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# FEASIBILITY STUDY OF BRASÍLIA WIND POTENTIAL BASED ON EXPERIMENTAL DATA FROM 2001 TO 2017

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***Abstract.*** *This paper presents a study of the energy availability of Brasilia based on the statistics from the years 2001 to 2017. The data referring to a meteorological station of INMET (Instituto Nacional de Meteorologia) and the results were presented in the form of wind roses and Weibull distribution (punctual and accumulated) with an inference performed by MLM (Maximum Likelihood Method) and quantile-quantile plot. The results showed a massive presence of winds originating from the eastern region, with an error of less than 2 % for the adjustment of the statistical distribution. As a main result, Brasília presented a wind potential of 13.50 W/m*$^2$*, accumulating practically all this energy with winds of up to 7 m/s.*

***Keywords:*** *Renewable Energy, Wind Energy, Statistical Methods, Wind Potential*

## 1. INTRODUCTION

One of the most viewed and analyzed solutions on the dilemma regarding the energy consumption and the environmental problems are the renewable energies. This alternative aims to distribute energy to society through the use of naturally available energy (Harjanne and Korhonen, 2019).

The transition of the energy matrix in order to limit the increase of the average temperature of the global surface to less than 2 degrees Celcius has become a critical point, culminating in some attitudes, like Paris Agreement (Nations, 2015). Despite positive results, such as 2017, where a quarter of the world energy produced was from renewable sources, the growth was not fast enough; $CO_2$ emissions increased by 1.4 % from 2014 to 2016 (Gielen *et al.*, 2019).

In this scenario, several studies show that a successful implementation of renewable energies depends on diversification to mitigate risks associated with a lack of energy (Harjanne and Korhonen, 2019; Hansen *et al.*, 2019). Specifically, wind energy technology has been gaining an important prominence in the contribution to the insertion of these changes as its cost has been decreasing substantially and more governments recognize its importance in the greenhouse gas reduction targets (Wang *et al.*, 2019).

Due to the relevance of the theme, several countries and cities are studying the feasibility of maintaining small and large-scale systems, such as Central California Coast (Wang *et al.*, 2019), Poland (Gnatowska and Moryń-Kucharczyk, 2019), Texas (Chang and Starcher, 2019), Kuwait (Al-Nassar *et al.*, 2019; Alkhalidi *et al.*, 2019), Spain (Rosales-Asensio *et al.*, 2019) and Kenya (Kazimierczuk, 2019).

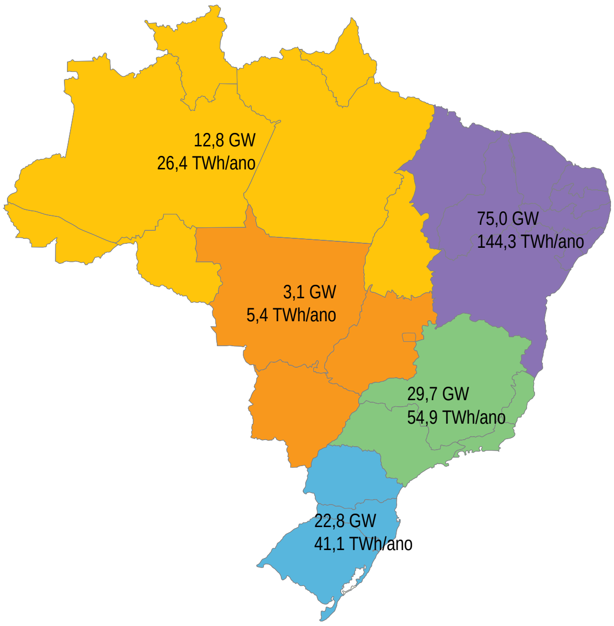


Figure 1. Brazil wind potential (Aneel, 2008)

Brazil has enormous potential for renewable energy available throughout its territory, facilitating diversification and energetic mitigation. It is estimated that by 2026, the energy capacity from photovoltaic and wind power sources in Brazil could reaches approximately 10,000 MW and 28,000 MW, respectively (de Jong *et al.*, 2019). In addition, Brazil has one of the most intense energy policies in the fight against greenhouse gases (Pischke *et al.*, 2019).

