate the wind energy potential of a specific region. In this work, windPRO software has been utilized to analyze the wind energy potential of the selected location. By employing windPRO, different types of parameters such as wind speed, predominant wind direction and wind power can be determined based on Weibull distribution.

In this study, Ayvacık, a district of Çanakkale province of Turkey, was examined in terms of wind energy potential. Çanakkale province is one of the regions with the highest wind energy potential in Turkey. Fig. 1 presents wind speed of maps of Çanakkale and Turkey. Wind speed of Çanakkale varied between 3.06-9.86 m/s. Also, average wind speed of the entire province is 6.14 m/s. Çanakkale province has average capacity factor of %34.63. Moreover, minimum and maximum capacity factor values of Çanakale province is %6.66 and %63.2, respectively.

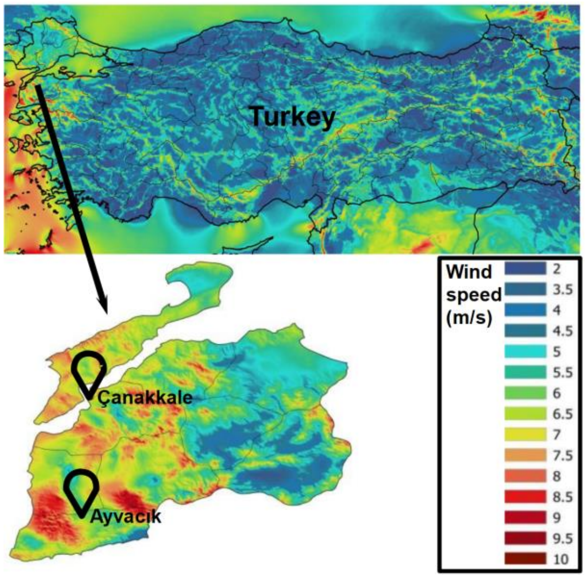

Figure 1. Wind speed distribution of Çanakkale province and Turkey (at 100 m height) (Wind Energy Potential Atlas, 2022)

Fig. 2 shows capacity factor of Çanakkale and Turkey. Given figures (Fig. 1 and Fig. 2) were adapted from the official website of Ministry of Energy and Natural Resources of Turkey (Wind Energy Potential Atlas, 2022). It should be indicated that capacity factor distribution maps are given by considering the technical values of a 3 MW wind turbine.

Analyzed region in map view is given in Fig. 3. Investigated region is located in the south west of the Ayvacık center. It should be indicated that, two different wind turbines including Enercon E-101/3000 and Nordex N117/3000 were selected in the analyses of the region. Selected wind turbines are widely utilized in commercial wind energy power plants. Also, selected wind turbines (manufacturers) were utilized in many scientific papers that analyzed wind energy potential of specific regions [17, 18]. Specifications and power curves of the selected wind turbines are given in Table 1 and Fig. 4, respectively.

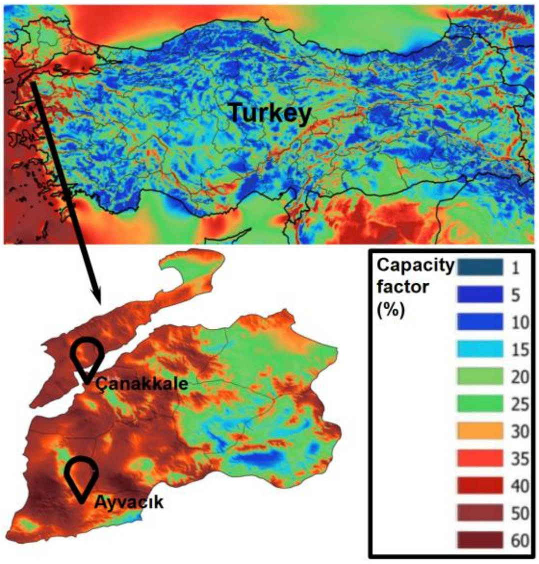

Figure 2. Capacity factor distribution of Çanakkale province and Turkey (at 100 m height) [19]

