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# Evaluation of Wind Energy Potential in a Sahelian Zone: A Case Study of Ouahigouya, Burkina Faso

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**Abstract** This study investigates the characteristics of the wind energy potential in Ouahigouya, Burkina Faso. For this purpose, eleven-years data (2006-2016) of wind speed (at 10 m above ground level (AGL)) and surface temperature data from Burkina Faso meteorological agency and wind speed (50 m AGL) from the NASA were used. Based on the mean vertical profile of wind speed at monthly and annual scales, the Weibull function was used to characterize the wind speed frequency distribution and to calculate the wind power density. Major results indicate that the peaks of mean wind speeds are estimated at 3.51 $m.s^{-1}$ (May) and 5.18 $m.s^{-1}$ (March) for the 20 m and 50 m altitudes respectively. The mean annual wind speed at the 20 m AGL at the site is estimated at 2.87 $m.s^{-1}$ while at 50 m AGL, a value of 4.33 m.s-1 is recorded. The estimated wind power density reveals that the largest amounts of energy are generally collected during the months corresponding to the dry season with peaks in March or May depending on the height. The amount of energy available at 20 m AGL varies from 32.90 W/m2 (September) to 84.97 W/m2 (May). At 50 m AGL, this value varies respectively from 68.68 W/m2 (August) to 346.47 W/m2 (March). Average annual power density amounts are estimated at 65.92 W/m2 at 20 m and 223.17 W/m2 at 50 m, respectively, for a growth rate of 70.46 %. In view of these results, the Ouahigouya site could be conducive to the installation of small and medium-sized turbines to supply rural communities with electrical energy.

***Keywords:*** *wind potential, Weibull distribution, power density, vertical profile*

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## 1. Introduction

Electricity is the backbone of socioeconomic development of any nation. With the massive industrialization and a growing population, electricity supply has become a challenge since the last decades. According to the International Energy Agency, most of the electricity worldwide comes from fossil fuels. The combustion of fossil fuels is well acknowledged in the literature that is the major source of carbon dioxide (CO2) which is the main cause of climate change; hence the increase of global mean temperature. Due to the negative effect of fossil fuels on the environment, many countries are turning towards renewable energy sources for electricity generation. Renewable energy is defined as energy that naturally replenishable in human lifetime and does not emit CO2 into the atmosphere. The potential of renewable energy worldwide is sufficient to the meet the energy demand. In addition, renewable energy will be an opportunity for developing countries like Burkina Faso to stand on to increase the electricity production for their population.

The electricity production in Burkina Faso comes mainly from thermal power (42%) plant and hydro-power (8%) and 50% comes from imported electricity (Ghana and Cote D'Ivoire) [1]. With a growing population, the country is challenging to meet the electricity demand. Only 18% of the population in the urban areas has access to electricity from the grid while 3% in the rural areas. Also, the country is experiencing interrupted electricity throughout the year and mostly during the hottest period (March to May). Since 2016, the internal electricity production remains constant while the population is still growing. Therefore, to meet the electricity demand in the country, there is a need to increase the electricity production in an environmentally friendly manner in combination with existing power plants. Wind energy could contribute to the energy mix in Burkina Faso. With the recent technological developments in wind energy, the evaluation and development of the wind potential for electricity production could be an additional energy solution for the country. In this context, this study evaluates the wind energy potential to serve as benchmark for decision-makers and as a tool in the framework of Burkina Faso' energy policy. To achieve that, an evaluation of wind speed at the site is needed.

Various studies have evaluated the wind energy potential over different regions based on the work of Justus et al. (1976) [2]. In last decade, many studies have been assessed the onshore and offshore wind power over Africa. For instance, in the Northern part of Africa, Nfaoui et al. (1991) [3] and Merzouk et al. (2007) [4] have assessed the potential of wind energy over Morocco and Algeria respectively. Over the West Africa region, Toure et al. (2000) [5] have used the Weibull distribution of wind speed to evaluate the potential of wind energy in Cote D'Ivoire. The work of Madougou (2010) [6] has also quantified the wind energy in Niamey. He found the economically feasible of wind energy potential at 150 m above the ground level (AGL) while at 65 m (AGL) the wind energy potential is not economically feasible in Niamey (Abdou, 2011) [7]. Similar study has been carried out in Cotonou coastal area by Donnou et al. (2018) [8] where their results showed that the area is suitable for the installation of wind turbines. Souloukngа et al. (2017) [9] and Didane et al. (2017) [10] have also investigated the wind energy potential over Chad. In the northwestern coast of Senegal, the wind power density is estimated between 30.05 W/m2 and 120.01W/m2 (Bilal et al., 2013) [11].