Acoording to Aneel (2008), Figure 1 shows a wind power distribution in Brazil, with its respective values delimited by geographic regions: South with 22.8 GW and 41.1 TWh/year; Southwest with 29.7 GW and 54.9 TWh/year; Northeast with 75.0 GW and 144.3 TWh/year; Midwest with 3.1 GW and 5.4 TWh/year; North with 12.8 GW and 26.4 TWh/year. The coastal regions present the greatest potential, while the others have smaller but non-negligible values. The present article will make an analysis in the Midwest region.

One of the ways promoted and adopted in Brazil as an incentive for sustainable development in the social, environmental and economic spheres is called the Agenda 2030. There are 17 objectives divided into sub-objectives, in which the following are highlighted for this present article: universal, reliable, modern and affordable access to energy services; a substantial increase the share of renewable energy in the global energy matrix; to double the overall rate of energy efficiency improvement (Government, 2015).

## 2. METHODOLOGY

The methodology of this paper, as well as its description, are included in the current session. Several methods are available for the prediction of potential wind power models, however, the present study was based only on standards with the support of the experimental data. For the numerical analysis, R and RStudio were used. Both consist a programming language and interface for running big data packages and writing programs.

### 2.1 WIND DATA

The wind velocity and directions informations were received from the automatic weather station (AWS) from the National Institute of Meteorology (INMET - Instituto Nacional de Meteorologia), without statistic treatment. The characteristics of AWS used to measure is shown in table 1.

Table 1. Automatic weather station data

| **Station** | Brasília-A002 |
|---|---|
| **OMN code** | 86715 |
| **Start** | 7th May 2000 |
| **Latitude** | -15.789343° |
| **Longitude** | -47.925756° |
| **Altitude** | 1161 m |

Vaisala MAWS 301 is the equipment used in INMET's AWS and the transmitter used to measure the wind directions and velocity is WT521. The WT521 takes measurements every 0.25 seconds and uses those to calculate the 3-second moving average for both wind velocity and wind direction. Those short-term averages are sent through the serial port once per second. The AWS receives these 3-second values and uses them as input variables to calculate the 10-minute averages and burst rates (INMET, 2011; Vaisala, 2000, 2009).

The possible sensors available to Vaisala MAWS 301 are WM30, WA15, WA25, WINDSONIC, WMT52 and WS425. There is no history available from INMET for all sensors used in the period from 2001 to 2017. Table 2 summarizes the accuracy of all possible sensors.

Table 2. Available sensors for MAWS 301

| **Sensors** | **Wind velocity** | **Wind directions** |
|---|---|---|
| WM30 Vaisala (2017a) | Wind speed <10 m/s: ±0.3 m/s<br>Wind speed >10 m/s: ±2 % | >±3 % |
| WA15 Vaisala (2017b) | For 0.4 to 60 m/s<br>With characteristic transfer function<br>(standard deviation): ±0.17 m/s<br>With simple transfer function: ±0.5 m/s | Better than ±3° |
| WA25 Vaisala (2018) | For 0.4 to 60 m/s<br>With characteristic transfer function<br>(standard deviation): ±0.17 m/s<br>With simple transfer function: ±0.5 m/s | Better than ±3° |
| WINDSONIC GILL (2017) | ±2 % @ 12 m/s | ±2 % @ 12 m/s |
| WMT52 Vaisala (2012) | ±3 % | ±3 % |
| WS425 Vaisala (2010) | For 0 to 65 m/s: ±0.135 m/s or 3 % of reading, whichever is greater | ±2 |

In the present study, hourly wind direction and velocity data were analyzed from 2001 to 2017. Eventually, some measurements presented false data, possibly corresponding to maintenance periods or a simple failure in the measurement system, such as zero velocity measurements or null results. These results were excluded from the analysis.

### 2.2 WIND ROSE

As an important part of the present study, the wind rose plays a key role in orienting the wind speed and its direction.

