Numerical Study of the Power Range of Wind Devices Adapted to the Wind Potential of the Coastal Region of Cameroon

O.T. SOSSO MAYI*‡, Daniel Alain ANYOUZO'O*, A.NGNISSOUN NDACHIGAM *

*Department of Electrical Engineering, Advanced Teachers' Training College for Technical Education, Universityof Douala, 1872 Douala, Cameroon

(O_SOSSO@yahoo.fr, danielalain200x@yahoo.fr,ngniss@yahoo.fr)

‡Corresponding Author,O.T SOSSO MAYI,1872 Douala,Tel: +237 677738114,Fax: 237 677738114+237,O_SOSSO@yahoo.fr

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Abstract-Profitable exploitation of wind energy requires a good estimation of the wind's potential. This preliminary study phase represents a key factor in the implementation of a wind project. In this perspective, this article assesses the wind energetic potential of the coastal region of Cameroon and offers a range of suitable wind turbines. The wind analysis is carried out using a Weibull model with two parameters, the shape factor k and the scale factor C. The determination of the Weibull's parameters is then carried out by the Maximum Likelihood Method (MLM), using measured wind data from the meteorological station of the multinational company COTCO-Cameroon for the period of 2009 to 2019.The study reveals that the average annual wind speed varied between 2.64 m/s in 2009 and 4.36 m/s in 2019 at 10 m from ground level. By contrast, the annual average power density varies between 35.9 W/m^2 to 195.3 W/m^2, respectively from 10m to 100m from ground level. The range of wind turbines retained is that of small wind turbines, whose powers are included between 1kW to 100 kW, with cut-in speeds and rated speeds respectively in the intervals (1.5 – 3m/s) and (10 – 12 m/s).

Keywords: Wind potential, Cameroon coastline, Weibull distribution, range of wind turbines, small wind turbines.

1. Introduction

Located on the Gulf of Guinea and also known as the economic power house of the central African sub-region, Cameroon has a rich hydro power potential which is the second in Africa estimated at 294 TWh/year [1, 2]. Cameroon's population and industrialization have more than doubled in the last three decades and the evolution of this population is particularly noticeable in the Littoral region. This region bordered by the Atlantic Ocean with Douala as its chief Capital city and also the economic capital, the industrial house of Cameroon with many heavy and light industries concentrated in this town. The rapid increase in the population of this industrial city creates a problem of energy shortages and distribution, especially as the country solely relies on hydroelectric power and every small percentage of thermal power generation to meet its energy demand [1].

Electricity is considered as one of the main drivers that contributes to the improvement of economic opportunities, social and economic development and even a better quality of life. For over six years, Cameroon has experienced persistent economic growth, with annual growth rates ranging from 3.3% in 2010 to 4.1% in 2011, 4.6% in 2012, 5.6% in 2013 and 5.1% in 2014. This rate of consumption which keeps rising, requires per annum at least 100 MW of new electricity generating capacities. On the other hand, electricity consumption per capita in the country stands at around 115 kWh nowadays and keeps going down as population continues steadily to grow, while the cost of electricity is rising steadily and stands at US$0,136 these days. Yet, the supply of electricity at national level which is insufficient and intermittent, has witnessed a high frequency of load shedding as well as a very high rate of losses in electricity generation, transmission and distribution [2].

Industries, businesses and individuals all suffer from this instability of energy production and all need alternative solutions which justifies, the massive recourse to the autonomous production of electric energy. This recourse to emergency sources is mainly oriented towards thermal devices for the production of electrical energy, namely generator sets. This paradox in a city that has a high potential in renewable energy resources is not justified in view of the cost of producing electrical energy generated by this type of device, with the very low standard of living of the populations, with pollution and environmental noise generated by the use of generator sets. These various shortcomings motivated the taking into account of the production of electric energy by renewable energy sources. Today the use of photovoltaic solar energy has gained momentum and represents the first source of renewable energy used by populations. This anguish is aroused by the fall in the prices of photovoltaic solar cells, and the miniaturization of these devices which make it possible to use them easily and everywhere. Despite these significant breakthroughs in photovoltaic solar power, there is still a lack of energy justified by the still high cost of kWh of solar energy production, a very short lifespan of the equipment used in solar installations. Faced with these shortcomings, given promising growing wind trends and previous studies carried out, wind energy could contribute to supporting the demand for electrical energy on the coast, both in self-production and for injection into the electrical network.

The wind potential of Cameroon and particularly that of Douala city has been widely demonstrated in the literature. In 2000, Réné Tchinda et al. [3] studied and evaluated the wind potential in the Far North for 5-year wind observations (1991-1995). In addition, F.H. Abanda in 2012 [4] presents a review on the potential of renewable energies in Cameroon, it highlights a significant factor of wind potential in the Far North. Similarly, D. Kidmo Kaoga et al. in 2014 [5,6,7] and 2016 [2,8] respectively present several works on the study of wind potential in the Adamawa, North and Far North regions from measurements of data and several methods of analysis. In the North-West, D. Afungchui et al. are studying the wind regime and the estimation of exploitable energy in Bamenda [9]. On the other hand, on the coastal part of Cameroon, Nkongho Ayuketang. A et al. in 2016 [1] using NASA data, studied over 31 years (1983-2013) the evolution of the wind potential for the installation of wind farms in the cities of Limbe, Douala and Kribi. In this work, the highlight a significant increase in wind speed from the 2009 year. However, there is limited scholarly work on the methods of exploiting this wind potential, the type of equipment's which could suit the wind profile exiting in the coastal region. Literature on the potential of renewable energy in Cameroon is known but still very limited and scattered because of an insufficient practical use. The exact sizes of the different devices used for wind renewable energy sources, their benefits and the market potential that can stimulate their uptake are not well-known. Therefore, stakeholders including policy makers, researchers and investors lack guidelines on how and at what level to invest, intervene, and design policies that can lead to the practical exploitation of wind renewable energy sources [4].

