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Statistical Analysis of Wind Speed & Wind Direction in Tantan Province, Morocco

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***Abstract*: In this paper, a two-parameter Weibull statistical distribution is used to analyze the characteristics of the wind from the Saharan area, located in the Tantan province, Morocco, for 08 years at 10 m. During those 08 years (2009-2017) the frequency distribution of the wind speed, the wind direction, the mean wind speed, the shape and scale (k & c) Weibull parameters have been calculated for the province.**

The mean wind speed for the entire data set is 6.4 m/s. The parameters k & c are found as 1.9 and 2.52 m/s in relative order. The study also provides an analysis of the wind direction along with a wind rose chart for the province. The analysis suggests that the highest wind speeds that vary (v_m = 5.1m/s; v_{max} = 18.5m/s) prevail between sectors 165-175 ° with an average frequency of 1.4% and lower wind speeds (v_m = 2.5m/s; v_{max} = 9.7m/s) occur between sectors 245-255° with an average frequency of 0.6%. The results of this document help to understand the wind power potential of the province and serve as a source of wind power projects. From a perspective, the wind energy system is an alternative to the future of the Sahara province of Morocco.

***Keywords* : Wind speed, Weibull distribution, Weibull parameters, Wind direction, Tantan.**

I. INTRODUCTION

The development of renewable energy is at the heart of the national energy policy that requires a diversification of energy sources by 2020 with 42% of the total installed electrical energy provided by green energy.

Energy efficiency together with the development of renewable energy is a priority of the national energy strategy: the objective is to save 12% of energy consumption by 2020 and 15% by 2030 [1]. With this in mind, energy efficiency action plans have been implemented in all key sectors, especially in transportation, industry and construction.

Given the enormous potential of renewable energy (solar and wind) available to Morocco, the construction of a diversified energy mix that benefits renewable energies has been planned to meet the growing demand for electricity, preserve the environment and reduce dependence on the Energy from other countries. In response to these challenges, Morocco has launched a large-scale integrated program to generate electricity from renewable sources. This is one of the largest projects in the world, thanks to the construction of a new wind farm and the construction of five solar power plants, with a total capacity of 4 GW by 2020 [2, 3].

This integrated and structured project is a lever for economic and human development (competitiveness, training, R&D, outsourcing, industry integration). Fulfilling these projects provides an opportunity to create and develop a renewable energy and energy efficiency industry, support these programs and maximize socio-economic benefits.

As part of its energy use strategy, Morocco has implemented a large wind energy program to support the country's renewable energy development and energy efficiency. The Moroccan Wind Energy Integrated Project, which covers a period of 10 years with an estimated total investment of 31,500 million dirhams [4], will allow the country to carry the installed wind power capacity of 280 MW in 2010 to 2000 MW in 2020 [5, 6].

Our objective in this work is to contribute to the energy industry by identifying possible renewable energy sources and proposing effective ways to add significant megawatts of electricity to the national grid.

This study is using wind speed measurements from the Tantan province in Morocco (Fig. 1) [7]. Data collected during 2009-2017 were analyzed using the Weibull and Rayleigh distributions. The results of the study determine the monthly parameters of Weibull k and c in the province, and the probability of observing wind speed and direction.

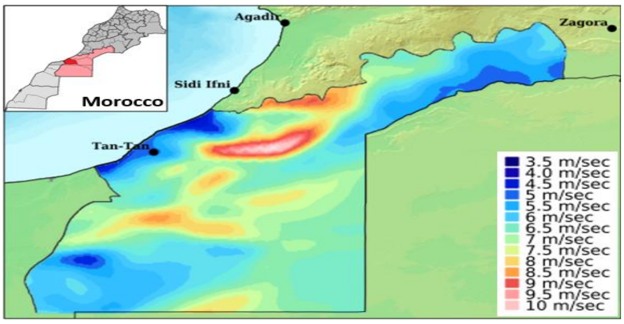

Fig. 1. Wind resource map of Morocco showing distribution of wind speed in Tantan province [7].

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II. THEORY

In the literature, it is a two-parameter distribution function widely used to describe wind speed data in many provinces [8-13]. Variations in wind speed are characterized by two functions, the first is the probability density function that indicates the percentage of time during which the wind flows with a specific wind speed. It is expressed mathematically as follows [14, 15]:

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

The second is the cumulative distribution function, which provides the percentage of time that the wind speed is less than or equal to the wind speed v_0, expressed as the integral of the probability density function [15]:

$$F(v \le v_0) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

A special case of the Weibull distribution with a parameter value of k = 2 is the Rayleigh distribution, defined by [16-18]:

$$f(v) = \left(\frac{2v}{c^2}\right)\exp\left[-\left(\frac{v}{c}\right)^{2}\right] \tag{3}$$

