

Scientific Review – Engineering and Environmental Sciences (2020), 29 (1), 37–53
Sci. Rev. Eng. Env. Sci. (2020), 29 (1)
Przełąd Naukowy – Inżynieria i Kształtowanie Środowiska (2020), 29 (1), 37–53
Prz. Nauk. Inż. Kszt. Środ. (2020), 29 (1)
<http://iks.pn.sggw.pl>
DOI 10.22630/PNIKS.2020.29.1.4

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An assessment the wind potential energy as a generator of electrical energy in the coastal area of southern Iraq

Key words: wind energy, Basrah, wind speed analysis, wind potential

Introduction

Energy is the basis of the economic, social growth of countries, and is a measure of human development for all countries, including Iraq. The need for the energy sector, especially electric power, is constantly increasing, which in turn increases the demand for energy to meet these requirements (Keyhani, Ghasemi-Varnamkhasti, Khanali & Abbaszadeh, 2010). On the other hand, fossil fuels are considered to be depleted and non-renewable. It is therefore necessary to find new alternative and non-exhaustible energy such as wind energy. By the end of 2018 the overall output energy harvest from all wind turbines installed world-

wide reached 600 GW, depending on the statistics published by WWEA (2009). Such that, about 54 GW were added in the year 2018, little more than year 2017 where about 53 MW were installed. The preceding amount of electricity generation represents a third largest number installed since the years 2015 and 2014. However, the recorded annual growth rate shows that the year 2017 has the most growing number with almost 11%. While 2018 represents the lowest growth in wind energy since the renewable industrial was begun at the end of 20th century (WWEA, 2009; Elmokadem, Megahed & Noaman, 2016). In Iraq there are many natural resources available in different geographical sources, most of these resources are distributed over large geographical area, which allows for a degree of flexibility in choosing locations (Kazem & Chaichan, 2012).

Distribution of wind speed in Iraq

According to International Renewable Energy Agency (IRENA) wind atlas map it is possible to divided Iraq into three areas. The first area covered 85% from the total area and it possesses wind speeds that vary between $6\text{--}7\text{ m}\cdot\text{s}^{-1}$. The second territory covered about 10% of total Iraq area and it possesses wind speeds that vary between $4\text{--}5\text{ m}\cdot\text{s}^{-1}$. The third one covered about 5% of total Iraq area and possesses low wind speeds less than $4\text{ m}\cdot\text{s}^{-1}$ (Fig. 2). The approximate wind power densities for all preceding areas at height of 100 m are as follows: $150\text{--}800$, $75\text{--}150\text{ W}\cdot\text{m}^{-2}$ and less (Fig. 3; Kazem & Chaichan, 2012; IRENA, 2015).

by the turbine is determined by the different wind velocities; (2) the potential energy of wind regime and (3) the wind speed distribution and behaviour within the regime.

The total power produced by a wind turbine can be calculated over a specified period of time by adding the power corresponding to all wind velocities available in the regime where systems operate. Also, from probability density function belongs to different wind speed and wind turbine characteristics it is possible to make energy calculations. It is easy to determine the appropriate turbine type for that location by determining cut-in velocity, rated velocity, and the cut-out velocity. Thus, it is necessary to

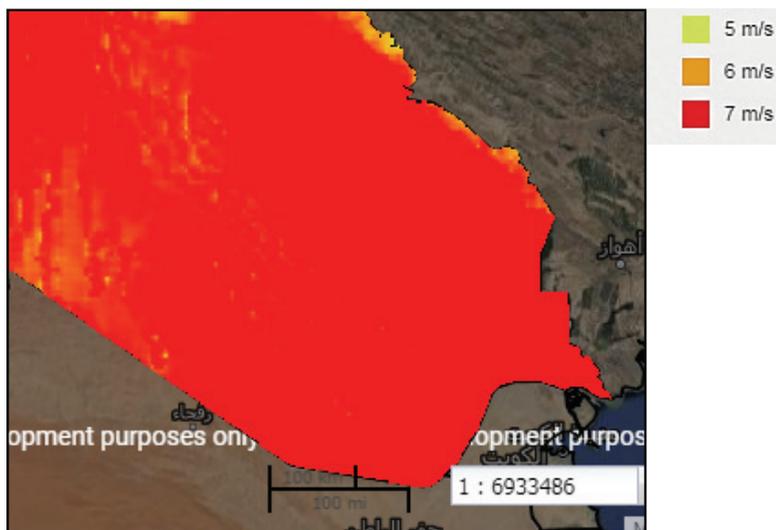


FIGURE 2. Wind speed classes in Iraq (IRENA, 2015)

The factors affecting the wind energy conversion systems (WECS) production at any given location over a certain period of time can be summarized as follows: (1) the power and energy produced

know the characteristics of the winds for a site in order to reach a conclusion on the possibility of investing wind energy for a particular site (Keyhani et al, 2010; Firas, 2014).

