

Wind and Solar Assessment in the Sahelian Zone of Chad

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Abstract: Renewable energy sources have long been renowned as potential sources of free, clean and inexhaustible energy. However, energy in Chad is still exploited from non-renewable sources due to lack of comprehensive wind and solar maps, skills and public awareness pertaining to its significance in the country. This study is therefore set out to provide assessments of both wind and solar energies in the Sahelian zone in Chad, using the statistical two-parameter Weibull distribution function and Angstrom-PreScott model, respectively for a ten-year period. The evaluation of wind potential shows that the annual mean of the shape and scale parameters for all stations under study varied in the range of 1.26 – 1.56 and 2.49 m/s – 3.91 m/s, respectively. Stronger wind speed was observed during the dry season and a relatively slower wind speed was perceived during the wet season. Among the four stations, N'Djamena showed the highest power density compared to the other three stations with a mean power density that ranges between 100 W/m² – 220 W/m². The prediction of solar potential in this region indicates that the global solar radiation for all stations is promising with station Abeche however, to show the highest solar energy density on average. A good agreement between Angstrom model and NASA data was also observed.

Keywords: Wind energy; solar energy; Weibull distribution; Angstrom-PreScott model, renewable energy in Chad

1. Introduction

Renewable energy sources such as wind and solar have long been renowned as potential sources of free, clean and inexhaustible energy that could play an important role in contributing towards energy demands in the coming years, particularly where a small amount of energy is needed such as the rural areas or small individual households [1], [2], [3]. It is, however, perceived that the sources of energy in many third world countries including Chad are still exploited from non-renewable and depleting sources such as fossil fuels and biomass, although recent evidence suggests that alternative energy sources in these countries appear to be abundant [4],[5]. Thus, discovering and establishing the potentials of these sensible renewable sources are vital. Moreover, the fact that Chad's population are scattered with the vast majority living in rural areas, complicated the government's effort to provide electrified grid system throughout the country. As a result, the electrical grid system is only available in big towns [6]. Therefore, a renewable energy conversion system such as a wind turbine or solar panels might be the most viable option or a more reasonable approach for such situations [7].

While the development and adaptation of renewable energy sources are widely undertaken and fully established globally, in Chad, however, up to now, there is only a little, published data on the assessment or feasibility study on renewable energy resources. They are now starting to take a turn in the last couple of years. Currently, assessment of wind and solar resources have emerged and begins to see the light. Far too little attention has been paid to other forms of renewable resources. This partly due to lack of political will, limited skills and public awareness pertaining to the impact of renewable resources on the ground. Thus, they are still unexploited and underutilized in both industrial and household scales.

Recently, Didane *et al.* [6] studied broadly the potential of wind energy in Chad while covering thirteen meteorological stations from the three main zones in the country which are the Sahara desert, the Sahel and the Sudanian zone. It was found that the potential of wind energy in Chad is promising with the Sahel and the Sahara zones seem to show the highest potentials of wind energy harvesting in the country. Soulouknga *et al.* [8] also carried wind assessment in the Sudanian zone in Chad. It is, however, indicated that in this zone, wind energy could be regarded as a potential alternative only at 67 m height above the ground for electricity generation, heating and

pumping water. In terms of solar energy, Soulouknga *et al.* [9] revealed that the Sahel zone has an encouraging potential for solar energy harvesting. However, previously published studies are either limited to one region in the case of solar assessment or failed to explore extensively with regard to a higher altitude in the case of wind energy assessment. It is recognized that this study is important for transitioning Chad's energy infrastructure to renewable energy. Therefore, it is hoped that the findings should make an important contribution by providing and outlining the untapped wind and solar energy resources in the Sahelian zone in Chad which may likely reassure interested parties that the future of these energies in this region is promising.

2. The Sahel Zone in Chad

The Sahel or Sahelian zone in Chad which is largely a semi-desert country is semi-arid zone located in the middle of the country between the dry Sahara desert in the north and Sudanian tropical zone in the south. It creates an about 500 kilometers wide belt that stretches from the western border with Niger and Nigeria to the eastern border with Sudan as shown in Fig. 1. The main cities that have been covered in this study as shown in Fig. 1, are Abeche, Mao, Mongo and N'Djamena. The Geographic coordinates of these stations are given in Table 1. The raining or wet season in this zone starts as early as June to September and a dry season from October to May. The Sahel zone is studied in particular due to its variety and presence of a large number of population beside the huge untapped potential of wind and solar. The cities selected for study are the main cities with highest population density in the Sahelian zone.

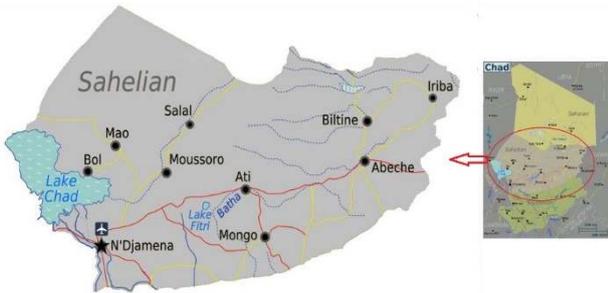


Fig. 1 Sahel zone in Chad.

