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Assessment of Wind Energy Potential in the Sudanese Zone in Chad

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Abstract

In this study, wind characteristics and wind power potential are analyzed for three meteorological stations in the Sudanese zone of Chad for the period of 35 years (from 1975 to 2010). Assessment of the wind power potential was carried out using the two parameters of Weibull distribution. Results of the study shows that the average annual wind speeds at 10 m above ground for Moundou, Pala and Sarh are 2.69, 2.33 and 1.91 m/s, respectively. The mean annual value of the Weibull shape parameter k and scale parameter c range from 2.376 to 3.255 and 2.099 to 3.007, respectively. The maximum annual power density of 204.85 W/m^2 was obtained at Moundou. Results of this study further shows that the selected locations are not suitable for large-scale wind energy production at 10 m altitude. However, by extrapolation, assessment of wind speed at 67 m altitude combines with wind turbine Vestas 2 MW/80 that adapts to the Sudanese local conditions, and the wind power potential can be exploited for water pumping, heating and production of electricity.

Keywords

Assessment, Wind Energy, Weibull Distribution, Electricity, Sudanese Zone

1. Introduction

Energy plays a significant role in human and economic development. Demand for energy is growing exponentially. In addition, conventional energy resources are limited and their use contribute major proportion to environmental pollution [1] [2] [3] [4] [5]. The world total energy demand is increasing faster than the increase of total population day-by-day. To satisfy this energy demand, it is necessary to embark on alternative sources such as renewable energies which are clean sources of energy and nonpolluting [6] [7]. Among these renewable energies is wind energy. The wind energy production in the world is about 318.510 MW as at 2013 [8]. The highest growth rate of wind energy was 64.3% and this occurred in 1999. It is now recognized as the source of energy which develops most quickly on a worldwide scale. As a result of technologies development in the recent years, the production of electricity by wind power technology has reached a high level of technological maturity and industrial reliability [9] [10].

The knowledge of wind characteristics based on the wind velocity is essential, not only for the evaluation of the wind power potential but also for the dimensioning of the wind power stations and the selection of suitable choice of the aerogenerators [11] [12].

Chad is a country with 80% of her population living in rural area, without a particular grid system of electricity. Only 2% to 4% of the population has access to electricity. Therefore, renewable energy is fitted to its development and the well-being of its population [13]. Due to the fact that the country has no devices for capturing parameters for evaluating the solar and wind potentials, in this study some data were gotten from satellite measurement. Chad has a significant natural energy potential. In particular, the exploitation of the solar energy and wind power could help to achieve sustainable energy development. Presently, to the best knowledge of the authors, there have been no much research works on assessment of solar and wind energy potentials in Chad. This study aims at assessment of the potential of wind energy in the Sudanese zone of Chad using Weibull distribution.

2. Wind Data and Analysis

2.1. Wind Speed Data

Vast of 1,284,000 km^2, Chad extends between 7˚ and 24˚ of north latitude and between 14˚ and 24˚ of longitude east. A country in central Africa at an average altitude of 200 meters above the sea, Chad is totally enclave. It is surrounded by six countries: in the north Libya, in the east Sudan, in the south the Central African Republic and in the West Cameroon, Nigeria and Niger. There are three major climatic zones in Chad: the Saharan Zone in the North, the Sahelian zone in the Center and the Sudanese zone in the South. In these three climatic zones of Chad, the speed of the wind was measuredin the weather observation stations. The data for this study were obtained from the division of Climatology of Chad National Meteorological General Direction (**Figure 1**). The velocity measurements of the wind were made at 10 m height. The geographical coordinates of the selected sites are given in **Table 1**.

2.2. Data Analysis

The Weibull distribution is usually used, accepted and recommended in the literature. It proved not only adapted for the description of the statistical properties

