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Research Article

# Evaluation of the Wind Energy Potential of Guinea's Administrative Regions

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## Abstract

In this article, we assess the wind potential of the different administrative regions of Guinea. To do this, we use data from national weather stations covering a period of six years (2010–2015). The measurements were recorded every hour at a height of 10 meters above the ground. The analysis focuses on the characteristics of the average wind speed at different temporalities: monthly, annual and interannual. In order to model the velocity distributions, the data were fitted according to Weibull's law, and the shape and scale parameters were determined for each region. In addition, the study of the compass rose made it possible to identify the dominant directions and their associated frequencies in all the territories examined. The results indicate that the Conakry region has the highest wind potential, with average speeds above 3.5 m/s and an estimated power density of around 27 W/m ² Analyses of wind characteristics reveal that August stands out as the most favourable month for wind energy development in all regions, while November has the least windy conditions. Statistically, the dominant wind directions vary according to the area: in Middle Guinea, Upper Guinea and Forest Guinea, the winds are mainly north-east and south-west, which reflects a significant spatial variability in air flows. On the other hand, in the Lower Guinea region, the wind shows an almost unidirectional trajectory, oriented from the southwest. In summary, the study highlights a marked regional disparity in Guinea's wind potential, with Conakry as the main attractive area for the development of wind capacity, supported by directional patterns and seasonal variability that guide operational and planning choices. These results provide a robust quantitative basis to guide investments and strategies for the deployment of wind technologies in the country.

## Keywords

Wind Energy Potential, Weibull Distribution, Wind Speed Analysis, Wind Direction

## 1. Introduction

Rising energy prices, supply uncertainties, and growing environmental concerns are prompting many countries to seek alternatives to conventional fossil fuels. Consequently, renewable energy systems have seen significant development over the past two decades. These systems play a vital role in achieving the Sustainable Development Goals (SDGs), supporting industrialization, promoting economic growth, enhancing energy security, and preserving the environment [1-3].

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Among renewable energy sources, wind energy stands out as one of the most promising [4]. Over the past few decades, the development of renewable energy has become a central component of national energy policies aimed at diversifying the energy mix, reducing dependency on fossil fuels, and lowering greenhouse gas emissions [5]. Wind energy, when combined with solar or hydropower, is a viable solution for enhancing energy access in rural areas where electrification rates remain critically low [6, 7]. In wind energy systems, wind speed is a fundamental parameter for assessing the available wind resource [8, 9].

In Guinea, access to electricity remains relatively low, with the electrification rate increasing from 18.5% in 2010 to 35.5% in 2020. Electricity consumption is predominantly concentrated in urban areas, while rural communities have limited or no access to the national grid [10]. In this context, the development of wind power systems presents a promising opportunity to increase electricity access, particularly in underserved regions. However, the deployment of such systems requires a comprehensive understanding of the country's wind characteristics.

This study therefore aims to evaluate the wind energy potential across the administrative regions of Guinea. The main objective is to build a robust database on the spatial and temporal distribution of wind resources, which will support evidence-based decision-making for the planning and implementation of wind power projects. To achieve this, it is necessary to examine the methodologies commonly used in the literature to assess wind energy potential, particularly in the African context.

For example, Chayakorn Chaitammachok et al. [11] conducted a study on wind resource assessment in Thailand. Their temporal analysis showed that spring is generally the windiest season. The wind resource map revealed annual average wind speeds ranging from 1.2 to 6.3 m/s, with the Adrar region exhibiting the highest average (6.3 m/s), followed by Hassi R'mel (6.1 m/s) and Tindouf (6.0 m/s). In another study, Mourad Djamai and Nachida Kasbadji Merzouk [12] analyzed the feasibility of a 10 MW wind farm in Adrar, where wind speeds reached 8.44 m/s at 80 m height.

In Senegal, Serigne A. A. Niang et al. [13] used ERA5 reanalysis data at 100 m height to assess wind speeds ranging from 3 to 9 m/s, showing north-south and west-east gradients. The highest speeds were recorded between December and May, with a nocturnal peak in wind velocity. The most favorable sites for wind power development were identified as Saint-Louis, Podor, Matam, Dakar, and Taïba Ndiaye.

Charles Fant et al. [14] examined wind resource reliability in Southern Africa. Their findings indicated that significant wind resources exist in parts of South Africa, Tanzania, and Kenya, with greater reliability during the summer months and daytime hours.

In Chad, Ali Ahmat Younous et al. [15] assessed wind resources using ERA5 data at 100 m, finding speeds between 1.5 and 11 m/s, increasing from south to north. Peak wind speeds were observed between October and April, while minimum values (<5 m/s) occurred during the rainy season.