In Burkina Faso, a study of Landry et al. (2016) [12] have evaluated the wind speed at 30, 50 and 80 m above the ground level (AGL). The results shown that, the northeastern part, the northern and the western part of country exhibit wind speed value of more than 9.01 m/s. Another study of Seydou Ouedraogo et al (2017) [13] have also assessed the wind power density at specific location (Dori, Ouagadougou and Ouahigouya) at 10 m (AGL). However, these studies done in Burkina Faso have some shortcomings. For instance, the study of Landry et al. (2016) [12] did not tackle the wind power density which is an indicator for wind energy resource. The results present the wind power density at 10 m (AGL) which is not sufficient for wind energy at large scale. So, the lack of information on wind power density at the hub height could be an obstacle for wind energy development in Burkina Faso. In addition, these different studies extrapolated the wind speed from 10 m (AGL) at the different heights with the power law or logarithmic model (Sen et al., 2012 [14]; Gualtieri and Secci, 2014 [15]) while the vertical profile of wind speed differ from one site to another due to the atmosphere condition (Boro et al., 2019) [16].

The study therefore, aims to evaluate the wind power potential from 10 to 50 m AGL by considering the atmospheric condition of Ouahigouya. More specifically, to determine the wind shear coefficients of the power law according to atmospheric conditions. Moreover, the wind power density and its variability has been also assessed. The next section describes the study area, the data used and presents the methodology used in this study. The section 3 exhibits the results and discussions on the evaluation of wind energy at Ouahigouya site.

## 2. Data and Methodology

### 2.1. Study Area

The study focuses on the city of Ouahigouya, located in the Sahelian zone of Burkina Faso (Figure 1). Burkina Faso is a landlocked country located in the heart of West Africa and surrounded by six other countries. The country has three major climatic zones. The Sahelian climatic zone located in the northern part of the country is characterized by an annual rainfall less than 650 mm while the Sudano-Sahelian climatic zone (between 11° and 14° North latitude) is characterized by annual precipitation between 650 and 1000 mm. The Sudanian climatic zone (below 11° 30 'North latitude) is characterized by annual precipitation greater than 1000 mm (FAO, 1986) [17].


**Figure 1.** Geographic location of the study site

## 2.2. Data

We used two types of the data. The first data comes from the national meteorological agency of Burkina Faso. The data are recorded for the Ouahigouya' synoptic weather station at 3 hourly time steps. We have collected temperature and wind speed (10 m AGL) data for the period of eleven years (from 2006 to 2016). The second data consist of using the NASA Prediction of Worldwide Energy Resource. From their platform (https://power.larc.nasa.gov/data-access-viewer), We retrieved daily wind speed data at 50 m AGL (2006-2016).

## 2.3. Methodology

### 2.3.1. Wind Speed Extrapolation

The study of Boro et al. (2019) [16] has determined the vertical profile of wind speed in Bobo-Dioulasso from wind speed and temperature data at 10 and 50 m AGL. They have showed that the log-linear law and the power law are needed to be adapted to characterize the vertical profile of the wind speed. The authors have developed an adjustment equation based on the power law within the boundary layer between 10 and 50 m AGL. We apply the same methodology in this study for the vertical profile of wind speed in Ouahigouya.

#### 2.3.1.1. Log-linear Law

The log-linear law considers the friction wind speed, the roughness length and the length of Monin-Obukhov. It expresses as (Monin and Obukhow, 1954) [18].

$$v(z) = \left(\frac{u_*}{\kappa}\right)\left[\ln\left(\frac{z}{z_0}\right) - \psi\left(\frac{z}{L}\right)\right] \tag{1}$$

Where $L$ is the length of Monin-Obukhov, $z_0$ the roughness length, $u_*$ is the friction wind speed (m/s). $\psi(z/L)$ is the correction function of stability and $k$ is the constant of Von Karman ($k = 0.4$).

