

## Wind Energy Potential Assessment and Wind Turbine Performance Investigation in the Cotonou Coast (Benin Republic)

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**Abstract.** This paper presents a study of the monthly variability of wind energy potential at several heights and an investigation of the best fitting commercial wind turbine in the Cotonou coast (Benin Republic). The monthly Weibull parameters are calculated at 10 m and extrapolated at 30 and 50 m heights. The monthly Weibull wind power density and the wind speed carrying maximum energy are calculated at 10, 30 and 50 m. We showed that wind resource in the Cotonou coast is favorable for wind energy production at 30 and 50 m heights. The capacity factor of selected commercial wind turbines is calculated to investigate the best fitting wind turbine in the Cotonou coast. It turns out that Polaris 19-50 is the best fitting wind turbine in the selected turbines with a mean capacity factor of 0.49.

### Introduction

Wind power potential assessment is a vital point before any later wind energy exploitation. In this context, several researches have been conducted for different countries in the world [1–7]. The wind speed distribution is generally modeled using statistical laws such as the Weibull law and the Rayleigh law [1, 2, 8, 9]. The wind power density is then calculated from the selected distribution parameters [10–12]. Moreover, the wind resource is generally classified using classification schemes for wind energy potential assessment like the Pacific Northwest Laboratory (PNL) scheme [1, 2, 13, 14]. This latter consists of 7 different classes of wind potential in term of power density and wind speed for 10, 30 and 50 m heights [14]. After wind resource evaluation, the most suited turbines among a list of turbines is selected based on performance metrics [1, 2, 13].

From the previous researches, it was demonstrated that the coastal region of Benin Republic is favorable to wind energy production and particularly small wind turbines applications [15, 16]. These studies were conducted for wind resources at 10 m height. But, for the moment, there is no study carried on the variability of the wind energy potential at different heights. This paper proposes the study of the variability of wind energy potential in the Cotonou coast at several heights, and a study on the performance of selected wind turbines.

After this introduction, the methodology adopted is presented. Then, the results obtained from the wind potential assessment and the selected turbines performance in the Cotonou city coast are presented.

### Methodology

#### Wind Speed Data Description

Benin Republic is a West African country bounded by Togo, Burkina Faso, Niger, Nigeria and the Bight of Benin (see Fig. 1). The country is one of the smallest of West Africa with a coastline of 121 km. In this paper, the wind speed data for Cotonou city coast is satellite data collected from [17].



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

where  $k$  is the dimensionless Weibull shape parameter,  $c$  is the Weibull scale parameter ( $m/s$ ),  $v$  is the wind speed and  $f(v)$  is the probability of observing the wind speed  $v$ . The Weibull parameters  $c$  and  $k$  are generally calculated by using:

- the Weibull probability plotting paper method [21];
- the moment method [22, 23];
- the maximum likelihood method [22, 23];
- the energy pattern factor method [22, 23].

In this paper, the maximum likelihood method is used since it is the most recommended method for estimating the parameters of Weibull distribution for wind energy analysis [22]. Its application leads to (2), which is solved by using iterative techniques [22–24].

$$\begin{cases} \sum_{i=1}^N \frac{1}{k} + \left[1 - \left(\frac{v_i}{c}\right)^k\right] \cdot \ln\left(\frac{v_i}{c}\right) = 0 \\ \sum_{i=1}^N \left(\frac{k}{c}\right) \cdot \left[-1 + \left(\frac{v_i}{c}\right)^k\right] = 0 \end{cases} \quad (2)$$

where  $v_i$  represents the value of the wind speed at time  $i$  and  $N$  the total number of wind speed data.

### Wind Speed Distribution Parameters

Wind speed characteristics for a given site are the mean speed, the most probable wind speed and the speed carrying maximum energy [25]. The wind speed carrying maximum energy is calculated by [1, 2, 26]:

$$v_e = c \cdot \left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (3)$$

According to the literature, it is recommended that wind speed carrying maximum energy be as close as possible to the rated speed of the wind turbine [26, 27].