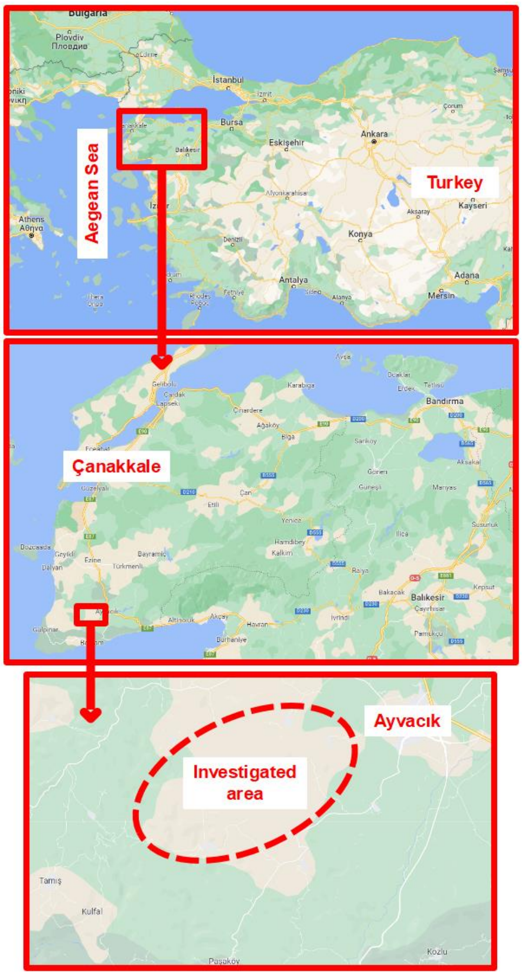

Figure 3. Presentation of the analyzed region

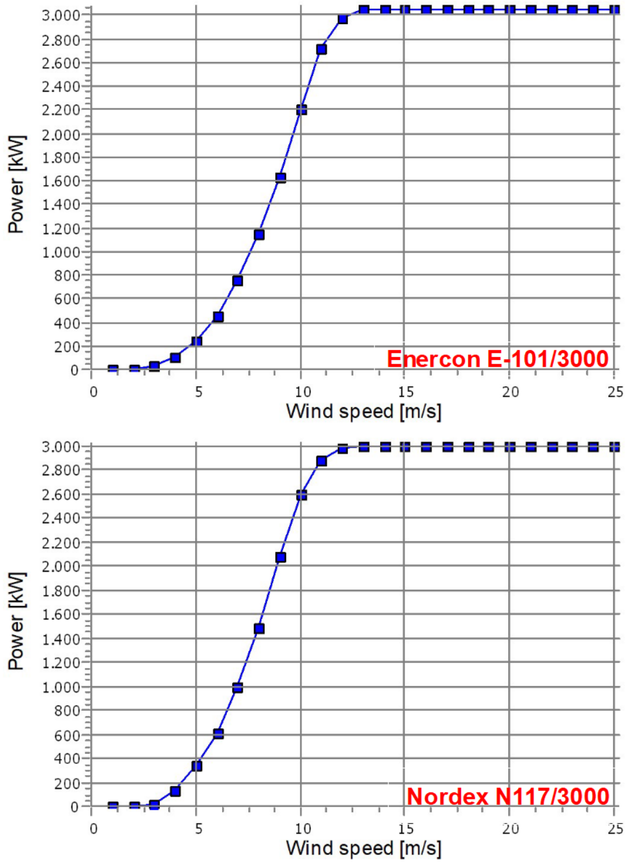

Figure 4. Power curves of the selected wind turbines

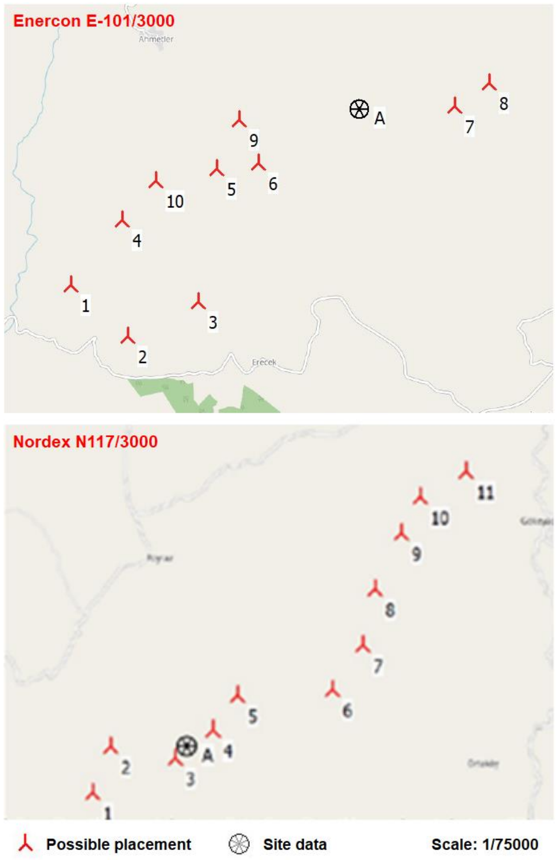

Figure 5. Possible placement locations for the analyzed wind turbines

Table 1. Specifications of the selected wind turbines

Brand	Model	Hub height	Specifications	
Enercon	E-101/3000	99 m	Rated power	3000 kW
			Rotor diameter	101 m
			Number of blades	3
			Specific area	2.68 m^2/kW
Nordex	N117/3000	91 m	Rated power	3000 kW
			Rotor diameter	116.8 m
			Number of blades	3
			Specific area	3.58 m^2/kW

Table 2. Calculated wind speed and energy data for the planned locations for two types of turbine type

Enercon E-101/3000			Nordex N117/3000		
Location	Wind speed (m/s)	Generated energy (MWh/year)	Location	Wind speed (m/s)	Generated energy (MWh/year)
1	8.64	11087	1	8.00	10156
2	8.63	11091	2	7.84	10157
3	9.02	11835	3	8.21	10546
4	8.76	11175	4	7.61	9314
5	8.65	10776	5	8.27	10954
6	8.83	11465	6	7.87	9955
7	9.13	11731	7	7.93	10014
8	9.00	11925	8	7.86	10017
9	8.60	11186	9	7.57	9283
10	8.21	10177	10	8.31	10671
			11	8.04	10372

Coordinates of the analyzed site were entered to the software and ten-minute wind speed data between 12.03.2014-11.06.2015 has been achieved. The losses in the received data are negligible. By using WindPRO, 10 and 11 possible placement locations have been determined for Enercon E-101/3000 and Nordex N117/3000 wind turbines, respectively considering the terrain features of the analyzed site. Possible settlement plan for Enercon E-101/3000 and Nordex N117/3000 wind turbines are given in Fig. 5.

2.2. Theoretical Calculations

The start of energy production of wind turbines takes place after a certain wind speed. For this reason, the selection of the place where the wind farm will be installed, the placement of the wind turbines and the determination of the wind turbine type to be used in the region are of great importance. For this reason, statistical analysis of the wind potential of the region is made using wind data. For statistical analysis, the Weibull distribution is generally used because it has few parameters and is easy to estimate and is suitable for the wind potential of many regions. Shape (k) and scale (c) parameters are important metrics in analyzing wind energy potential by using Weibull distribution. Probability density function of the Weibull distribution can be given as follows [17]:

