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Research Article

Wind Speed Data and Wind Energy Potential Using Weibull Distribution in Zagora, Morocco

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ABSTRACT. This paper presents the wind energy potential at 10 m during a period of 09 years (2009-2017) in the province of Zagora using the Weibull distribution method. Extrapolation of the 10 m data, using the power Law, has been used to determine the wind data at heights of 30 m; 50 m and 70 m. The objective is to evaluate the most important characteristics of wind energy in the studied site . The statistical attitudes permit us to estimate the mean wind speed, the wind speed distribution function and the mean wind power density in the site at the height of 30 m; 50 m and 70 m. From the primary evaluation indicate that the annual energy output and capacity factor increases with increasing the wind speed, it can obtain about 2.62 GWh/year, that is acceptable quantity for the wind energy.

Keywords: Wind speed; Weibull distribution; Wind turbine; Power density; Zagora.

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1. Introduction

Renewable energy systems are rapidly becoming more efficient and cheaper and their share of total energy consumption is increasing (IRENA 2015). As of 2019 worldwide, more than two-thirds of all new electricity capacity installed was renewable (Global renewable energy trends 2019). Growth in consumption of coal and oil could end by 2020 due to increased uptake of renewables and natural gas (IRENA 2019).

Today, the use of wind energy technology has been developing very fast. Given that modern turbines have become an appropriate technique for extracting wind energy. Wind energy is economical, sustainable, renewable and a clean energy (Abbasi and Abbadsi 2016). Wind-generated electricity met nearly 4% of global electricity demand in 2015, with nearly 63 GW of new wind power capacity installed. Wind energy was the leading source of new capacity in Europe, the US and Canada, and the second largest in China. Denmark is the world's leading country in installed wind turbine capacity by population, wind power in this country covered more than 40% of its electricity demand, while Ireland, Portugal and Spain each covered nearly 20%.

In 2018, worldwide installed capacity of wind power was 564 GW (IRENA 8 April 2019). Modern utility-scale wind turbines range from around 600 kW to 9 MW of rated power. The power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases up to the maximum output for the particular turbine. (European Wind Energy Association 2007) Areas where winds are stronger and more constant, such as offshore and high-altitude sites, are preferred locations for wind farms.

Morocco has 3500 km of coastline which mean wind speeds can reach up to 10 m/s. Therefore, the estimated total theoretical potential of wind power in Morocco is 25 GW. Morocco's goal is to increase the installed wind energy capacity from 280 MW in 2010 to 2000 MW 2020 (IRENA 2014). According to statistics, Morocco's energy demand is rapidly increasing by economic and demographic growth and is expected to triple by 2030. Many research studies have been carried out on potential, feasibility and assessment of wind energy at many locations in Morocco, e.g., (Afilal *et al.* 2013; Allouhi *et al.* 2017; Doukkali 2005; Enzili *et al.* 1998; Haddouche 2006; Kousksou *et al.* 2015; Nfaoui *et al.* 1991). The work in most of these studies was concentrated on the Morocco's coastal regions. However, to our knowledge, no studies have been carried out so far on this area of Morocco.

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This work has two objectives, in particular the analysis of wind speed for a period of 09 years from 2009 to 2017 and the choice of a wind turbine for said zone. To determine the wind energy potential of a site, there are different distribution functions (Conradsen *et al.* 1984; Keyhani *et al.* 2010; Mostafaeipour *et al.* 2014). In the literature, it is known that Weibull is the most widely used distribution to estimate wind energy potential because of its flexibility and easy computation (Akpinar and Akpinar 2004; Altunkaynak *et al.* 2012; Ouammi et al. 2010; Philippopoulos *et al.* 2012; Safari and Gasore 2010; Weisser 2003;). To achieve these objectives, we intend to approach this work by presenting the data collected, using the two-parameter Weibull distribution, extrapolating the Weibull parameters and presenting the characteristics of the wind turbines in this study.

2. Methodology

2.1 Sites description and wind data

Zagora is a town in the Draa River valley in the Drâa-Tafilalet region of southeastern Morocco.
The data used for this work are monthly data for 09 years and correspond to the period from 2009 to 2017. The simple statistical method was therefore used to calculate the average monthly wind speed at 10 m.
The map of Morocco, with the Saharan zone represented in Fig. 1 (IRESEN 2019) where Zagora is located and the geographical coordinates of Zagora are shown in Table 1.

