Journal of Renewable Energies 25 (2022) 169 – 186

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page : https://revue.cder.dz/index.php/rer

Research Paper

Wind data modeling and energy mapping of the wind potential in the city of Douala (Cameroun)

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A R T I C L E I N F O

Article history:

Received 07 July 2022

Accepted 15 November 2022

Keywords:

Weibull parameters

Wind potential

Energy density

Energy mapping

Turbulence

A B S T R A C T

This work helps in the implementation of wind energy projects in the city of Douala. Wind data used (speed and direction) were collected from January 1, 2020, to December 31, 2020, at a height of 10m. The use of wind speed distribution laws allowed us to obtain predictions of the available wind energy on-site at different altitudes. Then, the wind direction is established for the orientation of the wind turbines and the turbulence analysis is done to highlight the exploitable wind periods. The results show that harnessing wind energy is possible on site from 10 AM to 06 PM. The wind potential at 138 m height has an average speed of 8.15 m/s for an overall energy density of 749.78 W/m^2 for roughness class 0, and an average speed of 3.7 m/s for an overall energy density of 69.118 W/m^2 for roughness class 4. The wind turbines will be installed in front of the north-north-east direction between 15 and 25°. Finally, the energy mapping of the city's wind resources allows us to estimate the total energy available at a reference height.

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Tel.: + 237 656579873 / + 237 691625284

ISSN: 1112-2242 / EISSN: 2716-8247

1. Introduction

The development of a country's industrial fabric depends largely on the energy resources available [1]. Faced with the depletion of several conventional energy resources in recent decades around the world, the production of energy through new energy resources is an issue of increasing interest to research.

In Cameroon, there is a wide variety of energy sources, from fossil fuels to decarbonized energy, also known as renewable energy. Despite this variety of energy sources, the energy supply is still dominated by hydroelectricity and thermal energy [2]. However, due to the increasing scarcity of hydrocarbons used to produce thermal energy, the numerous pollution problems caused by high-carbon products, and the constant seasonal variations that make the flow of rivers oscillate for the production of hydroelectric energy, the national electrification rate in 2014 is estimated at less than 30%. [3]. Moreover, despite numerous efforts, the map of households without electricity in both rural and urban areas remains alarming [2]. It is, therefore, necessary to focus on the development of renewable energies, which have great potential given the climatic diversity of our country.

The exploitation of wind for electricity production is still marginal in Cameroon. It is in the study phase with a few small achievements in the field [3, 4]. In most regions of the country, the average wind speed is about 2 to 4 m/s at 100 meters height [1, 5]. The northern part of Cameroon and the coastal areas are favorable sites for the installation of existing wind power plants [1].

Most of the work carried out in Cameroon to determine the wind potential has so far only concerned the far north [6, 7, 8, 9]. This area is heavily studied because of the very low electrification rate in the region [2]. The mathematical laws used for the study and modeling of this work are mainly the Weibull distribution and the hybrid Weibull distribution. These are modeling laws based on data collected at a collection site, to predict certain wind parameters (speed and direction).

The objective of this work is to investigate the wind potential of the city of Douala and to define precisely the energy contribution that the wind exploitation of a coastal region could bring to the electricity production of Cameroon. Two velocity distribution modeling laws will be used and the results compared: the Weibull distribution and the hybrid Weibull distribution. The energy density will then be determined at the collection site. Finally, the energy mapping of the wind resource at $138\,m$ height, the energy mapping of the wind resource at height will be modeled to enable the installation of a wind farm in the city.

2. Material and method

2.1 Equipment

2.1.1 Presentation of the study area and data description

Douala is the economic capital of Cameroon and the capital of the Littoral region. The exploitation of the breeze and the geographical location of the site requires an interest in the wind resource of the region. The geographical coordinates of the collection point are given in Table 1.

Table 1: Geographical data of the collection point

Geographical data	
Latitude	$04°00'53'' N$
Longitude	$009°43'03'' E$
Altitude	$8\ m$
Collection height	$10\ m$

Wind data used in this work (respectively wind speed and wind direction) were collected by the meteorological service of the Douala International Airport during the period from January 1, 2020, to December 31, 2020, at a height of 10m, and 3 hours intervals.

2.1.2 Materials used

The geolocation of the different points of the city was done using *Google Earth Pro* software. Wind speed and direction data were collected on a three-hourly basis for one year (2020) by the ASECNA (Air Safety Agency in Africa and Madagascar) P30 station. *Matlab* software was used to make a simulation using a Modified Maximum Likelihood Methode (MMLM) code, determine the average wind characteristics, and plot the wind rose. *MS Excel* software was used to plot the curves and perform vertical extrapolations of the data. Finally, *GPS Visualizer* and *Golden Surfer* were used to model energy maps of the city using topographic terrain data of 123 269 coordinate points and the results of vertical extrapolation of k and C parameters.