#### 2.3.1.2. Power Law

The power law has been proposed by G. Hellman and it is based on wind speed observation. In general, this method is simple to use for engineering studies (Bañuelos-Ruedas et al., 2010) [19]. Moreover, the power law makes possible to overcome the difficulties encountered in the use of the log-linear law in terms of input parameters. The expression is given by (Secci and Gualtieri, 2011; Rehman and Al-Abbadi, 2005; Richards and Spera, 1979):

$$\frac{v_h}{v_1} = v_1\left(\frac{z_h}{z_1}\right)^{\alpha} \tag{2}$$

where $v_1$ is the wind speed at 10 m AGL. α is the wind shear coefficient and it is a function of atmospheric stability and the roughness length (Gualtieri, 2019 [20]; Leclerc and Foken, 2014 [21]). it is given by the Equation (3) and Equation (4):

$$\alpha_{insta} = \frac{\left(1-16(Z/L)\right)^{-1/4}}{\ln\left((\eta-1)(\eta_0+1)/(\eta+1)(\eta_0-1)\right) + 2Arc\tan(\eta_0)} \tag{3}$$

with $\eta = \left(1-16(Z/L)\right)^{1/4}$ and $\eta_0 = \left(1-16(Z_0/L)\right)^{1/4}$

$$\alpha_{sta} = \frac{1+5(Z/L)}{\ln(Z/Z_0)+5(Z/L)}. \tag{4}$$

From Eq. (3) and Eq. (4) the wind shear coefficients are computed at annual average at 10 m AGL, and then we inferred the vertical wind speed profile. This vertical wind speed profile is used to evaluate the wind energy at 20 m and 50 m AGL.

### 2.3.2. Evaluation of Wind Power

#### 2.3.2.1. Statistical distribution of wind speed

Over the last decades, many mathematical distribution functions have been developed and tested by researchers in the wind energy field. For example, we have the Beta, Erlang, exponential, Gamma, Log normal, Pearson V, Pearson VI, Uniform and Weibull distribution function. For this study, we use the Weibull distribution function because it is the most appropriate distribution to analyse and represent the wind speed and it is expressed as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{5}$$

$$k > 0, v > 0, c > 0$$

Where $k$ is the shape parameter and it is dimensionless; $c$ is the scale parameter (m/s) and $v$ is the wind speed (m/s). The cumulative of Weibull distribution function is given by

$$F(v) = 1-\exp\left[-(v/k)^{k}\right]. \tag{6}$$

The mean wind speed ($\underline{v}$) and the stand deviation (σ) can be expressed from the Weibull distribution parameter:

$$\bar{v} = c\Gamma(1+1/k). \tag{7}$$

$$\sigma^2 = c^2\left[\Gamma(1+2/k) - \Gamma^2(1+1/k)\right] \tag{8}$$

Where $\Gamma$ is the gamma function and it is expressed as:

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

Many methods are used to determine the Weibull distribution parameters. In this study we use the maximum likelihood method to compute the shape and the scale parameters and the equations are given by:

$$k = \left(\frac{\sum_{i=1}^{n} V_i^k \ln V_i}{\sum_{i=1}^{n} V_i^k} - \frac{1}{n}\sum_{i=1}^{n}\ln V_i\right)^{-1} \tag{9}$$

$$c = \left( \frac{1}{n} \sum_{i=1}^{n} V_i^k \right)^{1/k} \qquad (10)$$

Where $v_i$ is the wind speed at the course of time i and n is the non-zero wind speed observation number. Equation (9) can be solved using an iterative procedure (k = 2 is the appropriate initial conjecture), then equation (10) is solved explicitly. Equation (9) must be used for non-zero wind speed data points only. The most probable wind speed and the wind speed carrying the maximum energy are defined by expressions (11) and (12) [16].

$$v_{mp} = c\left(\frac{k-1}{k}\right)^{1/k} \qquad (11)$$

$$v_{E\max} = c\left(\frac{k+1}{k}\right)^{1/k} \qquad (12)$$

#### 2.3.2.2. Wind power density

Wind power density is the most important characteristic of wind energy. It represents the amount of mechanical energy produced by the wind speed. Considering that S is the cross section through which the wind blows perpendicularly, the mean power density of the wind is given by Rasouli et al. (2015) [22]:

$$\overline{P} = \int_0^{\infty} P(v) f(v) dv \qquad (14)$$

with $P(v) = \frac{1}{2}\rho s v^3$ representing the power carried by the wind speed $v$. By integrating equation (14), we obtain the expression of the average available wind power density:

$$\overline{P} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \qquad (15)$$

where $\rho$ is the density of air depending on the height. In this study we will consider the air density constant with a value of 1.23 kg/m$^3$

## 3. Results

The Table 1 exhibits the wind shear coefficients according to the atmospheric conditions at monthly and annual average. The analysis shows two main conclusions. First, the values of the wind shear coefficients are higher under stable atmospheric conditions than the unstable ones throughout the year. Second, the maximum values are recorded during the dry season while the minimum values occurred during the rainy season. This may be explained by the turbulence above the ground which slows down the wind shear during the rainy season than the dry season where there is no turbulence.