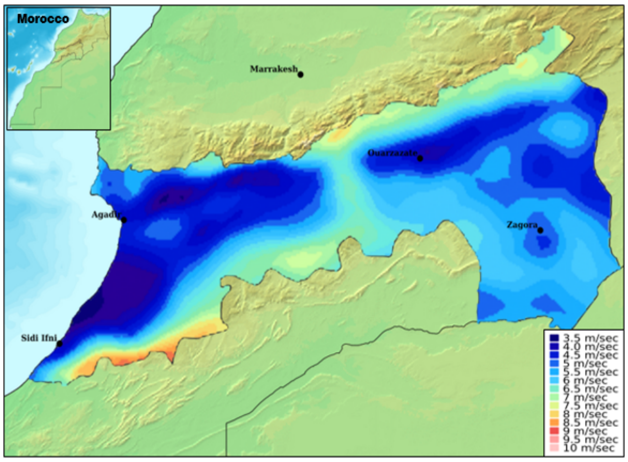

Fig. 1. Wind resource map of Morocco showing distribution of wind speed in Zagora province

Table 1
Geographical location of the Zagora.

Site	Zagora
Latitude (°)	30° 3' N
Longitude (°)	5° 9' W
Elevation (m)	836

2.2 Wind speed distribution

Wind data obtained with various observation methods has wide ranges. Therefore, in the wind energy analysis, it is necessary to have only a few key parameters that can explain the behavior of a wide range of wind speed data (Conradsen *et al.* 1984). The simplest and most practical method for the procedure is to use a probability distribution function. There are several probability density functions, which can be used to describe the wind speed frequency curve. The Weibull, Rayleigh and Lognormal functions are commonly used for fitting the measured wind speed probability distribution. Here we use Weibull probability Distribution.
The probability density function is given by (Baseer *et al.* 2015; Ould Bilal *et al.* 2013):

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

Where $f(v)$ is the probability density at the speed v (m/s).
The cumulative distribution function is given by (Fazelpour *et al.* 2015):

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

The mean speed v_m and standard deviation σ of the distribution are expressed using the Γ function can be defined by the Eqs. (3) and (4) respectively (Bilir *et al.* 2015):

$$v_m = c\Gamma\left(\frac{1}{k}+1\right) \tag{3}$$

and

$$\sigma = c\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right] \tag{4}$$

Γ is the gamma function defined by:

$$\Gamma(x) = \int_0^\infty t^{x-1}\exp(-t)dt \tag{5}$$

With $x \geq 0$; $t = \left(\frac{v}{c}\right)^{k}$; $(x-1) = \left(\frac{1}{k}\right)$ (6)

The integration of $f(v)$ between v and ∞ give the expression of the distribution function $f(v)$.
The expression of Weibull distribution is valid for k > 1, and c > 0.While k is the shape factor (dimensionless), specified by the user. The shape factor will typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed.

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

For c (m/s) values in the range found at most sites, the integral expression can be approximated to the gamma function:

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

2.3 Power and energy

The wind power density is considered to be a better indicator of wind resource as it takes into account the frequency distribution of the wind speed, the air density and the cube of wind velocity. Thus, it can be assessed using the following equation (Ayodele *et al.* 2016):

$$P = \int_0^\infty \frac{p(v)}{A} f(v) = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{9}$$

The wind energy density is expressed as (Manwell et al. 2010):

$$E = \frac{1}{2}\rho c^3 T\left(1+\frac{3}{k}\right) \tag{10}$$

In the Eq. (10), T is the number of days in the period considered.

2.4 Extrapolation of wind speed and Weibull parameters at different hub height

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. Proposed by (Chandel *et al.* 2014; Irwanto *et al.* 2014), it is written:

$$v = v_0\left(\frac{H}{H_0}\right)^\alpha \tag{11}$$

Where, v_0, the wind speed measured at height 10 m, v, the speed that must be calculated at height h, α, the power law exponent that is in function of the surface roughness, calculated by Eq. (12):

$$\alpha = \frac{0.37 - 0.088\ln(v_0)}{1 - 0.088\ln\left(\frac{z_0}{10}\right)} \tag{12}$$

The extrapolation of the Weibull parameters is obtained by Eqs. (13) and (14) (Shata and Hanitsch 2008; Gualtieri and Secci 2012; Justus and Mikhail 1976):

$$k_z = \frac{k_0}{1 - 0.088\ln\left(\frac{z_0}{10}\right)} \tag{13}$$

and

$$c_z = c_0\left(\frac{z}{z_0}\right)^\alpha \tag{14}$$

3. Results and discussion

In this study, the main results obtained from the statistical analysis of wind speed data from 2009 to 2017 are presented in the following section.

