



Modelling approach and predictive assessment of wind energy potential in the Nouakchott region, Mauritania

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Abstract

Mauritanian government has opted the utilization of renewables sources for power generation to reduce the carbon emissions foot print of the country. Accordingly, wind and wind power characteristics are being investigated in the present work in the northern and southern areas of Nouakchott, Mauritania. The study utilizes the wind speed data measured at 20, 40, and 60 m above the ground level (AGL) over a period of 12 months. The data is collected every 5 s- and 10-minutes averaged values are stored.

The Weibull probability density function is used to study the wind characteristics and its potential for the two selected sites. The results show that the mean annual wind speed and wind power density at the Nouakchott South site are, respectively (6.42 m/s and 185.25 W/m²), (7.06 m/s and 230.48 W/m²) and (7.72 m/s and 287.8 W/m²) at 20, 40 and 60 m. However, these values are (5.49 m/s and 116.79 W/m²), (6.51 m/s and 174.08 W/m²) and (7.33 m/s and 246.07 W/m²) at respective heights mentioned above at Northern site. Two statistical indicators are used to investigate the efficiency of used method. These indicators are the coefficient of determination (R²) and root mean square error (RMSE) between the measured and estimated wind speed values are found in the range of 0.962–0.981 and 0.014–0.02 respectively. This shows the reliability of the fitted distribution function and the accuracy of the estimation method used. Three wind turbines with rated power 2000 kW are selected to estimate the available wind power at the two sites. The results indicate a good and harness able wind power potential in the Nouakchott Mauritania region.

Keywords Wind energy potential · Weibull probability · Density function · Monitoring · Weibull parameters · Statistical analysis · Mauritania

Abbreviations

A Wind turbine swept rotor area (m²)
C Weibull scale parameter (m/s)
f Weibull probability density
F Cumulative distribution

K Weibull shape parameter
n Number of observations
p Wind power (W, kW, MW)
P Wind power density (W/m² or kW/m²)
R² Coefficient of determination

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RMSE	Root mean square error
x_i	Frequency of Weibull
y_i	Frequency of observations
v	Wind speed (m/s)
H	height (m)
C_F	Capacity factor
P_R	Rated power (kW)
\bar{V}	Average wind speed (m/s)
D	The rotor diameter (m)
E_{out}	Energy Production

Introduction

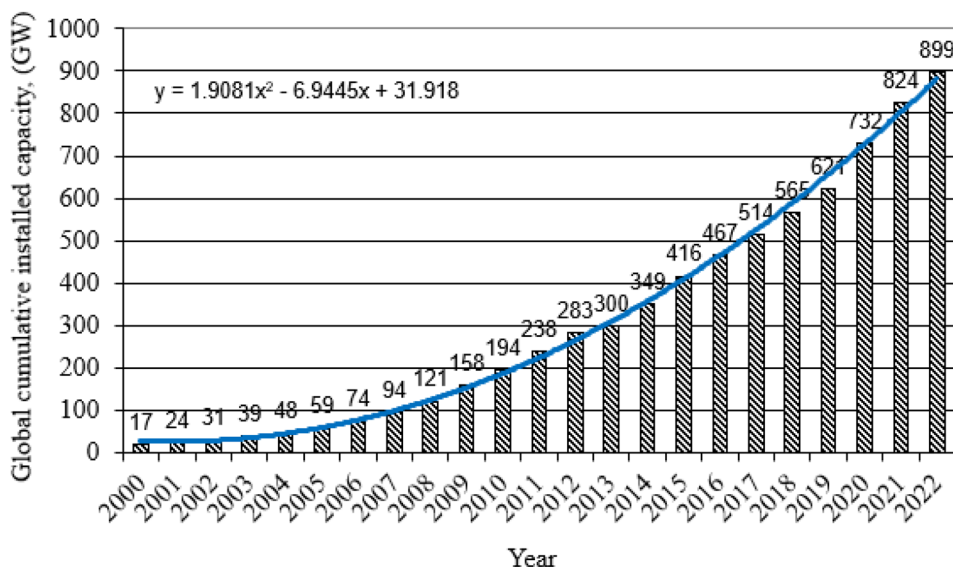
Globally increasing levels of greenhouse gases and adversely modifying environmental conditions have led the people from all walks of life to join hands and explore means and ways to safeguard the planet, Earth, for future generations. Engineers, scientists, environmentalists, power utilities, investors, and to certain extent the politicians are encouraging and working on developing and using clean and self-renewing sources of energy while also focusing on energy conservation aspect. The clean sources of energy include the wind (both onshore and offshore), solar (thermal and photovoltaics), geothermal, biomass, ocean (waves, currents, thermal, and salinity gradient). Of these sources, wind and solar photovoltaics are technologically mature and commercially acceptable and viable. The present study focusses on wind power potential in Mauritania. The installed capacity of global onshore wind power has reached to 899 GW in 2022, an increase of about 200% compared to 2013, Fig. 1. It is evident from this data that the installed capacity of wind power capacities are continuously increasing as indicated by the best fit line included in Fig. 1. Year to year; 2019–2020,

2020–2021, and 2021–2022; percent increases of 17.9, 12.6 and 9.1 are observed in wind power annual additions. As of now, around 156 countries have participated in wind power utilization in different installed capacities. Mauritania has a total wind power installed capacity of 34 MW (IRENA 2023).

In this context, Mauritania, with its enormous wind potential in large area, is one of the world’s leading countries which can be relied to play a key role in wind power development sector in the country. To support renewables sources, Mauritania launched the process of drawing national energy strategy for transforming the energy sector in 2020. In this transformation strategy, major emphasis is made on using country’s enormous gas and renewable sources in the medium and long term.