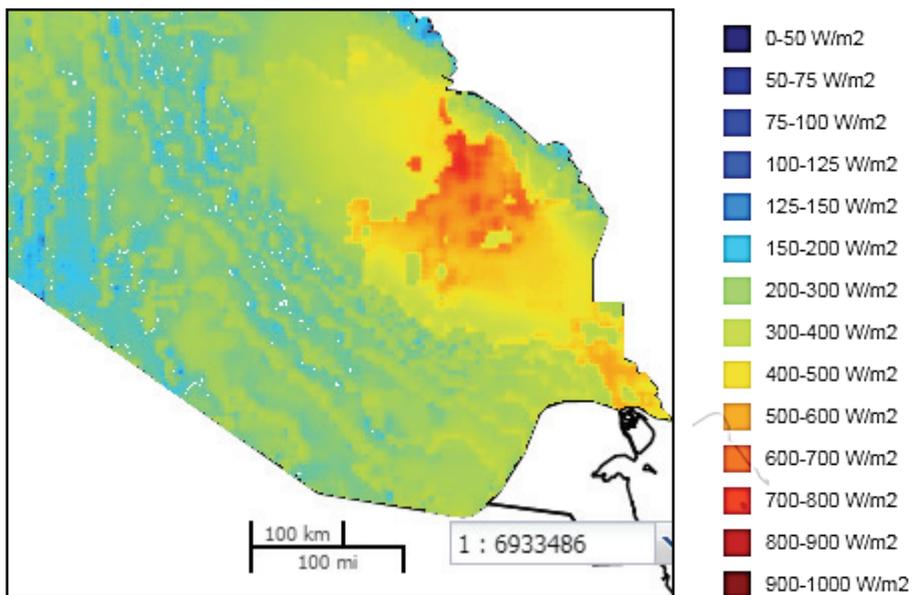


FIGURE 3. Wind power density in Iraq (IRENA, 2015)

Equivalent energy method (EEM)

This method uses a function optimization procedure based on the distribution energy content in order to obtain Weibull parameters which fit wind speed distribution. The wind speed probability which greater than a specific value (v), is defined by (Firas, 2014):

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

The probability of wind speeds ($P(v)$) greater than or equal to $v - 1$ and lower than v

$$P(v) = P_r(v-1) - P_r(v) \quad (2)$$

$$P(v) = e^{-\left(\frac{v-1}{c}\right)^k} - e^{-\left(\frac{v}{c}\right)^k} \quad (3)$$

Statistically, P_v represented a stochastic variable which can be defined as:

$$P_v = P(v) + \varepsilon = \left[e^{-\left(\frac{v-1}{c}\right)^k} - e^{-\left(\frac{v}{c}\right)^k} \right] + \varepsilon \quad (4)$$

Where ε corresponds to the stochastic term. The Weibull scale factor (c) can be written as:

$$c = \left(v_m^3 / \Gamma\left(1 + \frac{3}{k}\right) \right)^{1/3} \quad (5)$$

By substituting Eq. (5) in Eq. (4) it yields:

$$P_{v_i} = e^{-\left(\frac{(v_i-1)\left(\Gamma\left(1+\frac{3}{k}\right)\right)^{\frac{1}{3}}}{v_m}\right)^k} - e^{-\left(\frac{v_i\left(\Gamma\left(1+\frac{3}{k}\right)\right)^{\frac{1}{3}}}{v_m}\right)^k} + \varepsilon \quad (6)$$

Now, in order to find the Weibull shape factor (k), the least squares technique to the following expression can be estimated

$$\sum_{i=1}^n \left[P_{v_i} - e^{-\left(\frac{-(v_i-1)\left(\Gamma\left(1+\frac{3}{k}\right)\right)^{\frac{1}{3}}}{v_m}\right)^k} + e^{-\left(\frac{-v_i\left(\Gamma\left(1+\frac{3}{k}\right)\right)^{\frac{1}{3}}}{v_m}\right)^k} \right]^2 = \sum_{i=1}^n (\varepsilon_i)^2 \quad (7)$$

where:

P_{v_i} – probability of having wind speeds for i^{th} bin;

n – number of bins of the wind speed histogram;

v_i – the highest wind speed value of the for i^{th} bin;

v_m^3 – mean cube (observed).

After k is compute, the scale factor is calculated from Eq. (5).

Results and discussions

Wind speed analysis at height of 50 m

In contrast to solar energy, electrical energy production from wind is difficult to estimate. Wind energy depends on site characteristics and topography. Wind speeds can be significantly affected on

the advantages of local topography. The description and classification of any area to high potential and extensive effort to classify the site of the study to low or high winds, where the speed and direc-

tion of the wind in severe shifts in most locations and require a detailed study of the spatial and temporal changes of wind speed values. Before locating the wind farm, monthly and daily wind speed distributions, wind speed distributions and wind power density should be analysed carefully (Amani, 2007).

Monthly wind speed

The monthly mean wind speed values at Basrah coast are presented in Figure 4 for duration time 37 years (from 1 January 1979 to 3 January 2016). By analysed mean wind speed data of 444 months, it can be inferred that the average wind speed distribution varies markedly from month to month. This figure also shows that the most monthly frequent mean wind speed values are between two values 5 and 6 $\text{m}\cdot\text{s}^{-1}$, but

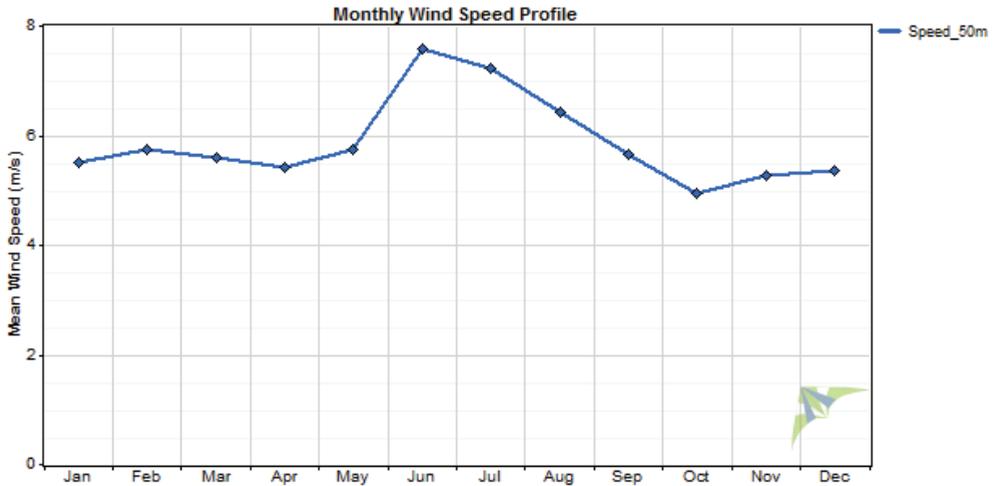


FIGURE 4. Monthly mean wind speeds

there are also mean wind speeds over than $6 \text{ m}\cdot\text{s}^{-1}$ by rate 25%, From other side, only a few mean wind speeds are over 7 and under $5 \text{ m}\cdot\text{s}^{-1}$ by rate 16 and 8% respectively. The highest mean wind speed value in June with $7.5 \text{ m}\cdot\text{s}^{-1}$, while the minimum mean wind speed value is observed in October with $4.9 \text{ m}\cdot\text{s}^{-1}$. In such a case, wind energy can be used to boost electricity.