Figure 2 and Figure 3 show the average vertical profiles of wind speed respectively in unstable and stable atmospheric conditions. In both conditions, the windiest months occur during the dry season with maximum values in March and December. For instance, the maximum wind speed in the unstable condition are estimated at 6.43 m / s and 6.29 m /s respectively at 50 m AGL while in stable condition the values 6.75 m / s (March) and 6.60 m / s (December). The minimum wind speed values are recorded during the months of July, August and September and the magnitudes are respectively 3.99 m / s; 3.56 m / s; 3.99 m / s for the unstable period However, under the stable condition the values are 4.19 m / s; 3.73 m / s and 4.19 m / s.

**Table 1. Values of wind shear coefficient based on atmospheric stability**

| Months | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| unstable | 0.53 | 0.47 | 0.58 | 0.43 | 0.30 | 0.16 | 0.15 | 0.24 | 0.36 | 0.57 | 0.65 | 0.65 | 0.67 |
| stable | 0.56 | 0.50 | 0.61 | 0.46 | 0.33 | 0.19 | 0.18 | 0.27 | 0.39 | 0.60 | 0.68 | 0.68 | 0.7 |

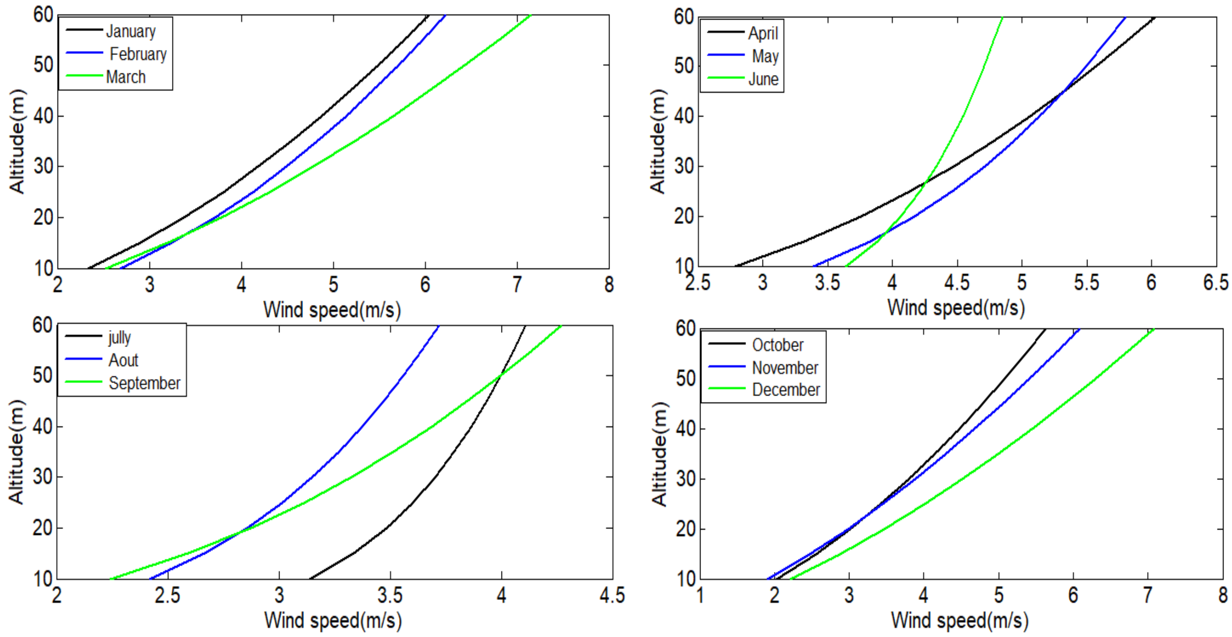


**Figure 2.** Vertical profile of the annual mean wind speed under unstable atmospheric condition

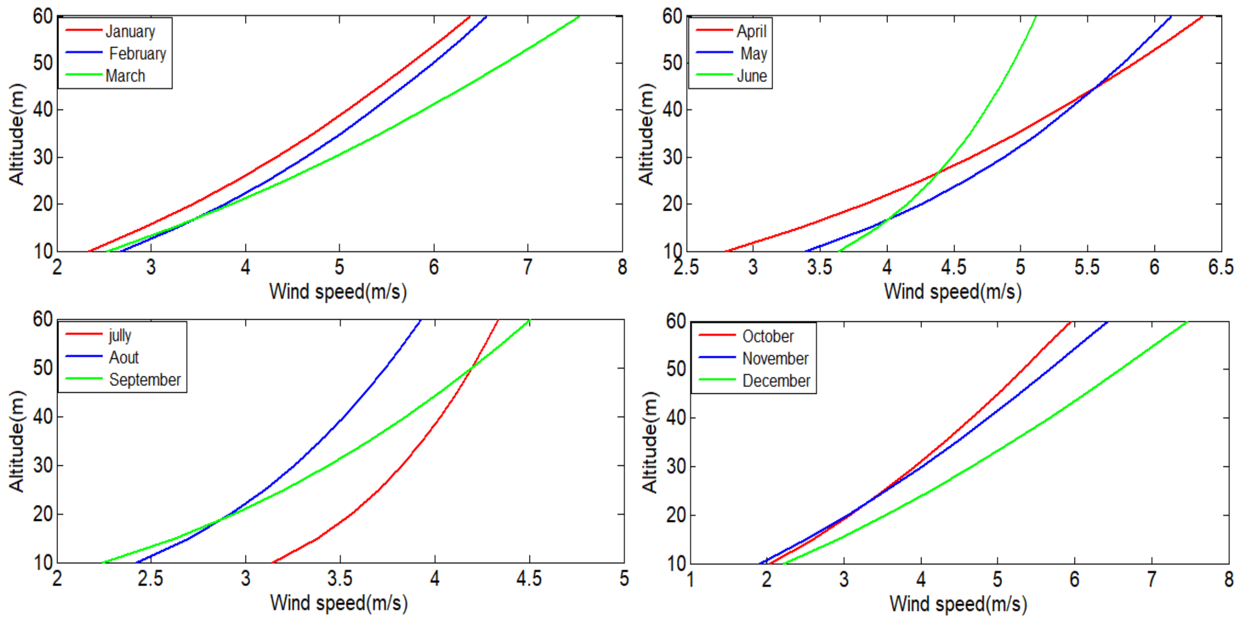


**Figure 3**. Vertical profile of the annual mean wind speed under stable atmospheric conditions

## 3.1. Variability of wind power density

### 3.1.1. Parameters of Weibull Distribution Function

Table 2 exhibits the values of the Weibull parameters as function of the height throughout the year. The two Weibull parameters (c and k) increase as the height increases. However, the shape parameter k slightly increases unlike the scale parameter c. For example, the shape parameter k varies from 1.72 (April) at 20 m and 2.14 (June) at 50 m AGL. Note that, the low values