The wind power density can be calculated using Weibull probability density function. This is given by [25, 26, 28]:

$$P(v) = \frac{1}{2} \cdot \rho \cdot c^3 \cdot \Gamma\left(\frac{k+3}{k}\right) \quad (4)$$

where  $\rho$  is the air density at the site in  $kg/m^3$  and  $\Gamma$  is the gamma function which is defined as  $\Gamma(x) = \int_0^{\infty} t^{(x-1)} \cdot e^{-t} \cdot dt$ .

### Wind Turbine Performance Evaluation

For an efficient performance of wind turbines, several parameters must be considered during the selection. The literature recommend a matching between the wind characteristic and the rated power ( $P_R$ ), the rated wind speed ( $v_R$ ), the cut-in wind speed ( $v_c$ ) and the cut-out wind speed ( $v_f$ ) of the selected wind turbine [1, 28]. The mean power output from the wind turbine is calculated by [1, 25, 28]:

$$P_{out} = P_R \cdot \left\{ A - \exp\left[-\left(\frac{v_f}{c(h)}\right)^{k(h)}\right] \right\} \quad (5)$$

$$A = \frac{\exp \left[ -\left(\frac{v_c}{c(h)}\right)^{k(h)} \right] - \exp \left[ -\left(\frac{v_R}{c(h)}\right)^{k(h)} \right]}{\left(\frac{v_R}{c(h)}\right)^{k(h)} - \left(\frac{v_c}{c(h)}\right)^{k(h)}} \quad (6)$$

where  $c(h)$  and  $k(h)$  respectively represent the extrapolated Weibull scale parameter and shape parameter at the height  $h$ . Dividing (5) by the rated power ( $P_R$ ) leads to the capacity factor or conversion efficiency factor  $c_f$  defined as:

$$c_f = \frac{P_{out}}{P_R} \quad (7)$$

Thus,

$$c_f = A - \exp \left[ -\left(\frac{v_f}{c(h)}\right)^{k(h)} \right] \quad (8)$$

The extrapolated Weibull parameters at height  $h$  are calculated by using the following expressions [1]:

$$c(h) = c_0 \cdot \left(\frac{h}{h_0}\right)^n \quad (9)$$

$$k(h) = k_0 \cdot \frac{1 - 0.088 \cdot \ln \left(\frac{h_0}{10}\right)}{1 - 0.088 \cdot \ln \left(\frac{h}{10}\right)} \quad (10)$$

where  $c_0$  and  $k_0$  are respectively the Weibull scale parameter and shape parameter at the measurement height  $h$ ,  $h_0$  the reference height and  $n$  an exponent defined as [1]:

$$n = \frac{0.37 - 0.088 \cdot \ln \left(\frac{h_0}{10}\right)}{1 - 0.0088 \cdot \ln \left(\frac{h}{10}\right)} \quad (11)$$

For effective selection of a wind turbine, capacity factor greater than 0.25 is recommended [1, 25]. Capacity factors greater than 0.40 indicate strong interactions between the wind turbine system and environment [25, 29].

## Results and Discussion

### Wind Speed Parameters

The hourly wind speed data collected are used to calculate the monthly Weibull shape factor and scale factor at 10, 30 and 50  $m$  heights. Weibull parameters at 10  $m$  are calculated using (2) whereas (9) and (10) are used at 30 and 50  $m$ .

Fig. 2 presents monthly variations of the Weibull shape factor at 10, 30 and 50  $m$  heights. It can be noticed that the monthly variations of the shape parameter are increasing with the height. It can also be noticed that the highest values occurs in August whereas the lowest happens in May whatever the heights.

Fig. 3 presents the monthly variations of the Weibull scale factor at 10, 30 and 50  $m$  heights for the Cotonou coast. It can be noticed that the highest variations of Weibull scale factor occurs during the month of August whereas the lowest occurs in December.

