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Assessment of Upper Guinea's Wind Energy Potential with a View to Identifying Exploitable Sites

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Abstract: As part of the national strategy to further develop the wind energy sector, the eight prefectures of Upper Guinea have been selected. Using meteorological data recorded over thirty years (1991-2021) at a height of 20 m, we assessed wind resources in terms of characteristic speeds, power and available energy. To this end, the Weibull distribution method was used and the following values were obtained: 3.66 m/s for the average speed; 1,102.83 W/m^2 for the available power and 8,747.06 kWh/m^2/year for the annual available energy.

Key words: Wind energy, Weibull distribution, high Guinea.

1. Introduction

Assessing Upper Guinea's wind energy potential is of crucial importance in the context of the global energy transition and the efforts being made by many countries to diversify their energy mix. Upper Guinea, with its mountainous terrain and vast expanses, offers ideal terrain for exploring the opportunities offered by wind power. This form of renewable energy offers undeniable advantages, such as its contribution to reducing greenhouse gas emissions and its ability to provide a reliable, sustainable source of electricity. Analysis of Upper Guinea's wind energy potential requires a multidimensional approach, encompassing geographical, meteorological, environmental and technological aspects [1]. The region's rugged topography directly influences wind patterns, while local weather conditions play a crucial role in determining the viability of wind farms. In addition, taking into account potential environmental impacts and socio-economic considerations is essential to designing wind energy projects that are sustainable and acceptable to local communities. This assessment of Upper Guinea's wind energy potential is part of a broader vision to diversify the country's energy sources and strengthen its energy independence. It aims to meet growing electricity needs, stimulate economic development and contribute to global targets for reducing greenhouse gas emissions [2]. By taking an in-depth look at the region's specific characteristics, this assessment aims to inform decision-makers, investors and energy sector players about the opportunities and challenges associated with exploiting Upper Guinea's wind energy potential.

2. Materials and Methods

2.1 Presentation of the Study Area

The Haute-Guinée region served as the setting for this study. One of the country's four natural regions, is closely linked to other regions by road networks and to the urban center of Conakry by rail. Airports are located at Kankan, Faranah and Siguiri. It has a total population of 1,094,584, including 568,570 women,

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living in 125,878 households. The average population density is 14.2 inhabitants per square kilometer, a lower value than the average of over 30 inhabitants in the country's other regions, covering an area of 245,857 km^2 according to the 2014 General Census of Population and Housing. The region comprises eight prefectures, including Kankan, Kouroussa, Siguiri, Faranah, Dabola, Dinguiraye, Kérouané and Mandiana. It stretches from latitude 10°50′ North to longitude 9°50′ West, at an altitude of 457 m. It is bordered to the west by Middle Guinea, to the north by Mali, to the east by Ivory Coast, and to the south by Forest Guinea. The region is mainly inhabited by the Malinké community, and the predominant religion among the population is Islam [3].

2.2 Study Framework

The Teaching and Research Laboratories in Applied Energy and Renewable Energy of the Gamal Abdel Nasser University of Conakry and the Higher Institute of Technology of Mamou served as a study framework for this present work.

2.3 Materials Used

Anemometer measuring device used:

- Matlab 2022 software;
- Wasp software 8.2;
- QGIS software 2.18;

Microsoft Excel.

Operation of the anemometer.