2.2 Method

2.2.1 Pre-stage

For better exploitation of the data and because of the methods used, the wind speeds must first be organized in frequency classes with a constant step of one meter per second. Then, a statistical analysis is necessary. Equations (1) to (3) then allow the calculation of the different parameters [8] :

- Arithmetic average speed : $\bar{v} = \frac{1}{n} \times \sum_{i=1}^{n} v_i$ (1)

- Arithmetic weighted average speed : $\langle v \rangle = \frac{\sum_{i=1}^{n} v_i \times f(v_i)}{\sum_{i=1}^{n} f(v_i)}$ (2)

- Average power per unit area (energy density) :

$$\langle P\rangle = \frac{\sum_{i=1}^{n} P(v_i)\times f(v_i)}{\sum_{i=1}^{n} f(v_i)} \ ; \ P(v_i) = \frac{1}{2}\times\rho\times {v_i}^3 \ ; \ \langle P\rangle = \frac{1}{2}\times\rho\times\frac{\sum_{i=1}^{n} {v_i}^3\times f(v_i)}{\sum_{i=1}^{n} f(v_i)} \quad (3)$$

2.2.2 Mathematical modeling

2.2.2.1 Modelling the wind frequency distribution

a. The Weibull distribution

This is the most commonly used law to translate the variation of wind speeds. Its probability density is given by equation (4) [10] :

$$f(v) = \left(\frac{k}{C}\right)\left(\frac{v}{C}\right)^{k-1}\exp\left(-\left(\frac{v}{C}\right)^{k}\right) \quad (4)$$

It includes a scale parameter $C\ (m/s)$ which provides information on the average wind speed characteristic of the site and a shape parameter $k\ (without\ unit)$ indicating the sharpness of the distribution [6, 11].

The probability density $f(v)$ represents the frequency distribution of the measured speeds. The corresponding cumulative Weibull distribution function $F(v)$ is determined by the following equation (5) [12] :

$$F(v \le v_x) = \int_0^{v_x} f(v)dv = 1 - \exp\left(-\left(\frac{v_x}{C}\right)^{k}\right) \quad (5)$$

The average wind speed V_m can be calculated from equation (6) :

$$V_m = \int_0^{\infty} v f(v)dv \quad (6)$$

b. The hybrid Weibull distribution

It is used when the frequency of calm winds recorded at a site is greater than or equal to 15%. This distribution is calculated from the following equations (7) and (8) [5, 9, 12, 13] :

$$f(v) = (1 - F_0)\left(\frac{k}{C}\right)\left(\frac{v}{C}\right)^{k-1}\exp\left(-\left(\frac{v}{C}\right)^{k}\right) \qquad for\ v > 0 \quad (7)$$

$$f(v) = F_0 \qquad for\ v = 0 \quad (8)$$

Where F_0 is the frequency of calm winds.

2.2.2.2 Determination of Weibull parameters

There are several methods for determining the parameters C and k of Weibull. These include the method of least squares, the method of moments, the method of energy factor, or the method of maximum likelihood [6, 13]. However, the literature indicates that the Modified Maximum Likelihood Method (MMLM) is the most accurate in areas with a high rate of calm wind. It uses the frequency classes of wind speeds for the determination of the two parameters [6, 14].

The Weibull parameters are calculated by equations (9) and (10) :

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k \ln(v_i) f(v_i)}{\sum_{i=1}^{n} v_i^k f(v_i)} - \frac{\sum_{i=1}^{n} \ln(v_i) f(v_i)}{F(v \geq 0)}\right]^{-1} \tag{9}$$

$$C = \left[\frac{1}{F(v \geq 0)} \sum_{i=1}^{n} v_i^k f(v_i)\right]^{1/k} \tag{10}$$

Where v_i is the non-zero wind speed at time i, $f(v_i)$ the frequency of occurrence of the speed v_i and $F(v \geq 0)$ the probability that the wind speed is greater than zero.

To solve these equations, an iterative calculation of the shape parameter with an initial value $k = 2$ is done through a Matlab code until a convergent value is obtained. Then, the value of k is used to calculate the scale parameter C.

2.2.2.3 Calculation of wind parameters

The wind parameters represent the mean wind speed, its standard deviation, the available energy density, and speeds with useful properties [15, 16]. The values for each of the distribution laws are obtained from equations (11) to (18) :

For the Weibull distribution

$$\bar{V} = C \times \Gamma\left(1 + \frac{1}{k}\right) \tag{11}$$

$$\sigma = C\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]^{\frac{1}{2}} \tag{12}$$

$$\bar{P} = \frac{1}{2} \times \rho \times C^3 \times \Gamma\left(1 + \frac{3}{k}\right) \tag{13}$$

For the hybrid Weibull distribution

$$\bar{V}_H = (1 - F_0) \times C \times \Gamma\left(1 + \frac{1}{k}\right) \tag{14}$$

$$\sigma_H = (1 - F_0) \times C\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]^{\frac{1}{2}} \tag{15}$$

$$\bar{P}_H = (1 - F_0) \times \frac{1}{2} \times \rho \times C^3 \times \Gamma\left(1 + \frac{3}{k}\right) \tag{16}$$

- Most frequent wind speed on site : $V_{mp} = C.\left(\frac{k-1}{k}\right)^{1/k}$ (17)

- Maximum wind speed on site : $V_{\max E} = C.\left(\frac{k+2}{k}\right)^{1/k}$ (18)

Finally, the mean square error (MSE) and its root (RMSE) are used to determine the distribution law with the most relevant results. It is calculated using equation (19):

$$MSE = \frac{1}{N} \sum_{i=1}^{N} (\langle v_i \rangle - p_i)^2 \tag{19}$$

$\langle v_i \rangle$: Measured speed, which is the monthly arithmetic weighted average speed shown by equation 2

p_i: Predicted speed, which is the monthly mean wind speed obtained by using Weibull parameters for the 2 considered laws shown by equations 11 and 14