Mauritania’s wind energy potential is promising, given the favourable wind conditions in certain parts of the country. Country’s Atlantic coastline has strong and steady winds and vast stretches of desert in the north offering opportunities for large-scale wind power deployment. Currently the government is built a national energy policy steps to develop wind power and diversify its electricity production. It has already completed some wind power projects, including a 30 MW Nouakchott wind farm, which was commissioned in 2014. This is the first commercial scale wind farm in Mauritania. In addition, a 100 MW Boulouvar wind farm is scheduled to be operational in 2024. This project aims to provide clean and renewable energy, reduce Mauritania’s dependence on fossil fuels, and contribute to a sustainable energy system. The country has put in place a favourable regulatory framework, offering incentives and concessions to investors interested in developing wind energy projects. Mauritania has has looked for to expand international cooperation in wind energy field, working with regional and

Fig. 1 Global onshore cumulative wind power installed capacities (2000–2022), (IRENA 2023)



international partners to benefit from their expertise and technical support.

In local context, wind power offers diversification of the existing energy mix portfolio, reduction of greenhouse gas (GHG) emissions, creation of local jobs and strengthening of the country's energy security. Furthermore, harnessing wind power can help provide access to electricity in remote rural areas, improving living conditions of the local communities.

However, for realistic development it is important to note that the wind power development cost in Mauritania can be high due to lack of power grid network required for the evacuation of wind power and high installation, engineering, environmental, social, and assessment costs. Despite these challenges, Mauritania continues its efforts to develop wind power sector and fully exploit its wind potential. With continued commitment and adequate investment, wind power can play an important role in the country's energy mix and contribute to its transition to a more sustainable, environmentally-friendly economy.

Beside all of these backdrops, numerous studies have focused on estimating wind potential in the country and globally, encourages us to conduct the feasibility and viability study of exploiting wind power resources in different regions. Among the methods used and reported in the literature, the Weibull distribution has gained in popularity due to its ability to accurately model the wind speed data and its characteristics. To date, several studies, relating to the assessment of wind power potential and wind speed characteristics, have been carried out in different countries and reported in the literature (Rehman et al. 2023; Libanda 2022; Himri et al. 2022; Al-Shaikhi et al. 2022; Kassem et al. 2020 and Amarasinghe et al. 2020). These studies have demonstrated the importance of wind power resources assessments prior to the actual deployment of wind farms.

El Khchine and Sriti (2021) examined the wind energy potential in the coastal regions of Morocco based on hourly wind speed and wind directions data over the period of four years, 2015–2018. The study reported higher wind speed values of 8.5 m/s in February and 10.0 m/s in July at 50 m above AGL. Highest wind power densities (WPD) of 642.98 and 634.70 W/m² were reported at Boujdour and Essaouira sites. Soulouknga et al. (2022) used five wind turbines and estimated the wind potential of five sites in Chad. The results showed that the power density varied between a minimum of 20.80 W/m² and a maximum

of 44.17 W/m² corresponding Mongo and Faya-Largeau sites. The annual mean wind speed, the scale parameter, the standard deviation, and the wind power density of 6.34, 7.15, 3.31 m/s and 322 W/m² were reported for a location in Turkey. Çakmakç and Hunter (2020) stated that a predominant wind direction was prevalent from NE and availability of wind for more than 1400 h during the year. Caligiuri et al. (2022) presented a new satellite-based methodology for deep offshore installation in the Ionian Sea and reported a 19.06 GWh of annual energy yield from a single wind turbine. Khchine et al. (2019) used wind data at 50 m AGL over a period of three years (2015–2017) along with the Weibull probability density function to assess the wind power potential in the Moroccan region (Taza and Dakhla). Ben et al. (2021) used ten-year daily average wind speed data from 13 cities in central and southern Nigeria and analysed using six methods (graphical method Justus and Lysten empirical methods, maximum likelihood method and energy model factor) to estimate Weibull parameters.

This paper proposes an innovative approach to study the wind energy potential using the graphical Weibull distribution method. This approach offers a practical and visual alternative to traditional methods, facilitating the assessment of wind potential in different regions. The results obtained can contribute to the transition towards a more sustainable economy and promote wind power as a clean and renewable energy source.

Identification, location and instrumentation of measurement masts

The data used in this paper was collected at two sites: Nouakchott north and Nouakchott south in Mauritania. The data covers the period of one year (April 2021–March 2022) and is recorded every 10 min. Wind speed measurements are made at 20, 40, and 60 m AGL at both the sites. Wind direction is measured by using a wind vane at the 20 m height. The geographical locations of the masts equipped with instruments and sensors from NRG, are summarized in Table 1. Photos of the masts, in operation and fully instrumented, are shown in Figs. 2, 3 and 4.

Table 1 Identification of measurement masts

Mats	Height (AGL)	GPS Position	Type of instrumentation
Nouakchott North	20, 40 and 60 m	18°19'23.30"N 15°48'30.40"W	- Thermometer, - NRG #40 C Anemometer Calibrated, With Boo
Nouakchott South	20, 40 and 60 m	17°58'02.80"N 15°58'52.10"W	- NRG #200P Wind Direction Vane, 10 K with Boot

Fig. 2 Geographic location for the two meteorological stations

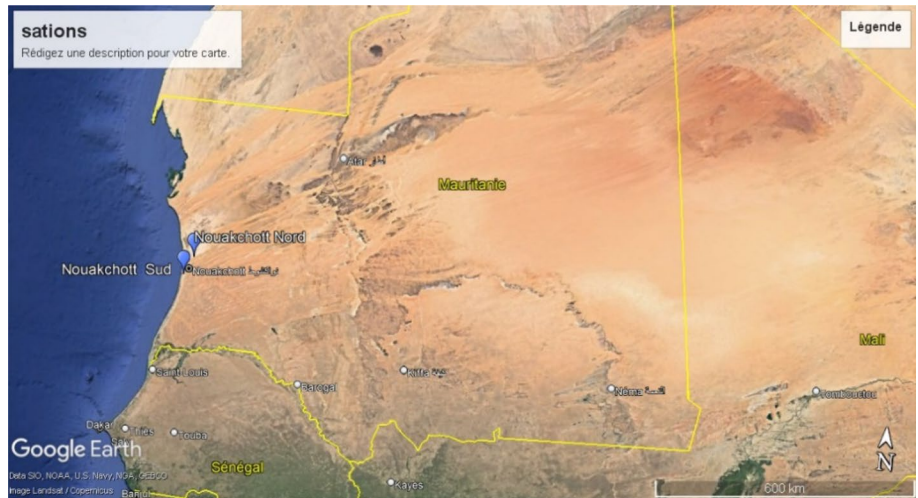


Fig. 3 Meteorological station at Nouakchott North



Fig. 4 Meteorological station Nouakchott South

Materials and methods

This section presents an innovative approach of estimating wind potential using the graphical two-parameter Weibull distribution method which involves complex calculations and sophisticated mathematical models. This graphical method offers a more intuitive and visual approach for assessing the wind potential of a given region. The study focuses on the Nouakchott region, where wind characteristics are analyzed over a 12-month period using the wind speed data measured at different heights 20, 40 and 60 m. In this study, as mentioned earlier, Weibull distribution is used to model the wind speed probability through specific graphs.