The monthly variations of the wind speed carrying the maximum energy for the Cotonou coast are presented in Fig. 4. From the analysis of Fig. 4, it turns out that higher wind speeds occurs at higher elevations. It can also be noted that August is the month presenting the highest wind of maximum energy whereas December presents the lowest ones.

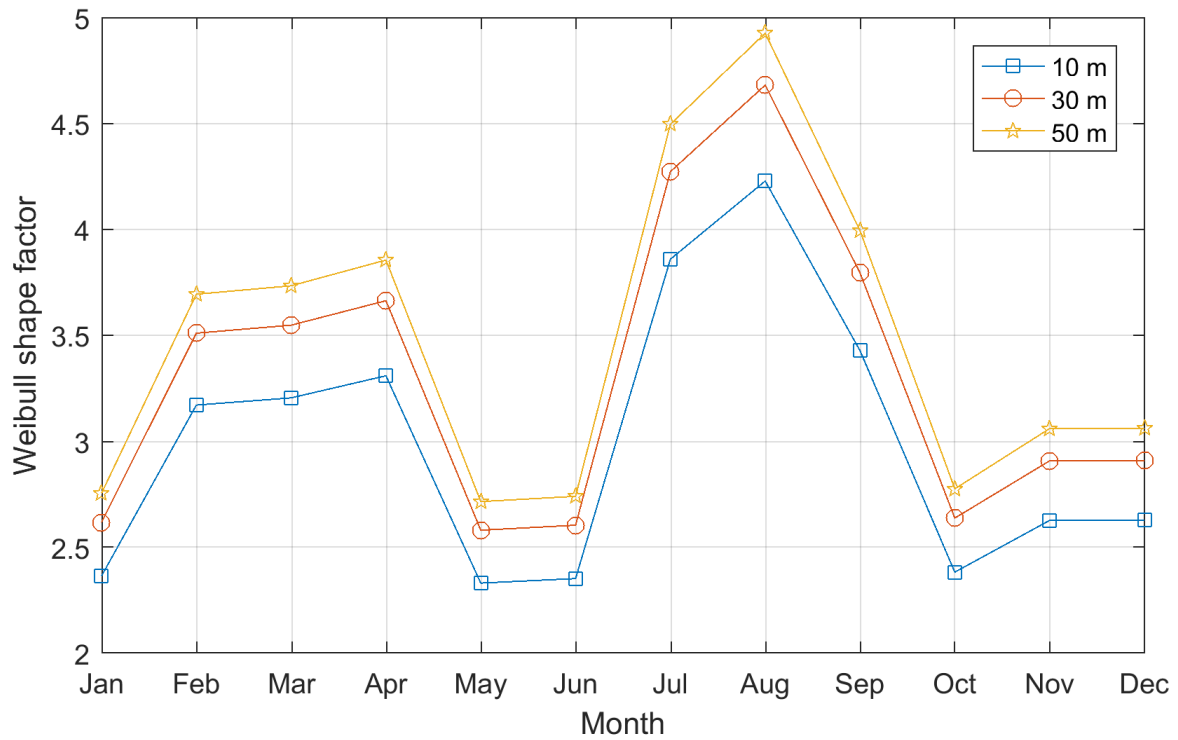


Fig. 2: Monthly Weibull shape factor.

