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Research Note

Investigation of the compliance of offshore wind data with the Weibull distribution function using six different methods

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Numerical methods.

Abstract. The aim of this study is to investigate how the Weibull Distribution Function (WDF) is compatible with the wind data in offshore regions. Many academic studies on wind energy have been conducted. Determining potential offshore wind energy and making investments in this area have gained further significance today. Although many studies have been made on wind energy, offshore wind energy has received less attention. The compatibility between wind data and WDF on land has been investigated by many academic studies, and the results have been evaluated. However, the compatibility of the offshore wind data with the WDF has not been investigated sufficiently and there are steps to be taken in this regard. In this study, a point was selected in Iskenderun Gulf to examine the compatibility of offshore wind data with WDF function. This study determined both the wind energy potential of the selected region and made many contributions to the literature. Six different methods were used to determine the parameters of the WDF and then, their performance were evaluated in different statistical error analysis tests.

1. Introduction

The need for energy is constantly increasing due to the rapidly increasing population and technology. In order to meet energy needs, research in this regard has gained unprecedented attention all over the world. Given the energy deficit, rapid depletion of nonrenewable resources, and rising environmental pollution, governments are increasingly turning to cleaner alternatives such as renewable energy sources [1]. Many developed and developing countries have turned to renewable energy sources to meet their energy needs [2–4]. Energy representing the basic input of the production process is an essential element in improving the welfare level in societies and is used in almost every field in daily life [5,6]. The renewable energy sources are inexpensive and everlasting and are achievable in many countries of the world [7,8]. In recent years, renewable generation, especially wind power and photovoltaic (PV) systems, has been increasingly used in power systems [9,10]. There are many studies on the subject of Wind Energy (WE) since wind speed is constantly variable; the compatibility of the wind data with the distribution functions is one of the most studied topics. Long-term wind speed data are required to examine the fit of wind data with distribution functions. Statistical error analyses are used to examine the fit of wind data with distribution functions. In these analyses, wind speed distribution functions are employed to determine the wind characteristics of long-term wind measurement data in different selected regions and

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different heights. Offshore wind farms are known to have many advantages over traditional onshore wind farms. For example, higher stability and higher wind speed make offshore wind farms a promising alternative [11]. In developed and developing countries, many studies are being conducted to evaluate WE potential more efficiently. Installation and operating costs of off-shore turbines are much higher than those of terrestrial turbines. However, as the winds in the sea have much more energy than terrestrial winds, it is possible to produce energy far above the terrestrial turbine capacities. Considering the geographical location of Turkey, it can be said that there is a serious off-shore WE potential. Increasing investments in this area depends on examining wind characteristics and determining the current wind potential in the determined areas. The technical WE potential for Turkey is estimated to be nearly 83 GW [12].

Figure 1 shows how the installed onshore wind power around the world has changed between 2010 and 2021. The total installed wind power has been increasing by more than 50 GW each year since 2013. 2021 was a solid year with 71.4 GW installed - a increase by more than 10% compared to the last year; thereby, the total installed power reached 780 GW [13].

One of the rapidly developing application areas of WE is the offshore WE. Offshore winds are generally stronger and more regular than land and provide logistics to their advantage. More energy can be produced due to the more stable and higher wind speeds in regions above the sea level.

Installation cost of offshore wind power plants is higher than that of on-land systems. New-generation offshore turbines with a rotor diameter greater than about 200 m, larger than the next-generation 10 MW power, are developed by almost all offshore wind turbine manufacturers. Figure 2 shows how the installed offshore WE has changed since 2010. If the figure is analyzed in detail, it is seen that the installed power of the above sea WE has increased effectively worldwide

