Statistical Analysis of Wind Speed Distribution Based on Five Weibull Methods for Wind Power Evaluation in Maan, Jordan

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Abstract

Due to the increasing environmental and economic cost of fossil fuels, alternative sources of energy are needed. One of these sources is wind energy. The wind-turbines extract kinetic energy from the wind to convert it to mechanical energy and then transfer to electrical energy. Wind speed is the most important parameter for an efficient wind energy system. In this work the Microsoft excel software used to analysis of wind speed data and evaluate the wind speed distribution. the wind speed probability estimated and analyzed by using five methods of Weibull and Rayleigh distributions and evaluated the best methods to represent the actual data based on monthly mean wind speed data of the Ma'an city site, Jordan. furthermore, from the analysis, it has been found that the energy pattern factor method EPFM is the best method to represent the actual data and the EPFM is the best and most accurate and efficient method to determine the Weibull distribution parameters (k) and (c). In addition, in this work, the annual average shape parameter (k) is 3.4 and the annual average scale parameter (c) is 4.0 m/s. The most probable wind speed is 4.4 m/s in August and the maximum wind speed carrying maximum energy is 5.2 m/s occurs in October. Meanwhile, the maximum power and energy density are 57.5 W/m^2, 42.8 kWh/m^2 respectively in August. Moreover, the site has annual power density 39.3W/m^2 and 345.5 kWh/m^2 of energy density.

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1. Introduction

The energy crisis and growing environmental awareness within the present day has become more important, and as a result of that, there are a global shifting towards substitutes of the conventional energy to sustainable resources and new technologies for the demand consumption. This resulted increase in the renewable energy plants in different part of the world. The wind power sector increased to reach the annual growth rate over 25% for the past 7 years. Wind expansion almost doubled in 2020 compared to 2019 (111 GW compared to 58 GW previous year), about 700GW was installed until the end of 2020, (IRENA, 2021). In the onshore market, 54.2 GW was installed, an increase of 17 % compared to 2018 (GWEC, 2018) Jordan faces a high growth rate in population; with this growing in the population, the energy consumption and the electricity demand will be increased to double by 2020 and triple by 2030. Since the energy resources discovered in Jordan are limited and the cost of fossil fuel that imported from the outside is increasing, and generated air pollution such CO_2 and much health and environmental problems. So, the government of Jordan towards to use the renewable energy to produce the electricity from the solar and wind resources. The Wind energy conversion systems are chosen based on wind speed potential analysis of a region, Jordan has high potential of wind energy resources, where at 10 m height the annual average wind speed exceeds 7 m/s in some areas of the country such Amman, Irbid, Ma'an, Tafilah, Aqaba and Mafraq. This energy has a very low cost (Baniyounes, 2017). (MEMR, 2018) (Rahim, 2014). The long-term wind potential data are available at MEMR, the Jordan Meteorological Department (JMD) and the Royal Scientific Society (RSS) for most sites in Jordan.

Jordan uses wind energy to generate electricity. The wind atlas indicates two regions in Jordan that have large potential wind energy especially in southern and northern parts of Jordan (Alrawashdeh, 2018) furthermore, there are another studying of wind energy potential in the world and in Jordan such as the (Al Nhoud and Mohammad, 2015) studied the Weibull parameters in the Azraq south, Northeast Badia of Jordan using real wind speed data, the data measured at 10 m height and the mean wind speed data was analyzed, he found the highest and the lowest wind power potential are in July and December, respectively. Also, it was indicated that the shape and scale parameters for Azraq south varied over a wide range. The monthly mean value of Weibull shape parameter (k) was 3.06. While the monthly value of the Weibull scale parameter (c) was 4.57 m/s. (Ahmed, 2013) studied the method MOM to estimate the Weibull distribution parameters c and k, estimated accuracy of these methods by using coefficient of determination (R2) and RMSE for Halabja, Iraq.

(Fouad, et al., 2015) estimated the Weibull distribution parameters to evaluate the wind energy and estimated the WPD at East region of Mohammedia and other Moroccan sites. (Shiva and Safy, 2015) studied the parameters of Weibull distribution by using the four statistical methods, energy pattern factor method, method of moments and mean standard deviation method to evaluate and assess the wind energy potentiality at four selected locations of northern Ethiopia. Found the least squares regression method is the better performance method than other selected methods in the investigation.

(Islam, et al., 2011) studied the parameters of Weibull distribution to evaluate and assess the wind energy potentiality at Kudat and Labuan, Malaysia. (Keyhani, et al., 2010) studied the parameters of Weibull distribution to assess the wind energy potentiality in the Tehran, Iran.

