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Assessment of Wind Energy Potential in Kassa (Guinea) Using NASA Satellite and ERA5 Reanalysis Data

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Abstract

This study evaluates the wind energy potential of Kassa Island, located in the Loos Archipelago, Guinea, using 10 m wind speed data from NASA POWER and ERA5 over the 2020-2025 period. ERA5 wind speeds were determined from the zonal and meridional wind components, whereas NASA POWER data were directly obtained from the WS10M variable. The wind regime was characterized using the Weibull distribution, whose shape kk and scale cc parameters were estimated from monthly mean wind speeds and their standard deviations. The results reveal pronounced seasonal variability. Monthly mean wind speeds range from 2.26 to 5.60 m/s for NASA POWER and from 3.26 to 5.02 m/s for ERA5, with maximum values occurring in August and July, respectively. The maximum available wind power densities reach 107.6 W/m^2 for NASA POWER and 77.5 W/m^2 for ERA5. The annual available wind energy is estimated at 352.04 kWh/m^2 for NASA POWER and 393.00 kWh/m^2 for ERA5. According to the theoretical Betz limit $C_p = 0.593$, the corresponding maximum theoretical wind energies are 208.76 and 233.05 kWh/m^2/year, respectively. These values represent theoretical aerodynamic limits and should not be interpreted as the actual electrical energy produced by a wind turbine. The period from June to September accounts for approximately 62.6% of the annual energy for NASA POWER and 49.2% for ERA5, highlighting more favorable wind resource conditions during the wet season. At the reference height of 10 m, the site generally exhibits a low wind energy resource, despite more favorable seasonal conditions. *In situ* measurements, wind speed extrapolation to turbine hub heights, and techno-economic analyses are therefore required to more accurately assess the site's exploitable wind energy potential.

Keywords

Wind Energy, Wind Energy Potential, Wind Speed, Weibull Distribution, NASA POWER, ERA5

1. Introduction

Assessing the wind energy potential of a site is an essential step in any strategy for the development and exploitation of wind energy, particularly in regions where ground-based meteorological observations are limited or discontinuous [1] [2]. In a global context characterized by increasing energy demand, the need to reduce dependence on fossil fuels, and international commitments to combat climate change, renewable energy sources are playing an increasingly important role in energy policies. Among them, wind energy represents an important solution due to its renewable nature, availability, and potential contribution to reducing greenhouse gas emissions [3].

However, the viability of a wind energy project strongly depends on a thorough understanding of the local wind regime. Mean wind speed, its temporal variability, frequency distribution, and the associated power density are key parameters for characterizing the available resource. In regions where meteorological measurement networks are insufficient, satellite data and atmospheric reanalysis products are particularly useful tools for conducting a preliminary assessment of wind energy potential. In this regard, ERA5, developed by the ECMWF, and NASA POWER, which notably uses MERRA-2 reanalysis data, provide access to long-term meteorological datasets covering extensive geographical areas [4] [5].

The quality of these data for energy applications has, however, been the subject of numerous investigations. Wilczak *et al.* [6] evaluated ERA5 against several observational datasets and showed that, despite its usefulness for large-scale energy studies, biases may persist in the estimation of wind speeds and wind power. Similarly, the quality of MERRA-2 surface winds, which constitute the source of the meteorological parameters used by NASA POWER, has been assessed through comparisons with surface observations, demonstrating both the usefulness and limitations of these data for characterizing wind regimes [7]. These findings highlight the importance of comparing multiple data sources when long-term local measurements are unavailable.

The statistical characterization of the wind regime constitutes another important step in resource assessment. Among the various probability distributions proposed, the two-parameter Weibull distribution remains one of the most widely used. The shape parameter (k) provides information on wind speed dispersion, whereas the scale parameter (c) characterizes the wind speed level. This distribution therefore makes it possible to represent the frequency of occurrence of wind speeds and to estimate the corresponding power and energy densities. Drobinski and Coulais [8] nevertheless showed that, despite its widespread use in wind energy applications, the Weibull distribution has certain limitations and that its suitability depends on the characteristics of the wind regime under consideration.

The combined use of reanalysis products and statistical modeling has been applied in several regions worldwide. Sakuru and Ramana [9], for example, assessed the wind energy potential of India using nearly forty years of ERA5 data and Weibull distributions. Their results revealed strong seasonal variability in the resource, with particularly favorable conditions during the monsoon season. These findings illustrate the value of long-term reanalysis datasets for the spatial and seasonal assessment of wind energy potential.

In West Africa, several studies have also focused on the statistical and energy characterization of wind resources. Guenoukpati *et al.* [10] compared seven numerical methods for estimating Weibull parameters at three West African coastal sites: Lomé in Togo, Accra in Ghana, and Cotonou in Benin. Their results showed that the method used to determine the (k) and (c) parameters can significantly influence the estimation of the energy resource, thereby highlighting the importance of selecting an appropriate statistical characterization method.

On the Beninese coast, Houekpoheha *et al.* [11] used the Weibull distribution to characterize the wind regime in Cotonou, in the Gulf of Guinea, and to assess the corresponding wind power potential. This study highlighted the energy potential of coastal winds and the importance of their prior statistical characterization. In the same geographical context, Aza-Gnandji *et al.* [12] investigated the offshore wind energy potential of Benin using the Weibull distribution to model the spatial distribution of daily wind speeds. The authors also extrapolated the Weibull parameters to different heights in order to identify areas with the most favorable conditions for wind resource exploitation.

More recently, Sedzro *et al.* [13] compared different methods for estimating wind energy potential at sites in Togo and Benin. Their study confirms that Weibull-based methods remain widely used to characterize wind speeds and estimate available and recoverable energy, while also showing that estimation performance depends on the method used to fit the statistical distribution.

In Guinea, studies devoted to wind energy potential remain relatively limited. Mathos *et al.* [14] investigated the sites of Conakry, Mamou, and N'Zérékoré using satellite data recorded between 2001 and 2015. The Weibull distribution and vertical wind speed extrapolation were used to assess power density at different heights. The authors identified Conakry as the windiest of the three sites studied, with a mean wind speed of approximately 2.83 m/s at 10 m and an estimated annual mean power density of 45.77 W/m^2 at this height. Extrapolation to 100 m resulted in a mean wind speed of 4.23 m/s and a power density of 113.31 W/m^2, thereby demonstrating the significant influence of height on wind resource assessment.

A more recent study conducted by Barry *et al.* [15] across the different administrative regions of Guinea, based on hourly measurements taken at 10 m between 2010 and 2015, also confirmed that the Conakry region has the highest wind energy potential among the regions studied. The authors reported mean wind speeds exceeding 3.5 m/s and a power density of approximately 27 W/m^2, with marked seasonality and particularly favorable conditions in August. These results confirm the specific interest of the Conakry coastal area for more localized investigations.

However, despite these various studies, the wind regime of the island sites of the Loos Islands Archipelago remains insufficiently documented. In particular, few studies have specifically focused on Kassa Island by comparing, for the same site and over the same period, wind speed data from NASA POWER and ERA5, while simultaneously incorporating statistical characterization using the Weibull distribution and an estimation of the corresponding energy potential. This research gap justifies a specific analysis aimed not only at characterizing the local wind resource but also at assessing the consistency and differences between these two data sources.