Diurnal wind speed

Another important property of site characteristics which should be studied when preparing to any wind power project is the profile of daily wind regime at area of study. Figure 5 shows the change in daytime of mean wind speeds at height of 50 m above ground level (a.g.l.). From this figure, we can also find that the hourly mean wind speeds start in increasing gradually from 12 pm up to the highest value at 8 pm. Mean wind speeds then become decreasing, while from 4 am to 11 am wind speed will remain calm. This mean that at night time is almost windy

through whole the year, while the daytime is quiet through whole the year.

Wind direction frequency

Wind direction calculations is important for conducting wind energy researches and wind farms geometry. Also, it displays the impact of geographical features on the wind. There are many ways used for wind direction charts representations one of these is shown in the polar chart (concentric circles) and the method of measurement is in degrees and the direction of rotation is clockwise. This diagram consist of 360° concentric cycles divided into 16 sections, each one of them included arc with 22.5° . In Figure 6, the wind direction and its frequency data are combined in the polar diagram for Basrah coast (the area of study) are presented for the period 1979–2016. It is clear that the prevailing trend of wind throughout this period is the northwest and within section 15 between 292.5° and 337.5° .

Also, it is convenient to study the average monthly occurrences of wind

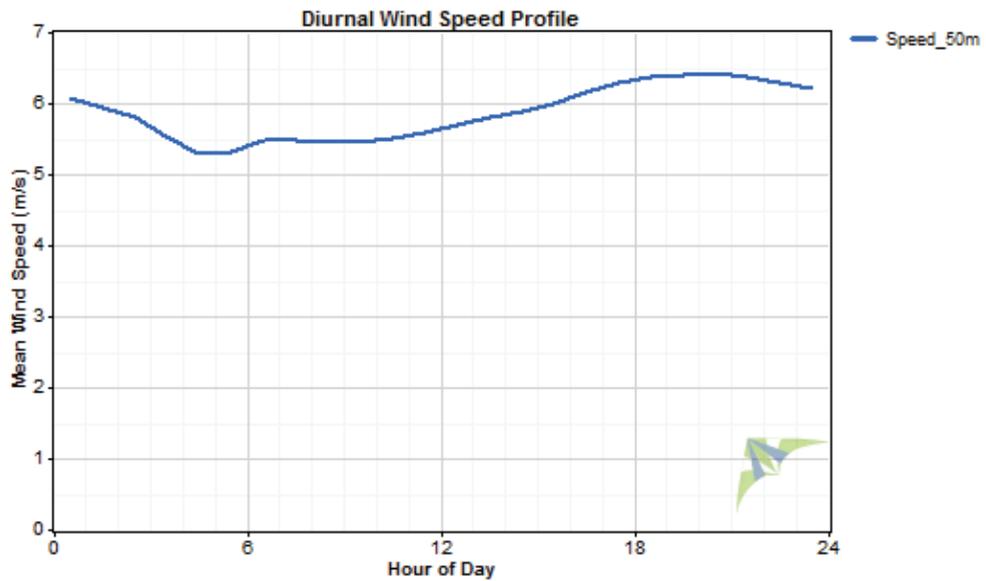


FIGURE 5. Daily mean wind speeds

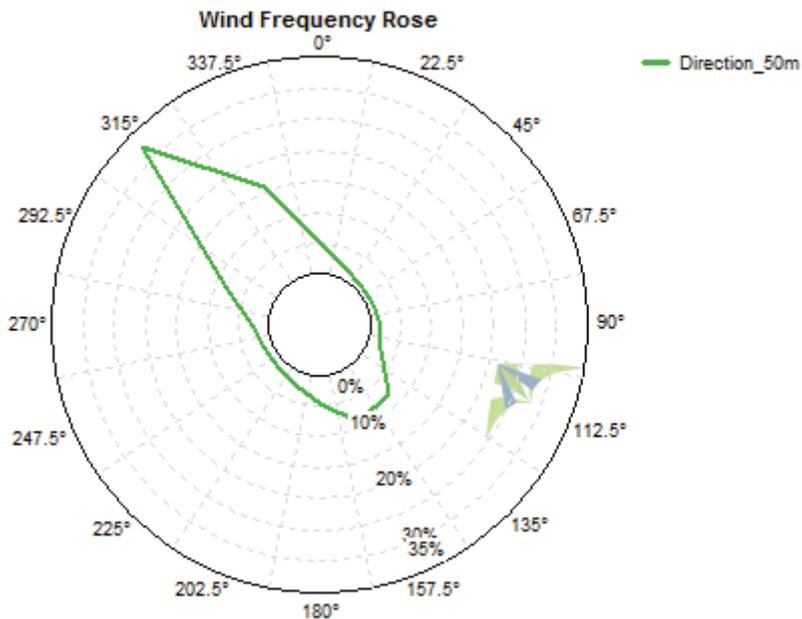


FIGURE 6. Polar diagram – wind direction at height of 50 m

speed blowing direction, this will give an idea of how the wind changes for different seasons. Figure 7 shows a com-

parison between different polar diagrams for the monthly average wind speed frequency and its relation with the direction

