A Study of the Wind Potential in Climatic Zones of Chad

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Abstract. This paper focuses on the assessment of wind energy potential in the three climatic zones of Chad: the Saharan (north), the Sahel (center) and the Sudan (south) zones. For each zone, three representative meteorological locations were chosen and assessed based on satellite data provided by NASA. The data comes from MERRA (Modern-Era Retrospective Analysis for Research and Applications) and covers the period 2005–2014. The wind speed frequency distribution of locations was found by using Weibull distribution function. From this statistical data analysis, we found that the wind regime is different in the three regions. It is higher in the Saharan region (with annual mean wind speed of 5.78 m/s) followed by the Sahel (4.32 m/s) and Sudanian (3.7 m/s) regions. There are two distinct seasons in Chad: the dry and the rainy seasons with varying periods, with respect to the regions (2 months of rain in the Saharan zone vs 7 months in the Sudanian zone). For all regions the mean wind speed is higher in the dry season. Diurnal variations of mean wind speed show two regimes characterized respectively by high values in the early morning and the night and low values during the day. The corresponding power density was 193 w/m^2, 76.15 w/m^2 and 29.0 w/m^2, resp. for the Saharan, Sahelian and Sudanian regions. The wind regimes are globally stable with dominant directions North-East (for Saharan region), East (Sahelian), South-Southwest (Sudanian).

Keywords: Wind energy · Wind potential · Chad climatic zones
Weibull · Power density · Turbulence index

1 Introduction

Chad's ability to achieve increased energy access and poverty reduction is constrained by significant challenges in the power sector. It currently only has about 125 MW of installed generation capacity to serve a population of 14.5 million people. As a result, Chad's

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government is working to expand its electricity supply and encourage investment in the energy sector to stimulate the economy. Chad is endowed with the tenth-largest oil reserves in Africa, as well as wind and solar resource potential. The majority of its existing capacity comes from diesel and HFO generation [1]. Usage of fossil energy resources can create new problems environment and natural resources (NR). In addition, high oil prices and the growing depletion of existing sources, will require new and renewable energy sources to replace fossil energy. One of new and renewable energy resources is wind energy. Wind is a solar energy formation which occurs when the sun heats the air and causing air to rise and form a vacuum, then vacuum down to the cooler air form the wind. Wind occurs because of uneven heating by the sun. Experts estimate that the energy of sunlight received by the earth may be converted into wind kinetic energy of nearly 2% [2]. So, wind energy appears as a clean and good solution to cope with 11 a great part of this energy demand [3]. Meanwhile exploitation of Wind energy need precious evaluation of potential in the desired location. This means to have good database for minimal one entire year with a good time resolution. Recently, many researchers [4–10] have studied the wind energy resources in the sites all over the world. Government of Chad strategy involved the use of Renewable energy for rural electrification and income activities. So, the contribution of this paper is to evaluate the wind power potential in the three climatic zones of Chad: Sudanian, Sahelian and Saharan zones to undertake it, the paper is arranged in three sections; in Sect. 2, we present the material (data) and mathematical models of the underlying theory and statistically analyze the data set. Section 3 is dedicated to discussing the results of our findings and we end with a conclusion in Sect. 4.

2 Material and Method

2.1 Description of the Sites and Used Data

Chad is located between the 7th and 24th degrees North and the 13th and 24th degrees East. It is divided into three (3) major bioclimatic zones, namely the Saharan, Sahelian and Sudanian zones.

The Saharan zone covers an area of 600’350 km^2 or 48% of the land area. Its climate ranges from isohyets 0–200 mm and is characterized by low annual rainfall (less than 200 mm).

The Sahelian zone covers an area of 490’570 km^2. It extends between isohyets 200 to 600 mm.

The Sudanian region, is the wettest part of the country and is characterized by a rainfall of 600 to 1200 mm.

For our study we selected nine (9) cities; three (3) in each climatic zone. The geographical positions of these cities are shown in Table 1 below.

