Wind energy potential assessment of Cameroon’s coastal regions for the installation of an onshore wind farm

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Abstract

For the future installation of a wind farm in Cameroon, the wind energy potentials of three of Cameroon’s coastal cities (Kribi, Douala and Limbe) are assessed using NASA average monthly wind data for 31 years (1983–2013) and compared through Weibull statistics. The Weibull parameters are estimated by the method of maximum likelihood, the mean power densities, the maximum energy carrying wind speeds and the most probable wind speeds are also calculated and compared over these three cities. Finally, the cumulative wind speed distributions over the wet and dry seasons are also analyzed. The results show that the shape and scale parameters for Kribi, Douala and Limbe are 2.9 and 2.8, 3.9 and 1.8 and 3.08 and 2.58, respectively. The mean power densities through Weibull analysis for Kribi, Douala and Limbe are 33.7 W/m\textsuperscript{2}, 8.0 W/m\textsuperscript{2} and 25.42 W/m\textsuperscript{2}, respectively. Kribi’s most probable wind speed and maximum energy carrying wind speed was found to be 2.42 m/s and 3.35 m/s, 2.27 m/s and 3.03 m/s for Limbe and 1.67 m/s and 2.0 m/s for Douala, respectively. Analysis of the wind speed and hence power distribution over the wet and dry seasons shows that in the wet season, August is...
the windiest month for Douala and Limbe while September is the windiest month for Kribi while in the dry season, March is the windiest month for Douala and Limbe while February is the windiest month for Kribi. In terms of mean power density, most probable wind speed and wind speed carrying maximum energy, Kribi shows to be the best site for the installation of a wind farm. Generally, the wind speeds at all three locations seem quite low, average wind speeds of all the three studied locations fall below 4.0m/s which is far below the cut-in wind speed of many modern wind turbines. However we recommend the use of low cut-in speed wind turbines like the Savonius for stand alone low energy needs

Keywords: Mathematics, Applied mathematics, Computational mathematics

1. Introduction

Located on the Gulf of Guinea and also known as the economic power house of the central African sub-region, Cameroon’s population and industrialization has more than doubled in the last three decades. Three of its regions border with the Atlantic ocean which are; the Littoral region with Douala as its chief Capital city and also the economic capital of Cameroon, is the industrial house of Cameroon with many heavy and light industries concentrated in this part of the country. Some other Industrialized regions are the Southwest region with Limbe as the key industrial town and the South region with Kribi as the key industrial town. The rapid increase in the population of these industrial cities, post a problem to energy shortages and distribution especially as the country solely relies on hydroelectric power and a very small percentage of thermal power generation to meet its energy demand. The recent creation of the Kribi deep sea port will require megawatts of electrical energy for operation which will be extracted from the main grid. This will also post a lot of problems to the total energy demand and supply. So it is good to look for other alternative sources of energy like the wind and solar. To successfully harness wind power at a site, a wind energy assessment need to be carried out which usually results in analysing the wind speed data at the particular site and also studying the topographic nature of the site [1]. In this work, our main focus will be to carry out a wind energy assessment of the Cameroon coastal regions for the future installation of a wind farm to meet the energy demand of the ever increasing population in these coastal cities. These sites where chosen because of the ever available ocean winds and also because of the flatness of the terrain and also on the accessibility to the sites.

