POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

Gharyan şehri (Libya) rüzgar verilerine dayalı dikey eksenli rüzgar türbini kurulumu

Vertical axis wind turbine installation based on wind data collected in gharyan city, Libya

Yazar(lar) (Author(s)): *Nagi NASSIR[1], Bahadır ACAR[2], Abdel karim FAHED[3]*

ORCID[1]: 0000-0003-4040-1004

ORCID[2]: 0000-0002-9494-6301

ORCID[3]: 0000-0003-1995-7630

Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Nassir N., Acar B. ve Fahed A., "Vertical axis wind turbine installation based on wind data collected in gharyan city,Libya", ***Politeknik Dergisi***, 25(3): 975-984, (2022).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.781397

Vertical Axis Wind Turbine Installation Based on Wind Data Collected in Gharyan City, Libya

Highlights

- *The determination of wind patterns in Ghayran city of Libya by integrated analysis of wind resources*
- *Computerization of wind flow simulations to determine micro-settings of wind turbine*
- *Regular and advanced monitoring program for wind resources*

Graphical Abstract

The study indicates the possibility of utilizing wind for power generation in selected areas, where feasible annual energy, capacity factor, and acceptable power generation capacity were recorded. As a result, proposed method is more efficient that general approach in order to produce electrical energy as 6.26 USD cent/kWh.

Item	Description
Turbine	Vestas (V60- 850kW).
Configuration	3-blade vertical turbine
Rated Power	850kW
Wind speed (cut-in)	3m/s
Wind speed (rated)	13m/s
Wind speed (cut-out)	20m/s
Speed of rotor	14-29rpm
Diameter of Rotor	60m
Sweep area	2,828m^2

Table. Model wind turbine and its technical specifications

Aim

The aim of this study is to determine wind energy potential of the Ghayran city of Libya in terms of annual energy, capacity factor, and acceptable power generation capacity.

Design & Methodology

The data of wind resources was continuously recorded at high spots. Recorded data was processed using graphical method (GM), empirical method (EM), and error analysis as well.

Originality

There are not any national or international study on the wind energy potential of Libya's Gharyan city. In addition, the integrated analysis method was carried out in similar studies.

Findings

The generated power can be linked with the main power grid in case it is generated from locations like Gharyan-4, Gharyan-2 and Gharyan-3 while the Gharyan-1 can be used for other applications such as battery charging or water pumping.

Conclusion

The results show that the wind energy project is feasible and cost-effective within the lifetime of a turbine.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Gharyan Şehri (Libya) Rüzgar Verilerine Dayalı Dikey Eksenli Rüzgar Türbini Kurulumu

(Bu çalışma ECRES 2017 konferansında sunulmuştur. / This study was presented at ECRES 2017 conference.)

Araştırma Makalesi / Research Article

Nagi NASSIR*, Bahadır ACAR , Abdel karim FAHED
Karabük Üniversitesi, Enerji Sistemleri Mühendisliğ Bölümü, Karabük
(Geliş/Received : 16.08.2020 ; Kabul/Accepted : 19.02.2021 ; Erken Görünüm/Early View : 25.03.2021)

ÖZ

Rüzgar enerjisinin değerlendirilmesi, herhangi bir yerde bulunan potansiyel rüzgar enerjisi hakkında uzmanları bilgilendiren entegre analizlerin bir biçimidir. Bu tür değerlendirmenin başlangıç noktası, belirli bir yerde yaygın olarak meydana gelen rüzgar modellerini anlamaktır. Bunu, rüzgar verileri toplama ve toplanan verileri analiz etme izler. Bu makale, birinci ve ikinci bölgelerin kapsamlı bir çalışmasıdır. Bu nedenle, ortalama rüzgar hızı, yön verisi, kısa vadeli varyasyonlar (veya rüzgarlar), yıllık, mevsimsel ve hatta günlük değişiklikler / varyasyonlar ve yüksekliğe bağlı varyasyonlar gibi birkaç parametre dikkate alınmalıdır. Bahsedilen tüm parametreler sahaya özgü olduğundan, uzun bir süre boyunca yerinde ölçümlerle doğru bir şekilde belirlenebilir. Bu çalışma, rüzgar değerlendirmesi ve potansiyel rüzgar enerjisi üzerine odaklandığından Gharyan şehri bir konum olarak seçildi ve alt konumları Gharyan 1, 2, 3 ve 4 olarak adlandırıldı. İlk olarak, rüzgar enerjisi kaynağı ile ilgili konumun yakınında bulunan meteoroloji istasyonlarından alınan veriler arka planda toplandı. Genellikle, her bir konum için 3 saatlik uzun vadeli rüzgar verileri kullanılır ve daha sonra, göbek yüksekliğindeki gerçek rüzgar hızını bulmak için rüzgar verilerinin yeniden hesaplanması yapılır. Önemli hesaplama parametreleri arasında, önerilen her bir saha için hesaplanması gereken Weibull dağılımı, ortalama rüzgar hızı, yıllık kapasite faktörü ve yıllık enerji faktörü yer alır. Yıllık kapasite ve enerji faktörlerinin hesaplanması, genellikle Vestas (V60, 850kW) olarak adlandırılan rüzgar türbinini seçmek için gereklidir. Bu makale, Libya'daki bazı tesislerin, özellikle yıllık enerji, kapasite faktörü ve kabul edilebilir enerji üretim kapasitesinin kaydedildiği Gharyan'da bulunan dört bölgede yeterli rüzgar enerjisine sahip olduğunu açıkça göstermektedir.

Anahtar Kelimeler: Şekil parametresi, ölçek parametresi, yıllık kapasite faktörü, kümülatif weibull dağılımı.