Wind data analysis procedure

Weibull probability density function

Various statistical distributions are used to describe and analyze wind resources. Among these, Weibull distribution is one of the widely used distribution to describe the wind characteristics. The two-parameter Weibull function $f(v)$ can be calculated using Eq. 1, (Charabi et al.2020; Wais 2017 and Bidaoui et al. 2019)

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

Where $f(v)$ is the probability of observing the wind speed $v(m/s)$, k and c are the shape and scale parameters respectively. The cumulative Weibull density function can be expressed as follows (Didane et al.2017; Azad et al. 2019 and Hamady et al. 2021)

$$F(V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right] \tag{2}$$

There are several methods for determining the Weibull parameters. The least squares method (LSM) is the most appropriate and is used in this study. The Weibull parameters are numerically estimated for both the sites as summarized in Table 2.

Estimation of the Weibull parameters

Least squares (LS) method

The graphical method is used by transforming the Weibull cumulative distribution function in to its linear equivalent. This is done by performing a double logarithmic operation on Eq. (3) and then rearranging the results (Akdağ et al.2009 and kang et al. 2021) to obtain Eq. (4)

$$\ln\{-\ln[1 - F(v)]\} = k\ln(v) - k\ln(c) \tag{3}$$

This method performed by organizing the wind speed data into a cumulative frequency distribution model and plotting the transformation of the transformed data into line graphs. The straight line can be described as follows (Adaramola et al.2014):

$$y = ax + b \tag{4}$$

Using the regression technique, the shape and scale parameters k and c are calculated as follows:

$$k = a \tag{5}$$

$$c = \exp(-b/a) \tag{6}$$

Performance analysis

To test the goodness of fit of the fitted distribution function and to determine the accuracy of the estimation method, two statistical tests are performed. The coefficient of determination R^2 and the root mean square error (RMSE) are used to evaluate the quality of the fitted distribution function. The R^2 test is given by the equation (Shoab et al.2017, Kaplan et al.2018)

$$R^2 = \frac{\sum_{i=1}^n (y_i - z_i)^2 - \sum_{i=1}^n (y_i - x_i)^2}{\sum_{i=1}^n (y_i - z_i)^2} \tag{7}$$

Where x and y are the measured and estimated wind speed values, n is number of data points, and z_i is the actual mean wind frequency percentage in time step i . The values of R^2 lie between 0 and 1. Higher values indicate that the calculated results better describe the observed results and vice versa. The RMSE test values are given by (Katinas et al. 2017):

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (y_i - x_i)^2 \right]^{1/2} \tag{8}$$

The lower RMSE values means that the Weibull distribution describes better the measured data.

Wind energy density

Wind energy density is a useful way of estimating the wind energy available at a given height. It shows the energy available for conversion by the wind turbines through its rotor swept area, A . the power for the given swept area A (m^2), at a certain location can be estimated as (Arreyndip et al.2016,Ongaki et al..2021, Ammari et al. 2015):

$$P(v) = \frac{1}{2} \rho A v_m^3 \tag{9}$$

While the wind power per unit area (Ulazia et al. 2019; Ucar et al. 2009) is given by:

$$P(v) = \frac{1}{2} \rho v_m^3 \tag{10}$$

The wind power density can be expressed using Weibull parameters as follow (Serban et al. 2020):

$$p(v) = \frac{P(v)}{A} = \frac{1}{2} \rho c^3 \Gamma \left(1 + \frac{3}{k} \right) \tag{11}$$

where $P(v)$ is the wind power (W), $p(w)$ is the wind power density (W/m^2), ρ is the air density at the site, and $\Gamma(x)$ is the gamma function of (x) given by (Pishgar-Komleh et al. 2015; Nawri et al. 2014):

$$\Gamma(x) = \int_0^{\infty} \exp(-t)t^{x-1} dt \tag{12}$$

Energy production

The annual energy production (E_{out}) can be estimated using the capacity factor (C_F) at the site, the total number of hours per year (h), and the rated power P_R of the wind turbine (Gilbert M 2004).

$$E_{out} = 8760.P_R.C_F \tag{13}$$

Capacity factor (C_F)

One of the important characteristics of any electrical system is its power rating, or the number of kilowatts it can produce

continuously at full power. Since electrical systems, especially wind turbines, do not operate at full power year-round and generate less than the rated power. Thus the capacity factor C_F is a practical dimensionless quantity between 0 and 1 that relates the rated power to the actual energy produced/delivered. This capacity factor (C_F) is calculated from the following Eq. (14) (Gilbert 2004):

$$C_F = 0.087 \bar{V} - \frac{P_R}{D^2} \tag{14}$$

where D is the and \bar{V} is the mean speed.

Results and discussion

Assessing wind potential using the Weibull distribution method offers valuable results and discussions for determining the viability of a specific site for the development of wind farms. Here are some key results and discussions that are derived using this method:

The monthly average wind speed, at three measurement heights, show that wind speed increases with height (Figs. 5 and 6). The effect of height on wind speed magnitude is seen to be more pronounced during winter time compared to summer months. The wind speed values further reveal higher values at the Nouakchott South site compared to that at Nouakchott North site. The wind speed is observed to be higher during winter time and decrease from February till October and then again increases towards the end of the year at Nouakchott Noth (Fig. 5). At Nouakchott South site, the monthly mean wind speed values increases from January till May and then decreases till October and regains again towards December (Fig. 6). In fact, the monthly mean trends of wind speeds at both the sites are similar but differ in magnitude.

