Eurasian Journal of Science Engineering and Technology

Research

A COMPARISON OF WEIBULL AND RAYLEIGH DISTRIBUTION FUNCTIONS WITH MOMENT METHOD: A CASE STUDY OF OSMANİYE REGION IN TURKEY

Yusuf Alper KAPLAN[1,*], Gülizar Gizem ÜNALDI[2]

[1, 2] *Osmaniye Korkut Ata University, Department of Energy Systems Engineering, Osmaniye, Turkey*

ABSTRACT

In this study, wind energy potential of Osmaniye region is assessed statistically by using the hourly wind speed data of Turkish State Meteorological Service between 2009 and 2013. This study introduced the evaluation of Weibull Distribution Function and Rayleigh Distribution Function for Osmaniye Region. Weibull function is utilized for the situations such as there exist no information about wind speed distribution measurement or frequency distribution. Moment Method is used to calculate the Weibull and Rayleigh parameters. Moment Method, Weibull and Rayleigh Distribution Functions are explained in detail in this paper. Additionally, the Relative Percentage Error (RPE) statistical test is used to compare the efficiency of these distribution functions. The calculated power density of all used distribution function is a major key issue for suitability of wind energy. The evaluation of parameters and wind power distribution have a crucial role in producing electricity from wind power. The calculated power densities of all used distribution functions were compared with wind power density derived from measured wind data. This paper reveals the effectiveness of Weibull and Rayleigh Distribution Functions by using Moment Method for Osmaniye region of Turkey.

Keywords: Wind Energy, Weibull Distribution, Rayleigh Distribution, Moment Method.

1. INTRODUCTION

Nowadays, the need of energy has been increasing day by day with the population growth and the advancements of technology [1]. It can be said that energy is consumed rapidly globally and as a result of this consumption, the energy demand increases day by day. Hence, the search of new energy resources becomes vital for the entire world. Energy is the most significant factor which affects economic structure of a country. As is known, energy is seen as not only the internal dynamics of the countries but also a strategic case which affects international relations, including political as well as military conflicts. Energy is also a primary element of economic and social development in the world [2].

The world has begun to focus on resources that will cause less harm to the environment and to the people in order to satisfy the energy need that cannot be prevented and these sources are called as sustainable energy resources. It is explained that the use of renewable energy sources which are environmentally sensitive, do not cause global warming and climate change are friendly to the world and significantly reduce foreign dependency in the economy. The utilization of these renewable energy resources should be increased instead of the conventional energy which are used in our contemporary life to fulfill energy demand. One of the most common and useful renewable energy resource can be thought as wind power.

Wind energy has been used in irrigation, wheat-grinding, vessels and many other fields because it is an environment-friendly future energy resource. Furthermore, wind energy is used for providing the energy requirement that will be the most important problem of the future world. Currently, wind energy is seen as a positive alternative to fossil fuels and also a way to assist the expansion of local economies in future. The world will use renewable energy instead of using fossil fuels in order to satisfy the demands of the world's energy [3], [4].

The wind power density is an important indicator to determine the potential of wind resources and to describe the amount of wind energy at various wind speed values in a particular location. The knowledge of wind power density is also useful to evaluate the performance of wind turbines and nominate the optimum wind turbines. Wind power density resembles the level of accessible energy at the site which can be converted to electricity by using wind turbines. There are two approaches to calculate wind power density. In the first approach which is more accurate, the wind power density is computed based on measured wind speed data. However, as an alternative method, the wind power density can also be calculated using a proper distribution function.

Among several probability distribution functions suggested in the literature for different applications of wind energy, the Weibull function is unquestionably one of the most popular and broadly used statistical distributions. The main merits of the

* Corresponding author, e-mail: alperkaplan@osmaniye.edu.tr
Recieved: 04.06.2020 Accepted: 24.09.2020

This article is the extended version of the paper that was presented in the UTUFEM Conference 2019.

Weibull function have been explained properly in Section 3.1. Furthermore, it should be mentioned that simplicity, flexibility, adaptability and favourable capability to fit with wind data are among the major advantages of this function. Therefore, Weibull distribution function is adopted in this study for wind power density calculation [5].