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

Here, v, k and c represent instantaneous wind speed, shape parameter and scale parameter, respectively. Given equation indicates the probability of realization of instantaneous wind speed v.

Cumulative probability density function can be expressed as below:

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \quad (2)$$

Cumulative probability density function expresses the probability of occurrence of v wind speed or less wind speed. Moreover, average wind speed can be achieved by using Eq. (3):

$$V_{ave} = c\,\Gamma\left(1 + \frac{1}{k}\right) \quad (3)$$

Power density expression can be given as follows:

$$P/A = \frac{1}{2}\rho c^{3}\Gamma\left(1 + \frac{3}{k}\right) \quad (4)$$

In Eqs. (3) and (4), Γ depicts Gamma function. Also, ρ shows density of air. The scale parameter changes in direct proportion to the average wind speed. The shape parameter depends on the variation of the wind speed. Weibull parameters are determined by different methods in the scientific literature (Bulut and Açıkkalp, 2013).

3. RESULTS AND DISCUSSION

The wind speed data obtained from each turbine for the determined locations and the amount of energy likely to be produced are given in Table 2. As can be seen from the table, the average wind speed at 99m hub height varies between 8.21-9.13 m/s, while the average wind speed at 91m hub height varies between 7.57-8.31 m/s.

The possible amount of energy and losses that can be produced from each turbine according to the directions are given in Fig. 6. While the maximum energy for the Nordex N117/3000 turbine is obtained in the southeast direction, the most loss is also obtained in this direction. The least production for Nordex N117/3000 is in the south-west direction. The least energy production for the Enercon E-101/3000 turbine is in the west direction, while the highest production is in the east direction. The superiority of the Nordex N117/3000 turbine can be clearly seen from the given figure. Moreover, Weibull distribution frequency values are given in Fig. 7. The suitability of the region's wind potential to the Weibull distribution can be seen from the figure given for both turbines.