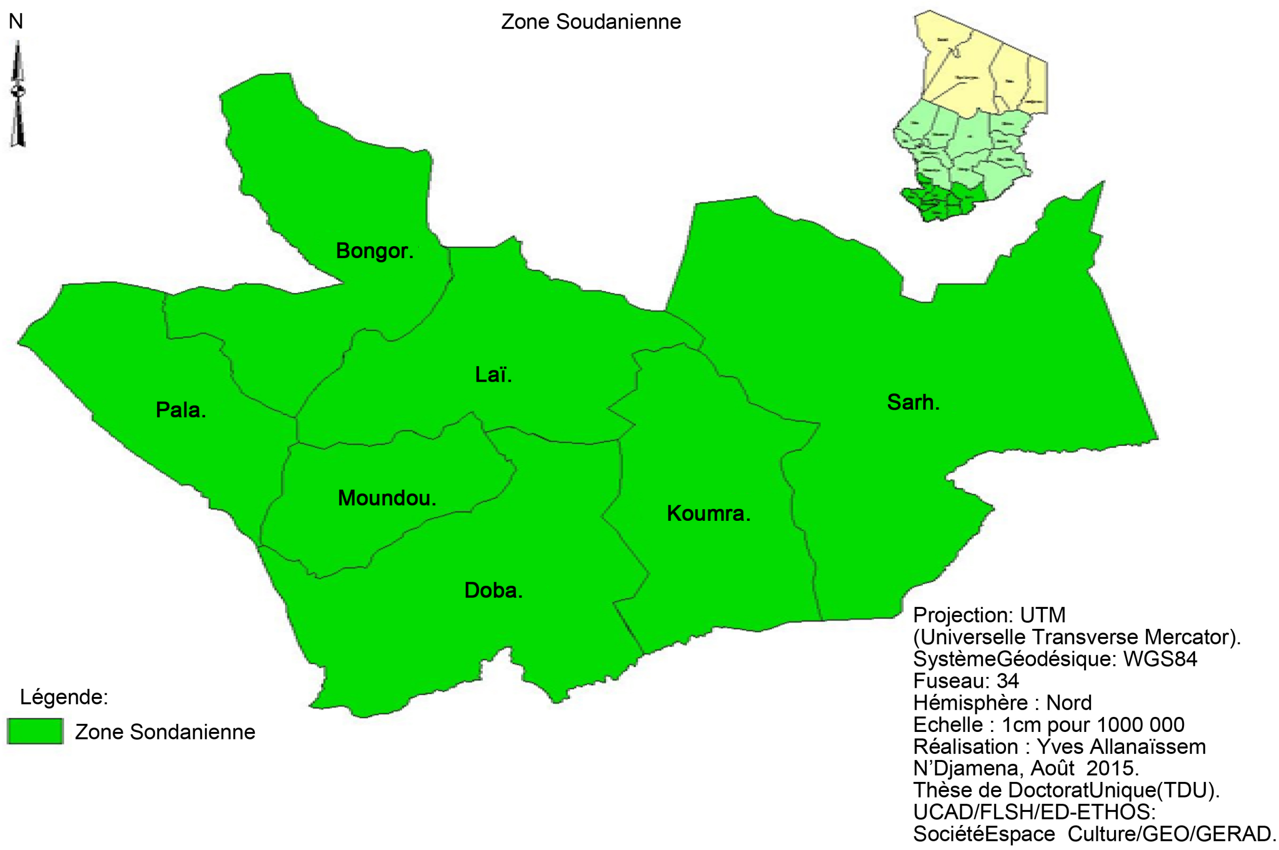

Figure 1. Sudanese zone in Chad [14].

Table 1. Geographical coordinates of stations used in the study.

Station	Longitude	Latitude	Elevation	Period of	Height of the
	˚E	˚N	(m)	measurement (year)	Mast (m)
Moundou	16.4	8.37	420	20	10
Pala	14.55	9.22	420	30	10
Sarh	18.23	9.9	364	20	10

of the wind but gives a good agreement with the experimental data [15]. The function of Weibull distribution with two parameters in particular the shape factor k (without dimension) and the scale factor c (m/s) for a place at a particular time is given by [16] [17] [18] [19]:

$$f(v)=\left(\frac{k}{c}\right)\cdot\left(\frac{v}{c}\right)^{k-1}\cdot\exp\left(-\left(\frac{v}{c}\right)^{k}\right),\left(k>0,v>0,c>1\right) \tag{1}$$

where v the speed of the wind (m/s), k is an adimensional factor of form which characterizes the frequency distribution and C is the scale factor which is the dimension speed.

The determination of k and c called parameters of Weibull makes it possible to know the distribution of the winds for a given site. Once these parameters are determined, the mean velocity of the wind is calculated according to the following expression [19] [20]:

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

where $F(v)$ represents cumulative distribution function. The energy pattern factor method is related to the averaged data of wind speed and is defined by the following equations [21] [22] [23]:

$$E_{pf} = \frac{\overline{V^3}}{\overline{V}^3} = \frac{\left(\frac{1}{n}\sum_{i=1}^{n} v_i^3\right)}{\left(\frac{1}{n}\sum_{i=1}^{n} \overline{v}_i\right)^2} \tag{3}$$

$$k = \frac{1 + 3.69}{\left(E_{pf}\right)^2} \tag{4}$$

$$\overline{V} = C\left(1 + \frac{1}{k}\right) \tag{5}$$

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

where, E_{pf} is the energy pattern factor and is the gamma function defined by

$$\Gamma(x) = \int_0^\infty t^{x-1} \exp(-t)\, \mathrm{d}t \tag{7}$$

$$\Gamma(x) = \left(\sqrt{2\pi x}\right)\left(x^{x-1}\right)\left(\mathrm{e}^{-x}\right)\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{1}{51840x^3} + \cdots\right) \tag{8}$$

2.3. The Probable Wind Speed

The most probable speed of wind can be determined from the shape parameter and scale parameter of Weibull distribution function. The speed of the most probable wind is obtained as [24]:

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{1/k} (\mathrm{m/s}) \tag{9}$$