In this context, the present study aims to assess the wind energy potential of Kassa Island, located in the Loos Archipelago in Guinea, using wind speed data at 10 m from NASA POWER and ERA5 over the 2020-2025 period. Monthly mean wind speeds will be analyzed according to their seasonal variation, and the wind regime will be characterized using the Weibull distribution. The shape parameter k and scale parameter c will be determined to estimate the available wind power densities and the maximum theoretical wind power densities according to the Betz limit, as well as the corresponding wind energies. The results obtained from both data sources will be examined to characterize the seasonal variability of the wind resource and assess the wind energy potential of the site at the reference height of 10 m.

The article is structured as follows: the first part presents the study site, the NASA POWER and ERA5 data sources, and the adopted methodology. The second part presents and discusses the results related to wind speeds, Weibull parameters, power densities, and estimated wind energies. Finally, the conclusion summarizes the main findings and presents the perspectives of the study, particularly *in situ* measurements, wind speed extrapolation to wind turbine hub heights, and complementary techno-economic analyses.

2. Materials and Methods

2.1. Study Site and Data Sources

In this study, the site of interest is Kassa Island, located in the Loos Islands Archipelago, off the coast of Conakry, Republic of Guinea. This coastal site is characterized by meteorological conditions influenced by its proximity to the Atlantic Ocean, making it a particularly relevant area for wind energy potential assessment. Figure 1 shows the reference site selected for data extraction. This site is defined by the geographical coordinates 9.477˚N and 13.749˚W. The same coordinates were used for both data sources to ensure the spatial consistency of the comparison [16].

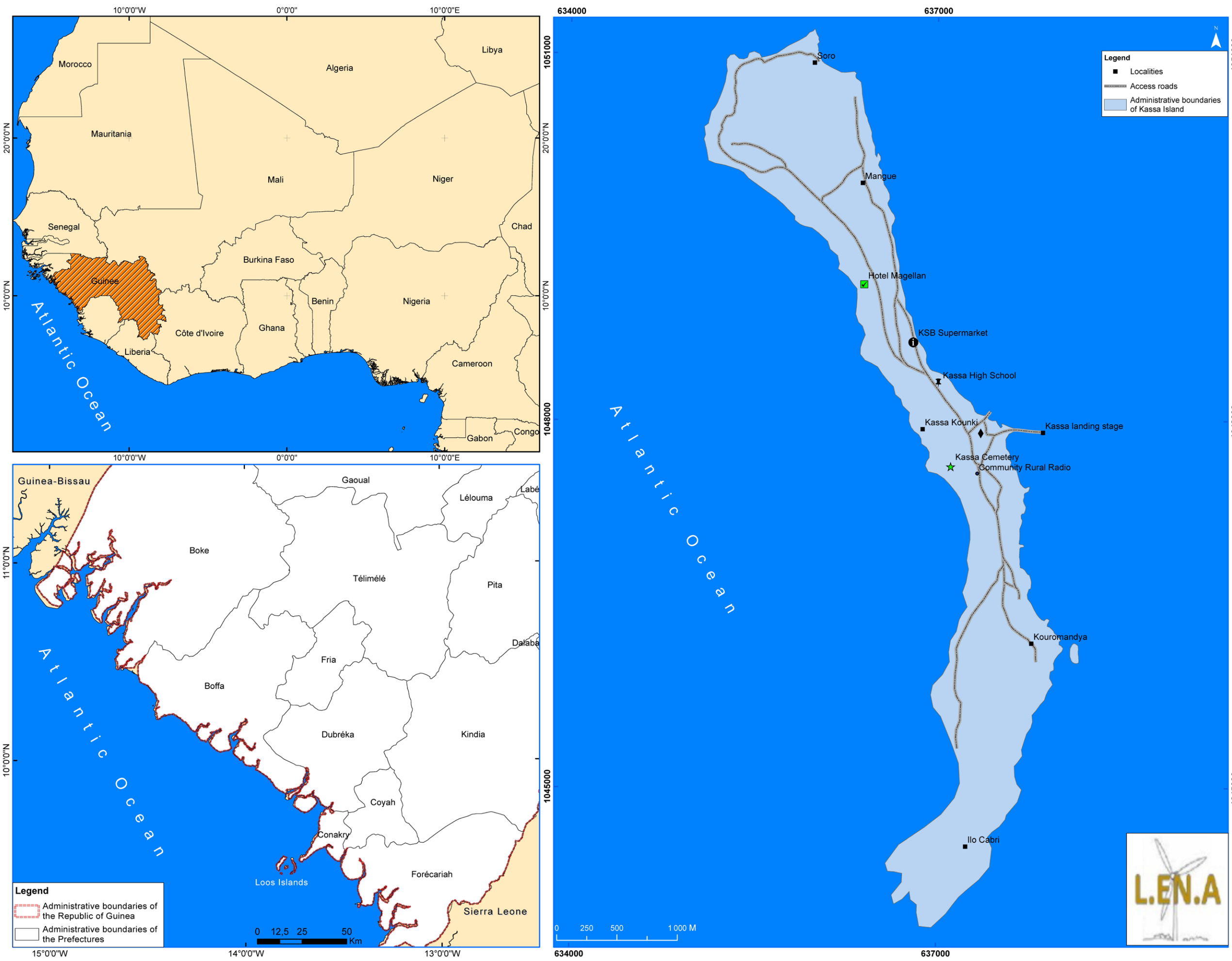


Figure 1. Location of Kassa island in the loos islands archipelago (Conakry).

The data used in this study were obtained from two widely recognized atmospheric data sources: the ERA5 reanalysis dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), and the NASA POWER platform, whose meteorological parameters are mainly based on the MERRA-2 reanalysis (*Modern-Era Retrospective Analysis for Research and Applications*, *Version* 2) [16]-[18].

The data were extracted for the Kassa site, defined by the geographical coordinates 9.477˚N and 13.749˚W, over the period from January 1, 2020 to December 31, 2025. To ensure comparability between the two data sources, wind speeds were considered at a common reference height of 10 m above ground level.

For ERA5, the zonal u_{10} and meridional v_{10} wind components at 10 m were extracted for the grid cell corresponding to the reference site. For each monthly observation, the resulting wind speed was calculated from these two components according to $V_{10} = \sqrt{u_{10}^2 + v_{10}^2}$ [16] [17].

For NASA POWER, the WS10M variable, which directly corresponds to the monthly mean wind speed at 10 m, expressed in m/s, was used [16] [18]. The temporal consistency of the series was verified over the entire study period. The final datasets comprise 72 monthly observations for each data source, corresponding to the six years of the 2020-2025 period, with no missing data in the series used. The use of the same reference site, the same height, and a common analysis period therefore ensures the comparability of the NASA POWER and ERA5 series, while accounting for differences in their spatial resolutions and data production methods [16]-[18].

2.2. Method

2.2.1. Wind Regime Modeling Using the Weibull Distribution

For each calendar month, the mean wind speed v_m and standard deviation σ were determined from the six-monthly observations corresponding to the years 2020-2025 ($n = 6$). Thus, the monthly statistics presented in **Table 2** and **Table 3** represent the interannual mean and dispersion for each month over the study period.