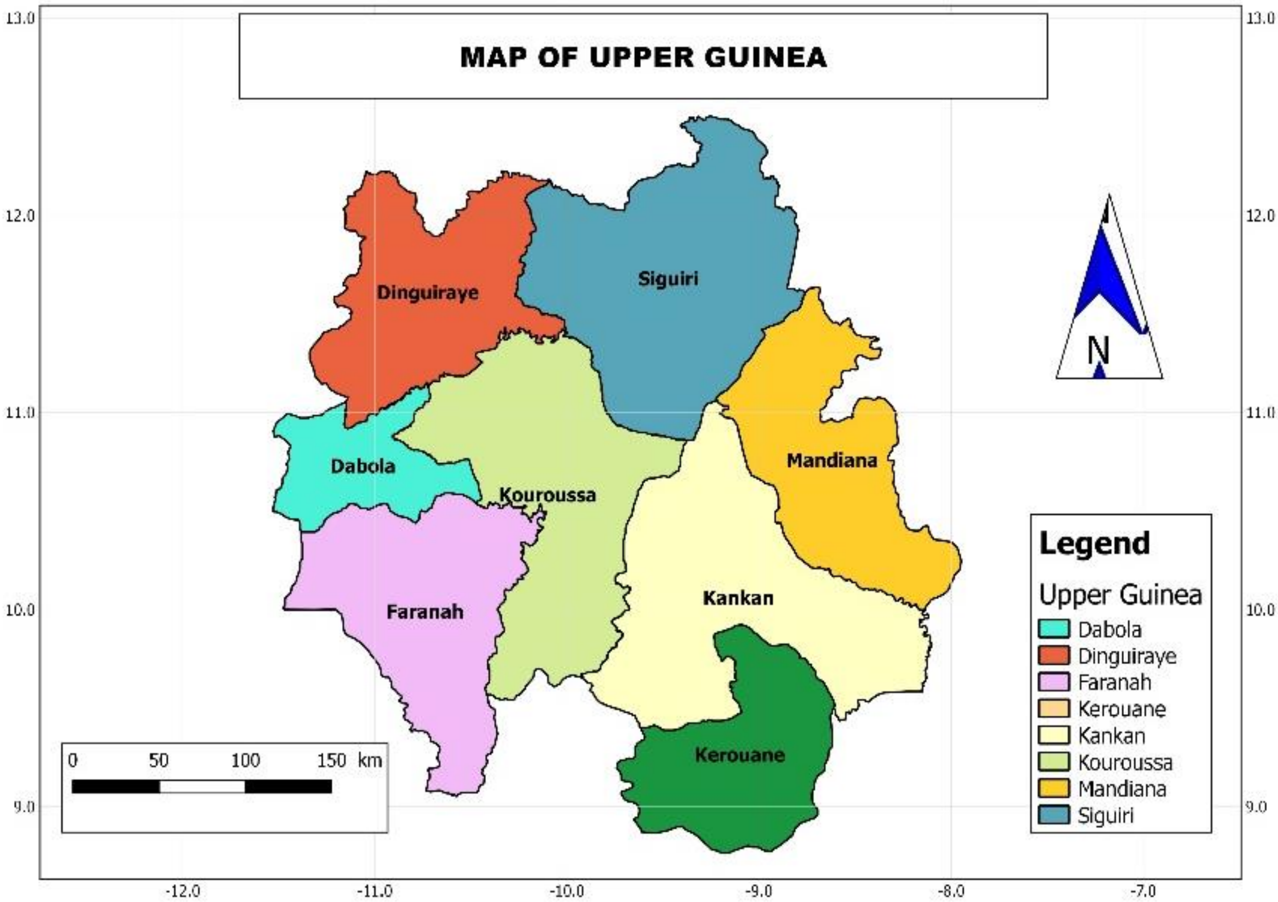

Fig. 1 Location of the study area.

Fig. 2 Photo of the anemometer measuring device.

The anemometer, an essential device for meteorologists, plays a crucial role in detecting wind by measuring its speed, direction and pressure. To evaluate wind speed, the anemometer uses different mechanisms. When the wind blows, these cups begin to rotate, driving a rod to which they are connected. The rotation of this rod is directly proportional to the wind speed. As the wind intensifies, the number of rotations increases. The anemometer records these rotations and calculates the average wind speed over a specific period. In summary, it measures wind speed by observing the rotation of its cups, thus providing an effective method for assessing weather conditions [4].