2.2.3 Determination of wind speed for each roughness class

The relief and urbanism observed from Google Earth pro allowed the Douala site to be classified as a roughness class 3.5 with a length $z_0 = 0.8\, m$ (Danish Wind Industry Association chart

[17]). Thus, the velocity value for the approved roughness classes $(0, 1, 2, 3\ et\ 4)$ is obtained by multiplying the velocity obtained on-site by a roughness coefficient given by equations (20) and (21) :

$$c_r(z) = k_r \times \ln\left(\frac{z}{z_0}\right), \quad k_r = 0.19 \times \left(\frac{z_0}{0.05}\right)^{0.07} \qquad (20, 21)$$

2.2.4 Vertical Extrapolation of Data

The speed and power values obtained are generally not satisfactory at the data collection height of $10\ m$. The need to extrapolate the data to higher altitudes to obtain usable wind speeds, therefore, appears to be imperative. The extrapolation to different heights is generally done using the extrapolation model of Justus and Mikhail which takes into account the heights of calculation and the roughness of the environment [11, 15, 16, 18]. To characterize the wind potential of a site with the Weibull model at different altitudes knowing the parameters at a reference altitude ($10\ m$ in our case), the simplified formulas used to extrapolate Weibull parameters are presented in equations (22) and (23):

$$\frac{k_z}{k_{10}} = \frac{1}{1-0.0881\ln\left(\frac{z}{10}\right)} \qquad (22)$$

$$\left(\frac{C_z}{C_{10}}\right) = \left(\frac{z}{10}\right)^n \quad \text{with } n = 0.37 - 0.0881\ln C_{10} \qquad (23)$$

The knowledge of Weibull parameters at a given altitude by vertical extrapolation using Justus and Mikhail's law makes it possible to determine at different points of a site wind parameters and thus to establish the energy maps.

2.2.5 Turbulence analysis

By observing the evolution of wind speeds daily, it is usually possible to observe periods of exploitable winds and periods when the wind speed is below the starting speed of the turbines. The assessment of the overall annual potential depends only on the hours when the winds are exploitable. Therefore, the wind speed curve should be plotted against the daily hours and the potential production period at the site should be determined.

3. Results and discussion

3.1 Statistical analysis and Weibull parameters

Table 2 shows the distribution of speeds in frequency classes:

Table 2: Wind speeds in frequency distribution format (m/s)

Speed class	$[0;1[$	$[1;2[$	$[2;3[$	$[3;4[$	$[4;5[$	$[5;6[$	$[6;7[$	$[7;8[$
frequency	0.545	0.029	0.184	0.165	0.059	0.011	0.0016	0.0003

The values of the statistical characteristics are recorded in the following Table 3.

Table 3: Results of the annual statistical averages

Features	$\overline{v}$ (m/s)	$\langle v \rangle$ (m/s)	$\langle \sigma \rangle$	$\langle P \rangle$ (W/m^2)
Annual values	1,24	1,70	1,02	9,37

The annual value of the Arithmetic weighted average speed is the one that best defines the situation because it takes into account the frequency of each speed class. The average speed values obtained show that the winds in Douala city are calm. Table 4 presents the values of the parameters C and k.

Table 4: Monthly and annual values of Weibull parameters

Month	***k***	***C*** (m/s)	***F_0***
January	1,44	1,80	0,56
February	1,37	1,92	0,55
March	1,37	2,02	0,54
April	1,39	1,87	0,57
May	1,41	1,86	0,56
June	1,42	1,76	0,60
July	1,42	1,76	0,59
August	1,37	2,09	0,50
September	1,45	1,82	0,58
October	1,37	2,04	0,55
November	1,38	2,21	0,47
December	1,41	2,12	0,47
Annual	**1,40**	**1,94**	**0,55**

The scale parameter C has an annual average value that is close to the Arithmetic weighted average speed, which reflects the appropriateness of the method for determining these parameters. However, this value is still very low, which is reasonable given the height of the collection point. Concerning the shape factor, its annual average value is close to 1.5. This means that the power density curve will have a maximum value for a non-zero value of the speed. Finally, the frequency of zero winds is 55 %, which indicates the very calm nature of the winds in the region at 10 m height.

3.2 Wind speed distribution

The power densities of the winds on a monthly scale using the Weibull distribution are shown in Figure 1. The analysis of these curves shows a uniform distribution throughout the year with very low speeds at the height of the collection point. Nevertheless, the homogeneity of the curves confirms the potential exploitation of wind energy during the 12 months of the year.