Table 1: Geographic coordinates of four synoptic stations.

Station	Latitude (°N)	Longitude (°E)	Altitude (m)
Abeche	14.40	20.50	545
Mao	14.08	15.18	327
Mongo	12.10	18.40	431
N'Djamena	12.08	15.02	295

3. Theoretical formulation for wind energy

3.1 Extrapolation of Wind Data

The meteorological wind data are collected from the National Meteorological General Administration at N'Djamena airport in Chad for a ten-year period. They were recorded in a monthly-average form at the standard height of 10 m. The measured data vary from one station to another due to lack of consistent wind data record. Thus, the data used were recorded between the year 1970 and 2013. Given that the wind speed at a site varies with altitude, which is also known as wind shear, the raw meteorological data needs to be extrapolated to the required heights when the annual energy production (AEP) of a site is being assessed. That is owed to the fact that the meteorological data are typically measured at the standard height of 10 m. However, the usual height of a wind turbine hub is usually beyond 10 m, which makes such analysis imperative in order to achieve a reliable estimation of the particular site's potentials. Furthermore, Al-Mohamad & Karmeh [10] also indicated that the Weibull parameters are deemed accurate at higher wind speeds which is available at higher altitude. Hence, the wind profile power law as given in Equation 1 is commonly used to measure the wind speed at the desired heights.

$$V_2 = V_1 \left(\frac{Z_2}{Z_1} \right)^\alpha \tag{1}$$

where V_1 and V_2 are respectively the actual wind speed at height Z_1 and the required wind speed at the height Z_2 . The exponent, α is a coefficient that depends on the stability of the atmospheric condition (surface roughness). A value of approximately 0.143 is usually used for well-exposed, low surface roughness or neutral stable sites [11]. In the present study, a constant value of 0.143 is used throughout the assessment analysis.

3.2 Weibull Distribution Function

The statistical assessment in study adopts the common two-parameter Weibull distribution function. It is among the common and accepted approach utilized to evaluate the wind speed characteristics at a particular site. It is considered as one of the standard approach in the wind assessment due to its close approximation and capability to fit in the measured wind speed data for a given period of time, typically monthly or annually averaged data [12]. The wind speed probability density function and cumulative distribution function are respectively given in Equation 1 and Equation 2. The probability density function or velocity frequency and the cumulative distribution function characterize the wind speed variations at a site [13]–[16].

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

$(k > 0, v > 0, c > 1)$

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (3)$$

where c and k are the Weibull scale parameter and the dimensionless shape parameter, respectively. They are given as follows:

$$k = 0.83 \bar{V}^{0.5} \quad (4)$$

$$c = \frac{\bar{V}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (\text{m/s}) \quad (5)$$

where \bar{V} and Γ are respectively, average wind speed and gamma function. The average wind speed is calculated using the following equation:

$$\bar{V} = \frac{1}{n} \left[\sum_i^n v_i \right] \quad (\text{m/s}) \quad (6)$$

3.3 Wind Power and Energy Density

The wind power density based on Weibull distribution and the wind energy density for the desired time, T are predicted using Equation 7 and Equation 8, respectively.

$$\frac{P}{A} = \int_0^\infty \frac{1}{2} \rho c^3 \Gamma\left(\frac{k+1}{k}\right) \quad (7)$$

$$\frac{E}{A} = \frac{1}{2} \rho c^3 \Gamma\left(\frac{k+3}{k}\right) T \quad (8)$$

where the air density, ρ is 1.225 kg/m^3 at sea level with a mean temperature of 15°C and 1 atmospheric pressure.

4. Theoretical formulation for solar energy

For a country like Chad that does not have meteorological stations equipped with a Pyranometer to measure sunshine, the evaluation of solar potential must be made by empirical models such as that of Angstrom to overcome this insufficiency. The results obtained can be validated by comparing them with those provided by international databases such as those of NASA [17]. Several solar potential assessment studies have been carried out in some sub-Saharan countries such as Nigeria [18],[19],[20],[21], Burkina Faso [22] and Ghana [23]. In order to evaluate the solar energy potential of Chad, a

series of meteorological data (sunshine duration, average temperatures, maximum temperatures, relative humidity, etc.) were collected from four regional synoptic stations in the Sahelian zone (Abeche, Mao, Mongo and N'Djamena) for a duration of 10 years.

4.1 Global solar radiation

In general, on a horizontal plan, the relation of Klein [24] defines the solar radiation (H_0) outside the atmosphere as:

$$H_0 = \frac{24}{\pi} I_{sc} \left[1 + 0.33 \cos\left(\frac{360 D_n}{365}\right) \right] * \left[\cos L \cos \delta \sin \omega_s + \frac{2\pi \omega_s}{360} \sin L \sin \delta \right] \quad (9)$$

where:

I_{sc} : a solar constant which equals 1367 W/m^2

D_n : number of days of the year

L : latitude of the site in degrees

δ and ω_s are respectively the solar declination angle and the angle of the sunset hour angle that are calculated by the following relationships [25]:

$$\delta = 23.45 \sin\left[\frac{360(284 + D_n)}{365}\right] \quad (10)$$

$$\omega_s = \cos^{-1}(-\tan L \tan \delta) \quad (11)$$

From H_0 , there are several models for estimating global solar radiation (H) according to the climatic parameters of the site such as the duration of sunshine, the maximum and minimum temperature, the relative humidity, etc. [17]. Three models are typically used to estimate global solar radiation on a horizontal plane: the Angstrom-Prescott model, the Allen model and the Sabbagh model.

