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Wind Energy Potential in Tetuan City Northern of Morocco

A. Sadouk[1], A. Djebli[2]

[1, 2]EEMFM, Faculty of Sciences, Abdelmalek Essaadi University, Tetuan, Morocco

Abstract: ***This study is included in wind energy sector, which seems a more promising in Tetuan city northern of Morocco, where it is part of very Moroccan region windy, with annual average speeds close to 11 m/s. So for this, estimating of wind energy potential values of three sites in Tetuan city in northern of Morocco is made, taking account of weather data provided by quantifying of wind resources of each site and its yearly average power available estimations. We begin by determining the various parameters of wind such as mathematical modeling of Weibull distribution frequency, also the processing and simulation of real wind data collected. We evaluated for each site the wind energy potential, the generated electricity prediction based on a judicious choice appropriate to wind turbine energy needs from wind climate.***

Keywords: component; formatting; style; styling; insert (key words)

1. Introduction

The choice of a wind farm is critical in an energy production project, because a produced energy is depends on resources of every site. Estimation of these resources has a particular difficulty because of the variability of wind since the available amount of energy at a site varies with the season and time of day. This is why a prior study reveal an extreme interest to the extent that we can identify the conditions and constraints to be considered in the implementation of a wind project. These resources and machine adaptation predictions at a given site are based on the statistical distribution of wind speed of this site. The statistical distribution of wind speed varies from one place to another, because it depends on the local weather, the landscape and it surface. Wind characteristics at a given site (average speeds, frequencies, directions ...) help to estimate the amount of energy actually extracted from the wind resource, since these parameters directly affect the wind turbine operation (start, stop, orientation, etc.). By calculating the wind potential of a given site, it is customary to represent the frequency distributions of gear by statistical Weibull distribution, for many authors, this distribution is the best approximation of most wind speed histograms.

For this, we calculate the energetic wind potential at a given site, case study Tetuan city in northern of Morocco, to determine the typical wind turbine values. In addition, it is recommended to do a thorough study to determine the wind turbine characteristics and the targeted site, to choose the best suited system and to determine energy needs following the wind climate before to set up of a wind farm.

So, our efforts were primarily directed toward understanding the wind regime characteristics and the determination of basic elements necessary to design most of suitable wind systems based on sectoral classifications, which allows to precise the most suitable machine for all every site to produce the maximum wind power.

2. Wind Data Collection

In this study, the wind speed data are drawn by the REDC for El koudia Al baida and El haouma stations, covering period of 1993-1994 as first phase part program (1991-1994) of evaluation the wind resource launched by REDC, it has been devoted to evaluation of wind resources in coastal areas of Dakhla, Tangier and Tetuan cities. Thus, for period of 1996-1999, the wind speed data of Torreta station was determined in the second phase (1995-2000) which has reserved for Northeast provinces [2], [6].

Currently, in context of this program, REDC has installed more than forty measurement stations in all regions of Morocco. The REDC has collected wind speed data from these stations at a height varying between 9m and 10m mast for climatological and practical reasons, it was agreed that this should be the standard meteorological reference level to achieve registration representing the wind potential of the region. In addition, the wind speed at higher heights could be calculated by using the power law. Wind speed was taken every 10 s and an average of over a minute and stored in a data logger. The minute average wind speed data were also averaged over an hour. At the end of each hour, the hourly average wind speed was calculated and sequentially stored in a permanent memory [6].

Table 1: Studied station coordinates

Station name	Measurment period	Latitude ˚N	Longitude ˚E	Altitude (m)
Torreta	3/1996 - 6/1999	35°33'29"N	5°22'24"E	208
El haouma	2/1993 - 4/1994	35°52'48" N	5°30'0" E	250
El koudia Al baida	2/1993 - 5/1994	35°49'12" N	5° 27' 0" E	400

3. Mathematical Formulation

A. Wind speed probability density function

In wind energy applications, the statistical methods are usually employed to describe random variations of wind speed. Statistical analyses are an useful tool to estimate the available wind power potential. Therefore, the most commonly used to characterize the wind speed distributions and the probability distribution model is Weibull distribution. It is expressed mathematically by its probability density function [7-11]:

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

The Weibull distribution is an exponential function with two parameters:

- k (dimensionless) is a parameter related to the shape of the function: high values are related to distribution concentrated around a given value; low values are related to a distribution very spread in different values.
- c (m/s) is the scale parameter that fixes the curve position, with higher values for strong wind sites and lower values for still sites.