of k (k <1) indicate a prevailing weak wind; k = 2 indicate the isotropic conditions. For values of k ranging between 1 and 2, the winds are dispersed in all directions (spread distribution), while values greater than 2 indicate a preferred direction (narrow distribution). The high values of k are observed during the windiest months and the low values during the least windy months. The scale parameter c, varies from 3.34 $m.s^{-1}$ in September at 20 m to 7.25 $m.s^{-1}$ in March at 50 m AGL. The study suggests that the more frequent wind in a month corresponds to high Weibull parameters.

### 3.2.2. Wind Speed Distribution

Figure 4 shows the distribution of wind frequencies from the Weibull probability density function on an annual scale. The frequency of occurrence of the wind speed reaches different peaks depending on the altitude (20 to 50 m AGL). The average annual wind speed is estimated at 2.57 m/s at 20 m AGL with an occurrence frequency of 19%. The wind speed reaches the value of 4.21 m/s with a frequency of 13% at 50 AGL. This suggests that wind turbines with a starting speed in the range 2 m/s and 4 m/s will be the most suitable for optimizing production at 20 m and 50 m AGL.

### 3.2.3. Maximum Wind Energy Carried by the Wind Speed

The maximum wind energy carried by the wind speed varies throughout the year and increases as the height increases (Figure 5). The values are 4.78 m/s (September) and 6.67 m/s (April) at 20 m AGL while at 50 m AGL, the values reach 6.5 m/s and 9.5 m/s respectively. The average annual value of maximum wind energy carried by the wind speed at 20 m and 50 m are 6.17 m/s and 9.22 m/s respectively. Therefore, wind turbines with nominal operating speeds close to 6 m/s and 9 m/s are suitable for optimizing wind energy production at 20 m and 50 m AGL respectively.