The statistical characterization of the wind regime is performed using the two-parameter Weibull distribution, which is widely used to represent the frequency distribution of wind speeds and assess the energy potential of a site. This approach makes it possible to account for both the characteristic wind speed level and its dispersion around the mean value [19] [20]. The Weibull probability density function is expressed as:

$$f(v) = \left(\frac{k}{c}\right) \cdot \left(\frac{v}{c}\right)^{k-1} \cdot \mathrm{e}^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

where:

- $f(v)$: probability density function of wind speed; it describes the relative frequency of occurrence of the different values of v over the period considered;
- v: wind speed, in m/s;
- k: shape parameter, dimensionless, which characterizes the dispersion and regularity of wind speeds;
- c: scale parameter, expressed in m/s, which represents the characteristic level of wind speeds.

The shape parameter k can be estimated from the mean wind speed $\overline{v}$ and the standard deviation σ using the following empirical relationship [19]:

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \tag{2}$$

with:

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

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(v_i - v_m\right)^2}$$

where:

- n: total number of observations;

- v_m : mean wind speed (m/s);
- σ : standard deviation;
- i : index number of each wind speed observation;
- v_i : wind speed observed at the i^{th} measurement (m/s).

Once k has been determined, the scale parameter c can be obtained from the mean wind speed and the Gamma function [19]:

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{3}$$

where:

- Γ denotes the Gamma function, defined as:

$$\Gamma(x) = \int_0^\infty \exp(-t) t^{x-1} \mathrm{d}t, (x > 0).$$

Thus, a high value of k generally indicates a distribution that is more concentrated around the characteristic wind speed and, consequently, a relatively regular wind regime, whereas c provides information on the characteristic intensity of the wind: the higher its value, the higher the characteristic wind speeds at the site. The combined use of k and c therefore makes it possible to characterize the wind regime and obtain the parameters required to estimate wind power density and wind energy [19] [20].

The selected method estimates the Weibull parameters k and c from the monthly mean wind speed and standard deviation. In this study, the high k values observed for some months mainly reflect a low interannual dispersion of monthly wind speeds around their mean. Therefore, these values should not, by themselves, be interpreted as an indicator of the goodness of fit of the Weibull distribution. Furthermore, since each monthly statistic is based on six observations ($n = 6$), the separate application of goodness-of-fit tests such as the Kolmogorov-Smirnov or Anderson-Darling tests would have limited statistical robustness. This limitation should be taken into account when interpreting the estimated parameters.

2.2.2. Wind Energy Potential Assessment: Power and Energy

The assessment of wind energy potential is based on determining the kinetic power contained in the wind and the corresponding energy over a given period. Wind Power Density (WPD), expressed in W/m^2, is a relevant indicator for characterizing and comparing the energy potential of sites, particularly because of its cubic dependence on wind speed [21].

1. Calculation of the Available Wind Power Density

The available wind power density represents the kinetic power carried by the wind per unit area perpendicular to the airflow. It mainly depends on the air density and the cube of the wind speed [21].

For an instantaneous wind speed v, it is expressed as:

$$P_d(v) = \frac{1}{2}\rho v^3 \tag{4}$$

where:

- P_d : available wind power density, in W/m²;
- ρ : air density, in kg/m³;
- v : wind speed, in m/s.

Under standard atmospheric conditions at sea level, the air density can be taken as:

$$\rho = 1.225\ \text{kg/m}^3$$

For a series of n observations, the mean power density is determined from the cube of the individual observed wind speeds:

$$\overline{P}_d = \frac{\rho}{2n}\sum_{i=1}^{n} v_i^3 = \frac{1}{2}\rho\overline{v}^3 \tag{5}$$

This formulation provides a better representation of the temporal variability of wind than directly using the cube of the mean wind speed, $\overline{v}^3$. Recent studies have shown that temporal resolution and wind speed averaging can significantly influence the estimation of wind power density [21].

When wind speeds are represented by a Weibull distribution with parameters k and c, the mean available power density can also be expressed as:

$$\overline{P}_d = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{6}$$

The use of Weibull parameters to determine the power density and energy potential of a site has also been applied in recent studies, particularly using wind speed data measured at a height of 10 m [22]. **Table 1** presents the classification of wind energy potential at 10 m above ground level, based on the mean wind speed and wind power density.

Table 1. Classification of wind energy potential at 10 m based on mean wind speed and power density [23].

Site Class	Power Density (W/m²)	Mean Wind Speed (m/s)	Potential (Quality)	Interpretation
Class 1	<100	<4.4	Low	Low wind resource
Class 2	100 - 150	4.4 - 5.1	Marginal	Limited potential
Class 3	150 - 200	5.1 - 5.6	Moderate	Moderate potential
Class 4	200 - 250	5.6 - 6.0	Good	Favorable resource
Class 5	250 - 300	6.0 - 6.4	Excellent	High wind energy potential
Class 6	300 - 400	6.4 - 7.0	Excellent	Very high wind energy potential
Class 7	400 - 1000	7.0 - 9.4	Excellent	Exceptional wind resource

Note: This classification is established for a reference height of 10 m. Wind speed and power density thresholds differ when the measurement height changes.

2. Calculation of the Extractable or Recoverable Power Density

Not all the kinetic power available in the wind can be converted into mechanical power by a wind turbine. The fraction effectively extracted is characterized by the power coefficient C_p. The recoverable power density can therefore be expressed as:

$$P_r = C_p P_d \tag{7}$$

By substituting P_d with its expression:

$$P_r = \frac{1}{2}\rho C_p v^3 \tag{8}$$

where:

- P_r : recoverable power density, in W/m²;
- P_d : available power density, in W/m²;
- C_p : wind turbine power coefficient.

For an ideal wind turbine, the maximum power coefficient is limited by the **Betz limit**:

$$C_{p,max} = \frac{16}{27} \simeq 0.593$$

The maximum theoretically recoverable power density is then given by:

$$P_{r,max} = \frac{16}{27} P_d \simeq 0.593 P_d \tag{9}$$

This value represents a theoretical maximum aerodynamic limit and not the electrical power actually recoverable by a wind turbine. The power actually produced is necessarily lower and depends mainly on the turbine's actual power coefficient, its power curve, as well as the mechanical, electrical, and operational losses of the system.

3. Estimation of the Available Wind Energy at the Site

Power characterizes the energy potential at a given instant, whereas available energy takes into account the duration over which this power is considered. Recent wind energy potential assessment studies therefore jointly determine the power density in W/m² and the corresponding energy density in kWh/m² [24].

For each month m, the available wind energy is determined from the corresponding mean power density and the number of hours in the considered month:

$$E_{d,m} = \frac{P_{d,m} T_m}{1000} \tag{10}$$

where:

- $E_{d,m}$: available wind energy for month mm, in kWh/m²;
- $\overline{P}_{d,m}$: mean available wind power density for month mm, in W/m²;
- T_m : number of hours in the considered month.

The monthly duration is determined as follows: $T_m = 24 N_m$

where:

- N_m , number of days in the considered month;
- T_m , number of hours in the considered month, which, for the reference calendar year, is equal to:
  - o 744 h for a 31-day month;
  - o 720 h for a 30-day month;

o 672 h for February.

The annual available wind energy is then obtained by summing the energies of the twelve months:

$$E_{d,ann} = \sum_{m=1}^{12} E_{d,m} \tag{11}$$

This procedure avoids applying an annual duration of 8760 h to each monthly power density and takes into account the specific duration of each month. It remains consistent with the expression of the wind energy resource in kWh/m² based on the mean power density of the site [22] [24].

