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Comparative characterization study of the variability of wind energy potential by wind direction sectors for three coastal sites in Lomé, Accra and Cotonou

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Abstract

This paper presents the characterization of the distribution of wind speeds across sectors of directions in order to study the variability of wind energy potential on sites in Lomé (Togo), Accra (Ghana) and Cotonou (Benin) in the Gulf of Guinea. To this end, we developed a software application in MATLAB aimed at wind data processing. Each site's wind speed data collected over a period from January 2000 to December 2012 at a height of 10 m above the ground were divided into eight sectors of direction of 45 degrees each, according to the wind directions measured. Parameters such as K (shape factor) and C (scale factor) of Weibull distributions as well as the skewness and kurtosis coefficients were obtained for each sector. The study analyzes the variations of the statistical parameters computed based on the number of hours during which wind blows in each sector of direction. The results show that the South and South-West sectors are areas of prevailing winds and have higher wind energy potential compared to other sectors in general on the 3 sites considered. The more frequent the wind blows in a sector of direction, the higher the Weibull parameters, while the coefficients of skewness and kurtosis of the distributions of wind speeds show a downward trend for all 3 sites.

Keywords: Wind energy potential, Weibull Distribution, Compass rose, Modeling.

1. Introduction

The explosive growth of energy needs, the depletion of oil stocks and environmental degradation have led mankind to turn in recent decades to clean and renewable energy resources including wind energy. The electrical energy from wind power is produced from wind kinetic energy [1]. Due to wind variability in time and space, two aspects must be considered when installing wind energy conversion systems: the wind resource study and its characterization for different sites. So, a well-designed processing system will definitely lead to more accurate evaluation of wind energy potential and output power forecast [2, 3]. Several studies have shown that the Weibull distribution function is the most appropriate for wind distribution characterization. A recent study on the site of Lomé in Togo confirms that the hybrid Weibull distribution function is recommended for a better fit of the wind speed distribution on a site with high frequency of calm winds [4].

The choice of wind turbine orientation and positioning on a site must take into account certain criteria: the wind speed distribution in each direction and the most frequent wind directions. In this paper, we will characterize the wind speed distributions and evaluate the wind energy potential for different sectors of direction for three sites in the Gulf of Guinea: Lomé (Togo), Accra (Ghana) and Cotonou (Benin). We will also analyze for each direction: variations of parameters such as K (shape factor) and C (scale factor) of Weibull distributions as well as the skewness and kurtosis coefficients. We developed a computer program in MATLAB that will help us process the wind data.

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Table 1: The geographical coordinates of the sites [5]

Sites	Coordinates
Accra (Kotoka)	5.60N 0.17W 69 meters
Cotonou (Cadjehoun)	6.35N 2.38E 9 meters
Lomé (Tokoin)	6.17N 1.25E 25 meters

Table 2: Sectors of direction, breakdown

Direction	Sector, degrees
East (E)	[67.5 ; 112.5 [
North (N)	[337.5 ; 360 [U]0; 22.5 [
North East (NE)	[22.5 ; 67.5 [
North West (NW)	[292.5 ; 337.5 [
West (W)	[247.5 ; 292.5 [
South (S)	[157.5 ; 202.5 [
South East (SE)	[112.5 ; 157.5 [
South West (SW)	[202.5 ; 247.5 [

2. Wind data source

Our purpose through this article is to characterize the wind speed distribution across sectors of direction in order to study the variability of wind energy potential on the sites of Lomé (Togo), Accra (Ghana) and Cotonou (Benin). Table 1 presents the coordinates of the aforementioned sites that formed the, subject of our study. Series of wind data were obtained through the meteorological database of the website ‘http://weather.uwyo.edu/surface/meteorogram/’ [5].

