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RESEARCH ARTICLE **RENEWABLE ENERGY**

Prediction of Wind Energy Potential in Tajoura and Mislata Cities

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ABSTRACT

Estimating the potential of wind energy is the first step on the path to transitioning to renewable and environmentally friendly energy sources. Therefore, it is essential to have information and knowledge about the availability of wind energy for each specific location. This study focuses on the wind energy and wind assessment in Tajoura city (1,2) and Mislata city (1,2) This paper first provides background information about wind power and its resource, including a review of available data, which are obtained from the representative meteorological stations. For each location, long term time series of 3-hourly measured wind data were used; the wind data has been recalculated to represent the actual wind speed at hub height. The mean wind speed, the Weibull distribution, annual energy and annual capacity factor are calculated for each site. The annual energy and annual capacity factor calculation are based on specification of wind turbine known as Vestas (V60- 850kW), This study indicates that wind energy is available in both Tajoura and Mislata have an acceptable power, annual energy and capacity factor.

تقدير امكانيات طاقة الرياح في مدينتي تاجوراء ومسلاتة

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الملخص

يُعد تقدير امكانيات طاقة الرياح الخطوة الاولى في طريق التحول نحو الطاقات المتجددة والصديقة للبيئة. وبالتالي فانه من الضروري توفر معلومات ومعرفة عن توفر طاقة الرياح لكل موقع معين. تركز هذه الدراسة على طاقة الرياح وتقييم الرياح في مدينة تاجوراء (1،2) ومدينة مسلاتة (1،2). تقدم هذه الورقة أولاً معلومات خلفية حول طاقة الرياح ومصدرها، بما في ذلك مراجعة للبيانات المتوفرة التي تم الحصول عليها من محطات الأرصاد الجوية الممثلة. بالنسبة لكل موقع، تم استخدام سلاسل زمنية طويلة الأمد لبيانات الرياح المقاسة كل ثلاث ساعات؛ وقد أُعيد حساب بيانات الرياح لتمثل السرعة الفعلية للرياح على ارتفاع محور التوربين. تم حساب متوسط سرعة الرياح، وتوزيع ويبول، والطاقة السنوية، ومعامل القدرة السنوي لكل موقع. ويستند حساب الطاقة السنوية ومعامل القدرة السنوي إلى مواصفات توربين الرياح نوع VESTAS (V60-850KW). تشير هذه الدراسة إلى أن طاقة الرياح متوفرة في كل من تاجوراء ومسلاتة بطاقة سنوية وبمعامل القدرة مقبولين.

الكلمات المفتاحية

معلمات الشكل
معلمات القياس
تكلفة الكربون الاجتماعية
معامل القدرة
توزيع ويبل التراكمي

Introduction

Due to concerns about climate change and global warming, the global renewable energy capacity reached 4,448 GW by the end of 2024, including 1,136 GW from wind energy. This growth in the renewable energy market reflects a global shift towards renewable and sustainable energy technologies [1]. Looking ahead, Africa and the Middle East are anticipated to introduce 17 GW of new capacities in the next five years (2023-2027), with specific projections including 5.3 GW in South Africa, 3.6 GW in Egypt, 2.4 GW in Saudi Arabia, and 2.2 GW in Morocco [2]. The importance of wind energy is paramount, especially given its role as an optimal complement to both renewable and conventional energy sources within hybrid energy systems such as PV, concentrated solar power (CSP), biomass energy (BE), integrated with energy storage systems such as: Pumped hydropower system (PHS), electrical batter (EB), hydrogen (H_2), and flywheel (FW). These systems are widely deployed globally due to their robustness and reliability in energy production from various sources [3,4], including wind/PHS [5], wind/PV/PHS [6], wind/PV [7], wind/Diesel [8], wind/CSP [9], PV/wind/Diesel [10], PV/wind/diesel/EB [11], wind/Diesel/FW [12] and PV/wind/EB [13] configurations.