Vertical Axis Wind Turbine Installation Based on Wind Data Collected in Gharyan City, Libya

ABSTRACT

Assessing the potential of wind energy involves an integrated analysis approach, the conclusions of which inform the experts of the field about the possibilities of harnessing wind energy on a certain location. This type of analysis is made of multiple steps, starting from observing and understanding commonly occurring wind patterns at the designated site, followed by collection of data and finally analysis. The current paper is an extended study on the first two steps where several parameters such as wind's average speed and its direction, as well as various changes such as short-term ones (or gusts), yearly, seasonal, and even daily changes, and height-related variations were collected. Since the above-mentioned parameters are site-specific, they can be accurately determined through on-site measurements during extended time periods. The site for this study is the city of Gharyan in Libya which was divided into four sub-locations. Data were gathered from meteorological stations located in the vicinity of the designated area in three-hours periods, and they were then used to recalculate wind's real speed and height at a specific hub. Among the important calculation parameters were Weibull's distribution, average wind speed, annual capacity factor, and the annual energy factor, all of them required for each proposed site. The calculations of the annual capacity and energy factors are necessary for choosing the appropriate wind turbine, generally named Vestas (V60, 850kW). The current study clearly shows that some sites, in particular four locations in Ghayran where feasible annual energy, capacity factor, and acceptable power generation capacity were recorded have wind energy for civilian purposes.

Keywords: Shape parameter, scale parameter, annual capacity factor, cumulative weibull distribution.

1. INTRODUCTION

Population size around the globe is raising at a rapid rate, estimated to approach 10 billion by 2050. This increase is not distributed evenly, but it is mostly concentrated in the developing countries, and as a result, major urban developments are currently taking place which are expected to increase even more in the future to keep up with new demands. One of the most important pillars of modern civilization is energy, especially in terms of power generation. Growing concerns about environmental degradation and the rapidly growing energy demands led to increased interest in alternative or renewable energy sources, especially wind power which currently is the most popular form. Energy is vital for economic development and its consumption rate is a strong indicator of a nation's economic activity and prosperity. Until

**Sorumlu Yazar (Corresponding Author)*
e-posta : nagi181966@gmail.com

recently, most of the energy sources used to fulfill the world's ever-increasing demands were fossil-fuel based, such as oil, coal, and natural gas. However, studies have been showing for a long time that they are finite and being depleted at a higher rates, leading to potential scenarios where the world may run out of energy and modern civilization collapse if alternative sources are not found within the not so distant future. Therefore, the issue of sustainable energy sources is of major strategic importance, and wind is one of best and easiest sustainable energy sources because it has massive power generation potential and is available almost everywhere. Developments in technology have made it possible to generate energy out of wind power at feasible costs and in an eco-friendly manners, and future promises further improvements. The most important factor in determining the amount of power generated by wind-based energy-to-power conversion systems is wind speed since minor changes in it lead to major power output because velocity and power have a cubic relation. Studies have shown that wind patterns change frequently, from day to season and entire year and such changes reach between 15-35%, leading to a need for meticulous analysis for assessing wind properties, especially speed and direction before installing wind turbines for its harvest. The current paper describes some physical processes pertaining to the wind properties at Ghayran city in Libya. It is an established fact that the cost of wind-based power generation depends heavily on how sensitive the wind resource is; therefore, the economic feasibility of wind power can be assured through conducing several studies on wind patterns. The assessment of wind energy is done by conducting integrated analysis of wind resources at a potential location. This process starts with understanding general patterns of wind at a location besides collection, processing, and analyses of the data. It involves a regular and advanced monitoring program and computerized wind-flow simulations for determining micro-settings of a wind turbine.

2. WIND ASSESSMENT

The first step in assessing the potential of wind for power generation is selecting a specific area where data about wind's direction and speed are collected. Comprehensive assessment of wind resource requires a complex set of interconnected anemometers at wind monitoring stations, which continuously collect data on various properties of wind year round. This process of wind monitoring takes time, so the experts also utilize the previously recorded data to get the better understanding of wind pattern for longer term. In our case, many sources can help in getting the existing meteorological data such as airports and climatologically centers, both of which are reliable data sources. Spot measurements can be added to the existing data sets potential turbine installation site selection because such spots are ideal for power generation as high wind speeds are recorded on them. For this research, the data was continuously recorded at high spots using a cup generator anemometer for different stations located in that area as shown in Figure 1.

Figure 1. The location of the sites in Libya

3.WIND REGIME ANALYSIS

After data collection, analysis id the next natural step in assessing wind resources because it helps understanding the existing patterns in the wind direction, duration, and magnitude.

The average/mean speed of wind (Vm) is a generally applied and a common indicator that shows potential of wind is given in the equation below [1–3] :

$$V_m = \frac{1}{N}\sum_{i=1}^{N} V_i \tag{1}$$

Here N represents sample size while Vi shows the speed of wind monitored for i observation.

In this case, there is a large sample size, which helps grouping the wind speed data in different intervals, and helps creating histogram to show how the speed of wind is distributed.

On surface, the wind speed is zero because of the friction between the ground surface and the air. When the wind speeds up closer to the ground, its speed doesn't increase as rapidly at a higher altitude. At 2000m altitude the variation in the speed of wind reduces to 0. This variation in the wind speed is mathematically expressed through different functions, out of which, two functions are common, as they appropriately describe the average wind speed variation with respect to height; they are as follows [4–6] :

Power exponent function:

$$V(Z) = V_R\left(\frac{Z}{Z_r}\right)^{\beta} \tag{2}$$

Here Z represents the altitude, V(z) represents wind speed at altitude z, wind speed is VR at reference height Zr r (above ground level), and β is exponent that is dependent on the terrain roughness. Typically, β is around 0.1.