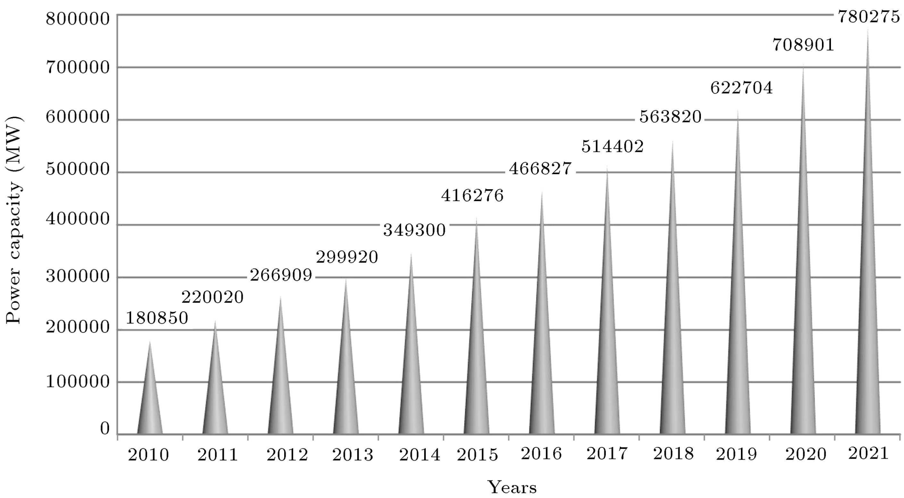

Figure 1. The installed onshore wind power in the world by years [13,14].

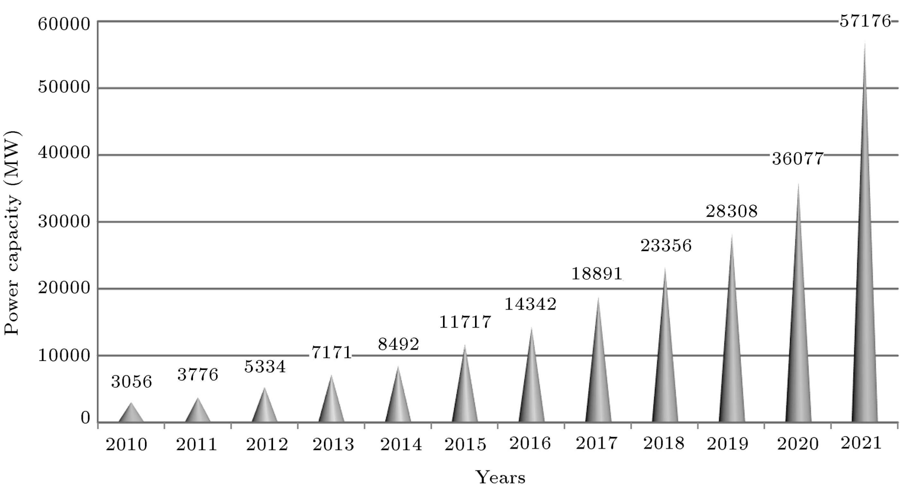

Figure 2. The installed offshore wind power in the world by years [13,14].

after 2013. Approximately, a new offshore wind power capacity of 21.1 GW was installed in 2021 and the total installed power exceeded 57.1 GW.

According to Figures 1 and 2, it is seen that the above-ground WE constitutes about 4.5% of the WE in terms of installed power in the world. It is observed that the use of offshore WE has increased with the increasing technology. It is expected that the installed offshore WE power will increase further in the future. For this reason, studies on offshore WE are very important.

The aim of this study is to reveal the compliance of wind data of a selected off-shore region with the Weibull Distribution Function (WDF). With this study, the coefficients of the WDF were calculated by six different methods and the performances of the methods used were compared using different error analysis tests. Based on a detailed review of the literature, it becomes clear that the compliance of wind data with the WDF is examined in many different regions, but there is not enough study about the compliance of off-shore wind data with WDF. This detailed study will be a viable model research for other studies to be carried out on this subject and it provides many contributions to the literature.