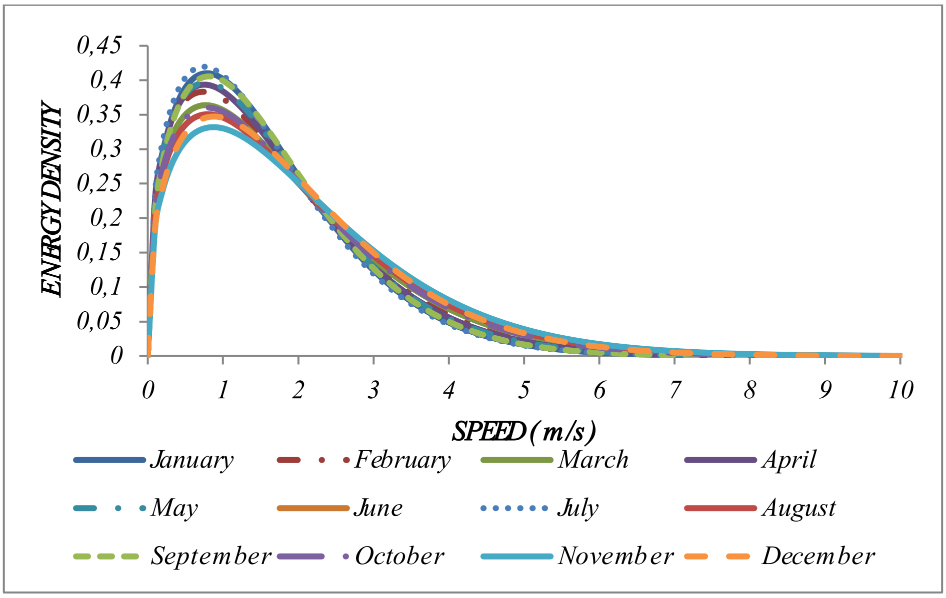


Figure 1: Monthly wind speed frequency distribution curves at 10 m altitude at the Douala International Airport site

Based on the calculated Weibull parameters, the annual power density curves by the Weibull distribution and the hybrid Weibull distribution were also plotted. Regardless of which distribution law is used, the curves are roughly similar in shape. Furthermore, the maximum values are reached using the Weibull distribution. The combined superposition of the two curves on the histogram of wind speed frequencies as presented in Figure 2 shows that the Weibull distribution is the law that best represents the distribution of wind speeds in Douala.

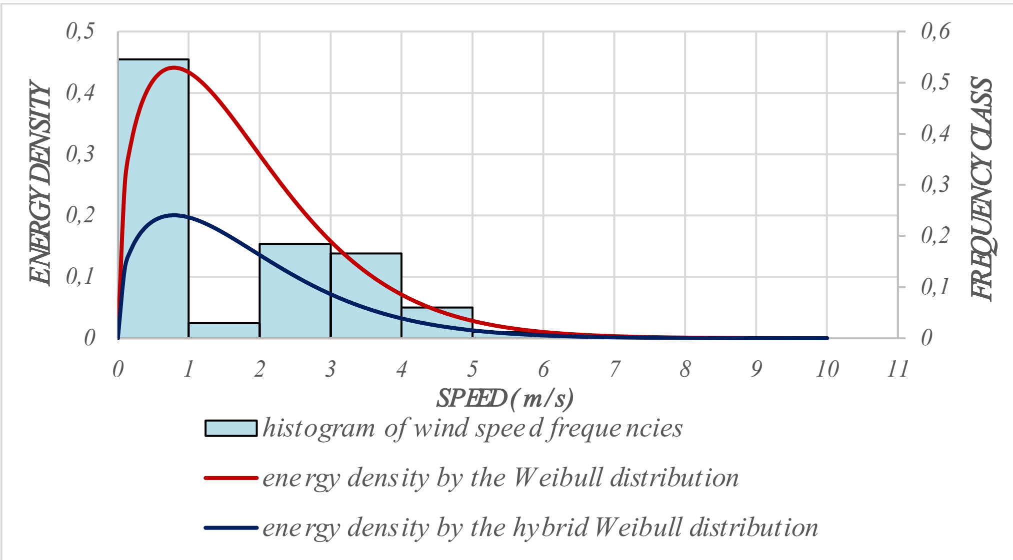


Figure 2: Annual frequency curve of wind speed modeled by the different Weibull distributions

3.3 Wind potential of the airport site at collection height

For each month, the mean speed, standard deviation, and power available in the wind were calculated for each of the distributions (Table 5).

Table 5: Wind characteristics obtained by the two-speed distribution laws

Month	$\bar{V}$ (m/s)	σ	P (W/m^2)	F_0	$\bar{V}_H$ (m/s)	σ_H	P_H (W/m^2)
January	1,63	1,15	6,53	0,56	0,71	1,11	2,84
February	1,75	1,29	8,68	0,55	0,79	1,23	3,89
March	1,85	1,37	10,23	0,54	0,86	1,31	4,74
April	1,70	1,24	7,77	0,57	0,73	1,17	3,34
May	1,69	1,22	7,43	0,56	0,74	1,16	3,27
June	1,60	1,15	6,28	0,60	0,64	1,07	2,51
July	1,60	1,14	6,22	0,59	0,65	1,07	2,53
August	1,92	1,42	11,41	0,50	0,95	1,38	5,66
September	1,65	1,16	6,66	0,58	0,70	1,11	2,83
October	1,86	1,37	10,40	0,55	0,83	1,30	4,66
November	2,02	1,48	13,16	0,47	1,08	1,48	7,02
December	1,93	1,39	11,09	0,47	1,02	1,40	5,86
Annual	**1,77**	**1,28**	**8,82**	**0,55**	**0,81**	**1,23**	**4,10**

Table 6 presents the results of the calculation of errors in the average speed obtained for the two methods used.

