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Technical Feasibility of Wind Energy in Morocco through a Potential Analysis, Case Study

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***Abstract* - This article studies the wind energy potential in the Taroudannt province by means of 09-years (2010-2018) wind speed data at 10 m altitude of wind energy using two-parameter Weibull distribution in Morocco, in order to develop this desert area which suffers from long dry seasons and poorly developed energy resources. The results provided the opportunity to implement and develop the urban wind energy sector in the Taroudannt province. The mean monthly wind speed and power density were calculated. Compared to other technologies, considered for their reasonable cost, the EWT DW 52 - 500kW - 50m wind turbine offered the best capacity factor of 13.81% and the best energy production more than 785 MWh. After analyzing the generation of wind energy, the province of Taroudannt must install wind turbines with a high blade height of more than 50 m in order to achieve an efficient harvest.**

Keywords: Wind speed, Weibull distribution, Weibull parameters, Wind turbines, Taroudannt province.

I. INTRODUCTION

Wind energy is anticipated to play a crucial role in the future energy supply of the world. In 2020, worldwide, wind energy will provide a significant amount of electricity - around 16%, according to predictions by the World Wind Energy Council [1]. The development of renewable energies is a priority worldwide, which will make it possible to comply with international climate agreements and meet the growing demand for energy. GWEC reports that Africa and the Middle East installed 962 MW of wind capacity in 2018. Prediction data from the "Global Wind Report" projects that an additional capacity of 6.5 GW will be added by 2023. According to the World Wind Energy Council, the three main markets in Africa and the Middle East in 2018 are:

- Egypt, with a wind capacity of 380MW;
- Kenya, with a wind capacity of 310MW;
- Morocco, with a wind capacity of 120MW.

However, Morocco is the African country which has the most wind projects under construction.

Taroudannt is a town in the southern Moroccan region of Souss-Massa. It is the capital of Taroudannt province and recorded a population of 80149. In the Souss Massa region, the poverty rate in rural areas is estimated at 9.8 %, slightly close to the national average (9.5 %), while in urban areas, this indicator is 2.7 % versus a national average of (1.6 %). Provincially, the poorest province is Tata (17.01 %), followed by Taroudannt (9.65 %) and Tiznit (6.13 %) [2]. The causes of this poverty are multiple. Among these causes, a large part is due to the African bioclimatic environment and the absence of investment in the energy sector. The Abdelmoumen (Initiated in 1990) is a dam on the Massa river, in the Aoulouz (80 Km from Taroudannt), in Morocco [3]. Long periods of drought or dry season in Morocco, give rise to seasonal rivers. Consequently, the energy production of these dams is generally very low during the dry season, which forces some large communities to spend days without electricity [4].

Our objective in this study is contribute to the energy sector by identifying potential renewable energy sources probable to add significant megawatts to the national grid. This will go an extended approach in making electrical energy available in poor areas like Taroudannt province. Morocco has one of the largest wind fields in Africa and is still far from being fully exploited. Assessing the wind potential of a site is a key step before building a wind farm to estimate future electricity production. The assessment of the potential is based on the wind measurements on the site considered. This step is essential because in situ measurement is the only way to correctly assess the wind fairly accurately. The Weibull distribution has quickly established itself for wind power applications since the late 1970s [5] until it is now widely used by industry and is the only distribution implemented in all wind software. Many other distributions have been proposed and used to represent wind statistics 2009 [6]. Historically it has been modeled in particular by the lognormal, Gamma, Beta distributions, but that of Weibull has been considered more suitable and has become generalized. The Rayleigh distribution has also been used alongside the Weibull, especially in cases where it was easier to have a single parameter, but it is less flexible than the Weibull, therefore less efficient, and has given way to the Weibull.

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More recently, new, more complicated, often mixed, distributions have been proposed. Many research studies on the potential, feasibility and evaluation of wind energy have been carried out in many places in Morocco, for example [7-13]. Most of these studies are concentrated in the coastal areas of Morocco. However, it is the first time that such a study will be carried out in this Saharan zone. The main purpose of this study is to evaluate the wind potential of Taroudannt province using two-parameter Weibull distribution in Morocco.