Data are recorded every day at one hour intervals (the average over the 10 minutes before the hour) at a height of 10 m above the ground. The data sheet provided by [5] (an example is shown in Fig. 1) includes, respectively for each record: site name (STN), recording date and time (TIME), atmospheric pressure (ALTM), ambient temperature (TMP), dew temperature (DEW), relative humidity (RH), wind direction (DIR), wind speed (SPD), visibility (VIS) and cloud details (CLOUDS). The measurement point of the meteorological data for each station on the website [5] is in an airport area.
The data for the three stations cover the period from January 2000 to December 2012. For our current work, we are interested only in the columns TIME, SPD and DIR.

3. Data Processing

Wind data collected for this study are filtered initially to eliminate errors, omissions and other non-usable values. Wind direction 0 degree is excluded from this study, because calm winds are always coded to 0 degree.
When processing data according to the wind direction, we decided to use the smallest possible interval. Thus the wind speed data are grouped into eight (08) sectors of direction, 45 degrees each (see Table 2) as in [2].

The number of hours during which the wind blows in every sector of directions is obtained, as well as Weibull parameters [2, 4, 6] of wind speed distributions for each sector of direction. The parameters of the distribution function [7] obtained are used to determine the proportion of average power density available in a considered sector of direction according to equation (1) [8].

$$P(\theta) = f(\theta) \int_v E(v, \theta) dv \tag{1}$$

with,

$$E(v, \theta) = \tfrac{1}{2} \rho v^3 f(v, \theta) \tag{2}$$

Where: $f(v, \theta)$ is the wind speed probability density function for the sector θ considered; $f(\theta)$ is the frequency of occurrence of the wind direction θ, this quantity is used to characterize the share of the sector of direction θ in the average power density of the site.
We calculated the skewness (equation 3) and kurtosis (equation 4) with regard to the wind speed data.

$$Skewness = \frac{E(X - \overline{X})^3}{\left[\sqrt{E(X - \overline{X})^2}\right]^3} \tag{3}$$

$$Kurtosis = \frac{E(X - \overline{X})^4}{\left[E(X - \overline{X})^2\right]^2} \tag{4}$$

Where: E is the expectation function.
For more convenient data processing, we developed a computer program to handle all the above computations.

4. The software application

We developed a software application in MATLAB to perform the wind data processing. In this article we will discuss only the results provided by this software application. The software application accesses the data files and dispatches the wind speed data by sectors of direction predefined by the user. For each sector, it provides the wind speed histogram and its fitting Weibull curve; the Weibull parameters and other statistical parameters are sought. It provides scatter plots and linear regression lines for correlation study between the statistical parameters and assesses the percentage of time the wind blows in a sector

Observations for LOME TOKOIN MIL, Togo (DXXX)

1300Z 5 Jul 2004 to 1700Z 5 Jul 2004

```
STN     TIME  ALTM    TMP DEW RH   DIR  SPD VIS   CLOUDS
     DD/HHMM  hPa     °C  °C    %  deg  m/s km
==== ======= ======  === === ===  ===  === ====  ======= =======
DXXX 26/1500 1009.2  30  24  70  200   6  10    FEW020  BKN250
DXXX 26/1400 1010.2  31  24  66  190   7  10    FEW020  BKN250
DXXX 26/1300 1010.8  31  25  70  200   6  10    FEW020  BKN250
DXXX 26/1200 1011.9  31  26  75  200   6  10    SCT020  BKN250
DXXX 26/1100 1012.9  31  25  70  210   5  10    SCT016  BKN250
DXXX 26/1000 1012.9  30  25  75  210   6  10    BKN015  BKN230
DXXX 26/0900 1013.9  29  25  79  210   5  10    BKN013  BKN230
DXXX 26/0830 1012.9  29  26  84  220   4  10    BKN013  BKN230
DXXX 26/0800 1012.9  28  25  84  220   3  8     SCT012  BKN230
DXXX 26/0730 1011.9  27  25  89    0   0  7     FEW010  BKN230
DXXX 26/0630 1011.9  26  23  84    0   0  3     FEW010  BKN050 BKN230 F
DXXX 26/0600 1010.8  26  24  89    0   0  4     FEW010  BKN050 BKN230 F
DXXX 26/0530 1010.8  26  23  84    0   0  6     SCT010  BKN100
```

Figure 1: Presentation of website data [5] forming the source of data

of direction. It also presents the results in form of a compass rose for a better analysis of the distribution of various parameters sought by sector of direction.