Other relevant studies include:

1) Baldé et al. [16] who evaluated the wind potential along Guinea's coastal regions and in Kanfarandé, identifying sites with economically viable resources;
2) Ould Bilal et al. [17] who modeled wind potential at the Nouakchott site, determining the most favorable periods for wind exploitation;
3) Zohbi and Hendrick, who analyzed wind characteristics in Lebanon, including monthly averages and Weibull distribution parameters;
4) Ndiaye et al. who performed short-term wind forecasting using linear prediction models at Gandon, Senegal, achieving a coefficient of determination above 0.86.

This study focuses on the characterization of wind patterns in all administrative regions of Guinea, with the goal of producing a national wind speed map. This mapping effort will serve as a basis for identifying priority zones for wind energy development and contribute to the broader objective of expanding sustainable electricity access in the country.

## 2. Methodology

### 2.1. Presentation of the Study Area

Guinea is located in southwestern Africa, between latitudes 7°N and 13°N and longitudes 15°W and 7°W. It is bordered by Senegal to the northwest, Mali to the north, Côte d'Ivoire to the east, Liberia and Sierra Leone to the south, and the Atlantic Ocean to the west, along a 300 km-long coastline. The country covers an area of 245,857 km² and had an estimated population of 13 million in 2023 [18].

Guinea is administratively divided into eight regions, which are grouped into four major natural zones: Lower Guinea (BG), Middle Guinea (MG), Upper Guinea (HG), and Forest Guinea (GF).

Lower Guinea, also referred to as Maritime Guinea due to its coastal position, comprises the administrative regions of Conakry, Kindia, and Boké. It forms a coastal strip approximately 300 km long and 100–150 km wide, located between Guinea-Bissau to the north and Sierra Leone to the south. This region accounts for about 15% of the country's total land arean [18].

Middle Guinea, consisting of the Labé and Mamou regions, covers approximately 26% of the national territory. It is characterized by the Fouta-Djalon highlands, which extend over roughly 80,000 km². The highest peak in this region is Mount Loura (1,532 m). Elevations typically exceed 750 m and can surpass 1,200 m in certain areas (Frenken, 2005). Notably, this region serves as the headwater zone for many major rivers in West Africa [18].

Upper Guinea, which includes the Kankan and Faranah regions, represents 39% of the national area. It is situated between Forest Guinea and Middle Guinea, bordering the

Niger Basin to the east. The region is characterized by a relatively flat topography with an average elevation of 500 m. Due to its climatic and ecological conditions, it is often considered Guinea's arid or Sahelian zone [18].

Forest Guinea comprises only the N'zérékoré region, located in the southern part of the country. It accounts for 20% of the national territory and features rugged terrain, including the Simandou and Nimba mountain ranges. Mount Nimba, at 1,752 m, is the highest point in Guinea [18, 19].

The geographical coordinates of these regions are summarized in Table 1.

***Table 1.*** *Geographic coordinates of Guinea's administrative regions.*

| Geographical coordinates | Conakry | Kindia | Boké | Labe | Mamou | Kankan | Faranah | Nzérékoré |
|---|---|---|---|---|---|---|---|---|
| Longitude (°) | -13,71 | -12,86 | -14,29 | -12,27 | -12,09 | -9,30 | -10,73 | -8,33 |
| Latitude (°) | 9.50 | 10,05 | 10,93 | 11,32 | 10,43 | 10,38 | 10,04 | 7,75 |
| Altitude (m) | 30 à 50 | 152 | 59 | 1067 | 700 | 378 | 329 | 467 |