Logarithmic function:

$$\frac{V(Z)}{V(10)} = \frac{\ln\left(\frac{Z}{Z_0}\right)}{\ln\left(\frac{10}{Z_0}\right)} \quad (3)$$

Here, V (10) stands for wind speed at 10m altitude, and Z0 represents length of roughness, and β and Z0 parameters represent different terrain types, which are given in Table 1.

Table 1. Different Terrians' roughness

Type of terrain	Roughness level	Z0 (m)	β
Watery areas	0	0.001	0.01
Country areas with limited surface features	1	0.12	0.12
Farmlands, hedges and buildings	2	0.05	0.16
Farmland with villages and forests	3	0.3	0.28

These two functions are used to calculate the average wind velocity on certain altitudes when the average speed of wind is already calculated at a reference altitude.

This study uses the power exponent function with β value of 0.12 for calculations. Our samples represent the average monthly speed of wind in 2016, as shown in Table 2. The tables above show that at 50m height, the maximum value (wind speed = 7.98m/s) was measured at Gharyan4. On the other hand, 5.43m/s was the minimum value, which was observed at Gharyan 1. Figures 2-5 compare the average monthly wind speeds at our selected locations while Figure 6 shows the average wind speed per season.

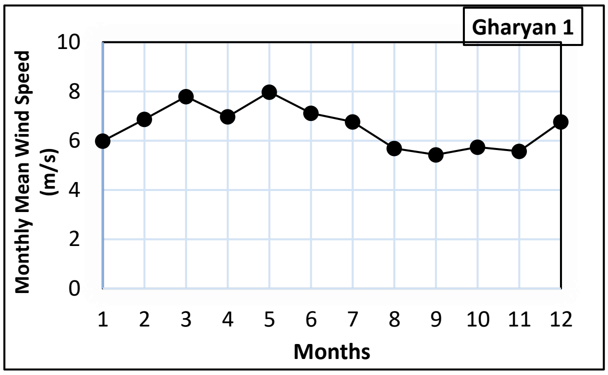

Figure 2. Monthly variation of wind speeds for Gharyan 1

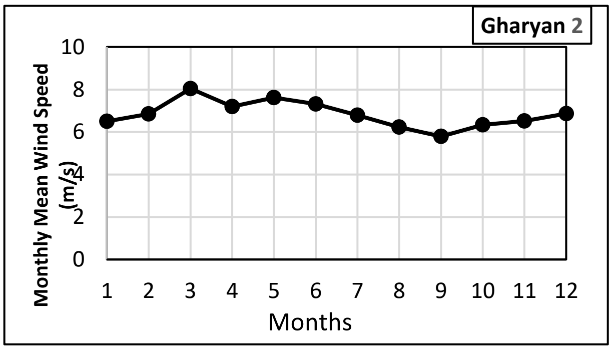

Figure 3. Monthly variation of wind speeds for Gharyan 2

Table2. Average monthly wind speed (m/s) REAOL ‘‘Renewable Energy Authority of Libya” Director of Projects Department, Tripoli, [7].

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Gharyan1	5.99	6.87	7.79	6.98	7.98	7.12	6.76	5.69	5.43	5.74	5.57	6.77
Gharyan2	6.5	6.85	8.04	7.2	7.61	7.32	6.78	6.23	5.79	6.34	6.52	6.86
Gharyan3	5.76	6.98	7.67	7.67	7.66	6.67	6.74	6.21	5.67	5.89	6.10	6.91
Gharyan4	6.65	7.12	7.94	7.43	7.67	7.98	7.95	7.49	7.53	7.12	6.74	7.91

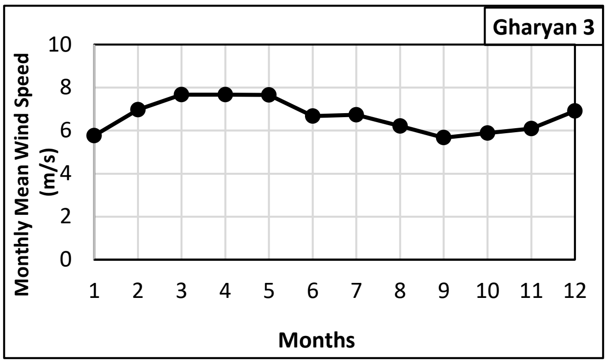

Figure 4. Monthly variation of wind speeds for Gharyan 3

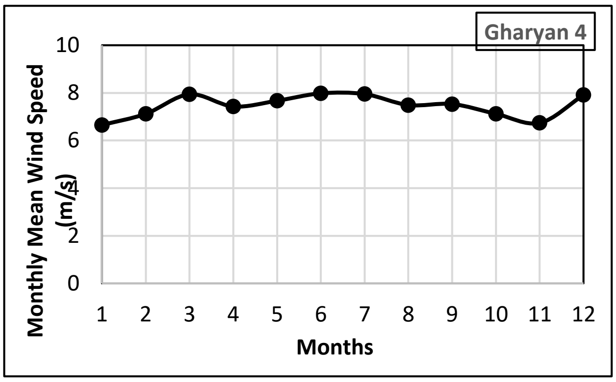

Figure 5. Monthly variation of wind speeds for Gharyan 4

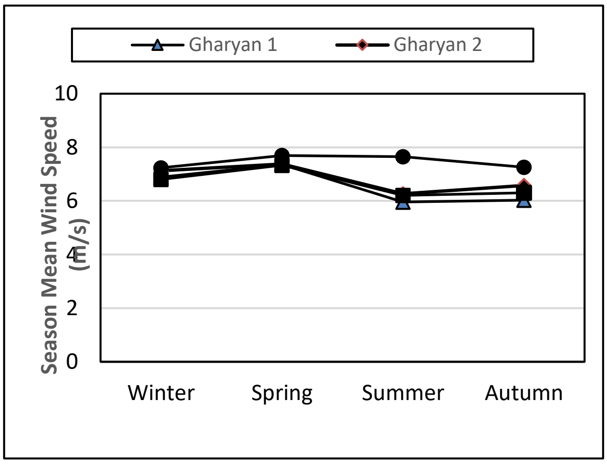

Figure 6. Seasons variation of wind speeds

4. WIND STATISTICS

According to studies, distribution of wind speed is generally described through the non-cumulative Weibull distribution, which assumes the following equation [8–10] :