5. Results

We applied the aforementioned processing method to ten minute averaged hourly data collected on the site of Lomé, Accra and Cotonou from January 2000 to December 2012 as presented in section 2.

The software application presents the parameters (percentage of time (% time), form factor K, scale factor C, coefficients of skewness and kurtosis) characterizing, by sector of direction, for better interpretation. Fig. 2, 3 and 4 show us the representation parameters such as the compass rose respectively on the sites of Lomé, Accra and Cotonou.

5.1. Characterization of wind speeds by sector

We notice that the values of the hybrid Weibull parameters C and K vary widely depending on the sector considered on each site (Tables 3, 4 and 5). In general, the shape factor K ranges from 1.63 to 3.25 for Lomé, 1.59 to 3.3 for Accra and 1.72 to 4 for Cotonou. The scale factor C is between 1.83 and 5.49 m/s in Lomé, 2.78 and 6.09 m/s in Accra, and 1.97 and 5.41 m/s in Cotonou. Moreover, the highest values of K and C on the site of Cotonou are obtained in the sector where the wind is dominant (South-West).

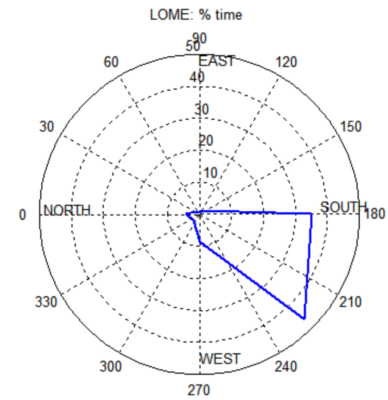
South (S) and South-West (SW) are dominant wind sectors of direction, with nearly 80% of the total of wind

Table 3: Numerical values of the shape factor K, scale factor C, coefficients of skewness and kurtosis for Lomé

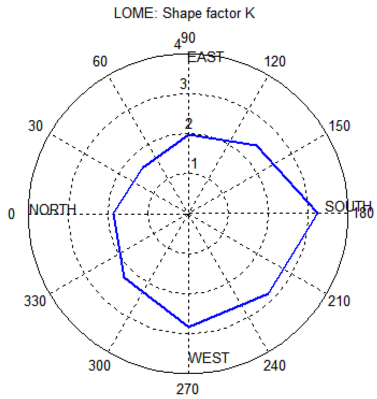
LOME					
Direction	% time	K	C, m/s	Kurtsis	Skewness
N	4.1169	1.872	2.233	6.3664	1.5828
NE	1.2622	1.626	3.641	5.0521	1.2305
E	0.6431	1.963	3.985	4.8127	1.2860
SE	1.5741	2.417	3.636	8.0408	1.4005
S	35.077	3.244	5.487	2.6250	0.0701
SW	46.465	2.820	4.694	2.8927	0.4306
W	8.4589	2.833	2.559	3.5019	0.5029
NW	2.4017	2.252	1.830	4.6218	1.2194

data on the Lomé site (Fig. 2-(a)). The dominant direction on the Accra site is the West (W) sector (Fig. 3-(a)). On the Cotonou site the South-West sector accounts for more than half the number of wind measurements (Fig. 4-(a) and Table 5).

With regard to the distribution of wind speeds in the various sectors, the analysis shows firstly, that the skewness coefficients are positive for all sectors on the 3 sites. The wind speed distribution is shifted slightly to the left of the average wind speed in all sectors in general. Therefore, the effective wind speeds below the average speed are, in general, slightly higher in all sectors of direction on the sites. Fig. 5 shows the skewness as a function of the wind frequency (% time) for each station. Linear regression shows that the values of skewness are lower when the frequency increases. Indeed, on the study sites, skewness proves to be a decreasing function of wind frequency with



(a)