(Kidmo, et al., 2015) studied the performance assessment of six numerical methods for estimating Weibull distribution parameters EM, GM, EPFM and MOM, analyzed the efficiency of the methods by using RMSE, the coefficient of determination (R2) and chi square error (χ2), also estimated the most frequent wind speed, maximum energy carrying wind speed, wind energy density and the wind power density in Garoua, Cameroon.

Nomenclature	Description	Units
CDF	Cumulative Distribution Function	
c	Weibull Scale Factor	[m/s]
EM	Empirical Method	
EPFM	Energy Pattern Factor Method	
$F(U)$	Cumulative Distribution Function	
$f(U)$	Weibull Probability Density Function	
GM	Graphical Method	
IRENA	International renewable Energy Agency	
JMD	Jordan Meteorological Department	
k	Weibull Shape Factor	
MAPE	Mean Absolute Percentage Error	
MEMR	Ministry of Energy and Mineral Resources	
MOM	Method of Moments	
MPE	Mean Percentage Error	
N	Number of Wind Data Monthly	
PDF	Probability Distribution Function	
R^2	Coefficient of Determination	
RMSE	Root Mean Square Error	
RSS	Royal Scientific Society	
T	Number of Hours per year	
t	Time	[sec]
U	Wind Speed	[m/s]
U_i	Each averaged over the time.	[m/s]
$\overline{U}$	Average Wind Speed	[m/s]
U_{rel}	Relative Wind Speed	[m/s]
$U_{F\ max}$	Most Probable Wind Speed	[m/s]
$U_{E\ max}$	Speed Carrying the Maximum Energy	[m/s]
WED	Wind Energy Density	[kWh/m^2]
WPD	Wind Power Density	[W/m^2]
x^2	Chi-Square Error	
$x_{i,w}$	i-th Calculated Value From the Weibull	
$v_{i,m}$	i-th Calculated Value From Measured Data	
$z_i, \overline{v}$	Mean of i-th Calculated Value From Measured Data	
ρ	Air Density at Site Elevation	
σ	Standard Deviation	
Γ	Gamma Function	
m	measure	
max	maximum	
rel	relative	
w	Weibull	

2. Statistical analysis of wind data

The Weibull and Rayleigh distributions methods can be used to represent the wind velocity distributions and to estimate the wind power and energy density in a regime with an acceptable accuracy level (Stevens and Smulders, 1979) (Justus, et al., 1978) (Hennessey, 1977) (Gungor et al., 2020)

The wind speed data of this work in daily time-series format over a period of one year have been collected and statistically analyzed. The wind speed data were recorded at a height of 10 m, continuously by a cup-generator anemometer at the Jordan Meteorological Department/ Ma'an City.

2.1 Measured average and distribution of wind speed

2.1.1 Average wind speed

One of the most important information on the wind spectra available at a site is average velocity. The average velocity ($\bar{U}$) is given by:

$$\bar{U} = \frac{1}{N} \sum_{i=1}^{N} U_i \tag{1}$$

Where: $\bar{U}$ is the average wind speed, N is the number of wind data; U_i is each averaged over the time.

2.1.2 Distribution of wind speed

The distribution of velocity that means the standard deviation of data velocities (σ_U), which is the deviation of individual velocities from the mean value (Manwell, et al., 2010), thus, the deviation given by:

$$\sigma_U = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (U_i - \bar{U})^2} \tag{2}$$

The low value of σ_U means the data of velocities are near to the mean value, uniformity of the data.

2.2 The Weibull distribution

There are different methods for determining the wind speed distributions, the Weibull distribution as it is more accurate in this field.

The Weibull distribution function PDF (F (U)) indicates the fraction of time for which the wind is at a given velocity U (Mostafaeipour, et al., 2014) (Al Zohbi, et al., 2014) (Petkovic, et al., 2014) (Oner, et al., 2013) (Costa, et al., 2012) (Ohunakin, et al., 2011) (Changa and Tu, 2007) (Genc, et al., 2005) (Celik, 2004) (Stevens, et al., 1979) (Justus, et al., 1978). It given by equation (1):

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

Where: (k) is the Weibull shape factor dimensionless and (c) is the scale factor (m/s), U is the wind speed (m/s). The Cumulative Distribution Function CDF (F (U)) of the velocity U gives the fraction of time that the wind velocity is equal or lower than U. Thus, the cumulative distribution F (U) is the integral of the PDF (Manwell, et al., 2010).it is given as:

$$F(U) = 1 - exp\left[-\left(\frac{U}{c}\right)^k\right] \tag{4}$$

2.3 Methods to estimate Weibull parameters

There are several methods to estimate the c and k parameters of the Weibull distribution. In this work, the four different mathematical methods are used for calculation of Weibull parameters scale and shape are Graphical Method (GM) Empirical Method (EM), Method of Moments (MOM) and Energy Pattern Factor Method (EPFM).