2.4. Maximum Energy Carrying by the Wind Speed

Determination of the maximum speed of wind energy can be calculated from the shape parameter and scale parameter of Weibull distribution function. The wind speed carrying the maximum wind power can be to calculate as [25] [26]:

$$V_{\max.E} = c\left(1 + \frac{2}{k}\right)^{1/k} (\mathrm{m/s}) \tag{10}$$

2.5. Wind Power Density

The power density of the wind power is the most significant characteristic of the wind. It represents the quantity of energy produced by the wind. Assuming that A is the cross sectional area through which the wind spins out perpendicularly. The power of the wind is given by the following relation [27] [28] [29]:

$$P(V) = \frac{1}{2}\rho A v_m^3 \quad (11)$$

where, ρ is the density of air which depends on the pressure (elevation), temperature and moisture content present. In this study, it is assumed to be constant since its variation does not affect the calculation of resource of the wind in a significant way [30] [31]. By using the Weibull probability density function, the density of power of wind (by unit of surface) can be obtained by using the following equation [19] [32]:

$$P(V) = \frac{P(V)}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (12)$$

ρ is often written in a simple form [25]: $\rho = \rho_0 - 1.194 \times 10^{-4} \times H_m$ where, H_m = site elevation in meters. The air density value at sea level is $\rho_0 = 1.225\ \text{kg/m}^3$.

2.6. Extrapolation of Wind Speed and Wind Power at Different Hub Height

The precise evaluation of the wind potential for a given site requires the knowledge the speed of the wind to various heights. The standard height of measurement is generally of 10 m, but during a prospection of a site, in order to draw up a wind project, it is preferable to take measures with two or three levels for one period at least of a year in order to know the evolution the speed of the wind at altitudes representing an energy interest. To model the vertical profile is written by the law of power by the expression [12] [22] [33] [34] [35] [36] [37]:

$$v(z_2) = v(z_{10})\left(\frac{z_2}{z_{10}}\right)^{\alpha_1} \quad (13)$$

where,

$v(z_2)$ is wind speed at the hub height z_2,

$v(z_{10})$ is wind speed at the original height z_{10},

α_1 is surface roughness coefficient, it is determined from following expressions:

$$\alpha_1 = \frac{\left[0.37 - 0.088\ln(v_{10})\right]}{\left[1 - 0.088\ln\left(\frac{z_{10}}{10}\right)\right]} \quad (14)$$

The Weibull parameters at measurement height are related to the parameters at the wind turbine height by the following expressions:

$$c(h) = c_0\left(\frac{h}{h_0}\right)^n \quad (15)$$

$$k(h) = k_0\left[1 - 0.088\ln\left(\frac{h_0}{10}\right)\right] \Big/ \left[1 - 0.088\ln\left(\frac{h}{10}\right)\right] \quad (16)$$

where c_0 and k_0 are the scale factor and shape parameter respectively at the measurement height h_0 and h is the hub height.

In addition, for a height less than 130 m, the power density of the wind above the ground level is given by:

$$P_h = P_{10}\left(\frac{h}{10}\right)^{3\alpha_1} \tag{17}$$

where P_{10} is the corrected power available in wind at a height of 10 m.

2.7. Power Output of Wind Turbine and Capacity Factor

In order to determine which wind turbine is the most efficient and best suited to the area studied, three turbines characterized by a starting speed lower than the average annual speed of the site were selected. Two of the machines are high powers and one of low power. Wind turbine performance is estimated with the capacity factor (C_f) which represents the fraction of the average power delivered by the wind turbine ($P_{e,ave}$) to the nominal power of the wind turbine (P_{eR}). The mean power ($P_{e,ave}$) and the capacity factor of the wind turbines are calculated using the following equations [38] [39]

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_{eR}\dfrac{v^k - v_c^k}{v_R^k - v_c^k} & (v_c \le v \le v_R) \\ P_{eR} & (v_R \le v \le v_F) \\ 0 & (v_F < v) \end{cases} \tag{18}$$

$$P_{e,ave} = P_{eR}\left\{\frac{e^{-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_R}{c}\right)^k}}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_r}{c}\right)^k} - e^{-\left(\frac{v_F}{c}\right)^k}\right\} \tag{19}$$

The capacity factor (C_f) of a wind turbine installed at a given site is defined as the ratio of the output power to the maximum theoretical output of the wind turbine, if it operates at its nominal (maximum) capacity during the whole of the 8760 hours of the year (365 d × 24 h) or 720 hours of the month (30 d × 24 h). In practice, the capacity factor varies between 25% and 40%. A capacity factor of 0.4 or more indicates that the adaptation of the system to the wind speed is very good. The capacity factor is given by [40] [41] [42]

$$C_f = \frac{P_{e,ave}}{P_{eR}} \tag{20}$$

3. Results and Discussion

In this study, wind speed data analysis was carried out using MATLAB and Excel®. The dimensionless Weibull scale parameter c and shape parameter *k* were estimated using the E_{pf} method.

In addition, Weibull mean speed V_m, shape parameter (*k*), and scale parameter (*c*) for the three selected locations Moundou, Pala and Sarh are summarized in Table 2.

Table 2 shows the various speed and Weibull parameters for the three sites of

Table 2. Parameters of Weibull.