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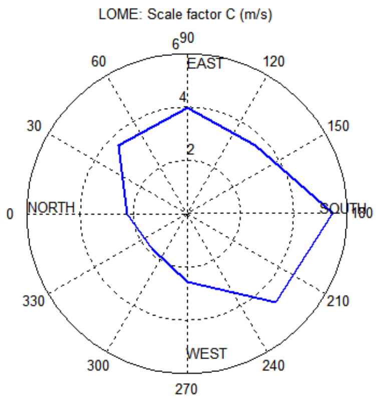

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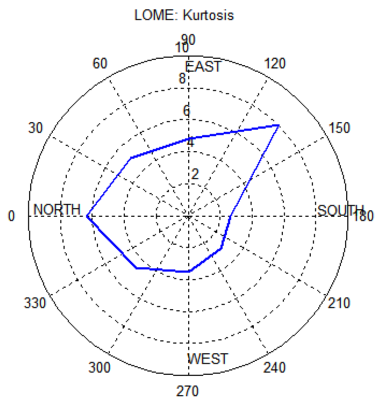

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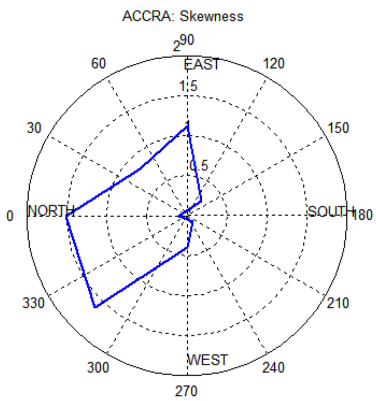
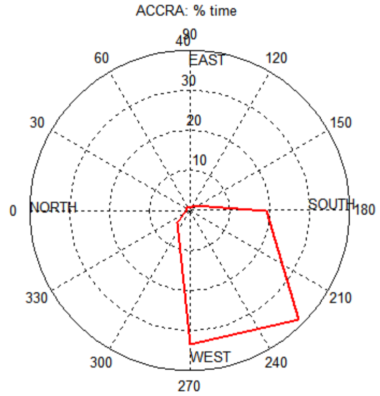
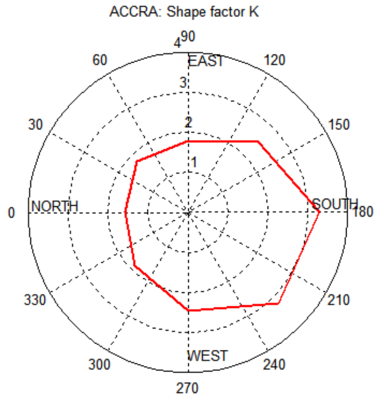


(e)

Figure 2: Forty-five degrees (45°) sectoral breakdown of wind occurrence frequencies (a), shape factor K (b), scale factor C (c), coefficients of kurtosis (d) and skewness (e) on the site in Lomé.



(a)



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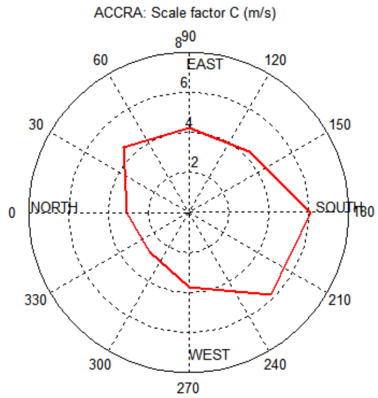

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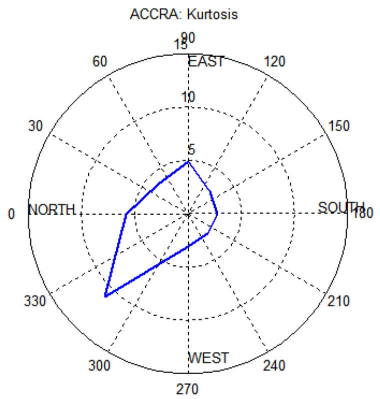