2.3.1 Graphical method (GM)

In the graphical method, the cumulative distribution is transformed into a straight line. (Kidmo, et al., 2014) (Doka, et al., 2014) (Danwe, et al., 2014) (Petkovic, et al., 2014) (Azad, 2014) The Weibull shape and scale parameters are estimated, the shape parameter k is the slope of the line and the y-intercept is the value of the term $- k \times \ln(c)$.

$$ln\{-ln\,[1 - F(U)]\} - k\,ln\,(U) - k\,ln\,c$$

2.3.2 Empirical method (EM)

The Weibull factors k and c can be also estimated from the average and standard deviation of wind data (Boweden, et al., 1983)

$$k = \left(\frac{\sigma_U}{v}\right)^{-1.086} \tag{5}$$

The Weibull factors c can be rewritten as:

$$c = \frac{v}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{6}$$

Where Γ: gamma function, and can be approximated by: (Jamil, 1994, Touré, S. 2019) and can be rewritten as:

$$\frac{c}{v} = \left(0.568 + \frac{0.433}{k}\right)^{\frac{-1}{k}} \tag{7}$$

2.3.3 Energy pattern factor method (EPFM):

The energy pattern factor (EpF) is related to the averaged data of wind speed and is defined by following Eqn.(8). (Kidmo, et al., 2014) (Doka, et al., 2014) (Azad, et al., 2014) (Indhumathy, et al., 2014) (Costa, et al., 2012).

$$Epf = \frac{v^3}{(U^3)} = \frac{\left(\frac{1}{N}\sum_{i=1}^N U^3\right)}{\left(\frac{1}{N}\sum_{i=1}^N U\right)^3} \tag{8}$$

Where, Epf is the energy pattern factor and the Weibull shape parameter (k) is estimated from the following:

$$k = 1 + \left(\frac{3.69}{(epf)^2}\right) \tag{9}$$

The Weibull factors (c) can be rewritten as in equation (6):

2.3.4 Method of moments (MOM)

This method can be calculated based on the numerical iteration of the average wind speed data and standard deviation.

The value of (k) can be easily determined by the following: (Mohammadi and Mostafaeipowr, 2013)

$$k = \left(\frac{0.9874}{\frac{\sigma}{U}}\right)^{1.0983} \tag{10}$$

The Weibull scale parameter (c) is determining by equation (6):

2.3.5 Rayleigh distribution

The data required for Rayleigh distribution are the mean wind speed (Manwell, et al., 2010) (Mathew, 2006). The Rayleigh distribution is a special case from the Weibull distribution, which is approximating at $k = 2$.

The scale factor (c) can be determining by:

$$c = \frac{2U}{\sqrt{\pi}} \tag{11}$$

The PDF and the CDF can be determining by these equations:

$$p(U) = \frac{\pi}{2}\left(\frac{U}{U^2}\right) exp\left[-\frac{\pi}{4}\left(\frac{U}{\sigma}\right)^2\right] \tag{12}$$

$$F(U) = 1 - exp\left[-\frac{\pi}{4}\left(\frac{U}{\sigma}\right)^2\right] \tag{13}$$

2.3.6 Evaluation of Weibull and Rayleigh distributions

To check on the accuracy of a theoretical PDF with the observation data, in this work the five types of statistical errors are used to evaluate the performance of the Weibull methods the Root Mean Square Error (RMSE), the chi-square test (χ^2), the coefficient of determination R^2, the Mean Percentage Error (MPE) and the Mean Absolute Percentage Error (MAPE).

- The RMSE provides the deviation between the observed value and the predicted from the Weibull methods is calculated by:

$$RMSE = \left[\frac{1}{N}\sum_{I=1}^{N}\left(y_{i,m} - x_{i,w}\right)^2\right]^{1/2} \tag{14}$$

- The chi-square test (χ^2) is the mean square of the deviations between the calculated values from the measured data and the Weibull distributions (Azad, et al., 2014). And it is expressed as:

$$\chi^2 = \sum_{I=1}^{N}\left(\frac{\left(x_{i,w} - y_{i,m}\right)^2}{x_{i,w}}\right) \tag{15}$$

- The coefficient of determination (R^2) represents the linear relationship between the calculated values from the measured data and the Weibull distributions. The best or ideal value of R^2 is equal to 1 (Danwe, et al., 2014) (Al Zohbi, et al., 2014). And it is expressed as:

$$R^2 = \frac{\sum_{i=1}^{N}(y_{i,m} - z_{i,v})^2 - \sum_{i=1}^{N}(y_{i,m} - x_{i,w})^2}{\sum_{i=1}^{N}(y_{i,m} - z_{i,v})} \tag{16}$$