Table 6: Value of the different errors

Weibull		***Weibull_H***	
MSE	*RMSE*	*MSE*	*RMSE*
0,0037	**0,0615**	0,8085	0,8991

The analysis of Table 5 makes it possible to identify the months of high and low productivity. The months whose average monthly speed is higher than the average annual speed are the months of high potential. These are March, August, and the last three months of the year. On the other hand, June and July are the months with the lowest potential. Each of these periods can be identified with a particular time of the year, noting that the high potential months correspond to the transition periods between seasons (dry to rainy) and the months of high precipitation while the low potential months correspond to the months of low precipitation. Finally, the calculation of the root mean square error gives the best accuracy of the method used by associating it with the Weibull distribution.

Despite the smallness of the databases collected, a study makes in 2020 in Cameroon [5] with the data collected in the period of 38 years (from January 1982 to December 2019) from the NASA website shows that the mean speed of wind in the city of Douala during this period is $1{,}66\ m/s$ at 10 m height, with a standard deviation of $0{,}41$. Since in 2020 the arithmetic weighted average speed is $1{,}70\ m/s$ at 10 m height, the database can be used to obtain a good result of simulation. Moreover, some works which use just one year of data have satisfactory results [9, 13], which is a good clue to consider that the use of just one year's data doesn't have a big impact on the results when the wind characteristics have a slight variation over the years.

3.4 Wind Atlas of Douala City

The average wind speed obtained at $10\ m$ height is very low and does not allow for wind exploitation. The extrapolation of data to different heights allowed us to obtain exploitable wind speeds and sufficiently high power. The different extrapolation calculations lead to the following table 7:

Table 7: Wind Atlas of the city of Douala

Height		**R-class 0 (0.000 m)**	**R-class 1 (0.030 m)**	**R-class 2 (0.100 m)**	**R-class 3 (0.400 m)**	**R-class 4 (1,500 m)**
10 m	k	1,32	1,29	1,31	1,32	1,32
	C	4,96	3,64	3,17	2,49	1,65
	$\bar{V}\ (m/s)$	4,57	3,37	2,92	2,29	1,52
	$P\ (W/m^2)$	164,59	68,21	43,74	20,85	6,03
25 m	k	1,43	1,40	1,42	1,43	1,44
	C	6,11	4,60	4,05	3,24	2,23
	$\bar{V}\ (m/s)$	5,55	4,19	3,69	2,95	2,02
	$P\ (W/m^2)$	257,25	114,16	76,02	38,50	12,32
50 m	k	1,53	1,50	1,52	1,53	1,54
	C	7,16	5,50	4,88	3,97	2,79
	$\bar{V}\ (m/s)$	6,45	4,96	4,40	3,57	2,51
	$P\ (W/m^2)$	363,73	170,02	116,47	61,75	21,33
100 m	k	1,65	1,62	1,64	1,65	1,66
	C	8,40	6,56	5,88	4,85	3,50
	$\bar{V}\ (m/s)$	7,51	5,88	5,26	4,34	3,13
	$P\ (W/m^2)$	518,31	255,23	179,85	99,83	37,22
200 m	k	1,79	1,75	1,78	1,79	1,80
	C	9,84	7,84	7,08	5,93	4,93
	$\bar{V}\ (m/s)$	8,75	6,98	6,30	5,27	3,90
	$P\ (W/m^2)$	744,69	386,40	280,05	162,73	65,47

From the Weibull parameters calculated for all roughness classes, the calculation of wind speeds with useful properties is performed (Table 8). These are the most frequent wind speed (V_{mp}) and the wind speed carrying the maximum energy (V_{maxE}).

Table 8: Wind speeds with useful properties

H	R-class 0 (0.000 m)		R-class 1 (0.030 m)		R-class 2 (0.100 m)		R-class 3 (0.400 m)		R-class 4 (1,500 m)	
	V_{mp}	V_{maxE}	V_{mp}	V_{maxE}	V_{mp}	V_{maxE}	V_{mp}	V_{maxE}	V_{mp}	V_{maxE}
10 m	1,68	10,00	1,15	7,51	1,05	6,44	0,84	5,02	0,57	3,31
25 m	2,65	11,25	1,90	8,64	1,73	7,51	1,40	5,98	0,98	4,08
50 m	3,60	12,34	2,66	9,64	2,42	8,46	1,99	6,84	1,42	4,79
100 m	4,78	13,58	3,63	10,78	3,32	9,56	2,76	7,84	2,01	5,63
200 m	6,22	14,97	4,85	12,10	4,45	10,83	3,75	9,02	2,79	6,65

3.5 Topographical map of Douala

The collection of geographical coordinates of 123 269 points in the city of Douala has made it possible to establish a 2D and 3D topographical map (Figure 3). The observation of the map shows that the city of Douala has a relatively low altitude to sea level. The average altitude of the city is $19.4\ m$ while the difference between the highest and lowest points is $79.813\ m$. It can therefore be said that the site is a relatively flat terrain. In addition, two zones can be distinguished: the low-lying area around the Wouri River and the high-lying area in the northeastern part of the city.