This study we are proposing, is one of the rare studies which links the wind energy potential to the supply of equipment on the current market, aims to assess beforehand the wind potential of the Cameroon coast and to seek a classification of ranges of wind turbines adapted according to wind data in this region. From meteorological data measured from 2009 to 2019, we modeled the frequency distribution of the wind and the available energy density, using the Weibull distribution.

In the framework of this paper, we evaluate the wind potential, and link it to the choice of a range of wind turbines adapted to the Cameroon coast. In this perspective, we start by determining the different parameters related to the wind using the Weibulldistribution model. The parameters of the Weibull model, namely the form factor k and the scale factor C are determined by the maximum likelihood method (MLM), from a sample of 4048 digital wind speed data from (2009-2019) provided by the COTCO-CAMEROON weather station. Obtaining the Weibullparameters will help to determine the probable minimum and maximum wind speeds necessary to estimate the energy density linked to the available wind potential. In accordance with the model obtained from the wind distribution on the coast, the suitable choice and classification of commercially available wind turbines is made according to the simulation performance, the technical and economic compromises linked to the criteria of nominal power, capacity factor, annual energy produced, starting and nominal speeds. It is clear from our work that the range of wind turbine suitable for the Littoral region of Cameroon is that of small wind turbines, with varying powers from 1 to 100kW, with low starting speeds (1.5-3 m/s) and nominal speeds (10-12 m /s).

2. Materials and methods

The study carried out within the framework of this work is of qualitative-quantitative nature, and is essentially based on the analysis of wind data in the Littoral region of Cameroon over a ten-year period going from 2009 to 2019. These data are then exploited in order to bring out a Weibull mathematical model with two parameters which will permit to obtain a general wind profile, allowing not only to appreciate the wind potential of the said region, but also and above all to bring out the essential parameters selecting the best wind turbines for our region. Optimizing the exploitation of wind energy potential requires knowledge of several parameters, a poor estimation of these would impact the performance of a wind project. In this approach, the resource estimation phase is justified, in so far it makes it possible to identify the conditions and constraints to be taken into account for the implementation of a project. This phase necessarily involves the acquisition and analysis of meteorological wind data for the area in question, using the appropriate equipment and methods.

2.1. Materials

The development of this research work, prompted the use of a set of hardware and software tools to aid in the treatment and analysis of data. Indeed, the location of the studied area and its geographic coordinates are made on the Google Earth site. Concerning the data, a sample of 4048 numerical data of the daily average wind speeds, taken on the coasts of the littoral are provided by the metrological station of COTCO an important multinational whose main activity is the transport of oil. Microsoft Excel and Matlab software are used for calculating Weibull's parameters and plotting curves. For the estimation of the wind power potential, WAsP software was used. The performance evaluation by simulations and the wind turbines tests are done by the Software Windographer and WasP.

2.2. Methods

2.2.1. Presentation of the study area

The Littoral region is one of the ten regions of Cameroon, located in the southwestern part of Cameroon, at latitude 4.05 ° North and longitude 9.7 ° East, with an elevation of about 19 meters. Its regional capital is Douala which is the economic capital of the country. It covers an area of approximately 20,248 km², for a population estimated at more than 3 million in 2015. The region benefits of an opening to the Atlantic Ocean, which gives it some wind potential. Figure 1shows the location of the coastline on the map of Cameroon.

Fig. 1. Location of Cameroon's Coastline (Google Earth).

2.2.2.Wind speeds on the coast

The estimation of the Cameroon Coastal wind resource requires the evaluation of the distribution of wind speeds using statistical analysis and suitable methods. Within the framework of this work, the data used are provided by the metrological station of the multinational COTCO-Cameroon. The extract of the daily wind profile, compiled between January 2009 to December 2019, measurements at 10 m from the ground, are presented in Figure 2. Large fluctuations in the wind are observed, with minimum speeds below 1m/s and maximum speeds having regularly exceeded 6m/s. We can also appreciate the quasi-periodic nature of the annual variations in wind speed, which is a function of the different seasons that occur during the year in the coastal region.

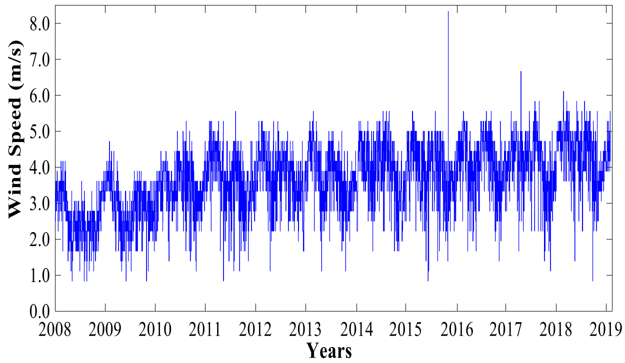

Fig. 2. Daily wind speeds at 10m from ground level.

It can be noticed that between 2008 and 2011, there was an increasing trend in wind speed, however between 2011 and 2019, there was a tendency of increase in low speed. Nevertheless, between 2018 and 2019 we have maximum speeds which approach or are higher than 6m/s.

2.2.3.Analysis of Wind Data

Modeling the wind distribution is a fundamental step in predicting wind generation. We use the Weibull distribution as an adapted statistical processing method for wind speed data [8, 9]. It makes it possible to estimate the probability of occurrence and the duration of the different wind speeds and the energy contained. The Weibull distribution is a model with two parameters, shape factor k and scale factor c (in m/s). It is formulated by the probability density function***f(v)*** and the cumulative probability density function***F(v)***, respectively given by equations (1) and (2).

$$f(v) = (k/c)(v/c)^{k-1}\exp\left((-v/k)^{k}\right) \qquad (1)$$

$$F(v) = 1 - \exp\left((-v/k)^{k}\right) \qquad (2)$$

where *v* is wind speed.