II. SITE DESCRIPTION AND THEORETICAL BACKGROUND

The site used to assess the potential of wind power is located in the province of Taroudannt (30 ° 28 ′ 45 ″ north, 8 ° 52 ′ 34 ″ west; 1035 m above sea level). The province is located in the southeast of Morocco and has a dry warm climate.

In this plan, the province's elevation, meteorological characteristics and wind speed in the early stage are the main criteria for estimating data. Table 1 lists the monthly mean parameters at a height of 10 m in the province. Temperatures are high at 19.1–29.1°C from May to October and 9.5–16.3°C from November to April. Relative humidity (from 22.9 % to 55.8 %), atmospheric pressure (from 89.9 kPa to 90.4 kPa) and precipitation (from 03.90 mm to 40.61 mm) change with the season.

Table 1: Monthly climate parameters at a height of 10 m for Troudannt province

Month	Air temperature (°C)	Relative humidity (%)	Precipitation (mm)	Atmospheric pressure (kPa)
January	9.5	53.3	30.38	90.4
February	11.2	51.3	33.04	90.3
March	14	47.2	34.41	90.1
April	16.3	45.2	17.40	89.9
May	19.4	40.8	9.30	89.9
June	24.1	33.7	3.90	90
July	29.1	22.9	4.03	90.1
August	28.6	25.3	5.58	90.1
September	23.8	36	10.50	90.1
October	19.1	44.5	23.87	90.2
November	14.1	49.4	35.10	90.2
December	10.7	55.8	40.61	90.4
Annual	18.4	42.1	24.81	90.1

Wind projects require detailed analysis. Several methods are used to evaluate the wind potential [14-19]. Table 2 shows the measurement of wind speed performance.

Table 2: Summary of wind energy analysis performance measurement equations

Performance measures	Definition	Equations
Weibull probability density function f(v)	$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right]$	(1)
Weibull cumulative density function F(v)	$F(v\le v_0)=1-\exp\left[-\left(\frac{v}{c}\right)^{k}\right]$	(2)
Weibull shape parameter k	$k=\frac{1}{\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)P(v_i)}{\sum_{i=1}^{n} v_i^k P(v_i)}-\sum_{i=1}^{n}\ln(v_i)P(v_i)}$	(3)

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Weibull scale parameter c	$c = \left(\sum_{i=1}^{n} v_i^k P(v_i) \right)^{1/k}$	(4)
Mean wind speed v_m	$v_m = c\Gamma\left(\frac{1}{k} + 1\right)$	(5)
Most probable wind speed v_{mp}	$v_{mp} = c\left(-\frac{1}{k} + 1\right)^{1/k}$	(6)
Maximum speed of the energy carrying wind $v_{\max E}$	$v_{\max E} = c\left(\frac{2}{k} + 1\right)^{1/k}$	(7)
Wind power density P	$P = \int_0^{\infty} \frac{p(v)}{A} f(v) = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right)$	(8)
Wind energy density E	$E = \frac{1}{2}\rho c^3 \left(1 + \frac{3}{k}\right) T$	(9)
Extrapolation of the wind speed v	$v = v_0 \left(\frac{z}{z_0}\right)^{\alpha}$	(10)
Exponent α	$\alpha = \frac{0.37 - 0.088\ln(v_0)}{1 - 0.088\ln\left(\frac{z_0}{10}\right)}$	(11)
Extrapolation of k_z	$k_z = \frac{k_0}{1 - 0.088\ln\left(\frac{z_0}{10}\right)}$	(12)
Extrapolation of c_z	$c_z = c_0 \left(\frac{z}{z_0}\right)^{\alpha}$	(13)
Capacity factor C_f	$C_f = \left[\frac{\left(e^{-(V_c/c)^K} - e^{-(V_r/c)^K}\right)}{(V_r/c)^k} - (V_r/c)^k \right] - e^{-(V_f/c)^K}$	(14)
Annual energy output AEP	$AEP = C_f \times T$	(15)

III. RESULTS AND DISCUSSIONS

a) Wind speed data

The probability density function can be used to determine which level of wind speed is prevalent in the province. The cumulative distribution curve indicates how long the wind speed is below a certain level. The parameters found in the analysis of the measurement wind data are used to form the wind frequency distribution of Weibull and Rayleigh.