The wind rose is presented in circular form and shows the frequency at which the winds blow from a particular direction. Markers represent the probability that the wind blows at a given speed within a range. In this way, each concentric circle represents different probability, starting from zero, in the center, and growing with distance.

In order to compute the probabilistic variations related to the velocity field and its respective direction, the wind rose was divided into 16 parts, with 0 degree corresponding to the east direction, 90 to the north, 180 the west and 270 the south.

The analysis consists of two parts. The first is the annual study of wind direction and speed and the second, an overall assessment using all the hourly data available in the study range.

### 2.3 WEIBULL DISTRIBUTION

For the statistical calculation of wind power, it is necessary to know the probabilistic distribution in a given region; the greater the amount of data available to analyze this correlation, the better the results will be. Among the several specific statistical models for the analysis of velocity distribution, the one recommended by international standard IEC 61400-12 is the Rayleigh distribution, which is equal to the Weibull distribution with a form factor corresponding to 2 (Wais, 2017; IEC:61400-12, 1998).

The use of the mentioned procedure is part of a methodology that aims to measure the power performance characteristics of a single wind turbine generator system as consistently and as accurately as possible. As a result, it is possible to measure and analyze the power performance of wind turbine.

The two-parameter Weibull distribution is expressed according to probability density function (PDF) in Eq. (1):

$$p(v, \lambda, k) = \left(\frac{k}{\lambda}\right)\left(\frac{v}{\lambda}\right)^{k-1} e^{-\left(\frac{v}{\lambda}\right)^k} \tag{1}$$

$v > 0$, $k > 0$, $\lambda > 0$.

The variable $\lambda$ in the Weibull distribution is called a scale parameter, $k$ is the shape, and $v$ is the wind velocity (m/s). For each combination of these two values, the Weibull distribution assumes varied forms. Two special forms, referred to as exponential distribution and Rayleigh distribution occur when $k = 1$ and when $k = 2$ and $\lambda = \sqrt{2}\sigma$, respectively.

For each given velocity, the available wind power and energy can be estimated by its mechanical energy, as shown in Eq. (2):

$$\phi_i = \frac{1}{2}\rho A_r v_i^3 \tag{2}$$

where $\rho$ is the specific mass in kg/m$^3$, $A_r$ is the rotor cross-sectional area in m$^2$ and $v_i$ denotes the velocity at a point $i$.

If $\phi_i$ represents the annual average of the speeds at a specific point, the cumulative available wind power is given by Eq. (3):

$$\phi_v = \int_0^v \phi_i p(v,\lambda,k)dv = \frac{1}{2}\rho A_r k \frac{1}{\lambda^k}\int_0^v v_i^{k+2} e^{-\left(\frac{v}{\lambda}\right)^k} dv \tag{3}$$

The total energy can be achieved when $v \to \infty$ or expressed in terms of Gamma function without any dependence of velocity profile, as shown in Eq. (4):

$$\phi_{total} = \frac{1}{2}\rho A_r \lambda^3 \Gamma\left(\frac{k+3}{k}\right) \tag{4}$$

Two other statistical parameters will be used for statistical analysis in order to provide alternative resources for analysis. The first is called quantile-quantile plot, or Q-Q plot, and the cumulative distribution function (CDF), given by Eq. (5) for Weibull distribution, where its result represents the probability that $V$ will take a value less than or equal to $v$.

$$P[V \leq v] = 1 - e^{-\left(\frac{v}{\lambda}\right)^k} \tag{5}$$

The velocity distribution inference was performed by the Maximum Likelihood Method (MLM) with the Weibull distribution. This decision is due to the fact that the sample is considerably large and a classical confidence interval (CI) would have the variance approaching zero. Assuming the distribution to be an independent and identically distributed, random sampling and the estimation process is followed by sampling and resampling, calculating the CI for the adjusted curve (Robert and Casella, 2004).

## 3. RESULTS AND DISCUSSIONS

The results in the current section are presented graphically, numerically and as a mathematic model of wind energy potential based on the methodology adopted. Two types of graphs, the wind rose and Weibull distribution, are presented, based on 141,643 data samples of velocities and wind direction, analyzed hourly during the years of 2001 and 2017.