The Weibull parameters k and C once determined make it possible to calculate the average speed and the typical standard deviation from the following relations (3) and (4) [9, 10].

$$\bar{v} = c.\Gamma(1 + 1/k) \qquad (3)$$

$$\sigma = c[\,\Gamma(1 + 2/k) - \Gamma^{2}(1 + 1/k)]^{1/2} \qquad (4)$$

Where $\bar{v}$ is mean of wind speed and standard deviation σ

2.2.4. Weibull parameters

There are different methods for estimating the parameters k and C of Weibull D.K. kidmo et al. [6, 8] over a period. In this work, we will make an annual estimation of the form factor and scale factor. According to Prem Kumar et al. [10], the maximum likelihood method, offers good accuracy in iterative digital application on a large volume of data. The shape factor and scale factor are respectively determined by equations (5) and (6) [11]:

$$k = \left[\left(\sum_{i=1}^{n} v_i^k\, lnv_i^2 / \sum_{i=1}^{n} v_i^k\right) - \sum_{i=1}^{n} lnv_i^2/n\right](5)$$

$$c = (1/n)\left(\sum_{i=1}^{n}(v_i)^k\right)^{1/k}(6)$$

2.2.5.Extrapolation of Weibull Parameters

The measured height of 10 meters does not represent the appropriate altitude for harnessing wind energy. Extrapolation makes it possible to find an altitude with more stable winds, far from obstacles which generate turbulence. It is expressed by the law of Davenport and Harris [11, 12, 27].

$$v(h) = v_0(h/h_0)^{\alpha}(7)$$

Where $v_0$and *v(h)*are the wind speeds at the respective heights of reference h_0 and *h*, the height of determination of the wind speeds, and dimensionless wind shear coefficient, according to [12,13, 27] is given by equation (8):

$$\alpha = (0.37 - 0.0881 ln v_0)/(1 - 0.0881 ln h_0/10) (8)$$

The corrected Weibull parameters are obtained from equations (9) and (10) following [3, 12, 14]:

$$k(h)/k_0 = (1 - 0.0881 ln h_0/10)/(1 - 0.0881 ln h/10) \quad (9)$$

$$c(h)/c_0 = (h/h_0)^m (10)$$

$$m = (0.37 - 0.0881 ln c_0/10)/(1 - 0.0881 ln h/10) (11)$$

After the corrected Weibull parameters, we determine the most probable wind speed indicates the most frequent wind speed for a wind probability distribution and the optimal wind speed,as a speed that produces maximum energy along the yearmaximum wind speeds can be calculated at the desired altitude, by equations (12) and (13) [13,14,15, 22, 25].

$$v_{mp} = c(1 - 1/k)^{1/k} \quad (12)$$

$$V_{max} = c(1 + 2/k)^{1/k} \quad (13)$$

2.2.6. Power density and energy density

The evaluation of wind potential implicitly involves the evaluation of power and energy density [14,15,16,18, 26]. The power density defines the power per unit area generated by the wind. It is determined from wind speeds and air density. It can be estimated by the average speed over a specific period, according to equation (14).

$$P_D = \frac{1}{2} \rho . v_m{}^3 \quad (14)$$

The Weibull distribution analysis approach allows the average power density to be evaluated by equation (15).

$$P_D = (1/2) \rho . c^3 \Gamma(1 + 3/k) (15)$$

With P_D the power density (W/m^2), Γ the Gamma function andρ the air density (kg/m^3).

From the power density we will extract the average daily, monthly or annual energy density according to equation (16) [3,16].

$$WPD = P_D . t (16)$$

With ***t*** the extraction time in hours.

2.2.7. Capacity factor and Annual Energy produced

The choice of a wind turbine is a compromise between the characteristics of the installation site and that of the machines [12]. The capacity factor and the annual energy produced are factors determining the on-site efficiency of a wind turbine. Knowing the capacity factor, it's possible to assess the performance of wind turbines and determine the fraction of average power delivered by the generator given by equation 17 [17, 28]. The annual energy produced must be able to justify the investment. According to Weibull's approach, it is a function of form and scale factors, but also of the characteristic speeds of wind turbines, according to equations (18) and (19) [7, 15, 19,22,28].

$$P_{e,ave} = P_{eR} \left(\frac{e^{-\left(\frac{V_f}{c}\right)^k} - e^{-\left(\frac{V_r}{c}\right)^k}}{\left(\frac{V_r}{c}\right)^k - \left(\frac{V_c}{c}\right)^k} - e^{-\left(\frac{V_f}{c}\right)^k} \right) (17)$$

$$C_f = P_{e\,ave}/P_{eR} (18)$$

$$AEP = C_f P_{eR} . t (19)$$

With**V**$_C$is Cut-inwind turbine speed,**V_f**theCut-out wind turbine speed, ***Vr*** rated wind speed turbine, ***Pe$_R$***, ***Peave***ratedand average power wind turbine generated. ***Cf***theCapacity factor of a wind turbine, ***AEP***the annual energy produced.

3. Results and Discussions

The starting point towards the implementation of a wind energy project in a region is the thorough understanding of the prevalent characteristic wind regimes. Consequently, there is need of a systematic analysis of the short term and long term wind velocity distribution from which the energy density of the site can be estimated. Such information is required for the choice and optimal sizing of the appropriate wind turbines for the region of interest [20]. Consequently, we will first analyze the wind data obtained in order to be able to make a judicious selection of the different ranges of wind turbines that can be used in the Cameroon coastal region.

3.1. Comparative Average wind speed profiles from 2009 to 2019

The monthly variations in the average wind speeds, over 10 years, are presented in Figure 3.