4. Estimation of the Maximum Theoretical Energy According to the Betz Limit

To assess the maximum theoretically extractable fraction of the available wind energy, the Betz limit is applied to the power density for each month:

$$P_{Betz,m} = 0.593 P_{d,m} \tag{12}$$

The corresponding maximum theoretical energy for month m is then:

$$E_{Betz,m} = \frac{P_{Betz,m} T_m}{1000} = \frac{0.593 P_{d,m} T_m}{1000} \tag{13}$$

The annual maximum theoretical energy is obtained by summing the twelve (12) monthly values:

$$E_{Betz,ann} = \sum_{m=1}^{12} E_{Betz,m} \tag{14}$$

This energy represents only a maximum theoretical limit imposed by Betz's law. Therefore, it should not be considered equivalent to the electrical energy actually recoverable or produced by a wind turbine. Actual energy production depends mainly on the turbine power curve, its actual power coefficient, cut-in and cut-out wind speeds, overall efficiency, and availability.

3. Results and Discussion

3.1. Presentation of Mean Wind Speeds and Weibull Parameters

The data presented in **Tables 2-3** correspond to the monthly mean wind speeds at 10 m, together with the statistical and Weibull parameters obtained from NASA POWER and ERA5 data over the 2020-2025 period. These data, already used in our previous comparative study conducted at the same site [16], are included here as input data required for the wind energy potential calculations developed in the present study. Their presentation is therefore not intended to repeat the detailed comparative analysis performed in [16], but rather to provide the parameters required for the assessment of wind power density and wind energy.

For descriptive purposes, NASA POWER monthly mean wind speeds range from 2.26 m/s in November to 5.60 m/s in August, whereas ERA5 values range from 3.26 m/s in January to 5.02 m/s in July. The Weibull parameters k and c, as well as the standard deviations σ, are also presented in both tables and are used for the statistical characterization and wind energy calculations of the site.

Table 2. Monthly mean wind speeds, standard deviations, and Weibull parameters from NASA POWER over the 2020-2025 period (n = 6 per month).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
$\bar{v}_{nasa}$	3.01	3.51	4.04	4.01	3.49	4.06	5.46	5.60	4.36	2.81	2.26	2.65
σ_{nasa}	0.22	0.14	0.18	0.16	0.14	0.28	0.48	0.30	0.26	0.30	0.18	0.24
k_{nasa}	16.82	32.20	30.11	33.99	33.03	17.97	14.05	23.73	21.42	11.45	15.30	13.44
c_{nasa}	3.10	3.57	4.11	4.07	3.55	4.19	5.67	5.73	4.47	2.93	2.34	2.75

Table 3. Monthly mean wind speeds, standard deviations, and Weibull parameters from ERA5 over the 2020-2025 period (n = 6 per month).

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
$\bar{v}_{era}$	3.26	3.31	3.53	3.84	4.34	4.74	5.02	4.79	4.44	4.22	4.02	3.75
σ_{era}	0.25	0.23	0.29	0.19	0.08	0.32	0.20	0.11	0.18	0.19	0.32	0.35
k_{era}	16.49	18.10	15.11	26.29	79.13	18.88	33.79	58.39	31.96	29.05	15.67	13.23
c_{era}	3.36	3.41	3.66	3.92	4.37	4.88	5.11	4.83	4.52	4.30	4.16	3.90

The data presented in Tables 2-3 highlight a seasonal variation in wind speeds. The associated Weibull parameters show a consistent evolution with these data, particularly the scale parameter cc, which reaches its maximum values in August for NASA POWER (5.73 m/s) and in July for ERA5 (5.11 m/s).

The standard deviations remain generally low, ranging from 0.14 to 0.48 m/s for NASA POWER and from 0.08 to 0.35 m/s for ERA5. The high values of the shape parameter kk observed for some months mainly reflect a low interannual dispersion of wind speeds around their mean and should be interpreted considering the limited number of observations per month (n = 6). These data and parameters, already examined in the comparative analysis conducted at the same site [16], are used here primarily as input data for the wind power density and wind energy calculations developed in the following sections.

3.2. Temporal Analysis of Monthly Mean Wind Speeds

The curves in Figure 2 show the monthly variation in mean wind speeds obtained from NASA POWER and ERA5. They highlight a seasonal variation in the wind regime, with generally lower values during the dry season and higher values during the wet season. Maximum values are observed in August for NASA POWER (5.60 m/s) and in July for ERA5 (5.02 m/s). Differences between the two datasets are also observed depending on the month, particularly during the dry season.

The bar charts in Figure 3 provide a more direct visualization of the monthly differences between the two data sources. NASA POWER shows higher values particularly in July and August, whereas ERA5 shows higher values during several months of the dry season. These differences are taken into account in the wind energy potential calculations performed separately for each data source. Since a detailed comparative statistical analysis of NASA POWER and ERA5 data has already been conducted for the same Kassa site in our previous study [16], it is not repeated here. In the present study, the datasets are mainly used to

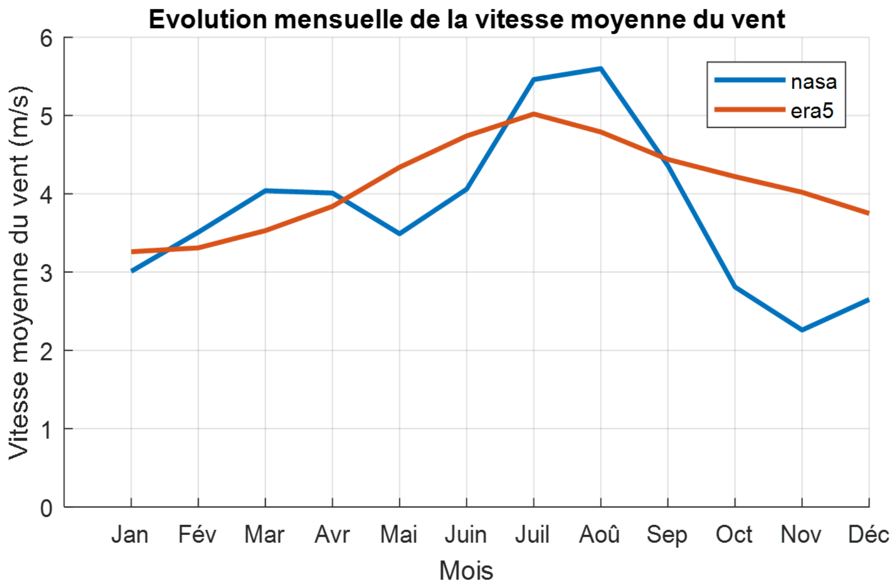


Figure 2. Monthly variation in mean wind speeds from NASA POWER and ERA5.