Fig. 5 Monthly average wind speed at different height at Nouakchott North site

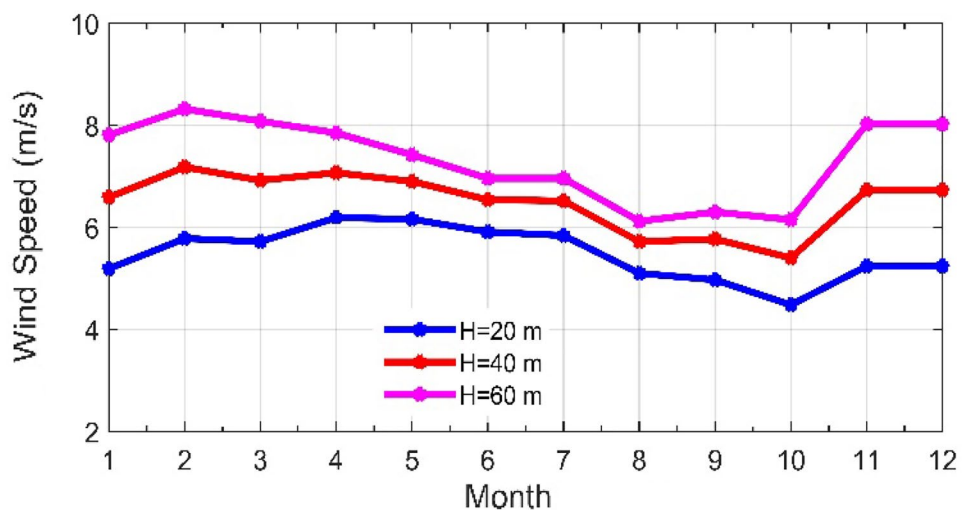
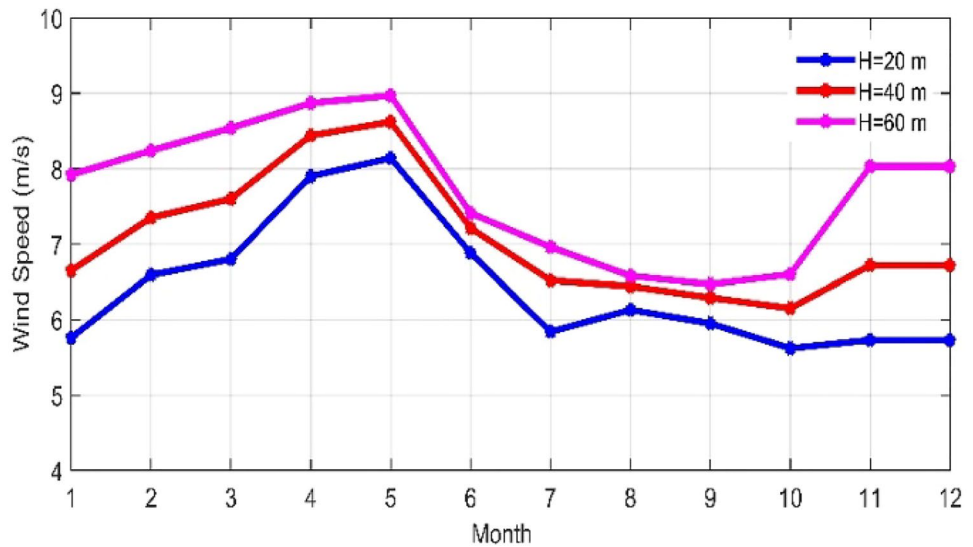


Fig. 6 Monthly average wind speed at different height at Nouakchott South site



The Nouakchott North site has slightly lower wind speed values compared to those at Nouakchott South site. The monthly average values lie between a minimum and a maximum of 4.48 , and 6.19, 5.4 and 7.18 and 6.12 and 8.32 m/s at 20 m, 40 and 60 m; respectively. Wind speeds reach maximum values of 8.14 , 8.62 and 8.97 m/s in February corresponding to measurement heights of 20 , 40 and 60 m at South site. However, the minimum values are observed in October (5.62 , 6.15 and 6.6 at 20 , 40 and 60 m; respectively), Fig. 6.

In this study, the Weibull parameters are estimated based on the least square method (graphical method), as summarized in Tables 2 and 3. The values of shape parameter k vary between (2.44 and 4.75), (2.54 and 5.18) and (2.47

and 4.79); respectively at 20 , 40 and 60 m heights for the Nouakchott South site (Table 2). However, for the Nouakchott North site (Table 3), these values varies between (2.08 and 3.79), (2.31 and 6.82), and (2.41 and 4.63). The scale factor c varies between 5.78 and 8.37 m/s, 6.34 and 8.85 m/s, and 6.68 and 9. 22 m/s corresponding to 20 m, 40 and 60 m heights at Nouakchott South (Table 2). At Nouakchott North, it vary from 4.64 to 6.49 m/s, 5.6 to 7.51 m/s, and 6.16 to 8.8 m/s at respective heights, as discussed earlier.

The wind frequency distribution, which indicates the availability of wind speeds in different speed bins, is shown Figs. 7 and 8 at the chosen site at different heights. Such wind duration distribution is important and helps in estimating the wind potential of a site. It is evident that the

Table 2 Monthly and annual variation of Weibull parameters (k and c) for Nouakchott South station