- MPE and MAPE is calculated by:

$$MPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_{i,w} - y_{i,m}}{y_{i,m}}\right) x100\% \tag{17}$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{x_{i,w} - y_{i,m}}{y_{i,m}}\right| x100\% \tag{18}$$

Where N is number of observations, $y_{i,m}$ is probability of ith calculated value from measured data, $x_{i,w}$ is probability of ith calculated value from the Weibull distribution and $\overline{xi,y}$ is the mean of ith calculated value from measured data (Manwell, et al., 2010).

2.4 Wind power density estimation (WPD)

The WPD can be calculated using expression given as (Adaramola, et al., 2014) (mohammadi and Mostafaeipour, et al., 2013) (Bagiorgas, et al., 2012):

$$WPD = P(U) = \frac{p(U)}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{19}$$

By using the Rayleigh approach, the WPD becomes as (Mathew, 2006):

$$WPD = P(U) = \frac{p(U)}{A} = \frac{3}{\pi}\rho\overline{U}^3 \tag{20}$$

Where: P (U), wind power, W; p (u): wind power density, W/m²; A: sweep area of the rotor blades, m²; ρ: air density at the site (kg/m³) (assumed to be 1.225 kg/m³), $\overline{U}$: wind speed average (m/s).

2.5 Wind energy density estimation (WED)

When the Wind Power Density estimated, the Wind Energy Density can be obtained by multiplying the WPD by the number of hours per year (8760 hrs.) (T). to get the annual WED in kWh/m² (Bagiorgas, et al., 2012) as following:

$$WED = P(U) T = \frac{p(U)}{A}T = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right)T \tag{21}$$

By using the Rayleigh approach, the WED becomes as (Mathew, 2006):

$$WED = P(U) T = \frac{p(U)}{A}T = \frac{3}{\pi}\rho\overline{U}^3 T \tag{22}$$

The other important factors can be calculated by using the Weibull shape (k) and scale (c) parameters are the most frequent wind speed ($U_{F\ max}$) $U_{F\ max}$ is the peak of the probability density curve and the speed contributing or carrying the maximum energy ($U_{E\ max}$) to the site. The velocity carrying maximum energy is usually higher than the most frequent wind velocity.

The most probable wind speed can be calculated by the following equation: (Adaramola, et al., 2014) (Bagiorgas, et al., 2012).

$$UF\ max = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{23}$$

By using the Rayleigh distribution method, the most frequent wind speed ($U_{F\ max}$) becomes:

$$UF\ max = \frac{1}{\sqrt{k}} = \sqrt{\frac{2}{\pi}}\,\overline{U} \tag{24}$$

The wind speed carrying the maximum energy ($U_{E}\ max$) can be calculate as:

$$UE\ max = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{25}$$

By using the Rayleigh method, the ($U_{E\ max}$) becomes:

$$UE\ max = \sqrt{\frac{2}{k}} = 2\sqrt{\frac{2}{\pi}}\,\overline{U} \tag{26}$$

3. Results and discussions

In this work, the wind speed data were recorded at a height of 10 m, continuously by a cup-generator anemometer at the Jordan Metrological Department/ Ma'an City and the two parameters of the Weibull

probability density function have been determined by MOM, EM, EPFM and GM. Table 4.1 shows the annual Weibull parameters, (k) and (c) for Ma'an City that has been calculated for this particular year.
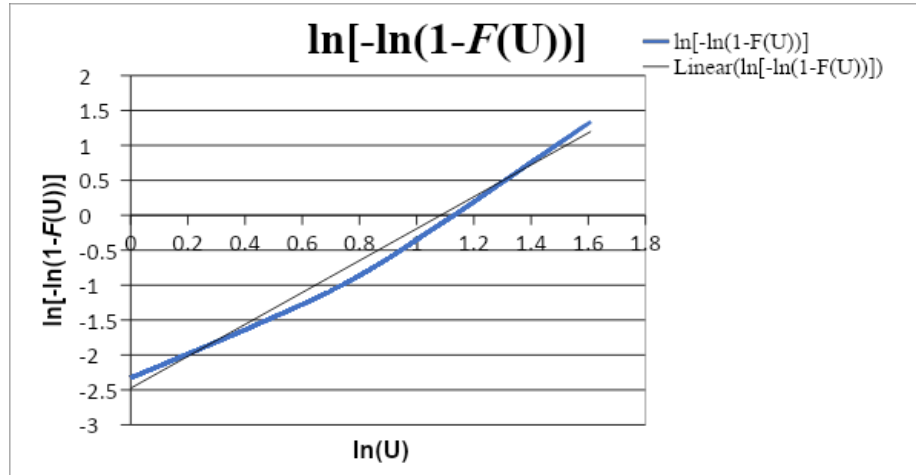