There are several methods to calculate Weibull parameters such as the analytical method. Average wind speed $\bar{v}$ and standard deviation σ are known. Weibull parameters can be calculated using the following approximations [12]:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (3)$$

Where Γ is the upper incomplete gamma function defined as:

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-t} dt \quad (4)$$

Weibull parameters c and k depend of site characteristics. Therefore, some adjustments should be made since the exact plant positioning, where it is usually different in function of wind speed monitoring, it is taken also because it subject to the soil characteristics and for quite homogenous topography, it has been shown that, the vertical gradient of the wind speed affects of Weibull distribution relative to the hub height H_{hub} according to the following relationship to define the new parameters Weibull C_{hub} [13,14] and K_{HUB} [15]:

$$C_{hub} = c.\left(\frac{H_{hub}}{H_0}\right)^{\alpha} \quad (5)$$

$$\alpha = \frac{1}{\ln\left[\frac{H_{hub} \cdot H_0}{z}\right]} - \frac{0.0881}{1-0.0881.\ln\frac{H_0}{10}} \ln\frac{\bar{v}}{6} \quad (6)$$

Where H_{hub} and H_0 are heights of hub and wind measurements, respectively, c_{hub} and c_0 are the Weibull scale parameters, respectively, at the hub height and of wind measurements, and z is the ground roughness. Similarly, parameters of the shape k_{hub} and k0 are also strictly related according the following [15]:

$$k_{hub} = k + 0{,}03.H_{hub} + 0{,}02 \quad (7)$$

For practical applications, such as the vertical variation in wind speed or estimation of wind power energy at aerogenerator hub heights, it is easier to use the power law expressed as (Johnson, 1985; Lysen, 1983; Troen and Lundtang, 1988) [20]:

$$\frac{V(z)}{V(z_a)} = \left(\frac{z}{z_a}\right)^{\alpha} \quad (8)$$

B. Most Probable Wind Speed

As the scale and shape parameters have been calculated, two meaningful wind speeds for wind energy estimation, the most probable wind speed and the wind speed carrying maximum energy can be easily obtained. The most probable wind speed denotes the most frequent wind speed for a given wind probability distribution and it is expressed by [16]:

$$V_{mp} = c\left(k - \frac{1}{K}\right)^{1/K} \quad (9)$$

C. Maximum Energy Carrying by Wind Speed

Wind speed carrying maximum energy represents wind speed which carries maximum wind energy, and it can be expressed as following [17]:

$$V_{Max,E} = c\left(k + \frac{2}{K}\right)^{1/K} \quad (10)$$

D. Wind Power and Wind Energy Densities

1. Wind power density

Air density is noted by ρ. Wind power density of a site is based on Weibull probability density function, and it can be expressed as follows [18, 19]:

$$\frac{P}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{K}\right) \quad (11)$$

2. Wind energy density

By a given wind power density of site, the wind energy density for a desired duration can be calculated as [16]:

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{K}\right) T \quad (12)$$

Where T is time period.

4. Results and Discussions

a) Average Wind Speed

The average wind speed of selected stations in Tetuan city is presented in Table 1, where we found that its wind speeds are higher. The annual average of wind speed in Torreta, El Haouma and El Koudia Al Baida stations are 7.55 m/s, 9.45 m/s and 10.42 m/s, respectively.

From these stations, El Koudia Al Baida site is considered the most promising region, where it monthly average wind speed is very regular and the availability of land for a wind farm installation. Minimum wind speed is noticed in winter season (October Vm = 8.2 m/s) and maximum in summer season (June, July Vm = 11 m/s). Generally, we note that for three studied cases, June remains the windiest with an interval turret of 7.24 m/s and 11 m/s to El koudia Al baida. However, October is the low windy with an interval turret between 6.26 m/s in Torreta and 8.94 m/s in El Haouma.