Due to the lack of data from meteorological stations during period and with good time resolution, we use the MERRA (Modern-Era Retrospective Analysis for Research and Applications) satellite data from NASA. Data have tested and validate using field

Table 1. Geographical position of the selected sites

Zones	Cities	Latitude	Longitude	Altitude (m)
Saharan	Bardaï	21.3544	17.001	1088
	Fada	17.1667	21.55	588
	Faya	18	19.1667	235
Sahelian	Abéché	13.85	20.85	628
	Bol	13.4667	14.7167	281
	Ndjamena	12.1333	15.0335	296
Soudanian	Moundou	8.5667	16.0853	423
	Pala	9.3667	14.9667	460
	Sarh	9.1333	18.3833	363

truth. Data have been sampled hourly that includes wind speed, relative humidity, pressure, and temperature and wind directions. It covers the period 2005 to 2014 that is ten year, with 87648 records for each site. Data are available at 10 m of altitude above Sea level.

The duration of the rainy season in Chad decreases from South to North. There are seven (7) months of rainfall in the Sudanian zone, around 4–6 months in the Sahelian zone and 0–2 months in the Saharan area.

2.2 Approach and Theoretical Models

The estimation of the wind potential is based essentially on the determination of the mean wind speed, the power density, the turbulence index, the shear coefficient, allowing the extrapolation of the wind speed at altitude, as well as the determination of the wind rose to indicate the dominant wind direction.

As part of this paper, the average of these parameters was determined for each year, each month and for each season. This work was done for each of the three regions of Chad. The analysis of the influence of the hourly variation of these parameters on the quality of the potential was also carried out. The model to calculate the last parameters is given the following seven equations.

2.2.1 Mean Wind Speed

In the present study, the wind speeds data measured every hour for ten years in each site were used to calculate the wind potential. The annual, monthly and seasonal mean wind speed values were calculated by using Eq. (1), [11].

$$v_m = \frac{1}{n} \cdot \sum_{i=1}^{n} v_i \tag{1}$$

Where n is the observation number and v_i is the wind speed in time stage *i*.

2.2.2 Weibull Distribution

Weibull distribution has been commonly used in literature to express the wind speed distribution and to estimate the wind power density. The Weibull distribution is a good match with the experimental data. The probability density function of Weibull is given by Eq. (2) [16]. In the case of this study the Weibull distribution was determined and for every year, month and season. The Weill parameter (C and K) was calculated.

$$f(v) = \frac{K}{C} \cdot \left(\frac{v}{C}\right)^{K-1} \exp\left(-\left(\frac{v}{C}\right)^{K}\right) \tag{2}$$

Where C and K are respectively the scale and the shape parameters of Weibull, which can be determined by using the Maximum likelihood method Eqs. (3) and (4) [17].

$$K = \left(\left(\frac{\sum_{i=1}^{n} v_i^K \ln(v_i)}{\sum_{i} v_i^K}\right) - \left(\frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right)\right)^{-1} \tag{3}$$

$$C = \left(\frac{\sum_{i=1}^{n} v_i^K}{n}\right)^{\frac{1}{K}} \tag{4}$$

Smaller k values correspond to more variable (more gusty) winds and the higher A values correspond to a good potential.

2.2.3 Wind Power Density

The long-term wind speed distribution f (v) is combined with the available wind power to give the average wind power density, which can be expressed as follows [18]:

$$\bar{P} = \frac{1}{2} \cdot \rho \cdot C^3 \cdot \Gamma\left(1 + \frac{3}{K}\right) \tag{5}$$

Where Γ(x) is the gamma function of (x) given by:

$$\Gamma(x) = \int_{\grave{a}}^{\infty} t^{x-1} e^{-t} dt \tag{6}$$

2.2.4 Turbulence Index

The turbulence index is defined as the ratio of the standard deviation to the wind-speed (Eq. 1) [38]. It provides information on the turbulence of the site and can be used to explain the effects of the tower on the quality of the measured wind-speed data.

$$I_n = \frac{\sigma}{v_n} \tag{7}$$

σ: the standard deviation of the wind-speed (m/s)
v_m: mean wind-speed (m/s)