The graph of the cumulative and probability distribution functions of Weibull and Rayleigh is shown in Figs. 1 and 2. During a period 09-years (from 2010 to 2018), wind speed data were measured at 10 m height in Taroudannt province. The probability density function f (v) and the cumulative Weibull density function F (v) are calculated using Eqs. (1) and (2) [20- 22], respectively. The values of the shape and scale parameters are determined by equations (3) and (4) [23, 24], respectively. In the statistical analysis, the cumulative distribution offers the possibility of being equal to or less than the wind speed.

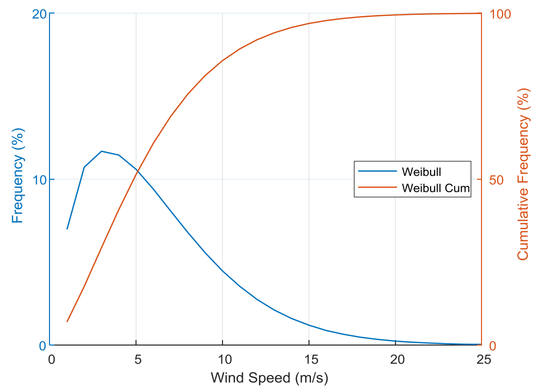

Figure 1: Weibull distribution of wind speed of Taroudannt site at 10m height

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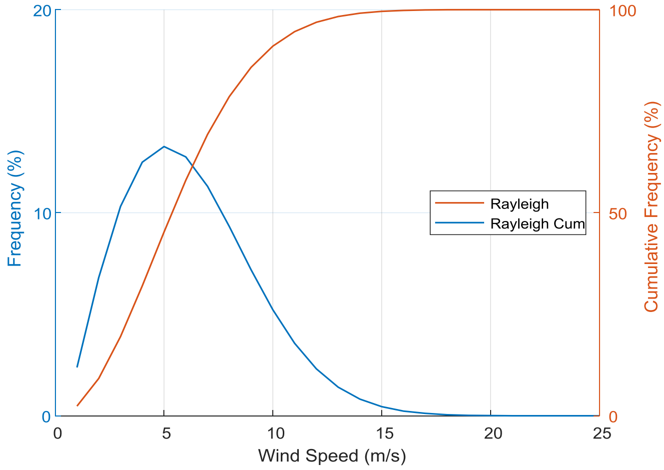

Figure 2: Rayleigh distribution of wind speed of Taroudannt site at 10m height

As you can see in Figs. 1 and 2, the Weibull and Rayleigh distributions are very consistent for this province. It was found that the shape parameter for the Weibull distribution is 1.59, which is a value very close to the fixed Rayleigh parameter of 2. A more detailed analysis shows that both distributions have a good fit with the real measured data.

The Figs. 1 and 2 shows the most frequent wind speed, 3 m/s, with a probability of 11.68 % for Weibull distribution and 4.5 m/s, with a probability of 13.2 6 % for Weibull Rayleigh. Fig. 3 shows the graph of the comparison between the observed data and the Weibull and Rayleigh distributions.

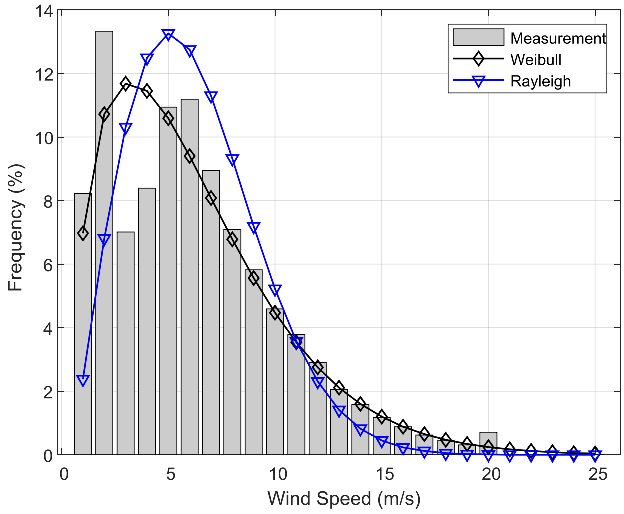

Figure 3: Comparison between Measurement, Weibull and Rayleigh probability distributions of Taroudannt site at 10m height

