Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 33(1), ss. 17-26, Mart 2018
Çukurova University Journal of the Faculty of Engineering and Architecture, 33(1), pp. 17-26, March 2018

Statistical Analysis of Wind Energy Density in the Babuburnu-Çanakkale Region of Turkey

Akın İLHAN[1], Mehmet BİLGİLİ[*2], Beşir ŞAHİN[1]

[1]*Çukurova Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Adana*
[2]*Çukurova Üniversitesi, Ceyhan Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Adana*

Geliş tarihi: 22.09.2017 *Kabul tarihi: 14.03.2018*

Abstract

The total of feasible wind energy potential is estimated to be 47 GW in Turkey, and especially Çanakkale, İzmir, Balıkesir and Hatay basins are excellent wind resources for wind farm installations. Therefore, the capability of the wind power potential of Bababurnu-Çanakkale province in the Marmara region of Turkey was reported in the context of this study. Parameters including the superior wind velocity direction, average wind velocity, Weibull and Rayleigh parameters, probability distribution, and wind power potential of this province were processed and analyzed in terms of annual, seasonal and monthly point of view. Finally, at a level of 10 m over the ground surface, the average wind velocity and average wind energy potential in this site were determined as 6.01 m/s and 257 W/m^2, respectively according to the whole processed data. These data indicated that Bababurnu-Çanakkale region has an acceptable wind energy potential, which is quite reasonable for planting wind power turbines.

Keywords: Installed capacity, Wind speed, Wind direction, Wind power, Power density, Weibull model, Rayleigh model, Frequency distribution, Sustainable energy

Bababurnu-Çanakkale Bölgesindeki Rüzgar Enerji Yoğunluğu İstatistik Analizi

Öz

Türkiye'deki uygulanabilir rüzgar enerjisi potansiyelinin 47 GW dolaylarında olduğu tahmin edilmektedir. Özellikle, Çanakkale, İzmir, Balıkesir ve Hatay havzaları rüzgar çiftliklerinin kurulumu için mükemmel rüzgar kaynaklarına sahip bölgelerdir. Bu sebeple, Türkiye'nin Marmara Bölgesi, Bababurnu-Çanakkale yöresindeki rüzgar gücü potansiyelinin uygulanabilirliği, bu çalışma kapsamında bildirilmektedir. Bu yörenin rüzgar hızı ve yönü, ortalama rüzgar hızı, Weibull ve Rayleigh parametreleri, olasılık dağılımı ve rüzgar gücü potansiyeli gibi parametreleri, yıllık, mevsimlik ve de aylık işleme tabii tutularak analiz edilmiştir. Sonuçta, yer seviyesine ilaveten 10 m üzeri bir rakım değerinde, mevcut verilerin analiziyle, bu mevkiye ait, ortalama rüzgar hızı ve ortalama rüzgar hızı potansiyeli, sırası ile 6,01 m/s ve de 257 W/m^2 olarak tespit edilmiştir. Böylece, Bababurnu bölgesinin; rüzgar türbinlerinin inşaası kapsamında, kabul edilebilir bir rüzgar enerjisi potansiyeline sahip olduğu gösterilmiştir.

Anahtar Kelimeler: Kurulu güç, Rüzgar hızı, Rüzgar yönü, Rüzgar gücü, Güç yoğunluğu, Weibull modeli, Rayleigh modeli, Frekans dağılımı, Sürdürülebilir enerji

[*]Sorumlu yazar (*Corresponding author*): Mehmet BİLGİLİ, *mbilgili@cu.edu.tr*

1. INTRODUCTION

Renewable energy is the type of energy that is obtained from non-depletable sources which create relatively a low level of carbon-dioxide emissions. In this regard, renewable energy necessarily differs from other types of energy sources such as fossil fuels, therefore, many countries all over the world including Turkey develop different incentives and subsidy schemes to promote its use [1]. In addition, renewable energy being an important agent for the alleviation of future's global climate change is a promising method of energy obtainment. Wind energy has attained a relatively better position among other renewable energy sources and has demonstrated the highest growth throughout the world for the last years as it has been used for quite a long period of time throughout the world. Thus, wind energy which is an environmentally friendly renewable energy source makes its usage to become rapidly widespread [2].