$$PF(\mathrm{V}) = \frac{k}{C}\left(\frac{\mathrm{V}}{C}\right)^{k-1} \exp\left\{-\left(\frac{\mathrm{V}}{C}\right)^{k}\right\} \tag{4}$$

Cumulative Weibull distribution is as follows:

$$F(v) = 1 - \exp\left\{-\left(\frac{\mathrm{V}}{C}\right)^{k}\right\} \tag{5}$$

In this function, C stands for the scale parameter, and k shows the parameter shape. The Weibull distribution conveniently approximates distribution of continuous wind speed using discrete values, which are practically observed. Moreover, it is useful because in an area, the wind regime can be explained using just k and C, which are Weibull parameters [11–15].

a- Graphical Method (GM): through plotting on a graph ln V (logarithmic function of V) against ln(-ln(F(V)). In this case, "ln" represents logarithm of base e that fits a straight line through the points. Here, k is the slope of this line while C equals exp (ln V), or simply V. The ln(-ln(F(V)) equals 0. The logarithms of cumulative Weibull distribution are taken twice to implement this technique [16].

b- Empirical Method (EM): The empirical method is considered as special case of the moment method, where the Weibull parameters, k, and, c, are given by the equations shown below [17]:

$$k = \left(\frac{\sigma}{V_m}\right)^{-1.086} \tag{6}$$

$$c \approx \frac{V_m\, k^{2.6674}}{0.184 + 0.816\, k^{2.73855}} \tag{7}$$

Where, σ, is the standard deviation of the observed data defined as [18]:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(v_i - V_m)^2} \tag{8}$$

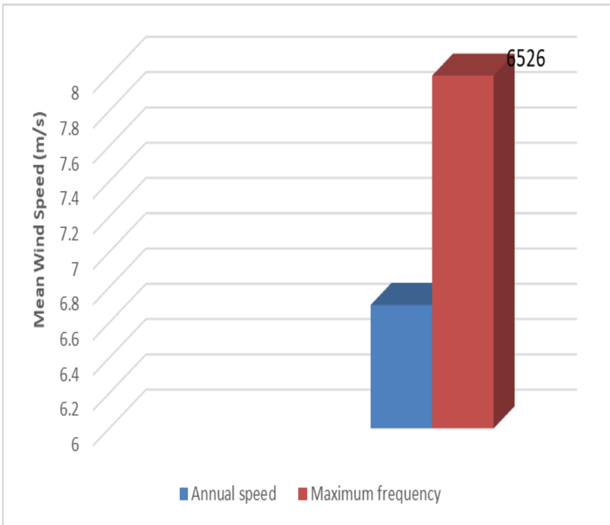

Figure 7. Maximum frequency and mean wind speed (Gharyan-4)

5. ERROR ANALYSIS

The error analysis is carried out to verify the accuracy of the Weibull distributions which are obtained by the different methods mentioned in the previous section. To do so, the coefficient of determination, R^2, is the square of the ratio between the Weibull frequencies to the actual frequencies. It is defined in Eq. (9) ,the Root Mean Square Error, RMSE, and the Mean Bias Absolute Error, MAE, are calculated. [19,20]

$$R^2 = \frac{(\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(y_i - x_i)^2)}{\sum_{i=1}^{N}(y_i - z_i)^2} \quad (9)$$

Where, N, is the number of observations (number of actual data), yi, is the actual frequency, , is the Weibull frequency and, zi, is the average wind speed. The root mean Square Error, RMSE, is a measure of the residuals between Weibull frequency and the actual frequency. It is defined in Eq. (10) as [19,21]:

$$RSME = \sqrt{\frac{1}{N}\sum_{i=N}^{N}(\boldsymbol{y_i} - \boldsymbol{x_i})^2} \quad (10)$$

Similarly, the Mean Bias Absolute Error, MAE, is another measure found from Eq. (11) [19,20]

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i) \quad (11)$$

6. ANNUAL ENERGY AND CAPACITY FACTOR

The expected yearly energy yield of a wind turbine needs to be calculated because it is significant for feasibility analysis of a project. The wind speed distribution over the long-term in combination with the turbine's power curve gives the estimate of power generation at each wind speed, which is used to calculate the annual power generation. For accurate outcomes, the calculation should be performed at 1m/s wind speed. Any turbine's annual energy production (AEP) is mathematically expressed as follows [17–19]. The wind speed v0 has a probability to fall between wind speeds v_i and v_{i+1}, which can be obtained through cumulative distribution function as given below:

$$F(v_i < v_0 < v_{i+1}) = exp\left[-\left(\frac{v_i}{c}\right)^k\right] - exp\left[-\left(\frac{v_{i+1}}{c}\right)^k\right] \quad (12)$$

The calculation of total annual energy production is as follows:

$$AEP = \sum_{i=1}^{N-1}\frac{1}{2}[P(v_{i+1}) + P(v_i)] \cdot F(v_i < v_0 < v_{i+1}) \cdot 8760 \quad (13)$$

Capacity/load factor is another measure that is the ratio between the actual power generation to the energy produced during a specific time period when the wind turbine runs at the rated power level in that time period. For instance [13,20,21]:

$$Annual\ load\ factor = \frac{energy\ per\ year(Kwh)}{rated\ power(Kw) \times 8760} \quad (14)$$

Many methods are available to evaluate the performance of the power plant. For avoiding issues while comparing the performances of different wind turbines, accurate load factor and other parameters should be considered.