Sites	V_m (m/s)	k (−)	c (m/s)
Moundou	2.69	3.101	3.007
Pala	2.33	3.255	2.602
Sarh	1.91	2.376	2.099

Chad. It is noticed that Moundou and Pala are the two sites for which the speeds are respectively 2.69 and 2.33 m/s. Sarh is the site of the Sudanese zone for which the speed of the wind is lowest, 1.91 m/s. Pala, the site which possesses the highest parameter of form that is 3.225. Whereas, the site with the lowest parameter of form is Sarh with $k = 2.376$.

Table 3 presents the different values of the annual averages of wind speed, power density and energy produced. The lowest wind speed is observed at Sarh (1.908 m / s) and the highest at Moundou (2.692 m/s). On the other hand, the lowest power density and energy are observed in Pala, with respective values of 11.212 W/m^2 and 97,816 kWh/m^2 /year.

Figure 2 shows the different values of the speed obtained after extrapolation. Thus, this figure shows that for the three cities of the Sudanese zone, Moundou is the city where the wind speed is highest (4.608 m/s) at 67 m altitude. On the other hand, at the same height, the lowest speed recorded at Sarh was 3.464 m/s.

Figure 3 shows that the largest power recorded at Moundou are 36.616 W/m^2, 41.068 W/m^2 and 43.858 W/m^2 at 30 m, 50 m and 67 m altitude, respectively. At these same heights, the minimum powers were recorded at Sarh: 20.643 W/m^2, 25.815 W/m^2 and 29.344 W/m^2, respectively.

Figure 4 presents the different values of the mean wind speed at 10 m altitude for the three selected cities. The minimum speed of 1.91 m/s was recorded at Sarh while the maximum speed recorded was 2.69 m/s at Moundou.

Figure 5 shows that at 50 m altitude, Moundou is the site where the wind speed is highest. On the other hand, the lowest speed is at Sarh.

Figure 6 shows the different variations in wind speed at 30 m altitude for the three selected sites, of which Moundou appears to be most favorable site.

As for Figure 7, it presents respectively the different monthly values of the wind speed at 67 m altitude. From Figures 4-7, it can be seen that the wind speed varies as a function of altitude and Moundou is the windiest site of the Sudanese zone of Chad.

Table 4 presents the monthly and annual changes in Weibull parameters (k and c) estimated at 10 m above ground level. The minimum monthly value of the Weibull (k) form parameter of 1.194 is observed at Sarh in January and the maximum value 3.983 at Pala in July. The monthly scale parameter (c) has a minimum value of 1.564 m/s at Sarh in August and September and the highest value is 3.702 m/s in April at Moundou. The annual shape parameter varied between 2.376 at Sarh and 3.255 at Pala, while the annual scale parameter varied between 2.099 m/s at Sarh and 3.007 at Moundou. As a result, it is obvious that the shape parameter (k) has a much greater variation; this implies that the wind speed of the different zones does not vary enough with respect to the average speed.

The monthly and annual values of the most probable wind speed variations (V_{mp}) and the highest energy velocity ($V_{\max E}$) at a height of 10 m are shown in Table 5. Thus, in Moundou, the highest annual values of V_{mp} and $V_{\max E}$ are 2.647

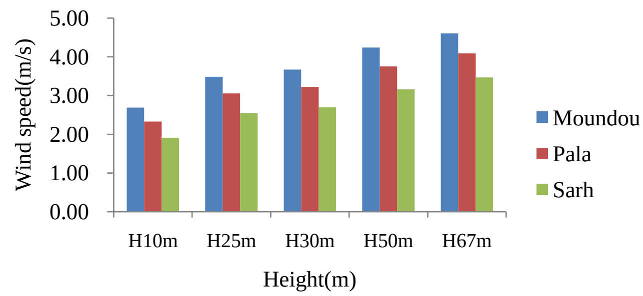

Figure 2. Annual mean wind throughout the year at the heights from 10 to 67 m.

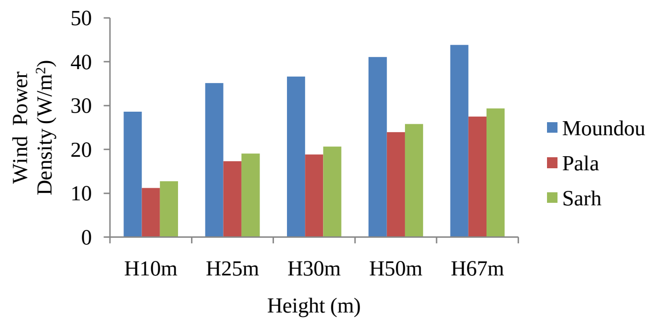

Figure 3. Annual mean wind power throughout the year at the heights from 10 to 67 m.