The importance of this research lies in its alignment with Libyan efforts within the global initiatives to mitigate environmental damage and reduce pollution, as agreed upon in the Paris Agreement on climate change. It also aims to achieve the Libyan energy strategy for the next twenty-five years (2025-2050), which stipulates increasing the contribution of renewable energy to the country's energy mix

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to over 50% by the year 2050 [14-17]. This will be accomplished through increased investment in solar and wind energy projects. This research is part of a series of studies aimed at testing the wind energy potential in various regions of Libya [18-38]. It is considered a fundamental component for achieving Libya's strategy and goals for transitioning towards sustainability, conserving natural resources, creating a clean local environment, and preserving the fragile local ecosystems of the country [39,40].

Energy is one of the crucial inputs for socio-economic development. The rate at which energy is being consumed by a nation often reflects the level of prosperity that it could achieve. The global energy demand is met from a variety of sources. Fossil fuels consisting of coal, oil, and natural gas, but unfortunately, these fossil fuels are finite resources and will be completely exhausted one day or the other, hence, while our energy demand is increasing day by day, the available resources are depleting. This will definitely lead us to the much discussed energy crisis. However, the crisis may not be an imminent reality as the time scale may prolong due to discoveries of new resources. Here comes the significance of sustainable energy sources like wind. The quantum of energy, associated with the wind is enormous. With today’s technology, wind is an environment friendly and economically viable source of energy which can be tapped in a commercial scale. The most critical factor influencing the power developed by a wind energy conversion system is the wind velocity. Due to the cubic relationship between velocity and power, even a small variation in the wind speed may result in significant change in power. The Speed and direction of wind at a location vary randomly with time. Apart from the daily and seasonal variations, the wind pattern may change from year to year, even to the extent of 15 to 35 per cent. Hence, the behaviour of the wind at a prospective site should be properly analysed and understood. This paper outlines physical phenomena that are related to the characteristics of the wind for the selected areas. Knowing that the cost of wind energy development depends sensitively on the nature of the wind resource, hence any detailed evaluation of wind energy economics requires a series of wind assessment studies. A wind energy assessment is an integrated analysis of the potential wind energy resources of a particular area. Such an assessment begins with an understanding of the general wind patterns of the area, and progresses to the collection and analysis of wind data. Wind assessment may also involve a monitoring program and, at the most advanced stages, computer simulations of wind flow to determine wind turbine micro-sitting

Sites Information

Tajoura (32.8818306°N 13.3399333°E) and Mislata (32.5836375°N, 14.0362587°E), are located east of the capital city, Tripoli. A geographical map for the study sites are shown in Fig. 1.

Hourly time series climatic data has been obtained from SODA platform (https//www.soda-pro.com/web-services/ radiation/helioclim-3-archives-for-free). The wind speed, ambient temperature, and global horizontal solar irradiance of Tajoura and Mislata are illustrated in Figs. 2 and 3 respectively.

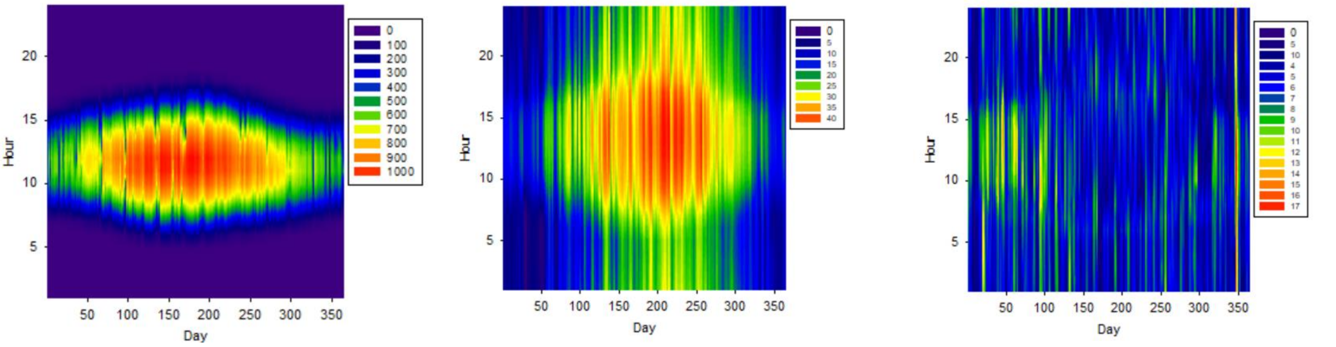
In Tajoura (Tagoura), the summers are hot, muggy, arid, and clear and the winters are cool, windy, and mostly clear. Over the course of the year, the temperature typically varies from 9°C to 33°C and is rarely below 7°C or above 38°C. The average hourly wind speed in Tajoura experiences significant seasonal variation over the course of the year. The windier part of the year lasts for 6.4 months, from November 9 to May 23, with average wind speeds of more than 5.0 m/s. The windiest month of the year in Tajoura is December, with an average hourly wind speed of 5.8 m/s. The calmer time of year lasts for 5.6 months, from May 23 to November 9. The calmest month of the year in Tajoura is August, with an average hourly wind speed of 4.1 m/s [41].