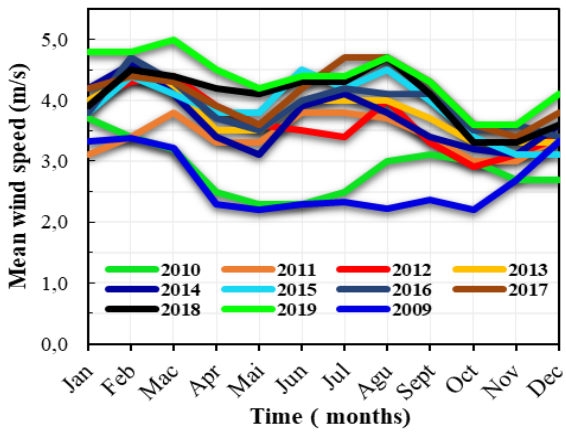

Fig.3. Average monthly wind speeds at 10m from ground level

This figure shows the average monthly wind speeds from 2009 to 2019 at 10m from the ground. One can appreciate, a priori the general decreasing trend of wind speeds, from

January to December of each year. Just like K. Bedoud et al., in 2016 [17], Kumar et al. in 2019 [19], the maximum average speeds were observed in the months of February, March and August.

On the other hand, the minimum average speeds appeared during the months of May, October and November. In addition, the graph shows two profiles; the first relates to the winds of 2009 and 2010, presents a correlation between February and July, with maximum average speeds of 3.3m/s, and constant minimum average speeds at 2.3m/s, between April to July. The second profile is that of the winds from 2011 to 2019, we observe a correlation of the average variations during the 12 months, we have maximum average speeds of 4.5m/s, in February, March and August, bycontrast the minimum average speeds in October and November. In this range, the winds in 2011 were the weakest, and the winds were the strongest in 2019.

The different profiles of wind speeds over the years 2009 to 2019 are all quite complex and difficult to predict, however we can afford to appreciate the general average trend in wind speeds over this 11-year period, illustrated by Figure 4. That figure shows the average annual change in wind speed from 2009 to 2019. We can observe an increasing trend in the average annual wind speed, with values varying between a minimum of 2.64 m/s in 2009 and maximum of 4.36m/s in 2019. Just like, Nkongho Ayuketang A. et al. in 2016 [1], there is an upward trend from 2009. A linear regression allows this annual average variation to be estimated around 0.21m/s/year. However, there were almost constant trends between 2015-2016 and 2017-2018.

3.2. Winds trend

The different profiles of wind speeds over the years 2009 to 2019 are all quite complex and difficult to predict, however we can afford to appreciate the general average trend in wind speeds over this 11-year period, illustrated by Figure 4. That figure shows the average annual change in wind speed from 2009 to 2019. We can observe an increasing trend in the average annual wind speed, with values varying between a minimum of 2.64 m/s in 2009 and maximum of 4.36m/s in 2019.