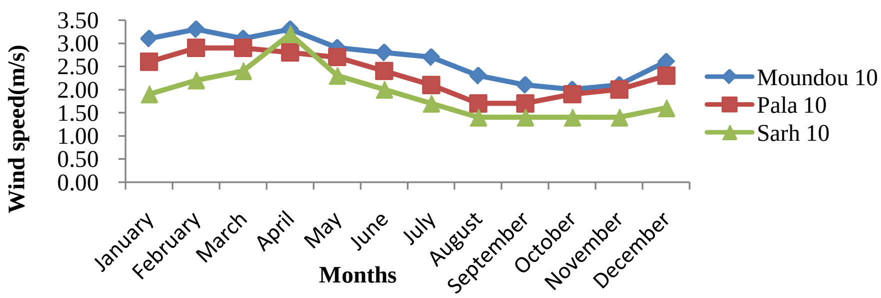

Figure 4. Mean wind speed for Moundou, Pala and Sarh at height 10 m.

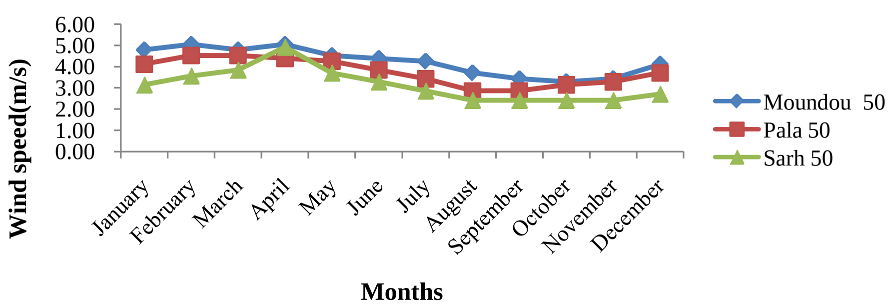

Figure 5. Mean wind speed for Moundou, Pala and Sarh at 50 m height.

m/s and 3.539 m/s, respectively, while Sarh and Pala have the lowest annual values of V_{mp} and $V_{\max E}$ which are 1.296 m/s and 3.042 m/s, respectively. The most likely wind speed (V_{mp}) varies from 0.441 m/s at Sarhin in January to 3.286 m/s at Moundou in February, while the highest wind speed ($V_{\max E}$) varies from 1.829

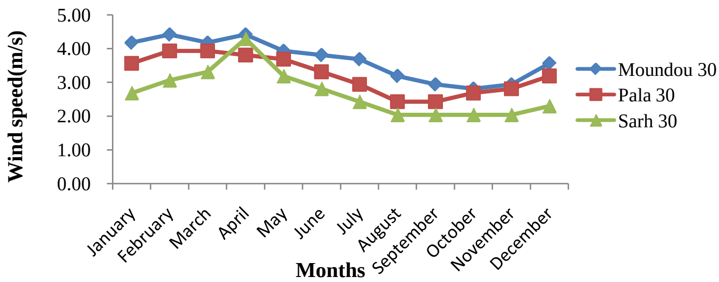

Figure 6. Mean wind speed for Moundou, Pala and Sarh at height 30 m.

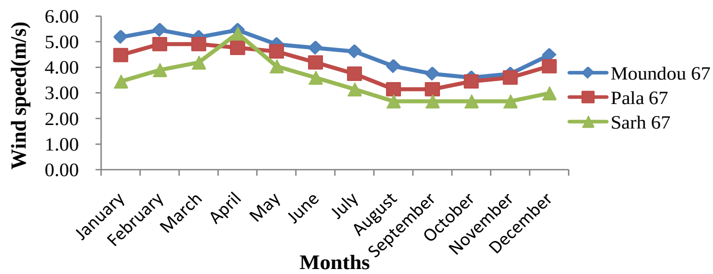

Figure 7. Mean wind speed for Moundou, Pala and Sarh at height 67 m.

Table 3. Annual wind characteristics for three sites at 10 m height for the period of 1975-2010.

Locations	Annual mean wind speed (m/s)	Annual mean power density (W/m²)	Annual energy (KWh/m²/year)
Moundou	2.692	17.071	148.85
Pala	2.333	11.212	97.816
Sarh	1.908	12.762	110.799

Table 4. Monthly and annual variation of Weibull parameters (*k* and *c*) for the selected points at 10 m heights.

Month	Moundou		Pala		Sarh	
	k	*c*	*k*	*c*	*k*	*c*
January	3.613	3.439	3.193	2.903	1.194	2.017
February	3.242	3.682	3.539	3.221	1.232	2.353
March	3.256	3.458	3.143	3.24	1.307	2.601
April	2.876	3.702	3.205	3.126	1.621	3.573
May	3.028	3.246	3.482	3.001	3.396	2.56
June	3.144	3.128	3.277	2.676	3.73	2.215
July	3.306	3.009	3.983	2.317	3.741	1.882
August	2.705	2.586	3.559	1.888	3.144	1.564
September	3.058	2.349	3.108	1.9	3.144	1.564
October	2.397	2.256	3.646	2.107	2.924	1.569
November	3.235	2.343	2.64	2.25	1.678	1.567
December	3.355	2.896	2.263	2.596	1.294	1.731
Annual	3.101	3.007	3.255	2.602	2.376	2.099

Table 5. Average monthly and annual values of the most probable wind speed (V_{mp}) and maximum energy carrying wind speed ($V_{\max E}$) at 10 m heights.