4.2 Estimation of global solar radiation by Angstrom-Prescott model

The first pioneer on solar radiation modelling was Angstrom (1924). Using sunshine data collected from the meteorological stations of a site, he developed a linear model for estimating the ratio of solar radiation (S/S_0), where S_0 is the maximum of the average monthly duration sunshine on the site and S is the average daily sunshine duration [25].

This model was then improved by Prescott in 1940 and Page in 1961 by taking into account the mean global radiation on a horizontal surface H and the duration of sunshine in a relation stated as follows [26]:

$$\frac{H}{H_0} = a + b \left(\frac{s}{s_0} \right) \quad (12)$$

where:

$$a = -0.110 + 0.235 \cos L + 0.323 \left(\frac{s}{s_0} \right) \quad (13)$$

$$b = 1.449 - 0.533 \cos L - 0.694 \left(\frac{s}{s_0} \right) \quad (14)$$

$$s_0 = \frac{24}{\pi} \cos^{-1}(-\tan L \tan \delta) \quad (15)$$

5. Results and discussion

The results are presented in two distinct parts in order to give the reader a sense of continuity and clarity. The first part comprises the assessment/analysis of wind data, while the second part embodies the assessment of solar potentials in Sahel region. The evaluation of the wind resources in each site was investigated at four different heights including 10 m, 30 m, 50 m and 100 m. This is done in an effort to highlight the zones with the most favorable potentials for wind energy exploitation.

5.1 Monthly wind speed variation

The annual average wind speed for the four meteorological stations at the Sahel zone ranges between 1.75 m/s to 4.5 m/s at 10 m height and from 2.5 – 6.5 m/s, at 100 m above ground level. As shown in Figs. 2 – 5, the variation of the mean speed fluctuates between 2.5 m/s to 4.5 m/s at N'Djamena, Abeche and Mongo. However, it drops to less than 3 m/s at Mao throughout the year. The trends of monthly mean wind speed variations between the different stations are almost similar throughout the years under study. The peak wind speed tends to occur during the dry season with March to be the month with highest wind speed potentials. This also corresponds to the highest electrical demand in the country [6]. This indicates that a wind energy conversion system could solve the incessant power outage in this period. On the other hand, the lowest mean wind speed occurs during the wet season in September. Among the four Sahel zones, N'Djamena station exhibits the highest mean wind speed values, while Mao shows the lowest mean.

Moreover, it is observed that the seasonal variation along the year indicates that strong mean wind speed is found during the dry season (November to April), while a relatively low mean speed is found in autumn (June to October). A similar pattern is observed for all stations.

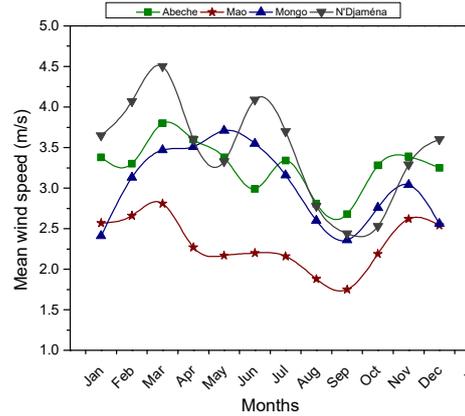


Fig. 2 Monthly variations of wind speed at 10 m.

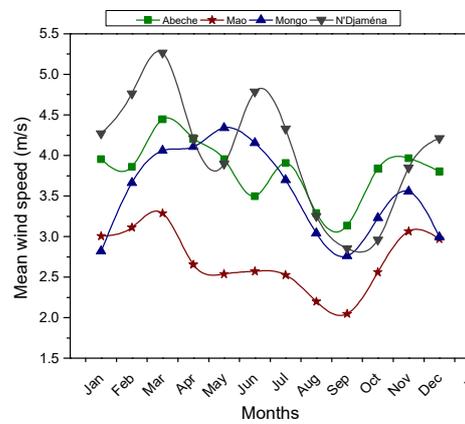


Fig. 3 Monthly variations of wind speed at 30 m.

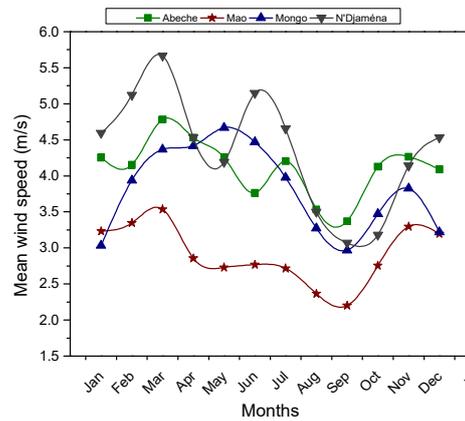


Fig. 4 Monthly variations of wind speed at 50 m.