A wind energy assessment usually involves the tasks of selecting, installing, and operating wind measurement equipment, as well as collecting and analysing the associated data [1], once one or more measurement sites are located. It also involves the analysis of wind resource maps. The wind resource map usually shows the variation over an area of the mean wind speed or power density for a given
height above ground level [1]. A more common analysis of the wind energy potential of a site is making use of statistical distributions like the commonly used Weibull statistics. Many researchers in wind energy in Cameroon have used the Weibull approach for describing the wind characteristics of a site. Some of which are; D. Afungchui et al. [2] carried out an analysis of the wind regime for energy estimation in Bamenda, of the North West Region of Cameroon, based on the Weibull distribution. By estimating the scale and shape parameters using the least square graphical method, they found that the Weibull distribution can be used with acceptable statistical accuracy for prediction of the wind energy potential of Bamenda. D.K. Kaoga et al. [3] carried out a comparison of five numerical methods for estimating the Weibull parameters for wind energy applications in the district of Kousseri, Cameroon. By making use of the correlation coefficient $R^2$ and root mean square error (RMSE), they found that all the proposed five methods are effective in evaluating the parameters of the Weibull distribution for the available data but the energy pattern factor shows more accuracy, followed by the method of maximum likelihood and graphical method. R. Tchinda et al. [4] studied the wind energy in the Adamaoua and North provinces of Cameroon using the method proposed by Hennessey. They observed that the North province has a higher wind potential than the Adamaoua province but both provinces have very low wind speed. Hence only windmills for water pumping was recommended. But in this paper, a Weibull analysis of the data over Cameroon’s coastal cities is carried out for the first time for the purpose of estimating and comparing the power densities, maximum energy carrying wind speeds and most probable wind speeds and finally following the analysis, selecting the best site for the installation of a wind farm. The paper is arranged in three sections; in Section 2, we present the mathematical models of the underlying theory and statistically analyse the data set. Section 3 is dedicated to discussing the results of our findings and we end with a conclusion in Section 4.

2. Materials and methods

The data provided to us for analysis is NASA wind data over Limbe, with latitude 4.02° N, longitude 9.21° E and elevation of about 69 m above sea level, Douala with longitude 9.76° E, latitude 4.05° N and with an elevation of 19 m above sea level and Kribi with longitude 9.98° E, latitude 2.88° N with an elevation of 10 m above sea level. These data sets contains 31 (1983–2013) years of mean daily data with missing values in the years 1992 and 1994 for the Limbe data which is taken at Debouncha, on the western coast of Limbe. Hence these years were considered as outliers. Fig. 1 is a google map showing the location of Cameroon coastal cities and the data descriptive statistics is presented in Table 1. The data was sorted out into mean monthly data and fitted into the two parameter Weibull distribution.
The second analysis deals with comparing the wind energy potentials of the two main seasons that exist in Cameroon which are the wet and dry seasons. The wet season usually runs from April to September. While the dry season usually runs from October to March. The data is again partitioned into the six months dry season (October to March) and six months wet season (April to September) for analysis over the 31 years period. The time series of these data set over the 31 years period is shown in Fig. 2, Fig. 3 and Fig. 4 with the peak of the wind speeds usually observed around August and September.

These months are usually at the heart of the wet season. Various mathematical models have been used to analyse the wind energy potential of a site like the commonly used Weibull analysis [2, 3, 5], and a combination of Weibull and other statistical analysis techniques like the Reyleigh statistics, the gamma and Lognormal distribution have also been used by some authors [7] and also the

| Data     | min(m/s) | max(m/s) | median(m/s) | mean(m/s) | s.d  | skew | kurt | P-value |
|----------|----------|----------|-------------|-----------|------|------|------|---------|
| Kribi    | 1        | 6.45     | 2.3         | 2.5       | 0.87 | 1.45 | 5.47 | 2.1e-10 |
| Douala   | 0.8      | 3.45     | 1.6         | 1.7       | 0.43 | 0.9  | 4.43 | 2.89e-05 |
| Limbe    | 1.45     | 4.62     | 2.04        | 2.31      | 0.7  | 1.35 | 3.88 | 4.19e-09 |
The three parameter generalized extreme value distribution has also been applied [6, 7]. But it has been shown that, the Weibull distribution is most preferred and has highly been recommended for use to analysis wind speed data [5, 6, 7, 8].

We have the Weibull distribution with probability density function, cumulative probability distribution and quantile distribution given by,

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

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

\[
Q(v) = \left(-\ln(1 - v)\right)^{1/k} \tag{3}
\]

The mean value of the wind speed \(v_m\) and standard deviation \(\nu\) is defined in terms of the Weibull parameter \(k\) and \(c\) are given as:

\[
v = c \Gamma(1 + 1/k) \tag{4}
\]

\[
\nu = (c^2(\Gamma(1 + 2/k) - [\Gamma(1 + 1/k)]^2))^{1/2} \tag{5}
\]

**Fig. 2.** Time series for Kribi data over the 31 years period.
Fig. 3. Time series for Douala data over the 31 years period.