In the literature, Saeed et al. [15] proposed an AI optimization approach based on the Chebyshev metric. It was mathematically proven that the proposed method would guarantee convergence in all cases of Weibull parameter estimation. Weibull fitness tests were calculated using real-time wind data from a site located near Pakistan's coastal region. Gungor et al. [16] investigated the suitability of four different numerical methods for estimating the Weibull distribution using İzmir-Turkey wind speed information. Root-mean square error, coefficient of determination, and Chi-square goodness of fit tests were employed to determine the robustness of the methods. Wan et al. [17] evaluated the WE resource potential in the Urat region of Inner Mongolia, China based on the data measured from four wind towers at 70–100 m/s. First, they modeled the wind speed with the Weibull distribution, in which the parameters were estimated by various numerical and intelligent optimization methods. Specifically, they used Cross-Entropy Method (CEM) and claimed that this method would outperform other methods. Wen et al. [18] analyzed the spatio-temporal variations of wind resources in the South China Sea based on the Japanese 55-year Reanalysis (JRA-55) dataset. Based on the results obtained, an approach is proposed and implemented to identify suitable sites for offshore WE extraction on the south and southeast coasts of China. Cevasco et al. [19] presented a comprehensive review and discussion of the identification of critical components of current- and next-generation offshore wind turbines. Li et al. [20] conducted a comparative assessment of onshore and offshore wind characteristics and WE potentials in the southeast coastal region of China based on two original sets of wind records from onshore and offshore wind measurement towers in the region. Raju et al. [21] statistically analyzed wind characteristics and conducted a wind potential assessment for India's onshore, offshore, and nearshore locations, especially Kayathar in Tamilnadu, Gulf of Khambhat, and Jafrabad in Gujarat, using wind distribution methods. Akin and Kara [22] studied WE potential in the coastal areas of Bursa region in Turkey. They investigated and estimated the potential of the wind power in Bursa. Satir et al. [23] determined the feasibility of an offshore wind farm in the Turkish seas. They attempted to determine the technical WE potential using some programs. Li and Yu [24] studied statistical analysis of the offshore, terrestrial, and nearshore wind power potential of Lake Erie near Cleveland, Ohio. Emeksiz and Demirci [25] investigated the offshore WE potential of Turkey. In this study, a methodology entitled Novelty Hybrid Site Selection Method was proposed for determining suitable coastal regions for the installment of offshore wind farms in Turkey. Bilir et al. [26] calculated the coefficients of WDF with five different methods. The performance of these five different methods was evaluated for the determined period. Shoaib et al. [27] used the WDF to estimate the wind power potential for the investigated site and utilized four statistical methods namely Maximum Liklihood Method (MLM), Moment Method (MM), Energy Pattern Method (EPM), and Power Density Method (PDM) to determine shape (k) and scale (c) parameters.

The objective of this study is to obtain the mean wind speed, wind power density, and energy potential upon determining Weibull distribution parameters using a variety of methods. In particular, the fact that this study is carried out on the sea increases the importance of this study. Based on the literature, while there are many studies conducted for different regions onshore, there is no detailed study on offshore regions.

In the following sections, instrument and wind data collection are detailed and the used distribution function is explained in detail. Each method used to determine the coefficients of this distribution function is introduced, and annual figures 'k' and 'c' are given for each method. The obtained results are compared and the performances of the used methods are given in the final section.

2. Place, instrumentation, and data

Turkey's geographical position remains quite favorable in terms of WE. The WE potential is considered to be quite high given the existence of high regions and sea coasts. It is a country with a high potential for WE

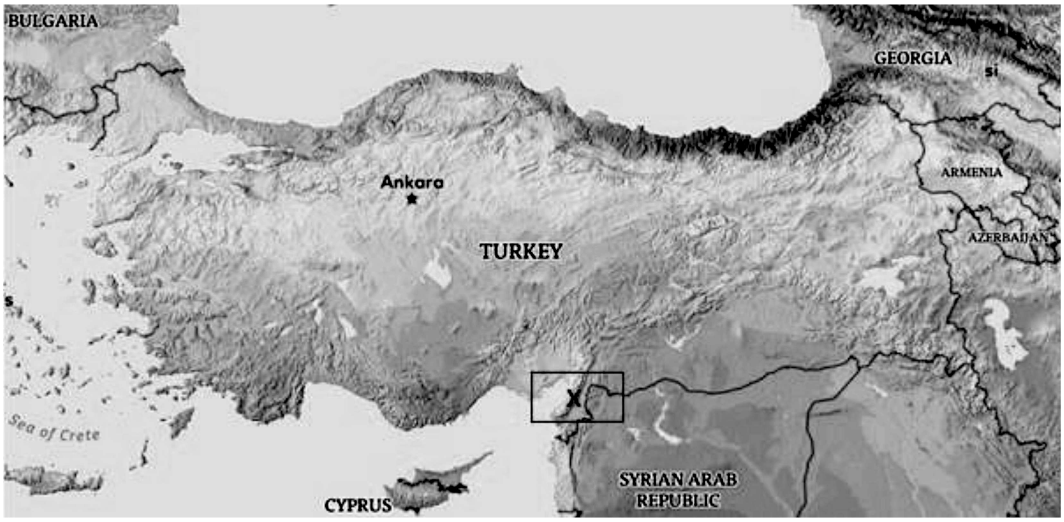

Figure 3. Location of the measurement point.