Figure 1. Regression graph of ln[-ln(1-F(U))] against n (U)

Fig. (1) Present a regression graph of ln [- ln (1-F(U))] against ln (U) to find the shape and scale parameters of Weibull distribution by using the Graphical Method.
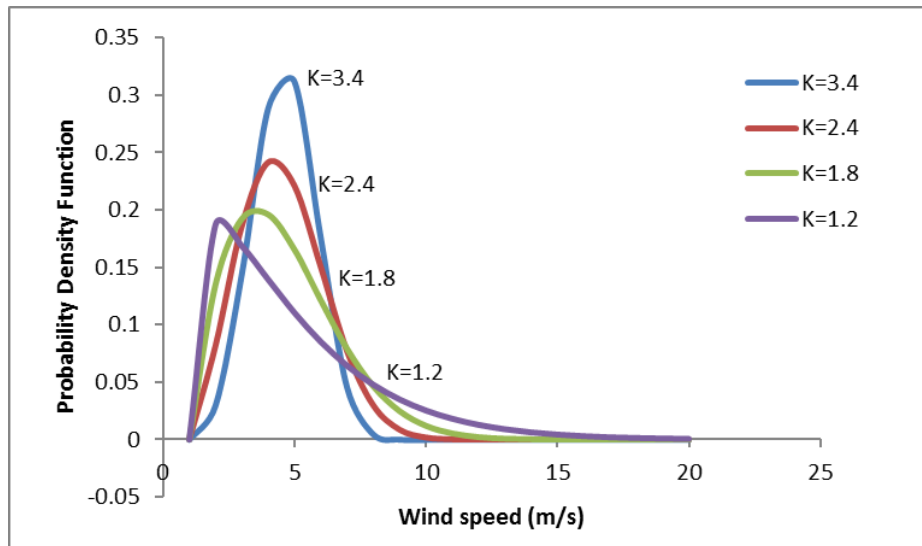

Figure 2. Weibull probability density function for different shape parameters

Fig. (2), the shape parameter (k) is 2.284 and by ln (c) = 2.284/2.476 and taking the exponential function for the two sides the scale parameter (c) becomes equal to 2.93 m/s.

The higher value of parameter (c) indicates that the wind speed is higher, while the value of (k) shows the wind stability. The wind power potential of the site increases with increases the value of scale parameter (c) (Manwell, et al., 2010) (Mathew, 2006) (Gungor,et al., 2020)

Table 1. The value of Weibull parameters analyzed by different methods for Ma'an city

Month	method of Moments (MOM)		Empirical method (EM)		Energy Pattern method (EPFM)	
	k	c	k	c	k	c
January	2.7	3.4	2.7	4.2	2.9	3.4
February	3.0	3.6	3.2	4.3	2.9	3.6
march	4.0	4.5	3.6	5.6	3.5	4.6
April	2.9	4.0	2.6	4.9	3.0	4.0
May	3.0	4.0	3.1	4.7	3.4	4.0
June	4.5	4.2	3.9	5.2	3.7	4.3
July	4.8	4.2	4.0	5.1	3.8	4.2
August	5.4	4.6	4.8	6.0	4.0	4.7
September	5.8	4.4	4.3	5.6	4.1	4.4
October	3.4	3.9	3.3	4.7	3.4	3.9
November	3.1	3.5	3.1	4.4	3.2	3.5
December	3.0	3.7	3.4	4.4	2.9	3.7
Average	3.8	4.0	3.5	4.9	3.4	4.0

In this work, it can be shown from the table (1) that the annual averages values of shape parameter (k) for the three methods are 3.8, 3.5 and 3.4 respectively. The MOM shows higher values of shape parameter 3.8 and the EPFM, EM show very closely values. The (k) parameter indicates the range of wind speeds distributions, as shown in the figure (2), the higher values of (k) represent the wind speeds most probable and staying within the narrow ranges (Manwell, et al., 2010) (Hennessey, 1977) and from the table, the highest values of (k) are from February to November, while the lowest value occurs in January and December, that means the winds are tend to vary into a large range of speeds in these two months.