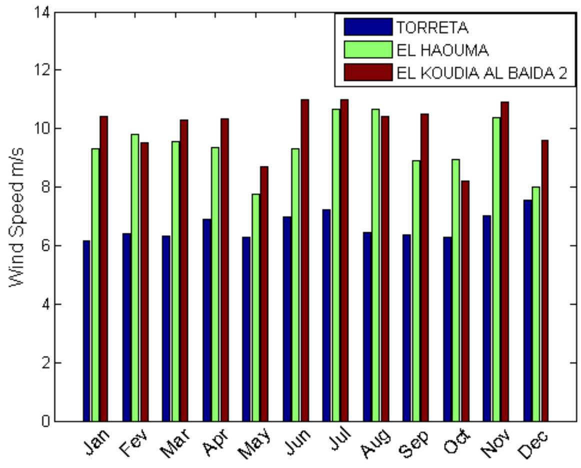

Fig.1. Monthly average wind speed of three stations

b) Vertical Profile of Wind Speed

The vertical profile of relative wind at ground can be used to estimate the wind at a different height. Height of wind turbines is generally higher than that of meteorological station anemometers (9-10 meters). Extrapolations are often necessary. The wind speed increases with altitude above the ground, and we can represent this variation by expression (9) to achieve the following results:

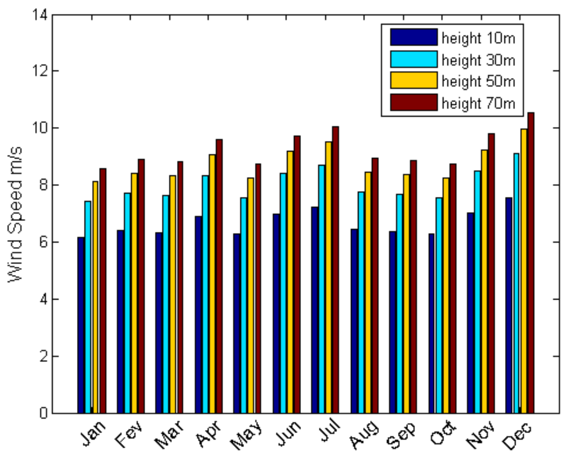

Figure 2: Monthly average wind speed for different heights of Torreta

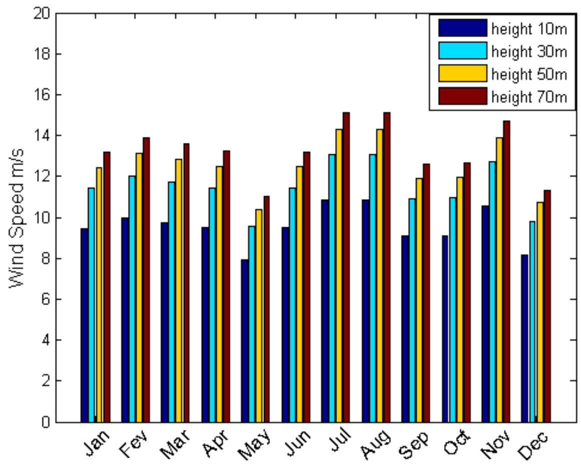

Figure 3: Monthly average wind speed for different heights of El Haouma

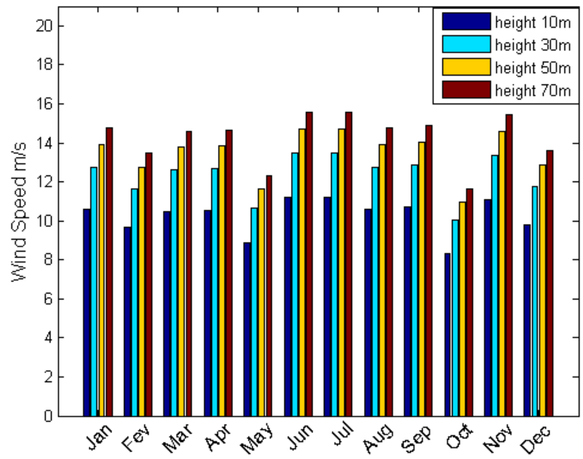

Figure 4: Monthly average wind speed for different heights of El koudia Al baida

Figures 6-8 show the monthly average wind speed for 10 m, 30 m, 50 m and 70 m heights of three sites. It is noted that the monthly average wind speed is between 6.16 m/s to 7.56 m/s, 7.43 to 9.12 m/s, 8.10 m/s to 9.94 m/s and 8.58 m/s to 10.53 m/s for turret station, and between 8,14 m/s to 10,85 m/s, 9,81m/s to 13.07 m/s , 10,70 m/s to 14.26 m/s and 11.33 m/s to 15.10 m/s for El Haouma station and finally 8.34 m/s to 11,19 m/s , 10,06 m/s to 13.49 m/s, 10,97 m/s to 14.72 m/s and 11.62 m/s to 15.59 m/s for El Koudia Al Baida station. The maximum wind speeds occurs in June and July months and the minimum in October month. We also note that wind speed rate may be exceed to 31%, 29% and 25% at height of h = 45m for Torreta, El Haouma and El Koudia Al Baida, respectively (Table 2).