Among the numerous advantages of wind power including low cost, purity, sustainability and being abundance in anywhere in the world establishes its position to become further stronger among other renewable sources. There is no transportation problem in wind energy and high technology is not necessary for its employment. Wind energy is a clean energy resource and it cannot be depleted ever in contrast to fossil fuel sources. All types of energy production put some negative effects on the environment; however, wind energy causes considerably low and local effects which are manageable and negligible compared to traditional energy resources. In fact, the importance of wind energy comes from its friendly effects on the environment. For this reason, wind power is demanded electricity production to reduce air pollution resulting from fossil fuels [3].

In addition, wind power can be put into use more rapidly than other energy technologies, which is another advantage of wind energy. While a conventional power plant takes 10 to 12 years or even more to be installed, wind power plant can be put into operation in a few months; as well as a conventional power plant cannot produce power unless it is completely built up, however, a wind power plant can start power generation as long as the installation of the first power plant in the wind farm is completed [4].

Wind power currently is the fastest growing sector for electricity production, and it has demonstrated the fastest growth among all renewable energy sources for the past years [5]. Turkey has a considerable wind power potential particularly in the region of Marmara, western coasts and southern Anatolia. However, wind energy potentials in other regions of Turkey are reported by Yumak et al. [6], Yaniktepe et al. [7], Genc et al. [8], Bilgili et al. [9], and Sahin et al. [10]. In this regard, this study was performed in order to report the wind power properties in Bababurnu-Çanakkale location in the Marmara region of Turkey. Certain parameters including wind velocity probability or frequency distribution, frequency distribution of the wind velocity directions, Weibull and Rayleigh parameters, average wind velocity and variations of wind power potential were calculated. Each of these wind characteristics was separately investigated using seasonal, monthly and hourly data.

2. MATERIALS AND METHODS

The Weibull distribution function is considered in wind power applications to conform well with wind data [11-13]. A two-parameter distribution is defined as indicated in Eq. (1) below;

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

Considering parameters of Eq (1); k, $f_w(v)$, and c are the dimensionless Weibull shape parameter, the probability of observing wind velocity v, and finally the Weibull scale parameter, respectively.

On the other hand, the cumulative probability function of the Weibull distribution is calculated as below:

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

There are several methods of determining Weibull k and c parameters, such as least-square fit to observed distribution method, mean wind speed-standard deviation method, the maximum likelihood method [14-21]. In this study, the two parameters k and c, are obtained using mean wind speed-standard deviation method. According to this method, Weibull k and c parameters are expressed with Eq. (3) and Eq. (4), respectively.

$$k=\left(\frac{\sigma}{v_m}\right)^{-1.086} \quad (1 \leq k \leq 10) \quad (3)$$

$$c=\frac{v_m}{\Gamma(1+1/k)} \quad (4)$$

Where v_m is the mean wind speed and is calculated using Eq. (5). σ is the standard deviation and is calculated using Eq. (6). Γ() is the Gamma function. For any y value, it is usually written as Eq. (7).

$$v_m=\frac{1}{n}\left[\sum_{i=1}^{n} v_i\right] \quad (5)$$

$$\sigma=\left[\frac{1}{n-1}\sum_{i=1}^{n}\left(v_i-v_m\right)^2\right]^{\frac{1}{2}} \quad (6)$$

$$\Gamma(y) = \int_0^\infty \exp(-x)x^{y-1}dx \quad (7)$$

Where n is the number of hours in the period of the considered time such as month, season or year.