Figure 4. Location of the measurement point in relation to Iskenderun Gulf.

in terms of its geographical location and its three sides surrounded by seas. The amount of speed required to obtain WE is available in various regions, thanks to the elevations and coasts in the country. According to the report published by the Turkish Wind Energy Association (TUREB) in 2018, a new wind power plant of 497 MW was installed in the last year, and the total installed wind energy capacity has reached the level of 7369 MW. This value means a 7.24% increase compared to the previous year, and Turkey's Ministry of Energy and Natural Resources has announced 10 GW offshore WE potential [28,29].

In this study, a location in the Hatay region, being rich in WE potential, was chosen. The geographical features of the selected region are shown in Table 1.

The location, which is shown in Figure 3 is 1250 m from the coastline and the closest building is another pier about 2 km away. The measurement point is 10 m above the sea level. The depth of the sea water (draft) in the region where it is located is 14 m.

Table 1. The geographical coordinates of the study area.

Variable	Value
Latitude	36,51 °N
Longitude	36,49 °E
The depth of sea	14 m
Measurement height	10 m

Dörtyol location in the Iskenderun Gulf is the location to be measured in the region, as shown in Figure 3. A close view of the region where this measurement was conducted is given in Figure 4.

Determining the wind speed blowing frequency in a region is one of the most important parameters

Table 2. The wind densities of the selected region.

i	v_i (m/s)	v_i(m/s)	f_i	$p(v_i)$	$P(v_i)$
1	0–1	0,5	921	0,106919	0,106919
2	1–2	1,5	1769	0,205363	0,312282
3	2–3	2,5	1912	0,221964	0,534247
4	3–4	3,5	2031	0,235779	0,770026
5	4–5	4,5	495	0,057465	0,827490
6	5–6	5,5	706	0,081960	0,909450
7	6–7	6,5	272	0,031577	0,941026
8	7–8	7,5	169	0,019619	0,960645
9	8–9	8,5	169	0,019619	0,980265
10	9–10	9,5	48	0,005572	0,985837
11	10–11	10,5	26	0,003018	0,988855
12	11–12	11,5	24	0,002786	0,991642
13	12–13	12,5	14	0,001625261	0,99326678
14	13–14	13,5	27	0,003134432	0,99640121
15	14–15	14,5	5	0,00058045	0,99698166
16	15–16	15,5	12	0,001393081	0,99837474
17	16–17	16,5	7	0,000812631	0,99918737
18	17–18	17,5	1	0,00011609	0,99930346
19	18–19	18,5	1	0,00011609	0,99941955
20	19–20	19,5	0	0	0,99941955
21	20–21	20,5	2	0,00023218	0,99965173
22	21–22	21,5	0	0	0,99965173
23	22–23	22,5	3	0,00034827	1,000000

of the energy to be obtained. By determining the wind speed frequency distribution in the region, the most appropriate wind power conversion system can be selected for that region. It is possible to obtain the most economical results by determining the appropriate distribution for the region. The measurements cover only one year (2018). The data recorded every hour were used. 744 data sets for the months drawing 31 days and 720 data sets for 30 days were evaluated; in total, 8614 data sets were gauged. The wind speed data obtained from the selected region were studied in detail, and how the wind speed densities changed in different wind speed ranges, as shown in Table 2 in detail.

3. Methodology

WE potential of the region should be determined in order to establish electrical energy production by setting up a wind power plant in a region. Since wind speed is defined as a random event, it is useful to use statistical methods for wind speed estimation. Therefore, wind speed can be estimated using probability distribution. First, the average wind speed value should be determined in order to determine the WE potential in any region. It is well known that the power of the WE depends on wind velocity 'v', blade swept area of wind turbine 'A', and air density of region 'ρ'; the power of WE is given in the following equation [30].

$$P_A = \frac{1}{2}\rho A v^3 \qquad (\mathrm{W/M^2}). \tag{1}$$

As can be seen from the equation, the most important parameter affecting wind power is wind speed, because the average wind power we need to determine in a region is proportional to the cube of wind speed.

3.1. Weibull Distribution Function (WDF)

The most widely used distribution in calculating wind power potential is WDF. The WDF has been employed in many articles to determine WE potential. The reasons for using this method include such factors as suitability for wind distribution and ease of determining its parameters (two parameters found) [31–33]. By using the parameters of the Weibull distribution in the analysis of wind data, it is possible to make a precise estimate of the frequency of the wind speed in any region. The WDF is a function that shows the frequency of wind blowing at any speed. To obtain the WDF, shape and scale parameters must be known.