3.1. Wind speed characteristics and Weibull parameters

Fig. 2 depicts the variation in wind speed over the 09 years. The speed of the wind has a maximum value of 4.4 m/s (April and May), whereas the minimal speed of the wind of 3.2 m/s is recorded in December. Thus, we obtained that with 10 m altitude the speed of the wind varies between 3.2 and 4.4 m/s.

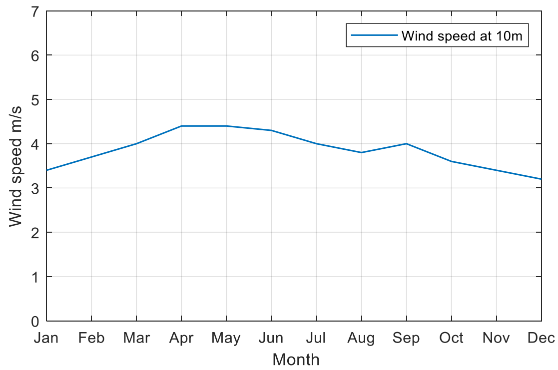

Fig. 2 Monthly variation of mean wind speed in Zagora, Morocco

The estimated annual Weibull frequency distribution of wind speed at 10 m in Zagora station is represented by Fig. 3, whereas, Table 2 presents the monthly values of the shape parameter k and the scale parameter c of the Zagora site. The shape and scale factor values were obtained using Eqs. (7) and (8). Thus, the results obtained show that the values of the shape and scale parameters are respectively in the range 1.53-1.75 and 2.8-3.78 m/s.

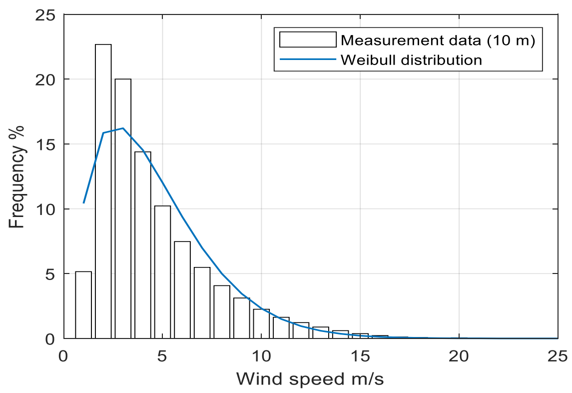

Fig. 3 Frequency distribution of wind speed for Zagora site at 10 m height

Table 2
Monthly Weibull parameters (k, c) of Zagora site at 10 m height.

Month	Wind speed v_i (m/s)	k (dimensionless)	c (m/s)
January	3.4	1.57	3.50
February	3.7	1.63	3.20
March	4	1.69	3.00
April	4.4	1.75	2.80
May	4.4	1.75	2.80
June	4.3	1.74	2.85
July	4	1.69	3.00
August	3.8	1.65	3.13
September	4	1.69	3.00
October	3.6	1.61	3.29
November	3.4	1.57	3.50
December	3.2	1.53	3.78

3.2. Extrapolation of wind speed and parameters Weibull at different hub height

Fig. 4 presents the extrapolation of the wind speed at Zagora at 30; 50 and 70 m altitude. Hence, it can be noted in this Fig. 4 that with the variations in altitude, the minimum speeds are observed in December respectively 3.20 m/s; 4.18 m/s; 4.73 m/s and 5.14 m/s.

The maximum speeds are recorded in April and May respectively 4.44 m/s; 5.62 m/s; 6.30 m/s and 6.80 m/s. This figure shows that the wind speed increases with the height. The highest speed corresponds to the highest height.