In addition, table (1) shows the scale (c) parameter, the annual average scale values for the three methods are 4.0, 4.9 and 4.0 respectively. The EM shows the largest average value of (c) 4.9 m/s, the maximum value reaches at 6.0 m/s in August and minimum at 4.2 m/s in January while the MOM, EPFM shows the same annual average value of (c) is 4.0 m/s. The largest values of (c) for all methods from February to November, while the lowest values in January and December.

Table 2. Statistical analysis / test of goodness of fit of Weibull methods.

Weibull Method	Statistical test				
	RMSE	χ^2	R^2	MPE (%)	MAPE (%)
MOM	0.0317	0.3524	0.8886	0.002	0.39
EM	0.0763	1.8238	0.3556	1.139	1.888
EPFM	0.0265	0.2003	0.9223	-0.036	0.302
GM	0.0440	0.2343	0.7858	0.0109	0.4971
Rayleigh	0.0363	0.2271	0.8542	0.130	0.656

Also In this work, the four Weibull probability distribution function methods accuracy (Table 2), which is used to estimate the wind speeds with respect to the measured values were evaluated based on the five statistical test tools; MAPE, RMSE, MPE, chi-square error test ($\chi 2$), and the coefficient of determination (R2). Table (2) shows the efficiency of each method, the efficiency of the methods are relatively closer but the EPFM shows lower percentage of error which is (-0.036) and lower values of RMSE and ($\chi 2$) which are (0.0265), (0.2003) respectively.

In addition, EPFM shows a higher value of R2 to reach 0.9223, which means that this method represents the actual wind potential of selected site. Therefore, the EPFM is the best method to determine the Weibull distribution.

The EPFM and the MOM are the most accurate and efficient methods for determining the value of (k) and (c) to approximate wind speed distribution to reduce uncertainties related to the wind energy output calculation (Kidmo, et al, 2015).

Since the scale and shape parameters have been determined using the EPFM as the best fitting Weibull distribution, the annual average shape parameter (*k*) is 3.4, and the annual scale parameter (*c*) value at the EPFM method is 4.0 m/s.

The annual probability density distributions obtained from the Weibull and Rayleigh methods were compared to the measured distributions histogram in bin size of 1 m/s for the same year. The annual comparison shows the EPFM better than the Rayleigh method to fit the measured probability density distribution as shown in Fig.2. In addition, Fig.3 shows the comparing cumulative density of two methods with the measured data of wind speed. The figure also shows the EPFM better than the Rayleigh method.
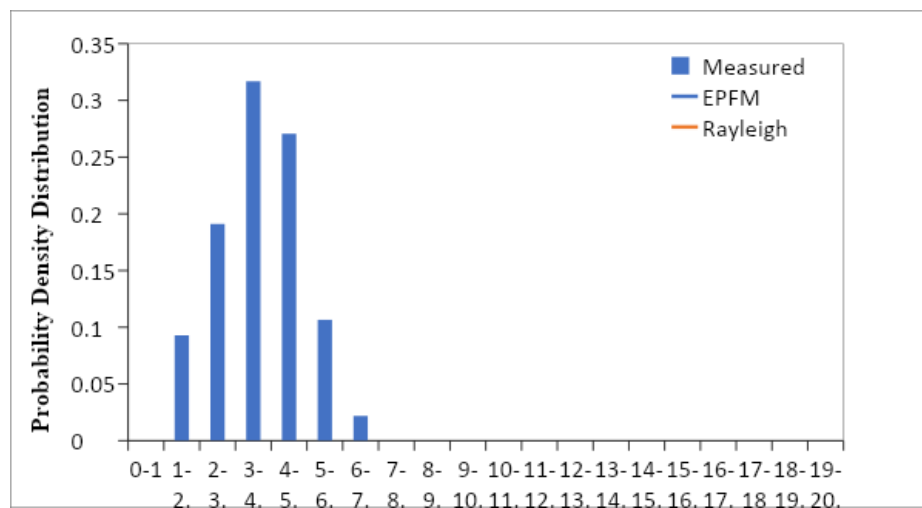