**Table 2. Scale and shape parameters of Weibull function for Ouahigouya site at 20, 30, 40 and 50 m AGL**

| | 20m | | | 30m | | | 40m | | | 50m | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | $\overline{V}$ | k | c | $\overline{V}$ | k | c | $\overline{V}$ | k | c | $\overline{V}$ | k | c |
| January | 2.66 | 1.94 | 3.94 | 3.30 | 1.95 | 4.88 | 3.85 | 1.96 | 5.69 | 4.33 | 1.98 | 6.40 |
| February | 3.01 | 1.81 | 4.03 | 3.65 | 1.82 | 4.87 | 4.18 | 1.83 | 5.58 | 4.64 | 1.84 | 6.20 |
| March | 3.04 | 1.88 | 4.26 | 3.85 | 1.89 | 5.39 | 4.55 | 1.90 | 6.37 | 5.18 | 1.91 | 7.25 |
| April | 3.09 | 1.72 | 4.26 | 3.68 | 1.73 | 5.07 | 4.16 | 1.74 | 5.74 | 4.58 | 1.75 | 6.32 |
| May | 3.51 | 1.88 | 4.51 | 3.97 | 1.89 | 5.10 | 4.32 | 1.90 | 5.56 | 4.62 | 1.92 | 5.94 |
| June | 3.51 | 1.96 | 4.35 | 3.74 | 1.97 | 4.64 | 3.92 | 1.98 | 4.86 | 4.06 | 1.99 | 5.04 |
| July | 2.93 | 1.89 | 3.78 | 3.11 | 1.90 | 4.02 | 3.25 | 1.91 | 4.20 | 3.36 | 1.92 | 4.34 |
| August | 2.27 | 1.86 | 3.38 | 2.51 | 1.87 | 3.73 | 2.69 | 1.88 | 3.99 | 2.83 | 1.89 | 4.21 |
| September | 2.23 | 1.96 | 3.34 | 2.59 | 1.97 | 3.86 | 2.87 | 1.98 | 4.29 | 3.11 | 1.99 | 4.65 |
| October | 2.27 | 1.88 | 3.60 | 2.86 | 1.89 | 4.54 | 3.38 | 1.90 | 5.35 | 3.83 | 1.91 | 6.07 |
| November | 2.04 | 1.87 | 3.44 | 2.66 | 1.88 | 4.48 | 3.21 | 1.89 | 5.40 | 3.71 | 1.90 | 6.24 |
| December | 2.68 | 2.00 | 4.01 | 3.50 | 2.10 | 5.21 | 4.21 | 2.11 | 6.29 | 4.87 | 2.14 | 7.27 |
| Annual | 2.87 | 1.79 | 4.06 | 3.44 | 1.80 | 4.88 | 3.92 | 1.81 | 5.55 | 4.33 | 1.82 | 6.14 |