	Moundou		Pala		Sarh	
Month	V_{mp}	$V_{\max E}$	V_{mp}	$V_{\max E}$	V_{mp}	$V_{\max E}$
January	3.144	3.885	2.581	3.381	0.441	4.597
February	3.286	4.27	2.932	3.655	0.606	5.151
March	3.089	4.006	2.869	3.79	0.859	5.29
April	3.191	4.447	2.781	3.636	1.976	5.867
May	2.843	3.838	2.723	3.419	2.31	2.934
June	2.77	3.659	2.395	3.095	2.037	2.485
July	2.699	3.472	2.155	2.566	1.732	2.111
August	2.18	3.173	1.72	2.14	1.385	1.829
September	2.064	2.77	1.677	2.23	1.385	1.829
October	1.801	2.905	1.929	2.375	1.36	1.875
November	2.09	2.719	1.879	2.786	0.914	2.502
December	2.606	3.329	2.006	3.435	0.551	3.561
Annual	2.647	3.539	2.304	3.042	1.296	3.336

m/s at Sarh in August and September to 5.867 m/s in April.

Depending on the wind speed classes, the frequency distribution of the measured wind speed has been established and presented in Figure 8 while the cumulative distribution of the frequencies of the measured wind speed is presented in Figure 9.

Table 6 shows the characteristics of selected wind turbines. In order to bring out the model of the park with a real wind turbine, three types of wind turbine, 1 medium power and 2 high powers were selected.

Table 7 shows the monthly values of average power (P_{OUT}) delivered by the BONUS 300 kW/33 wind turbine, capacity factor (C_f) and cumulative energy production (E_{WT}) for the selected three sites.

Table 8 shows the monthly values of average power (P_{OUT}) delivered by the BONUS 1 MW/54 wind turbine, capacity factor (C_f) and cumulative energy production (E_{WT}) for the selected three sites.

Table 9 shows the monthly values of average power (P_{OUT}) delivered by the BONUS VESTAS 2 MW/V80 wind turbine, capacity factor (C_f) and cumulative energy production (E_{WT}) for the three cities.

Table 10 presents the annual performance and capacity factor of the selected wind turbine for the three selected locations. Note that the Bonus 300 kW/33 wind turbine has a good capacity factor 38.50% for the city of Sarh and Bonus 1 MW/50, 25.73% for the city of Moundou.

Table 11 presents the average monthly energy for the selected three sites in the Sudanese zone of Chad. The lowest and highest wind energy densities were observed at Sarh for the three selected sites, respectively, at 1.598 kWh/m^2/month and 33.966 kWh/m^2/month, respectively. In addition, the highest annual energy of 148.85 kWh/m^2/year was recorded in Moundou and the lowest of

97.816 kWh/m^2/year in Pala. Table 12 presents the standard deviation of wind speed for the selected three locations.

It is observed in Table 12 that the city in the Sudanese zone of Chad having a small gap of 0.6 is Sarh and high gap of 0.92 is Moundou.

Table 13 presents the different seasonal values of the Weibull parameters. It is seen that in winter the parameter of form k for the site of Sarh is 1.24 which implies that the wind speed in this station is very variable with respect to the average speed. Moreover, in the spring the scale factor at Moundou is 3.49 m/s,

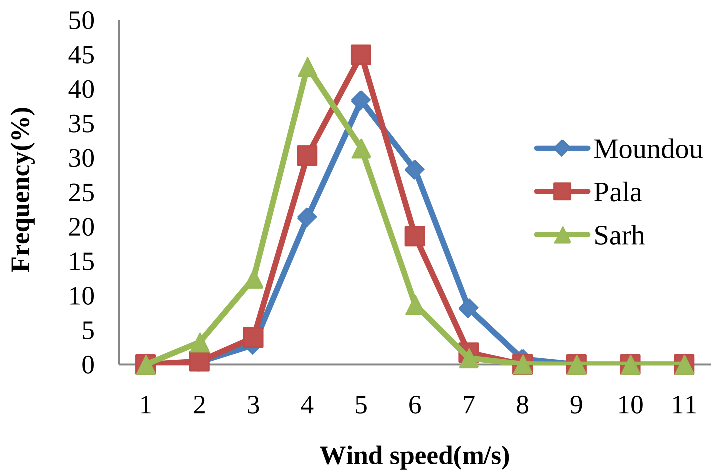

Figure 8. Frequency distribution of measured wind speed.

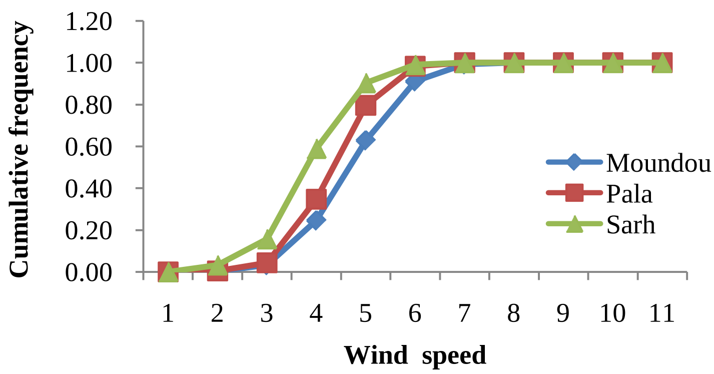

Figure 9. Whole year cumulative frequency distribution of measured wind speed.