2.4 Wind Speed and Available Power

For this work, we used the Weibull distribution method to determine the wind parameters. Thus, the dynamics of the wind present a random character, and to understand this phenomenon, it becomes essential to understand the parameters which define it. Among these parameters is the power available through the surface swept by the blades of a wind turbine, expressed in section in m ^{2} perpendicular to the wind flow, and the wind speed in m/s, represented by the energy flow [5-7]. This speed is calculated using the following formula:

$$P = 0{,}5\rho V^3 S \tag{1}$$

ρ is the density of air given in kg/m ^{3}

Simply knowing the average wind speed is not enough to assess wind potential; it is also necessary to understand the relative frequency of each speed, also called the probability density function. By having this function, the average wind speed can be calculated using the following formula:

$$\overline{V} = \int_0^\infty V f(V) dV \tag{2}$$

And the average of the cube of the speed is given by the formula:

$$\overline{V^3} = \int_0^\infty V^3 f(V) dV \tag{3}$$

If the wind distribution function is not continuous and only instantaneous wind speed values are available during the time interval *T*, the average values obtained in Eqs. (2) and (3) are equivalent to:

$$\overline{V} = \frac{1}{T}\int_0^T V(t)dt \tag{4}$$

$$\overline{V^3} = \frac{1}{T}\int_0^T [\mathrm{V(t)}]^3 \mathrm{dt} \tag{5}$$

T is the period over which the speed is averaged.

The estimation of wind speed fluctuations relative to the mean speed can be obtained from the standard deviation of the distribution, formulated as follows [8]:

$$\sigma_V^2 = \int_0^\infty \left[V(t) - \bar{V}\right]^2 \mathrm{dt} \qquad (6)$$

We also define the turbulence index by the following ratio:

$$I = \frac{\sigma_V}{\bar{V}} \qquad (7)$$

This standard deviation represents the degree of wind turbulence over a given period and exerts a significant influence on the durability of the wind turbine due to the fluctuations it induces on the blades and rotor of the wind turbine.

2.5 Variation of Wind Speed with Height

The relative increase in wind speed as a function of altitude above the ground in a homogeneous site shows variations from one point to another [9, 10]. This variation is described by the empirical law of Davenport and Harris [5].

$$\frac{V}{V_0} = \left(\frac{H}{H_0}\right)^\alpha \qquad (8)$$

V_0 (m/s) is the speed observed at height H_0 (m);

V (m/s) is the speed observed at height H (m);

α is the dimensionless shear coefficient, generally varying from 0.1 to 0.4 and is proportional to the roughness. Generally the height is taken equal to 10 m.

2.6 Wind Modeling

The Weibull model allowed us to carry out wind modeling. It is more appropriate to model the frequency histogram of wind speeds with a continuous mathematical function rather than with a discrete table of values. Thus, the Weibull model can be chosen, as shown in Eq. (9) [11].

$$f(v) = \frac{K}{A}\left(\frac{V}{A}\right)^{K-1} \exp\left[-\left(\frac{V}{A}\right)^K\right] \qquad (9)$$

V is the wind speed (m/s), A a scale parameter (m/s) and K a shape parameter.

For a given average wind speed, the higher the form factor, the greater the theoretical average recoverable energy [12-14]. In terms of Weibull parameters, the wind potential available on a site per unit area is [15]:

$$\bar{P} = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \qquad (11)$$

The wind energy available per year is equal to:

$$E_{an} = 5{,}3655 c^3 \Gamma\left(1 + \frac{3}{k}\right) \text{ (kWh/m}^2\text{)} \qquad (12)$$

3. Results

The Upper Guinea wind potential results found are shown in Figs. 3-7 and Table 1.

Fig. 3 illustrates the monthly variation of the average wind speed of each site at the height 20 m relative to the earth's surface. This speed is important in the selected sites. It varies between 2.68 m/s and 3.20 m/s in the month of October and between 3.69 m/s and 4.81 m/s in the month of January.

The seasonal representation of the characteristic speeds is given in Fig. 4. This figure shows that the dry season is the windiest. The maximum average speed was observed in the prefectures of Siguiri and Mandiana, with values of: 4.22 to 4.31 m/s. That is a difference in variation of 0.09. However, the rainy season remains the least windy, with the minimum average speed observed in Dinguiraye being 3.31 m/s. This value is close to that found in the dry season, i.e. 1.02 m/s difference. This is likely due to the adverse effects of climate change.