Month	NKC South									
	Height									
	20 m			40 m			60 m			
	k	c	PD (W/m ²)	k	c	PD (W/m ²)	k	c	PD (W/m ²)	P (kg/m ³)
Jan	3.87	6.65	159.41	4.15	7.28	206.46	4.57	8.28	299.75	1.172
Feb	4.27	6.84	170.34	4.52	7.54	226.45	4.79	8.55	328.17	1.171
Mar	4.75	7.19	197.98	5.18	7.88	258.85	4.70	8.67	347.49	1.187
Apr	3.59	8.08	292.97	3.60	8.75	371.80	4.14	9.07	402.16	1.180
May	4.43	8.37	316.64	4.66	8.85	372.10	4.70	9.22	420.37	1.194
Jun	3.84	7.18	203.03	3.78	7.57	238.76	3.80	7.75	255.90	1.184
July	3.36	7.35	224.55	3.44	7.67	253.36	3.50	7.87	272.35	1.179
Aug	2.60	6.10	144.59	2.54	6.46	174.21	2.47	6.68	196.15	1.185
Sep	2.78	6.11	137.54	2.84	6.46	160.84	2.85	6.74	182.37	1.164
Oct	2.44	5.78	126.51	2.55	6.34	162.19	2.58	6.84	202.21	1.170
Nov	3.25	6.3	142.24	3.68	6.76	169.50	3.66	7.59	240.23	1.173
Dec	4.53	6.18	124.98	4.63	6.87	171.26	4.15	8.30	306.50	1.174
Yearly	3.16	6.78	179.83	3.24	7.32	224.31	3.26	7.96	287.82	1.178

Bold value indicates the annual value of each parameter studied

Table 3 Monthly and annual variation of Weibull parameters (k and c) for Nouakchott North station

Month	NKC North									
	Height									
	20 m			40 m			60 m			P (kg/m ³)
k	c	PD (W/m ²)	k	c	PD (W/m ²)	k	c	PD(W/m ²)		
Jan	3.34	6.06	125.67	3.63	7.23	208.42	3.87	8.19	298.55	1.175
Feb	3.79	6.31	136.56	4.37	7.51	224.53	4.63	8.80	358.72	1.170
Mar	3.47	6.27	138.99	3.88	7.16	201.41	3.71	8.34	321.46	1.187
Apr	3.39	6.49	154.43	3.61	7.33	218.60	3.71	8.01	283.35	1.181
May	3.50	6.48	153.83	6.82	7.41	214.98	3.95	7.93	274.04	1.193
Jun	3.37	6.02	123.79	3.50	6.63	163.52	3.46	7.12	203.19	1.184
July	2.95	6.05	131.38	3.14	6.80	181.86	3.19	7.25	219.13	1.178
Aug	2.24	5.17	97.76	2.40	5.75	127.51	2.42	6.16	155.86	1.184
Sep	2.57	5.09	83.10	2.84	5.90	122.54	2.83	6.40	156.67	1.164
Oct	2.08	4.64	74.72	2.31	5.60	119.87	2.41	6.23	159.93	1.171
Nov	2.91	5.03	75.45	3.47	6.06	123.69	3.26	7.20	211.55	1.170
Dec	3.21	5.69	105.87	3.56	6.89	182.06	3.42	8.20	310.39	1.180
Yearly	2.85	5.65	108.72	3.01	6.69	176.11	3.04	7.39	236.41	1.178

Bold value indicates the average annual value of each parameter studied

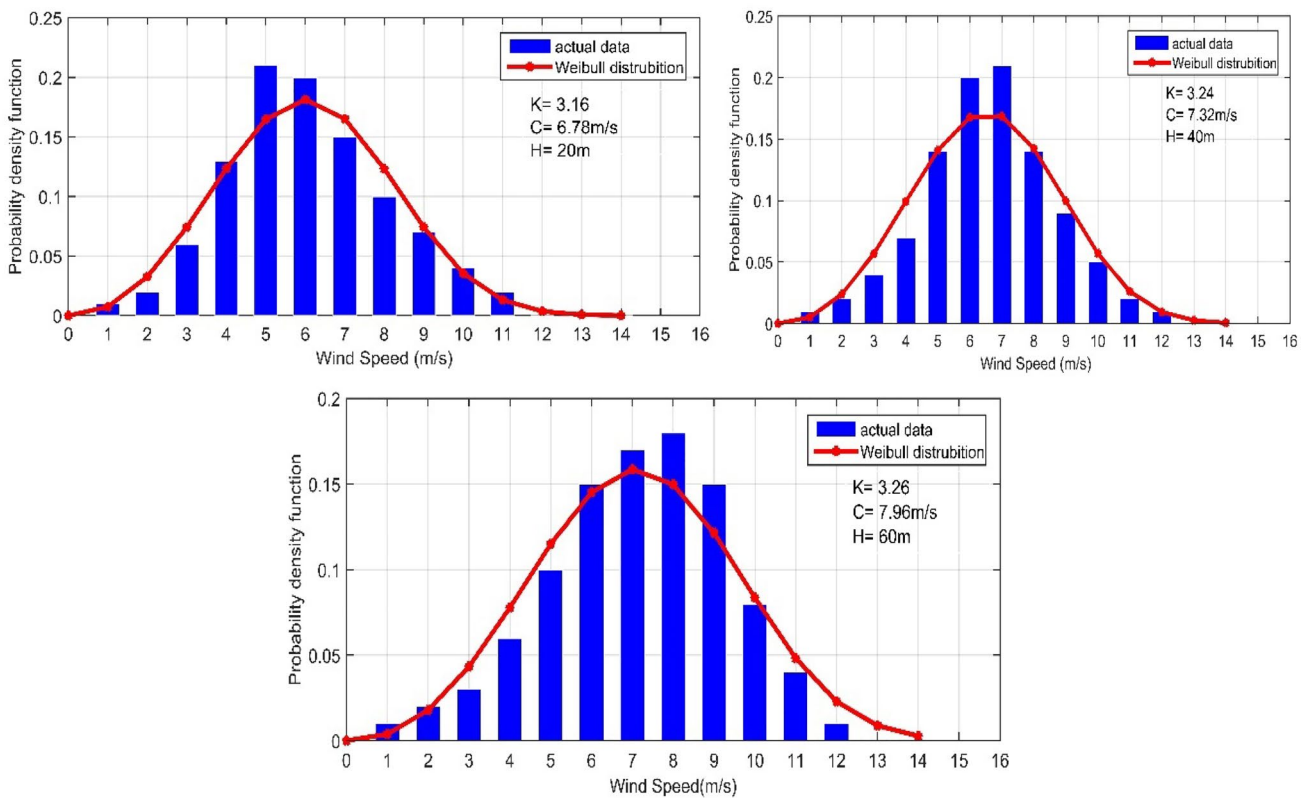


Fig. 7 Weibull probability density functions and actual wind data of Nouakchott South at different heights

measured wind speed values are very well represented by Weibull two parameter distribution and show a shift in the distribution peak towards the left as the measurement height

is increased at both the sites. This simply means that more power can be extracted at higher heights from a chosen wind turbine.