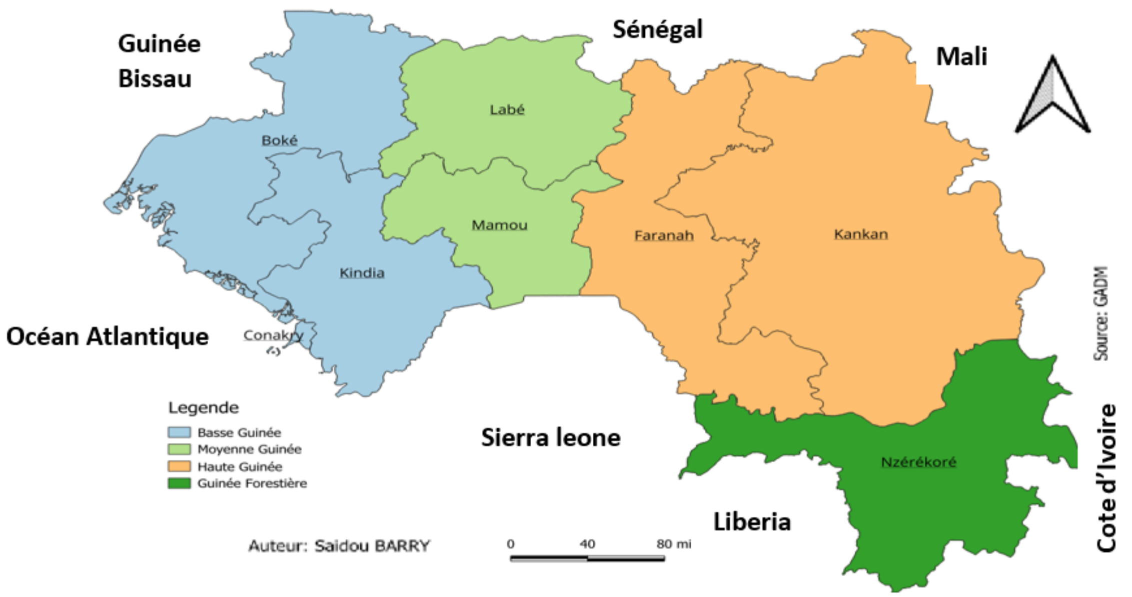



***Figure 1.*** *Study area.*

## 2.2. Presentation of the Methodology

Hourly wind speed and direction data, measured at a height of 10 meters above ground level, were collected from national meteorological stations over a six-year period (2010–2015). The methodological framework of this study involves a comprehensive statistical analysis of the measured data to:

1) Determine the mean wind characteristics;
2) Model wind speed variations using the Weibull probability distribution.

The mean wind speed is calculated using Equation (1).

$$V_m = \frac{1}{N}\sum_{i=1}^{n} V_i \tag{1}$$

For the modeling of wind speed variations, the Weibull distribution was chosen, as it is the most commonly used model in the literature and provides a closer fit to actual wind speed distributions compared to other statistical models. This approach allows for a detailed representation of wind speed variability at a given site, using the probability density function defined in Equation (2) [1].

$$f_{(V)} = y = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e\left[-\left(\frac{v}{k}\right)^{k}\right] \tag{2}$$

Where: V: average wind speed (m/s); c: scale parameter (m/s); k: shape parameter (dimensionless)

The Weibull parameters are also given by equations (3) and (4) [1, 2]:

$$C = \frac{V_m}{\gamma(1+\frac{1}{k})} \quad (3)$$

$$K = \left(\frac{\delta}{V_m}\right)^{-1,086} \quad (4)$$

δ is the standard deviation

The standard deviation and turbulence index are given by formulas (5) and (6)

$$\delta = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(V_i - V_m)^2} \quad (5)$$

$$I = \frac{\delta}{V_m} \quad (6)$$

### 2.3. Selection of the Typical Year for Each Region

The typical year within a study period is defined as the year whose measurements are closest to the overall average of the entire period. It is considered to be representative of the full set of years under analysis. In this study, the typical year is identified by computing the mean annual values, as described by Equation (7).

$$\overline{V}_{i,h} = \sum_{j=i}^{j=N_i} \frac{V_{i,j,h}}{N_i} \quad (7)$$

Where $\overline{V}_{i,h}$ is the average value for the month at time h.

The Root Mean Square Error (RMSE) is calculated for each year of the measurement period to identify the typical year—defined as the year with the smallest RMSE. RMSE quantifies the magnitude of the error between two data sets; it measures the difference between observed values and predicted (or reference) values. A lower RMSE indicates a better agreement between the two. The RMSE is computed using Equation (8).

$$RMSE = \sqrt{\frac{\sum_i (V_i - \overline{V}_i)^2}{n}} \quad (8)$$

n: The number of hours for a given year, $\overline{V}_i$: the average value for hour i, Vi: Represents the value of hour i for the given year.

A comparative study of wind speed variability across various geographical regions is performed to determine the regions most favorable for wind energy development.

## 3. Results and Discussion

### 3.1. Characteristics of Average wind Speeds in the Regions

The typical year found for each region is presented in Table 2.

***Table 2.*** *Typical year for the regions.*

| Regions | Conakry | Kindia | Bok é | Lab é | Mamou | Kankan | Faranah | N'zérékoré |
|---|---|---|---|---|---|---|---|---|
| Typical year | 2010 | 2014 | 2015 | 2013 | 2014 | 2015 | 2013 | 2014 |

The results of the study of wind potential in Guinea's eight regions are presented in this section.