Fig. 5 shows the variation in the annual average speed at 20 m, i.e.: 3.52 to 3.84 m/s; at 40 m from 4.65 to 5.07 m/s and at 60 m from 5.47 to 5.97 m/s. We see that as we increase in altitude, the wind speed increases as shown in Fig. 5. However, the lowest average speeds for all altitudes are observed at Dinguiraye and the highest at Siguiri. Among other things, the values found for the other prefectures (Dabola, Faranah, Kankan, Kerouané, Kouroussa and Mandiana) are intermediate.

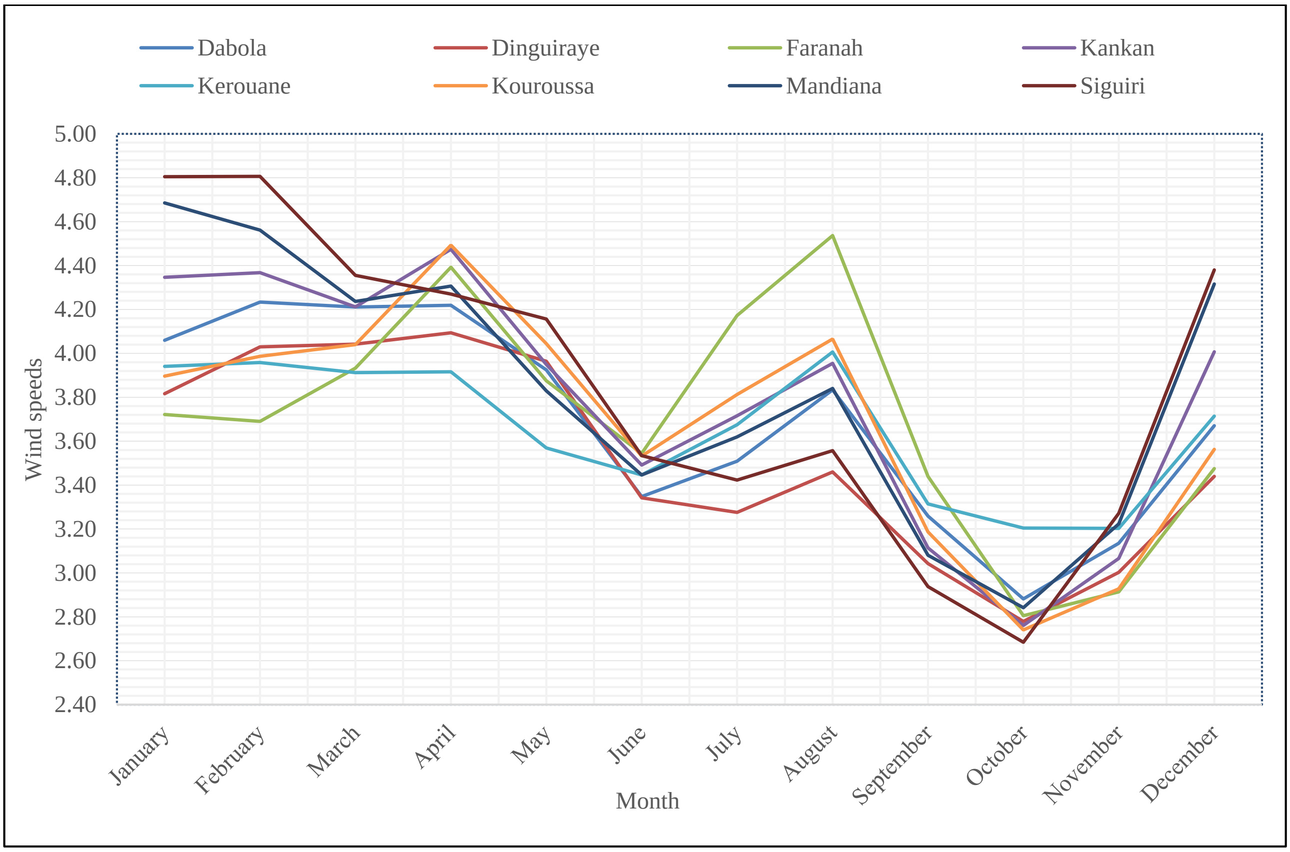

Fig. 3 Average monthly speeds of the different sites.