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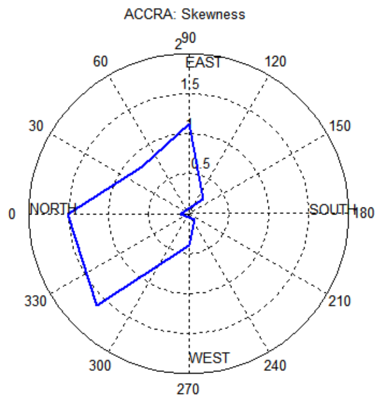
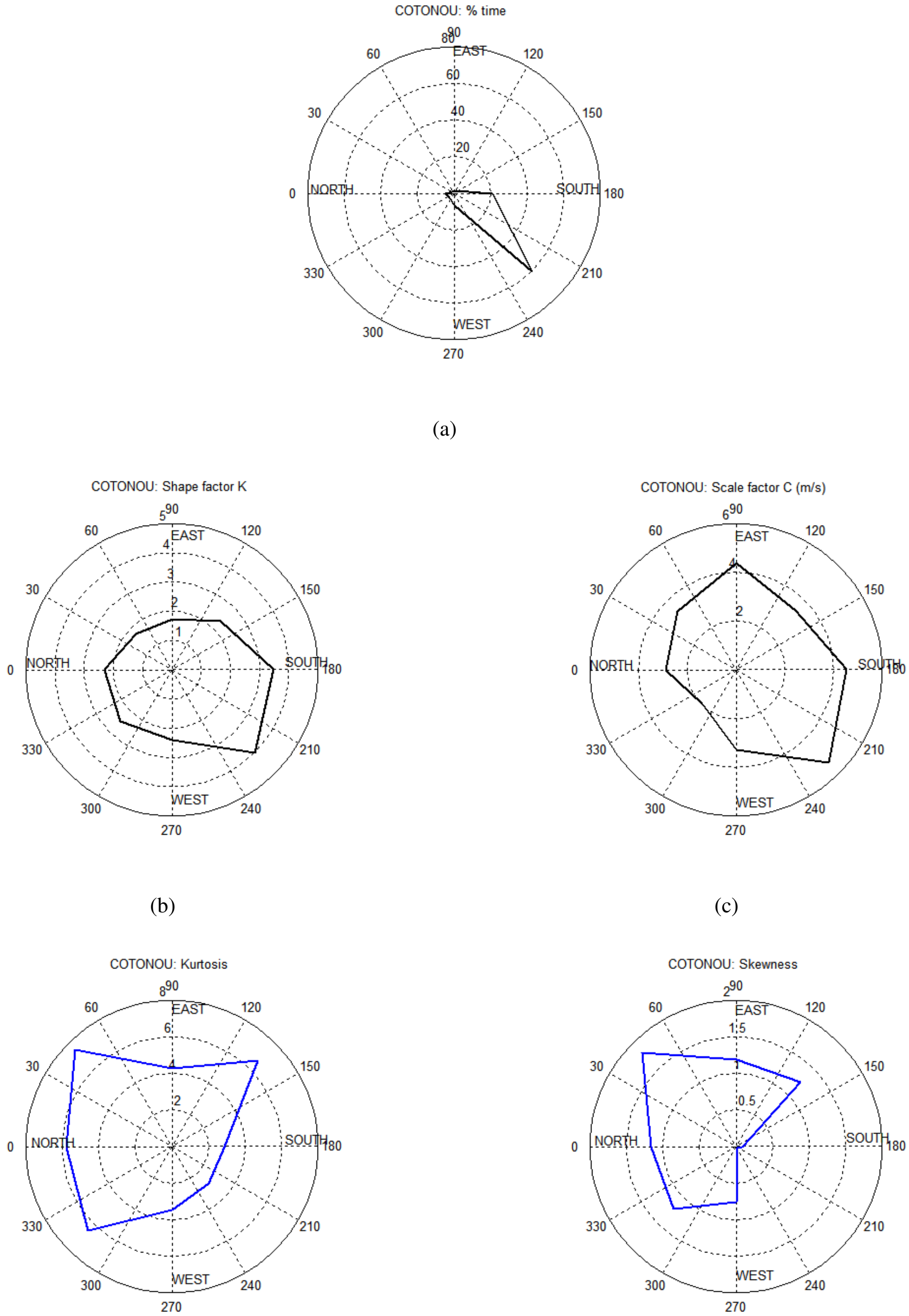


(e)

Figure 3: Forty-five degrees (45°) sectoral breakdown of wind occurrence frequencies (a), shape factor K (b), scale factor C (c), coefficients of kurtosis (d) and skewness (e) on the site in Accra.