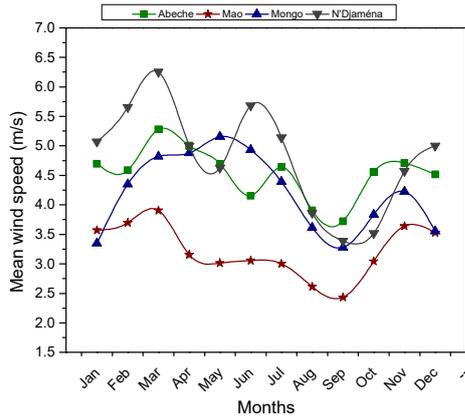


Fig. 5 Monthly variations of wind speed at 100 m.

5.2 Wind power and energy density

The yearly mean wind power density and wind energy density are calculated using Equation 7 and Equation 8, respectively. The calculated output for the four stations at four different heights starting from 10 m up to 100 m height are tabulated in Table 2 and illustrated in Fig. 6. It is clear that N'Djaména shows the highest amount of wind power density with a maximum of more than 160 W/m² at 100 m above ground level compared to nearly 74 W/m² at 10 m height. The corresponding wind energy density at the same station has peaked up to 1.34 MWh/m²/year at 100 m. The lowest power density occurred in Mao with only 30 W/m² at 10 m height and increased to 61 W/m² at 100 m. The annual mean wind at Mao station has not changed much with height due to the lowest mean wind speed at this station. It was observed that extrapolating the wind data from 10 m to 100 m height has increased the wind speed by nearly 40%, which resulted in an increase of power potentials by almost 125%.

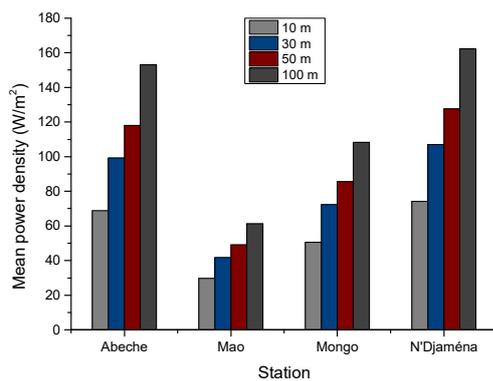


Fig. 6 Comparison of yearly mean wind power density at different heights.

Table 2: Wind energy density at different height.

Station	Parameters			
	10 m	30 m	50 m	100 m
	E/A (kWh/m ²)	E/A (kWh/m ²)	E/A (kWh/m ²)	E/A (kWh/m ²)
Abeche	602.72	868.39	1034.65	1340.36
Mao	260.79	365.34	429.31	536.73
Mongo	442.77	632.73	749.79	947.58
N'Djaména	648.71	937.79	1117.11	1421.33

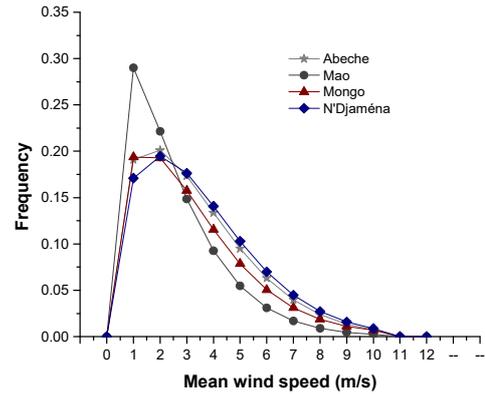


Fig. 7 Frequency distributions at 10 m.

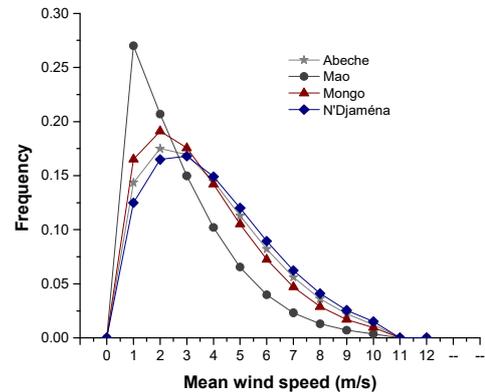


Fig. 8 Frequency distributions at 30 m.

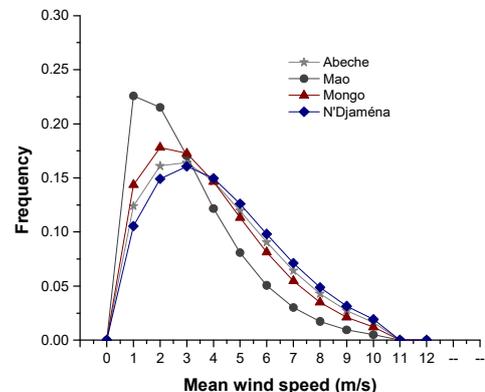


Fig. 9 Frequency distributions at 50 m.