Kantar and Usta [6] analyzed the use of the minimum cross entropy principle in the estimation of wind speed distribution and wind power density functions. Moreover, they compared the Weibull PDF (probability density function) with the MinxEnt (minimum cross-entropy principle) PDFs. Akdag and Dinler [7] reviewed different methods, i.e. the graphical, maximum likelihood, moment methods and energy pattern method. Bilgili and Sahin [8] investigated wind energy density in the southern and southwestern region of Turkey by using the Weibull and Rayleigh probability density functions. Rocha et al. [9] deal with the evaluation and comparison of different numerical methods for the assessment of efficiency in determining the parameters for the Weibull distribution function, using wind speed data collected in Camocim and Paracuru cities. Freitas et al. [10] introduced a new approach for the analyzing of numerical methods used in calculating the Weibull distribution parameters for the prediction of wind energy source. Chang [11] reviewed the six kinds of numerical methods commonly used for estimating Weibull parameters. Bilir et al. [12] collected wind data for a one-year period between June 2012 and June 2013. Wind speed data, collected for two different heights (20 m and 30 m) from a measurement station installed in Atılım University campus area (Ankara, Turkey), were recorded using a data logger as one minute average values. They determined shape (k) and scale (c) parameter of Weibull using five different methods. Bidaoui et al. aim to evaluate and discuss the energy wind potential of five major cities in Northern Morocco. The theoretical analysis is based on stochastic models of Weibull and Rayleigh using Probability Density Function approach. Various statistical indicators such as the determination coefficient (R^2), Chi square error (χ^2), root mean square error (RMSE) and mean bias error (MBE) are considered. Then, a numerical simulation of the potential electrical power is carried out using the Enercon E103/2350 wind turbine model. Consequently, the results show that Weibull is more accurate than Rayleigh, especially for Tetuan and Al-Hoceima cities [13]. Azhar et al. have selected four sites of coastal region of Balochistan (Gwadar, Pasni, Jiwani and Ormara) and taken data for these selected sites from Pakistan Metrological Department for a period of five years (2010–2014) and they have done the statistical analysis of wind data by Weibull and Rayleigh probability distribution. Weibull and Rayleigh distribution functions have been derived from the available wind data, its parameters are estimated. The annual cycle of Weibull functions is fitted on yearly basis; it is found that the Weibull distribution that is fitting to the measured yearly probability distributions is better and suitable than the Rayleigh distribution for the five-year period (2010–2014) [14]. Sumair et al. purpose that to estimate wind potential using Normal probability density function. A comparison of five probability distributions namely Normal, Gamma, Chi-Squared, Weibull, and Rayleigh was done using three performance evaluation criteria. Four years (2015–2018) hourly wind data at 50 m height at five stations near the coastline of Pakistan was used. It was found that normal distribution gives the best fit at each of these stations and against each evaluation criterion followed by Weibull distribution while Rayleigh distribution gives the poorest fit [15]. Akpınar analyzed the wind energy potential of the Sinop region by using the Turkish State Meteorological Station's hourly wind speed data between the years of 2005-2014. The two- parameter Weibull and one-parameter Rayleigh probability distribution functions were used to determine the wind energy potential of the region. The probability distribution functions were derived from the cumulative function and used to calculate the mean wind speed and the variance of the actual data. In conclusion, The Weibull distribution function was found to be more appropriate than the Rayleigh distribution function [16].

This study aims to determine the wind energy potential in Osmaniye by using Weibull and Rayleigh Distribution Functions. Five-year data of the wind speed which is measured at 10-meter height from the General Directorate of State Meteorology is used to evaluate the wind energy of region. Based on the hourly-measured wind speed data, the convenient of Weibull and Rayleigh Distribution Function with measured real data statistically analyzed for the region. Although the data used in the study are 2009-2013, it is a current study within the scope of calculating wind power densities of the Weibull Distribution Function and Rayleigh Distribution Functions. By comparing the accuracy of the distribution functions, it makes possible to guide future studies. In addition to the purpose of this study is to reveal the comparison and success between Weibull and Rayleigh Distribution Functions for evaluation of wind energy in Osmaniye region.

2. WIND ENERGY POTENTIAL

The industrial growth of any country depends on creating a balance between energy production and its consumption. The production of energy depends on the availability of renewable and non-renewable energy resources. Non-renewable energy resources are in a continuous state of depletion and their scarcity is much felt in countries which are less developed. Furthermore, the adverse effects of fossil-fuel consumption for the energy production results in environmental deterioration. Therefore, the usage of renewable energy resources not only helps in reducing the fossil-fuel consumption but also reduces the green-house effect. The renewable energy resources are constantly replenished, naturally means sustainable and eco-friendly energy sources are available to humanity. This makes them one of the widely studied source of energy that are rapidly replacing conventional energy sources [17]. One of the most popular and having a high preferability resource is wind energy.

Wind energy is a clean and emission-free type that has been previously known, developed continuously and can compete with fossil fuels. Since it has no emission, it does not directly generate greenhouse gases and does not contribute directly to global warming. There exist no energy cost and operating costs are low. It is a type of energy that does not depend on other countries and is very efficient in certain regions. These positive features of wind energy are effective for increment of interest in this type of energy. Especially electrical energy production has come to the fore in recent times. Wind power is a low-density energy that abounds in the air. Wind has a natural potential because of its kinetic energy. The part of this potential that can be transformed scientifically and technically to energy is 'wind energy technical potential' whereas the part that can be considered economically is 'wind energy economic potential'. Easily affected by topography, surface structure and obscure obstacles, wind energy is predicted more difficultly than solar energy. Wind turbines produce energy in a certain wind speed range. Thus, the recognition of the wind regime of a region where wind energy systems will be established is of prime importance. The improvements in aircraft propellers and airfoils have triggered the evolution of wind turbines [1], [18].

Figure 1 shows the installed wind power capacity in the world from 2009 to 2019. It is seen from the figure that the total installed capacity of the world was 236.803 GW with more than 20% growth rate in the annual market at the end of 2011. More than 70 GW of new wind power capacity was installed around the world in 2013, bringing the total installed capacity up to 318.919 GW. This represents a year-on-year growth of 29.41 %. At the end of 2014, wind power installed capacity reached 371.336 GW in the world. Finally, the installed wind power in the world reached over approximately 650.8 GW as of the end of 2019 [19].