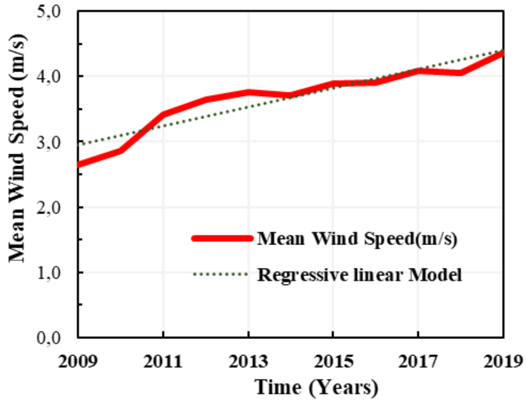

Fig.4. Average annual variation of wind speed

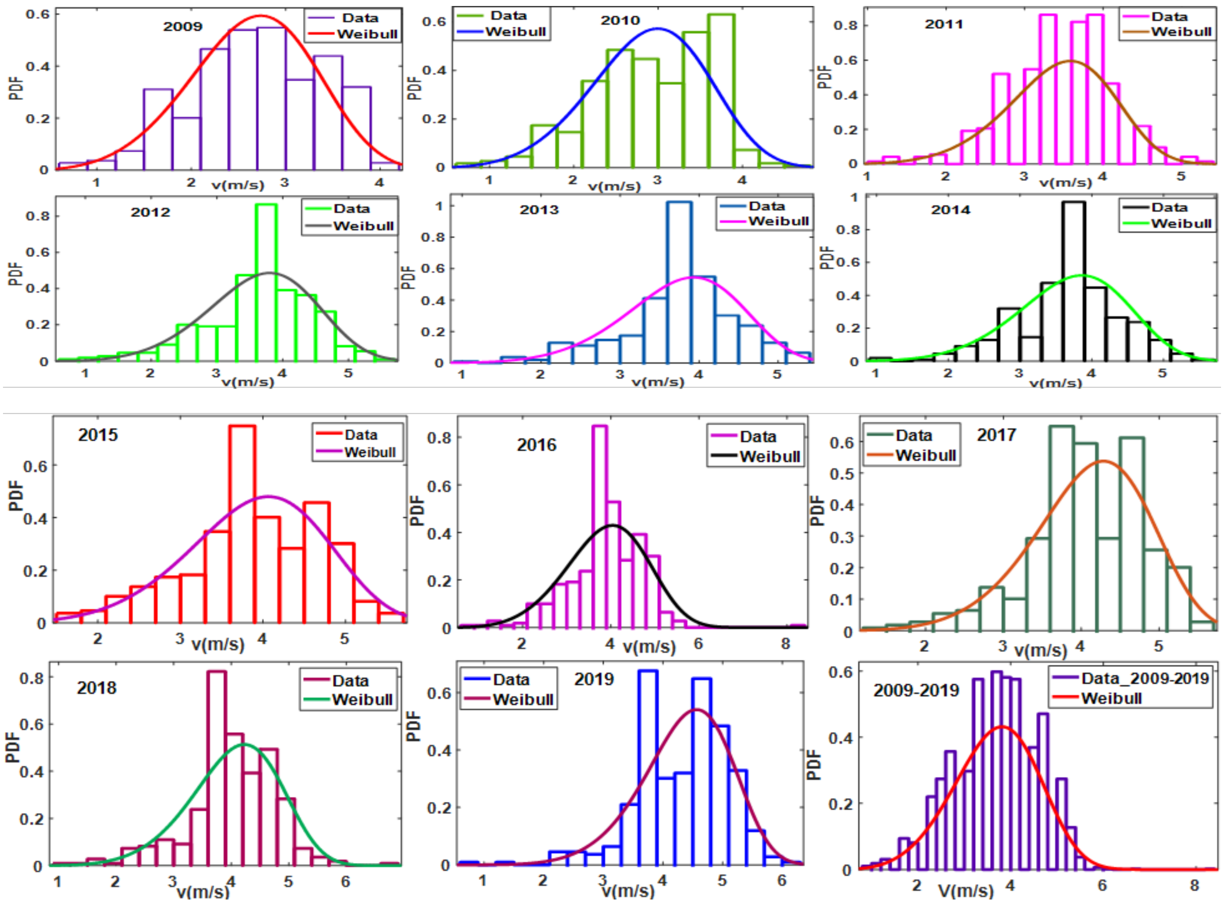

Fig. 5. Weibull distribution of wind speeds on the Cameroon's coast

The probability density linked to the distribution of the winds between 2009 and 2019 shows a decrease in the amplitude of the frequencies of occurrence, on the other hand we have compared to the increase the range of the range of speeds which increases, gradually with the high.

3.3. Annual wind distributions and Weibull model

The annual distribution of wind speeds on the Cameroon coast is shown in Figure 5 above, where are presented the histograms of the frequencies of wind speeds and the adjustments of the Weibull's probability density functions of the measurements at 10m from ground level, initially of the different years from 2009 to 2019. We observe a great centralization and concentration of the distributions around the annual average speeds, which could reflect a small variation of the speeds compared to their average values. This character shows a possible approach to modeling winds by a distribution of the normal law. The probability densities of the average speeds vary between the maximum value of 0.58 in a 2009 and minimum of 0.40 in 2016.

3.4 Annual Comparison of Weibull Distributions

Figure 6 presents the probability density and cumulative density functions of Weibull, at 10m (a) and 100m (b) from 2009 to 2019. Comparative observation of the distributions, shows a decrease in the probability densities of occurrence at high speeds, when the scale of wind speeds increases. Indeed, at 100 m, there is a moderate variation in probability densities between 0.4 in 2011 and 0.32 in 2016, reflecting the fact that the average wind speeds are the most likely, and necessarily more energetic.

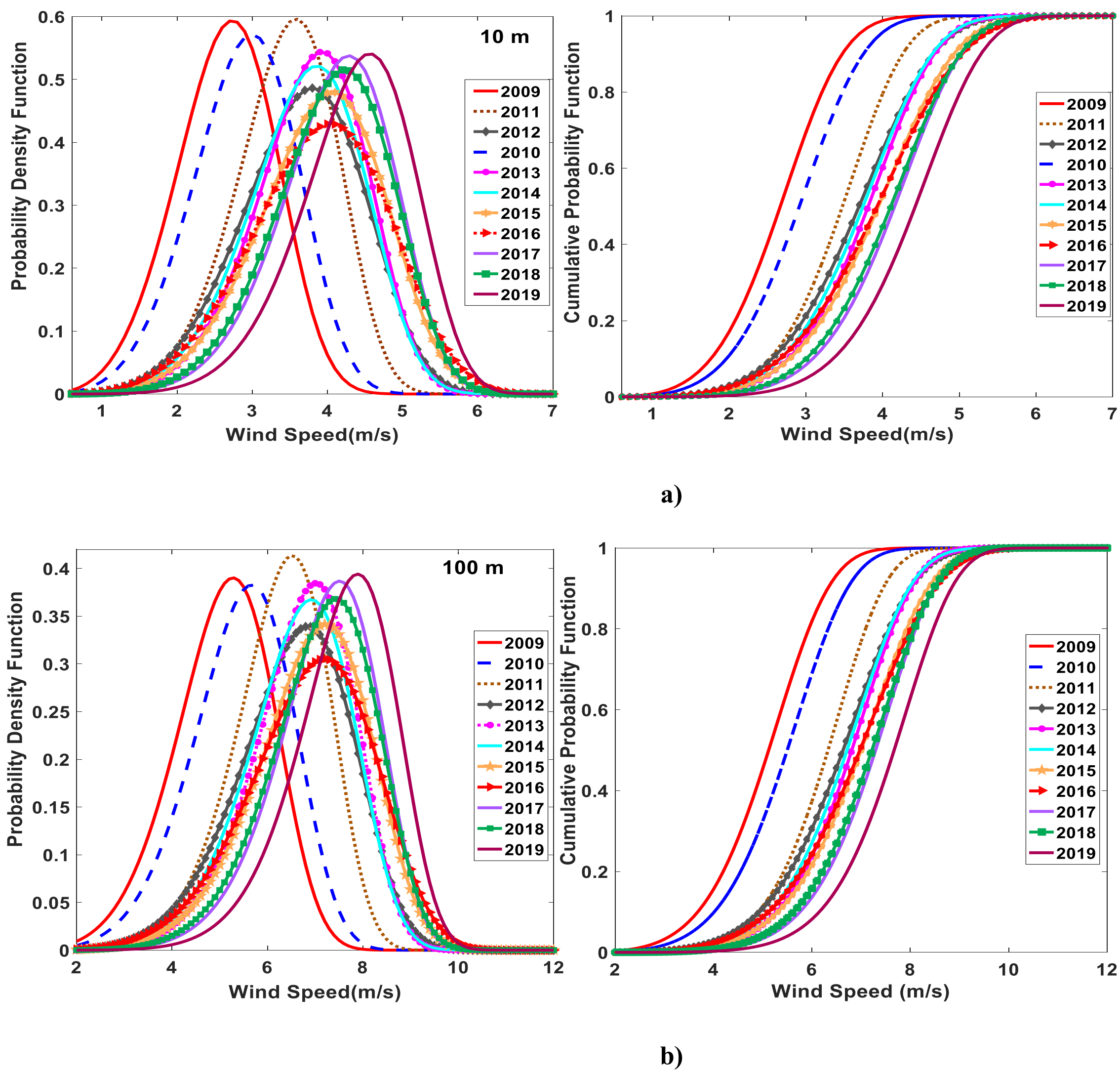

Fig .6. Annual Weibull Wind Distributions over 10(a) and 100m from ground level (b).