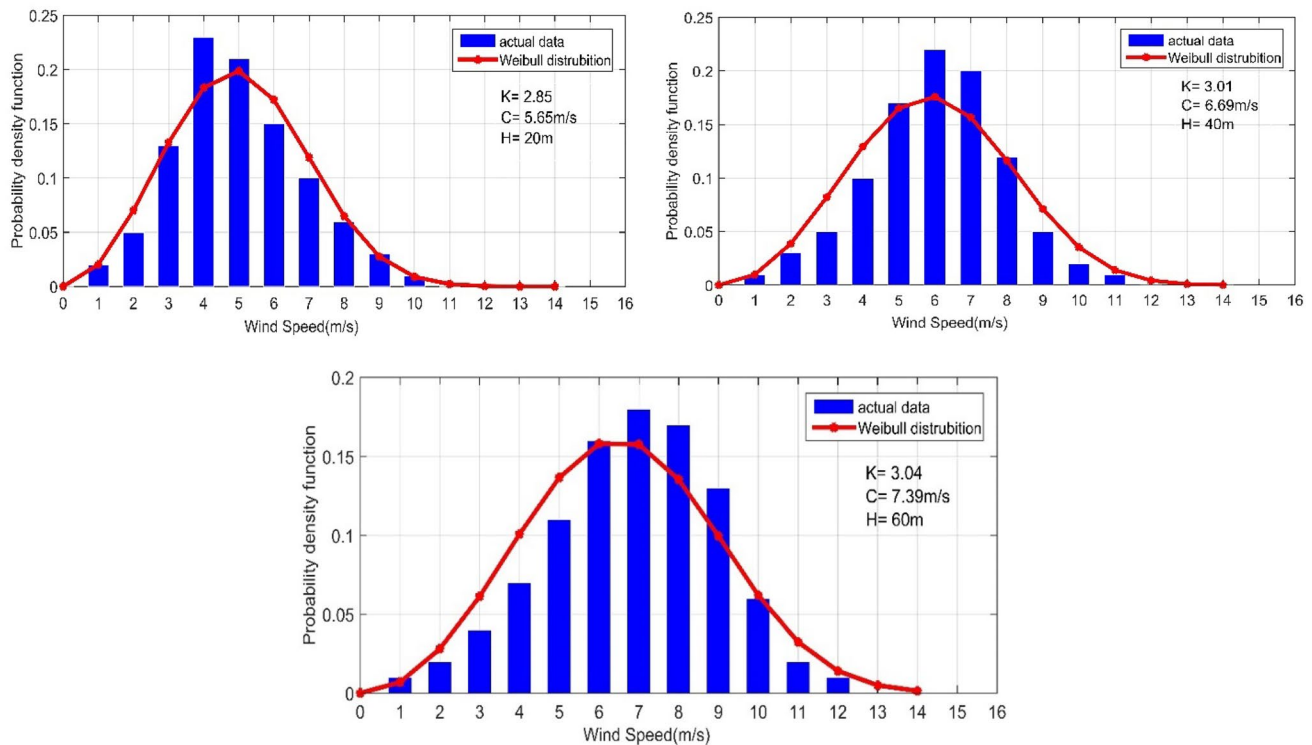


Fig. 8 Weibull probability density functions and actual wind data at Nouakchott North at different heights

The most common velocities at altitudes of 20 , 40 and 60 m for the Nouakchott South site are 5, 7 and 8 m/s respectively. The frequencies of occurrence of the average speeds calculated for these altitudes are 21, 22 and 18% (Fig. 7). For the Nouakchott North site (Fig. 8), the most common velocities at altitudes of 20, 40 and 60 m are 4, 6 and 7 m/s respectively. The frequencies of occurrence of the average speeds calculated for these altitudes are 22, 23 and 17%.

Although, wind speed characteristics are essential to provide a clear picture of the wind potential of a site, but wind power density is considered a better indicator. In this study, the power density values are calculated using the Eq. (8) and are presented in Tables 2 and 3 for the selected sites. The monthly variation of wind power densities is presented in Fig. 9 at the reference measurement heights. It can be seen that the South Nouakchott site (Table 2), has a higher wind power density than the North Nouakchott site (Table 3). At Nouakchott South site, the monthly mean wind power density varies between (124.98 and 316.64 W/m²), (160.84 and 372.1 W/m²) and (182.32 and 420. 37 W/m²) at 20, 40 and 60 m; respectively. On the other hand, at Nouakchott North site, the wind power density values lie between (74.72 and 154.43 W/m²), (119.87 and 224.53 W/m²) and (155.86 and 358.72 W/m²) at 20 , 40 and 60 m; respectively. The wind speed available from different directions is depicted through wind rose diagrams in Figs. 10 and 11 for the selected sites.

It is evident from these two rose diagrams that the wind predominantly flows from north, north east and north-west directions at both the sites. These prevailing directions at these sites correspond to the trade wind system, which is relatively constant, especially during the dry periods.

- In the present work, we used RMSE and R² matrix to test the effectiveness of the method used to determine the Weibull parameters. Tables 4 and 5 present the annual statistical indicators obtained for each site. The R² is found to be 0.974, 0.977, and 0.98 for Nouakchott South and 0.980, 0.967, and 0.962 for Nouakchott North at 20, 40 and 60 m heights; respectively. This simply shows that the method used for the estimation of Weibull parameters is justified and provide excellent results. The validity of the proposed method is further justified by the lower values of RMSE, given in Tables 4 and 5.

The technical characteristics of the three wind turbine models, selected to evaluate wind performance at the Nouakchott North and Nouakchott South sites in Mauritania, are summarized in Table 5 and the wind power curves are shpown in Fig. 12.