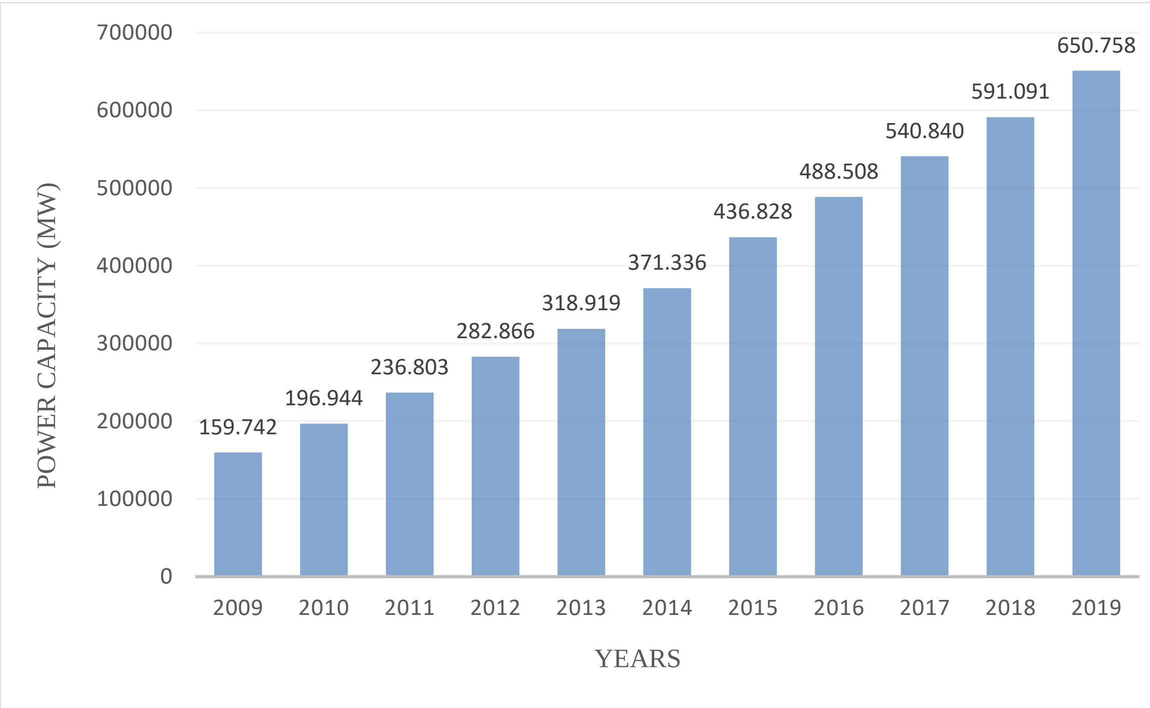

Figure 1. Installed Wind Power Capacity in the World

Turkey is one of the richest countries in terms of wind energy potential because the annual average speed of wind is greater than 7.5 m/s. According to the Turkey wind energy potential atlas prepared in 2007, at least 48.000 MW wind power is available in the regions where the annual wind speed is 7 m/s or over in Turkey [1]. Figure 2 shows that the installed wind power in Turkey year by year. In 2012, wind power capacity is increased with an amount of 506 MW and total installed wind power capacity is 2312 MW. In 2013, 646 MW of new wind power installed and total installed wind power has reached 2958 MW. Turkey added 804 MW of new wind power in 2014 for a total capacity of 3762 MW [20]. Finally, the installed wind power in Turkey reached 8056 MW as of the end of 2019. Turkey's installed capacity has grown by nearly 500 MW per year since 2010 and the national transmission company expects annual installations to reach 1,000 MW per year from 2019 onwards [21], [22].