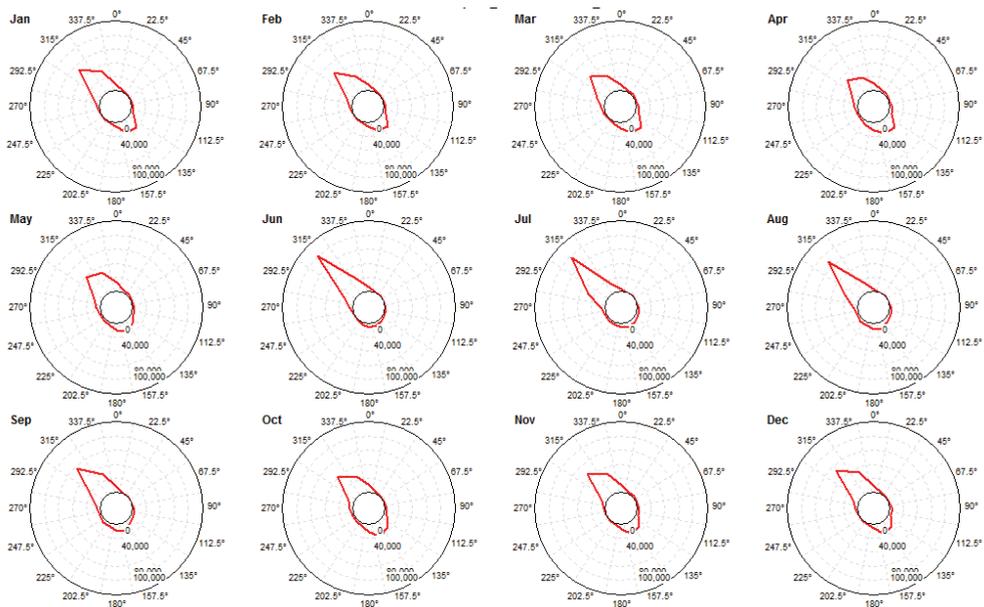


FIGURE 7. Occurrences of speed at height of 50 m versus wind direction

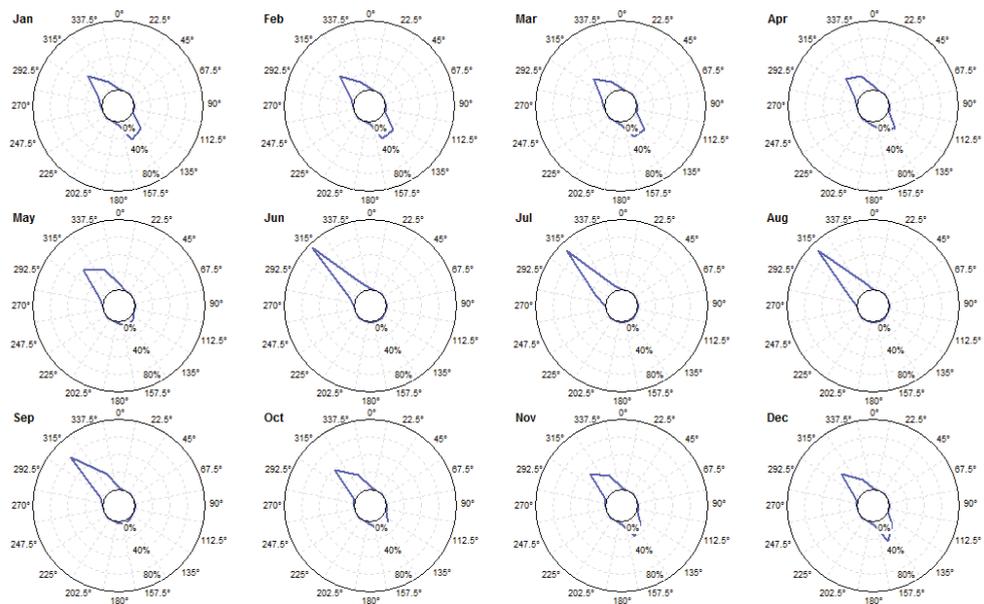


FIGURE 8. Proportion of total wind energy in speed at height of 50 m versus wind direction

from 1979 to 2016. The most probable wind direction for that period is at 315° , i.e. northwesterly winds. In the monthly polar diagrams, specifically in the most prevailing wind direction (northwest), wind frequency seems to be good. On the other hand, it should be noted that the prevailing wind frequency overall years ranges from 40–80%. The more stillness percentage is occurred at three months (June, July and August) which reach about 80%, while the less percentage is shown in April.

Also, it is convenient to study the relation between wind potential energy and wind direction. The average wind energy for each month from 1979 to 2016 as a relation with the direction of wind blow can be given in Figure 8. This figure have the same behaviour of Figure 7 and shows the wind energy percentage for each month. Jun has the most amount of energy, in other side, the dominant direction whole the year is northwest with little amount of energy for southeast di-

rection except for June, July, August and September.

Wind speed analysis at different heights

The wind speed at height of 50 m is taken as a reference height, then it was adjusted and is estimated at different heights: 30, 70 and 100 m a.g.l. Wind speed is calculated using the power law (Firas, 2014):

$$v_2(z_2) = v_1(z_1) \left(\frac{z_2}{z_1} \right)^\alpha \quad (8)$$

v_2, v_1 – synthesized and reference wind speeds at elevations z_2 and z_1 , respectively;

α – Hellmann exponent (friction or wind shear).