The general expression of this WDF is given in Eq. (2). As can be seen from the equation, this distribution function has "k" and "c" parameters [34]:

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

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

where $p(v)$ is the observed probability density function; $P(v)$ is the cumulative probability density function; shape (k) and scale (c) are the parameters of WDF. In these equations, v is the measured wind speed. The shape factor "k" obtained from the Weibull distribution indicates the frequency of wind blowing. If the changes in the wind speed in the measured period are quite a lot, the shape factor is large. A small shape factor suggests a relatively big wind speed distribution around the average wind speed, whereas a greater shape factor indicates a relatively small wind speed distribution around the average wind speed [35]. Scale parameter "c" is directly related to the average wind speed. The large "c" indicates that the average wind speed is high [2,36,37]. The frequency distribution of the wind speed in different ranges is shown in Figure 5. The changes in the cumulative frequency distribution of wind speed are shown in Figure 6.

3.2. Determination of weibull parameters

This distribution enjoys the following features: good compliance with the wind distribution, a flexible structure, ease of determining its parameters, small number

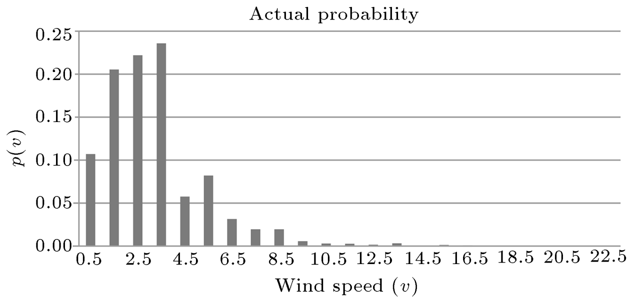

Figure 5. The actual probability of wind speed.

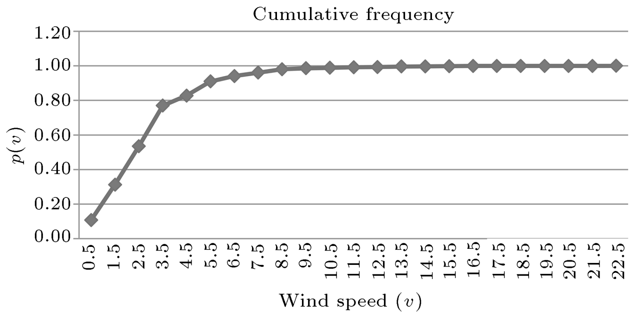

Figure 6. The cumulative probability of wind speed.

of parameters, and prediction of parameters for different heights. It is known that wind data generally fit this distribution. Many methods have been developed in the literature to calculate the values of Weibull distribution parameters. In this study, six different methods are utilized to estimate the parameters of WDF.

3.2.1. Graphical Methods (GM)

In this method, the least squared regression is employed to measure the shape and scale parameters. The basic principle of the graphic method is to minimize the vertical differences between the line representing wind speed data and the observed wind speed data. In the fitting process between measures and linear equations of the type $y = ax+b$, the GM aims at the smallest last square error [38]. By taking twice logarithm of general expression of WDF, the GM achieves the following:

$$-\left(\frac{v}{c}\right)^k = ln\left[1 - P(v)\right], \tag{4}$$

$$kln(v) - kln(c) = ln\left[-ln\left[1 - P(v)\right]\right]. \tag{5}$$

Here, $x = ln(v)$, $y = ln[-ln[1 - P(v)]]$, $A = k$ ve $B = -kln(c)$ is accepted and $y = Ax + B$; there is a form of linear equations. Also, from $B = -kln(c)$ and $c = exp(-B/A)$, this expression is obtained [32,39].