(a)

(b)

(c)

(d)

(e)

Figure 4: Forty-five degrees (45°) sectoral breakdown of wind occurrence frequencies (a), shape factor K (b), scale factor C (c), coefficients of kurtosis (d) and skewness (e) on the site in Cotonou.

Table 4: Numerical values of the shape parameter K, the scale parameter C, coefficients of skewness and kurtosis for Accra

ACCRA					
Direction	% time	K	C, m/s	Kurtosis	Skewness
N	1.0011	1.583	3.103	1.5078	1.0011
NE	1.0058	1.825	4.575	0.8274	1.0058
E	0.7590	1.792	4.205	1.1221	0.7590
SE	1.7213	2.497	4.273	0.2530	1.7213
S	19.305	3.297	6.086	-0.095	19.30-5
SW	38.472	3.200	5.857	0.1056	38.472
W	33.414	2.450	3.741	0.3995	33.414
NW	4.3211	1.890	2.778	1.6208	4.3211

Table 5: Numerical values of the shape parameter K, the scale parameter C, coefficients of skewness and kurtosis for Cotonou

COTONOU					
Direction	% time	K	C, m/s	Kurtosis	Skewness
N	4.4521	2.302	2.880	1.1576	4.4521
NE	1.2102	1.754	3.420	1.8149	1.2102
E	0.7536	1.723	4.362	1.1852	0.7536
SE	1.8314	2.372	3.466	1.2407	1.8314
S	21.482	3.485	4.546	0.0922	21.482
SW	60.163	4.011	5.407	0.0370	60.163
W	6.8129	2.393	3.300	0.7583	6.8129
NW	3.2940	2.476	1.966	1.2074	3.2940

slopes substantially similar.

Analyzing Fig. 6 one can easily notice that the kurtosis tends to decrease when the frequency increases on the sites. This reflects a relatively crushed distribution in sectors where the wind frequency is high. However, due to the low value of the correlation coefficient (R^2 = 0.45) on the Accra site, it is not possible to draw a conclusion regarding the variation law of the kurtosis on this site.

Fig. 7 shows the scale factor C as a function of wind frequency for each sector. The linear regression lines show that parameter C increases with the wind frequency on the three sites. Likewise with the variation of the shape factor K on the 3 sites (Fig. 8). Lower K and C values are mainly obtained in areas where the wind frequency is relatively low. The values of the correlation coefficients R^2 allow us to approximate K as a function of frequency, by linear regression on each site (Fig. 8). We obtained a high correlation on the Cotonou site (R^2 = 0.897). The determination of K and C allows us to estimate the proportion

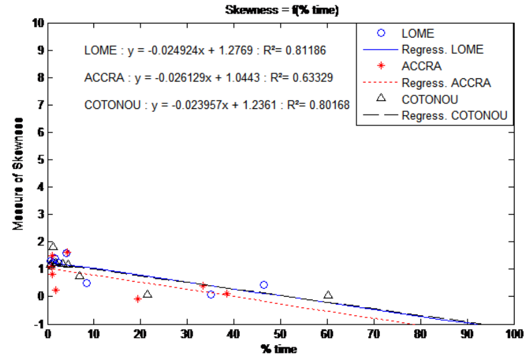


Figure 5: Skewness as a function of wind frequency in each sector

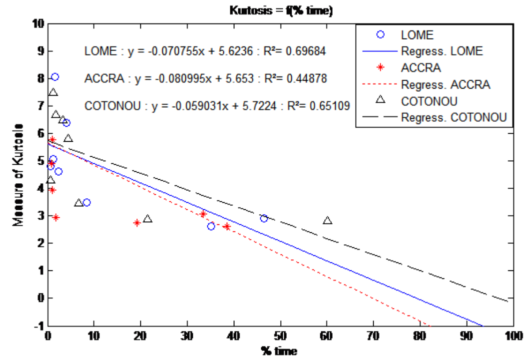


Figure 6: Kurtosis as a function of wind frequency in each sector

of average power density in each sector of direction.