For calculating Cf and AEP, the wind turbine specifications should be available, and its power curve should be constructed. Vestas (V60-850kW) is our selected wind turbine model, which requires low-rated wind speed and 60m hub height (wind data is available for this height). Table 3 mentions the turbine's technical specifications.

Table 3. Model wind turbine and its technical specifications

Item	Description
Turbine	Vestas (V60- 850kW).
Configuration	3-blade vertical turbine
Rated Power	850kW
Wind speed (cut-in)	3m/s
Wind speed (rated)	13m/s
Wind speed (cut-out)	20m/s
Speed of rotor	14-29rpm
Diameter of Rotor	60m
Sweep area	2,828m^2

Turbine power curve is demonstrated in Figure 8.

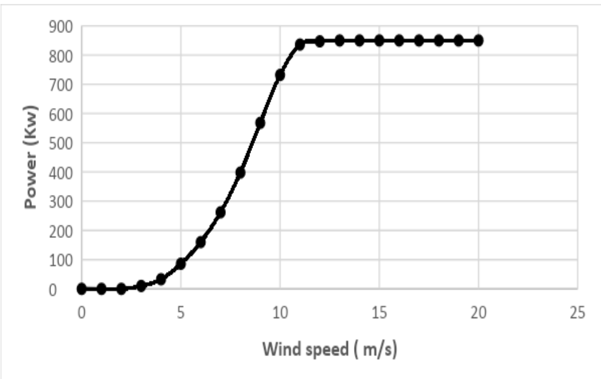

Figure 8. Vestas (V60- 850kW) power curve

7. RESULTS AND DISCUSSION

The Weibull frequency distribution is determined through initially determining the scale parameter *C*, and then the shape parameter *k*. For Gharyan-4 sample, Figure 9 shows how the parameters were determined; so, and the value of *C* = 9.34m/s. The shape parameter is the slope of the straight line: k = 3.23, while Cumulative Weibull distribution is given in Figure 10. The scale factors, shape parameters, annual mean wind speed were computed for locations, are shown in Table 4.

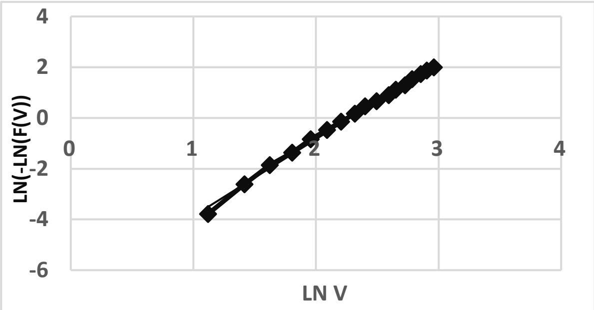

Figure 9. Weibull parameters (Gharyan-4)

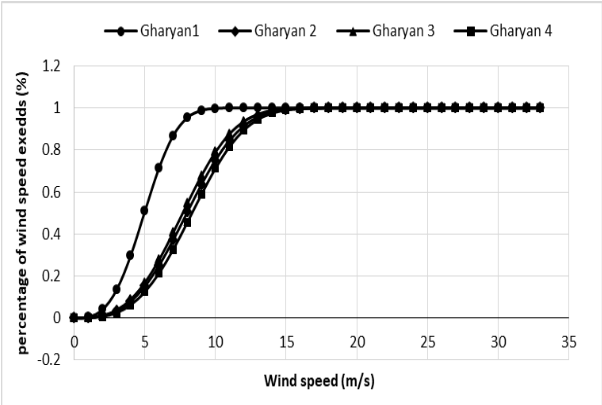

Figure 10. Cumulative Weibull distribution (all sites)

The Weibull parameters results for the different sites at 50m height are shown in Table 4.

Table 4. Weibull parameters estimated by three methods at 50m height

Site	Methods			
	GM		EM	
	k	*c*	*k*	*c*
Gharyan 1	3.1199	5.5835	3.2	6.40
Gharyan 2	3.0912	8.9768	3.17	9.01
Gharyan 3	3.0828	8.6479	3.44	8.85
Gharyan 4	3.23	9.3410	3.621	9.40

The errors associated with the different Weibull methods are calculated using equations (9 -11) and for the example at 60 m the error results are shown in Table 5.

The small values for RSME and MAE verifies that the methods for calculating the Weibull parameters in this study are accurate and can be used for wind energy assessment. Also, the R^2 values are close to 1.0 for all the methods in all the sites which proves the accuracy of the used methods once more.

Table 5. Error analysis results

Site	Method	$R^2 \rightarrow 1$	RSME→ 0	MAE → 0
Gharyan 1	GM	0.889389	0.01133	0.001665
	EM	0.864743	0.012529	0.001848
Gharyan 2	GM	0.963236	0.064188	0.001006
	EM	0.959998	0.066955	0.001044
Gharyan 3	GM	0.989971	0.047248	0.000706
	EM	0.983887	0.059887	0.000892
Gharyan 4	GM	0.89217	0.012481	0.001904
	EM	0.936468	0.095804	0.00148

The measured annual wind speed frequency curves are plotted for all the sites in Fig. 11. From Fig. 11 we notice that the distribution curves of the sites have comparable patterns. They increase to arrive at a peak value and diminishing after that. The peak value is near the annual mean speed of the comparing site. The peak value of the frequency ranges between 13 % and 14 %.