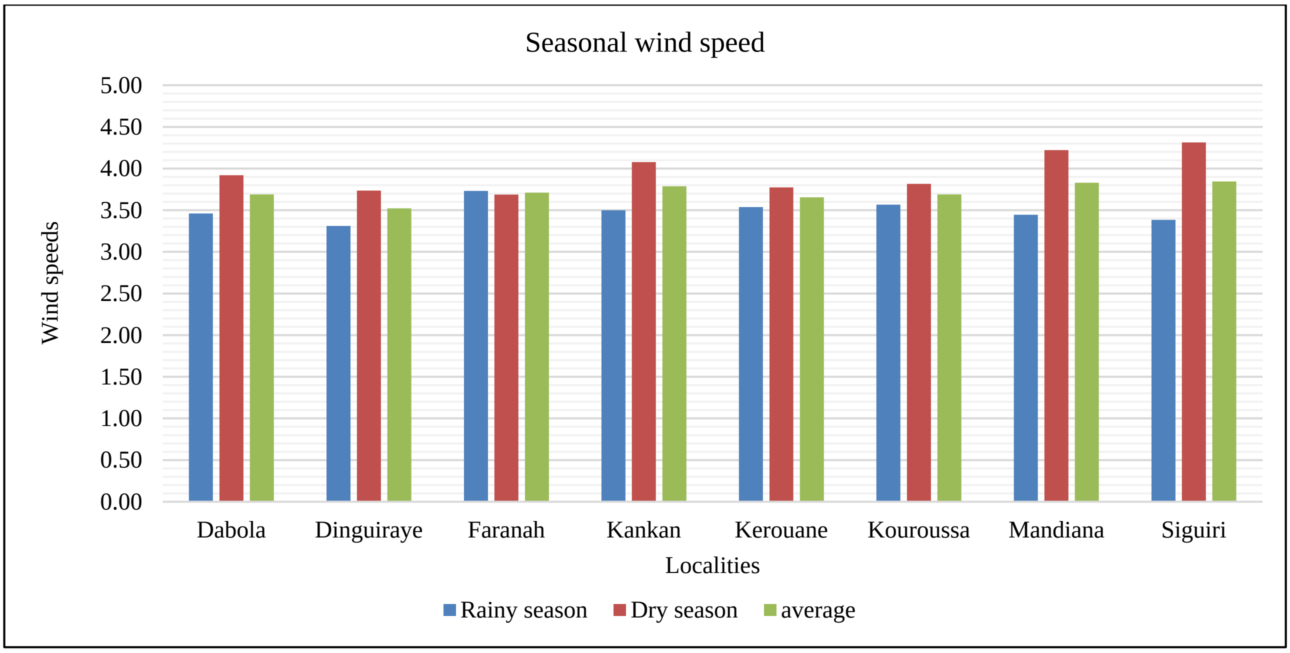

Fig. 4 Characteristic seasonal speeds for different sites.