Figure 2 presents the wind speed variation diagram for the study period. The Conakry region exhibits a significantly higher average wind speed compared to the other regions. The standard deviation analysis reveals substantial wind speed variability in Conakry, whereas in the other regions, this variability remains relatively low throughout the study period. This lower variability may be considered a positive indicator for the predictability and stability of wind energy production in those regions.

The results of the standard deviation calculations are presented in Table 3.

***Table 3.*** *Standard deviation of regions.*

| Regions | Conakry | Bok é | Kindia | Labe | Mamou | Kankan | Faranah | N'Zérékoré |
|---|---|---|---|---|---|---|---|---|
| Standard deviation | 1,13 | 0,90 | 0,85 | 1,00 | 1,02 | 0,93 | 0,93 | 0,84 |

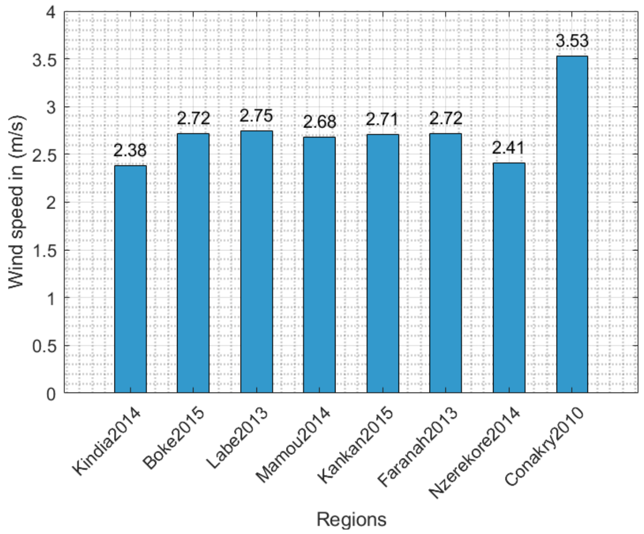



***Figure 2.*** *Wind speed diagram for regions in Guinea.*

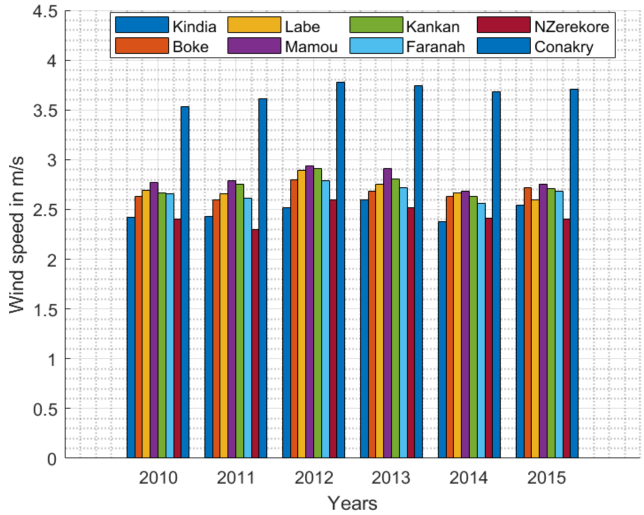



***Figure 3.*** *Monthly changes in wind speed 2010-2015.*

## 3.2. Monthly, Annual, and Interannual Variation in Average Wind Speed in Labe and Mamou

Figure 3 illustrates the mean annual wind speed variations across the regions of Guinea over the study period (2010–2015). The histograms display the average annual wind speeds for each region. Among the years analyzed, 2012 emerged as the most favorable for wind energy potential in all regions, with recorded mean wind speeds of 3.78 m/s in Conakry, 2.94 m/s in Mamou, and 2.91 m/s in Kankan.

The lowest annual average wind speed was observed in N'Zérékore in 2011 (2.30 m/s), followed by Kindia in 2014 (2.38 m/s). Throughout the study period, the Conakry region consistently recorded the highest wind speeds, with a mean value exceeding 3.60 m/s, highlighting its strong potential for wind energy exploitation.

## 3.3. Comparative Study of Hourly Variations in Average Wind Speed in Labe and Mamou

Figure 4 also presents the hourly variations in wind speed across the different regions of Guinea. The results indicate that the Lower Guinea regions (Conakry, Kindia, and Boké) experience higher wind speeds between 3:00 p.m. and 10:00 p.m., while the lowest wind speeds are observed between 4:00 a.m. and 6:00 a.m.