5.3 Weibull Distribution

The Monthly mean speed, scale parameter and shape parameter of Weibull distribution for all stations under study are presented in Table 3 and Table 4. The Weibull parameters of each station were assessed at heights that range between 10 m to 100 m above ground level. It was found that the shape parameter, k varies between 1.3 at 10 m height to almost 2 at 100 m height throughout the year for most of the stations such as Abeche, Mongo and N'Djamena. Given that the typical value of shape parameter is in the range of 1.5 to 3 for a stable and persistent site, stations such as Abeche, Mongo and N'Djamena could be considered stable in most of the months of the year starting from the height of 10 m above the ground. However, although Mao station showed the least output at low altitudes, nevertheless higher values of shape parameter were observed at 100 m height.

In terms of the scale parameter, c greater temporal variations were observed. The highest scale parameter was witnessed in N'Djamena in March with the value of 5 m/s at 10 m to 7 m/s at 100 m height. While the lowest values were witnessed again in Mao station in September with only 1.8 m/s and 2.6 m/s at 10 m and 100 m height, respectively. This clearly indicates the huge difference in the strength of wind in N'Djamena compared to Mao and also the significant variation of wind with altitude. An almost similar trend to this is observed throughout the year for all other stations with N'Djamena to exhibit the strongest wind speed.

Figs. 7 – 10 and Figs. 11 – 14, respectively show the frequency distribution and cumulative distribution for all stations at four different heights. It can be seen in Figs. 7 – 10 that the frequency distributions have similar trends with Abeche alone to possess a frequency percentage over 20% at every altitude and it is in the range of 1 m/s – 4 m/s wind speed. Moreover, the frequency distribution decreases as the altitude increases and cover more strong wind speed but with less frequency. On the other hand, the cumulative distribution increases with wind speed and reaches nearly a unity at 11 m/s wind speed.

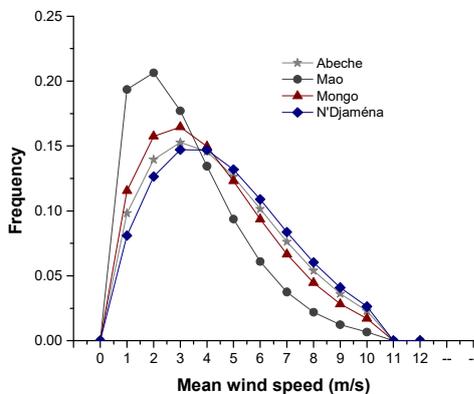


Fig. 10 Frequency distributions at 100 m.

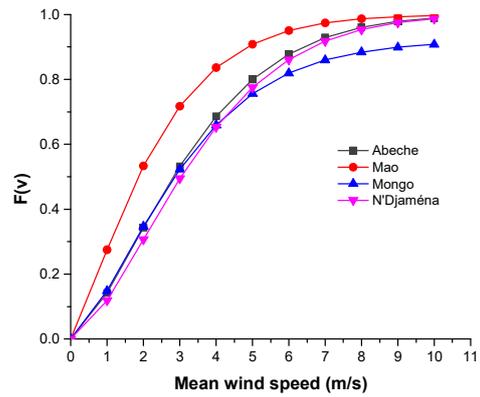


Fig.11 Cumulative distributions at 10 m.

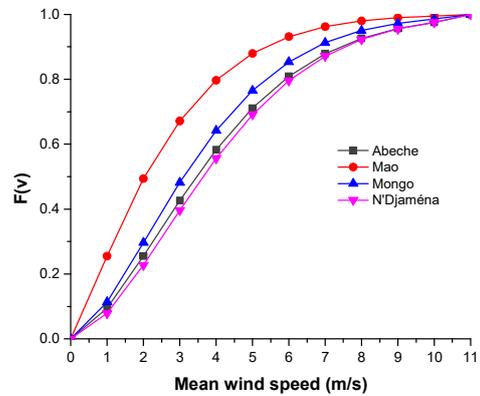


Fig. 12 Cumulative distributions at 30 m.

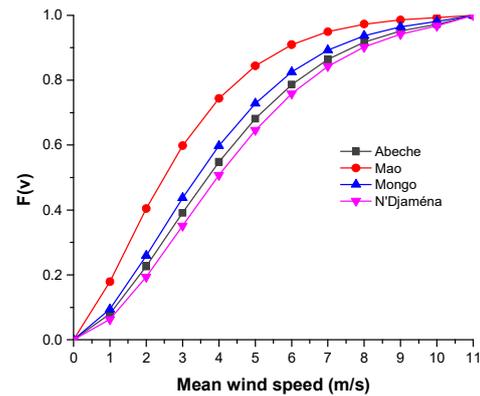


Fig. 13 Cumulative distributions at 50 m.

Table 3: Monthly mean wind speed and Weibull parameters (k, c).