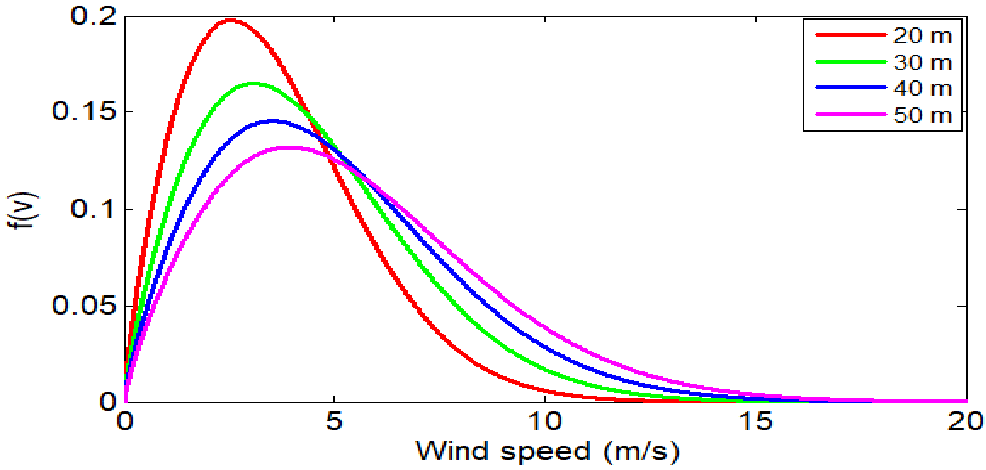


**Figure 4.** Annual distribution of wind speed of Weibull function at Ouahigouya (2006-2016)

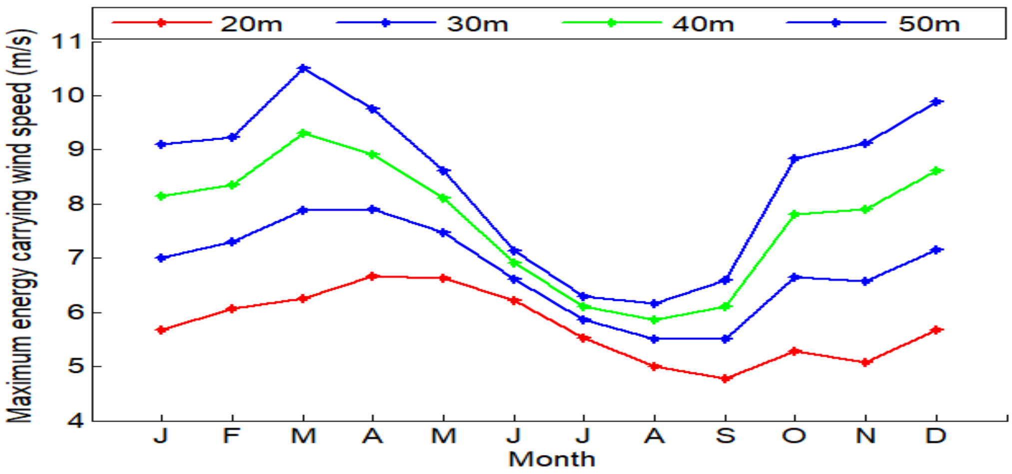


**Figure 5.** Monthly mean of the maximum energy carrying wind speed at 20, 30 40 and 50m AGL.

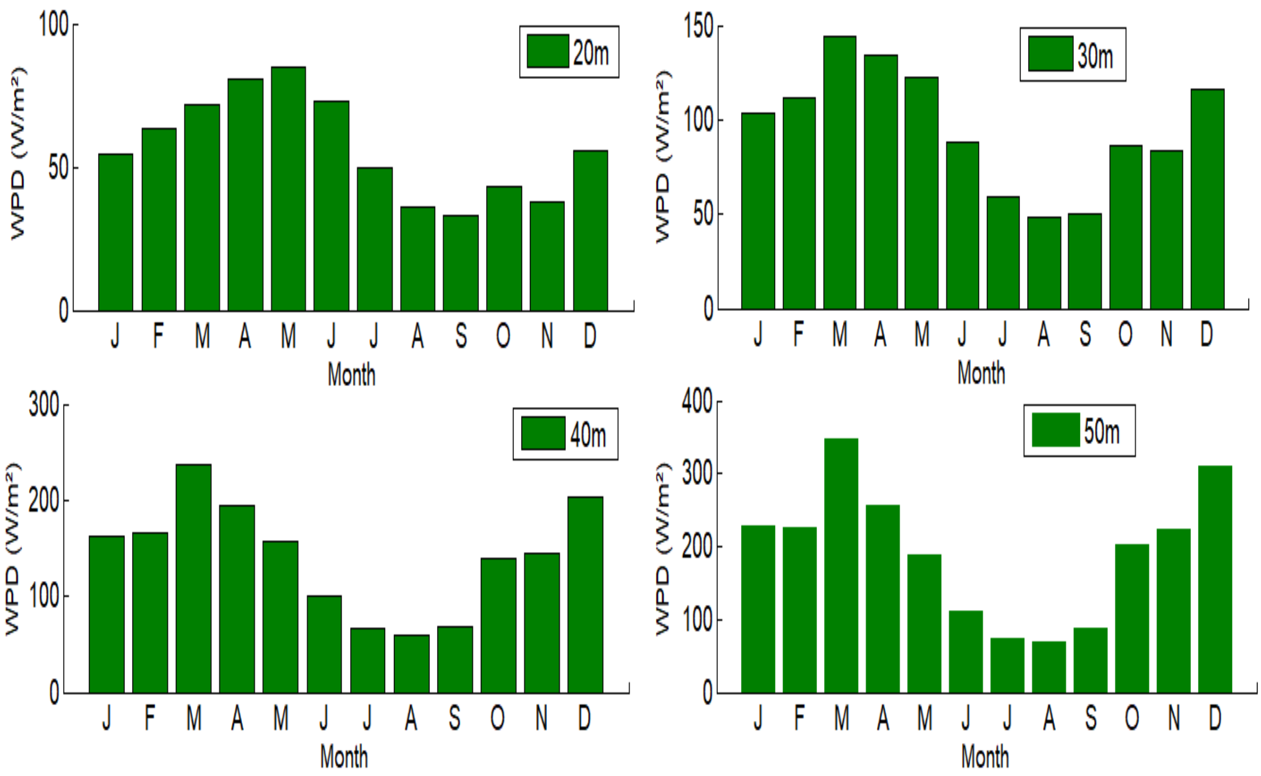


**Figure 6.** Monthly mean of wind power density at 20, 30, 40 and 50 m AGL at Ouahigouya site (2006-2016)

### 3.2.4. Wind Power Density

The wind power density varies according to the month. Moreover, it is strongly influenced by the different seasons of the year (dry and rainy season) and presents two peaks obtained during the year. The first peak appears in March and the second peak in December. There is an increase in wind energy from January to May, followed by a decrease from June to September. In October, there is again an increase until December for an increase of 20 m. For elevations of 30 m, 40 m and 50 m, we note an increase in wind energy from January to March, followed by a decrease from April to August. In September, there is again an increase until December. The period of the year during which the production of wind energy is most favorable is from January to June and from October to December while the unfavorable period of production is between July and September. The amount of energy available in terms of power density at 20 m from the ground on the Ouahigouya site varies from 32.90 W / m2 (September) to 84.97 W / m2 (May). At 50 m from the ground, this value varies respectively from 68.68 W / m2 (August) to 346.47 W / m2 (March). The average annual quantities of power density are estimated respectively at 65.92 W / m2 at 20 m and at 223.17 W / m2 at 50 m, i.e. growth rates of 70.46 %.

These different results obtained are comparable with previous studies done over the Sahel zone: Goundam (185 W/m2), Niafunke (170 W/m2), Timbuktu (136 W/m2), Koro (136 W/m2), Kayes (122 W/m2), Gao (119 W/m2), Nioro (110 W/m2), Bandiagara (101 W/m2), Mopti (95 W/m2), San (92 Wm2), Kangaba (60 W/m2), Kadiolo (51 W/m2) in Mali at 50 m AGL (Nygaard et al., 2017 [23]). The discrepancy between our results and those obtained on similar sites could be due to the time scale of wind speed data used. In addition, the extrapolation models used by some authors to determine the wind profile at hub height of wind turbines may underestimate or overestimate wind energy. To characterize the sites likely to host wind turbines or