A simplified form of the Weibull function provides the Rayleigh function. It is necessary to consider the scale factor, *c* of the Weibull function equivalent to 2 for the conversion of the Weibull function to the Rayleigh function. The Rayleigh probability density function is presented in Eq. 8 by [12],

$$f_R(v)=\frac{\pi v}{2v_m^2}\exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{v_m}\right)^2\right] \quad (8)$$

3. RESULTS AND DISCUSSION

The results considered in the present work were received from Bababurnu-Çanakkale station situated in the Marmara region of Turkey. This meteorological station was constructed by the (EIE). The location of the station presented in Figure 1 presents the map of the region. The long-term wind data consists of hourly wind velocities and their corresponding wind directions considering three different years. Monthly, annually and diurnal average wind velocities were determined through processing of hourly wind velocities. Anemometer positioned at the wind velocity measuring station is located at a height of 10 m over the ground surface. The station of wind observation is located at the coordinates of 39^{o}30'03'' N latitude and 26^{o}12'39'' E longitude. The altitude of this station is 348 m above the sea level. There is no obstacle around the wind velocity measuring area that would influence wind velocities and their corresponding wind directions. The models of Weibull and Rayleigh are employed in this study for the investigation of the wind characteristics in this site.

Figure 1. Map of the region and location of the station

Wind direction has a decisive importance in evaluating the possible utilization of wind power. Therefore, statistics of wind direction have a significant task for determining the right position of wind turbines according to the roughness of the terrain. It is known that wind direction and speed are also affected by the topography. The wind direction and frequency distribution in Bababurnu site are presented in Figure 2. Results of three years reveal that the dominant wind direction of Bababurnu site is obtained to be NE (30°) as clear from this figure.

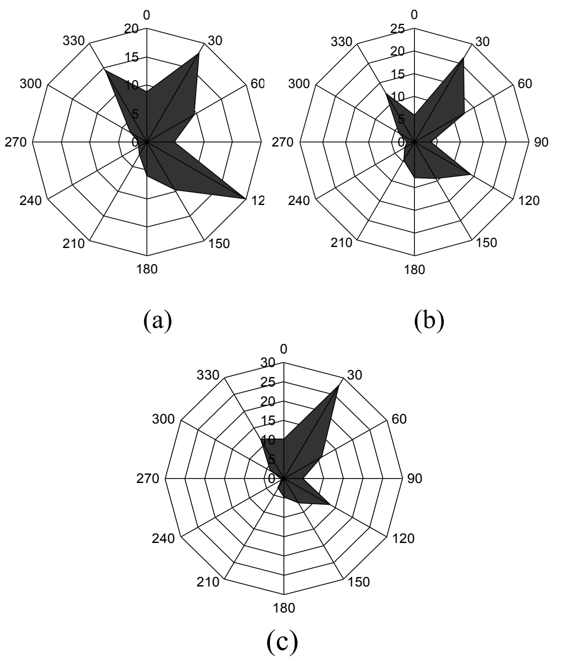


Figure 2. Wind direction and frequency distribution for Bababurnu station, considering (a) 1st (b) 2nd (c) 3rd years of measurement time

The diurnal wind velocity in terms of the hourly variation of the mean wind speed obtained from the first year data of Bababurnu site is indicated in Figure 3. In the consideration of the summer season, the diurnal wind velocity obtained in this study varies from 4.83 m/s to 8.16 m/s, and this speed interval indicates to be quite high for wind energy conversion systems. While the minimum level of diurnal wind speed occurs at morning hours, it was shown that maximum wind speed occurs at afternoon hours. Namely, after 12 o'clock and 11 o'clock, rapid increased values of wind speeds for the time ranges including 14-16 o'clock and 14-17 o'clock were reported for the autumn and summer seasons, respectively.

Maximum enhancements of wind speeds for both seasons were calculated to be 41% and 69% for autumn and summer seasons, respectively, according to the maximum and minimum values of the average daily results depending on the mean hourly variation of the wind speeds of first-year data. Also, maximum enhancements of wind speeds for spring and winter seasons according to the maximum and minimum values of the average daily results of first year data were reported to be 24% and 19%, respectively. This result is attributed to the high level of solar intensity throughout the afternoon times of the day. Namely, wind can be defined as a motion of air masses. Air masses move because of different thermal conditions of the masses. This motion of the air masses can be stated as global and regional phenomenons. During the day, the ground solar heating causes thermal mixing resulting in the downward transfer of momentum. As a result of these different thermal conditions, generally, a maximum wind velocity is observed after midday. On the other hand, after sunset, usually, wind velocities are relatively calm near the surface [13].