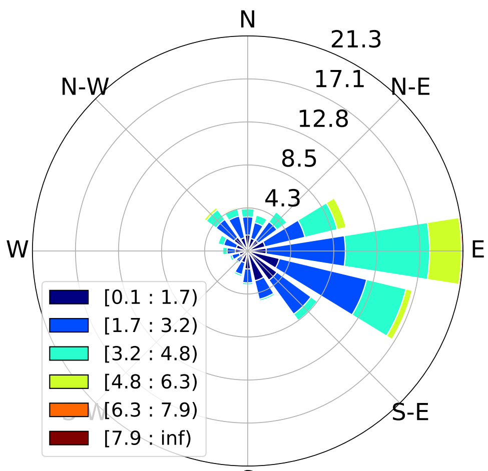


Figure 2. 2001 Wind rose

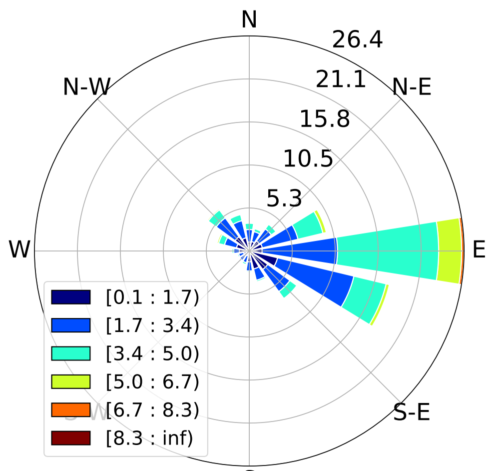


Figure 3. 2007 Wind rose

Figures 2, 3, 4 and 5 are excerpts from the sample space that make up, respectively, the distributions of the wind speed and direction probability from the years 2001, 2007, 2013 and 2017. Overall, the probability peaks are between 17.4 % and 26.4 %, with the majority of the winds originating from the east. In other directions, it is possible to observe a similar behavior, with the lowest probabilities coming from the southwest. The velocity distribution in each interval presents relatively close values, with maximums of up to 9.1 m/s. Additionally, after analyzing the data that was collected hourly, a strong seasonal correlation can be noticed (de Jong *et al.*, 2019).

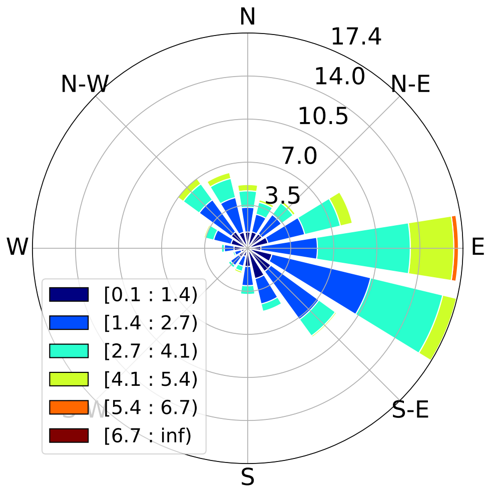


Figure 4. 2013 Wind rose

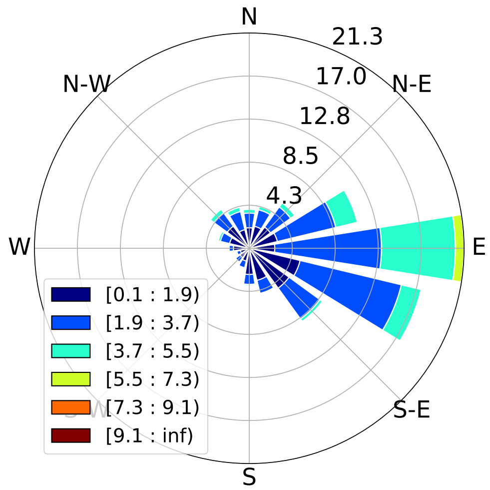


Figure 5. 2017 Wind rose

Figure 6 shows the wind rose produced by the data compiled from years 2001 to 2017. The first point to note is that most of the winds originate in the east, particularly in the 0° position. Looking at easterly direction, approximately 3.5 % of total winds are between 0.1 m/s and 2.1 m/s, 12 % between 2.1 m/s and 4.1 m/s, 4 % between 4.1 m/s and 6.0 m/s and 0.5 % with velocity above these values.