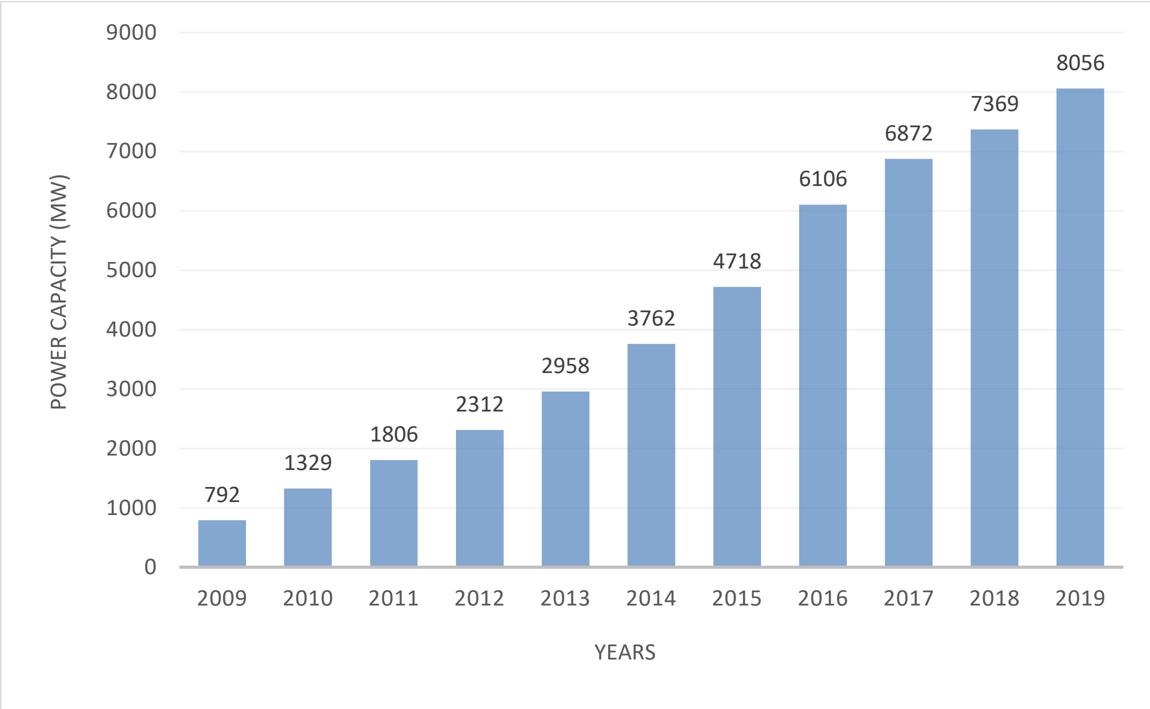

Figure 2. Installed Wind Power Capacity in Turkey

2.1. The wind characteristic of Osmaniye region

Osmaniye is a Turkish province located in southern of Turkey. It is shown in the Figure 3 that Osmaniye is in the Çukurova region of Turkey, the area of Osmaniye Province is 3,767 km² and Osmaniye is at an elevation of 125 meters (410.1 feet). This study aims to determine the wind energy potential in Osmaniye. It is collected the five years data of the wind speed measured at 10-meter height from the General Directorate of State Meteorology. Based on the hourly-measured wind speed data, the wind energy potential of this region has been statistically analyzed by using Weibull and Rayleigh Distribution Functions.

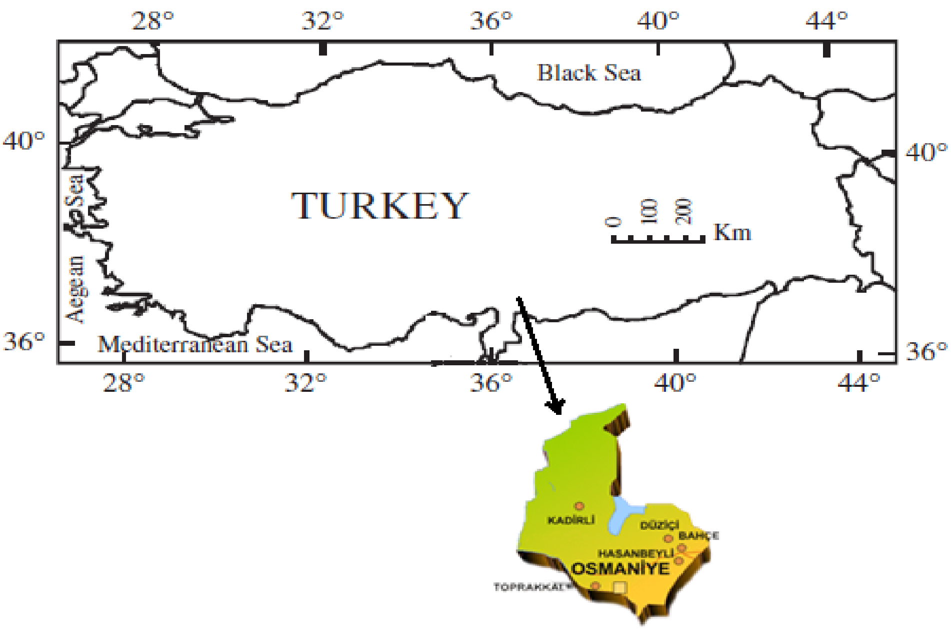

Figure 3. The map of Osmaniye

Figure 4 shows the density of wind directions according to wind frequency. The dominant wind direction of Osmaniye region is found by using a five-year wind data.

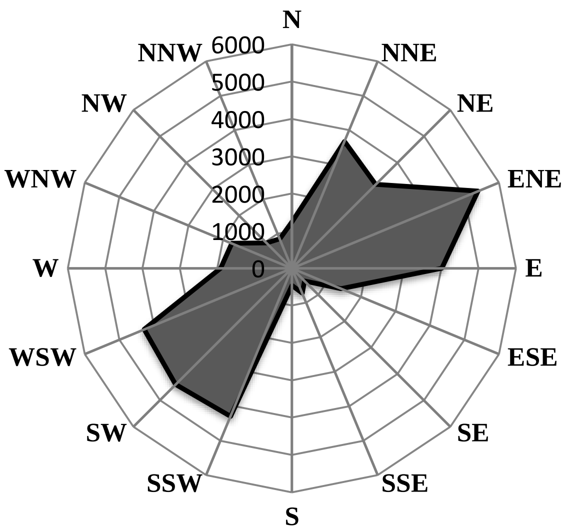

Figure 4: The variation of the wind directions.

3. STATISTICAL ANALYSIS

In practice, there exist various methods to determine the wind energy potential of a region. Wind speed distribution measurement or frequency distribution is used in order to determine the wind potential of a specific region if possible. If not, wind speed distribution can be presented by other analytic distribution functions. Weibull distribution function is one of these functions. Due to its simple and flexible application as well as giving results close to actual data, Weibull distribution is widely accepted in the wind energy analysis [23]. Two-parameter Weibull and Rayleigh distribution functions are the most popular of all. The Rayleigh distribution is less flexible than the Weibull as it is one-parameter. However, the calculation of parameters is easier in the Rayleigh distribution.