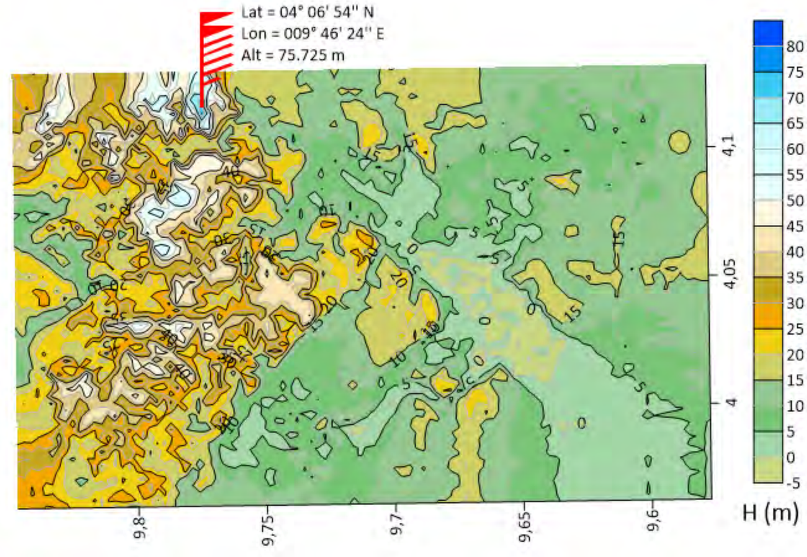
3.6 Wind speed mapping at $138\ m$ height in Douala

For the needs of future installation of a wind farm in the region, we opted for a height compatible with the mast of a high-power wind turbine [19]. in the specific case of this work, it is the ENERCON E-82 E2 specially developed for medium-force winds [20].

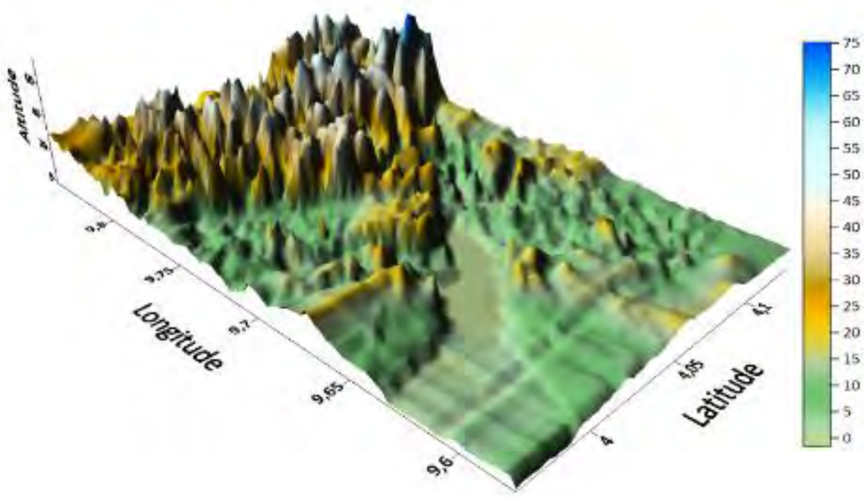
The observation of the speed maps shows that the lowest wind speeds are observed in the lowest altitude areas. Thus, the lowest speeds at $138\ m$ are observed around the Wouri River while the highest speeds are observed in the North-Eastern part of the city. Nevertheless, the difference between the lowest and the highest velocity is less than one meter per second. We can therefore consider a uniformity of the speed values at this height, proof that the roughness does not influence the wind speed when we rise in height.

3.7 Wind power mapping at $138\ m$ height in Douala

As the wind energy is homogeneous to the cube of the speed, the observations are similar and both areas are observed. On the 123 269 points identified, the difference between the power bounds is $145.81\ W/m^2$ (Table 9).

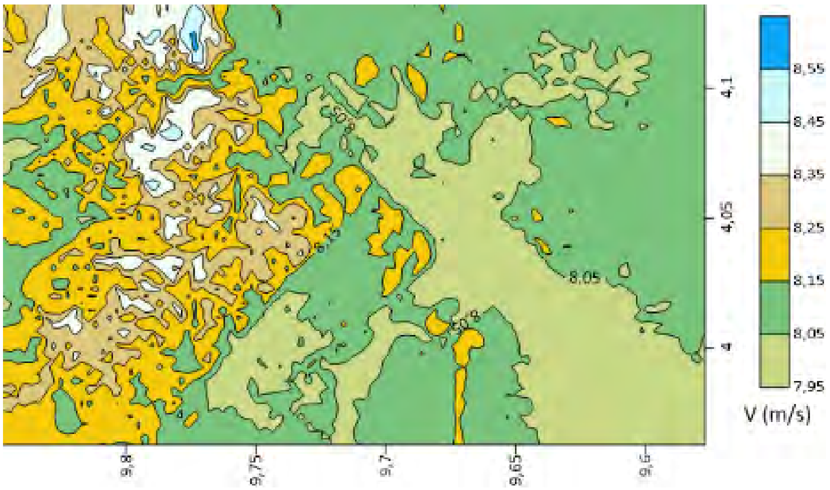


(3. a)

