Assessment of the wind Energy Potential on the Coast of Tripoli
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ABSTRACT
Estimation of wind characteristics is considered as the first essential step to evaluate a wind energy project based on information about all aspects of the implementation and operation of the project. It's therefore necessary to have detailed knowledge of the wind to select the suitable wind turbine for a certain zone and also to estimate its performance accurately. Various parameters need to be known of the wind, including the mean wind speed, directional data, variations about the mean in the short term (gusts), daily, seasonal and annual variations, and variations with height. These parameters are highly site specific and can only be determined with sufficient accuracy by measurements at a particular site over a sufficiently long period.

In this paper Tripoli seaport station is selected to show wind energy availability on the coast of Libya, and the wind characteristics have been analyzed based on long-term measured data of daily wind speeds, 3-hourly measured wind data at 10 m height, which are obtained from meteorological station. This paper first provides background information about wind power and its resource. Analysis of wind data included, daily wind data which has been recalculated to represent the mean wind speed, diurnal frequency, monthly variations, wind power density, the Weibull distribution which included calculations of scale and shape parameters, annual energy and annual capacity factor are calculated for the site. A technical assessment of the annual energy and annual capacity factor has been made of electricity generation from turbine has capacity(600 kW). This study indicates that the Tripoli seashore has energy potential available exceeding 200 W/m² and yearly energy output was 2303.42 MWh.

1- INTRODUCTION
Because of the negative environmental impacts of fossil fuel use, it is necessary to find ways to economically utilize non-polluting sources of energy like wind, solar, etc. Wind is considered as one of the cleanest sources of energy available today. Wind energy is an indirect form of solar energy. Only about 2 % of the solar energy of $1.5 \times 10^{18}$ kWh captured annually by the earth’s atmosphere is converted into energy of motion of the air envelope. Nevertheless, this results in a calculated power of the wind of about $4 \times 10^{12}$ kWh. This is one hundred times more than all of the power station output installed on this globe. The wind speed increases with the height above the ground, due to the frictional drag of the ground, vegetation and buildings. It is clear that any plans to harness the wind must take into account these variables.

Because the cost of wind energy development depends sensitively on the nature of the wind resource, any detailed evaluation of wind energy economics requires a series of wind assessment studies.
2- WIND ASSESSMENT AND DATA ANALYSIS

For estimating the wind energy potential of a site, the wind data collected from the location should be properly analyzed and interpreted. Long term wind data from the meteorological stations near to the candidate site can be used for making preliminary estimates. This data, which may be available for long periods, should be carefully extrapolated to represent the wind profile at the potential site.

**Vertical wind speed gradient**

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.

- **Power exponent function**

  \[ U(z) = U_r \left( \frac{Z}{Z_r} \right)^\beta \]  

  Where \( Z \) is the height above ground level, \( U_r \) is the wind speed at the reference height \( Z_r \) above ground level, \( U(z) \) is the wind speed at height \( Z \), and \( \beta \) is an exponent which depends on the roughness of the terrain, can be calculated in approximation by using the formula:

  \[ \beta = \frac{1}{\ln \frac{Z}{Z_0}} \]  

- **Logarithmic function**

  \[ \frac{U(z)}{U(10)} = \ln \left( \frac{Z}{Z_0} \right) = \ln \left( \frac{10}{Z_0} \right) \]

  Where \( U(10) \) is the wind speed at 10 m above ground level and \( Z_0 \) is the roughness length. The parameters \( \beta \) and \( Z_0 \) for different types of terrain are shown in Table 1 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.
Table 1 Roughness lengths and roughness classes for various surface characteristics [1]