Station		Abeche				Mao			
Month	Parameters	Height							
		10 m	30 m	50 m	100 m	10 m	30 m	50 m	100 m
Jan	\bar{v}	3.38	3.95	4.25	4.70	2.57	3.01	3.23	3.57
	k	1.53	1.65	1.71	1.80	1.33	1.44	1.49	1.57
	c	3.75	4.42	4.77	5.28	2.80	3.31	3.58	3.98
Feb	\bar{v}	3.3	3.86	4.15	4.59	2.66	3.11	3.35	3.70
	k	1.51	1.63	1.69	1.78	1.35	1.46	1.52	1.60
	c	3.66	4.31	4.65	5.15	2.90	3.44	3.71	4.12
Mar	\bar{v}	3.8	4.45	4.78	5.28	2.81	3.29	3.54	3.90
	k	1.62	1.75	1.82	1.91	1.39	1.50	1.56	1.64
	c	4.24	4.99	5.38	5.95	3.08	3.64	3.93	4.36
Apr	\bar{v}	3.60	4.21	4.53	5.00	2.27	2.66	2.86	3.15
	k	1.57	1.70	1.77	1.86	1.25	1.35	1.40	1.47
	c	4.01	4.72	5.09	5.63	2.44	2.90	3.14	3.49
May	\bar{v}	3.38	3.95	4.25	4.70	2.17	2.54	2.73	3.02
	k	1.53	1.65	1.71	1.80	1.22	1.32	1.37	1.44
	c	3.75	4.42	4.77	5.28	2.32	2.76	2.99	3.32
Jun	\bar{v}	2.99	3.50	3.76	4.15	2.20	2.57	2.77	3.06
	k	1.44	1.55	1.61	1.69	1.23	1.33	1.38	1.45
	c	3.29	3.89	4.20	4.65	2.35	2.80	3.03	3.37
Jul	\bar{v}	3.34	3.91	4.20	4.64	2.16	2.53	2.72	3.00
	k	1.52	1.64	1.70	1.79	1.22	1.32	1.37	1.44
	c	3.70	4.37	4.71	5.22	2.31	2.74	2.97	3.31
Aug	\bar{v}	2.81	3.29	3.54	3.90	1.88	2.20	2.37	2.61
	k	1.39	1.50	1.56	1.64	1.14	1.23	1.28	1.34
	c	3.08	3.64	3.93	4.36	1.97	2.35	2.55	2.85
Sep	\bar{v}	2.68	3.14	3.37	3.72	1.75	2.05	2.20	2.43
	k	1.36	1.47	1.52	1.60	1.10	1.19	1.23	1.29
	c	2.93	3.46	3.74	4.15	1.81	2.17	2.36	2.63
Oct	\bar{v}	3.28	3.84	4.13	4.56	2.19	2.56	2.76	3.04
	k	1.50	1.63	1.69	1.77	1.23	1.33	1.38	1.45
	c	3.63	4.29	4.62	5.12	2.34	2.79	3.02	3.36
Nov	\bar{v}	3.39	3.97	4.27	4.71	2.62	3.07	3.30	3.64
	k	1.53	1.65	1.71	1.80	1.34	1.45	1.51	1.58
	c	3.76	4.44	4.78	5.30	2.85	3.38	3.65	4.06
Dec	\bar{v}	3.25	3.80	4.09	4.52	2.54	2.97	3.20	3.53
	k	1.50	1.62	1.68	1.76	1.32	1.43	1.48	1.56
	c	3.60	4.25	4.58	5.07	2.76	3.27	3.54	3.93

Table 4: Monthly mean wind speed and Weibull parameters (k, c).