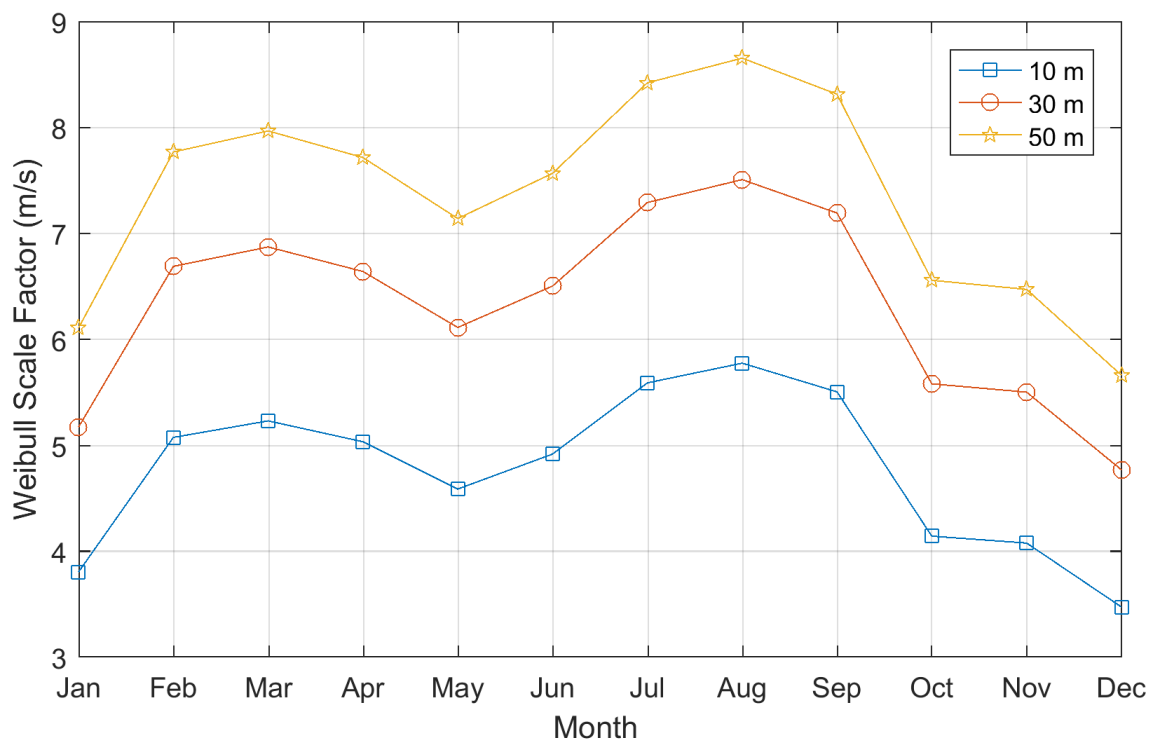


Fig. 3: Monthly Weibull scale factor.