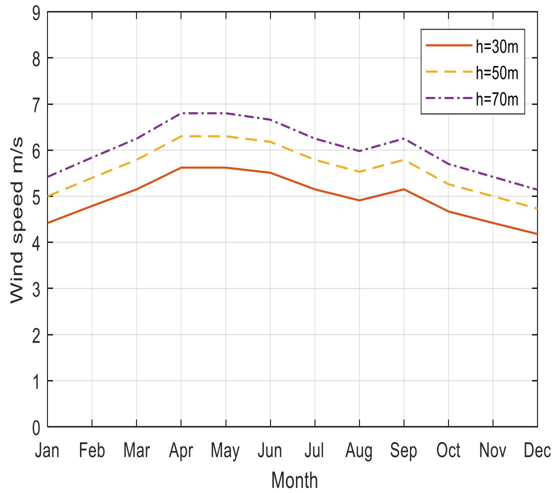

Fig. 4 Monthly wind speed at three heights of 30; 50 and 70 m in Zagora, Morocco

Table 3 shows the different values of the shape factor k extrapolated at 30; 50 and 70 m altitude. The minimum values respectively 1.72; 1.81 and 1.87 are recorded in December while the maximum values 1.93; 2.02 and 2.07 in April and May.

Table 3
Weibull shape parameter extrapolation 30; 50 and 70 m of Zagora site.

Month	k 30	k 50	k 70
January	1.76	1.85	1.90
February	1.81	1.90	1.96
March	1.87	1.95	2.01
April	1.93	2.02	2.07
May	1.93	2.02	2.07
June	1.92	2.00	2.06
July	1.87	1.95	2.01
August	1.83	1.92	1.98
September	1.87	1.95	2.01
October	1.80	1.88	1.94
November	1.76	1.85	1.90
December	1.72	1.81	1.87

We can therefore argue that the shape parameter increases with altitude. Therefore, the increase in the Weibull shape parameter of the Zagora site indicates that the wind speed is constant.

Table 4 highlights the different scale factor values extrapolated to 30; 50 and 70 m of altitude. According to this table, the maximum values are respectively 4.94 m/s; 5.59 m/s and 6.07 m/s are recorded in December. The minimum values 3.58 m/s; 4.02 m/s and 4.33 m/s are recorded in April and May.

Table 4
Weibull scale parameter extrapolation 30; 50 and 70 m of Zagora site.

Month	c 30	c 50	c 70
January	4.55	5.15	5.58
February	4.15	4.67	5.06
March	3.86	4.34	4.69
April	3.58	4.02	4.33
May	3.58	4.02	4.33
June	3.64	4.09	4.41
July	3.86	4.34	4.69
August	4.04	4.55	4.92
September	3.86	4.34	4.69
October	4.27	4.81	5.21
November	4.55	5.15	5.58
December	4.94	5.59	6.07

As for Table 4, it can also be noticed that the Weibull scale parameter expressed in m/s increases with altitude. 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.

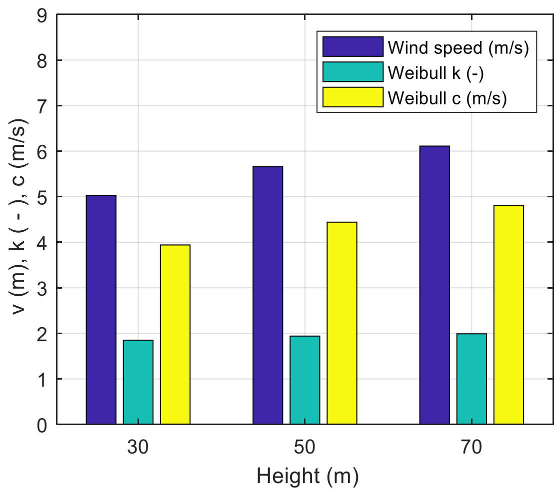

Fig. 5 Variation of v, k and c for different altitudes in Zagora, Morocco

3.3. Wind turbine energy production

In order to evaluate the performance of wind energy in Zagora region, three wind turbines with rated power ranging from 275 to 1500 kW were selected. The aim is to identify the turbine that best matches the wind regime at the selected site.

The technical specifications of these turbines and the power curves variation versus wind speed of the wind turbines are presented in Table 5 and Fig. 6, respectively. Three turbines with a hub height of 32; 50 and 70 m were considered in the performance analysis. Since the wind data are available at the height of 10 m, the power-law approximation to find corresponding speeds at the hub height of turbines.

Table 5
Technical specification of selected wind turbines.