<table>
<thead>
<tr>
<th>$z_0$ [m]</th>
<th>Types of terrain surfaces</th>
<th>Roughness class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>City</td>
<td>3</td>
</tr>
<tr>
<td>0.50</td>
<td>Forest</td>
<td></td>
</tr>
<tr>
<td>0.30</td>
<td>Suburbs</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td>Built-up terrain</td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>Many trees and/or bushes</td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>Agricultural terrain with a closed appearance</td>
<td>2</td>
</tr>
<tr>
<td>0.03</td>
<td>Agricultural terrain with an open appearance</td>
<td>1</td>
</tr>
<tr>
<td>0.01</td>
<td>Airports with buildings and trees</td>
<td>0</td>
</tr>
<tr>
<td>$5 \cdot 10^{-3}$</td>
<td>Bare earth (smooth)</td>
<td></td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>Snow surfaces (smooth growth)</td>
<td></td>
</tr>
<tr>
<td>$3 \cdot 10^{-4}$</td>
<td>Sand surfaces (smooth)</td>
<td></td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>Water surfaces (lakes, fjords and the sea)</td>
<td></td>
</tr>
</tbody>
</table>

**Mean wind speed**

Mean wind speed ($U_m$) is the most commonly used indicator of wind production potential where defined as:

$$U_m = \frac{1}{M} \sum_{j=1}^{M} U_j$$  \hspace{1cm} (4)

Where $M$ is the sample size, and the wind speed recorded for the $j^{th}$ 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.

**Wind power density**

Wind power density is the amount of wind power available per unit of area perpendicular to the wind flow

$$WPD = \frac{1}{2} \rho U^3$$  \hspace{1cm} (5)

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**3- WIND STATISTICS**

Studies show that a wind speed distribution can typically be described in terms of the Weibull distribution. In Weibull distribution, the variations in wind velocity are
characterized by the two functions; (1) The probability density function and (2) The cumulative distribution function. The probability density function \( p(U) \) indicates the fraction of time (or probability) for which the wind is at a given velocity \( U \). It is given by [1]:

\[
p(U) = \frac{k}{C} \left( \frac{U}{C} \right)^{k-1} \exp \left( -\left( \frac{U}{C} \right)^k \right) \tag{6}
\]

The cumulative distribution function of the velocity \( U \) gives us the fraction of time (or probability) that the wind velocity is equal or lower than \( U \). Thus the cumulative distribution \( P(U) \) is the integral of the probability density function. Thus [2],

\[
P(U) = 1 - \exp \left( -\left( \frac{U}{C} \right)^k \right) \tag{7}
\]

Here, \( k \) is the Weibull shape factor and \( C \) is scale factor. The common method for determining \( k \) and \( C \) is graphical method:

**Graphical method**

In the graphical method, the cumulative distribution function is transformed into a linear form, adopting logarithmic scales. The expression for the cumulative distribution of wind velocity can be rewritten as

\[
1 - P(U) = \exp \left( -\left( \frac{U}{C} \right)^k \right)
\]

Taking the logarithm twice, we get [2]:

\[
\ln \left\{ -\ln \left[ 1 - P(U) \right] \right\} = k \ln \left( \frac{U}{C} \right) - k \ln C \tag{9}
\]

Plotting the above relationship with \( \ln (U_i) \) along the \( X \) axis and \( \ln (-\ln[1-P(U)]) \) along the \( Y \) axis, we get nearly a straight line. From equation 9, \( k \) gives the slope of this line and \( -k \ln C \) represents the intercept. \( C \) is equal to \( \exp(\ln(U)) \), or \( U \), where \( \ln(-\ln(P(U))) \) is zero.

### 4- 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 expressed mathematically as

\[
\text{Energy} = \sum_{i=1}^{i=n} H(i) P(i) \tag{10}
\]

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, defined as the ratio of the actual energy generated in a time period to the energy produced if the wind turbine had run at its rated power over that period. For example,

\[
\text{Annual load factor} = \frac{\text{energy generated per year (kWh)}}{\text{turbine rated power (kW)} \times 8760} \tag{11}
\]
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.

5-RESULTS AND DISCUSSION
The wind data are obtained from the representative meteorological station. For long term time series(from 1993 to 2002) of 3-hourly measured wind data were used. The geographic location of the site is 32.9022 Latitude (N°) and 13.1858 Longitude (E°) . In this paper mean monthly wind speed have been calculated based on daily wind speed at 10 meters height which are obtained from the local meteorological station as shown in Table 1.