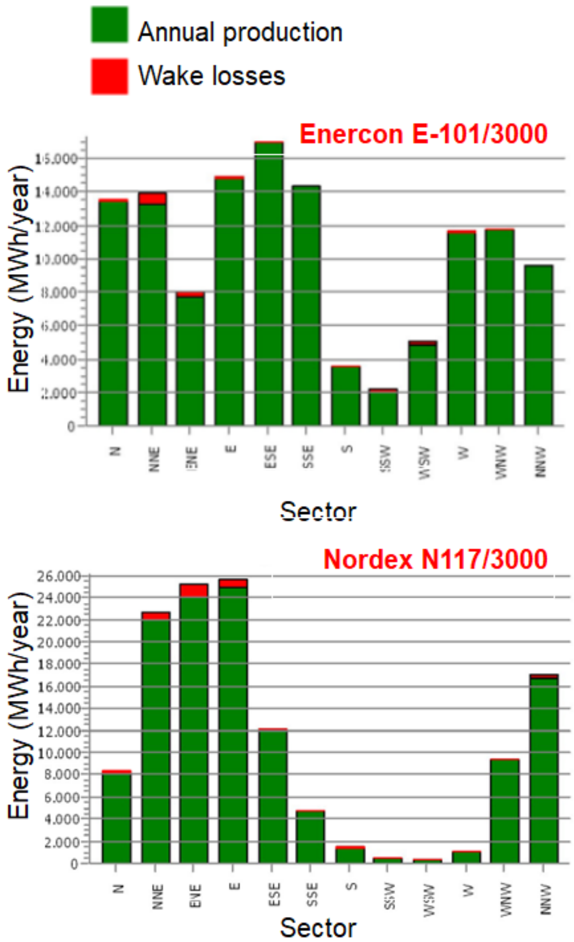

Figure 6. Amounts of energy produced according to wind directions

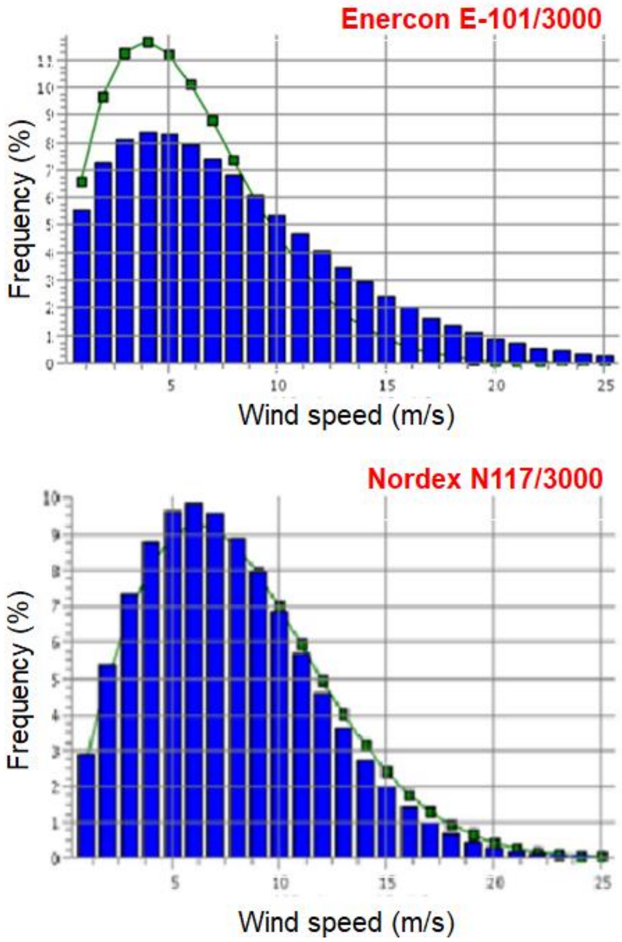

Figure 7. Weibull distribution frequency values

Wind measurements were made by entering the necessary coordinates into the WindPRO software for the Ayvacık district of Çanakkale. The prevailing wind direction was determined by taking daily average wind speed and wind direction data from March 13, 2014 to June 10, 2015. For the Weibull distribution, the shape parameter and scale parameter values were determined according to the directions and turbines. Since the scale parameter depends on the average wind speed, this value varies approximately between 4 and 9 for the Enercon E-101/3000 turbine. The scale parameter was higher in the prevailing wind direction. The scale parameter for the Nordex N117/3000 turbine ranges about between 5-10. Similar to the Enercon E-101/3000 turbine, the scale parameter is higher in the prevailing wind direction. The shape parameter approximately between 1.5-2 in the Enercon E-101/3000 turbine and approximately between 4.2 and 12 in the Nordex N117/3000 turbine. The determined values are given in Table 3. Additionally, wind roses for both turbines are presented in Fig. 8. It can be seen from the figure that the prevailing wind direction is south according to the Enercon E-101/3000 wind turbine, and east relative to the Nordex N117/3000 wind turbine.

Table 3. Calculated shape and scale parameters by using WindPRO for different wind directions

	Wind turbine type					
	Enercon E-101/3000			Nordex N117/3000		
Direction	c (m/s)	k	frequency	c (m/s)	k	frequency
N	7.59	1.74	8.1	10.01	2.19	11.4
NNE	9.81	2.32	16.3	8.54	2.49	9.8
ENE	8.35	1.98	20.6	6.57	1.92	5.6
E	8.49	2.04	18.8	9.07	1.78	7.9
ESE	8.55	1.84	8.5	10.09	1.63	10.4
SSE	7.81	1.62	4.5	12.69	1.48	12.1
S	5.96	1.48	2.3	6.8	1.15	5.3
SSW	4.61	1.84	1.3	5.17	1.32	4.2
WSW	4.35	2.07	1.0	5.51	1.50	5.8
W	5.47	1.99	1.4	7.21	1.85	8.2
WNW	8.97	2.04	6.5	8.35	1.76	9.3
NNW	9.93	2.24	10.8	9.50	1.49	9.9

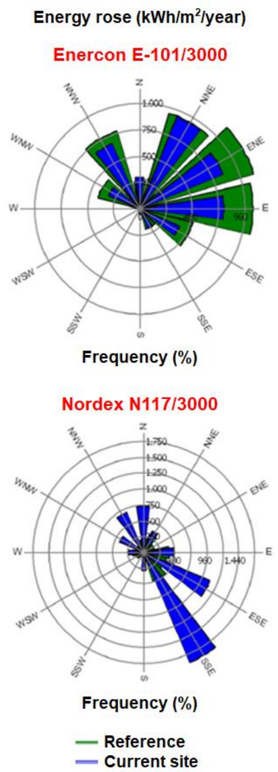

Figure 8. Energy roses for the investigated wind turbines

4. CONCLUSION