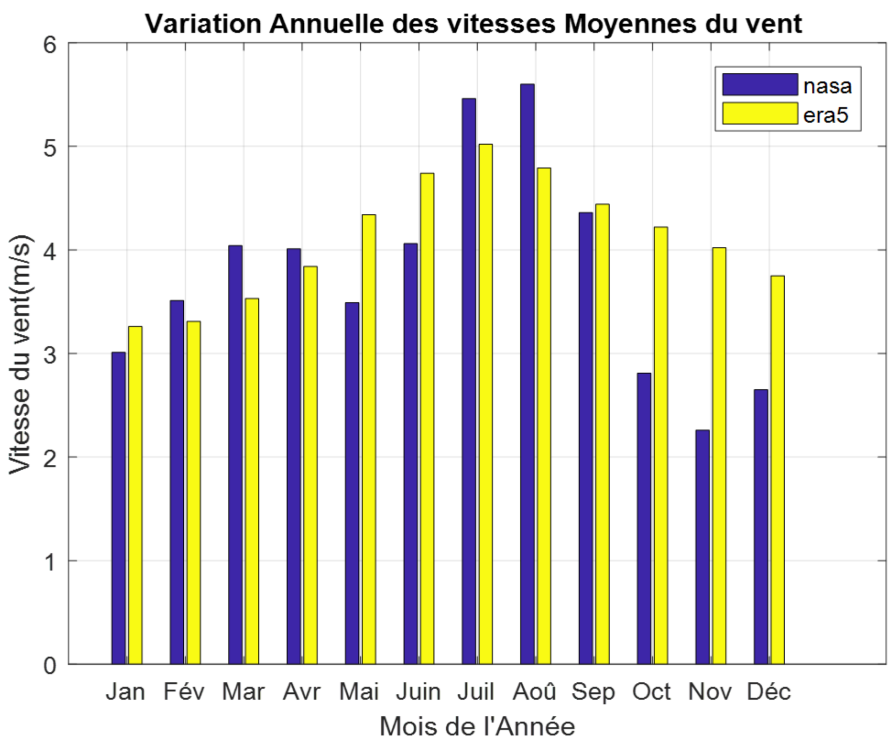


Figure 3. Monthly comparison of mean wind speeds from NASA POWER and ERA5.

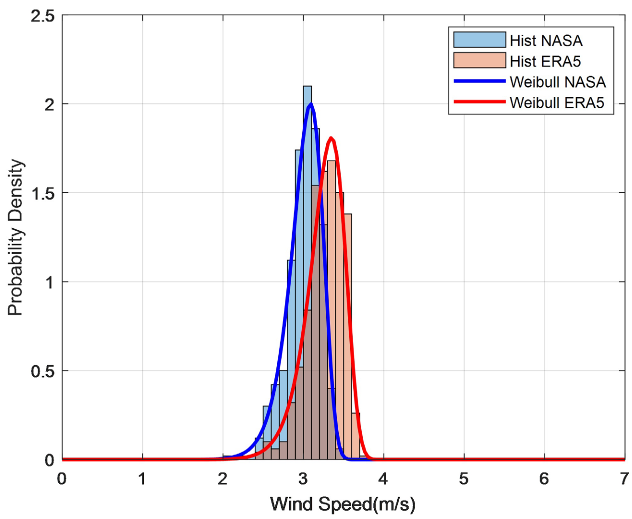
characterize the seasonal variation of the wind resource and as input data for the wind power density and wind energy calculations.

3.3. Analysis of Weibull Distributions

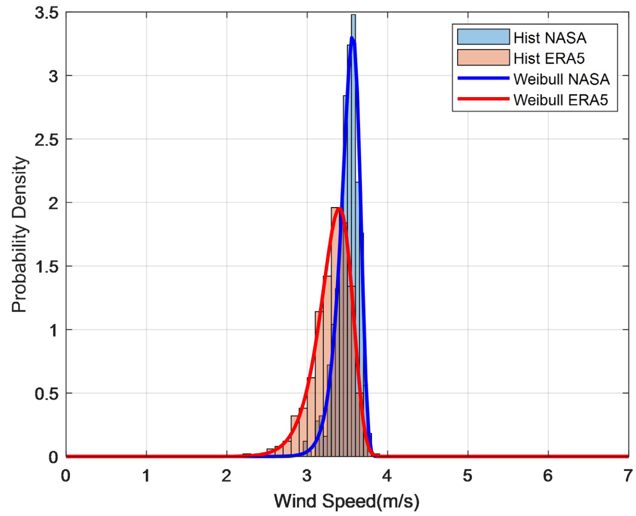
The Weibull distributions fitted to the histograms show a good agreement between the model and the data. As illustrated in Figure 4, the distributions obtained for the different months generally reproduce the shape of the observed wind-speed frequency distributions, confirming the relevance of the Weibull distribution for characterizing the wind regime at the study site.

The high values of k indicate a low occurrence of extreme wind speeds and favorable stability for energy production. The plots show that the distributions are broader during the wet season, indicating greater wind speed variability.

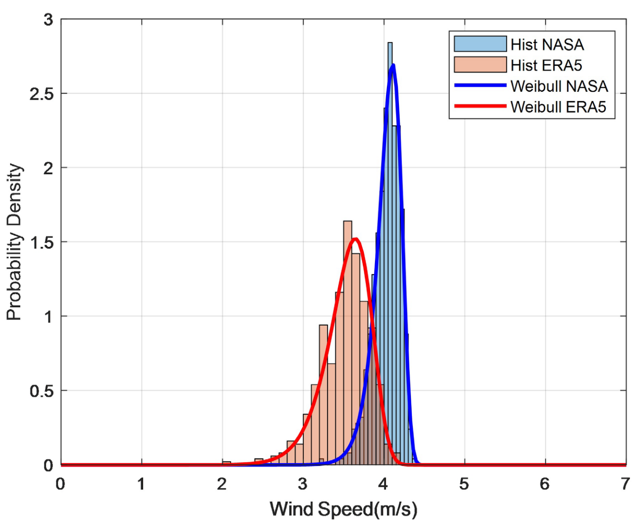
The ERA5 curves are narrower (less dispersed), whereas the NASA curves are more spread out, reflecting a better representation of wind speed variability.



(a)



(b)



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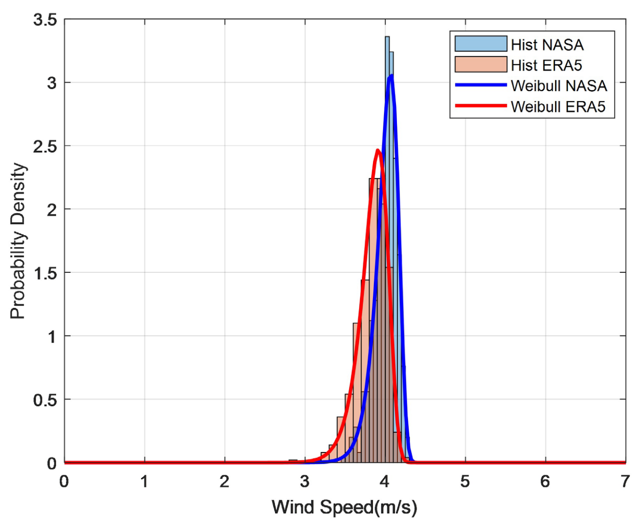