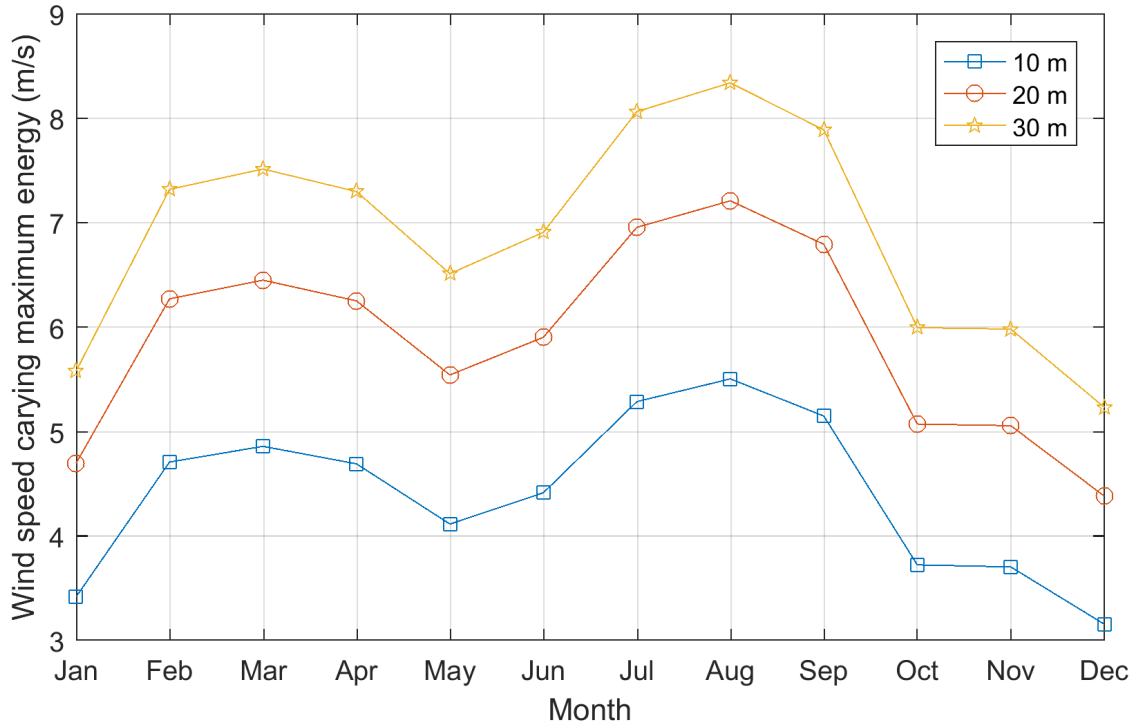


Fig. 4: Monthly variations of the wind speed carrying maximum energy.

The wind power density calculated from (4) is presented at Fig. 5 and Table 2 for the three different heights. It can be noticed that wind power density vary from  $27.47 W/m^2$  in December to  $107.55 W/m^2$  in August at 10 m height. At 30 m, wind power density vary from  $67.40 W/m^2$  in December to  $233.22 W/m^2$  in August. At 50 m, the wind power density vary from  $110.34 W/m^2$  in December to  $355.54 W/m^2$  in August.

Considering PNL classification scheme [27], wind power potential at 10 m height is class 1 ( $P_D \leq 100$ ) excepted in august which is class 2 ( $100 < P_D \leq 150$ ). At 30 m, wind power density is class 1 ( $P_D \leq 160$ ) excepted from February to April and from June to September which falls into class 2 ( $160 < P_D \leq 240$ ). At 50 m height, wind speed power density is class 1 ( $P_D \leq 200$ ) from October to January, class 2 ( $200 < P_D \leq 300$ ) from February to June and class 3 ( $300 < P_D \leq 400$ ) from July to September.

Table 2: Wind speed density probability  $P_D$  at different heights.

Month	$P_D$ at 10 m	$P_D$ at 30 m	$P_D$ at 50 m
Jan	38.66	90.79	145.37
Feb	78.41	173.78	268.67
Mar	85.53	187.92	289.12
Apr	75.41	168.17	260.78
May	68.53	151.21	234.13
Jun	83.83	181.16	277.29
Jul	99.12	216.10	330.60
Aug	107.55	233.22	355.54
Sep	97.52	211.94	323.97
Oct	49.65	113.59	179.28
Nov	44.43	103.54	164.84
Dec	27.47	67.40	110.34

According to PNL classification scheme, wind resources of class 1 are less prone for wind energy production whereas in class 2, small size wind turbines can be installed [14]. Wind resources of class 3 are suitable for wind energy production using taller wind turbines [14]. Considering PNL standard, it can be concluded that Cotonou coast does not fit for wind energy production around 10 m height. However, the potential is favourable for the development of small size wind turbines around 30 m height. At 50 m height, it can be concluded that wind resource is favourable for wind energy production.

The result obtained evaluating the wind energy potential at 10 m height in this research is similar to a research conducted for Ghana coastal region in [1]. Indeed, this study concluded that the wind resource along the coastal region of Ghana can be classified into Class 2 or less wind resource category by considering the PNL classification scheme. This similarity can be explained by the fact that Ghana coast and Benin Republic Coast both belong to the Bight of Benin. It is also important to report that Ghana initiated since 2012, the construction of a 225 MW wind power farm in Ayitepa on the east coast of Ghana [30].