3.5 Weibull Parameters and Energy Potential

Table 1presents the annual values for 10m, 50m and 100m, from 2009 to 2019, average speeds, scale and form shape factors, probable speeds, maximum energy extraction speeds and power densities. There are increasing proportional corrections linked to variations in average speeds between 2.64m/s in 2009 and 8.21m/s in 2019.

3.6 Weibull Parameters and Energy Potential

The Figure 7 below represents the monthly average distributions of wind speed and power density of the littoral region between 2009 and 2019, respectively on heights of 10 m (a) and 100m (b) from the ground. Note in these figures that the distribution of the monthly average power density follows the same variation as the monthly average wind speed. At 10m we have a fairly low wind energy potential varying between24 W/m^2 from October to September and 48W/m2. In contrast, the height of 100m presents average energy potential varying between 135 W/m2 and 250W/m^2.

3.7 Choice of wind turbines

To determine which wind turbines are best suited to the Cameroon coast, we assess the performance of 25 selected turbines in the Table 2 below from different manufacturers [7,8,13,14, 21, 22, 23,25].The choice takes into account on the one hand the interval of starting speeds (1.5-4.5m/s), the interval of nominal speeds (10-17m/s) and on the other hand, the almost complete coverage of the range of powers, in other words from small domestic wind turbines to large wind turbines. The nominal powers ranges from 1kW (AEOLOS-1) to 2500 kW (Nordex N80 / 2500).

Table 1. Characteristics of Wind turbines

Height (m)	Wind Parameters	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Synthesis
10	***Vm*** (m/s)	2.64	2.88	3.43	3.35	3.76	3.69	3.89	3.88	4.10	4.10	4.36	**3.67**
	σ	0.66	0.70	0.67	0.84	0.75	0.77	0.86	0.87	0.79	0.79	0.79	**0.77**
	k	4.54	4.78	5.90	5.14	5.91	5.57	5.40	4.83	6.35	6.35	6.80	**4.6**
	C	2.89	3.15	3.70	3.97	4.06	4.00	4.22	4.23	4.40	4.40	4.67	**4.02**
	Vf (m/s)	2.73	2.99	3.58	3.80	3.93	3.36	4.06	4.03	4.28	4.28	4.56	**3.81**
	Ve (m/s)	3.13	3.38	3.88	4.23	4.26	4.22	4.47	4.54	4.59	4.59	4.85	**4.35**
	WPD(W/m^2)	13.3	17.2	27.5	34.2	36.3	34.8	40.9	41.5	46.2	46.2	55.3	**35.9**
50	***Vm*** (m/s)	4.15	4.57	5.44	5.79	5.97	5.86	6.19	6.17	6.51	6.43	6.92	**5.52**
	σ	0.91	1.08	1.09	1.34	1.19	1.20	1.41	1.39	1.29	1.30	1.29	**1.23**
	K	5.29	4.87	5.57	5.11	5.44	5.64	5.16	4.83	6.13	5.72	6.52	**5.36**
	C	4.50	4.99	5.89	6.30	6.88	6.34	6.73	6.74	7.00	6.95	7.43	**5.99**
	Vf (m/s)	4.32	4.75	5.68	6.03	6.62	6.12	6.45	6.42	6.79	6.72	7.24	**5.76**
	Ve (m/s)	4.78	5.35	6.22	6.72	7.28	6.69	7.17	7.24	7.32	7.32	7.74	**6.35**
	WPD(W/m^2)	49.7	69.1	111.1	136.	177.3	138.6	166.5	168	186.1	182.4	222.5	**117.1**
100	***Vm*** (m/s)	5.05	5.42	6.24	6.54	6.71	6.62	6.90	6.88	7.19	7.11	7.57	**6.58**
	σ	1.03	1.33	1.36	1.66	1.48	1.47	1.77	1.73	1.61	1.63	1.61	**1.32**
	K	5.69	5.99	7.40	6.39	7.41	6.99	6.78	6.07	7.97	7.52	8.52	**5.77**
	C	5.46	5.84	6.65	7.02	7.16	7.08	7.39	7.41	7.64	7.58	8.01	**7.11**
	Vf (m/s)	5.27	5.66	6.52	6.83	7.02	6.92	7.21	7.19	7.29	7.43	7.89	**6.88**
	Ve (m/s)	5.75	6.12	6.86	7.32	7.39	7.33	7.67	7.76	7.85	7.82	8.21	**7.49**
	WPD(W/m^2)	88.5	108.1	159.8	187.7	199.4	192.6	219.0	220.8	242.8	236.7	280	**195.3**