Table 2: Increased percentage speed according to height variations

Height H(m)	TORRETA		EL HAOUMA		El KOUDIA Al BAIDA	
	V	$\frac{V-V_0}{V_0}$ %	V	$\frac{V-V_0}{V_0}$ %	V	$\frac{V-V_0}{V_0}$ %
H_0	7,55	0	9,46	0	10,59	0
15	8,12	7,63	10,13	7,15	11,27	6,41
20	8,56	13,41	10,64	12,54	11,78	11,18
25	8,91	18,09	11,05	16,91	12,19	15,05
30	9,21	22,06	11,41	20,59	12,54	18,31
35	9,47	25,52	11,71	23,81	12,84	21,13
40	9,7	28,61	11,97	26,64	13,11	23,63
45	9,91	31,38	12,21	29,21	13,35	25,88
50	10,11	33,92	12,43	31,55	13,56	27,92
55	10,28	36,25	12,64	33,69	13,76	29,81
60	10,45	38,42	12,82	35,71	13,95	31,55
65	10,6	40,45	13,01	37,56	14,12	33,17
70	10,74	42,34	13,16	39,31	14,29	34,69
75	10,88	44,14	13,32	40,96	14,44	36,12
80	11,01	45,84	13,47	42,52	14,58	37,47
85	11,13	47,45	13,61	44,01	14,72	38,75
90	11,24	48,99	13,74	45,41	14,85	39,97
95	11,36	50,46	13,87	46,75	14,97	41,14
100	11,46	51,86	13,99	48,04	15,09	42,25

c) Wind Speed Distribution

The Weibull annual parameter values, the scale parameter c (m/s) and the shape parameter k (size) are presented in **Table 3**. The annual range values of k is between 2.10 and 2, 81 with an average value closest to 2.46. Lowest scale value of c parameter is 8.52 m/s, and it is found at Torreta site. While the highest value is found to 11.71 m/s at El

Koudia Al Baida site. From obtained result, it is evident that the shape parameter k has a much lower variation than the scale parameter c. Equations (2) and (3) are used to evaluate Weibull probability distribution function. Figures. 9-11 show the annual change frequency of observed wind speed Weibull for three studied sites. Weibull frequency reached it top at about 8 m/s with value about of 0.1006. After this point, the curve decreases regularly at Torreta. In 14 m/s, the curve gives a frequency of 0.0225, approximately, and it closest to 0.0044 for wind speed of 20 m/s value. In El Haouma site, the wind speed found to 9 m/s, Weibull frequency reaches to 0.1085 and steadily decreases from this point. They are found to 0.0415 for the wind speed of 14 m /s and to 0.0207 for 20 m / s. Concerning El Koudia Al Baida, the wind speed is observed at the 11 m/s, the Weibull frequency reaches to 0.0978 and significant still to 14 m/s with 0.0627 value. Finally, the curve steadily decreases to 0.0157 for a wind speed of 20 m/s. Thus, the annual average of wind speeds become higher in these areas especially for El Koudia Al Baida and El Haouma.