The Internatioximum values in June (about $8.3 \text{ m}\cdot\text{s}^{-1}$) at height of 100 m a.g.l., while at height of 30 m the wind speed will reach about $7 \text{ m}\cdot\text{s}^{-1}$ from other side, the wind speed reach the minimum value

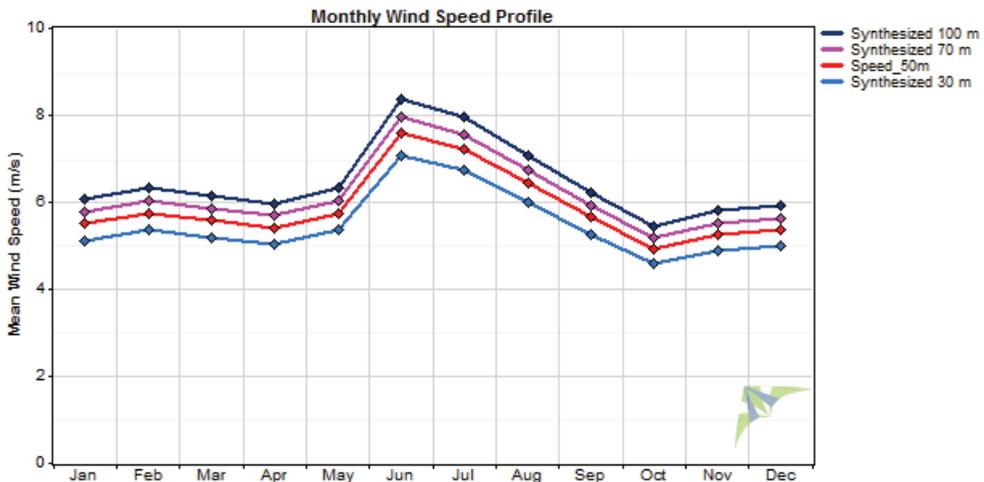


FIGURE 9. Monthly mean wind speed variation in Basrah in 1979–2016

in October, about $5.5 \text{ m}\cdot\text{s}^{-1}$ at height of 100 m a.g.l., while at height of 30 m the wind speed will reach about $4.5 \text{ m}\cdot\text{s}^{-1}$ (Fig. 9).

Diurnal wind speed profile

The mean daily wind speed behaviour for the year of study is very important in wind energy projects, its represents one of the facts that determine wind turbines. As in the previous section where the data taken from the source and at a height of 50 m were converted to different heights of 30, 70 and 100 m a.g.l., for our area of study (Basrah), daily wind speed variations are illustrated in Figure 10. From this figure it is possible to say that, at 10 am the wind speed at height of 50 m a.g.l. will increase gradually reaching to its maximum value $6.5 \text{ m}\cdot\text{s}^{-1}$ at around 8 pm, then wind speed will gradually decrease to its minimum value $5.3 \text{ m}\cdot\text{s}^{-1}$. The winds in this area are calm during

the day time but it starts to increase in the evening, which gives an opportunity to invest solar energy during the day and wind energy at night.

Mean wind power density diurnal profile

Another important characteristic of the site is the diurnal variations for hourly average data (reference and estimated wind speed) along the study time at the Basra coast site is shown in Figure 1. Mathematically, the mean wind power density in terms of wind speed is calculated as (Firas, 2014):

$$PD_v = \frac{1}{2} \rho \sum_{i=1}^n \frac{v_i^3}{n} \quad (9)$$

where n is the total sample data for a period of time.