In Mislata (Masallātah), the summers are hot, muggy, arid, and clear and the winters are cold, windy, and mostly clear. Over the course of the year, the temperature typically varies from 7°C to 33°C and is rarely below 4°C or above 38°C. While the average hourly wind speed experiences significant seasonal variation over the course of the year. The windier part of the year lasts for 6.9 months, from November 7 to June 3, with average wind speeds of more than 4.8 m/s. The windiest month of the year in Mislata is January, with an average hourly wind speed of 5.5 m/s [42].

Wind assessment

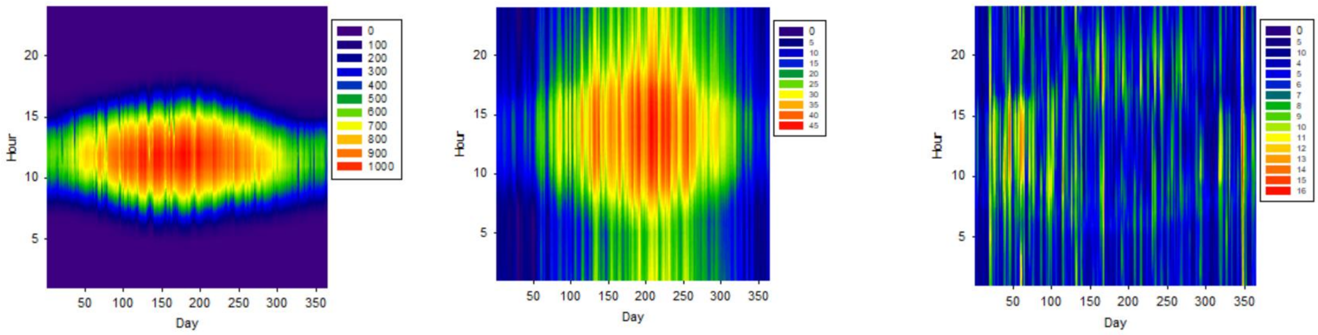
After the region has been selected for assessment, it is necessary to collect the wind data (wind speed and direction). A complete wind resource assessment involves a dense network of anemometers (wind monitoring stations) recording continuous wind data for at least one year.

Fig. 1: Study sites locations



(a) (b) (c)

Fig. 2: Key climatic parameters for Tajoura city: (a) Global solar irradiation; Wh/m^2, (b) Ambient Temperature; °C and (c) Wind speed; m/s at 10 above the ground.



(a) (b) (c)

Fig. 3: Key climatic parameters for Mislata city: (a) Global solar irradiation; Wh/m^2, (b) Ambient Temperature; °C and (c) Wind speed; m/s at 10 m above the ground.