According to $y = Ax+B$, the numerical values of A and B are determined from Figure 7 and the Weibull parameters can be found as follows. Parameters 'c' and 'k' are given in Eq. (6):

$$k = A \quad , \qquad c = exp\left(\frac{-B}{A}\right). \tag{6}$$

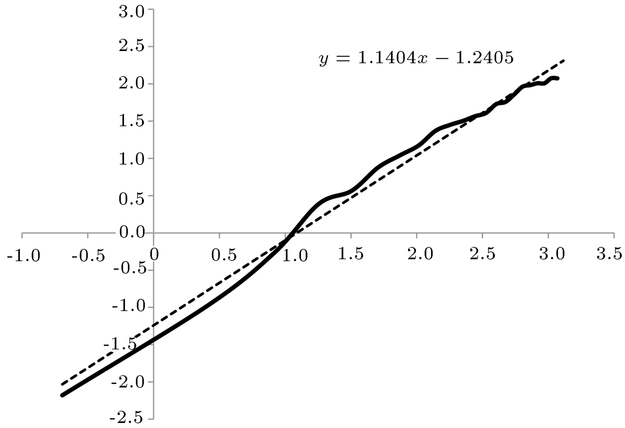

Figure 7. Linear equation of graphic method.

3.2.2. Empirical Method (EM)

In this method, average wind speed and variance values are used to calculate coefficients. In this method, the gamma function is employed to find the value of parameter c. Determination of parameters 'k' and 'c' is expressed in Eqs. (7) and (8) [2,32,40]:

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086}. \tag{7}$$

Here, Γ is the Gamma function:

$$c = \frac{v_m}{\Gamma\left(1 + \frac{1}{k}\right)}. \tag{8}$$

Here, σ and v_m show Empirical and the average speed, respectively.

$$v_m = \frac{1}{n}\sum_{i=1}^{n} v_i, \tag{9}$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(v_i - v_m\right)^2}. \tag{10}$$

3.2.3. Energy Trend Method (ETM)

In this method, which is a new approach to finding the parameters, the Energy Pattern Factor (EPF) is employed to find the Weibull distribution parameters. In this method, parameters 'k' and 'c' can be easily calculated using EPF [41]:

$$EPF = \frac{\frac{1}{n}\sum\limits_{i=1}^{n} {v_i}^3}{\left(\frac{1}{n}\sum\limits_{i=1}^{n} v_i\right)^3}, \tag{11}$$

$$k = \frac{1}{3.9557EPF^{0.898}}. \tag{12}$$

The scale parameter is calculated as follows:

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} {v_i}^k\right)^{1/k}. \tag{13}$$

3.2.4. Energy Pattern Method (EPM)

EPM is defined as the wind power estimated by the ratio of the total wind power to the mean wind speed. After computing the EPF, the parameter "k" can be obtained. Then, parameter "c" is calculated using the average wind speed [42,43]. In this method, the gamma function is used to find the parameter c.

$$EPF = \frac{\frac{1}{n}\sum_{i=1}^{n} {v_i}^3}{\left(\frac{1}{n}\sum_{i=1}^{n} v_i\right)^3}, \tag{14}$$

$$k = 1 + \frac{3.69}{EPF^2}, \tag{15}$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)}. \tag{16}$$

3.2.5. Maximum Likelihood Method (MLM)

MLM is a mathematical expression known as a probability function of time series wind speed data format. The definition of the maximum likelihood function corresponds to the product of the values obtained from the probability density function for different wind data from each zero. In the WDF, many iterations can be required to estimate the parameter k. Once you find the parameter 'k', the parameter 'c' is easily calculated. In this method, parameters k and c of WDF can be calculated via the following equation [26,32,43]:

$$k = \left(\frac{\sum_{i=1}^{n} {v_i}^k In\left(v_i\right)}{\sum_{i=1}^{n} {v_i}^k} - \frac{\sum_{i=1}^{n} In\left(v_i\right)}{n}\right)^{-1}, \tag{17}$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} {v_i}^k\right)^{1/k}. \tag{18}$$

3.2.6. Moment Method (MM)

MM is one of the oldest and most common methods used to find parameters of the WDF. Based on the literature, many studies have utilized the MM. It is the solution to the system of equations obtained using the equations established on the moments of the wind speed from various stages and the probability density functions in order to obtain the WDF in accordance with the available data. In this method, the gamma function is used to find the parameter c. The calculations are based on empirical, mean wind speed, and gamma function for the parameter [32,39].

$$k = \left(\frac{0.9874}{\sigma/v_m}\right)^{1.0983}. \tag{19}$$

Here, Γ is Gamma function as follows:

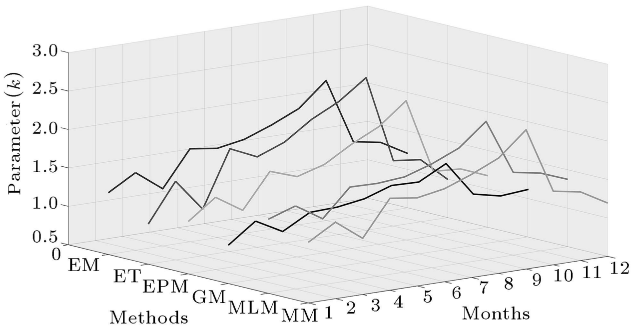

Figure 8. "k" parameter of WDF for all the used methods.