Month	Station	Parameters	Mongo				N'Djamena			
			Height							
			10 m	30 m	50 m	100 m	10 m	30 m	50 m	100 m
Jan		\bar{v}	2.41	2.82	3.03	3.35	3.65	4.27	4.59	5.07
		k	1.29	1.39	1.45	1.52	1.59	1.72	1.78	1.87
		c	2.60	3.09	3.34	3.71	4.07	4.79	5.16	5.71
Feb		\bar{v}	3.13	3.66	3.94	4.35	4.07	4.76	5.12	5.66
		k	1.47	1.59	1.65	1.73	1.67	1.81	1.88	1.97
		c	3.46	4.08	4.40	4.88	4.56	5.36	5.77	6.38
Mar		\bar{v}	3.47	4.06	4.37	4.82	4.5	5.26	5.66	6.25
		k	1.55	1.67	1.73	1.82	1.76	1.90	1.98	2.08
		c	3.86	4.54	4.90	5.42	5.05	5.93	6.39	7.06
Apr		\bar{v}	3.51	4.11	4.42	4.88	3.6	4.21	4.53	5.00
		k	1.56	1.68	1.74	1.83	1.57	1.70	1.77	1.86
		c	3.90	4.60	4.96	5.49	4.01	4.72	5.09	5.63
May		\bar{v}	3.71	4.34	4.67	5.16	3.33	3.90	4.19	4.63
		k	1.60	1.73	1.79	1.88	1.51	1.64	1.70	1.79
		c	4.14	4.87	5.25	5.81	3.69	4.35	4.70	5.20
Jun		\bar{v}	3.55	4.15	4.47	4.93	4.09	4.79	5.15	5.68
		k	1.56	1.69	1.75	1.84	1.68	1.82	1.88	1.98
		c	3.95	4.65	5.02	5.55	4.58	5.38	5.80	6.41
Jul		\bar{v}	3.16	3.70	3.98	4.39	3.7	4.33	4.66	5.14
		k	1.48	1.60	1.66	1.74	1.60	1.73	1.79	1.88
		c	3.49	4.12	4.45	4.93	4.13	4.86	5.23	5.79
Aug		\bar{v}	2.6	3.04	3.27	3.61	2.78	3.25	3.50	3.86
		k	1.34	1.45	1.50	1.58	1.38	1.50	1.55	1.63
		c	2.83	3.35	3.63	4.02	3.04	3.60	3.89	4.32
Sep		\bar{v}	2.36	2.76	2.97	3.28	2.44	2.85	3.07	3.39
		k	1.28	1.38	1.43	1.50	1.30	1.40	1.45	1.53
		c	2.55	3.02	3.27	3.63	2.64	3.13	3.39	3.76
Oct		\bar{v}	2.76	3.23	3.47	3.84	2.53	2.96	3.18	3.52
		k	1.38	1.49	1.55	1.63	1.32	1.43	1.48	1.56
		c	3.02	3.57	3.86	4.28	2.75	3.26	3.52	3.91
Nov		\bar{v}	3.04	3.56	3.83	4.22	3.29	3.85	4.14	4.57
		k	1.45	1.57	1.62	1.71	1.51	1.63	1.69	1.77
		c	3.35	3.96	4.27	4.74	3.65	4.30	4.64	5.14
Dec		\bar{v}	2.56	3.00	3.22	3.56	3.6	4.21	4.53	5.00
		k	1.33	1.44	1.49	1.57	1.57	1.70	1.77	1.86
		c	2.78	3.30	3.57	3.96	4.01	4.72	5.09	5.63

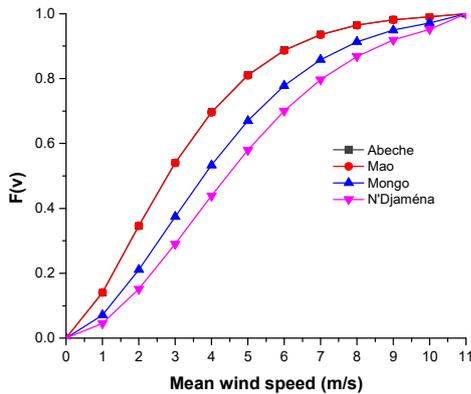


Fig. 14 Cumulative distributions at 100 m.

5.4 Analysis of solar parameters

This section presents the calculated parameters of global solar radiation by the Angstrom model and also a comparison with those NASA estimated for the four meteorological stations of the Sahelian zone of Chad. The data were collected for a period of 10 years. For each station, the parameters such as ω_s , δ , S_0 , S , a , b , H_0 and H were calculated using the equations of the model and the global solar radiation was described in the figures.

Fig. 15 illustrates the global solar radiation (H) for the four stations. The annual average global solar radiations observed are 6.52 kWh/m²/day, 6.66 kWh/m²/day, 6.78 kWh/m²/day and 6.82 kWh/m²/day, respectively at Mongo, N'Djamena, Mao and Abeche stations. In general, the value of the global solar radiation of the Sahelian zone is of the order of 6 kWh/m²/day. These results are similar to those obtained in the evaluation of global solar radiation made by Soulouknga *et al.*[9] and those of the NASA database as shown in Figs. 16, 17, 18 and 19. With a 13% rate of return for the solar photovoltaic sector, the solar energy produced is estimated, respectively at Mongo, N'Djamena, Mao and Abeche stations as 309.38 kWh/m²/year, 316.02 kWh/m²/year, 321.71 kWh/m²/year and 323.61 kWh/m²/year.

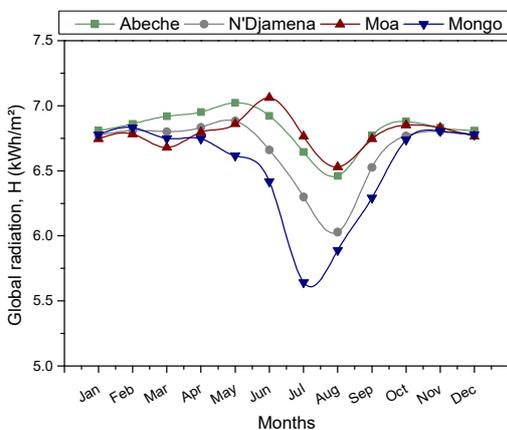


Figure 15: Global solar radiation-Angstrom model.