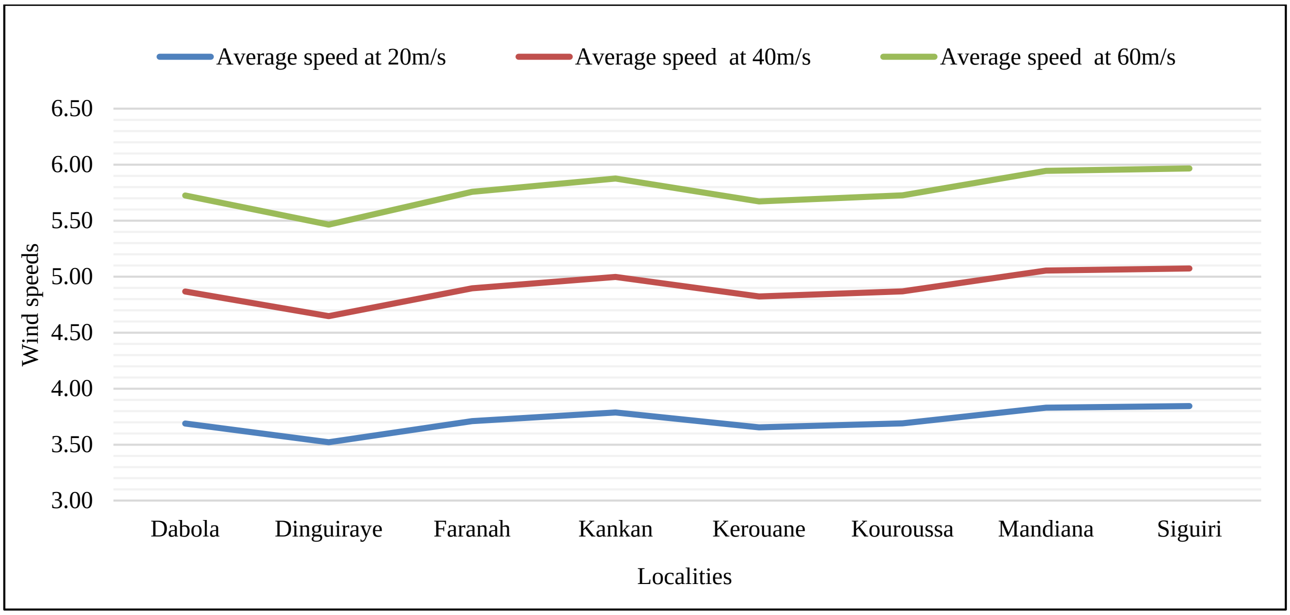

Fig. 5 Average speeds for different sites.

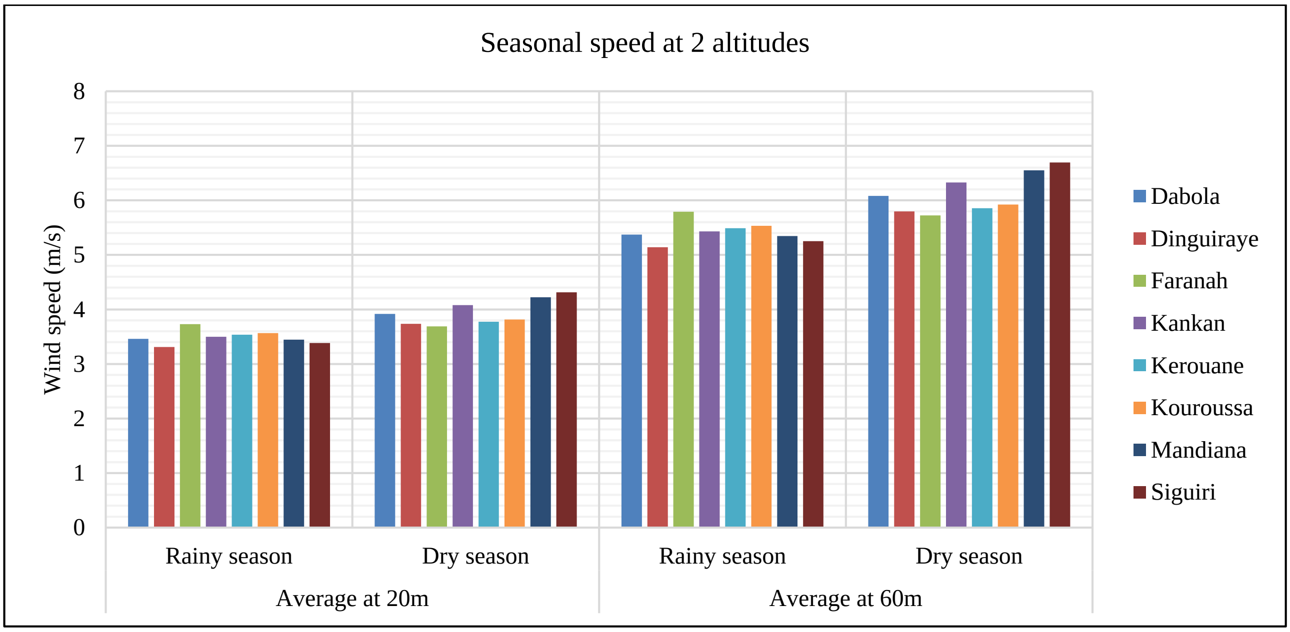

Fig. 6 Seasonal speeds for different altitudes.