Table 3 lists the monthly characteristics of average wind speed. The results show that the values of c and k parameters, obtained are in the range from 3 m/s to 3.63 m/s and from 1.55 to 1.69, respectively. The mean value of the wind speed v_m, calculated by Eq (5) [25], is low (3.3 m/s to 3.4 m/s) between July and January, while May seems to have the highest v_m of 4 m/s. The lowest and highest v_{mp} is 1.76 m/s and 1.86 m/s, respectively. The value of the wind speed indicates that v_{maxE} varies from 4.76 m/s to 6.19 m/s. These two values (v_{mp} and v_{maxE}) included in the design calculation of the wind turbine [26, 27] are obtained using equations (6) and (7) [28 - 30].

Table 3: Analysis of wind speed characteristics in Taroudannt province over considered period

Month	v_m (m/s)	c (m/s)	k	v_{mp} (m/s)	v_{maxE} (m/s)	P (W/m^2)	E (kWh/m^2)
Jan	3.3	3.63	1.55	1.86	6.19	21.56	16.04
Feb	3.7	3.20	1.63	1.79	5.23	30.39	22.61
Mar	3.7	3.20	1.63	1.79	5.23	30.39	22.61
Apr	3.9	3.06	1.67	1.77	4.90	35.59	26.48
May	4.0	3.00	1.69	1.76	4.76	38.4	28.57
Jun	3.8	3.13	1.65	1.78	5.06	32.92	24.49
Jul	3.4	3.50	1.57	1.84	5.90	23.58	17.55
Aug	3.4	3.50	1.57	1.84	5.90	23.58	17.55
Sep	3.4	3.50	1.57	1.84	5.90	23.58	17.55
Oct	3.3	3.63	1.55	1.86	6.19	21.56	16.04
Nov	3.3	3.63	1.55	1.86	6.19	21.56	16.04
Dec	3.4	3.5	1.57	1.84	5.90	23.58	17.55
Annual	3.5	3.39	1.59	1.82	5.61	27.23	20.26

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Using equations (8) and (9) [31], the energy density E and the power density P give the minimum value of 16.04 kWh/m^2 and 21.56 W/m^2 and the maximum value 28.57 kWh/m^2 and 38.40 W/m^2, respectively.

b) Extrapolation of wind speed and parameters Weibull at different hub height

The increase in wind speed with altitude depends on the terrain surface and the stability of the atmosphere. Wind speed changes with height. Many obstacles can slow the wind, so we are looking to install the hubs of the wind turbines in high and clear positions. For economic reasons, wind speed measurements are taken at 10 m, which is insufficient for the installation of a wind farm on a site. The power law is used to determine the vertical profile of the wind. Figure 4 presents the mean monthly profile of wind speed in Taroudannt province for the different heights during 09-years period.
As can be seen in Figure 4, the mean monthly wind speed has a similar distribution and varies for different heights, with maximum values observed in May (5.15 m/s; 5.79 m/s and 6.25 m/s).

The wind speed increases with the height variation (h = 30, 50 and 70 m), and the Weibull parameters are expressed in equations (10) - (13) [32-36]. Table 4 shows the different values of the shape factor k extrapolated at 30; 50 and 70 m altitude. The minimum values respectively 1.74; 1.83 and 1.88 while the maximum values 1.87; 1.95 and 2.01 in May.

We can therefore argue that the shape parameter increases with altitude. Therefore, the increase in the Weibull shape parameter of the Taroudannt site indicates that the wind speed is constant. Table 4 also highlights the different values of the scaling factors extrapolated to 30; 50 and 70 m altitude. According to this table, the maximum values are respectively 4.73 m/s; 5.35 m/s and 5.80 m/s. The minimum values 3.86; 4.34 and 4.69 are recorded in May.