Rayleigh's cumulative distribution function is given by:

$$F(v \le v_0) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{2}\right] \tag{4}$$

The mean speed v_m and the standard deviation σ of the distribution are expressed using the gamma function Γ and can be defined by equations (5) and (6), respectively [19]:

$$v_m = c\Gamma\left(\frac{1}{k}+1\right) \tag{5}$$

and

$$\sigma = c\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right] \tag{6}$$

The Weibull distribution expression is valid for k>1 and c>0. k is a shape factor (dimensionless), specified by the user. The shape factor is generally between 1 and 3. For a given mean wind speed v_m, a lower shape factor indicates that the wind speed distribution is relatively wide near v_m, while a higher shape factor indicates that the wind speed distribution is relatively narrow near v_m.

$$k = 0.9 + 0.2 v_m \tag{7}$$

For the values of c (m / s) in the range found in most places, the integral term can be approximated to the gamma function:

$$c = \frac{v_m}{\Gamma[1+(1/k)]} \tag{8}$$

To evaluate wind energy, two other significant wind speeds can be determined to know the speed of the most probable wind speed (v_{mp}) and the speed of the maximum energy carrying wind speed ($v_{max\,E}$). They are given by the expression [20-22]:

$$v_{mp} = c\left(-\frac{1}{k}+1\right)^{1/k} \tag{9}$$

and

$$v_{\max E} = c\left(\frac{2}{k}+1\right)^{1/k} \tag{10}$$

III. STATISTICAL ANALYSIS

In this study, according to the statistical analysis of wind speed data from 2009 to 2017, the main results were as follows:

A. Wind speed characteristics and Weibull parameters

With the Weibull and Rayleigh distribution functions, the wind properties are determined according to the data set in the Tantan province. The geographic coordinates of the Tantan province are shown in Table I.

Table- I: Geographical location of the Tantan site

Site	Tantan
Latitude (°)	28° 4' N
Longitude (°)	11° 1' W
Elevation (m)	152

The dataset was adapted to the probability distributions and the corresponding parameters k and c were calculated. For the province, the calculated parameters are used to derive probability distributions. Table II shows the calculated mean wind speed, k and c Weibull parameters.

Table- II: Mean monthly wind speed and Weibull parameters at 10 m from the Tantan site

Month	Wind speed v_i (m/s)	k (dimensionless)	c (m / s)
January	4.9	1.83	2.64
February	5.2	1.87	2.56
March	5.2	1.87	2.56
April	6.0	1.98	2.43
May	6.0	1.98	2.43
June	6.3	2.02	2.39
July	6.4	2.03	2.38
August	6.1	1.99	2.41
September	5.3	1.89	2.54
October	4.6	1.79	2.73
November	4.7	1.80	2.70
December	4.8	1.82	2.67
Annual	5.4	1.90	2.52

Based on the data entered, the mean wind speed calculated during the entire period is 5.4 m / s.

The mean wind speed has a maximum value of 6.4 m / s during June and a minimum in October (4.6 m / s). The shape parameter varies between 1.79 and 2.03. The scale parameters for the entire dataset are 2.38 and 2.73 m / s. The monthly variations of the mean wind speed are shown in Fig. 2. Given that these results are obtained at 10 m, the establishment of wind energy projects requires extrapolation of wind speed. Fig. 2 shows in the mean wind speed variations during the year.

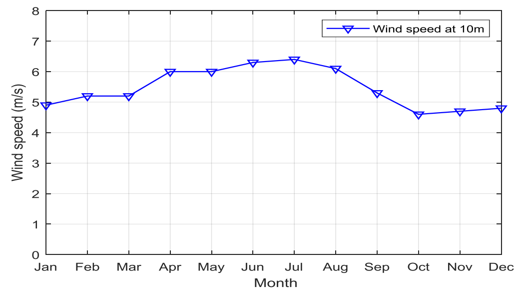

Fig. 2.Monthly wind speed (2009–2017) of Tantan site at 10 m height.

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. 3 and 4.

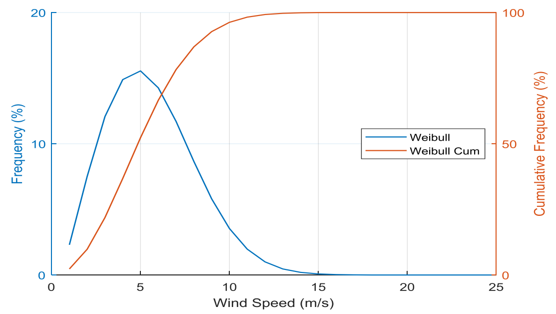

Fig. 3. Weibull distribution of wind speed of Tantan site at 10 m height.