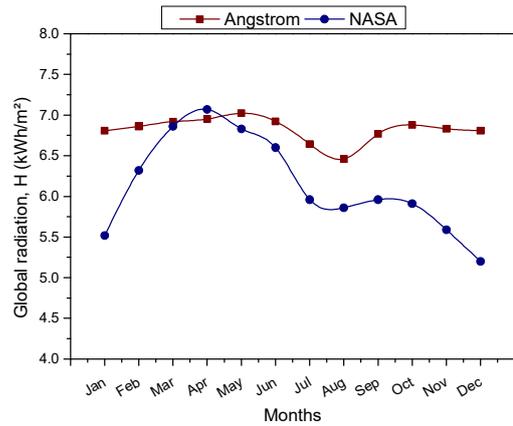


Figure 16: Global solar radiation of Abeche

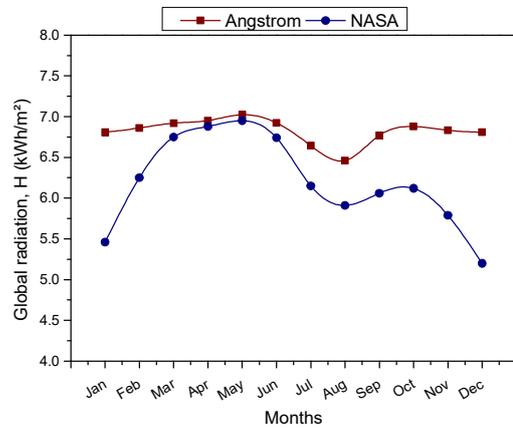


Figure 17: Global solar radiation of Mao

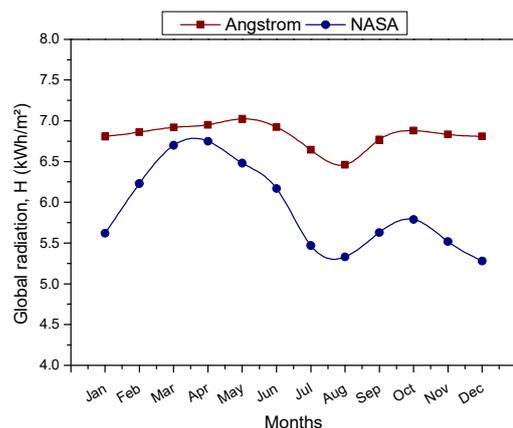


Figure 18: Global solar radiation of Mongo

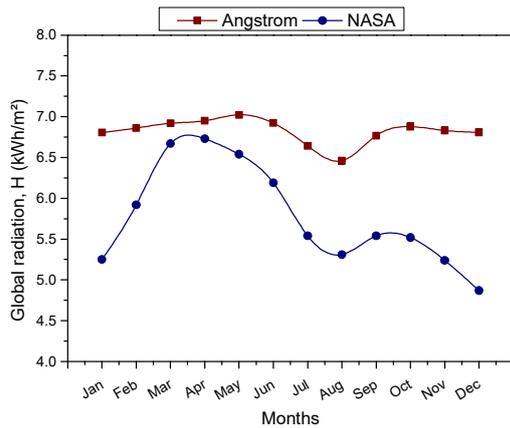


Figure 19: Global solar radiation of N'Djamena

6. Conclusion

In this assessment, a long-term meteorological data of ten years for four key stations at the Sahelian zone of Chad has been analyzed. The assessment has included the potential of wind power as well as solar power potential in the Sahel zone of Chad. The main goal of the current study was to determine the prospects of wind and solar energy and to provide the first comprehensive assessment of these energies at the Sahelian zone. The Weibull density function and empirical Angstrom model have been used to determine the wind energy and solar energy potentials, respectively. The yearly average shape and scale parameters of the Weibull distribution are broadly varied between 1.56 and 3.91 m/s at Abeche, 1.26 and 2.49 m/s at Mao, 1.44 and 3.33 m/s at Mongo and 1.54 and 3.85 m/s at N'Djamena, at the standard 10 m height.

The annual mean wind speed at this zone ranges between 2 m/s and 5.5 m/s with a corresponding mean power density between 69 W/m² to 74 W/m², at the standard height of 10 m. The data has been extrapolated to up to 100 m using the Power-Law. The power density has been found to increase significantly by nearly 120%, at 100 m height. The seasonal variations show that stronger wind speeds are generally available during the dry season between June and October and relatively lower wind speed is found during the wet season. The highest mean wind speed for all stations considered is found in the month of March except at Mongo where the highest speed occurred during May. The yearly maximum mean wind speed found was 4.42 m/s at N'Djamena, 3.8 m/s at Abeche, 3.79 m/s at Mongo and 2.76 m/s at Mao at 10 m height. However, with regard to energy density, Ndjamen showed the highest wind energy density, followed by Abeche, Mongo and Mao the exhibit the least energy density.

According to Angstrom, the more reliable mean global solar radiation value at the Sahelian zone is observed during the month of July with 5.64 kWh/m²/day at the meteorological station of Mao. Meanwhile, the highest mean global solar radiation is observed in June at the Mao station again with 7.06 kWh/m²/day. In comparison with the NASA data, the Angstrom model has proven to be favorable for the evolution of global solar

radiation in the four meteorological stations of Sahelian zone of Chad. Furthermore, it is also concluded that although the average wind energy density at N'Djamena was found to be the highest, the solar energy potential at Abeche was observed to be the most promising. Whereas, the lowest wind and solar potentials are found respectively at Mao and Mongo stations.

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