The comparison showed the daily patterns of the average wind speed in

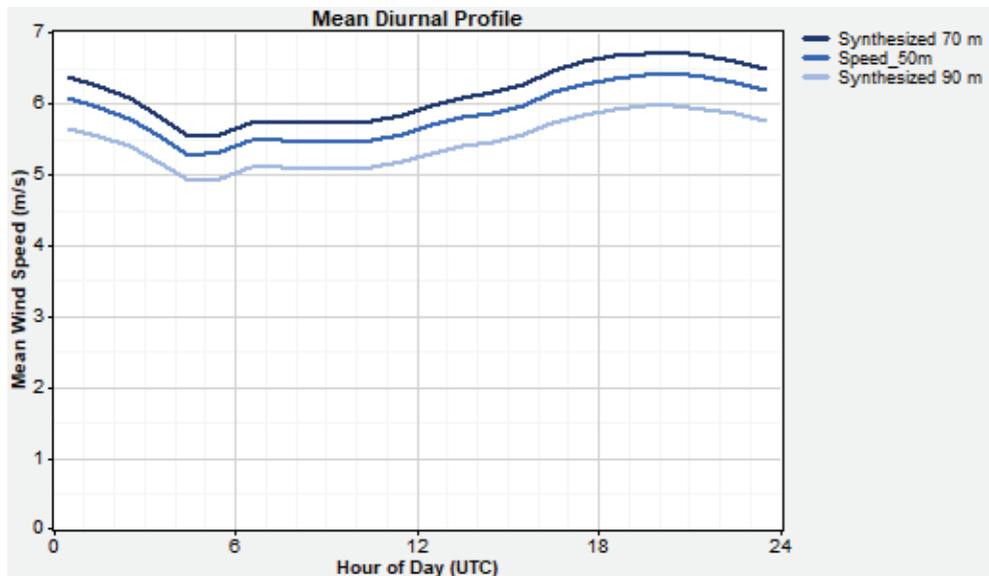


FIGURE 10. Diurnal mean wind speed

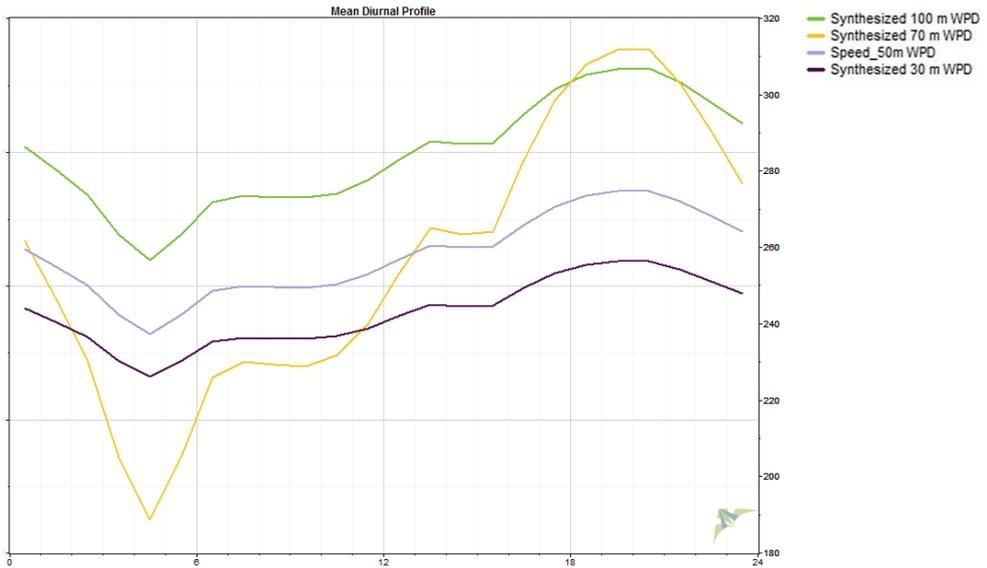


FIGURE 11. Mean wind power density profile

order to obtain and determine the maximum and minimum speed used in the production and generation of electricity from the located turbine. It is possible to observe the average maximum and minimum wind power density during the years of study of the wind at various heights, where the maximum power density at about 8 pm and the minimum power density at 5 am. The maximum value of wind power density for reference high at 50 m is almost $275 \text{ W}\cdot\text{m}^{-2}$ and near $240 \text{ W}\cdot\text{m}^{-2}$ for minimum value (Fig. 11).

Probability distribution function

The probability distribution function (PDF) is used to demonstrate how the site is suitable for wind energy systems and also used for wind data analysis. Figure 12 shows the distribution of wind frequency for 12 months at height of 50 m. The bin size of the distribution

showing $0.5 \text{ m}\cdot\text{s}^{-1}$. The curve plotted against the frequency distribution of measured wind speed is called Weibull distribution function, and this curve represent the best fit to the measured wind speed data. The two-parameter Weibull distribution given by (Firas, 2014):

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (10)$$

where:

k – shape parameter;
 c – scale parameter [$\text{m}\cdot\text{s}^{-1}$].

Fitting depends on two parameters called shape and scale parameters, best fit is obtained using the equivalent energy method (EEM) which is explained bellow. Weibull shape parameter for fitting curve is equal to 2.10, while Weibull scale parameter is $6.62 \text{ m}\cdot\text{s}^{-1}$. The wind speed is not uniform and take different

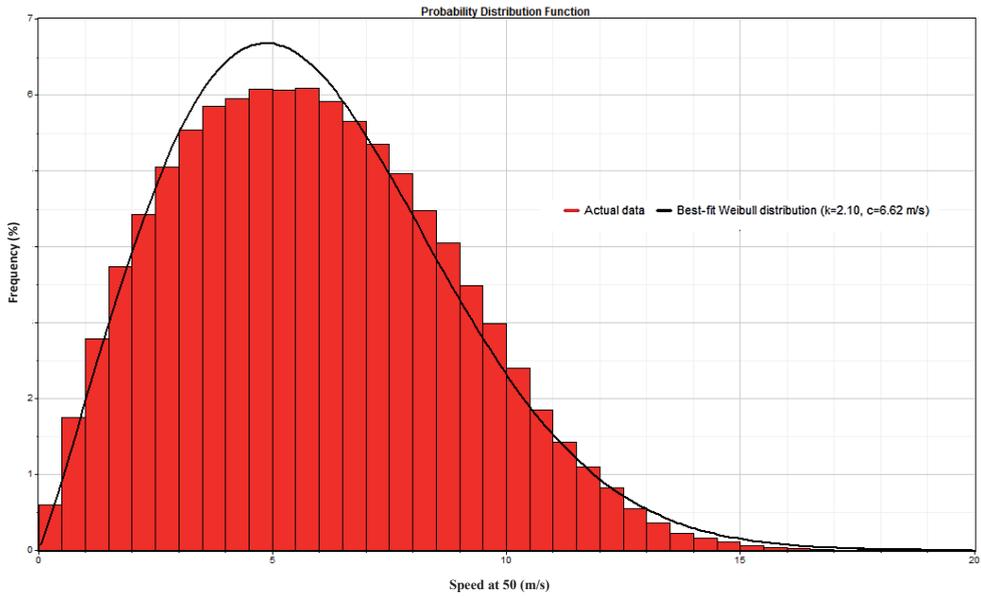


FIGURE 12. Weibull destitution function

values tend to produce different sets of ranges. The value of scale parameter shows the average wind speed at the wind farm, while the low values of shape parameter mean that the wind speed is not uniform.

Monthly frequency by bin

The monthly Weibull probability density of the measured data for the whole year of the location is shown in Figure 13. It is noticeable from this figure that the cold months (December, January, February, March) that the wind tends to quiet speed due to high pressure of cold air masses. We also notice an increase in wind speed in hot months, in contrast to the previous, due to the increasing in convection current of low air masse pressure. It is also possible to observe the increasing in wind speed frequencies in October and May as months in which seasons changes occur.