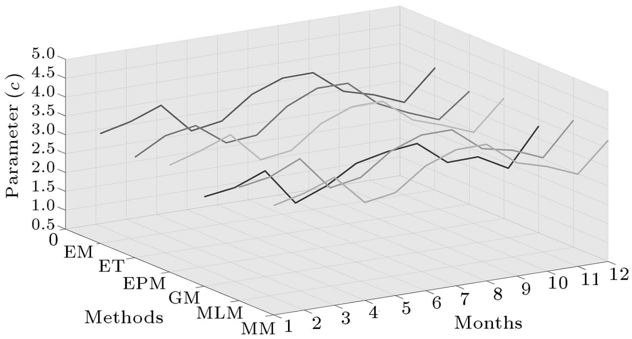

Figure 9. "c" parameter of WDF for all the used methods.

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)}. \tag{20}$$

4. Obtained results

Based on the measured data measured hourly from measuring station, the harmonization of real wind data and WDF was observed. The WDF parameters including 'k' and 'c' were computed using all methods in the mentioned period and the obtained results are given in Figures 8 and 9, respectively.

4.1. Statistical error analysis

There are different error analysis tests utilized in the literature to compare the performance of the methods used for such estimation purposes. In this study, three different statistical error analysis tests were employed to compare the performance of the methods used. The general equations of these statistical error analysis tests are given in the following equations [2,32]:

The Root Mean Square Error (RMSE):

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(y_i - x_i\right)^2\right]^{\frac{1}{2}}. \tag{21}$$

The Root Mean Square Error (RMSE) is frequently applied to investigate the disparities between real-data and model data, which are referred to as residuals.

Table 3. The results of statistical error tests.

	Statistical error tests		
Methods	**RMSE**	R^2	**MPE**
GM	0.460823	0.892430	–0.101329
EM	3.45458×10^{-5}	0.999999	–0.077679
MLM	0.019686	0.996547	0.0006685
EPM	3.45458×10^{-5}	1.000000	–0.1013286
ETM	0.046947	0.980359	–0.1580665
MM	3.45458×10^{-5}	1.000000	–0.0811300

RMSE is a measure of how much these residues spread [44,45].

Analysis of variance (R^2):

$$R^2 = \frac{\sum_{i=1}^{n}(y_i - z_i)^2 - \sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(y_i - z_i)^2}, \tag{22}$$

R^2 is expressed as the power to measure the dependent variable of the equation obtained in regression analysis. R^2 value is found in inferential analysis and if the value found is calculated correctly, it should be between 0 and 1. This analysis can be explained in various situations.

Mean Percentage Error (MPE):

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i - y_i}{y_i}\right) * 100\%. \tag{23}$$

MPE is mostly employed to compare predictive models. Since real values are used rather than absolute values of prediction errors when calculating MPE value, positive and negative prediction errors balance each other [46].

The results obtained by all the methods employed were examined in three different error analysis tests. The obtained test results are given in Table 3. The results were evaluated statistically using three different statistical error analysis tests. In the table, the performances of the methods utilized to find the coefficients of WDF are compared in detail [2].

Based on the obtained results, it is seen that only the results of the graphic method performed poorly, while the other five methods would perform well under the three different error analysis tests.

4.2. Power density assessment

The parameters "k" and "c" of WDF were calculated by the used methods. Thanks to these calculated parameters, each method can estimate the average wind speed for the selected region and the average wind power of the region can be predicted with these values. At the same time, the average wind speed value of the region was calculated with the real wind data, and the average WE power of the selected region was determined with this value. The estimated and calculated real values are given in Table 4 in detail. Calculation of average wind power is an important parameter in order to compare the performance of the used methods.

Table 4. The mean wind speed and average Power Density (PD).