Table 6 gives the estimated capacity factor and annual energy production of each wind turbine model. At Nouakchott North site, Gamesa wind turbine provided the

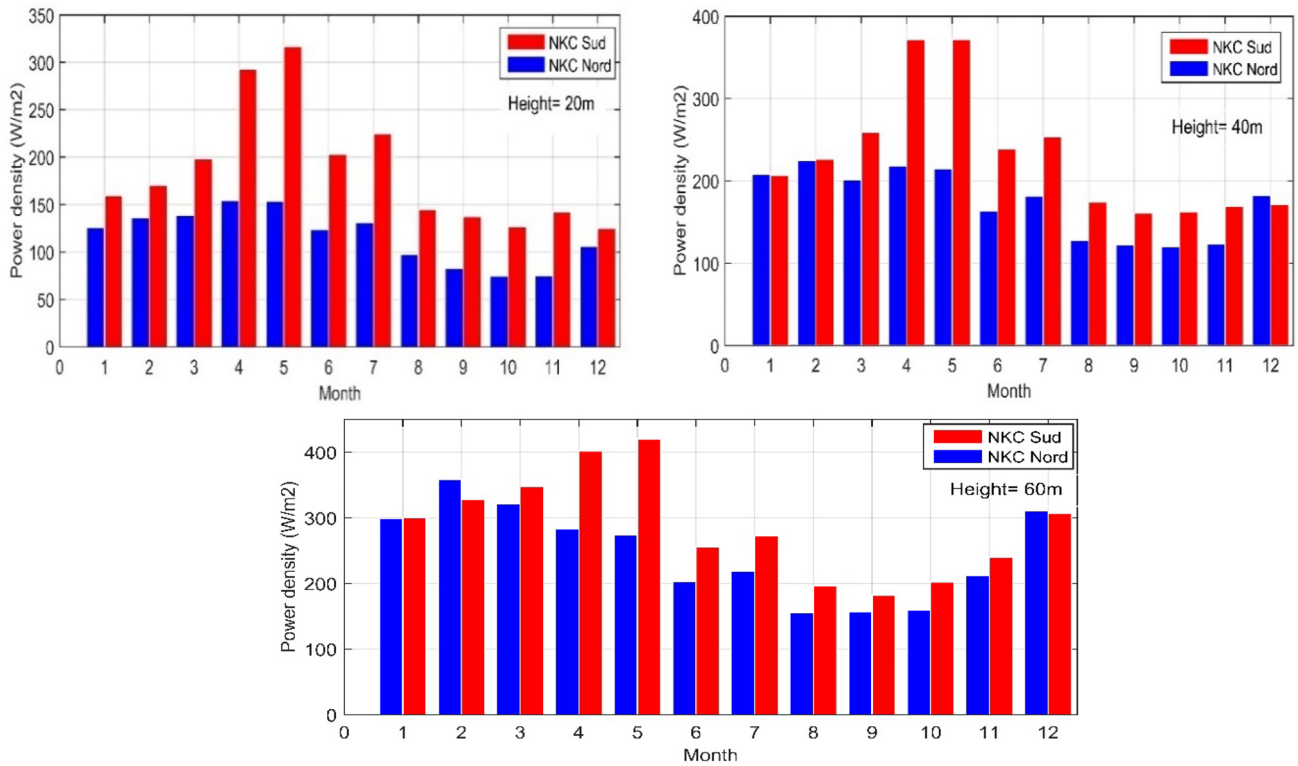


Fig. 9 Monthly wind power densities at different height for two sites

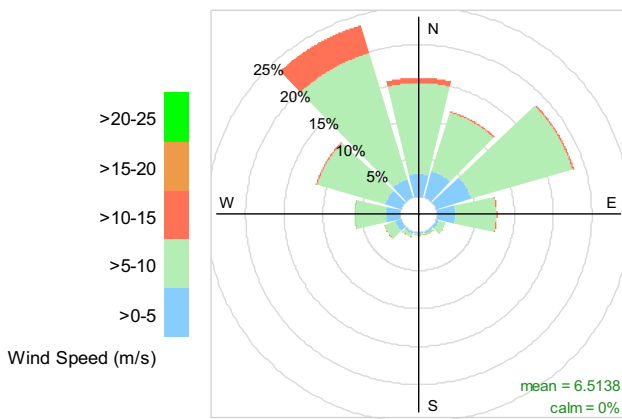


Fig. 10 Wind rose diagrams for Nouakchott South

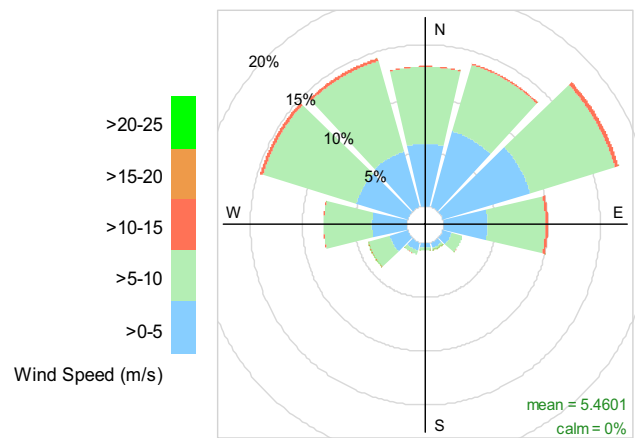


Fig. 11 Wind rose diagrams for Nouakchott North

maximum annual energy yield of 745.493 MWh with capacity factor of 43% while Darwind turbine produced 716.232 MWh of energy with 41% capacity factor. Similarly, at other site Gamesa and Darwind turbines exhibited better performance with annual energy yields of 823.44 and 794.603 MWh with respective capacity factors of 47 and 45%. However, wind turbine from Vestas is found to be the third best performer in terms of energy yield and capacity factors at both the site (Table 6). According to the results summarized in Table 6, Nouakchott South is listed to be more suitable

site compared to Nouakchott South site for wind power generation in the region under investigation. In terms of wind turbine technology, Gamesa is rated the best while Darwind the second best.