Table 6. Characteristics of the selected wind turbines.

Characteristics	Bonus 300 kW/33	BONUS 1 MW/54	Vestas 2 MW/80
hub height (m)	30	50	67
Rated power P_r (kW)	300	1000	2000
Diameter	33.4	54.2	80
Cut-in wind speed V_c (m/s)	3	3	4
Rated wind speed V_r (m/s)	14	15	16
Cut-off wind speed V_f (m/s)	25	25	25

which implies that the site is windy. The lowest average speed is 1.4 m/s at Sarh in the autumn, while the highest at 4.1 m/s is observed at Moundou in the spring. Thus, it can be concluded that Moundou remains a site where the characteristics of the wind are important and favorable throughout the four seasons.

4. Conclusions

In this study, the monthly and annual distributions of wind distribution and

Table 7. Monthly variations of mean turbine BONUS 300 kW/33.

	Moundou			Pala			Sarh		
Month	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)
January	4.14	1.38%	2977.98	3.32	1.11%	2387.04	17.64	5.88%	12,697.74
February	7.78	2.59%	5603.73	3.43	1.14%	2472.13	23.05	7.68%	16,593.8
March	6.11	2.04%	4400.9	5.4	1.8%	3889.52	25.39	8.46%	18,283.7
April	11.3	3.77%	8133.07	4.4	1.47%	3168.83	34.44	11.48%	24,795.38
May	6.16	2.05%	4432.26	2.72	0.91%	1959.69	1.46	0.49%	1054
June	4.72	1.57%	3399.19	2.1	0.7%	1514.54	0.41	0.14%	292.07
July	3.37	1.12%	2426.52	0.37	0.12%	268.97	0.12	0.04%	84.01
August	3.78	1.26%	2721.72	0.17	0.06%	121.32	0.08	0.03%	54.02
September	1.52	0.51%	1093.36	0.41	0.14%	293.37	0.08	0.03%	54.02
October	3.33	1.11%	2394.39	0.33	0.11%	238.28	0.14	0.05%	97.68
November	1.16	0.39%	838.35	2.28	0.76%	1640.81	2.89	0.96%	2078.49
December	2.71	0.9%	1951.21	6.84	2.28%	4924.41	9.82	3.27%	7073.74

Table 8. Monthly variations of mean turbine BONUS 1 MW/54.

	Moundou			Pala			Sarh		
Month	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)	P_{OUT}	C_f (%)	E_{WT} (kWh/mon)
January	18.61	1.86%	13,402.66	15.96	1.6%	11,493.18	76.73	7.67%	55,243.14
February	33.54	3.35%	24,151.84	15.89	1.59%	11,441.89	96.76	9.68%	69,665.62
March	27.01	2.7%	19,449.59	24.44	2.44%	17,597.86	105.27	10.53%	75,792.19
April	47.84	4.78%	34,442.1	20.33	2.03%	14,641.1	136.84	13.68%	98,527.15
May	27.66	2.77%	19,914.79	13.07	1.31%	9407.57	7.87	0.79%	5664
June	21.73	2.17%	15,647.8	10.78	1.08%	7761.49	2.7	0.27%	1943
July	15.99	1.6%	11,512.7	2.4	0.24%	1725.11	1.1	0.11%	790
August	18.85	1.89%	13,574.65	1.48	0.15%	1069.07	0.94	0.09%	676.66
September	8.54	0.85%	6151.73	3.1	0.31%	2230.59	0.94	0.09%	676.66
October	17.59	1.76%	12,663.71	2.36	0.24%	1701.16	1.47	0.15%	1057.55
November	6.72	0.67%	4838.38	12.57	1.26%	9052	16.67	1.67%	12,000
December	13.2	1.32%	9506.73	32.42	3.24%	23,342.94	46.45	4.64%	33,441.39

Table 9. Monthly variations of mean turbine VESTAS 2 MW/V80.