Table 2. Mean monthly wind speed (m/s)for Tripoli seaport

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>January</td>
<td>5.71</td>
<td>6.44</td>
<td>5.92</td>
<td>8.34</td>
<td>6.76</td>
<td>6.42</td>
<td>6.5</td>
<td>5.48</td>
<td>6.44</td>
<td>4.92</td>
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<tr>
<td>February</td>
<td>6.78</td>
<td>5.73</td>
<td>5.1</td>
<td>7.55</td>
<td>6.57</td>
<td>5.76</td>
<td>6.22</td>
<td>6.33</td>
<td>8.39</td>
<td>5.38</td>
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<tr>
<td>March</td>
<td>6.46</td>
<td>6.25</td>
<td>6.64</td>
<td>6.2</td>
<td>6.97</td>
<td>8.75</td>
<td>7.26</td>
<td>4.87</td>
<td>5.71</td>
<td>6.37</td>
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<tr>
<td>April</td>
<td>6.31</td>
<td>6.93</td>
<td>7.25</td>
<td>8.01</td>
<td>8.03</td>
<td>6.62</td>
<td>6.5</td>
<td>6.06</td>
<td>6.08</td>
<td>5.38</td>
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<tr>
<td>May</td>
<td>6.66</td>
<td>5.75</td>
<td>6.45</td>
<td>5.89</td>
<td>8.1</td>
<td>7.71</td>
<td>6.26</td>
<td>5.43</td>
<td>5.87</td>
<td>5.46</td>
</tr>
<tr>
<td>June</td>
<td>6.24</td>
<td>6.33</td>
<td>6.8</td>
<td>4.86</td>
<td>6.94</td>
<td>6.96</td>
<td>6.52</td>
<td>5.22</td>
<td>4.7</td>
<td>4.6</td>
</tr>
<tr>
<td>July</td>
<td>6.41</td>
<td>4.29</td>
<td>5.65</td>
<td>5.48</td>
<td>7.12</td>
<td>5.24</td>
<td>6.36</td>
<td>4.5</td>
<td>4.03</td>
<td>4.93</td>
</tr>
<tr>
<td>August</td>
<td>5.16</td>
<td>4.9</td>
<td>6.9</td>
<td>4.7</td>
<td>6.47</td>
<td>4.73</td>
<td>6.57</td>
<td>3.7</td>
<td>4</td>
<td>5.38</td>
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<td>September</td>
<td>7.17</td>
<td>6.25</td>
<td>8.03</td>
<td>5.38</td>
<td>6.28</td>
<td>5.67</td>
<td>6.68</td>
<td>4.89</td>
<td>5.74</td>
<td>4.8</td>
</tr>
<tr>
<td>October</td>
<td>6.65</td>
<td>5.58</td>
<td>8.37</td>
<td>5.36</td>
<td>6.02</td>
<td>5.97</td>
<td>6.73</td>
<td>5.4</td>
<td>4.02</td>
<td>4.45</td>
</tr>
<tr>
<td>November</td>
<td>5.56</td>
<td>4.97</td>
<td>7.37</td>
<td>6.26</td>
<td>5.82</td>
<td>5.27</td>
<td>6.9</td>
<td>4.42</td>
<td>6.45</td>
<td>6.18</td>
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<tr>
<td>December</td>
<td>4.61</td>
<td>4.87</td>
<td>7.54</td>
<td>6.79</td>
<td>5.9</td>
<td>5.56</td>
<td>7.49</td>
<td>5.79</td>
<td>6.99</td>
<td>6.74</td>
</tr>
</tbody>
</table>

In this study the analysis of vertical wind speeds with height was done based on nature of the site roughness class 0 (water surfaces) , power exponent calculated by using equations 2.1.

The mean speed values at 10 m height are shown in Figure 1. It’s frequency from 5.17 m/s to 6.83 m/s, for years, 2000,1995 respectively. the mean wind speed for ten years was 6.1 m/s, also this figure shows mean wind speeds at certain heights 20, 40, 60, 70 m. It can be seen that the changes in the mean wind velocity at heights of more than 60 m it decreases.

The wind power density calculated at different heights from equation 5.The result is shown in figure 2. This figure indicates that the maximum power density is 330.17 W/m² in 1995 and the overall mean power density is 238 W/m² at 70 m height. Also this figure shows the change of power density at various heights.