Wind turbine	Vergnet GEV MP R 30/275-32 m	EWT DW 52 - 500kW-50 m	Vestas NM72C-70 m
Hub height (m)	32	50	70
Swept area (m2)	804	2123.72	4071.5
Rotor diameter (m)	32	52	72
Rated power (kW)	275	500	1500

The estimation of the annual capacity factor and yearly energy generated by each wind turbine model is given in Table 6. The results clearly revealed that the annual capacity factor was increased when turbines with hub heights of 70 m are considered instead of turbines models with a hub height of 32 or 50 m. As expected, the best annual capacity factor was obtained at 70 m (20%) with Vestas NM72C – 70 m in opposition to 13% for 32 m with Vergnet GEV MP R 30/275 – 32 m.

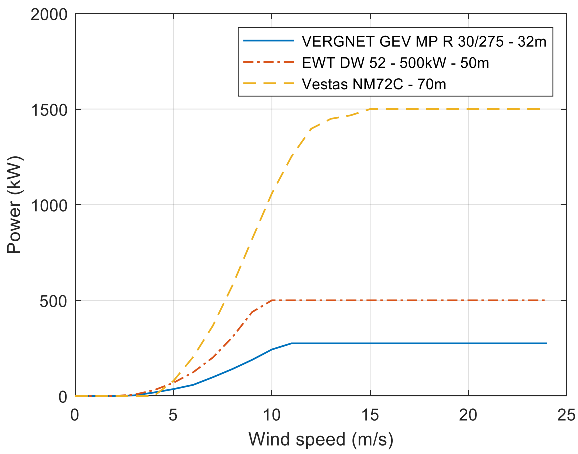

Fig. 6 Characteristic machine power curves

Table 6 and Fig.7 also present the annual energy produced by the wind turbines in study location. Annual output energy varied depending on the turbine models, wind turbines with higher rated power generated higher output energy. As indicated, the lowest annual energy output was predicted for Vergnet GEV MP R 30/275-32 m then EWT DW 52 - 500kW-50 m (0.31 GWh for turbine with 32 m hub height and 0.85 GWh for wind turbine with 50 m hub height). Vestas NM72C – 70 m presented higher energy output (2.62 GWh), that is acceptable quantity for the wind energy.

For a profitable investment in wind energy, it is recommended that the capacity factor and the energy produced be as high as possible. Based on this, only Vestas NM72C – 70 m (with its two variants) can be appropriate for grid integration. With installing a wind farm, it is possible to produce more energy at this site, which could be the subject of a future study.

Table 6
Annual energy production calculated for selected wind turbines for the Zagora site.

Turbines	E_v (GWh)	C_f (%)
Vergnet GEV MP R 30/275 – 32 m	0.31	13
EWT DW 52 - 500kW – 50 m	0.86	18
Vestas NM72C – 70 m	2.62	20

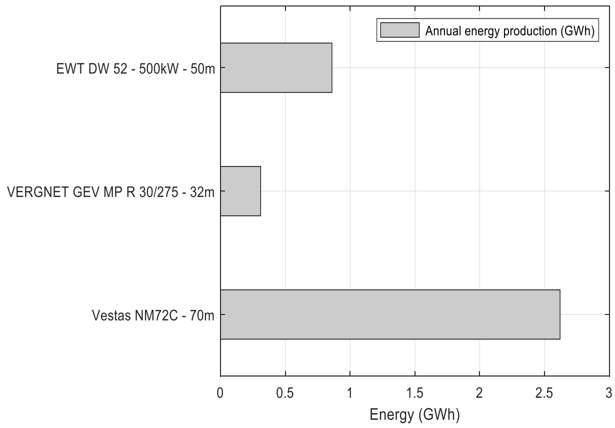

Fig. 7 Annual energy captured from wind turbines

4. Conclusion

Drawing from our analysis, and for a given location, the first step is to evaluate the wind power potential. For the city of Zagora, in the Saharan zone of Morocco, as well as in the southern region of Morocco, the assessment of the wind energy potential was realized.

The Weibull distribution method was used to statistically analyze the monthly Zagora wind speed data for 09 years. Over those 09 years (2009-2017), the maximum monthly wind speed of 4.4 m/s is recorded in April and May while the minimum monthly wind speed of 3.2 m/s is recorded in December. The more it rains, the lower the speed. The monthly variation at 10 m of the Weibull shape parameter k is between 1.53 and 1.75, while the monthly variation of the scale parameter c is between 2.80 m/s and 3.78 m/s.

The results indicate that the annual energy output and capacity factor increases with increasing the wind speed. Hence, an extrapolation of the wind speed for the establishment of a wind project is desired. In perspective wind energy systems is an alternative for the future in the Saharan zone.

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