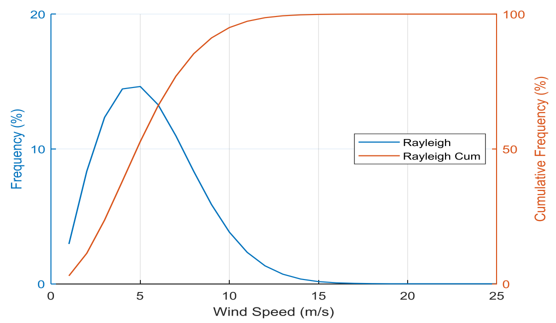

Fig. 4.Rayleigh distribution of wind speed of Tantan site at 10 m height.

As you can see in Figs. 3 and 4, the Weibull and Rayleigh distributions are very consistent for this province. It was found that the shape parameter for the Weibull distribution is 1.9, 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 Weibull parameter calculations show that 5.75 m / s is the most probable wind speed, while the Rayleigh parameters give a similar result of 5.12 m / s. Table III lists the wind speed frequency distributions of Weibull and Rayleigh. Fig. 5 shows the graph of the comparison between the observed data and the Weibull and Rayleigh distributions.

Table- III. Comparison between Measurement, Weibull and Rayleigh probability distributions of Tantan site at 10 m height.

Wind speed v_i (m/s)	Frequecy (%)				
	Measu-rement	Weibull	Weibull Cum	Rayl-eigh	Rayl-eigh Cum
$0 \le v_i < 1$	2.24	2.30	2.30	2.95	2.95
$1 \le v_i < 2$	6.17	7.51	9.81	8.34	11.29
$2 \le v_i < 3$	9.82	12.07	21.88	12.34	23.63
$3 \le v_i < 4$	14.25	14.89	36.77	14.45	38.08
$4 \le v_i < 5$	17.82	15.55	52.32	14.63	52.71
$5 \le v_i < 6$	17.03	14.26	66.58	13.28	65.99
$6 \le v_i < 7$	12.94	11.70	78.28	10.97	76.96
$7 \le v_i < 8$	8.06	8.65	86.93	8.34	85.30
$8 \le v_i < 9$	4.67	5.80	92.73	5.87	91.17
$9 \le v_i < 10$	2.77	3.54	96.27	3.83	95.00
$10 \le v_i < 11$	1.67	1.97	98.24	2.33	97.33
$11 \le v_i < 12$	0.95	1.00	99.24	1.33	98.66
$12 \le v_i < 13$	0.59	0.46	99.70	0.71	99.37
$13 \le v_i < 14$	0.38	0.20	99.90	0.35	99.72
$14 \le v_i < 15$	0.27	0.08	99.98	0.16	99.88
$15 \le v_i < 16$	0.18	0.03	99.99	0.07	99.95
$16 \le v_i < 17$	0.11	0.01	99.99	0.03	99.98
$17 \le v_i < 18$	0.05	0.00	99.99	0.01	99.99
$18 \le v_i < 19$	0.02	0.00	99.99	0.00	99.99
$19 \le v_i < 20$	0.00	0.00	99.99	0.00	99.99
$20 \le v_i < 21$	0.00	0.00	99.99	0.00	99.99
$21 \le v_i < 22$	0.00	0.00	99.99	0.00	99.99
$22 \le v_i < 23$	0.00	0.00	99.99	0.00	99.99
$23 \le v_i < 24$	0.00	0.00	99.99	0.00	99.99
$24 \le v_i < 25$	0.00	0.00	99.99	0.00	99.99

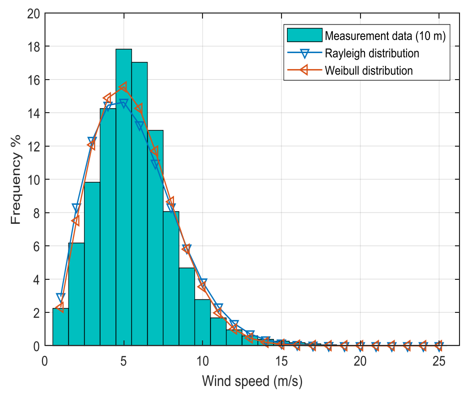

Fig. 5.Comparison between Measurement, Weibull and Rayleigh probability distributions of Tantan site at 10 m height.

By knowing the most probable wind speed (v_{mp}) and the maximum speed of the energy carrying wind ($v_{max\ E}$), it is possible to know if the location is suitable for installing a wind turbine. Thus, Figure 6 shows the monthly variation of v_{mp} and $v_{max\ E}$. It was observed that from January to December, the variations in v_{mp} and $v_{max\ E}$ were 4.4-6.3 m / s and 12.8-22.7 m / s, respectively.