Fig. 4. Time series for Limbe data over the 31 years period.
Where $\Gamma()$ is the gamma function. When assessing the wind energy potential of a site, there are two wind speeds that are of interest and must therefore be taken seriously into consideration. These are the most probable wind speed $v_{mp}$ and the wind speed carrying maximum energy $v_{Emax}$. They are given by the expression [9, 10]

$$v_{mp} = c \left( \frac{k - 1}{k} \right)^{1/k}$$  \hspace{1cm} (6)

$$v_{Emax} = c \left( \frac{k + 2}{k} \right)^{1/k}$$  \hspace{1cm} (7)

The most probable wind speed corresponds to the peak of the probability density function, while the wind speed carrying maximum energy can be used to estimate the wind turbine design or rated wind speed [5]. In this paper, we carry out an estimate of these energies by calculation using the $k$ and $c$ values estimated over the three cities and using the above equations.

Theoretically, the mean power density is proportional to the cube of the mean velocity given by

$$P_D = P(v_m)/A = \frac{1}{2} \rho v_m^3$$  \hspace{1cm} (8)

$$P_D = P(v)/A = \frac{1}{2} \rho \Gamma(1 + 3/k)c^3$$  \hspace{1cm} (9)

$$E_D = \frac{1}{2} \rho \Gamma(1 + 3/k)Tc^3$$  \hspace{1cm} (10)

It can also be calculated from the Weibull probability density function given by Eq. (9). The mean energy density is just a product of the mean power density with time as given in Eq. (10), where $P_D$ is the power density, $E_D$ the energy density, $P(v)$ wind power, $A$ cross sectional area of rotor, $\rho$ the air density assumed here to take the value 1.225, $c$ scale parameter, $k$ shape parameter, $T$ period, and $\Gamma()$ the gamma function [5, 6, 8]. The shape and scale parameters here, have been estimated from the maximum likelihood method given by the expressions:

$$k = \left[ \frac{\sum_{i=1}^{n} v_i^3 \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n} \right]^{-1}$$  \hspace{1cm} (11)

where $v_i$ is the wind speed in time step $i$ and $n$ is the number of data points.

The scale parameter is given by

$$c = \left[ \frac{1}{n} \sum_{i=1}^{n} v_i \right]^{1/k}$$  \hspace{1cm} (12)
The results of the parameter estimation, mean power densities, maximum power densities, most probable wind speeds and wind speed carrying maximum energy over these three cities are displayed in Table 2 and Table 3 below.

### 3. Results and discussions

The time series of the wind speed data over the cities within the 31 years period is presented in Fig. 2, Fig. 3 and Fig. 4. Here, we see that the periods of the year with a higher recorded wind speed is within August and September, with August being the windiest month for Douala and Limbe and September being the rainiest month for Kribi. We should also note that, these months are usually at the heart of the wet season. The yearly average wind speed over the 31 years period presented in Fig. 5, shows that in all the three regions, there is a significant increase in the wind speeds from the years 2006 to 2013. This might be as a result of some factors like urban development, changes in the local pressure gradient might also lead to observable changes in local wind speeds. The time series (Fig. 5) of all the three regions show an increasing trend in the wind speeds and hence an increase in the wind energy potential of the regions. We also see that even though Kribi has a higher annual wind speed value as compared to Douala and Limbe, but Limbe has a fairly constant wind speed values and does not fluctuate much as compared to Douala and Kribi which is also an interesting result as far as harnessing wind energy is concerned.