Month	Moundou P_{OUT}	Moundou C_f (%)	Moundou E_{WT} (kWh/mon)	Pala P_{OUT}	Pala C_f (%)	Pala E_{WT} (kWh/mon)	Sarh P_{OUT}	Sarh C_f (%)	Sarh E_{WT} (kWh/mon)
January	33.23	1.66%	23,927.4	26.08	1.3%	18,778.4	130.21	6.51%	93,751.06
February	60.54	3.03%	43,588.64	27.56	1.38%	19,844.78	167.33	8.37%	120,475.48
March	47.84	2.39%	34,442.22	42.13	2.11%	30,330.98	183.12	9.16%	131,845.55
April	85.71	4.29%	61,709.82	34.54	1.73%	24,867.3	244.71	12.24%	176,188.53
May	47.62	2.38%	34,287.9	21.83	1.09%	15,718.07	11.7	0.58%	8422.51
June	36.89	1.84%	26,560.62	16.67	0.83%	12,004.92	3.28	0.16%	2365.2
July	26.69	1.33%	19,213.97	3.08	0.15%	2217.82	0.93	0.05%	669.58
August	28.97	1.45%	20,857.96	1.34	0.07%	964.22	0.6	0.03%	433.48
September	11.9	0.6%	8568.4	3.21	0.16%	2311.22	0.6	0.03%	433.48
October	25.3	1.27%	18,217.75	2.66	0.13%	1914.21	1.09	0.05%	783.95
November	9.21	0.46%	6631.96	17.53	0.88%	12,618.15	22.51	1.13%	16,208.21
December	21.56	1.08%	15,526.74	51.23	2.56%	36,887.12	74.34	3.72%	53,523.47

Table 10. Annual power output and capacity factor of the selected wind turbine for the selected three locations.

Location	BONUS 300 kW/33		BONUS 1MW/54		VESTAS 2MW/V80	
	$P_{e,av}$ (kW/Year)	C_f (%)	$P_{e,av}$ (kW/Year)	C_f (%)	$P_{e,av}$ (kW/Year)	C_f (%)
Moundou	56.07	18.69	257.30	25.73	435.46	21.77
Pala	31.78	10.59	154.81	15.48	196.62	9.83
Sarh	115.50	38.50	493.72	49.37	840.42	42.02

Table 11. Monthly variations of mean wind energy density (kWh/m^2).

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Moundou	16.709	19.124	17.516	21.862	14.89	12.713	11.488	7.944	5.442	5.689	5.286	10.187	148.85
Pala	10.435	12.464	14.596	12.589	11.217	7.842	5.002	2.773	2.862	3.833	5.137	9.066	97.816
Sarh	12.149	16.035	20.644	33.966	7.052	4.31	2.732	1.651	1.598	1.718	2.717	6.226	110.799

Table 12. Standard deviation (σ) of the selected three stations.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Moundou	1.03	1.12	1.05	1.15	1.00	0.96	0.91	0.81	0.72	0.72	0.71	0.88	0.92
Pala	0.89	0.96	0.99	0.95	0.90	0.81	0.68	0.56	0.58	0.63	0.71	0.83	0.79
Sarh	0.47	0.58	0.69	1.09	0.77	0.66	0.56	0.48	0.48	0.49	0.48	0.46	0.60

Table 13. Presentation of Weibull characteristics by seasons.

Seasons	Moundou V (m/s)	Moundou K	Moundou C (m/s)	Moundou V_{mp}	Moundou $V_{\max E}$	Pala V (m/s)	Pala K	Pala C (m/s)	Pala V_{mp}	Pala $V_{\max E}$	Sarh V (m/s)	Sarh K	Sarh C (m/s)	Sarh V_{mp}	Sarh $V_{\max E}$
Winter	3	3.4	3.34	3.01	3.83	2.6	3	2.91	2.51	3.49	1.9	1.24	2.03	0.53	4.44
Spring	3.1	3.05	3.47	3.04	4.1	2.8	3.28	3.12	2.79	3.62	2.6	2.11	2.91	1.72	4.7
Summer	2.6	3.05	2.91	2.55	3.43	2.1	3.61	2.29	2.09	2.6	1.7	3.54	1.89	1.72	2.14
Autumn	2.1	2.9	2.32	1.99	2.8	1.9	3.13	2.09	1.83	2.46	1.4	2.58	1.57	1.22	2.07
Annual	2.7	3.1	3.01	2.65	3.54	2.35	3.26	2.6	2.31	3.04	1.9	2.37	2.1	1.3	3.34

wind energy density during the period 1975-2010 of selected three stations in the Sudanese zone of Chad were evaluated. The analysis was done on the basis of Weibull distribution function with two parameters. Based on the results of this study, it can be concluded that:

1) The minimum monthly average wind speed of 1.4 m/s in August, September, October and November in Sarh and a maximum value of 3.3 m/s in Moundou in February and April were recorded. A maximum value of the average annual wind speed of 2.692 m/s is obtained at Moundou.

2) The annual mean value of the Weibull *c* scale parameter ranges from 2.099 m/s to 3.007 m/s whereas the annual value of the form parameter *k* varies from 2.376 to 3.255. The highest of the values *c* and *k* are found in the Moundou and Pala stations, respectively. The average annual wind densities for Moundou, Pala and Sarh are 17.071 W/m^2, 11.212 W/m^2 and 12.762 W/m^2, respectively.

3) The wind turbine in turn offers a more profitable possibility for the Sudanese zone of Chad with the wind turbine Vestas 2 MW/80.

The wind power potential can be exploited to ensure sustainable development in the rural areas for pumping of water, heating of water, and production of electricity. The study recommends a long-term (at least ten years) wind speed data analysis for better understanding of energy potential and the design of suitable wind turbine for the selected cities.

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