During a typical day in Bababurnu site, the difference between the highest and lowest average hourly wind velocity is considerable which is much influenced by the seasonal variation. For instance, average diurnal ranges determined according to the maximum and minimum average hourly values of winter and summer seasons are observed to be 1.16 m/s and 3.33 m/s, respectively. Namely, this gives point on the diurnal variation to be more pronounced in summer season compared to the winter season. Thus, diurnal fluctuation in spring and winter seasons is less with respect to the autumn and summer seasons. Peak values of wind speed which were 6.36 m/s at 14 o'clock; and 7.17 and 7.24 m/s at 4 o'clock and 15 o'clock were obtained considering spring and winter seasons, respectively.

Especially the results of summer seasons occur due to surface heating, which increases mixing of the faster-moving air at the higher levels with the air near the surface. As long as the surface heating effect is diminished like in winter seasons, the wind velocity decreases and significant variation cannot be observed from hour to hour during the night. Also, the diurnal variation is the greatest on sunny days and least on dull days.

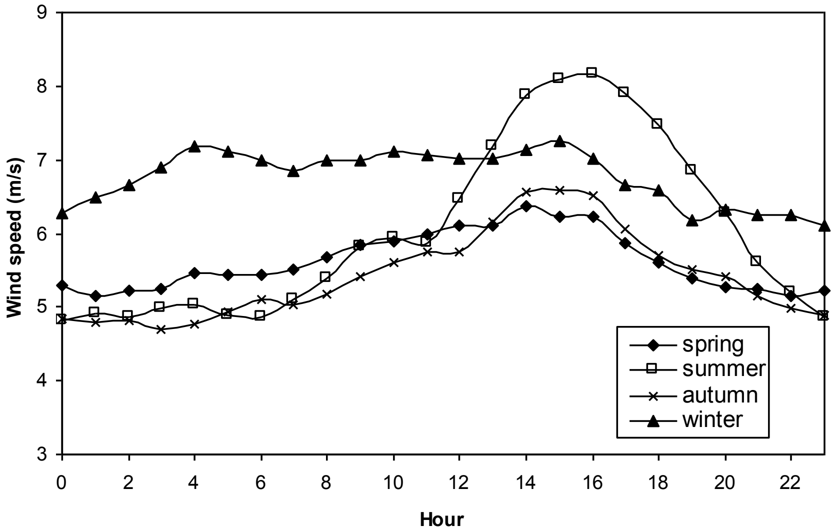


Figure 3. Hourly variation of the mean wind speed for Bababurnu station

The seasonal and yearly Weibull parameters for Bababurnu-Çanakkale station are indicated in Table 1. The value of Weibull shape parameters, *k* and Weibull scale parameters, *c* vary within the range of 1.78≤k≤ 2.14 and 6.1 m/s ≤c≤ 7.8 m/s, respectively according to the processed data of the first year as indicated in Table 1. Here, the maximum value of the *c* parameter is seen in winter season as 7.8 m/s. However, the minimum value of the *c* parameter is observed in autumn season corresponding to 6.1 m/s. Also, while the biggest value of *k* parameter is seen in summer season as 2.14, the smallest value of *k* parameter is seen in autumn season being equal to 1.78.