Wind speed statistical analysis

The Weibull PDF gives a better fit for measured probability density distributions than other statistical functions. This it could be depends on the Weibull PDF in order to find wind statistics. The most important statistics is given in Table 1. It show the characteristics of wind speed for whole years of study at 50 m a.g.l. with following observations:

1. The mean wind speed calculated for this site point out to the suitability of this location for micro and small wind energy systems.
2. The mean and the median are almost equal, then distribution appears to be near symmetric.
3. The maximum frequency is 0.13 at wind speed $4.8 \text{ m}\cdot\text{s}^{-1}$, which is also called most probable wind speed.
4. The positive sign of 3rd raw moment inferring to skewness of the distribution toward right.

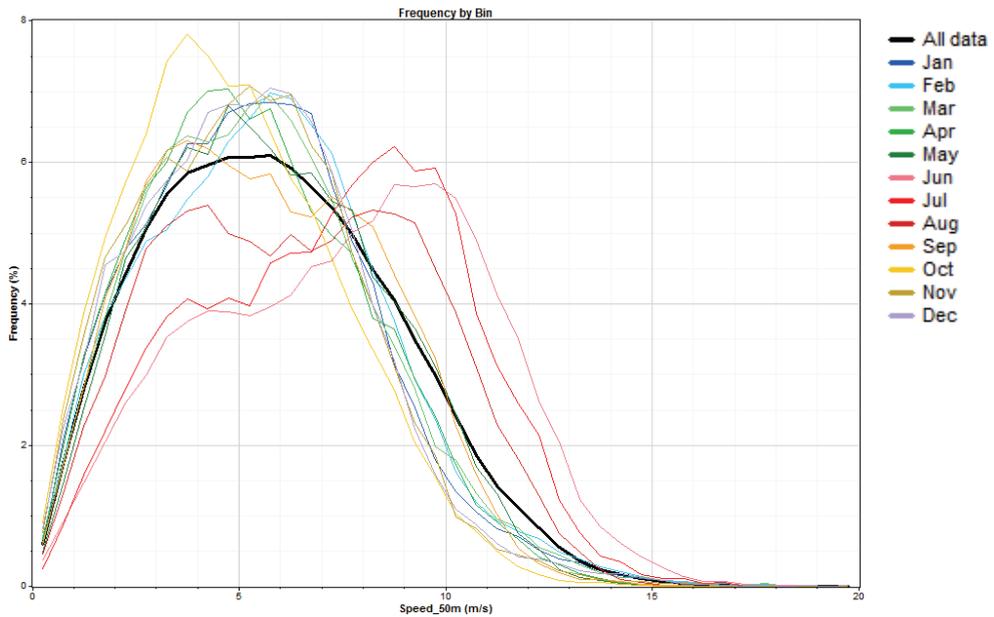


FIGURE 13. Monthly Weibull destitution function

TABLE 1. Some Weibull statistics

Specification	Value
c [$\text{m}\cdot\text{s}^{-1}$]	6.62
k	2.1
Mean speed [$\text{m}\cdot\text{s}^{-1}$], conventional method	5.8
Median speed [$\text{m}\cdot\text{s}^{-1}$]	5.5
Modal speed [$\text{m}\cdot\text{s}^{-1}$]	4.8
Maximum frequency	0.13
1 st raw moment (mean speed, Weibull-based) [$\text{m}\cdot\text{s}^{-1}$]	5.8
2 nd raw moment [$\text{m}\cdot\text{s}^{-1}$] 2 – measure of spread	42.9
3 rd raw moment [$\text{m}\cdot\text{s}^{-1}$] 3 – measure of skewness	367
4 th raw moment [$\text{m}\cdot\text{s}^{-1}$] 4 – measure of peakedness	3 524

The wind power density calculated from Weibull parameters (Fig. 14) is $224 \text{ W}\cdot\text{m}^{-2}$. In addition, the wind speed that carrying maximum energy (maximum power density) is $9.1 \text{ m}\cdot\text{s}^{-1}$.

Wind statistics at different heights

Since mean wind speed has a logarithmic variation with heights, thus wind statistics will have variation with height. Numerous mathematical equations were

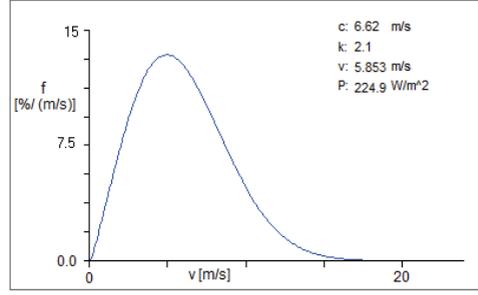
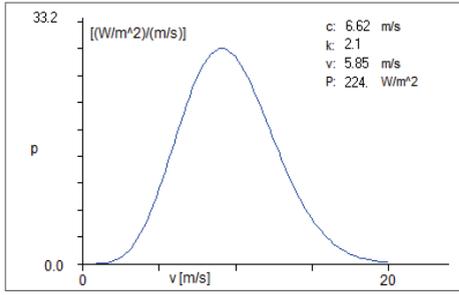


FIGURE 14. Power density versus wind speed at height of 50 m

used for the purpose of deriving wind statistics at different heights from certain source height. The extrapolation equation to get Weibull parameters at different heights can be given in bellow.