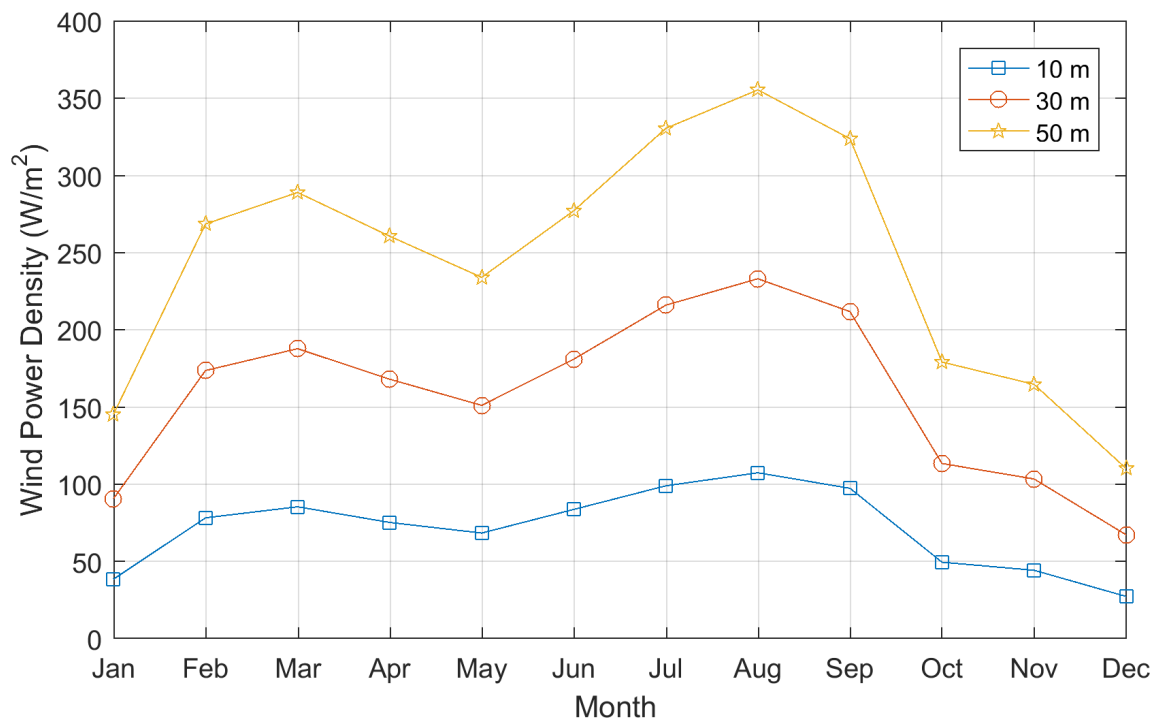


Fig. 5: Monthly variations of the wind power density.

### Wind Turbines Performance

In this section the performance of 8 selected turbines with power range from 1 kW to 3,600 kW is evaluated. These turbines were selected considering their low cut-in speed and their rated power. The selected wind turbines and their characteristics properties are presented in Table 3. The monthly capacity factors of these turbines have been calculated using (8) and are presented in Fig. 6. Wind turbines with capacity factor greater than 0.25 are recommended for wind energy production. From Fig. 6 it can be noticed that CF-100, Polaris 12-25 and Polaris 19-50 are respecting this criterion. Therefore, Polaris 19-50 shows strong interaction with the wind regime at its hub height with a capacity factor of 0.49 which is greater than 0.4. It can be concluded that Polaris 19-50 is the best fitted turbine for wind energy production in the Cotonou coast among the selected turbines.

Table 3: List of selected wind turbines.