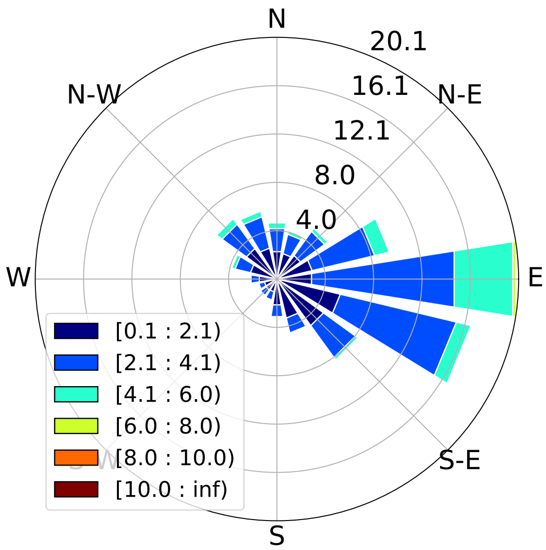


Figure 6. Wind rose using hourly data from 2001 to 2017

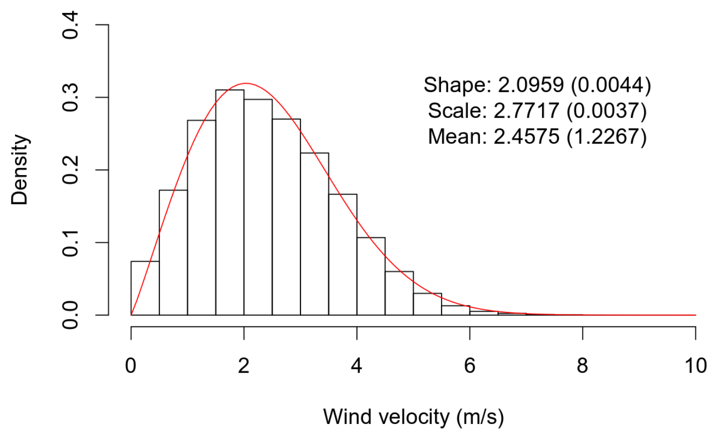


Figure 7. Weibull distribution using hourly data from 2001 to 2017

Between the east and southeast, there is a probability of speeds between 0.1 m/s and 2.1 m/s near 6 %, between 2.1 m/s and 4.1 m/s of 8 % and 2 % for values between 4.1 m/s and 6.0 m/s.

Between the east and northeast, the highest probabilities are between 2.1 m/s and 4.1 m/s and 0.1 m/s and 2.1 m/s, each representing approximate values of 5 % and 3 %, respectively. Values between 4.1 m/s and 6.0 m/s represent 1.5 %.

The southeast winds have only two significant variations, being basically 5 % for speeds between 0.1 m/s and 2.1 m/s and 3 % for speeds between 2.1 m/s and 4.1 m/s.

The least probable winds occur between the south and the west directions. The others contributed with average values close to 4 % each and speeds predominantly between 0.1 m/s and 4.1 m/s.

The Weibull statistical distribution was constructed using all data obtained from 2001 to 2017 and adjusted according to the intervals shown in the Fig. 7. Each bar has an width equivalent to 0.5 m/s, with the parameters $\lambda$ and $k$ corresponding to 2.7717 and 2.0959, respectively. The error obtained in the statistical analysis was 0.0044 for the shape and 0.0037 for the scale. According to the proposed model, the mean velocity according to the theoretical distribution is 2.4575 m/s, with a standard deviation equivalent to 1.2267.