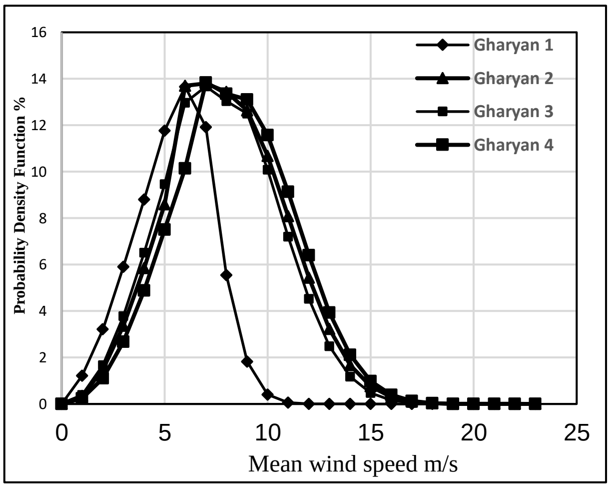

Figure 11: Measured annual frequency distribution

The capacity factor and annual energy calculations for every considered site were done using the Ventis v60 wind turbine data with 60m rotor diameter and 850kW rated power. The annual power generation through Gharyan-4 is given, which clearly demonstrates that the maximum annual power generation is 2,187.34MWh and minimum 1434.12MWh from Gharyan-1. The obtained values show that these wind turbines are appropriate for power generation in areas such as Ghrayan4. Table 6 summarizes the final outcomes of the calculations.