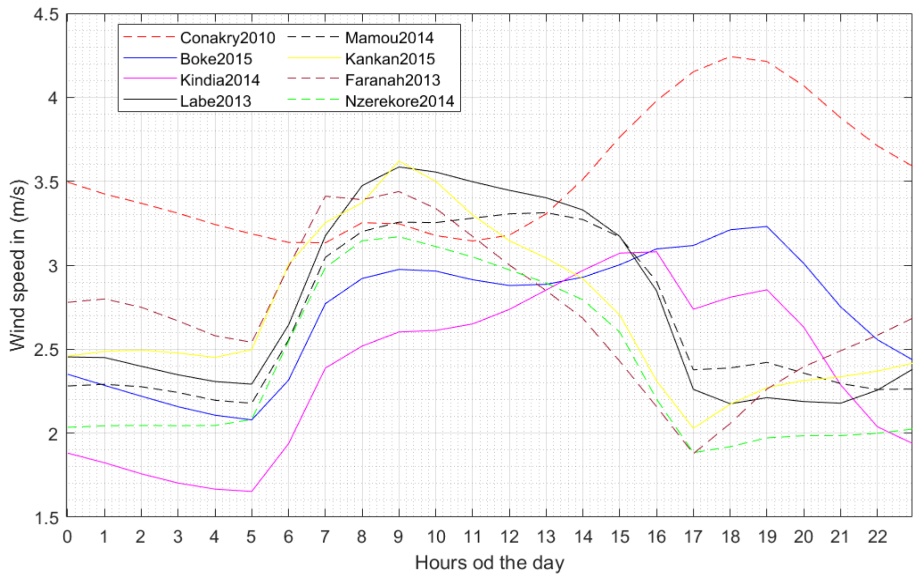



***Figure 4.*** *Hourly evolution of the average annual wind speed during the study period.*

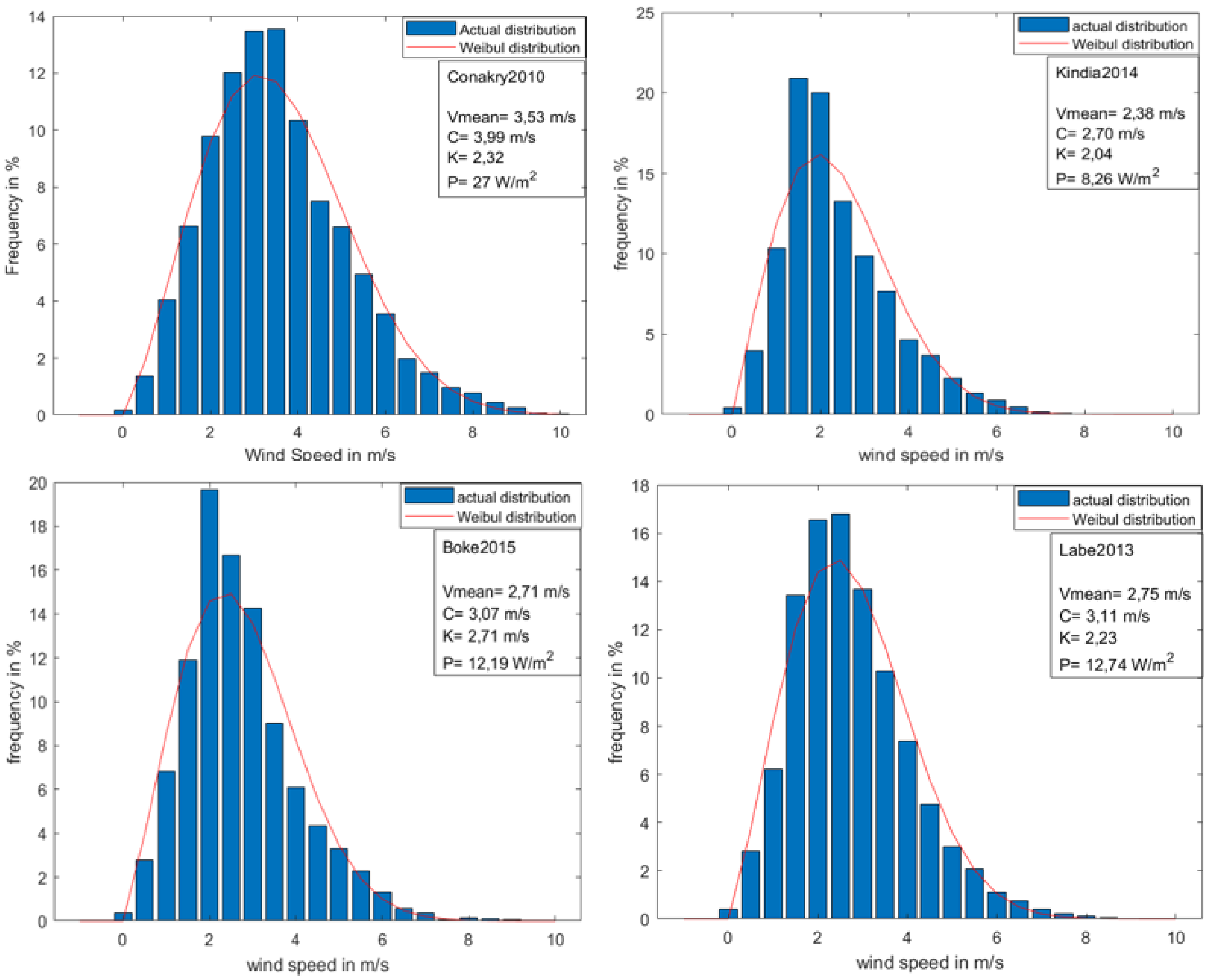
In the Middle Guinea, Upper Guinea, and Forest Guinea regions, wind speeds tend to be higher during the daytime (from 6:00 a.m. to 4:00 p.m.) than at night. This diurnal pattern can be attributed to several meteorological factors [20, 21]:

1) Daytime surface heating: Solar radiation heats the ground during the day, causing warm air to rise. This creates a low-pressure zone, which draws in cooler air from surrounding areas to balance the pressure gradient.
2) Sea breeze formation: When land surfaces heat up, the rising warm air is replaced by cooler air from the ocean or surrounding bodies of water, leading to stronger breezes during the daytime.
3) Atmospheric instability: The warming of the ground contributes to increased atmospheric instability, enhancing vertical air movement and resulting in stronger surface winds.
4) Stable nighttime conditions: At night, the ground cools and the atmosphere stabilizes, leading to reduced vertical air mixing and, consequently, lower wind speeds. Additionally, the absence of surface heating weakens sea breeze activity.

## 3.4. Frequency Distribution of Wind Speed

Weibull distributions were determined for each region based on the corresponding typical year. Figure 5 presents a comparison between the measured wind speed distributions and the Weibull-fitted distributions for Guinea's administrative regions. For each region, key parameters—namely the mean wind speed, scale parameter (c), shape parameter (k), and wind power density—were evaluated for the typical year.

The results show a strong agreement between the actual and Weibull distributions, indicating the reliability of the Weibull model in characterizing wind speed variations across the regions. Furthermore, the mean wind speeds and power density values confirm that Conakry remains the region with the highest wind potential.