Table1: Mean monthly wind speed (m/s)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tajoura-1	5.99	6.87	7.79	6.98	7.98	7.12	6.76	5.69	5.43	5.74	5.57	6.77
Tajoura-2	6.5	6.85	8.04	7.2	7.61	7.32	6.78	6.23	5.79	6.34	6.52	6.86
Mislata-1	5.76	6.98	7.67	7.67	7.66	6.67	6.74	6.21	5.67	5.89	6.10	6.91
Mislata-2	6.65	7.12	7.94	7.43	7.67	7.98	7.95	7.49	7.53	7.12	6.74	7.91

Since such wind monitoring efforts are time consuming and costly, wind researchers often obtain data sets that have been previously recorded. Several sources may be helpful in obtaining existing meteorological databases. For example, climatologically stations, and airports are likely to maintain reliable records. If possible, existing data sets should be supplemented with spot measurements. When choosing sites to examine for potential wind development, the researcher should focus on areas likely to have enhanced wind speeds. In this paper data were recorded at height 30 meters continuously by a cup generator anemometer for all stations of each area. Samples of this data which represents the mean monthly wind speed for one year (2012) are as shown in Table 1.

Methodology

Analysis of wind regimes

The next step in the wind resource assessment is to analyze the wind data set to determine patterns in the magnitude, duration and direction of the wind. The Mean wind speed (V_m) is the most commonly used indicator of wind production potential where defined as:

$$V_m = \frac{1}{N}\sum_{i=1}^{N} V_i \qquad (1)$$

Where N is the sample size, and V_i is the wind speed recorded for the ith observation. Where the sample size is large, it is useful to group the wind speed data into intervals to create a histogram of the wind speed distribution.

The wind speed at the surface is zero due to the friction between the air and the surface of the ground. The wind speed increases with height most rapidly near the ground, increasing less rapidly with greater height. At a height about 2 km above the ground the change in the wind speed becomes zero. The vertical variation of the wind speed, the wind speed profile, can be expressed by different functions. Two of more common functions which have been developed to describe the change in mean wind speed with height are based on experiments and are given below [43].

Power exponent function

$$V(z) = V_r\left(\frac{z}{z_r}\right)^{\beta} \qquad (2)$$

Where z is the height above ground level, V_r is the wind speed at the reference height z_r above ground level, $V(z)$ is the wind speed at height z, and β is an exponent which depends on the roughness of the terrain [44]. A typical value of β might be 0.1-0.5 [45].

Logarithmic function

$$\frac{V(z)}{V(10)} = ln\left(\frac{z}{z_0}\right)\Big/ ln\left(\frac{10}{z_0}\right) \qquad (3)$$

Where V(10) is the wind speed at 10 m above ground level and z_0 is the roughness length. The parameters β and z_0 for different types of terrain are shown in Table 2.

Table 2: Roughness of different terrains

Type of terrain	Roughness class	z_0; m	β
Water areas	0	0.001	0.01
Open country, few surface features	1	0.12	0.12
Farmland with buildings and hedges	2	0.05	0.16
Farmland with many trees, forests, villages	3	0.3	0.28

Both functions can be used for calculation of the mean wind velocity at a certain height, if the mean wind velocity is known at the reference height. In this study we used the power exponent function during the calculation and choose the value for β which equal 0.12 .

Wind statistics

Studies show that a wind speed distribution can typically be described in terms of the Weibull distribution. The equation of the non-cumulative Weibull distribution is [46]:

$$p(V) = \frac{k}{C}\left(\frac{V}{C}\right)^{k-1} exp\left[-\left(\frac{V}{C}\right)^{k}\right] \tag{4}$$

While the cumulative Weibull distribution is :

$$P(V) = exp\left[-\left(\frac{V}{C}\right)^{k}\right] \tag{5}$$

Where k is the shape parameter and C is the scale parameter. Finding a best fit Weibull distribution is a convenient way to approximate a continuous wind speed distribution from the discrete observed values. In addition, this method is also useful in that the wind regime of an area can then be described using only the two Weibull parameters, k and C.