In this work, wind energy potential of a specific region in western Turkey has been analyzed by using computational techniques. Coordinates of the analyzed site were entered to the software and ten-minute wind speed data between 12.03.2014-11.06.2015 has been achieved. The losses in the received data are negligible. Therefore, all data were used while determining the wind potential of the region. Main findings of the present research can be given as follows:

- Wind speed values obtained by using Enercon E-101/3000 and Nordex N117/3000 wind turbines are between 3-16 m/s and 3-17 m/s, respectively. Moreover, average standard deviation of wind speed data for Enercon E-101/3000 and Nordex N117/3000 wind turbines were found as 0.785 and 0.708, respectively.
- The maximum power density was found as 3 for Enercon E-101/3000 and Nordex N117/3000 wind turbines. For Nordex N117/3000 turbine, October gets maximum wind speed while February gets minimum wind speed. Depending on the wind speed, the amount of power obtained from the turbine also changes.
- Maximum energy output is obtained from the specific region in the autumn season. The prevailing wind direction determined according to WindPRO for Enercon E-101/3000 and Nordex N117/3000 turbines is NNW and SSE, respectively. It was determined that Nordex N117/3000 wind turbine is more suitable for the region in comparison to Enercon E-101/3000 turbine as more energy is achieved.

ACKNOWLEDGMENT

Authors would like to thank Vega Energy and Mr. Erman Kaya for their technical support during the preparation of this research.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Fatma Kadriye DÜDEN ÖRGEN: Calculated the therorical values and analyse the results.

Ayça ALTINTAŞ: Calculated the therorical values and analyse the results.

Sezai YAŞAR: Calculated the therorical values and analyse the results.

Murat ÖZTÜRK: Calculated the therorical values and analyse the results.

Erdem ÇİFTÇİ: Calculated the therorical values and analyse the results.

Azim Doğuş TUNCER: Calculated the therorical values and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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