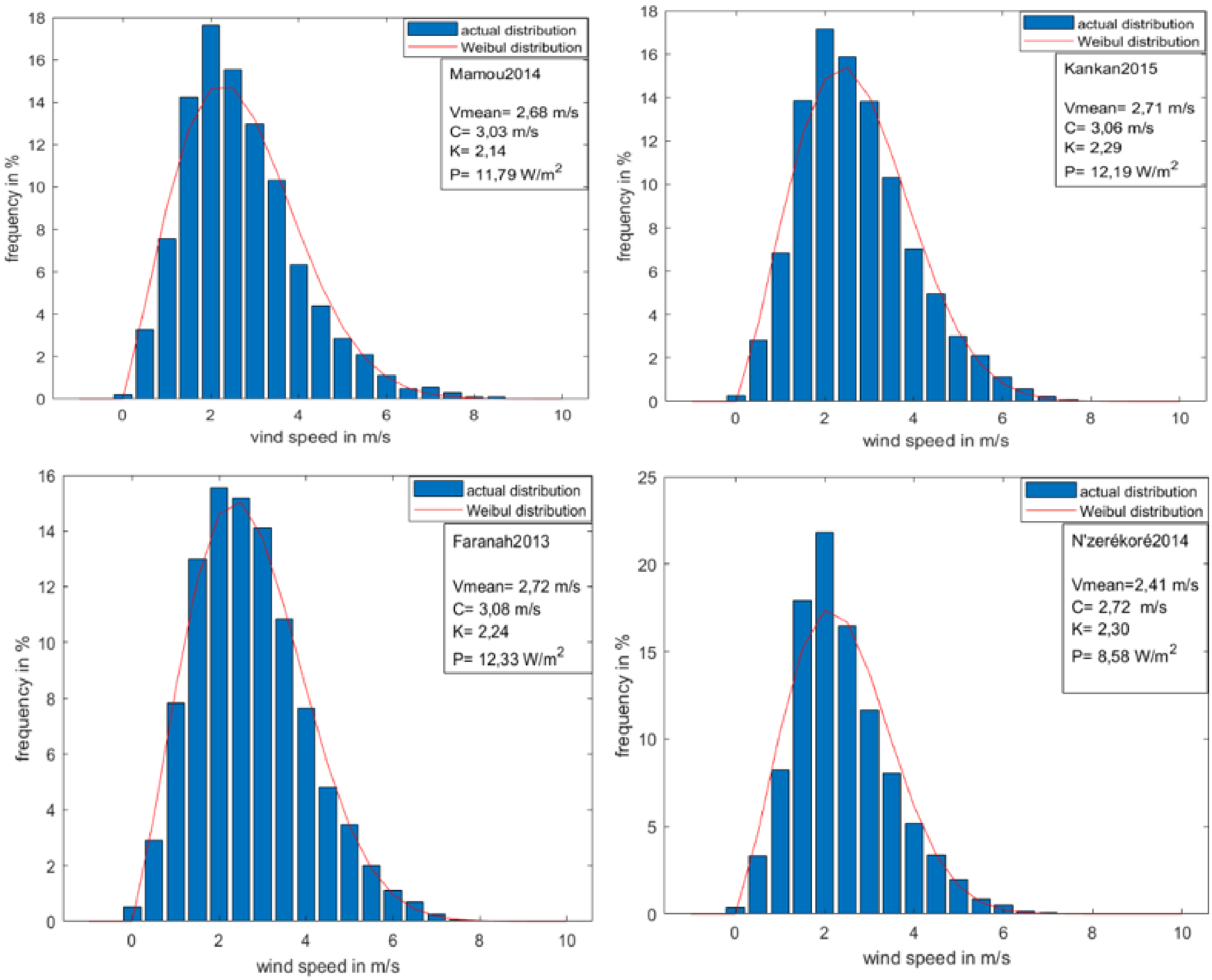



***Figure 5.*** *Actual and Weibull distribution of Guinea's administrative regions.*

## 3.5. Prevailing Wind Directions: Wind Rose

Determining prevailing wind directions is crucial for the optimal installation of wind turbines, as obstacles must be avoided along the preferred wind path. A wind rose represents the frequency distribution of average wind speeds across directional sectors. It is typically divided into 12 sectors of 30 ° each, with the radius of each sector corresponding to the relative frequency of wind from that direction. Wind roses are essential tools for identifying suitable sites for wind turbine placement.

Figure 6 presents the wind roses for the regions of Guinea, showing a dominant southwest wind direction in all regions of Lower Guinea. The frequencies of southwest winds are 28%, 17%, and 24% for Conakry, Kindia, and Boké, respectively. This pattern results from the region's proximity to the Atlantic Ocean, which creates a pressure gradient between the cooler ocean air and the warmer land. As a result, cooler air from the ocean moves inland from the southwest, generating a consistent wind flow in this direction [22].

In contrast, Middle Guinea, Upper Guinea, and Forest Guinea experience prevailing winds from both the northeast and southwest. This bimodal wind pattern is influenced by the seasonal migration of the intertropical discontinuity (ITD), which separates dry harmattan winds originating from the northeast Sahara and humid monsoon winds blowing from the southwest Gulf of Guinea [21, 22].