3.1. Weibull distribution function

The Weibull distribution is a distribution first introduced by Waloddi Weibull in 1951 to estimate the lifespan of machines. Today, it is widely used in statistical models in life-time data analysis and engineering. Depending on the values of the format parameter, the Weibull distribution, which also has Rayleigh and exponential distributions in some cases, is widely used in the models to be established for the data set related to failure rates. As it is known, continuous random variables are used to define random events in which the variable can take any value in a certain range. The Weibull distribution is also a continuous and at the same time flexible distribution and provides theoretically suitable solutions in many applications. In life analysis, logarithmic models are generally used instead of parametric models. In this sense, the Weibull distribution is also a logarithmic model.

The Weibull Distribution Function provides a close approximation to the probability laws of many natural phenomena. This function has been used to represent wind speed distributions for application in wind turbines studies for a long time. For more than half a century the Weibull Distribution Function has attracted the attention of statisticians working on theory and methods as well as various fields of statistics [24]. The wind data analysis of a region is prepared by the prediction of the region's potential performance through the pre-measured values. Hourly wind speed and wind direction details are observed in a place and statistical results are calculated for modelling the frequency and probability of the obtained results [8, 25]. First, as is seen in Table 1, the periodical frequency (the blowing number) and probability of wind speed are determined. Average wind speeds are grouped periodically in the second column of Table 1. The third column shows average wind speed for each speed ratio. The blowing number or frequency of each speed ratio is given in the fourth column.

The general expression of the two-parameter Weibull is given by,

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

The cumulative function of wind speed can be attained by computing the integral of the probability density function is given by,

$$P(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3}$$

Where $p(v)$ is the observed probability density function, $P(v)$ is the cumulative probability density function, shape (k) and scale (c) parameter of Weibull distribution function [26], [27].

Table 1. Periodical frequency and probability of hourly wind speeds

i	v_i **(m/s)**	v_{avg} **(m/s)**	f_i	$p(v_i)$	$P(v_i)$
1	0-1	0,5	9637	0,255467	0,255467
2	1-2	1,5	12295	0,325928	0,581396
3	2-3	2,5	5813	0,154097	0,735493
4	3-4	3,5	3141	0,083265	0,818758
5	4-5	4,5	2489	0,065981	0,884739
6	5-6	5,5	2113	0,056014	0,940752
7	6-7	6,5	1189	0,031519	0,972272
8	7-8	7,5	559	0,014819	0,98709
9	8-9	8,5	255	0,00676	0,99385
10	9-10	9,5	103	0,00273	0,99658
11	10-11	10,5	77	0,002041	0,998622
12	11-12	11,5	39	0,001034	0,999655
13	12-13	12,5	9	0,000239	0,999894
14	13-14	13,5	4	0,000106	1

Probability density of each speed ratio is given in following equation,

$$p(v_i) = \frac{f_i}{\sum_{i=1}^{N} f_i} \tag{1}$$

Here, f_i is frequency of occurrence of each speed class and N is number of hours in the period of time considered. $P(v_i)$ is the cumulated probability density which is illustrated in the sixth column of the Table 1.
The two-parameter Weibull distribution function is described for wind speed as follow Eq. (2) and as a cumulative distribution function given by Eq. (3) [26], [28]:

Actual probability density function and cumulative probability distributions derived from the long-term wind speed data of Osmaniye during 2009 to 2013 period are depicted in Figure 5.

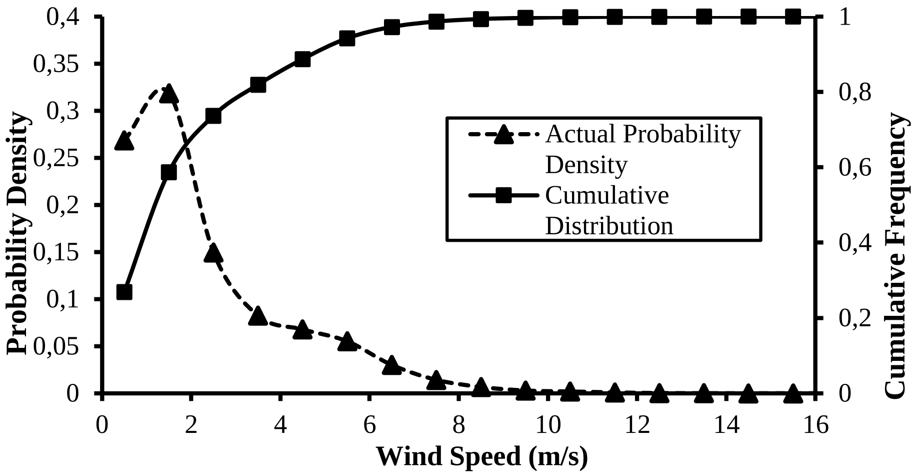

Figure 5: The wind speed probability density and cumulative distribution data of Osmaniye

The average wind speed 'V_m' and wind power density 'P_w' of Weibull Distribution Function can be estimated by the following equations:

$$V_m = c\Gamma\left(1 + \frac{1}{k}\right) \tag{4}$$

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{5}$$

Here, Γ shows the gamma function.