Figure 3 shows the monthly variation of the average wind speed for long period of time at 10 m height, the minimum value of average wind speed is in August and the maximum in April. Figure 4 shows the diurnal frequency of average wind speed at 10 m height. It can be seen, that the minimum average is at 6:00 AM and the maximum is at 3:00 PM.
Figure 1: Variation of annual mean wind speeds with height, (m/s)

Figure 2: Variation of wind power density with height

Figure 3: Monthly variation of the average wind speeds
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 ($k$). The two parameters $C$ and $k$ for the site data are calculated by using graphical method as illustrated, by plotting $\ln(U)$ in the $X$ axis and $\ln\{-\ln[1-P(U)]\}$ in the $Y$ axis. The resulting graph is shown in Fig 5. The points are slightly scattered. Fit a line through the points and deduce the best fit equation. The resulting equation for the plot is:

$$y = 2.1894 x - 4.4512.$$  Then by Comparing this equation with equation 9 the shape factor $k$ determined for the given location as $k = 2.19$. Similarly, we have $k \ln C = 4.4512$. From this can be solved scale factor as $C = 7.64$ m/s.

Figure 6 shows the histogram of the wind velocity for the station, from this figure it is clear that the speed $U = 6$ m/s has the maximum probability (11.93%).

Figures 7 shows the Weibull cumulative distribution which gives the probability of the wind speed exceeding the value of any given wind speed ($U$).
The calculation of the annual energy yield of a wind turbine is an important step to evaluate any project. It’s related to the specification of wind turbine and wind speeds at hub height. The tower height is an essential component of the horizontal-axis turbine, a fact determining the optimum tower height requires quantitative knowledge of the relationship between the additional cost for the increase in tower height and the additional gain in energy yield.

The annual energy and annual capacity factor were calculated at hub height and based on specification of wind turbine known as Vestas V42-600 wind turbine which has a power curve as shown in Figure 8, and its main characteristics are shown in table 3. Where the air density $\rho=1.225 \text{ kg/m}^3$. 

![Figure 7. Cumulative Weibull distribution to Tripoli seaport](image)

![Figure 6. Histogram and Weibull function for the probability (data measured in 1 m/s bins)](image)
Table 3 Main characteristics of wind turbine used in this study.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine model</td>
<td>Vestas V42-600</td>
</tr>
<tr>
<td>Rated power</td>
<td>600 kW</td>
</tr>
<tr>
<td>Tower height at hub</td>
<td>40 m</td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>42 m</td>
</tr>
<tr>
<td>Swept area</td>
<td>1385 m²</td>
</tr>
<tr>
<td>Number of blades</td>
<td>3</td>
</tr>
<tr>
<td>Cut-in wind speed</td>
<td>4 m/s</td>
</tr>
<tr>
<td>Rated wind speed</td>
<td>16 m/s</td>
</tr>
<tr>
<td>Cut-out wind speed</td>
<td>25 m/s</td>
</tr>
</tbody>
</table>

Yearly energy output for the selected station was 2303.42 MWh at hub height, with theoretical capacity factor exceeding 0.438.

Figure 9 shows the relation between the yearly energy output as a function of mean wind at hub height. It can be seen that the maximum yearly energy is derived from a wind speed 11.4 m/s and the annual energy is obtained for wind speeds between 4 and 25.

![Figure 8. Power curve of Vestas V42-600 wind turbine](image1)

![Figure 9. Yearly energy output by V42-600 turbine as function of mean wind speed for Tripoli seaport station](image2)
6- CONCLUSION AND RECOMENDATIONS

• This study shows that the wind energy is available in the Libyan seashore such as Tripoli seaport and it could be used to generate electricity, also wind energy may used for other applications like water sea desalination.

• Existing data resources indicate that the mean annual wind speed of over 6 m/s at Tripoli seaport which promising to generate 2303 MWh, with theoretical capacity factor exceeding 0.438.

• Since, the Libyan seashore extended about 2000 km, new modern equipment should be installed in different locations on the seashore to measure the wind data more accurately.

• This work should be extended to study possibility of extracting the available power in wind energy for generating electricity and other applications like sea water desalination by using HAWTs in different locations along the Libyan seashore.

• Modern and advanced softwares which are related to the wind power should be available

7- REFERENCES