5.2. *Wind energy potential by sector*

Table 6 shows available wind power densities at a height of 10 m above the ground on the 3 sites.

On the Cotonou site, the maximum power density available is 87.04 W/m^2, recorded in the South-Western (SW) sector. This sector has the highest frequency of wind, the largest scale factor (Table 5) and therefore, the highest wind energy potential (26% of the total available) on the

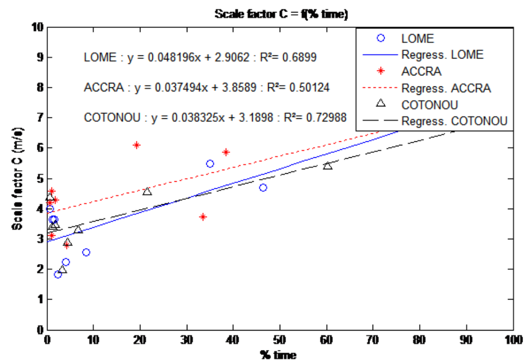


Figure 7: Parameter C as a function of wind frequency in each sector

Table 6: Numerical values of wind power densities available on the 3 sites

	LOME		ACCRA		COTONOU	
Direction	% time	P (W/m^2)	% time	P (W/m^2)	% time	P (W/m^2)
N	4.1169	9.5749	1.0011	32.6032	4.4521	16.7615
NE	1.2622	50.4341	1.0058	84.9072	1.2102	37.3860
E	0.6431	51.4806	0.7590	67.5052	0.7536	79.4782
SE	1.5740	32.5298	1.7213	51.6301	1.8314	28.5472
S	35.0775	96.1849	19.3053	130.5472	21.4827	53.5191
SW	46.4658	63.8568	38.4724	117.5883	60.1631	87.1230
W	8.4589	10.3267	33.4140	35.0962	6.8129	24.4925
NW	2.4017	4.3766	4.3211	18.2104	3.2940	5.0547

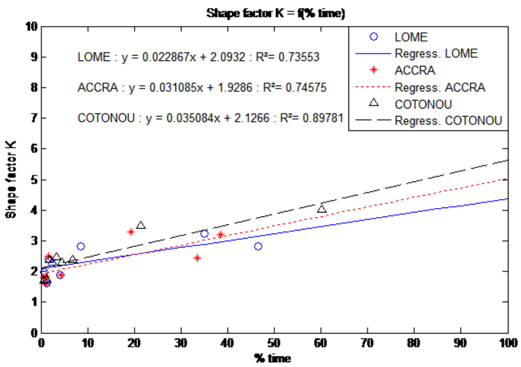


Figure 8: Parameter K as a function of wind frequency in each sector

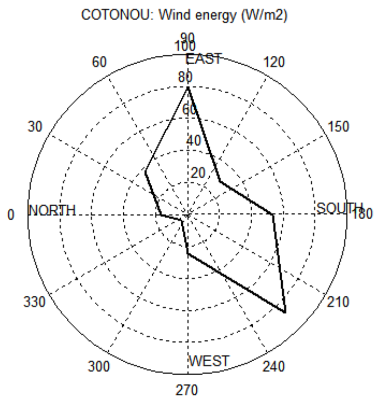


Figure 9: Forty-five degrees (45°) sectoral breakdown of power densities available on the Cotonou site

Cotonou site. Despite its interesting wind power, the Eastern sector (E) in Cotonou is very poorly represented due to the low wind frequency. Fig. 9 shows the distribution of the wind power density available by sectors of direction on the Cotonou site.