Table 1. Seasonal and yearly Weibull parameters for Bababurnu station

Season	Weibull scale parameters (*c*), m/s			Weibull shape parameters (*k*)		
	1^{st} year	2^{nd} year	3^{rd} year	1^{st} year	2^{nd} year	3^{rd} year
Spring	6.4	5.95	5.62	2.09	2.12	1.61
Summer	6.7	6.37	6.72	2.14	2.26	2.22
Autumn	6.1	5.12	6.10	1.78	1.98	1.79
Winter	7.8	6.21	7.22	2.09	1.81	1.89
Yearly average	6.8	5.92	6.42	1.98	2.00	1.84

Due to its convenience in statistical analysis, time series of wind velocity data are generally organized in the form of the frequency distribution. The frequency distribution and probability density of wind velocities provide answers to certain questions including duration of wind turbine that generates electricity. In this context, common questions that can be addressed during new wind power plant installments usually involve the duration of wind shortages, the most frequent wind velocity ranges and how frequently wind turbines attain their maximum efficiencies. Considering these reasons, the available times-series of wind data were transformed into a form of a frequency distribution in the scope of this study. The Mathematical representation of the wind velocity probability distributions and the corresponding functions are principal tools used in the wind-related literature.

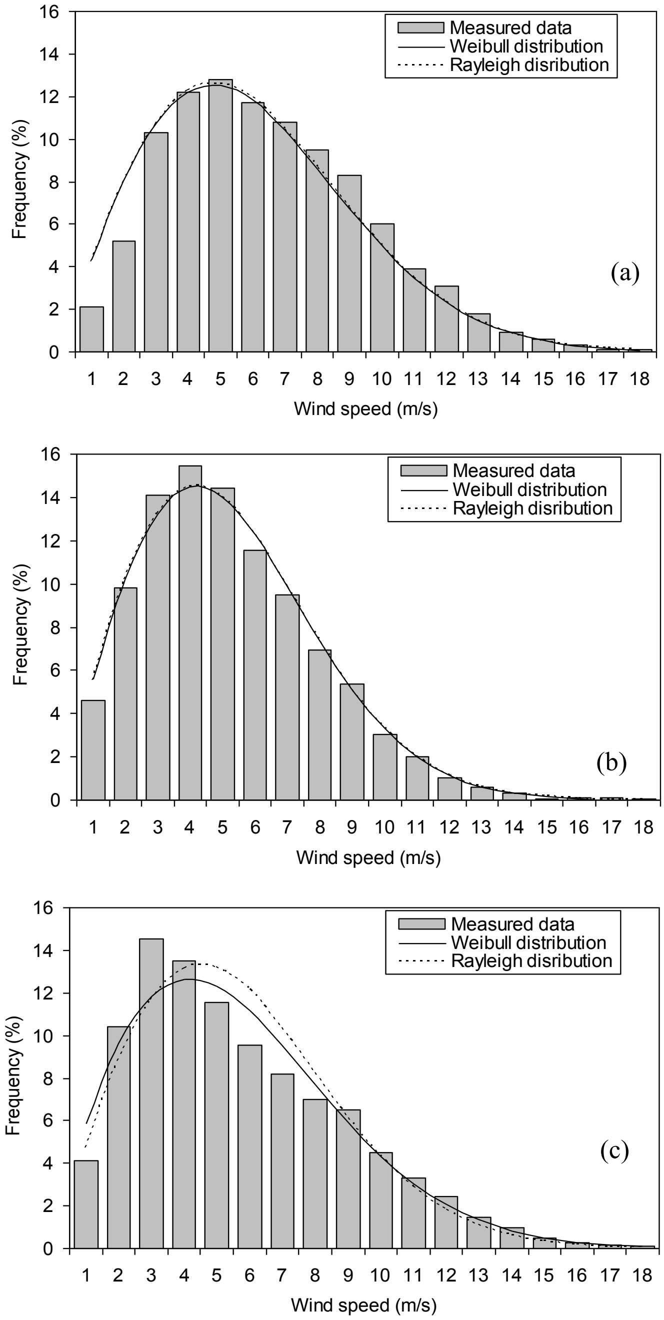


Figure 4. Wind speed frequency distributions for Bababurnu station, considering (a) 1st (b) 2nd (c) 3rd years of measurement time