After comparing the three wind turbine models, the G97/2000/Gamesa wind turbines had significant capacity factors of 43% and 47% respectively at the Nouakchott North and Nouakchott South sites, producing 745,493 MWh per year, 823,440 MWh per year at a height of 60 m. The

Table 4 Performance indicators of estimation method for Nouakchott South site

Height	Nouakchott South site			Nouakchott North site		
	20 m	40 m	60 m	20 m	40 m	60 m
RMSE	0.0157	0.0166	0.0140	0.0155	0.0209	0.0183
R ²	0.9774	0.9770	0.9816	0.9803	0.9673	0.9622

Table 5 Technical specifications of the selected wind turbines

Wind turbine	Nominal rating (kW)	Rotor diameter (m)	Rated speed (m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)
G97/2000/ Gamesa	2000	97	14	2.5	25
V80-2.0 MW/Vestas	2000	80	16	4	25
XE93-2.0 MW/DARWIND	2000	93.4	11	3	25

Fig. 12 Wind power characteristics of the selected wind turbines

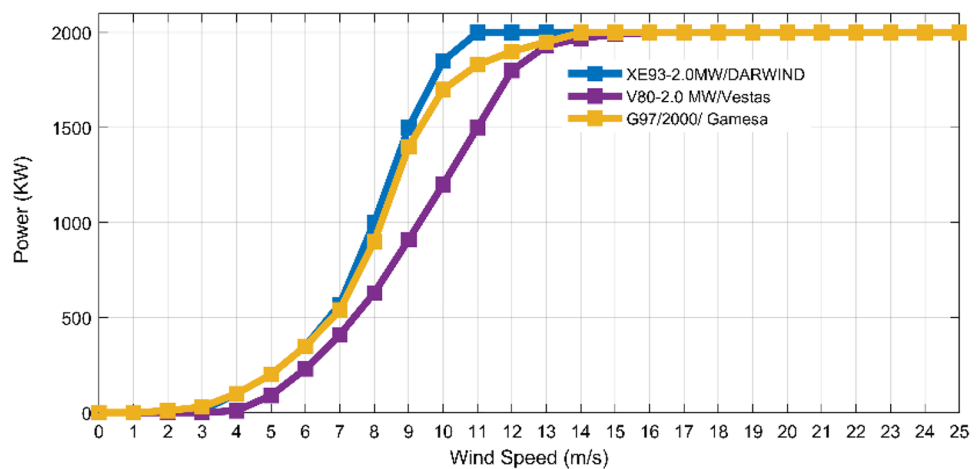


Table 6 Capacity factor and annual energy generated by selected turbines model at height 60 m

		G97/2000/ Gamesa	V80-2.0 MW/ VESTAS	XE93-2.0 MW/DARWIND
Nouakchott North	$C_F(\%)$	43	33	41
	$E_{out}(MWh)$	745.493	570.403	716.232
Nouakchott South	$C_F(\%)$	47	37	45
	$E_{out}(MWh)$	823.440	648.240	794.603

V80-2.0 MW/VESTAS turbine had the lowest capacity factor for both sites. Therefore, G97/2000/Gamesa is the most cost-effective technology of wind power generation with highest C_F and thus has great potential for wind power generation in the region.

Conclusion

Our assessment of wind potential using the graphical method confirmed the presence of significant wind potential in the study area. The data collected on wind speed

and wind direction are analyzed in depth, and the results showed that the areas of the Nouakchott region present favourable conditions for wind power exploitation.

The study identified two specific areas, Nouakchott North and Nouakchott South, located respectively at PK 25 and PK 28 on the Akjoujet road. Which display the geographical and topographical features conducive for high wind power production performance. These areas offer strong and constant winds, as well as adequate exposure to prevailing air flows. The study, therefore recommend paying particular attention to these areas when planning for future wind farm projects.

In this paper the wind characteristics and wind energy potential are determined for Nouakchott Mauritania city based on the measured wind speed and direction data obtained from two meteorological stations (Nouakchott South and Nouakchott North). Specifically, the present analysis can be summarized as follows:

- The Weibull distribution fits well to the measured averaged wind speed data recorded every 10 min at the two stations. The Weibull parameters vary over a wide range of values at the two sites. The annual shape parameter is obtained as 3.16, 3.24, and 3.26 at Nouakchott South and 2.85, 3.01, and 3.04 at Nouakchott North site corresponding to measurement heights, mentioned earlier.
- The Nouakchott South site has a good wind potential compared to Nouakchott North site with an annual wind power density of 179.83 W/m², 224.31 W/m², and 287.82 W/m² at 20, 40 and 60 m; respectively.
- The dominant wind directions at Nouakchott South are northwest and northeast, and north and northwest for the Nouakchott North site.
- The G97/2000/Gamesa turbine is suggested as the first choice for both sites.
- Based on the annual production and capacity factors of the turbine models studied, the XE93-2.0 MW/DAR-WIND and V80-2.0 MW/VESTAS turbines are considered as second and third options, respectively,
- Based on this study, the site of Nouakchott South is identified as being suitable for the development of grid-connected wind farm/s.
- In future studies, it is planned to carry out mapping of the wind potential in Mauritania and particularly on the coast between Nouakchott and Nouadhibou in order to determine the investment opportunities for the vision of the state in the framework of green energy.

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Author contributions EMBO: designed the idea in collaboration with the authors, did the simulation, prepared the drawings and wrote the paper; AMY: conceived the idea in collaboration with the authors, did the simulation, prepared the drawings and wrote the paper; SR: edited the paper, participated in the literary section, suggested changes in the manuscript to strengthen the content, helped in all stages of the work; MLS: editing, administrative and management support, consulting, partial writing; AKM and CM contributed to writing and revising the manuscript. All authors read and approved the final manuscript.

Data Availability Can be provided if requested.

Declarations

Conflict of interest Mauritania is moving towards the use of renewable energy because the country has excellent wind potential along its 700 km of coastline, the country enjoys constant sunshine and optimal wind speeds. All possible sources and applications are being explored to support Mauritania's 2050 vision of clean and green energy production. The development of floating solar power plants is one possible way to produce green hydrogen.

Consent to participate All the authors have participated in the preparation of the manuscript and have given respective consent to participate.

Consent for publication All the authors have consented to publish this manuscript.

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