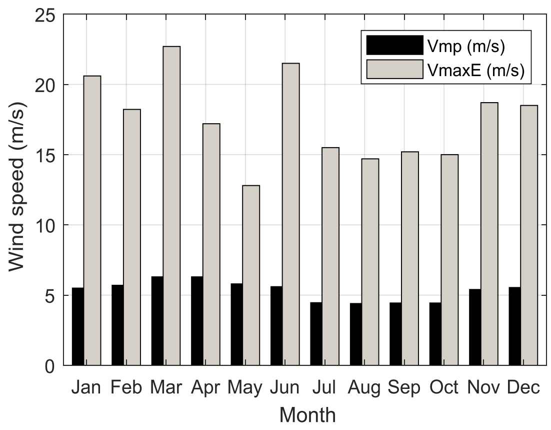

Fig. 6. Monthly variation of v_{mp} and $v_{max\ E}$ of Tantan site at 10 m height.

B. Wind direction analysis

The wind rose is a graph showing the time distribution of the wind direction and the azimuthal distribution of the wind speed in a given place.

This diagram shows the most common shape, consisting of several concentric circles arranged at equal intervals with 36 radial lines. Figs. 7-8 shows that the north direction at 10 m contributes approximately 11.8% of the total available energy. It is concluded that the direction in which the wind is strongest is the northeast (35-85°).

Analysis suggests that higher wind speeds which range (v_m = 5.1m/s; v_{max} =18.5m/s) are prevalent between the sectors 165–175° with an average frequency of 1.4% and lower wind speeds (v_m = 2.5m/s; v_{max} = 9.7m/s) occur between sectors 245–255° with an average frequency of 0.6%.

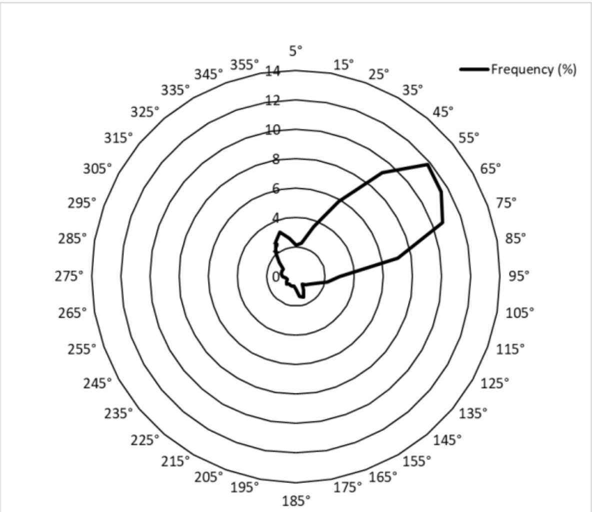

Fig. 7. 36-sectors wind rose diagram of Tantan site at 10 m height.

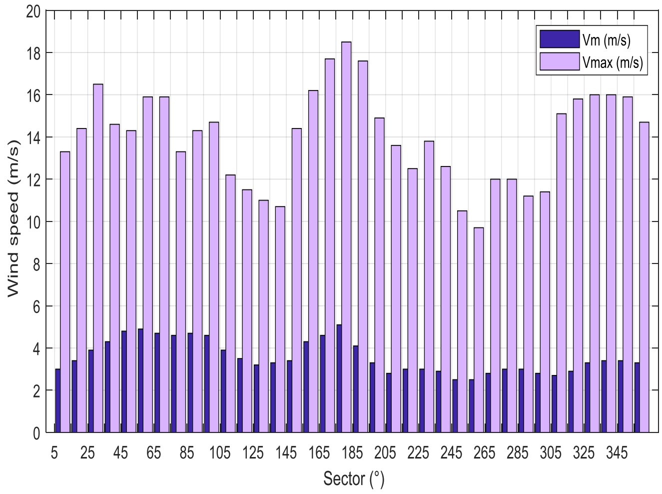

Fig. 8. Average and Maximum wind speeds of Tantan site at 10 m height.

IV. CONCLUSION

A detailed statistical study of the 10 m wind in the province of Tantan is given. The most important results of the study can be summarized as follows:

1. The Weibull probability function is used to simulate wind speed. Weibull parameters k (dimensionless) and c (m/s) are shown in Table II.
2. Winds at 10 m are giving a speed between 4.6–6.4 m / s.
3. The results of the 8-year wind speed and the Weibull distribution were adjusted to a Weibull distribution and the parameters of k & c were calculated as 1.9 and 2.52 m / s in relative order. As a result, the focus on this site and other essential characteristics for the viability of the province are determined.
4. The wind rose diagram at 10 m shows that the north direction contributes approximately 11.8% of the total available energy. It is concluded that the most windward directions and the directions where the wind is strongest are northeast.

Hence, for the establishment of a wind project extrapolation of the wind speed is therefore desirable. Wind energy plants are in perspective an alternative for the future in the Sahara.

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