The seasonal wind speeds are given in Fig. 6. We see that the dry season is the windiest at 20 m. Indeed, these speeds are average in Siguiri, Mandiana and Kankan which varies from 4.07 to 4.31 m/s; while the rainy season is the least windy, the average speed of which is minimum in Dinguiraye and is 3.31 m/s. On the other hand, at 60 m we notice that the dry season is the windiest with average speeds varying from 6.32 to 6.69 m/s in Siguiri, Mandiana and Kankan while for the rainy season the minimum average speed is observed in Dinguiraye with 5.13 m/s.

Likewise, the annual analysis (Fig. 7) shows that the annual average speed varies from 3.52 m/s (Dinguiraye) to 3.84 m/s (Siguiri). The minimum and maximum speeds vary between 0.73 m/s and 1.06 m/s and between 8.31 m/s and 9.90 m/s respectively for all prefectures. The Faranah and Kankan areas have close maximum values with a difference of 0.03 m/s, the

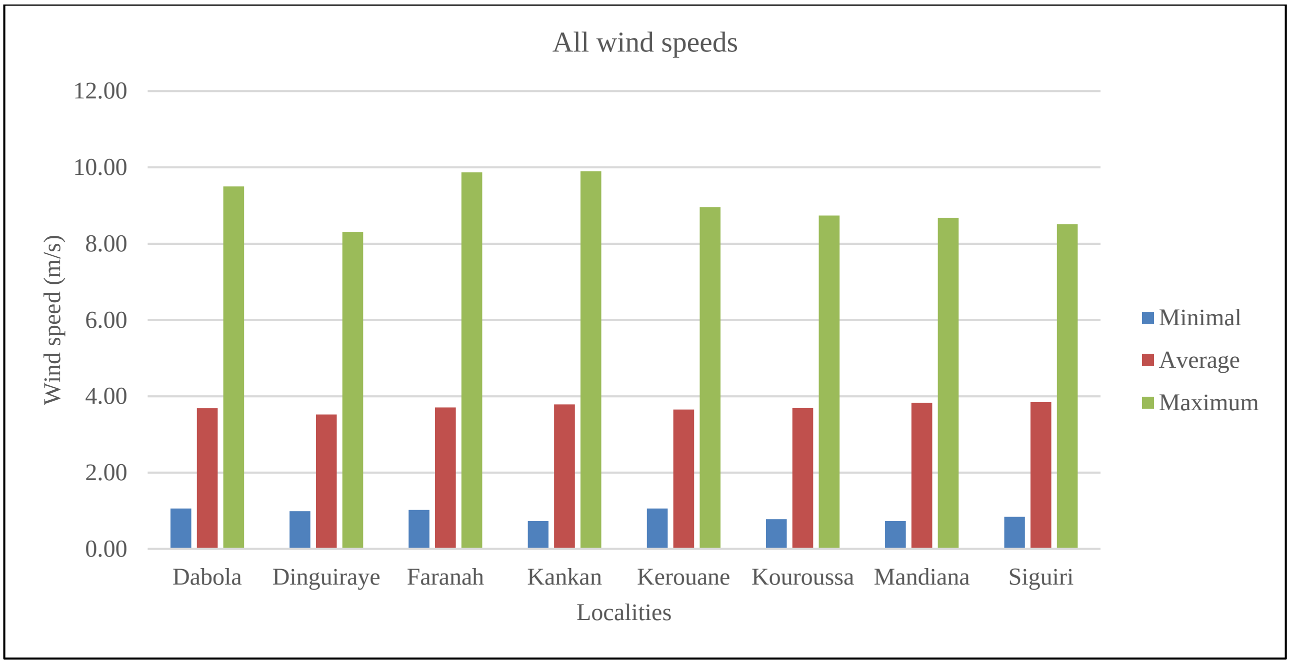

Fig. 7 Average annual speeds for various sites.