The probability density function and cumulative distribution function of Weibull distribution for Douala Fig. 6 and Fig. 7 shows a better fit with data than that of Kribi Fig. 8 and Fig. 9 and Limbe Fig. 10 and Fig. 11. This can also be confirmed by the values of their standard errors(s.e) and p-values of the Kolmogorov-Smirnov

### Table 2. Summary statistics for Weibull fit using method of maximum likelihood.

| Data   | K   | s.e | c(m/s) | s.e | loglikelihood | P-value of K-S |
|--------|-----|-----|--------|-----|----------------|----------------|
| Kribi  | 2.9 | 0.1 | 2.8    | 0.05| −475.6        | 0.14           |
| Douala | 3.9 | 0.14| 1.8    | 0.026| −232.27       | 0.118          |
| Limbe  | 3.0 | 0.128| 2.58   | 0.05| −333.17       | 0.18           |

### Table 3. Wind characteristics.

| Data   | longitude | latitude | Height/m | vmp(m/s) | vmax(m/s) | PD(W/m²) | Pmax(W/m²) |
|--------|-----------|----------|----------|----------|-----------|----------|------------|
| Kribi  | 9.98      | 2.88     | 15       | 2.426    | 3.35      | 33.7     | 160        |
| Douala | 9.7       | 4.05     | 41       | 1.67     | 2.0       | 8.0      | 30         |
| Limbe  | 9.21      | 4.02     | 36       | 2.27     | 3.03      | 25.42    | 60         |
**Fig. 5.** Annual average wind speed for Kribi, Douala and Limbe.

**Fig. 6.** Mean wind speed of Douala fitted to Weibull probability density at k = 3.9 and c = 1.8.
Fig. 7. Mean wind speed of Douala fitted to Weibull cumulative probability density at $k = 3.9$ and $c = 1.8$.

Fig. 8. Mean wind speed of Kribi fitted to Weibull probability density at $k = 2.9$ and $c = 2.8$. 
Fig. 9. Mean wind speed of Kribi fitted to Weibull cumulative probability density at $k = 2.9$ and $c = 2.8$.

Fig. 10. Mean wind speed of Limbe fitted to Weibull probability density at $k = 3.0$ and $c = 2.5$. 
Fig. 11. Mean wind speed of Limbe fitted to Weibull cumulative probability density at $k = 3.0$ and $c = 2.5$.

Fig. 12. Weibull power probability density for Kribi, Douala and Limbe.
statistics as presented in Table 2. We need to note that the power production estimates are based on the Weibull shape parameter, k, and the scale parameter, c. k determines the uniformity of the wind. The shape parameter, k, can be interpreted directly as follows: a value of $k < 1$ indicates that there is more concentration of energy in the wind below the average speed. A value of $k = 1$ indicates that the

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**Fig. 13.** Douala’s cumulative wind speed distribution in the dry season (a) and in the wet season (b).
wind speed is constant. A value of \( k > 1 \) indicates that wind speed in the site is dominated by values above the mean speed. Now we find values of \( k \) for Kribi, Douala and Limbe to be 2.9, 3.9 and 3.03 respectively, indicating that wind speeds in the site are dominated by values above the mean speed. We can substantiate this

Fig. 14. Limbe’s cumulative wind speed distribution in the dry season (a) and in the wet season (b).
Fig. 15. Kribi’s cumulative wind speed distribution in the dry season (a) and in the wet season (b).
with Weibull cumulative distribution plots for the three regions that for at least for 70% of the time the average wind speed is greater than or equal to 2 m/s.

From Table 1, the minimum, average and maximum wind speed for Douala was found to be 0.8 m/s, 1.71 m/s and 3.45 m/s. That of Limbe was found to be 1.45 m/s, 2.31 m/s and 4.62 m/s respectively and for Kribi we have 1.0 m/s, 2.5 m/s, and 6.45 m/s. From Table 3, the most probable wind speed which has been calculated using Eq. 6 and can also be gotten from the peak of the probability density function and the wind speed carrying maximum energy which has also been calculated from Eq. 7 was found to be 2.42 m/s and 3.35 m/s for Kribi, 2.27 m/s and 3.03 m/s for Limbe and 1.67 m/s and 2.0 m/s for Douala, respectively. Here, we see that in terms of most probable wind speed and maximum energy carrying wind speed, Kribi is a more preferred site as compared to Douala and Limbe.

From Eq. 8, the maximum power density of Douala, Limbe and Kribi can be calculated to be 30 W/m², 60 W/m² and 160 W/m², respectively, while through Weibull analysis in Eq. 9 and Fig. 12, the monthly average power density for Douala, Limbe and Kribi (see Table 3) is calculated to be 8.0 W/m², 25.42 W/m² and 33.7 W/m². Here, we clearly see that Kribi using both approaches, has a higher mean monthly power density as compared to Douala and Limbe.