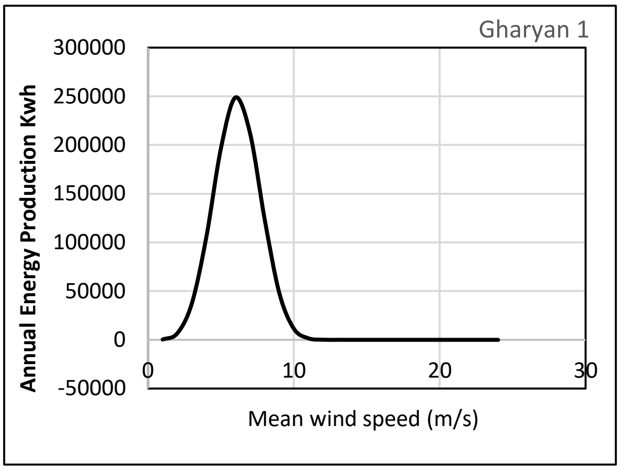

Figure 12: Annual power generation at Gharyan-1 at V60-850KW

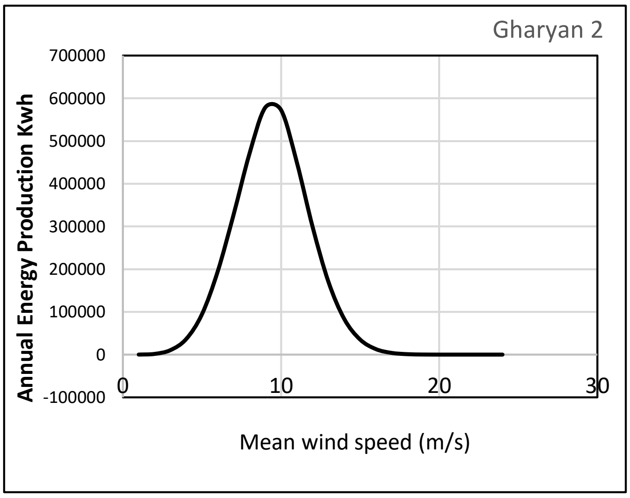

Figure 13. Annual power generation at Gharyan-2 at V60-850KW

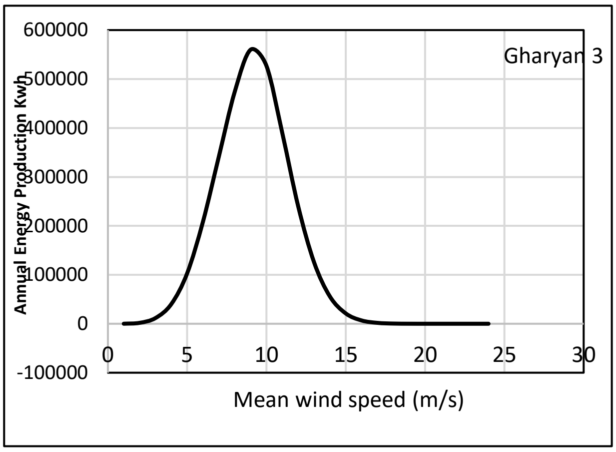

Figure 14. Annual power generation at Gharyan-3 at V60-850KW

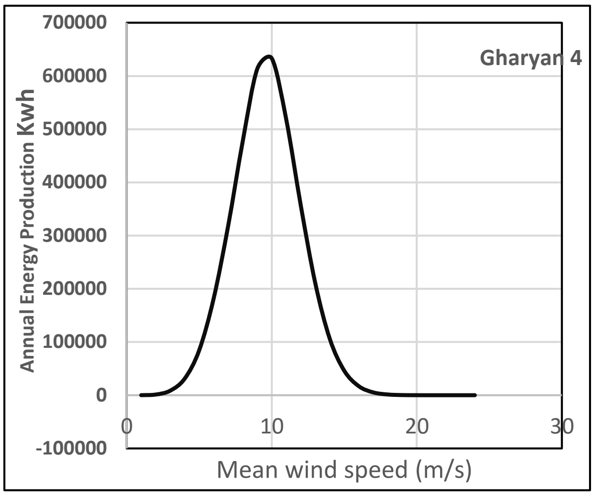

Figure 15: Annual power generation at Gharyan-4 at V60-850KW

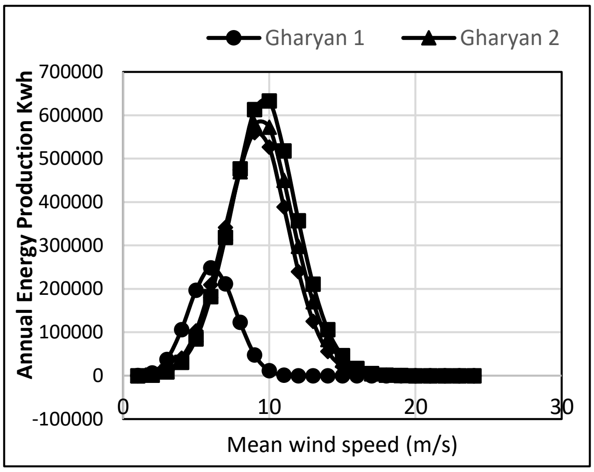

Figure 16. Annual power generation for all sites at V60 -850KW

Table 6. Results of the areas under study

City	Annual meanWind speed (m/s)	Annual energy (Mwh)	Annual capacity factor (%)
Gharyan-1	6.3	1434.12	19.30
Gharyan-2	6.7	1877.5	26.01
Gharyan-3	6.5	1743.58	24.15
Gharyan-4	7.2	2187.34	30.02

8. COST AND ELECTRICITY PRICE

In order to calculate the present value cost (PVC), values of different terms should be evaluated as given in Eq. 9. While conducting this study, we calculated the mentioned values using a method mentioned in previous works [22,23,24].

$$PVC = I + C_{omr}\left[\frac{1+i}{r-i}\right] \times \left[1 - \left[\frac{1+i}{1+r}\right]^{t}\right] - S\left[\frac{1+i}{1+r}\right]^{t} \quad (15)$$

Where:

Turbine Life, t

Investment, I

eration, Maintenance and Repair cost, $Comr$

Inflation Rate, I

Interest Rate, r

Scrap Value, S

$$kWh\ price = \frac{PVC}{AEP\ X\ t}\ X\ 100 \quad (16)$$

The results of the electricity price for each site are shown in Table 7.

Table 7. Electricity cost of each kWh.

Site	AEP(Kwh)	Electricity(USD cent/Kwh)
Gharyan 1	1434120	6.263
Gharyan 2	1877500	4.784
Gharyan 3	1743580	5.151
Gharyan 4	2187340	4.1063

According to Statista website, Electricity Tariff for the year 2015 was 6-15 cents/kWh, with an average of 9.43 cents/kWh in the United States and 11 cents/kWh in European countries. These data imply that Gharyan 2 and 4 offer the lowest cost, while the turbine output will compensate for the cost of turbine in a few years given that the average life of such a turbine is 20 years.

8.CONCLUSION AND RECOMMENDATIONS

1. The results of the current paper indicate that there is a possibility to utilize wind for power generation in our selected areas. The generated power can be linked with the main power grid in case it is generated from locations like Gharyan-4, Gharyan-2 and Gharyan-3 while the Gharyan-1 can be used for other applications such as battery charging or water pumping.
2. Our findings show that Gharyan-4 has the maximum capacity factor as well as annual power generation capacity whereas Gharyan-1 has limited potential in terms of both these factors.
3. The available data shows that average annual speed of wind is 7.2m/s at Gharyan-4. Moreover, its theoretical capacity factor is more than 30.02%. This means that Gharyan-4 is a feasible location because it has capacity to generate 2187.34MWh power per year.
4. Using the concept of the present value, cost analysis was conducted by focusing on the minimum power generation cost when wind turbines are used for power generation. The results show that the wind energy project is feasible and cost-effective within the lifetime of a turbine. The results also show that Gharyan 4 is more cost effective site for power generation followed by Gharyan 2, Gharyan 3 and 1, respectively.
5. The accuracy of the location assessment can be further improved if advanced software is developed and provided to the researchers.
6. More studies should be conducted to collect wind speed data throughout the country which can pave the way for wind Atlas.
7. Conducting further studies on effectively linking wind energy systems to the national grid will be very helpful to deal with current and future potential energy crisis.
8. Different areas should be examined across the country for installing wind turbines, and the government should initiate wind power generation projects in feasible locations.
9. The research centers and universities located in North African countries should form partnerships so as to build teams for research on renewable energy, making it more cost effective and less time consuming.
10. The annual energy production analysis showed that Gharyan 4 and Gharyan 2 sites have the highest wind energy potential compared to the other sites.
11. The results showed that Gharyan 4 site yields the lowest value of the kWh cost followed by Gharyan 2
12. The GM method gives lower values for AEP, and Cf and higher values for the electricity cost.
13. The kWh cost in Gharyan 1was calculated with the GM method as 6.26 USD cent/kWh and the average price for kWh sold in the world is about 8 USD cent/kWh. This means that even Gharyan 1 (with the lowest potential among the other cities in this study) would be feasible for wind projects and will be able to return the cost of the project in a period less than the wind turbine lifetime.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods they have used in their studies don't need any ethical committee permission and/or any legal-private permission.

AUTHORS' CONTRIBUTIONS

Naggi NASSIR: Performed the theoretical calculations and analyses.

Bahadır ACAR: Controlled the calculations and wrote the article.