Annual wind velocity frequency variations considering the data of three years taken into consideration for Bababurnu-Çanakkale station are presented in Figure 4a, Figure 4b, and Figure 4c respectively. These figures clearly show that the distributions of Weibull and Rayleigh parameters indicate the same variations for the considered years, however small discrepancies occurred according to two function results especially within the range of speed $3\,m/s < V \leq 9\,m/s$ considering the third year as shown in Figure 4c. On the other hand, the even small discrepancy is valid between both functions; taking measured data into account reveals that Weibull function generally generates better results with respect to the Rayleigh distribution within the considered wind speeds range. According to the wind speed frequency distributions during the third year, except values of wind speeds; V=1m/s, V=3m/s, V=4 m/s, V=9 m/s, and V=10 m/s; Weibull function gave better prediction results according to the measured data. While at wind speed values of V=3 m/s and V=10 m/s, both functions produced the same result; at wind speed values of V=1 m/s, V=4 m/s and V=9 m/s, Rayleigh distribution gave better results.

Considering this wind speed interval, it is clear from Figure 4c that Rayleigh distribution exceeded Weibull distribution with a maximum discrepancy percentage around 7.4% for wind speed of 5 m/s. Beyond this limit, i.e. at smaller wind speed values, exceeding of Weibull distribution over Rayleigh distribution was observed. Beyond wind speed values of $V < 3\,m/s$, discrepancies were also observed between Rayleigh and Weibull functions. But this is not distinct as much as the wind speed interval of $3\,m/s < V \leq 9\,m/s$. Furthermore, very small discrepancies are also observed considering the first year of the data. However, it was reported that the best fitted curves with each other according to results of both functions were obtained for the second year of the data.

Designers and researchers working on the winenergy conversion systems should take speed and power potential of wind into account to be the most two significant parameters for these systems. Wind power production is basically depended on the level and stability of wind velocities. In this regard, monthly variations of the average wind velocity and wind power potential of Bababurnu-Çanakkale station are presented in Figures. 5 and 6, respectively. According to the Figure 5, considering the monthly variations including mean wind speeds for 1st, 2nd and 3rd years, Weibull and Rayleigh models yielded similar data based on the measured data. About 79%, 52%, and 84% wind speeds increments were measured for 1st, 2nd and 3rd years of data. It is interesting to note that considering monthly variations of wind power potential of three years in Figure 6, the Weibull distribution is seen to be better compared with the distribution of Rayleigh parameter, also for the third year where Weibull distribution is also better. Furthermore, the wind speed and power density demonstrate rapid changes in each month. Thus, there is a general trend for the power density not to exceed 300 W/m^2 is observed, when first eleven months of 1st year data is taken into account. However, this value is observed to be exceeded more than two times in December. Also, again according to 1st year data, the monthly average wind velocities with the highest value are mainly seen in December and August as 8.3 m/s and 6.5 m/s, respectively. But, the smallest magnitudes of wind velocities are observed in September and May having 4.6 m/s and 4.9 m/s, respectively. In parallel with this, the highest monthly average wind energy potentials are mainly seen in December and August having 603 W/m^2 and 290 W/m^2 wind energy, respectively, while the smallest values of wind energy potential are observed in September and May such as 103 W/m^2 and 152 W/m^2, respectively according to 1st year data.

Table 2 presents the annual and seasonal mean wind speed and wind power potential of Bababurnu site. According to the 1st year of data, the annual average wind velocity is demonstrated to be 6.01 m/s corresponding to annual average wind energy potential of 257 W/m^2. Wind energy potential can be utilized for new installations of wind power plants since these wind properties are shown to be acceptable in this study.