large-scale wind applications, the study of [24] reported that the wind power density can be classified in three classes. Areas designated as Class 1 (0 W/m2 to 200 W/m2) are generally not suitable for wind turbine applications, while areas designated as Class 2 (200 W/m2 to 300 W/m2) are marginal. Areas that can be classified as Class 3 (300 W/m2 to 400 W/m2) or higher are suitable for most wind turbine applications at 50 m AGL. Therefore, the results of the study show that Ouahigouya is suitable for the installation of small and medium sized wind turbines to produce energy.

## 4. Conclusion

This study was carried out in two main stages, the first consisted to develop specific extrapolation models for the Ouahigouya site (located in the Sahel area) in Burkina Faso. The second one consisted to use these different extrapolation models to evaluate the wind power density at the height ranging between 20 m and 50 m. The power law model was therefore developed for the different classes of atmospheric stability. This model was then used to extrapolate the wind speed at 10 m AGL. The main results of our study can be summarized as follows:

- The mean annual wind shear coefficients over the unstable and stable period are estimated to be 0.67 and 0.7 respectively.
- The maximum mean wind speeds were estimated at 3.51 m.s-1 (May) and 5.18 m.s-1 (March) at 20 m and 50 m AGL respectively. The annual mean wind speed at the 20 m elevation at the site is estimated to be 2.87 m.s-1 while at 50 m, a value of 4.33 m.s-1.
- The estimated wind power density is generally high during the dry season with a maximum value in March or May depending on the height.
- The amount of energy available in terms of wind power density at 20 m AGL at Ouahigouya site varies from 32.90 W/m2 (September) to 84.97 W/m2 (May) while at 50 m AGL, the values vary from 68.68 W/m2 (August) to 346.47 W/m2 (March).

With regard to the wind power density values, Ouahigouya is only suitable for housing small and medium-sized wind turbines for power generation. Specifically, wind turbines with a starting speed between 2 and 3 m.s-1 will be valuable. This production can therefore provide energy autonomy to populations, especially in rural areas for water pumping, water heating and electricity production. These results are therefore useful to investors in the field of wind energy in order to properly explore for energy applications.

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