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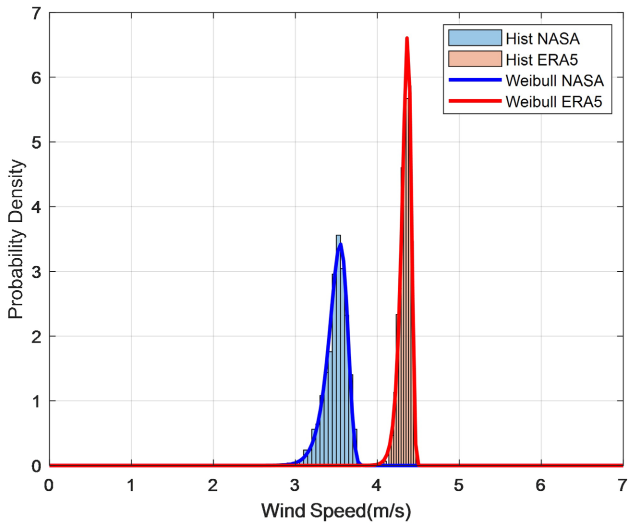
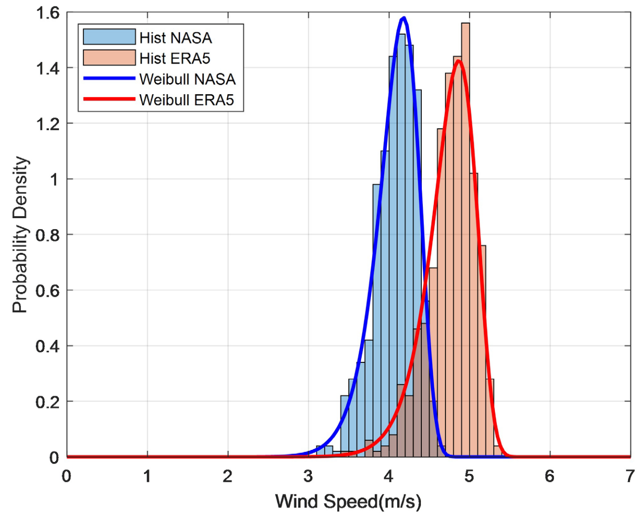
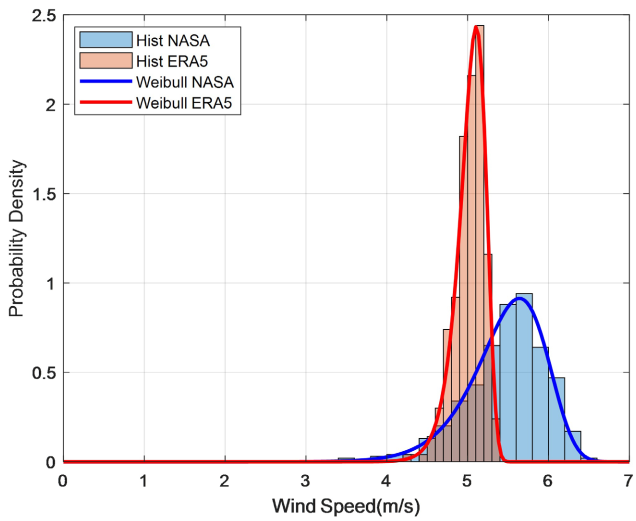

Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

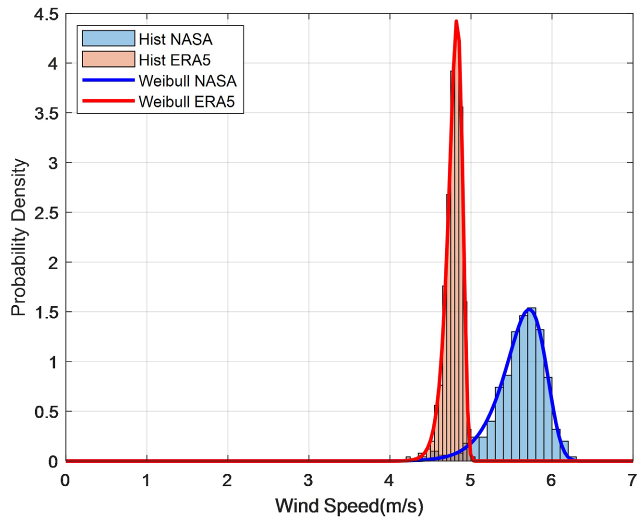
(e)


Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

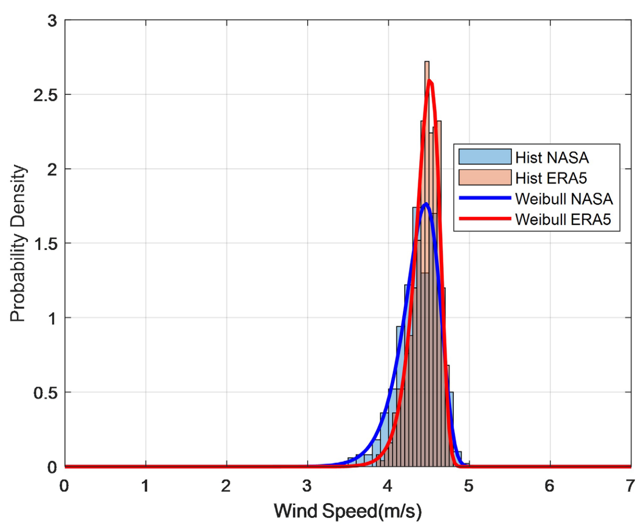
(f)


Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

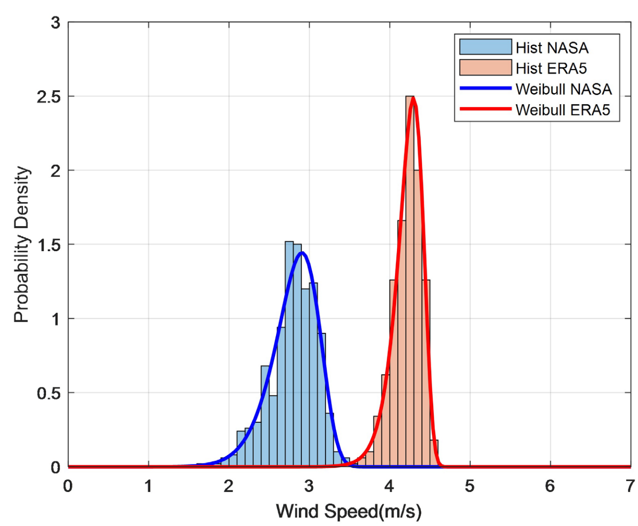
(g)


Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

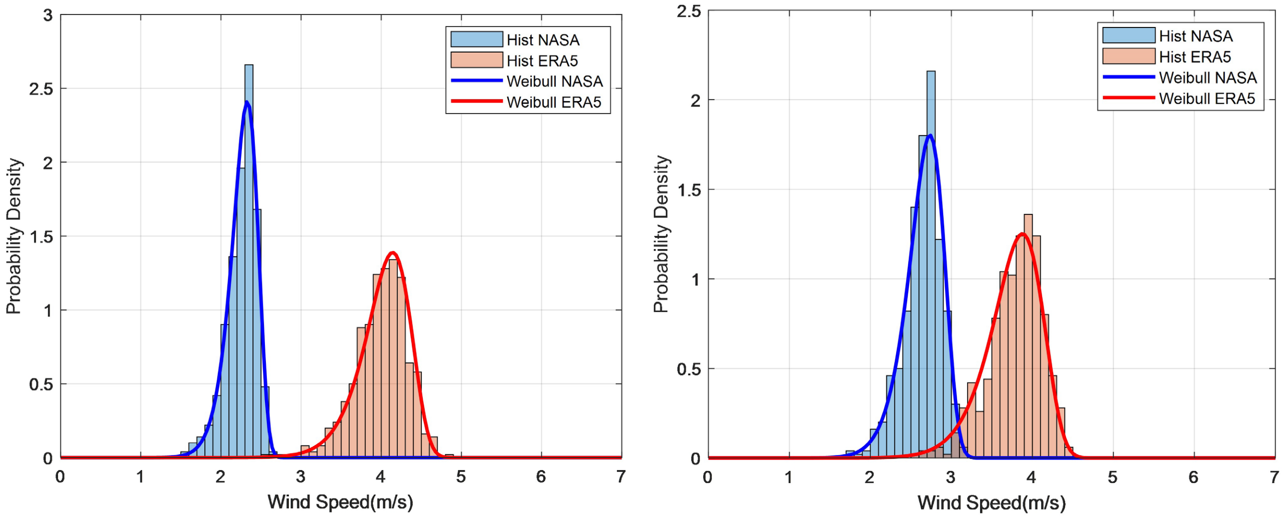
(h)


Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

(i)


Hist NASA
Hist ERA5
Weibull NASA
Weibull ERA5
Probability Density
Wind Speed(m/s)

(j)



(k) (l)

Figure 4. Monthly Weibull distribution plots fitted to wind speeds: (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November, and (l) December.

3.4. Assessment of Wind Power Densities

Wind power densities were evaluated using the Weibull parameters previously determined from NASA POWER and ERA5 data. Table 4 presents, for each month, the mean wind speeds and the Weibull parameters *c* and *k*, as well as the available wind power density P_d and the maximum theoretical wind power density P_r, calculated according to the Betz limit $C_p = 0.593$. These results provide an assessment of the monthly variation in the wind energy potential of the Kassa

Table 4. Monthly available wind power densities and maximum theoretical wind power densities according to the Betz limit (NASA POWER and ERA5).

Month	Mean Wind Speed NASA (m/s)		Scale Parameter *c* NASA (m/s)		Shape Parameter *k* NASA		Available Power Density P_d NASA (W/m²)		Recoverable Power Density P_r NASA (W/m²)	
	$\overline{V}_{nasa}$	$\overline{V}_{era}$	c_{nasa}	c_{era}	k_{nasa}	k_{era}	P_{d_nasa}	P_{d_era}	P_{r_nasa}	P_{r_era}
January	3.01	3.26	3.10	3.36	16.82	16.49	16.7	21.2	9.9	12.6
February	3.51	3.31	3.57	3.41	32.20	18.10	26.5	22.2	15.7	13.2
March	4.04	3.53	4.11	3.66	30.11	15.11	40.4	26.9	23.9	15.9
April	4.01	3.84	4.07	3.92	33.99	26.29	39.5	34.7	23.4	20.6
May	3.49	4.34	3.55	4.37	33.03	79.13	26.0	50.0	15.4	29.6
June	4.06	4.74	4.19	4.88	17.97	18.88	41.0	65.2	24.3	38.7
July	5.46	5.02	5.67	5.11	14.05	33.79	99.7	77.5	59.1	45.9
August	5.60	4.79	5.73	4.83	23.73	58.39	107.6	67.3	63.8	39.9
September	4.36	4.44	4.47	4.52	21.42	31.96	50.7	53.6	30.1	31.8
October	2.81	4.22	2.93	4.30	11.45	29.05	13.6	46.0	8.1	27.3
November	2.26	4.02	2.34	4.16	15.30	15.67	7.1	39.7	4.2	23.5
December	2.65	3.75	2.75	3.90	13.44	13.23	11.4	32.3	6.8	19.1

site for both data sources.

It should be noted that the monthly mean wind speeds at 10 m above ground level and the Weibull parameters c and k reported in **Table 4** constitute baseline data already used in our previous comparative study conducted at the same site [16]. In the present study, these data are used to determine the available wind power density and the maximum theoretical wind power density according to the Betz limit.

Figures 5-6 illustrate the monthly variation in wind power densities obtained from NASA POWER and ERA5 data. They respectively present the available wind power density and the maximum theoretical wind power density determined according to the Betz limit, thereby illustrating their seasonal variation for both data sources.

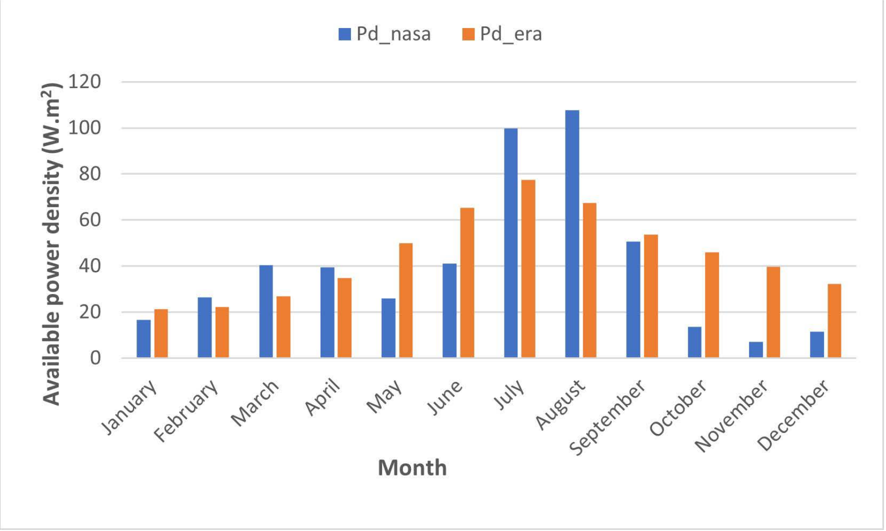


Figure 5. Available wind power density (NASA and ERA5).

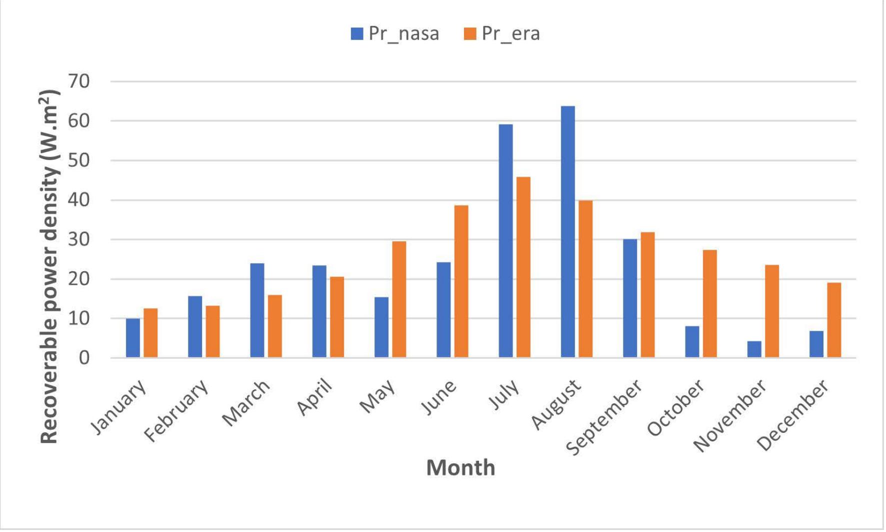


Figure 6. Maximum theoretical wind power density according to the Betz limit for NASA POWER and ERA5.

The power density graphs show a maximum in July-August and a minimum in November-December. NASA values are slightly higher during periods of strong winds due to the higher wind speeds.