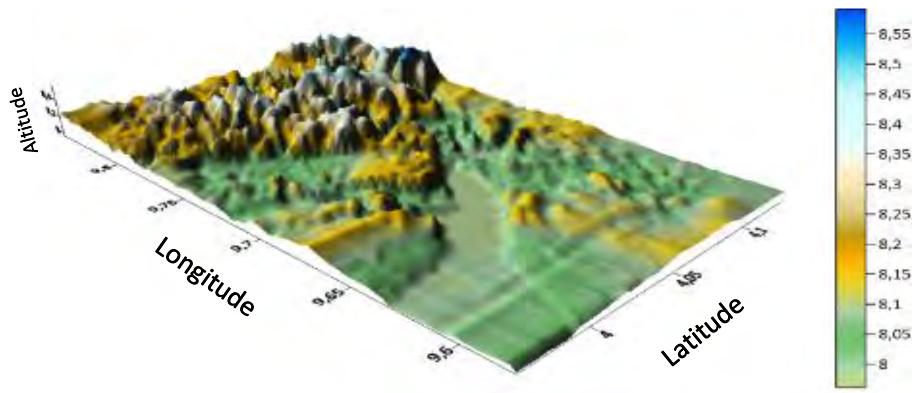


(3. b)

Figure 3: 2D and 3D topographic map of the city of Douala



(4. a)

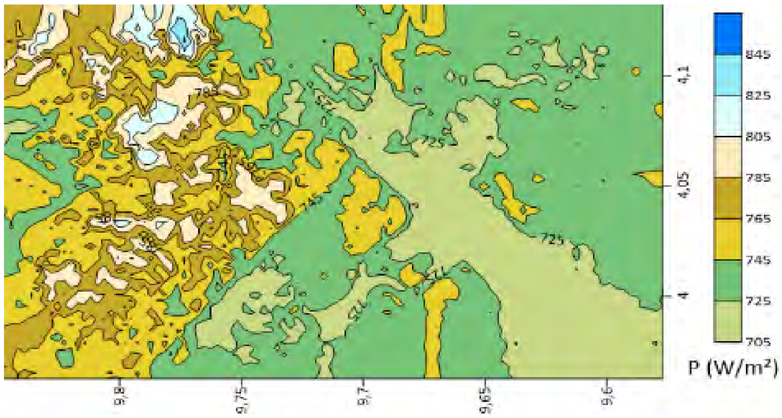


(4. b)

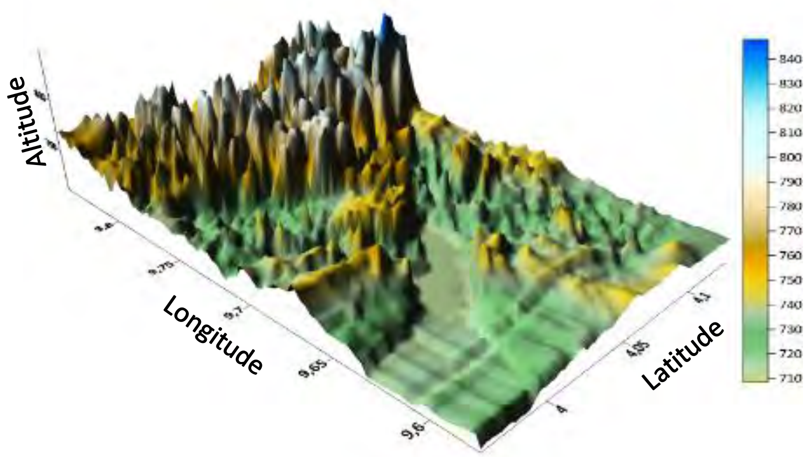
Figure 4: Wind speed map at 138 m in the city of Douala

Table 9: Average wind characteristics at 138 m height

	R-class 0 (0.000 m)								
	Lat.	**Long.**	**Alt. (m)**	k	C (m/s)	$\overline{V}$ (m/s)	P (W/m^2)	V_{mp} (m/s)	V_{maxE} (m/s)
Max	4,115216	9,773390	213,725	1,77	9,656	8,595	848,98	6,03	14,8
Min	4,068092	9,697489	133,912	1,69	8,893	7,936	703,17	5,26	14,07
Average			**173,82**	**1,72**	**9,146**	**8,154**	**749,78**	**5,51**	**14,31**
	R-class 4 (1.500 m)								
	Lat.	**Long.**	**Alt. (m)**	k	C (m/s)	$\overline{V}$ (m/s)	P (W/m^2)	V_{mp} (m/s)	V_{maxE} (m/s)
Max	4,115216	9,773390	213,725	1,80	4,475	3,979	82,168	2,86	6,75
Min	4,068092	9,697489	133,912	1,71	3,843	3,427	56,068	2,30	6,04
Average			**173,82**	**1,755**	**4,159**	**3,703**	**69,118**	**2,58**	**6,395**



(5. a)



(5. b)

Figure 5: Wind power mapping at 138 m in the city of Douala.