$$\Gamma(x) = \int_0^\infty e^{-u} u^{x-1} du \quad \text{and} \quad \Gamma(1+x) = x\Gamma(x) \tag{6}$$

3.2. Rayleigh distribution function

Rayleigh distribution is yet another statistical approach used for determining the wind speed distribution data. Depending on the reason of Rayleigh Distribution Function has single parameter, it behaves less flexible than Weibull Distribution Function; however, its parameters are easier to calculate. Also, it is known that when the average annual wind speed is greater than 4.5 m/s, the wind speed distribution approaches the Rayleigh distribution. In other words, the Rayleigh model is a special and simplified case of the Weibull model. It is obtained when the shape factor c of the Weibull model is assumed to be equal to 2. The probability density and the cumulative distribution functions of the Rayleigh model are given by [29], [30]:

$$f_R(v) = \left(\frac{2v}{c^2}\right) \exp\left\{-\left(\frac{v}{c}\right)^2\right\} \tag{7}$$

The Rayleigh cumulative distribution function is explained as follow:

$$F_R(v) = 1 - \exp\left\{-\left(\frac{v}{c}\right)^2\right\} \tag{8}$$

Average wind speed for the Rayleigh distribution is defined by Eq. (9) and power density by Eq. (10).

$$v_m = c\sqrt{\pi/4} \tag{9}$$

$$P_R = \frac{3}{\pi}\rho v_m^3 \tag{10}$$

One of the most distinct advantages of the Rayleigh distribution is that the probability density and the cumulative distribution functions could be obtained from the mean value of the wind speed [31]. Figure 6 illustrates the variation of Weibull, Rayleigh and observed wind speed frequencies of Osmaniye region for measured wind data.

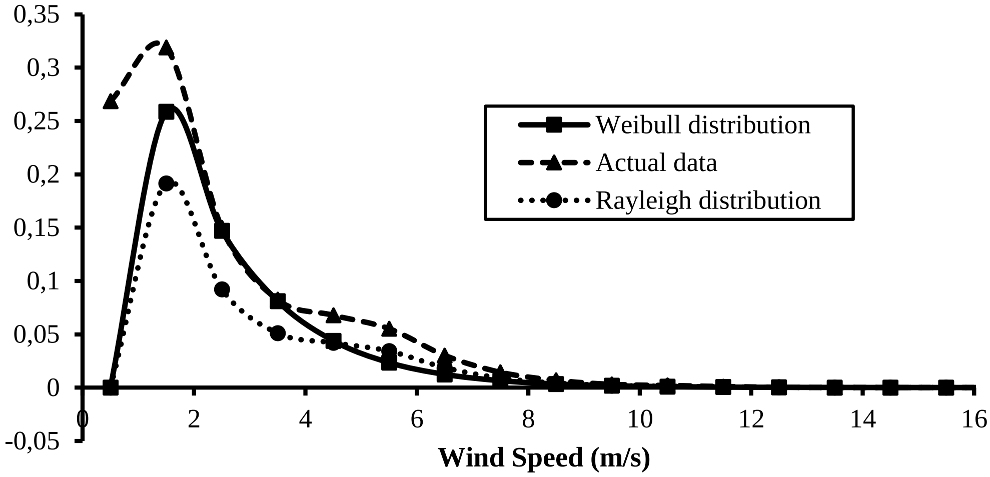

Figure 6: Weibull, Rayleigh and observed wind speed frequencies of Osmaniye

4. DETERMINATION OF WEIBULL PARAMETERS

There exist many different methods to determine the *k* and *c* parameters for used distribution functions. These parameters have a substantial role to calculate the average speed and power densities. In the literature, details on the use and application of four different mathematical methods, which are frequently used for the calculation of Weibull variables are Graphical Method, Most Likelihood Method, Least Squares Method and Moment Method. From all these methods, the Moment Method is used in this study to determine the scale and shape parameters.

4.1. Moment method

Moment method is one of the oldest method is used to determine Weibull distribution parameters. Moment method is a method that data distribution allows to solve the relationship between average and standard deviation values between the shape parameters using numerical methods for determining the scale of 1 to 10 and the shape parameter. Shape and scale parameters can be expressed as in Eq. (11) and Eq. (12) [9], [24].

$$\mathrm{k} = \left(\frac{\sigma}{\mathrm{v}_m}\right)^{-1{,}086} \tag{11}$$

Here Γ is Gamma function.

$$\mathrm{c} = \frac{Vm}{\Gamma\left(1+\frac{1}{\mathrm{k}}\right)} \tag{12}$$

Here, V_i is the measured wind speed σ, shows Standard deviation and $\mathrm{v_m}$ is average speed.

$$\mathrm{v_m} = \frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{v_i} \tag{13}$$

$$\sigma = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{Vi}-\mathrm{Vm})^2} \tag{14}$$

5. RESULTS AND DISCUSSION

In this study, two distribution functions are compared that it was compatible with actual data. The long term wind data must be measured in order to determine the wind potential of the selected area. The shape and scale parameters are separately calculated for each year. The Moment Method is used to determine the parameters of distribution functions, the calculated parameters are given in Table 2.