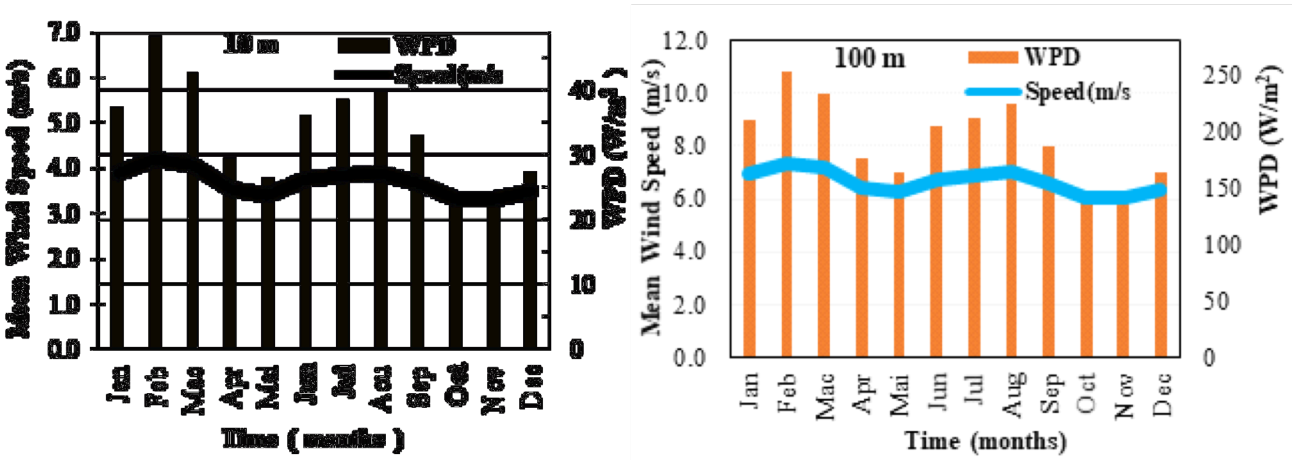

Fig. 7. Energy potential and average monthly speed at 10 m (a) and 100 m (b) from ground level.

Table 2. Characteristics of Wind turbines

Turbine Index	**Wind Turbine Model**	**Rated power PeR** (kW)	**Cut-in speed Vc** (m/s)	**Rated speed Vr** (m/s)	**Cut-out speed V*f*** (m/s)	**Rotor Diameter** (m)	**Hub height** (m)
A	AEOLOS-1	1	1.5	10	50	1.75	10
B	Tulipower 2.5Kw	2.5	3	10	18	5	12.5
C	AEOLOS V-5	5	2.5	10	52.5	5	12
D	AIRCON-10	10	3	11	32	7.1	18
E	Proven WT 15000	15	2.5	12	25	9	20
F	POLARIS P-10-20	20	2.7	11	25	10	30.5
G	POLARIS P-12-25	25	2.7	10	25	12	30.5
H	POLARI P-15-50	50	2.7	12	25	15	30.5
I	POLARI P-21-60	60	2.7	10	25	21	30.5
J	POLARI P-21-100	100	2.7	12	25	21	30.5
K	POLARI P-25-100	100	2.7	10	25	25	30.5
L	VESTAS V20	120	4.5	13	20	20	24
M	VESTAS V27	225	3.5	14	20	27	30
N	GEV MP C 275	275	3.5	12	25	32	60
O	AN Bonus 300 kW/33	300	3	14	25	33	30
P	Enercon E33-330	330	2.5	13	25	33	50
Q	AE-46	600	3	15	25	46	45
R	SUZLON S52	600	4	13	20	52	75
S	AE-52	800	3	12	25	52	50
T	Enercon E-53-800	800	2	13	28	53	60
U	Enercon E-44-900	900	3	17	28	44	45
V	AN Bonus 300 kW/54	1000	3	15	25	54.2	50
W	AE-61	1200	3	17	25	61	60
X	YDF-1500-87	1500	3	10.5	25	87	75
Y	Enercon E-82-2000	2000	2.5	12.5	25	82	130

3.8 Selection of wind turbines in relation to the coastal wind potential.

The performance results of the selected wind turbines in the conditions of the coastal winds are presented in table 3. They represent a preliminary aid to choose wisely the best adapted wind system.

Table 3 presents the results of the simulations of the wind turbines selected in the Cameroonian wind distribution conditions, from 2009 to 2019.

They take into account the installation heights of the manufacturers (Table 2).

We observe a low production; enough to be profitable. The usage factor varies between 0.52% for the AEOLOS-1 turbine and 7.5% for the YDF-1500-87 turbine, which suggests that the installation heights of the manufacturers does not necessarily offer the best possible wind energy extraction in theseconditions. In addition, an adjustment of the installation heights to 100m and the simultaneous comparison of the capacity factor, the couple of speeds (start-up, nominal), the maximum energy production, makes it possible to reach the range of wind turbines of the table 4.

Table 3. Performances of the Wind turbines

Turbine Index	**Vc** (m/s)	**Vr** (m/s)	**V*f*** (m/s)	**C** (m/s)	**K**	**P*eR*** (kW)	Peave (kW)	**C*f*** (%)	**AEP** (kWh)
A	1.5	10	50	4.02	4.60	1	0.01	0.52	45.868
B	3	10	18	4.25	4.69	2.5	0.04	1.49	325.576
C	2.5	10	52.5	4.45	4.77	5	0.07	1.50	656.315
D	3	11	32	4.65	4.85	10	0.14	1.36	1194.825
E	2.5	12	25	4.77	4.90	15	0.16	1.05	1376.212
F	2.7	11	25	5.30	5.10	20	0.47	2.33	4088.983
G	2.7	10	25	5.30	5.10	25	0.95	3.80	8316.596
H	2.7	12	25	5.30	5.10	50	0.75	1.50	6555.641
I	2.7	10	25	5.30	5.10	60	2.28	3.80	19959.831
J	2.7	12	25	5.30	5.10	100	1.50	1.50	13111.282
K	2.7	10	25	5.30	5.10	100	3.80	3.80	33266.386
L	4.5	13	20	4.99	4.99	120	0.56	0.47	4943.100
M	3.5	14	20	5.32	5.11	225	1.43	0.63	12495.139
N	3.5	12	25	6.27	5.46	275	7.59	2.76	66456.274
O	3	14	25	5.28	5.09	300	1.97	0.66	17258.922
P	2.5	13	25	5.99	5.36	330	5.13	1.55	44942.074
Q	3	15	25	5.84	5.30	600	3.90	0.65	34131.895
R	4	13	20	6.62	5.59	600	13.00	2.17	113896.021
T	2	13	28	6.27	5.46	800	14.81	1.85	129736.264
S	3	12	25	5.99	5.36	800	18.82	2.35	164867.417
U	3	17	28	5.84	5.30	900	3.01	0.33	26357.474
V	3	15	25	5.99	5.36	1000	7.11	0.71	62275.091
W	3	17	25	6.27	5.46	1200	5.05	0.42	44232.933
X	3	10.5	25	6.62	5.59	1500	112.54	7.50	985830.531
Y	2.5	12.5	25	7.59	5.94	2000	102.77	5.14	900258.402