Real time esries	Vm (m/s)	3,2204
	PD (W/m^2)	63,5193
Graphical method	Vm (m/s)	2,8314
	PD (W/m^2)	61,6235
Emprical method	Vm (m/s)	3,2204
	PD (W/m^2)	55,2798
Energy trend method	Vm (m/s)	3,1836
	PD (W/m^2)	57,8005
Energy pattern method	Vm (m/s)	3,2204
	PD (W/m^2)	63,1690
Maximum likelihood method	Vm (m/s)	3,2390
	PD (W/m^2)	52,3556
Moment method	Vm (m/s)	3,2204
	PD (W/m^2)	56,0467

The average wind speed and average WE power of the selected region are calculated via the following equations [2,46]:

$$v_m = \frac{1}{n}\sum_{i=1}^{n} v_i, \tag{24}$$

$$P_m = \frac{1}{2}\rho\overline{V^3}. \tag{25}$$

The wind power density is a critical metric for determining the capability of wind resources in a given place. The following equations are used to estimate average wind speeds and average WE power based on the methods used [47]:

$$v_w = c\Gamma\left(1 + \frac{1}{k}\right), \tag{26}$$

$$P_w = \frac{1}{2}\rho c^3\Gamma\left(1 + \frac{3}{k}\right). \tag{27}$$

According to the calculated mean wind speed and power densities, it was found that EPM gave the closest result to the real values.

5. Conclusions

In this study, the reliability and quality of wind speed for the selected region were evaluated by using the measured wind data and the values of Weibull Distribution Function (WDF) parameters 'k' and 'c' were determined using different types of estimation methods. The obtained results obtained by all the used methods were shown for each month and year separately. It was clearly seen that the WDF was compatible with real wind data at offshore wind speeds. The annual performances of the methods used to find the Weibull coefficients were examined, and the error analysis results were given for each month. The results of performance analysis demonstrated that all the methods gave very close results in the selected offshore region. According to the obtained results, all the methods achieved efficient results to determine the shape and scale parameters of WDF at the selected offshore point. Based on the result of all the methods, the selected offshore point showed the remarkable potential of Wind Energy (WE) for utilization.

The results and contributions of this study can be summarized as follows:

- The values of the parameters 'k' and 'c' for all the used methods in the selected region were examined. The yearly mean values of k and c for Weibull distribution were determined over the annual period of 2018. The results were given for each method, respectively. Graphic Method (GM); 1.1404 and 2.9677 m/s, Empirical Method (EM); 1.5061 and 3.5991 m/s, Energy Trend Method (ETM); 1.4300 and 3.5042 m/s, Energy Pattern Method (EPM); 1.3827 and 3.6263 m/s, Maximum Likelihood Method (MLM); 1.5837 and 3.6091 m/s, Moment Method (MM); 1.4922 and 3.5650 m/s;
- The performance of the used models was examined in detail via three different statistical error analysis tests. According to the Root Mean Square Error (RMSE) and Analysis of variance (R^2) tests, the MM found the best results, while the MLM exhibited the best performance according to the MPE;
- The mean wind speed and mean wind power were estimated and calculated for the selected offshore location;
- The shape and scale parameters of the WDF pointed out the accuracy of calculating the mean wind speed and average power density, the results are very close to each other;
- Based on the calculated parameters of the WDF, the estimated wind power density in the offshore area was calculated accordingly. The average monthly WE densities in the offshore region were 61.62 W/m^2, 55.27 W/m^2, 57.80 W/m^2, 63.16 W/m^2, 52.36 W/m^2, and 56.05 W/m^2 for GM, EM, ETM, EPM, MLM, and MM, respectively;
- The use of GM, EM, ETM, EPM, MLM, and MM methods with relatively small error levels and fluctuations can bring a highly acceptable estimation of wind power distribution in the offshore region;
- Based on the literature, there is no comprehensive study about the compatibility of offshore WE data with the WDF function. This study is a detailed study to emphasize the importance of offshore wind power plants.

Nomenclature

A	Swept area of turbine
v	Wind speed
k	Shape parameter of WDF
c	Scale parameter of WDF
ρ	Air density
σ	Standard deviation value
Γ	Gama function
$p(v)$	Probability density function
$P(v)$	Cumulative distribution function
f_i	Wind blowing frequency
N	Number of observations
xi	i-th Weibull data
yi	i-th measured data
zi	i-th average real data
P_w	Estimated wind power
P_m	Calculated wind power

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Biography

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