In Accra, the maximum wind power density available is 130.55 W/m^2 obtained in the Southern sector (S), while the South-West has 117.59 W/m^2 with a wind frequency twice as high. The Western sector (W), with a wind frequency nearly equal to that of the South-Western (SW) provides three times less energy than the latter. Fig. 10 shows the distribution of the wind power density available by sectors of direction on the Accra site.

On the Lomé site, the highest power densities are obtained in West and South sectors, respectively 63.86 and 96.18 W/m^2. These dominant wind sectors of direction concentrate 51% of the total power and are therefore preferred when installing wind turbines on the Lomé site. Eastern (E) and North-Eastern (NE) sectors, even if poorly represented, account each for 16% of the total wind power available on the Lomé site. Fig. 11 shows the distribution of the wind power density available by sectors of direction on the Lomé site.

6. Conclusion

The sites covered by this study have prevailing wind sectors of direction. These directions have higher wind energy potential compared to other sectors and are therefore preferred when installing wind turbines on these sites. It assumes a similar trend with respect to the variability of the parameters characterizing the distribution of wind speeds of these sites. Indeed, the Weibull parameters increase with wind frequency while wind speed distribution parameters such as skewness and kurtosis are low when the number of hours that the wind blows in a sector of direction is high on these 3 sites in the Gulf of Guinea.

References

[1] A. Judzińska-Kłodowska, Selected aspects of material and energy model assessment of onshore and offshore wind farms, Journal of Power Technologies 93 (5) (2013) 407–412.

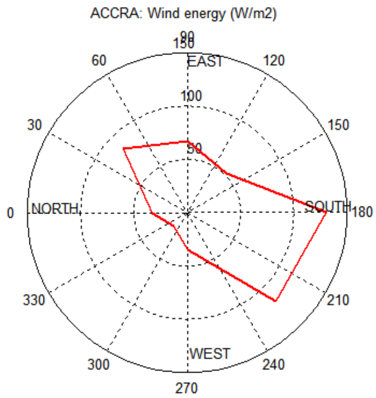


Figure 10: Forty-five degrees (45°) sectoral breakdown of power densities available on the Accra site

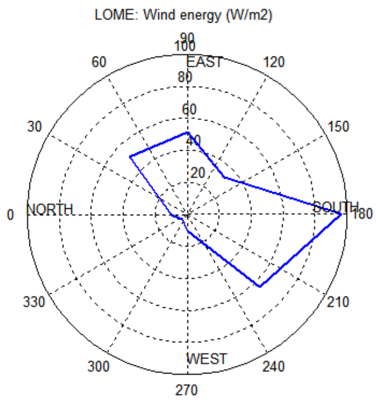


Figure 11: Forty-five degrees (45°) sectoral breakdown of power densities available on the Lomé site

[2] J. Torres, A. García, E. Prieto, A. De Francisco, Characterization of wind speed data according to wind direction, Solar energy 66 (1) (1999) 57–64.
[3] A. Islam, S. R. Hasib, M. S. Islam, Short term electricity demand forecasting of an isolated area using two different approach, Journal of Power Technologies 93 (4) (2013) 185–193.
[4] A. A. Salami, A. S. A. Ajavon, M. K. Kodjo, K.-S. Bedja, Contribution to improving the modeling of wind and evaluation of the wind potential of the site of lome: Problems of taking into account the frequency of calm winds, Renewable Energy 50 (2013) 449–455.
[5] http://Wheather.uwyo.edu/surface/meteogram/.
[6] J. Seguro, T. Lambert, Modern estimation of the parameters of the weibull wind speed distribution for wind energy analysis, Journal of Wind Engineering and Industrial Aerodynamics 85 (1) (2000) 75–84.
[7] F. Hacene, N. Boukli, M. Kasbadji, L. Loukarfi, Statistical analysis and development of a wind atlas for the cheliff valley, Journal of Renewable Energies 10 (2007) 583 – 588, university of Hassiba Ben Bouali, Algeria.
[8] Fichaux N., Evaluation of the offshore wind energy potential and satellite imagery. PhD thesis, Ecole des Mines de Paris, December 2003.