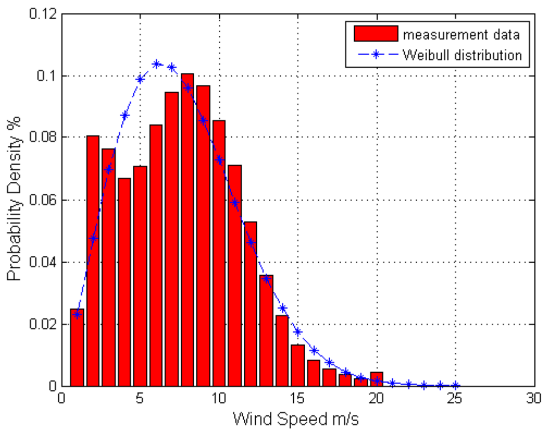

Figure 5: Wind speed distribution of Torreta site

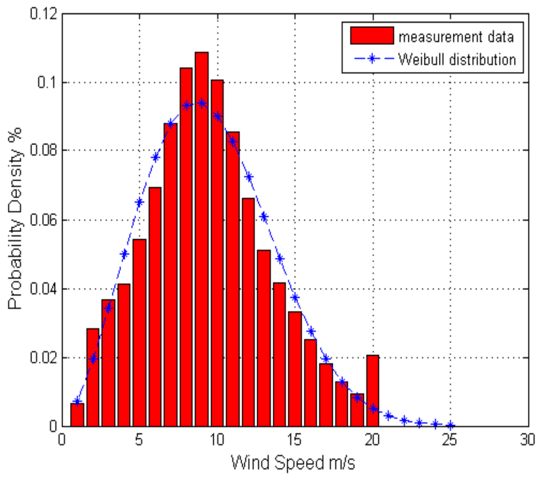

Figure 6: Wind speed distribution of El Haouma site

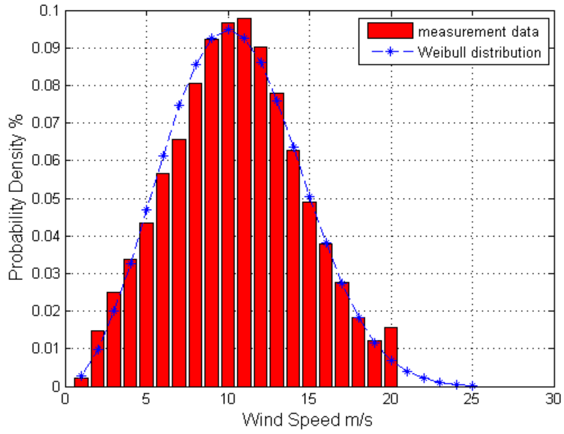

Figure 7: Wind speed distribution of El Koudia Al Baida

In addition, the frequency distribution of wind speed also shows that only 4%, 7% and 18%, respectively, of recorded wind speeds are less than 3 m/s. In interesting sites such as El Koudia Al Baida, El Haoma and Torreta, the cut-in speed decreases for most wind turbines, and these speeds rarely surpluses to 13 m/s. For this wind turbine type, it can estimate its rated power. This small average of wind turbines can be installed at these sites, at a height of 10 m, and they are able to produce an energy exceeds to 97%, 93% and 82% in El Koudia Al Baida, El Haouma and Torreta sites, respectively, but time is rarely operate at their rated power. However for large wind turbines that require for their height installation more than 10 m, the speeds will be larger and the turbines work much better in wide energy production ranges.

d) Wind power and Energy density

Table 3 illustrates the average annual of wind speed, standard deviation, Weibull parameters, most probable wind speed, maximum energy carrying by wind speed, power density and energy density. These are calculated by using (9), (10), (11) and (12) equations. It is observed that the greater value of energy density was 8679.63 kw/m² in El Koudia Al Baida and the lowest value of wind power density was 4112.05 kw/m² in Torreta. The range of wind power density values are 120.6 to 184,828.15 kWh/m², between 37 to 1,581,141.64 kWh/m² and 15 to 134,706.4 kWh/m² for Torreta, El Haouma and El Koudia Al Baida sites, respectively. Highest value of wind speed and of most probable wind speed are 10.73 m/s to 14.49 m/s in Torreta, 14.29 m/s to 17.24 m/s in El Haouma and 16.12 m/s to 18.33 m/s in El koudia Al baida.

Table 3: Yearly average values of wind speed parameters

Sites	Torreta	El haouma	K.baida
Wind speed m/s	7,55	9,45	10,43
Standar deviation	3,8	4,1	4,02
K	2,1	2,47	2,81
C m/s	8,52	10,66	11,71
Anemometer height	10	9	9
V_{mp}	10,73	14,29	16,12
$V_{max,E}$	14,49	17,24	18,33
Power density	1276,62	2938,83	4972,86
Enegy density	4112,05	7043,04	8679,63

According to results of available energy estimation from wind and statistical parameters. It is noted that wind distributions of three studied sites are more promising for available energy production in Tetuan city due to several factors:

- Its average wind speed.
- Its Weibull parameters c and k.
- Its available wind power.

5. Conclusion

This paper presents an integral study of wind energy potential estimations in Tetuan city northern of Morocco (35.57361 latitude, -5.37528 longitude) based on the meteorological data acquired by three stations of Torreta, El Haouma and El Koudia Al Baida sites.

Results shows that the studied sites have very high wind energy potential and they are more favorable to exploitation the electricity energy generations, where they have very large wind resource (annual average wind speeds between 8 and 11 m/s), that it can supported a wind farm installations to produce higher quantity electricity energy in connection with the national grid.

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