Turbine	Height [m]	Rated Power [kW]	Rated speed [m/s]	Cut-in speed [m/s]
WHISPER 200	33	1	11.6	3.1
Garbi150/28	30.3	150	10.4	2.5
SWT-3.6-107	80	3,600	13	3
Polaris 15-50	20	50	10	2.7
Polaris 12-25	59	25	10	2.7
Polaris 19-50	59	50	9	2.7
Fuhrländer FL600	50	600	13	3
CF-100	34.4	100	9.5	2.2

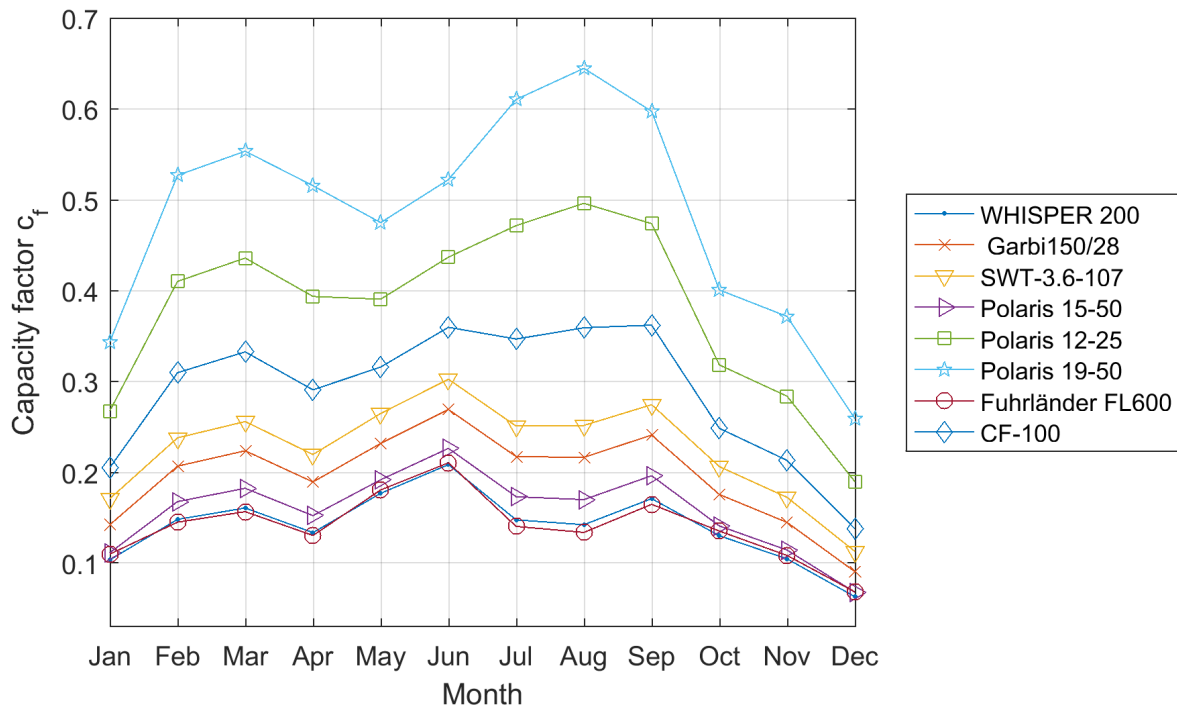


Fig. 6: Monthly capacity factor of the selected wind turbines.

**Conclusion**

The monthly variability of wind energy potential at different heights was evaluated and the performance of selected commercial wind turbines was studied in this paper. It was found that the wind resource around 50 m height is greatly favorable for wind energy production. The study of the monthly capacity factor of the selected commercial wind turbines revealed that Polaris 19-50 was the best fitted to wind energy production in the Cotonou coast. This study contributes to a clear classification of the wind resource in the Cotonou coast at several heights for wind energy production and an identification of commercial wind turbines fitting with the Cotonou coast. The results of this study can be used as decision tool for politics and NGOs for valorization of wind energy in Benin Republic.

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