Figure 2. Comparing the probability density of EPFM and Rayleigh methods with measured data
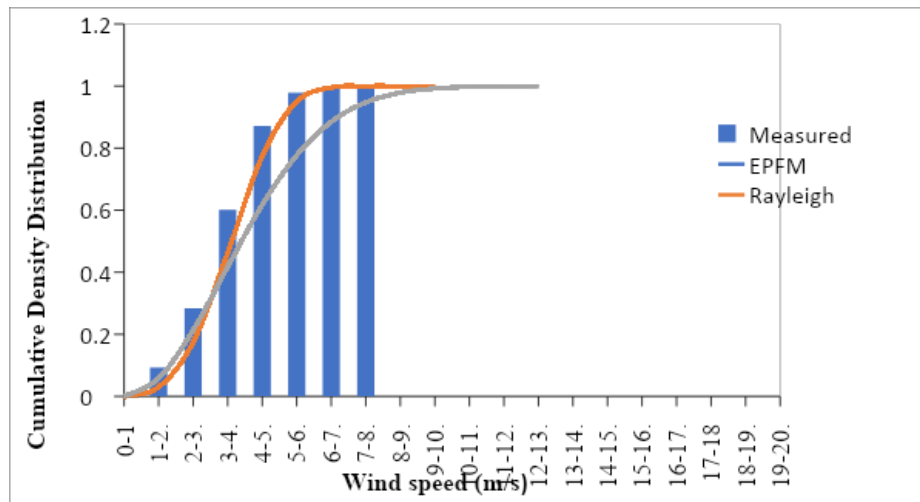
Figure 3. Comparing the cumulative density of EPFM and Rayleigh nethods with measured data

The monthly variation of the mean wind speed characteristics ($\overline{U}$, σ, UF max, UE max) and WPD and WED for the EPFM are presented in table (3), the annual average wind speed ($\overline{U}$) is 3.6 m/s. In addition, the table shows the most probable wind speed (UF $_{max}$), ranging from 2.9 m/s to 4.4 m/s with an average 3.6 m/s, which is equal to the annual average wind speed. Furthermore, the table shows the wind speeds carrying maximum energy (UE $_{max}$), the highest value is 5.2 m/s occurs in March, August and lowest value is 4.0 m/s occurs in January and November with an average 4.6 m/s.

Table 3. The Characteristic speeds and mean power density

Month	U (m/s)	σ	WPD (W/m^2)	WED (kWh/m^2)	UF max (m/s)	UE max (m/s)
January	3.0	1.20	23.5	17.48	2.9	4.0
February	3.2	1.20	29.9	20.12	3.1	4.4
March	4.1	1.15	55.8	41.51	4.2	5.2
April	3.5	1.32	38.7	27.88	3.5	4.7
May	3.6	1.29	37.3	27.74	3.6	4.6
June	3.9	0.97	44.7	32.18	3.9	4.8
July	3.8	0.90	43.3	32.18	3.9	4.7
August	4.2	0.90	57.5	42.77	4.4	5.2
September	4.0	0.81	48.7	36.22	4.2	4.9
October	3.5	1.13	34.2	25.44	3.5	4.4
November	3.1	1.11	24.9	18.50	3.1	4.0
December	3.3	1.22	32.6	23.47	3.2	4.5
Annual	**3.6**	**1.1**	**39.3**	**345.5**	**3.6**	**4.6**

The power and energy density predicted for the year by using the Weibull distribution method EPFM to assess the wind resource available in the site also shown in the same table, the monthly power density varies between 23.5 W/m^2 in January and 57.5 W/m^2 in August. The highest values occur from March to September, while the

lowest values occur in January. The annual power density and energy density are 39.3 W/m^2 and 345.5 kWh/m^2 respectively

Table (4) shows the comparison of the monthly WPD and the WED between the actual data (measured), Weibull method EPFM and the Rayleigh method. The results show that the average value of WPD calculated from mean wind speed is 29.8 W/m^2. The maximum value is 46.6 W/m^2 occurs in August and the lowest value is 16.4 W/m^2 occurs in January. The power density estimated by the Rayleigh method is higher than the power density calculated from the actual data and Weibull method as shown in the table.

The average annual power density estimated by Rayleigh and Weibull are 57.0 and 39.3W/m^2 respectively. The maximum value is 89.0 W/m^2 occurs in August, while the lower value is 31.3 W/m^2 occurs in January.

Table 4. Comparison the characteristic speed and mean power density between the measured data and the Weibull (EPFM) and Rayleigh methods