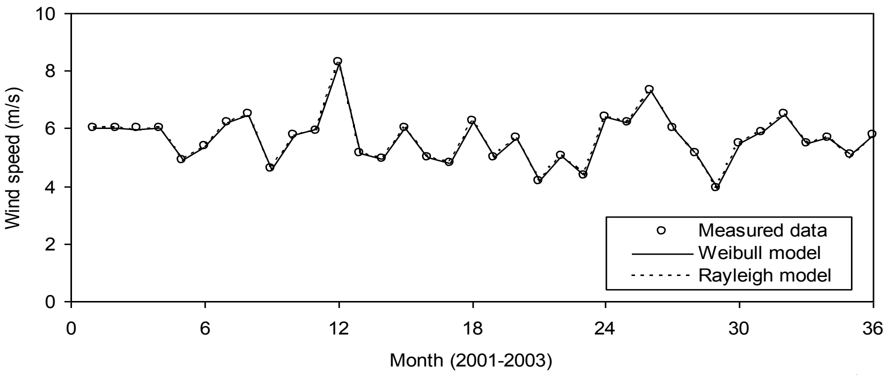
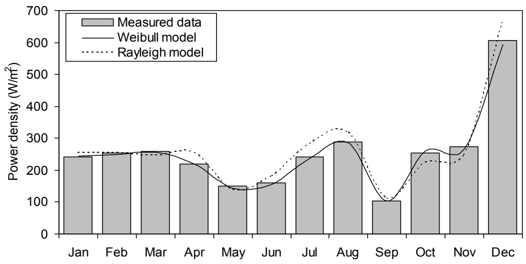
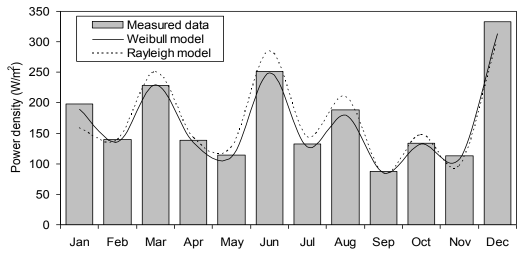


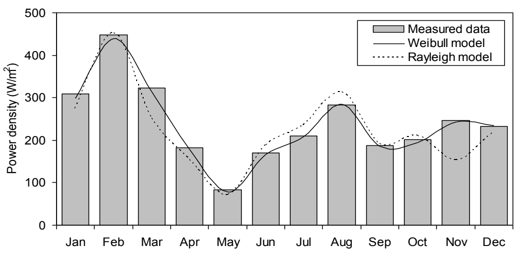
Figure 5. Monthly variations of mean wind speed for Bababurnu station, considering (a) 1st (b) 2nd (c) 3rd years of measurement time



(a)



(b)



(c)

Figure 6. Monthly variations of wind power potential for Bababurnu station, considering (a) 1st (b) 2nd (c) 3rd years of measurement time

Table 2. Seasonal and yearly wind speed and wind energy potential for Bababurnu station

Season	Wind speed, m/s			Wind energy potential, W/m^2		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year
Spring	5.71	5.27	5.04	209	161	196
Summer	5.96	5.64	5.95	232	187	222
Autumn	5.44	4.54	5.43	214	112	212
Winter	6.93	5.52	6.41	374	226	325
Yearly average	6.01	5.24	5.7	257	171	239

4. CONCLUSIONS

In Turkey, the total of feasible wind energy potential is estimated to reach 47 GW. There are also excellent wind resources in Turkey, particularly in Çanakkale, İzmir, Balıkesir and Hatay basins to be addressed for incoming wind farm installations. Based on the results of this study, the territory of Bababurnu-Çanakkale is shown to have an acceptable wind power potential. The hourly wind velocity magnitude was found to be bigger than 5 m/s around 70% of the total duration at a level of 10 m over the ground surface in this region. But, the monthly average wind velocities according to the 1st year of data were determined to be higher than 5 m/s throughout ten months of the year, and the monthly average wind energy potentials also considering 1st year of data were greater than 200 W/m^2 throughout nine months of the year. The yearly mean wind speed was measured as 6.01 m/s and this gave a corresponding yearly mean wind energy potential which was calculated as 257 W/m^2. These values in this study are shown to be acceptable for the generation of the wind power in this region.

5. ACKNOWLEDGEMENTS

The authors wish to thank the office of Scientific Research Projects of Cukurova University for funding this project under contract no. FBA-2017-8589.

6. REFERENCES

1. Ilkilic, C., 2012. Wind Energy and Assessment of Wind Energy Potential in Turkey. Renewable and Sustainable Energy Reviews, 16, 1165–1173.