3 Results

It was observed that between 01 h am and 05 and 08 pm to -11 Pm, the mean wind speed quite the highest. The values of mean wind speed become the lowest between 10 am and 03 Pm. This implies that all the nine, the wind potential was higher during the nighttime compared to the daytime. Notice that the curves of the three sites of the Sudanian zone are in the bottom, followed by the curves of the Sahelian sites in the middle and the curves of the Saharaian sites that are at the top of the figures. It should also be noted that the wind speeds of the Bardaï are similar to the speeds of the sites located in the Sahelian zone. The mean wind speed collect was also used to calculate the level of turbulence site by determine the turbulence index given using Eq. **7** this parameters was determined for the all data, seasonal period and every hour on during 2005 to 2014. Figure 2 illustrates results for the hourly variation of turbulence index. It can be seen that the curves are decreasing from 01 am to 05 am and then between 04 pm and 12 am. It was the higher between 01 pm and 03 pm. While, the site of Bardaï has a pseudo periodic variation within the period of the day and the turbulence index reaches the higher value between 10 am and 11 am. This shows that on the 9 locations, the turbulence index was the lowest during the night time and the highest during the day-time.

A wind rose diagram is a representation of the frequencies of directions from which the wind blowing, on a given site and for a given observation period. The wind direction collected on the sites (every hour, for the period of 10 years) was used to determine the wind rose on the located site. Results for the all sites are illustrated by Fig. 1. It can be noted that the sites of Bol, Ndjamena, and Faya-Largeau have North-Est dominant direction. The dominant direction was Nort-Northwestern for Abéché, Fada and Bardaï, Est for Moundou, It is Sourth-sourthwertern for Pala and South-western for the site of Sarh (Fig. 3).

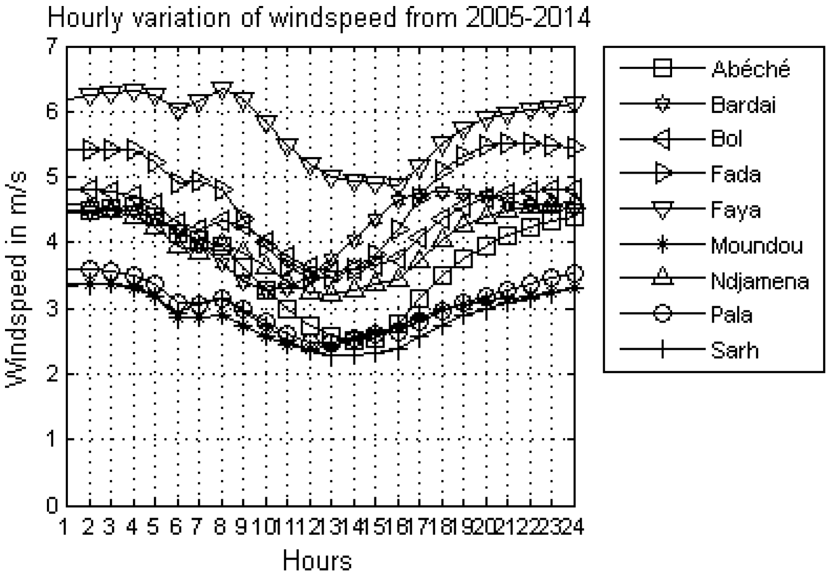

Fig. 1. Hourly variation of wind speed

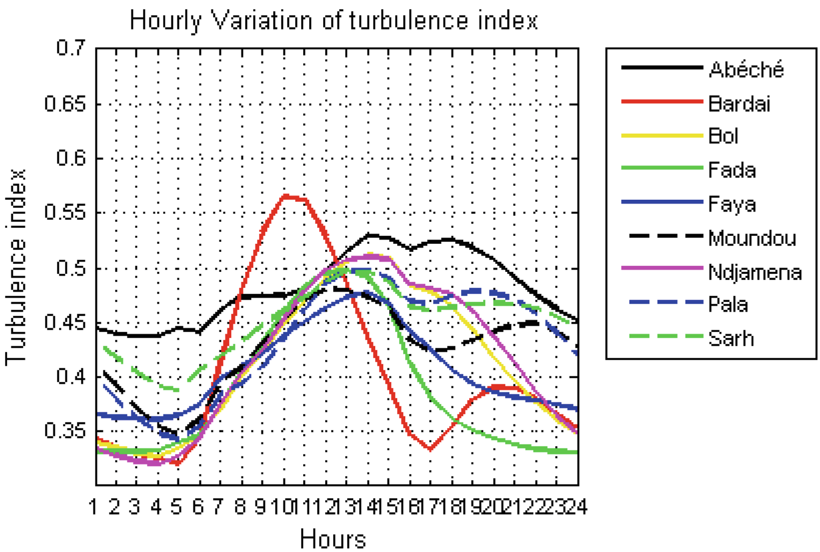

Fig. 2. Variations times of turbulence index.