3.8 Orientation of wind turbines

To give a preferred direction to the wind turbines at the time of their installation, the wind rose of the city of Douala presented in figure 6 was drawn:

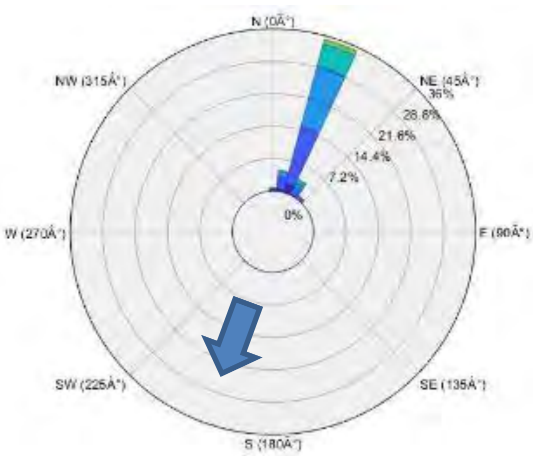


Figure 6: Wind rose in the city of Douala

The observation and analysis of the rose show that the wind blows from the North East to the South West, hence a predominance of wind frequency in the $[15 - 25°]$direction. This direction represents more than 77.5 % of the non-zero winds, i.e. a little more than 35 % of the total winds measured in the city. It is also in this direction that the wind speed has its highest values, reaching 7 m/s at the measured height.

3.9 Turbulence analysis

The average variations over the year are used to define the wind(s) that regularly visit the site. This measurement also allows us to see, depending on what we want to do with the electricity production of the wind turbines, whether or not this energy yield is in line with the electricity consumers, and with other forms of electricity production. Part of the explanation for these variations could be the change in roughness due to the changing seasons. The analysis of the wind turbulence on the Douala site represented by the monthly curve of Figure 7 makes it possible to identify the month of high and low productivity.

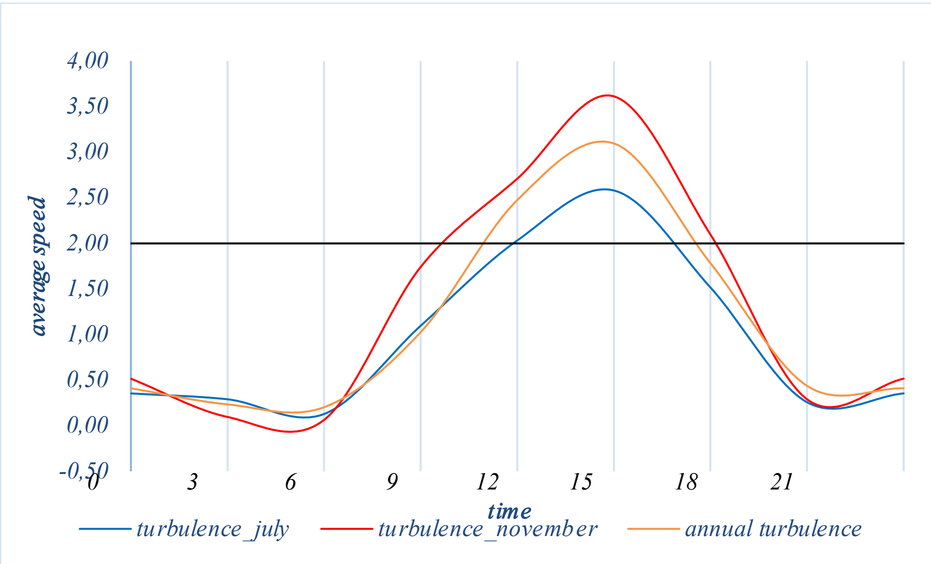


Figure 7: Annual wind turbulence

The observation of curves shows that the wind speed is very low, or almost zero, between 08 PM and 06 AM. This station should be:

- Or coupled with an existing local network to reinforce the energy supply;
- Be equipped with a substantial storage facility to ensure continuity of service.

Moreover, the knowledge of this period where the wind speed is not usable and taking into account that for average wind turbines the starting speed is about 2 m/s, the average operating time of the wind turbine on the site is 08 hours between 10 AM and 06 PM daily.

4. Conclusion

The research work undertaken is concerned with the determination of the wind potential in the city of Douala for the production of wind-generated electricity, and the establishment of the energy mapping of this wind potential. The MMVM (Modified Maximum Likelihood Method) was used to determine the Weibull parameters and to determine the wind characteristics at different heights from the Weibull distribution of wind speeds, for an error of less than 5% ($MSE = 0.0037$). The result of this work is that the wind at the site is regular and propagates mainly from the north-northeast to the south-southwest direction between 15 and 25°, with stable but low average speeds, on average $1.77\ m/s$ at the altitude of $10\ m$. This value is justified by the fact that the city of Douala is a zone with a strong disturbance of R-class 3.5. The best average speeds between 4 and 9 m/s, which are favorable to good electricity production, are obtained by extrapolation to altitudes of $25\ m$, $50\ m$, $100\ m$, and $200\ m$. Thus, the wind potential in the city of Douala at $138\ m$ height has an average speed of $8.15\ m/s$ for an overall energy density of $749.78\ W/m^2$ for roughness class 0, and an average speed of $3.7\ m/s$ for an overall energy density of $69.118\ W/m^2$ for roughness class 4. The velocity turbulence analysis shows that electricity production can take place between $10\ AM$ and $06\ PM$, i.e. a daily total of 08 hours. Finally, the measured and statistically calculated parameter values are very close to the values derived from the mathematical modeling approximation of the Weibull distribution, which validates the use of this model for prediction purposes.

The perspectives of this work aim at taking into account perturbation due to vegetation and urbanism of the city to make a roughness map and study the implantation of urban wind turbines in Douala.

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