Method	Month	JAN	FEB	MAR	APRL	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
Energy Pattern factor method (EPFM)	Um (m/s)	3.0	3.2	4.1	3.5	3.6	3.9	3.8	4.2	4.0	3.5	3.1	3.3
	σ	1.20	1.20	1.15	1.32	1.29	0.97	0.90	0.90	0.81	1.13	1.11	1.22
	UF max (m/s)	2.9	3.1	4.2	3.5	3.6	3.9	3.9	4.4	4.2	3.5	3.1	3.2
	UE max (m/s)	4.0	4.4	5.2	4.7	4.6	4.8	4.7	5.2	4.9	4.4	4.0	4.5
	WPD(W/m^2)	23.5	29.9	55.8	38.7	37.3	44.7	43.3	57.5	48.7	34.2	24.9	32.6
	WED(kWh/m^2)	17.5	20.1	41.5	27.9	27.7	32.2	32.2	42.8	36.2	25.4	18.5	23.5
Rayleigh distribution	Um (m/s)	3.0	3.2	4.1	3.5	3.6	3.9	3.8	4.2	4.0	3.5	3.1	3.3
	σ	1.20	1.20	1.15	1.32	1.29	0.97	0.90	0.90	0.81	1.13	1.11	1.22
	UF max (m/s)	1.4	1.4	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.4	1.5
	UE max (m/s)	2.8	2.9	3.2	3.0	3.0	3.1	3.1	3.3	3.2	3.0	2.8	2.9
	WPD(W/m^2)	31.3	39.7	81.7	51.9	54.1	66.9	65.4	89.0	76.3	49.7	34.8	43.2
	WED(kWh/m^2)	23.3	26.7	60.8	37.3	40.2	48.1	48.7	66.2	56.7	37.0	25.9	31.1
Measured	Um (m/s)	3.0	3.2	4.1	3.5	3.6	3.9	3.8	4.2	4.0	3.5	3.1	3.3
	σ	1.20	1.20	1.15	1.32	1.29	0.97	0.90	0.90	0.81	1.13	1.11	1.22
	WPD(W/m^2)	16.4	20.8	42.7	27.1	28.3	35.0	34.2	46.6	39.9	26.0	18.2	22.6
	WED(kWh/m^2)	12.2	14.0	31.8	19.5	21.1	25.2	25.5	34.6	29.7	19.4	13.6	16.3

Figure (4) shows the comparison WPD between the measured data and the Weibull (EPFM), Rayleigh methods. The figure shows the power density estimated by the Weibull method is better than the Rayleigh method to represent the actual data and the results are closer to the actual data.
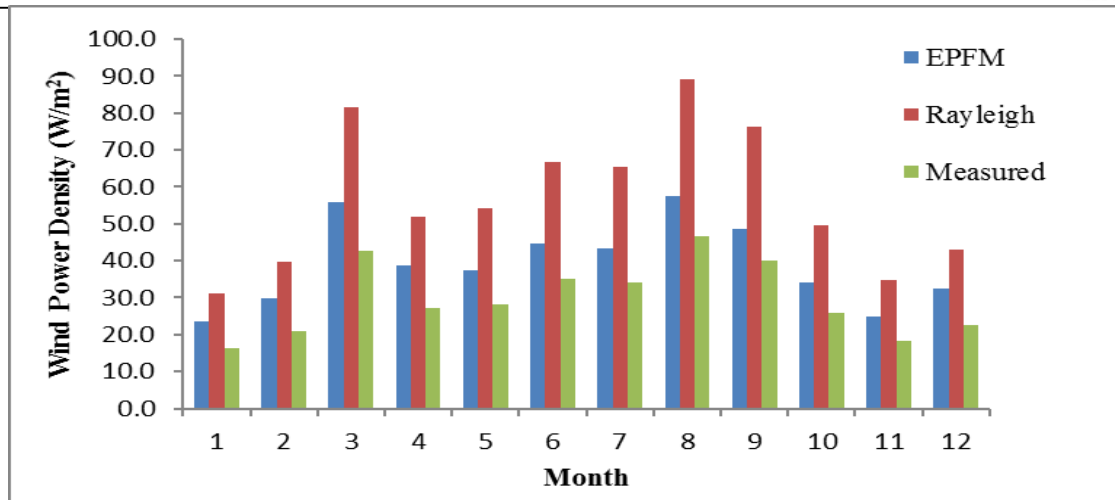
Figure 4. Comparing the wind power density of Weibull (EPFM) and Rayleigh methods with measured data

4. Conclusion

Monthly wind speed showed that the fastest wind speed is generally in the month of September/August and slowest in December/January. Results presented Weibull distribution to fit measured probability density distribution, cumulative density distribution better than the Rayleigh distribution. In addition to that, the power density estimated by the Weibull method is better than the Rayleigh method, and the results are closer to the actual data. The efficiency of the four methods of Weibull showed that the EPFM is the best method to determine the Weibull distribution based on higher values of R^2 and lower values of the MPE, RMSE and χ^2. From the analysis, it has been found that annual average shape parameter (k) is 3.4 and the annual average scale parameter (c) is 4.0 m/s. The most probable wind speed is 4.4 m/s occurs in August and the maximum wind speed carrying maximum energy is 5.2 m/s occurs in October. Meanwhile, the maximum power and energy density are 57.5 W/m2, 42.8 kWh/m2 respectively occurs in August. And the site has annual power density 39.3W/m2 and 345.5 kWh/m2 of energy density.

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