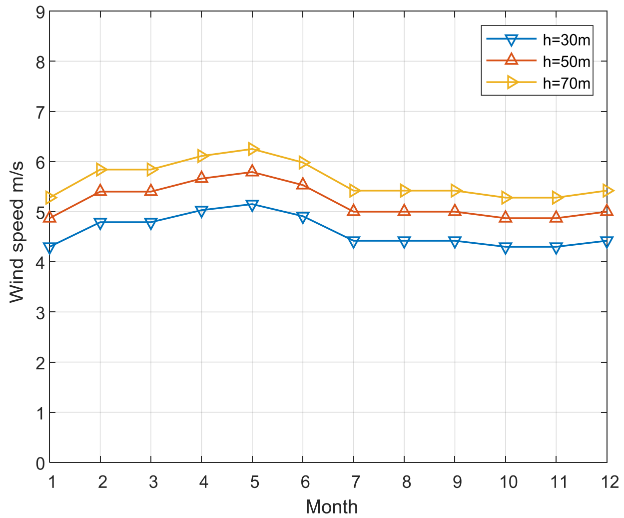

Figure 4: Monthly wind speed at three heights of 30; 50 and 70m in Taroudannt Province, Morocco

Table 4: Extrapolation of shape and scale parameters 30; 50 and 70 m for Taroudannt province

Weibull parameters	k (dimensionless)			c (m/s)		
Month	k at 30 m	k at 50 m	k at 70 m	c at 30 m	c at 50 m	c at 70 m
January	1.74	1.83	1.88	4.73	5.35	5.80
February	1.81	1.90	1.96	4.15	4.67	5.06
March	1.81	1.90	1.96	4.15	4.67	5.06
April	1.85	1.94	1.99	3.94	4.44	4.80
May	1.87	1.95	2.01	3.86	4.34	4.69
June	1.83	1.92	1.98	4.04	4.55	4.92
July	1.76	1.85	1.90	4.55	5.15	5.58
August	1.76	1.85	1.90	4.55	5.15	5.58
September	1.76	1.85	1.90	4.55	5.15	5.58
October	1.74	1.83	1.88	4.73	5.35	5.80
November	1.74	1.83	1.88	4.73	5.35	5.80
December	1.76	1.85	1.90	4.55	5.15	5.58

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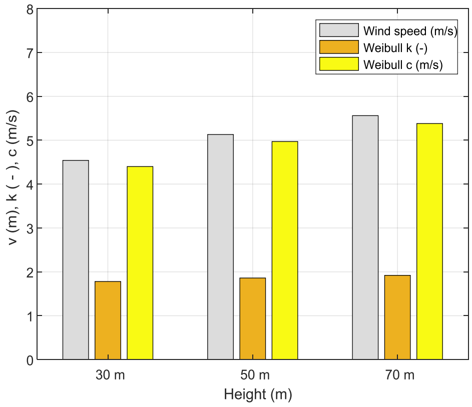

Figure 5: Variation of v, k and c for different altitudes in Taroudannt province, Morocco

We can therefore conclude for all three cases that there is a good correlation between the height and the Weibull parameters, in particular the wind speed, the scale parameter and the shape parameter because these three parameters increase as a function of the height. This correlation is represented by Fig. 5.

c) Wind turbine energy production

Based on the wind speed profile of the province, we have selected four commercial wind turbines whose technical parameters are presented in Table 5 and Fig. 6 illustrates the available power of each wind turbine over a range of wind speeds.