Table 2. Weibull and Rayleigh parameters for Moment Method

Moment Method	Weibull Parameters				Rayleigh Parameters			
	k	c(m/s)	V_M(m/s)	P_W(W/m²)	k	c(m/s)	V_M(m/s)	P_R(W/m²)
2009	1,3180	2,6514	2,4421	29,8923	2,00	2,7556	2,4415	17,0326
2010	1,2270	2,5727	2,4066	32,6371	2,00	2,7156	2,4060	16,3016
2011	1,2961	2,3207	2,1446	20,8568	2,00	2,4200	2,1441	11,5366
2012	1,4147	2,3641	2,1512	18,1422	2,00	2,4274	2,1507	11,6428
2013	1,2290	2,4413	2,2828	27,7674	2,00	2,5759	2,2823	13,9129
2009-2013	1,2656	2,4657	2,2902	26,5242	2,00	2,5841	2,2895	14,0462

The average wind speed 'V_M' and wind power density 'P_M' can be computed by the following equations for real time series data:

$$V_M = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{15}$$

$$P_M = \frac{1}{2}\rho\overline{V^3} \tag{16}$$

To determine the efficiency of the used methods and to find the best method of mentioned methods, the Relative Percentage Error (MPE) test can be used. The equation of RPE test is given in following equation [32].

$$RPE = \left[\frac{P_{w,R} - P_M}{P_M}\right] * 100 \tag{17}$$

The RPE statistical results of all methods for five years are given in Table 3.

Table 3. The RPE statistical results

RPE TEST	V_M(m/s)	P_M(W/m²)	P_W(W/m²)	P_R(W/m²)	RPE (Weibull)	RPE (Rayleigh)
2009	2,44	30,91	29,89	17,03	-3,30	-43,02
2010	2,41	33,12	32,64	16,30	-1,45	-50,06
2011	2,14	21,19	20,86	11,54	-1,56	-44,68
2012	2,15	21,62	18,14	11,64	-16,10	-38,83
2013	2,28	27,46	27,76	13,91	1,092	-49,90
2009-2013	2,29	27,04	26,52	14,05	-1,92	-47,02

According to the obtained results Weibull Distribution Function gave more accurate results than the Rayleigh Distribution Function. Based on five-year measured wind data it has been observed that the Weibull Distribution Function result is highly close to the actual data. It can be said that Weibull Distribution Function presented acceptable results [32]. It is observed that the Rayleigh Distribution Function fails to generate a result parallel to the actual data.

The utilization of Weibull and Rayleigh distributions in the expression of probability distributions of wind speeds is frequently used in the literature as an approach proved to be successful. It can be said that there exist high preferability for both functions according to their easiness to calculate and suitableness for wind evaluating shape and scale parameters. However, it is clearly seen that Weibull Distribution Function resulted more accurately than Rayleigh Distribution Function. In this study, by using the available wind data the reliability and the quality of wind speed for Osmaniye region are evaluated and the value of Weibull and Rayleigh parameters 'k' and 'c' were determined by using Moment Method. In this work, Weibull Distribution Function and Rayleigh Distribution Function are compared for wind data analysis of Osmaniye region. This study is a preliminary study for the determination of wind potential before making investment in wind energy for this region. The coherence of wind speeds with the Weibull and Rayleigh distribution functions have been examined by using wind speed data for the year 2009 to 2013. For all years the wind power density derived from using measured actual wind data were compared with wind power densities estimated from Weibull Distribution Function and the wind power density estimated from Rayleigh Distribution Function. According to obtained wind power densities, it was found that the closest result was obtained by Weibull Distribution Function. Moreover, it can be said that the Rayleigh Distribution Function is not suitable for estimating the wind power of this region. The wind power estimating issue is considered today one of the most important topics of renewable energy research. In future studies, the scope of this study can be expanded and detailed with using other numerical methods to determine wind energy potential of this region.

6. CONCLUSION

In aim to accomplish the purpose of this study, the data set which were used are hourly wind speed data of Osmaniye region between 2009 and 2013. This study introduced the evaluation of Weibull and Rayleigh Distribution Functions. Additionally, the method that is used for parameters in order to evaluate Weibull Distribution Function and Rayleigh Distribution Function is Moment Method. On the purpose of compare the efficiency of Weibull Distribution Function and Rayleigh Distribution Function, a statistical analysis is used called Relative Percentage Error. The calculation of parameters and wind power distribution are the cornerstones of the wind power producing process. Consequently, according to the Figure 6 and the results of RPE test, it is clearly observed that Weibull Distribution Function fits more accurately to actual data than Rayleigh Distribution Function. Furthermore, when Table 3 is analysed, it is concluded that the average of 2009-2013 RPE value is considerably smaller for Weibull Distribution Function in comparison with Rayleigh Distribution Function.

REFERENCES

[1] Kaplan Y.A., "Overview of Wind Energy in the World and Assessment of Current Wind Energy Policies in Turkey", Renewable and Sustainable Energy Reviews, 43 C, pp. 562-568, (2015)

[2] Kaplan Y.A., San I., "Current Situation of Wind Energy in the World and Turkey, Green Energy Conference-VI" (IGEC-VI), Eskisehir, Turkey, (2011)

[3] Çapika M, Yılmaz AO., Çavusoglu I., "Present situation and potential role of renewable energy in Turkey", Renewable Energy; 46, pp: 1-13, (2012)

[4] Gabbasa M, Sopian K, Yaakob Z, Zonooz M, Fudholi A, Asim N., "Review of the energy supply status for sustainable development in the Organization of Islamic Conference" Renewable and Sustainable Energy Reviews;28 pp:18–28, (2013)

[5] Mohammadi, Kasra, et al. Assessing different parameters estimation methods of Weibull distribution to compute wind power density. *Energy Conversion and Management*, 2016, 108: 322-335.