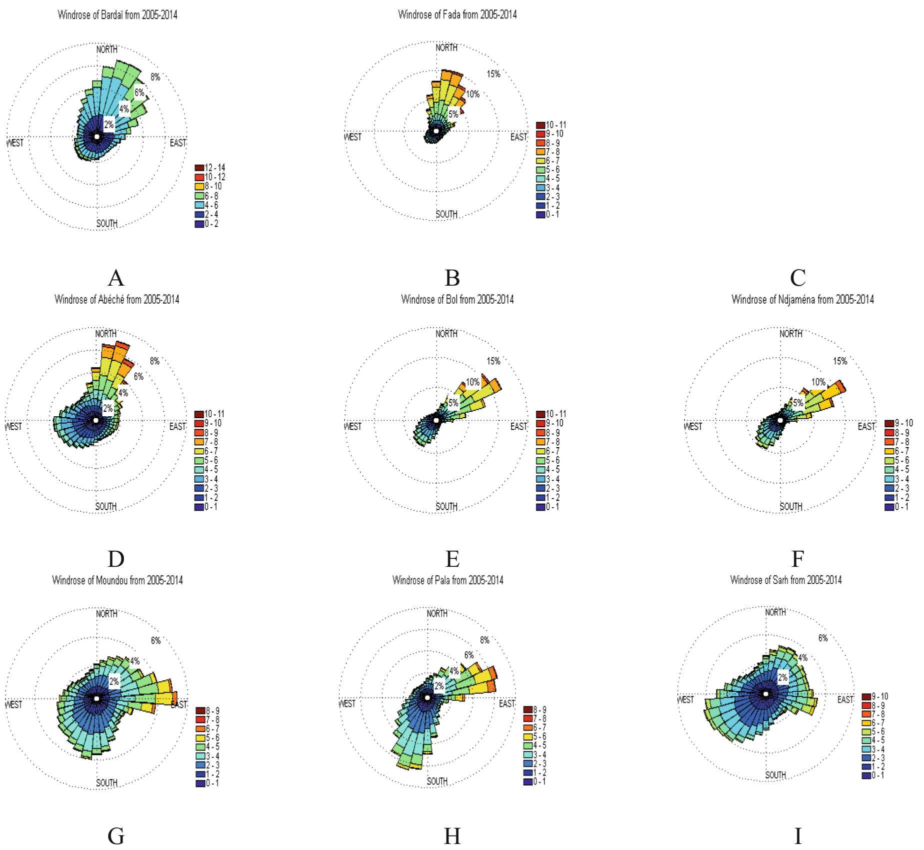

Fig. 3. The wind rose diagrams at an altitude of 10 m over 10 year period; A-Bardaï, B-Fada, C-Faya, D-Abéché, E- Bol, F-Ndjaména, G-Moundou, H-Pala and I-Sarh

4 Conclusion

This study has allowed us to have a better understand of the wind potential in Chad. It has shown that wind speeds on the nine selected sites are more important during the dry season than during the rainy season. We have also seen that during the 12 months of the year, there is a favorable month and an unfavorable month for each site. In addition it was found that the wind speeds are higher during the night than during the day. As for the wind roses, the most dominant directions oscillate between north and east during the dry season, and between south and west during the rainy season. However, we have noticed that the sites of Bardai and Faya-Largeau are not influenced by the rise of the monsoon; their dominant directions oscillate throughout the year between north and east. This means they often remain above the ITF (Intertropical Front) and under the domination of the Harmattan. This informs us on why this Saharan region remains suffers from scarcity of rain for the entire year. Still, the site of Bardai deserves special attention. In fact, despite being in the Sahara, its wind speeds are similar to those of the

Sahel zone. As such, this site requires a deep study with data measured on the ground, to understand its peculiarity vis-à-vis to other sites. Apart from this site, wind speeds are increasing going from the Sudan zone to the Sahara region. Finally, it is to be noted that the site of Faya-Largeau is windier than all the other sites, with an average speed of 5.78 m/s at altitude 10 m, a scale factor (C) of 6.5 m/s, and a form factor (K) 2.62.

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