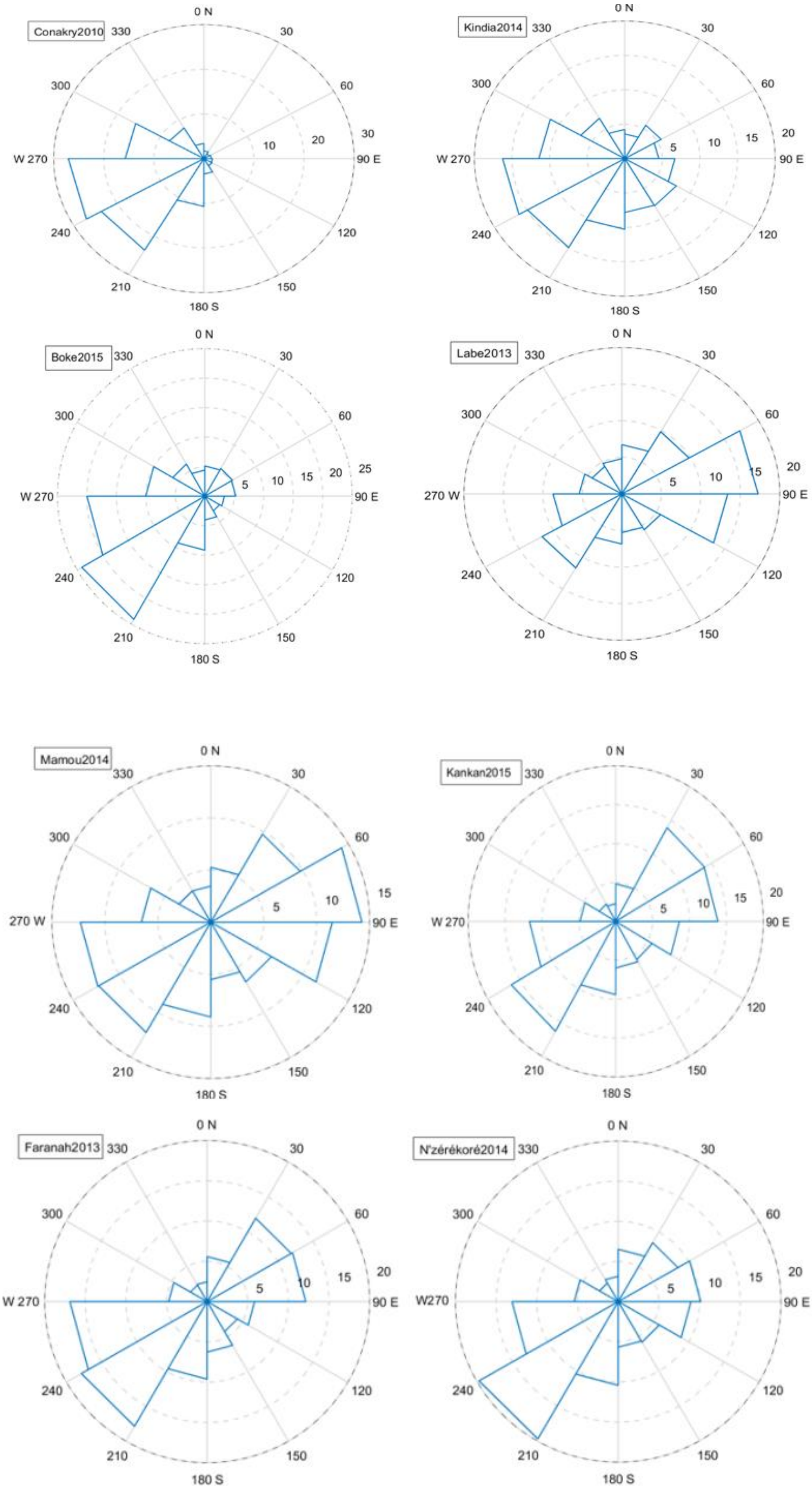



***Figure 6.*** *Wind rose for the regions of Guinea.*

## 4. Conclusion

The wind potential of Guinea's administrative regions was evaluated using hourly wind data collected over a six-year period (2010–2015) from meteorological stations across these regions. With complete spatial coverage of all study areas, the dataset provides a reliable basis for assessing regional wind potential during the study period.

Analysis of average wind speeds indicates that the Conakry region exhibits the highest wind potential, followed by Mamou and Kankan. Conversely, the N'Zérékoré and Kindia regions show the lowest wind speeds, averaging 2.44 m/s and 2.48 m/s, respectively.

Statistical analysis further enabled the determination of wind roses, revealing prevailing wind directions. For Lower Guinea, the dominant wind direction is southwest. In Middle Guinea and Forest Guinea, prevailing winds come from the northeast, southeast-east, and southwest directions. In Upper Guinea, the primary wind directions are northeast and southwest.

The wind speed data were fitted to the Weibull distribution, confirming that the highest wind power density was recorded in Conakry in 2010, reaching 27 W/m ².

Subsequently, the seasonal wind potential of Guinea's regions will be evaluated to develop a seasonal wind potential map for the country.

## Abbreviations

| | |
|---|---|
| BG | Lower Guinea |
| MG | Middle Guinea |
| HG | Upper Guinea |
| GF | Forest Guinea |
| RMSE | Root Mean Square Error |
| ITD | Intertropical Discontinuity |
| SDGs | Sustainable Development Goals |
| $\delta$ | Standard Deviation |
| C | Scale Factor |
| K | Form Factor |
| m/s | Meter Per Second |

## Conflicts of Interest

The authors declare no conflicts of interest.

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