[6] Kantar Y.M., Usta I., "Analysis of wind speed distributions: wind distribution function derived from minimum cross entropy principles as better alternative to Weibull function", Energy Convers Manage, 49, pp. 962–973 (2008)

[7] Akdağ S.A., Dinler A., "A new method to estimate Weibull parameters for wind energy applications", Energy Convers Manag, 50, pp 1761-1766 (2009)

[8] Bilgili M. ve Şahin B., "The finding of weibull parameters at the determination of Wind Power density", New and Renewable Energy / Energy Management Symposium, Kayseri, 229-234, (2005)

[9] Rocha P. A. C. R. Sousa R. C. D. Andrade C. F.D, and Silva M. E. V. D. "Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil", Applied Energy, 89, pp 395–400, (2012)

[10] Freitas de Andrade C., Maia Neto H. F., Costa Rocha P. A., Vieira da Silva M. E., "An efficiency comparison of numerical methods for determining Weibull parameters for wind energy applications: A new approach applied to the northeast region of Brazil", Energy Convers Manage, 86 (10) pp. 801–808 (2014)

[11] Chang T. P., "Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application". Appl Energy, 88, pp. 272–282 (2011)

[12] Bilir L. İmir M. Devrim Y. Albostan A. "Seasonal and yearly wind speed distribution and wind power density analysis based on Weibull distribution function" , IntJ.Hydrogen Energy http://dx.doi.org/10.1016/j.ijhydene.2015.04.140, (2015)

[13] Bidaoui, Hicham, et al. Wind speed data analysis using Weibull and Rayleigh distribution functions, case study: five cities northern Morocco. *Procedia Manufacturing*, 2019, 32: 786-793.

[14] Azhar, Noreen, et al. Wind Data Analysis of Coastal Region of Balochistan (Pakistan) by Weibull and Rayleigh Method. *Indian Journal of Science and Technology*, 2019, 12: 26.

[15] Sumair, Muhammad, et al. Application of five continuous distributions and evaluation of wind potential at five stations using normal distribution. *Energy Exploration & Exploitation*, 2020, 0144598720939373.

[16] Akpinar, Ebru Kavak. Statistical Analysis of Wind Speed Distribution With Sinop-Turkey Application. *Journal of Thermal Engineering*, 2019, 5.4: 277-292.

[17] Shoaib, Muhammad, et al. Assessment of wind energy potential using wind energy conversion system. *Journal of cleaner production*, 2019, 216: 346-360.

[18] Maheshwari M., Chandrasekaran RS., Babu D., "Optimization of Electrical Power Using Solar and Wind Energy Systems", Proceedings of7'h International Conference on Intelligent Systems and Control (ISCO 2013), (2012)

[19] GWEC (Global Wind Energy Council), Global Wınd 2019 Report

[20] EWEA (European Wind Energy Association), Wind in power 2010 European statistics, February 2011

[21] Simsek HA, Simsek N., "Recent incentives for renewable energy in Turkey", Energy Policy;63, pp: 521–530 (2013)

[22] Baris K, Kucukali S., "Availibility of renewable energy sources in Turkey: Current situation, potential, government policies and the EU perspective", Energy Policy, 42, pp: 377–391, (2012)

[23] Caglar, Ahmet. Investigation of Wind Characteristics for Antalya Region by Using Weibull Distribution. *Cumhuriyet Science Journal*, 2017, 38.4: 156-164.

[24] Azad A.K., Rasul M.G., Alam M.M., Uddin S.M.A., Mondal S.K., "Analysis of Wind Energy Conversion System Using Weibull Distribution", Procedia Engineering., 90, pp. 725–732, (2014)

[25] Kım.J.-Yum.B., "Selection between Weibull and Lognormal Distributions: A Comparative Simulation Study" Computational Statistics&Data Analysis, 53(2), pp: 477-485, (2008)

[26] Kose R., Arif M.O., Erbas O., Tugcu A.., "The analysis of wind data and wind energy potential in Kutahya, Turkey", Renewable and Sustainable Energy Reviews, 8, pp. 277–288, (2004)

[27] Yıldırım U., Gazibey Y., Güngör A., "Wind Energy Potential of Niğde", Journal of Niğde University, 1(2), pp: 37-47, (2012)

[28] Ahmet Shata SA, Hanitsch R. "Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt". Renew Energy, 31, pp: 1183–202, (2006)

[29] Gokcek M., Bayulken A., Bekdemir S., "Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey", Renewable Energy, 32, pp: 1739–1752, (2007)

[30] Zhou W, Yang H, Fang Z. "Wind power potential and characteristics analysis of the Pearl River Delta Region." Renew Energy, 31, pp: 739–53, (2006)

[31] Celik A.N., "A statistical analysis of wind power density based on the Weibull and Rayleigh models at southern region of Turkey", Renewable Energy, 29, pp. 593–604, (2003)

[32] Sabzpooshani M, Mohammadi K. "Establishing new empirical models for predicting monthly mean horizontal diffuse solar radiation in city of Isfahan, Iran" Energy; 69(5), pp 71–77 (2014)