The parameters C and k for the Weibull frequency distribution can be found by plotting ln V against ln(-ln(P(V)), where ln is the logarithm to base e, and fitting a straight line to the points. The slope of the line is equal to k and C is equal to exp(ln V), or V, where ln(-ln(P(V)) is zero. This technique is based on taking logarithms of cumulative Weibull distribution twice.

Annual energy and capacity factor

The calculation of the annual energy yield of a wind turbine is of fundamental importance in the evaluation of any project. The long-term wind speed distribution is combined with the power curve of the turbine to give the energy generated at each wind speed and hence the total energy generated throughout the year. It is usual to perform the calculation using 1m/s wind speed bins as this gives acceptable accuracy. The annual energy (E) expressed mathematically as:

$$E = \sum_{i=1}^{i=n} h(i)P(i) \tag{6}$$

Where H(i) is the number of hours in wind speed bin i and P(i) is the power output at that wind speed.

Another measure is the load or capacity factor (CF), defined as the ratio of the actual energy generated (E) in a time period to the energy produced if the wind turbine had run at its rated power (P) over that period. For example for one year,

$$CF = \frac{E}{8760 \times P} \tag{7}$$

There are several similar measures of power plant performance. To avoid confusion when comparing the performance of wind plant, the precise definitions of availability or load factor should be clearly understood.

Results and discussion

To determine the Weibull frequency distribution, and the Weibull cumulative distribution, it is necessary to determine first the scale parameter (C), and the shape parameter (k). Fig. 4 shows the technique that used to determine these parameters for Gerian4 (as a sample), the values of scale parameter is C = 9.34 m/s. While the slope of straight line is the value of shape parameter which is k = 3.23, and the Cumulative Weibull distribution for Grian 4 is as shown in Fig 5. The values of the shape parameters, scale factors, probability and the annual mean wind speed for all location are shown in table 3. The mean wind speed and the wind speed of maximum frequency for Gerian 4 is indicated in Fig. 6.

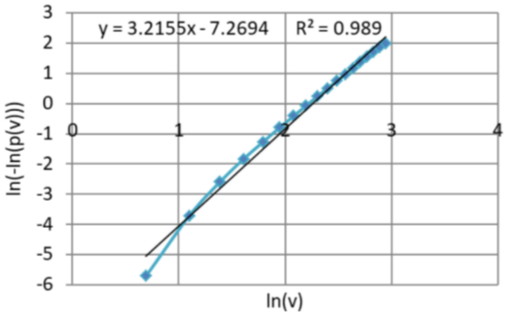


Fig. 4: Weibull parameters for Mislata-2

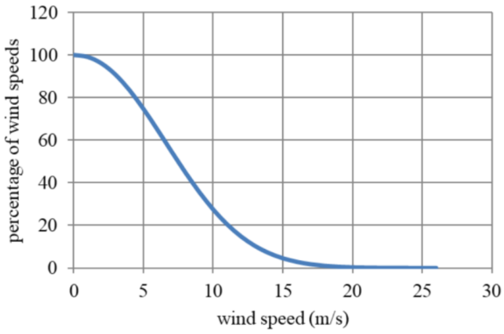


Fig. 5: Cumulative Weibull distribution for Mislata-2

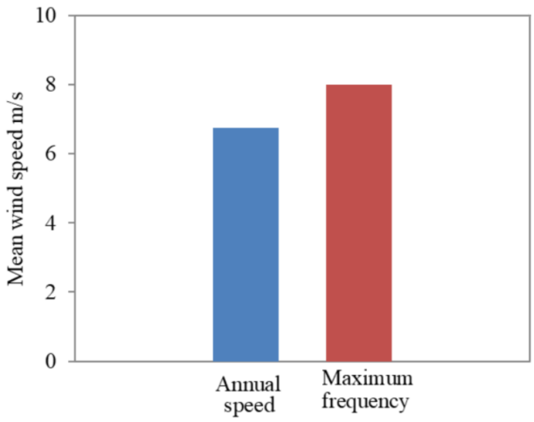


Fig. 6: Mean wind speed and the maximum frequency in Mislata-2

Table .3 show the value for the probability of wind speed which drawn by using the values of scale and shape parameters with equation 4, from this histogram its clear that the wind speed that has maximum frequency is 6.3. m/s in Gerian1 (Profitability =13.78%), 6.5 m/s in Tajoura2 (Profitability = 13.53%), 6.7 m/s in Mislata1 (Profitability = 13.66%)and 7.2 m/s in Gerian4 (Profitability = 12.54%). The annual mean wind speed can be estimated from the histogram