Table 5: Technical specification of selected wind turbines [37-39]

Wind turbine	NORDEX N27-30 m	Norwin 29-STALL -200 kW – 30 m	EWT DW 52 500 kW-50 m	NORDEX N50-70 m
Hub height (m)	30	30	50	70
Swept area (m^2)	572.56	664	2123.72	1963.5
Rotor diameter (m)	27	29	52	50
Cut-in wind speed V_C (m/s)	4	4	3	4
Cut-off wind speed V_D (m/s)	25	25	25	25
Rated wind speed V_r (m/s)	15	15	15	15
Rated power (kW)	150	200	500	800

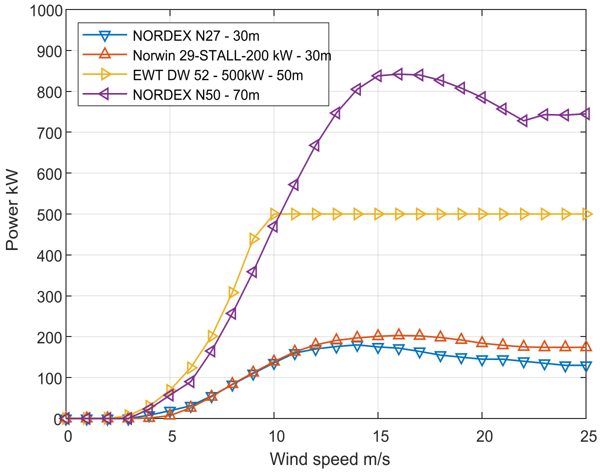

Figure 6: Power curves of selected four turbines

The wind turbines chosen have different capacities from 150 kW to 800 kW in order to estimate their performance, using the estimated capacity factor (C_f) and the annual energy production (AEP) in the province of Taroudant. Table 6 illustrates the monthly average C_f and AEP of production for four turbines over 09-years (determined by equations (14) and (15) [40]). The EWT DW 52 - 500kW – 50 m turbines had the maximum C_f (13.8117 %). The maximum AEP is delivered same the turbine with a value of 785.3064 MWh, while the minimum AEP is given by a Norwin 29-STALL-200 kW – 30 m turbine with a value of 6.5098 MWh.

The results are influenced by the wind speed profile of the province and the properties of each wind generators.

Table 6: Annual energy production calculated for selected wind turbines for the Taroudannt province

Turbines	AEP (MWh)	C_f (%)
NORDEX N27 - 30m	175.8653	10.3102
Norwin 29-STALL-200 kW -30m	148.054	6.5098
EWT DW 52 - 500kW - 50m	785.3064	13.8117
NORDEX N50 - 70m	749.9249	8.2434

On this basis, only the EWT DW 52 – 500 kW – 50 m (with Cf = 13.8117 %) may be suitable for integration into the network. Considering all selected installed turbines, for the remaining turbines, it was not economically feasible to install these models in the province of Tarouddant.

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In general, higher rated wind turbines generate higher output energy. Exceptionally, for the EWT DW 52 – 500 kW – 50 m (with a hub height of 50 m and a nominal power of 500 kW) which has achieved an annual energy output greater than that of NORDEX N50 – 70 m (with a hub height 70 m and a nominal power of 800 kW).

IV. CONCLUSION

In this study, wind energy potential and performance analysis of wind turbines were performed in the province of Tarouddant. Wind speed data at 09-years were statistically analyzed. The most important results are summarized:

1. The values of c and k parameters, obtained are in the range from 3 m/s to 3.63 m/s and from 1.55 to 1.69, respectively.
2. The mean value of the wind speed vm, is low (3.3 m/s to 3.4 m/s) between July and January, while May seems to have the highest vm of 4 m/s.
3. The energy density E and the power density P give the minimum value of 16.04 kWh/m2 and 21.56 W/m2 and the maximum value 28.57 kWh/m2 and 38.40 W/m2, respectively.
4. The performance of four wind turbines is analyzed, and the results show that the EWT DW 52 - 500kW - 50m turbine produces the highest capacity factor (with Cf = 13.81%) and generates energy (AEP = 785.3 MWh).

Finally, the results show that the province of Tarouddant has significant wind potential. However, to enable other measures for similar research projects in other locations, an in-depth study of the feasibility of electricity needs to be conducted in areas throughout the province to choose the best possible wind energy options at different scales. This research is only the first phase of a project with an electrical system for wind turbines.

A future study will be devoted to studying the socio-economic impact of the installation of a wind farm on the province.

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