The wind roses of Douala and Limbe as presented in Appendix A, shows that local wind speed direction is south west while that of Kribi appears to be both from south west and west directions. Seasonal variation of wind speed over Douala, Limbe and Kribi, shows that, for the dry season periods in Douala that is from October to March, the wind speed ranges from 0.8 m/s to 2.8 m/s while for the wet season that usually runs from April to September, the wind speed ranges from 0.9 m/s to 3.5 m/s. Hence there is not much significant difference between the seasonal wind speeds in this area. This can also be seen in the cumulative wind speed distributions of the dry and wet seasons of Douala in Fig. 13a,b.

For Limbe, the wind speed ranges from 1.4 m/s to 4.0 m/s in the dry season and 1.5 m/s to 4.62 m/s in the wet season as seen in Fig. 14a,b. For Kribi, we have the range to be 1.0 m/s to 4.5 m/s in the dry season and 1.5 m/s to 6.5 m/s in the wet season. The cumulative wind speed distributions in the dry and wet season over Kribi as shown in Fig. 15a,b. These plots also show that on average, the month of August show a higher cumulative wind speed distributions in the wet season for Douala and Limbe and in September for Kribi while March shows on average, a higher cumulative wind speed distribution in the dry season for Douala and Limbe and February for Kribi.

4. Conclusion

To conclude, we have carefully studied the wind speed distribution and wind power densities over Cameroon’s three coastal cities (Kribi, Douala and Limbe) located in
three different regions of the country for the purpose of choosing the best site for the installation of a wind farm that will make use of the onshore and offshore wind speeds to supply enough electrical energy to the ever increasing population and industrialization in these coastal cities. Using NASA average monthly wind data for 31 years (1983–2013) and Weibull statistics, the Weibull parameters have been estimated by the method of maximum likelihood and presented in Table 2 for the purpose of calculating the mean power density, the maximum energy carrying wind speed and the most probable wind speed. Finally, the cumulative wind speed distributions over the wet and dry seasons have been analysed. The results show that the shape and scale parameters for Kribi, Douala and Limbe are 2.9 and 2.8, 3.9 and 1.8 and 3.08 and 2.58, respectively as displayed in Table 2. From the power formula, the maximum power density for Douala, Limbe and Kribi have been calculated to be 30 W/m², 60 W/m² and 160 W/m², respectively. The mean power densities through Weibull analysis for Kribi, Douala and Limbe are 33.7 W/m², 8.0 W/m² and 25.42 W/m² respectively. Kribi’s most probable wind speed and maximum energy carrying wind speed was found to be 2.42 m/s and 3.35 m/s, 2.27 m/s and 3.03 m/s for Limbe and 1.67 m/s and 2.0 m/s for Douala, respectively. Analysis of the wind speed and hence power distribution over the wet and dry seasons show that the wind speed and power densities of Kribi, Douala and Limbe are higher in the wet season than in the dry season and more wind power is expected to be harnessed in the wet season than in the dry season. We have also seen that August is the windiest month for Douala and Limbe in the wet season while September is the windiest month for Kribi while in the dry season, March is the windiest month for Douala and Limbe while February is the windiest month for Kribi. For a site to be selected for the installation of a wind farm, Kribi has been found to be the better of the sites in terms of monthly and seasonal variation of mean wind speed.

Generally, the average wind speeds over all the three sites are relatively low as compared to the cut-in wind speeds of most modern wind turbines. Hence to generate wind energy over the chosen site, we also recommend a wind farm composed of low cut-in speed wind turbines like the Savonius for stand alone low energy needs. Interestingly, Kribi, Douala and Limbe are very close to the equator with high solar radiation. Hence a solar farm will be an alternative to energy capture.

**Declarations**

**Author contribution statement**

Nkongho A Arreyndip: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Ebobenow Joseph, Afungchui David: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.
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Competing interest statement

The authors declare no conflict of interest.

Additional information

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