Table 1 Ranking of sites.

Sites	Average speed (m/s)	Available power (W/m^2)	Available energy (kWh/m^2)
Dabola	3.69	109.34	977.74
Dinguiraye	3.52	104.56	935.00
Faranah	3.71	128.49	1,149.01
Kankan	3.79	135.19	1,208.89
Kérouané	3.65	109.81	981.94
Kouroussa	3.69	117.19	1,047.94
Mandiana	3.83	134.95	1,206.80
Siguiri	3.84	138.64	1,239.75

same as for the average values. This rapprochement of values would probably be due to the influence of the neighborhood with the prefecture of Dabola which would be at 9.50 m/s.

The evaluation of the wind potential of each site reported in Table 1 made it possible to classify them energetically. A first group with wind potential greater than 1,200 kWh/m^2 brings together the three sites namely: Siguiri, Mandiana and Kankan, i.e. 41.79% of the total energy available for the 8 selected sites. This group presents the most energetic and promising areas; a second group of wind potential varying between 1,000 and 1,200 kWh/m^2 including the two sites which are: Faranah and Kouroussa, i.e. 25.12% of the total energy followed by a third group of wind potential less than 1,000 kWh/m^2 which includes the rest of the sites namely: Dabola, Dinguiraye and Kérouané, i.e. 33.09% of the total energy.

4. Discussion

In this study, we examined the wind potential of Upper Guinea at 20 m altitude which allowed us to have a form factor of 2.97; a scale factor of 4.1m/s; an available power which varies from 104 to 138 W/m^2 per site for an average of 122.54 W/m^2 and an annual available power of 1,102.83 W/m^2. These values are close to that found by Ould et al. [1] and Nènè et al. [2] i.e. 1,071 and 1,047 W/m^2 respectively, with a slight difference in altitude rise of 10 and 20 m. In their studies for an altitude of 10 m, the first obtained: a form factor of 2.58; a scale factor of 5 m/s; a power available on the site varying from 60 to 116 W/m^2 for an average of 85 W/m^2 and an annual available power of 1,071 W/m^2. As for the second, he obtained the following results: 2.55; 5.08 m/s; 47.25 to 129.16 W/m^2 for an average of 87.29 W/m^2 and an annual available power of 1,047 W/m^2. Thus we noted that for an altitude twice as high, the form factor obtained is slightly higher than those found in the other 2 studies while the scale factor is lower; the average power and the annual available power obtained are higher than those of the other 2 studies with maximum differences of 37.54 and 55.83 W/m^2 respectively.

5. Conclusion

This in-depth study of wind energy potential in the eight prefectures of Upper Guinea has produced significant results and important conclusions. Data analysis over a thirty-year period revealed distinct trends in the region's wind potential. The southwest and northeast zones emerged as hotspots, demonstrating notable wind potential. This finding could have significant implications for regional energy development. After analysis, average annual wind speeds range from 3.52 to 3.84 m/s. These figures provide an indication of the consistency and strength of the wind in the region. The results for minimum and maximum wind speeds offer a perspective on the amplitude of wind in Upper Guinea, which are: 0.73 m/s to 1.06 m/s for minimum values and 8.31 to 9.90 m/s for maximum values respectively. These extremes testify to the diversity of wind conditions in the region. Focusing on available energy, the findings highlight Siguiri, Mandiana and Kankan as the most promising sites, with energy values in excess of 1,200 kWh/m^2. Faranah and Kouroussa also show strong wind energy potential, with values between 1,000 and 1,200 kWh/m^2. On the other hand, Dabola, Dinguiraye and Kérouané show wind energy below 1,000 kWh/m^2. These results provide a basis for the planning and development of wind power projects in Upper Guinea. Further studies are recommended, as knowledge of wind speed and the specific wind potential of each site offers prospects for optimal exploitation of this renewable resource in the region.

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