Abdelkarim FAHED: Helped the writing of the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

NOMENCLATURE

C	Scale parameter
Z	The altitude [m]
Z_0	Length of roughness [m]
k	Parameter shape
N	Sample size
V(Z)	Wind speed at altitude z [$m.s^{-1}$]
β	Factor depends on the terrain roughness
V_i	Speed of wind monitored for i observation [$m.s^{-1}$]
V_m	Average/mean speed of wind [$m.s^{-1}$]
V_R	Wind speed at reference height Z_r above ground level [$m.s^{-1}$]
V(10)	Wind speed at 10m altitude [$m.s^{-1}$]

REFERENCES

[1] Mathew, S., "Fundamentals, Resource Analysis and Economics", ***Wind Energy: 1st Ed. New York: Springer***, (2006).

[2] Manwell, J. F., McCowan, J. G., and Rogers, A. L., "Wind Energy Explained: theory, design and application", ***Wind Engineering***, 30 (2): 169 (2006).

[3] Christofferson, R. D. and Gillette, D. A., "A simple estimator of the shape factor of the two-parameter Weibull distribution", ***Journal Of Climate And Applied Meteorology***, 26 (2): 323–325 (1987).

[4] DuPont, B. L., Cagan, J., and Moriarty, P., "Optimization of Wind Farm Layout and Wind Turbine Geometry Using a Multi-Level Extended Pattern Search Algorithm That Accounts for Variation in Wind Shear Profile Shape", ***ASME 2012 International Design Engineering Technical Conferences And Computers And Information In Engineering Conference***, 3: 243–252 (2012).

[5] Garcia, A., Torres, J. L., Prieto, E., and De Francisco, A., "Fitting wind speed distributions: a case study", ***Solar Energy***, 62 (2): 139–144 (1998).

[6] George, M. and Banerjee, R., "Analysis of impacts of wind integration in the Tamil Nadu grid", ***Energy Policy***, 37 (9): 3693–3700 (2009).

[7] Patel, M. R., "Wind and solar power systems: design, analysis, and operation, 2nd edn, CRC Taylor & Francis", ***ISBN-10: 0-8493-1570-0, ISBN-13***, 970–978 (2006).

[8] Conradsen, K., Nielsen, L. B., and Prahm, L. P., "Review of Weibull statistics for estimation of wind speed distributions", ***Journal Of Climate And Applied Meteorology***, 23 (8): 1173–1183 (1984).

[9] ISHIHARA, T. and YAMAGUCHI, A., "The State-Of-The-Art on Wind Climate Assessment and Wind Power Forecasting", ***Wind Engineers, JAWE***, 2006 (106): 43–49 (2006).

[10] Jamil, M., Parsa, S., and Majidi, M., "Wind power statistics and an evaluation of wind energy density", ***Renewable Energy***, 6 (5–6): 623–628 (1995).

[11] Jaramillo, O. A., Saldaña, R., and Miranda, U., "Wind power potential of baja california sur, mexico", ***Renewable Energy***, 29 (13): 2087–2100 (2004).

[12] Lun, I. Y. F. and Lam, J. C., "A study of Weibull parameters using long-term wind observations", ***Renewable Energy***, 20 (2): 145–153 (2000).

[13] Manwell, J. F., McGowan, J. G., and Rogers, A. L., "Wind Energy Explained: Theory, Design and Application", ***John Wiley & Sons***, (2010).

[14] Kanagavel, P., Gomathinayagam, S., Srinivasaragavan, S., and Ramasamy, R. U., "A Scientometric Assessment of Wind Energy Research Productivity: A Scientometric Study", ***International Journal Of Scientific Research***, 2 (5): 333–336 (2012).

[15] Ranganathan, C. R., Ramanathan, M., and Swaminathan, K. R., "Estimation of wind power availability in Tamil Nadu", ***Renewable Energy***, 1 (3–4): 429–434 (1991).

[16] Hansen, M. O. L., "Aerodynamics of Wind Turbines", ***Routledge***, (2015).

[17] Ohunakin, O. S., "Assessment of wind energy resources for electricity generation using WECS in North-Central region, Nigeria", ***Renewable And Sustainable Energy Reviews***, 15 (4): 1968–1976 (2011).

[18] Pindado, S., Vega, E., Martínez, A., Meseguer, E., Franchini, S., and Sarasola, I. P., "Analysis of calibration results from cup and propeller anemometers. Influence on wind turbine Annual Energy Production (AEP) calculations", ***Wind Energy***, 14 (1): 119–132 (2011).

[19] Internet: The Wind Power, "Manufacturers and Turbines Technical Data", **https://www.thewindpower.net/turbine_en_113_vestas_v60-850.php.** .

[20] Rajpurohit, B. S., Singh, S. N., and Wang, L., "Electric grid connection and system operational aspect of wind

power generation", Wind Energy Conversion Systems, ***Springer***, 267–293 (2012).

[21] Ahwide, F., Spena, A., and El-Kafrawy, A., "Estimation of electricity generation in libya using processing technology of wind available data: The case study in derna", ***APCBEE Procedia***, 5: 451–467 (2013).

[22] S. Rehman, T.O. Halawani, M. Mohandes, "Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia" *Renew. Energy*, 28: 573-583 (2003).

[23] F. Ahwide, A. Spena, and A. El-Kafrawy, Estimation of Electricity Generation in Libya Using Processing Technology of Wind Available Data: The Case study in Derna", ***APCBEE Procedia***, 5: 451-567 (2013).

[24] Satyanarayana G. and Shiva P. K. K., "Wind energy potential and cost estimation of wind energy conversion systems (WECSs) for electricity generation in the eight selected locations of Tigray region (Ethiopia)", ***Renewables: wind, water and solar***, 3: 10 (2016).