If c_1 and k_1 are Weibull functions at some anemometer height h_1 the values of Weibull parameters at different c_2 and k_2 for any desired height h_2 (e.g. the turbine hub height) can be assessed by (Firas, 2014):

$$c_2 = c_1 \left(\frac{h_2}{h_1} \right)^n \quad (11)$$

$$k_2 = k_1 \frac{1 - 0.0881 \ln \left(\frac{h_1}{h_2} \right)}{1 - 0.0881 \ln \left(\frac{h_2}{h_1} \right)} \quad (12)$$

Here h_r is reference height of 10 m, n was found to be:

$$n = \frac{0.37 - 0.0881 \ln(c_1)}{1 - 0.0881 \ln \left(\frac{h_1}{h_2} \right)} \quad (13)$$

The expected monthly or annual wind power density per unit area of a site based on a Weibull probability den-

sity function can be expressed as follows (Firas, 2014):

$$PD_w = \frac{1}{2} \rho c^3 \Gamma(1 + 3/k) \quad (14)$$

The total energy generated is given by multiplication between annual wind speed distributions h with turbine power curve at wind speed v_i :

$$E = \sum_{i=1}^n h(v_i) p(v_i) \quad (15)$$

In order to yield the best estimation of wind statistics for whole the years, Windographer software uses power law to compute synthesized wind statistics (Firas et al., 2018). Table 2 shows the reference statistics at 50 m a.g.l. and the estimated of the synthesized wind statistics at 30, 70 and 100 m a.g.l.

From Table 2 it is obvious that the wind speed is increased with increasing in height, reaching maximum value $6.4 \text{ m}\cdot\text{s}^{-1}$ at 100 m a.g.l. The semi-equal values of mean and median wind speed indicates that wind speed distribution at that location tend to be almost regular. Since scale factor (c) is closely related to the mean wind speed thus this value is increased with height. In contrast to scale factor value of shape factor is a fixed

TABLE 2. Synthesized wind statistics

Variable	Synthesized at 100 m	Synthesized at 70 m	Speed at 50 m	Synthesized at 30 m
Measurement height [m]	100	70	50	30
Mean wind speed [$\text{m}\cdot\text{s}^{-1}$]	6.4	6.1	5.8	5.4
Median wind speed [$\text{m}\cdot\text{s}^{-1}$]	6.2	5.9	5.6	5.2
Weibull c [$\text{m}\cdot\text{s}^{-1}$]	7.29	6.94	6.62	6.16
Weibull k	2.09	2.09	2.09	2.09
Mean power density [$\text{W}\cdot\text{m}^{-2}$]	298	256	223	180
Mean annual energy content [$\text{kWh}\cdot\text{m}^{-2}$]	2 609	2 246	1 950	1 573

value and does not change with height, this is because shape factor (k) is a measurement of the width of the distribution and it does not change with height. Furthermore, it is shown that mean wind power density at height of 50 m was $223 \text{ W}\cdot\text{m}^{-2}$, and also keep the same class at height of 100 m.

Wind power class

The wind energy class refers to energy content anywhere. Table 3 shows seven classes and each one has a specific range of wind power density at 50 m a.g.l. By comparison between wind power density and Table 3 it is clear that the study site is assigned to the second class with marginal description. It is clear that the wind farm project is not suitable for

TABLE 3. Wind power class (Firas et al., 2018)

Class	Description	Power density at 50 m [$\text{W}\cdot\text{m}^{-2}$]
1	poor	100–200
2	marginal	200–300
3	fair	300–400
4	good	400–500
5	excellent	500–600
6	outstanding	600–800
7	superb	800–2 000

electric power generation at height of 50 m, even for heights of 70 and 100 m. It is worth mentioning that our studied area has less power density compared with Figure 3 due to different data sources. Figures 2 and 3 were built by IRENA using atmospheric simulation conditions with SKIRON model and 5 km resolution. Such spatial resolution is small for area representing the study site, while the data studied in this research taken from NASA depends mainly on recording stations with data extrapolation can be done for full coverage area.

Conclusions

In the present study, wind speed data of the Basra coast in Iraq were statistically analysed. Also, the daily and monthly mean wind speed behaviours beside probability density distributions were derived and the distribution parameters were identified, then Weibull parameters were used to study wind potential energy. The most important outcomes of the study can be summarized as follows:

- It was concluded that the study site is not suitable for the installation of large wind turbines, but this wealth

can be used to build small wind generators.

- NASA space data often give less a guess than IRENA wind atlas map.
- May, June, July and August months that the average wind speeds are the highest all around the year.
- The mean wind speed at height of 50 m for the period 1979–2016 was found about $6 \text{ m}\cdot\text{s}^{-1}$.
- The mean wind power density value at height of 50 m for the period 1979–2016 was found about $224 \text{ W}\cdot\text{m}^{-2}$.
- The most probable wind direction is 315° , i.e. northwest 315° .
- In case of diurnal wind speed variation evaluation, it was found that wind speed values are higher during the daytime.

Acknowledgements

We would like to express our sincere gratitude to Al-Karkh University of Science, Mustansiriyah University, and Ministry of Science and Technology for their assistance with the collection of our data and supporting this work.

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Summary

An assessment the wind potential energy as a generator of electrical energy in the coastal area of southern Iraq. Renew-

able energies have the potential to provide relatively clean energy, mostly for domestic energy. Wind power generation is expected to rise in the near future and has grown exponentially over the past decade in many countries. The most important parameter that must be taken into consideration when designing and studying wind power conversion systems is the wind speed. Probability density functions (PDF) such as Weibull is often used in wind speed and wind power analyses. This research presents an assessment of wind power based on the Weibull distribution statistics in the coastal of southern Iraq at Basrah province. Wind speed data for the study site were obtained from NASA at a height of 50 m for the period 1979–2016 with a time interval of 10 min. The data at a height of 50 m were extrapolated using the power law in order to estimate the wind speed at new heights: 30, 70 and 100 m. The different parameters of the Weibull function as well as the daily and monthly wind speeds, mean, variance and potential energy

at four altitudes were estimated and analysed using Windographer software. Results indicate that the maximum wind speed at 100 m is $6.4 \text{ m}\cdot\text{s}^{-1}$, giving an average power density of $298 \text{ W}\cdot\text{m}^{-2}$, which indicates that the location of the study has marginal and useless potential for installing large wind turbines.

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