of the probability of wind speed by take a summation of multiply each wind speed in its profitability, the mean wind speed is 7.2 m/s in Mislata-2.
The calculations of the annual energy and capacity factor for each site are based on the data of Ventis v 60 wind turbine, which has a rotor diameter of 60 meters and a rated power of 850 kW. Fig. 7 shows the annual energy for Mislata-2 which the maximum, annual energy 9 2187.34 MWh) in, while the minimum one is 1434.12 MWh in Tajoura-1, from these values it seems that this type of wind turbines is proper in some areas like Mislata-2. The final results of calculations are summarized in Table 4.

Table 3: Performance of the areas under study

City	Scale parameter C (m/s)	Shape parameter K	Probability (%)	Annual mean wind speed
Tajoura -1	5.5835	3.1199	13.78	6.3
Tajoura -2	8.9768	3.0912	13.53	6.7
Mislata-1	8.6479	3.0828	13.66	6.5
Mislata-2	9.3410	3.23	13.84	7.2

Table 4: Results of the areas under study

City	Wind speed of max. frequency	Annual energy, MWh	Capacity factor, (%)
Tajoura-1	7.1	1434.12	19.30
Tajoura-2	7.98	1877.5	26.01
Mislata-1	7.1	1743.58	24.15
Mislata- 2	7.99	2187.34	30.02

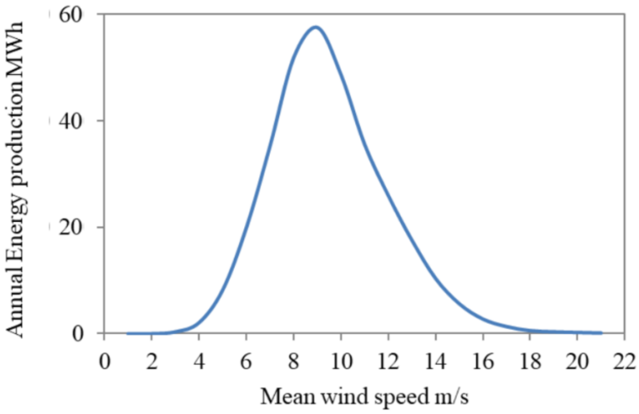


Fig. 7: Annual energy for Mislata-2 based on V60-850 wind turbine

Conclusion and recommendations

The following conclusions have been drawn from the article:

1. The results of this paper indicates the possibility of utilizing wind energy in electricity generation for some selected areas and linking it with the general electric power grid as in cases of Mislata-1,2, Tajoura-2, while the Tajoura-1 could be used in other applications such as battery charging or pumping water.
2. Mislata-2 has the maximum annual energy and capacity factor while Tajoura-1 has the minimum annual energy and capacity factor.
3. Existing data resources indicates that the mean annual wind speed of 7.9 m/s at Mislata with theoretical capacity factor exceeding 30.02 %. These values indicate that Mislata-2 could generate 2187.34 kWh.
4. More modern wind measuring equipments and an advanced soft wares should be available to increase the accuracy of the work.
5. Making campaigns to measure wind speed data in order to cover the majority in our country, paving the way for making a wind Atlas.
6. Making studies about the effect of penetration wind energy systems to the general electric grid.
7. The whole area of the country should be examined to detect the fields proper for the establishment of wind turbine farms, and public initiatives should start establishing wind energy farms in the selected areas.
8. The Universities and the scientific centers of North Africa countries should work together as one team in the field of renewable energy, this will reduce the cost and save the time required.

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