2. Saidur, R., Islam, M.R., Rahim, N.A., Solangi, K.H., 2012. A Review on Global Wind Energy Policy. Renewable and Sustainable Energy Reviews, 14, 1744–1762.

3. Bilgili, M., Simsek, E., 2012. Wind Energy Potential and Turbine Installations in Turkey. Energy Sources Part B, 7, 140–151.

4. GWEC. Global Wind Energy Council; 2013 http://www.gwec.net (last viewed June 25, 2013).

5. White, S.W., 2006. Net Energy Payback and CO_2 Emissions from Three Midwestern Wind Farms: An Update. Natural Resources Research, 15, 271-281.

6. Yumak, H., Uçar, T., Yayla, S., 2012. Wind Energy Potential on the Coast of Lake Van. International Journal of Green Energy, 9(1), 1-12.

7. Yaniktepe, B., Koroglu, T., Savrun, M.M., 2013. Investigation of Wind Characteristics and Wind Energy Potential in Osmaniye Turkey. Renewable and Sustainable Energy Reviews, 21, 703-711.

8. Genc, M.S., Gokcek, M., 2009. Evaluation of Wind Characteristics and Energy Potential in Kayseri, Turkey. Journal of Energy Engineering-ASCE, 135, 33-43.

9. Bilgili, M., Sahin, B., Kahraman, A., 2004. Wind Energy Potential in Antakya and İskenderun Regions, Turkey, Renewable Energy, 29(10), 1733-1745.

10. Sahin, B., Bilgili, M., Akilli, H., 2005. The Wind Energy Potential of the Eastern Mediterranean Region of Turkey. Journal of Wind Engineering and Industrial Aerodynamics, 93(2), 171-183.

11. Eskin, N., Artar, H., Tolun S., 2008. Wind Energy Potential of Gokceada island in Turkey. Renewable and Sustainable Energy Reviews, 12, 839-851.

12. Gokcek, M., Bayulken, A., Bekdemir, S., 2007. Investigation of Wind Characteristics and Wind Energy Potential in Kirklareli, Turkey. Renewable Energy, 32, 1739-1752.

13. Incecik, S., Erdogmus, F., 1995. An Investigation of the Wind Power Potential on the Western Coast of Anatolia. Renewable Energy, 6, 863-865.

14. Celik, A.N., 2004. On the Distributional Parameters used in Assessment of the Suitability of Wind Speed Probability Density Functions. Energy Conversion and Management, 45, 1735-47.

15. Genc, A., Erisoglu, M., Pekgor, A., Oturanc, G., Hepbasli, A., 2005. Estimation of Wind Power Potential using Weibull Distribution. Energy Sources, 27, 809-822.

16. Seguro, J.V., Lambert, T.W., 2000. Modern Estimation of the Parameters of the Weibull Wind Speed Distribution for Wind Energy Analysis. Journal of Wind Engineering and Industrial Aerodynamics, 85, 75-84.

17. Bilgili, M., Hassanzadeh, R., Sahin, B., Ozbek, A., Yasar, A., Simsek, E., 2016. Investigation of Wind Power Density at Different Heights in the Gelibolu Peninsula of Turkey. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 38, 512-518.

18. Bilgili, M., Yasar, A., 2017. Performance Evaluation of a Horizontal Axis Wind Turbine in Operation. International Journal of Green Energy, 14(12), 1048-1056.

19. Akpinar, E.K., Akpinar, S., 2004. Determination of the Wind Energy Potential for Maden-Elazığ, Turkey. Energy Conversion and Management, 45, 2901-2914.

20. Akpinar, E.K., Akpinar, S., 2004. Statistical Analysis of Wind Energy Potential on the Basis of the Weibull and Rayleigh

Distributions for Agin-Elazığ, Turkey. Journal of Power and Energy, 218, 557-565.

21. Akpinar, E.K., Akpinar, S., 2006. An Investigation of Wind Power Potential Required in Installation of Wind Energy Conversion Systems. Journal of Power and Energy, 220, 1-13.