ERA5 provides more regular power density values but underestimates the peaks. NASA provides a better estimation of the maximum energy potential.

3.5. Assessment of Wind Energy

The monthly wind energies were determined from the power densities presented previously and the number of hours corresponding to each month. Table 5 presents, for NASA POWER and ERA5, the available wind energies E_d and the maximum theoretical wind energies E_r determined according to the Betz limit $C_p = 0.593$. The annual energy is obtained by summing the twelve-monthly energy values. These results provide an assessment of the seasonal distribution and annual wind energy potential of the Kassa site.

Table 5. Monthly and annual available wind energies and maximum theoretical wind energies according to the Betz limit for NASA POWER and ERA5 ERA5.

Month	T_m (h)	NASA			ERA5		
		P_d (W/m²)	E_d (kWh/m²)	E_r (kWh/m²)	P_d (W/m²)	E_d (kWh/m²)	E_r (kWh/m²)
January	744	16.7	12.42	7.37	21.2	15.77	9.35
February	672	26.5	17.81	10.56	22.2	14.92	8.85
March	744	40.4	30.06	17.82	26.9	20.01	11.87
April	720	39.5	28.44	16.86	34.7	24.98	14.82
May	744	26.0	19.34	11.47	50.0	37.20	22.06
June	720	41.0	29.52	17.51	65.2	46.94	27.84
July	744	99.7	74.18	43.99	77.5	57.66	34.19
August	744	107.6	80.05	47.47	67.3	50.07	29.69
September	720	50.7	36.50	21.65	53.6	38.59	22.89
October	744	13.6	10.12	6.00	46.0	34.22	20.29
November	720	7.1	5.11	3.03	39.7	28.58	16.95
December	744	11.4	8.48	5.03	32.3	24.03	14.25
Total annuel	**8760**	-	**352.04**	**208.76**	-	**393.00**	**233.05**

Figure 7 illustrates the monthly variation in the maximum theoretical wind energy determined according to the Betz limit from NASA POWER and ERA5 data. It provides a visualization of the seasonal distribution of this energy and the variations observed between the two data sources.

The results highlight a marked seasonality of the wind resource at Kassa. The annual available wind energy is estimated at 352.04 kWh/m² for NASA POWER and 393.00 kWh/m² for ERA5. According to the theoretical Betz limit $C_p = 0.593$, the corresponding maximum theoretical energies are 208.76 kWh/m²/year and 233.05 kWh/m²/year, respectively. These values represent theoretical limits and do not correspond to the electrical energy actually produced by a wind turbine.

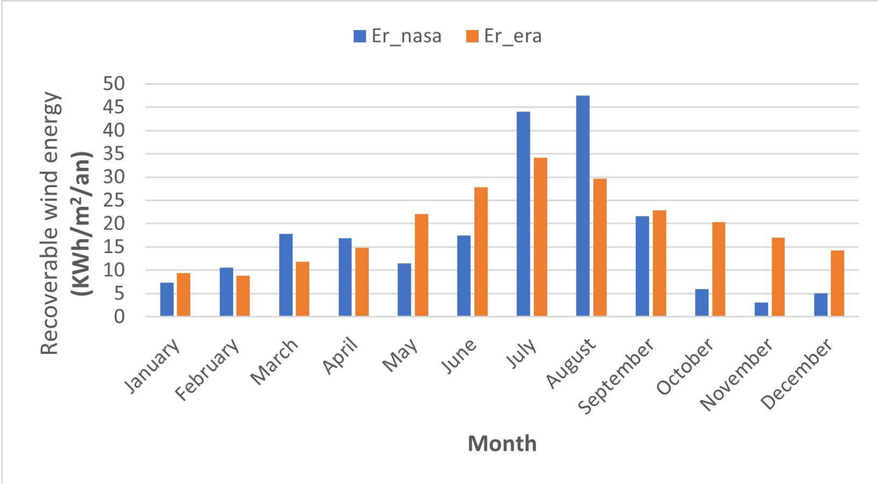


Figure 7. Maximum theoretical wind energy according to the Betz limit for NASA POWER and ERA5.

The period from June to September accounts for a significant share of the annual energy, contributing approximately 62.6% for NASA POWER and 49.2% for ERA5. This difference reflects a more pronounced seasonality in the NASA POWER data, whereas the annual distribution estimated by ERA5 appears more uniform. Despite the differences observed between the two data sources, the results therefore highlight a seasonal wind resource, mainly enhanced during the wet season.

4. Conclusions

This study assessed the wind energy potential of Kassa Island using wind speed data from NASA POWER and ERA5 over the 2020-2025 period, at a reference height of 10 m above ground level. The characterization of the wind regime using the Weibull distribution revealed a seasonal variation in the wind resource, with more favorable conditions during the wet season, particularly between June and September.

Monthly mean wind speeds range from 2.26 to 5.60 m/s for NASA POWER and from 3.26 to 5.02 m/s for ERA5. The maximum available wind power densities reach 107.6 W/m^2 and 77.5 W/m^2, respectively. The annual available wind energy is estimated at 352.04 kWh/m^2 for NASA POWER and 393.00 kWh/m^2 for ERA5, while the corresponding maximum theoretical energies according to the Betz limit Cp = 0.593 are 208.76 and 233.05 kWh/m^2/year, respectively. These values represent theoretical aerodynamic limits and therefore do not correspond to the electrical energy actually produced by a wind turbine. These values are consistent with the corrected results presented in Table 5.

The period from June to September accounts for approximately 62.6% of the annual energy estimated from NASA POWER and 49.2% of that estimated from ERA5, confirming the seasonal nature of the wind resource at the site. At the reference height of 10 m, the wind energy potential of Kassa remains generally low, despite more favorable conditions during certain months of the wet season. Nevertheless, this resource could be of interest for low-power local applications, subject to further assessment at heights more representative of the wind energy systems under consideration.

Finally, the absence of in situ meteorological measurements represents a limitation of this study. Measurement campaigns at the site, combined with wind speed extrapolation to wind turbine hub heights and a techno-economic analysis, would provide a more accurate assessment of the actually exploitable wind energy potential and the possibilities for integrating wind energy into the local electricity supply.

Author Contributions

The contributions of the different authors to this study are presented in the table below. They include, in particular, the conceptualization and methodology of the study, data collection and processing, analysis and validation of the results, preparation of figures and tables, writing and revision of the manuscript, as well as supervision and project administration.

No.	Authors—First and Last Names	Contributions
1	Mohamed Ansoumane Camara	Conceptualization; methodology; formal analysis; interpretation of results; writing—original draft; writing—review and editing; supervision; project administration.
2	Souleymane Soumah	Methodology; data processing and analysis; validation of results; writing—review and editing.
3	Ouaïdou Emmanuel	Methodology; data analysis; validation of results; review of the manuscript.
4	Kadiatou Aïssatou Barry	Data processing and analysis; validation of results; review of the manuscript.
5	Oumar Kourouma	Data collection and preparation; data processing; calculations; preparation of figures and tables.
6	Sidiki Fatta Condé	Data collection and preparation; data processing; calculations; preparation of figures and tables.
7	Amadou Oury Diallo	Data collection and preparation; data processing; calculations; preparation of figures and tables.

All authors have read the final version of the manuscript and approved its submission for publication.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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