Table 4. Favorable ranges of Wind turbines

Turbine Index	Vc (m/s)	Vr (m/s)	V_f (m/s)	C (m/s)	k	Pe*R* (kW)	Peave (kW)	*Cf*	AEP (MWh)
A	1.5	10	50	7.11	5.77	1	0.14	13.96	1.223
B	3	10	18	7.11	5.77	2.5	0.35	13.88	3.040
C	2.5	10	52.5	7.11	5.77	5	0.70	13.93	6.103
D	3	11	32	7.11	5.77	10	0.80	8.01	7.018
E	2.5	12	25	7.11	5.77	15	0.73	4.87	6.398
F	2.7	11	25	7.11	5.77	20	1.61	8.03	14.076
G	2.7	10	25	7.11	5.77	25	3.48	13.92	30.478
H	2.7	12	25	7.11	5.77	50	2.43	4.86	21.298
I	2.7	10	25	7.11	5.77	60	8.35	13.92	73.148
K	2.7	10	25	7.11	5.77	100	13.92	13.92	121.914
X	3	10.5	25	7.11	5.77	1500	157.18	10.48	1376.937

Table 4 presents the wind turbines offering favorable performances, compared to the coastal wind conditions. We can observe in this table 4 that low power wind turbines up to 100 kW, with starting speeds between (1.5-3 m/s) and nominal speeds between (10-12 m/s) are more favorable and appropriate for production with capacity factors between 4.86% and 13.96%. In addition, large wind turbines, for example the YDF-1500-87 (X), which operates at low speeds.

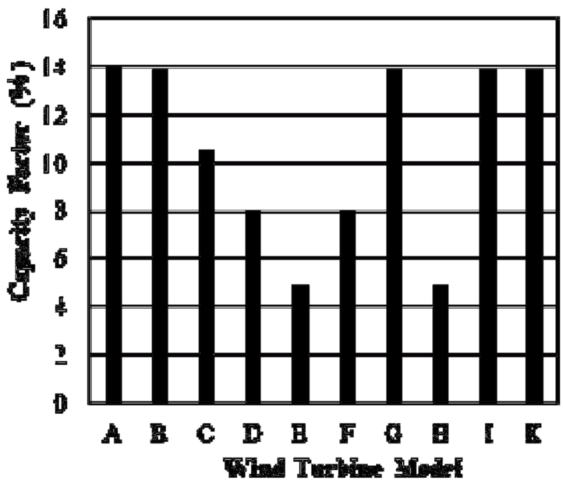

Fig.8.a. Capacity factor

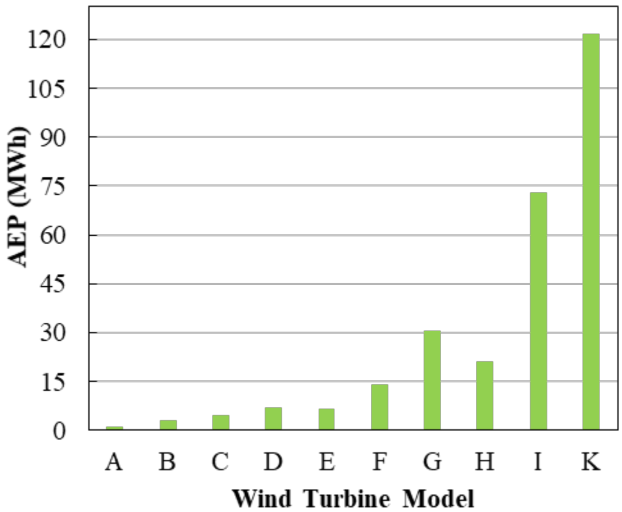

Fig .8.b. Annual Energy produced

Figure 8a and Figure 8b shows the performance of the wind turbines, chosen in relation to their utilization factor (a) and the annual energy produced (b). We observe that the turbines A, B, C, D, E, F (1- 60kW), present an annual production lower than 15MWh, with a capacity factor understood from 13.96% to 4.8. By contrast, the K turbine (100kW) is the most productive, with a utilization factor of 13.92%.

4. Conclusion

The work carried out in this article aimed to present the different possibilities for using wind energy by making a judicious choice of devices with regard to wind data in the Littoral region of Cameroon. This study makes it possible to avoid bad installation of wind turbines which can have harmful consequences on energy production. This is why, an emphasis was placed on the evaluation of wind energy potential, with a choice approach on the range of wind turbines adapted to the Cameroon coast. This approach is based on the exploitation of metrological data of wind speeds from 2009 to 2019 in the Littoral region of Cameroon. The probability of wind is modeled using the Weibull distribution, which makes it possible to assess the average available power density varying between 35.9 W/m^2 at 10m and 195.3 W/m^2 at 100m from the ground. In accordance with this energy potential, the choice of the appropriate range of wind turbines is made on the basis of a sample of 25 wind turbines, meeting the criteria, of nominal power, starting speeds and nominal speeds, the utilization factor and annual energy produced. The range of wind turbines used is that of small wind turbines, with powers varying from 1 to 100kW, with low starting speeds (1.5 – 3 m/s) and nominal speeds (10 –12m/s). It emerges from the study carried out that in the Cameroon littoral zone apart from a few specific sites where large wind turbines would be of interest, this zone has advantages only for low power wind turbines, thus several businesses where habitats could be found to offer wind energy especially for tall buildings such as can be found in the city of Douala. Consequently, the results of this research can serve at least a dual purpose: they can be directly exploited on one hand by policy makers in Cameroon in view of giving orientation for the exploitation of wind energy, and on the other hand by wind turbine manufacturers for the purchase and realization of wind turbine generator stocks that can operate in the range of the velocity containing maximum energy in the wind regimes (Vmax) characteristic of the Littoral region of Cameroon.

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