The quantile-quantile plot in Fig. 8 shows the relationship between the theoretical and empirical values. This result fulfills an important function from the point of view of validation of the model since most of the data is adjusted according

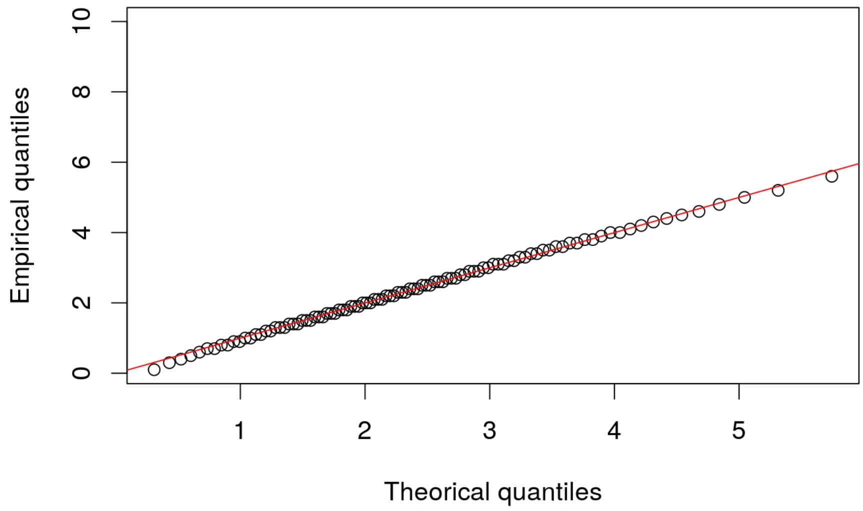


Figure 8. Q-Q plot using hourly data from 2001 to 2017

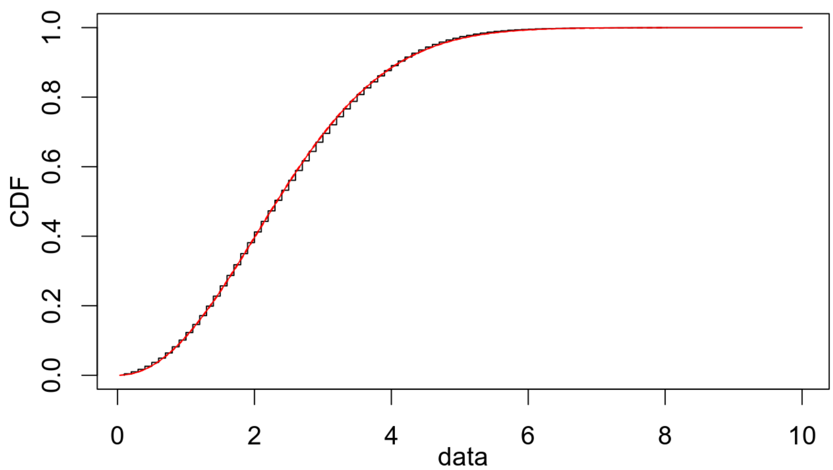


Figure 9. Cumulative distribution function using hourly data from 2001 to 2017

to the line, except for some points at the beginning and at the end, that may be considered outliers in some cases.

Figure 9 represents the cumulative distribution function with a well adjusted confident interval for CDF. The distribution stabilizes in the asymptotic to values close to 6 m/s and it is important to notice that the inferred results follow, disregarding the approximation error, the same path as Fig. 10, which analyzes the accumulated energy potential per unit area. The maximum cumulative power, seen at the top of Fig. 10, or calculated by Eq. (4), is equal to 13.50 W/m$^2$ and becomes constant for approximate values of 7 m/s.

## 4. CONCLUSION

The main objective of this study was to make a conclusion based on wind data collected between 2001 and 2017 by the INMET meteorological station located in Brasília. The device responsible for the measurements is a Vaisala 301, with a WT521 transmitter capable of taking a measurement every 0.25 seconds.

The individual data of each year make it possible to identify a strong seasonal phenomenon, since the available data was acquired on an hourly basis.

An analysis was made using the wind rose, whose results showed a relatively predominance in easterly winds, including all the regions between the southwest and the northeast. The winds originating from this direction amount to almost 45 % when added. The southwest was the region with the lowest incidence rate, with the other directions with probability close to 6 %.

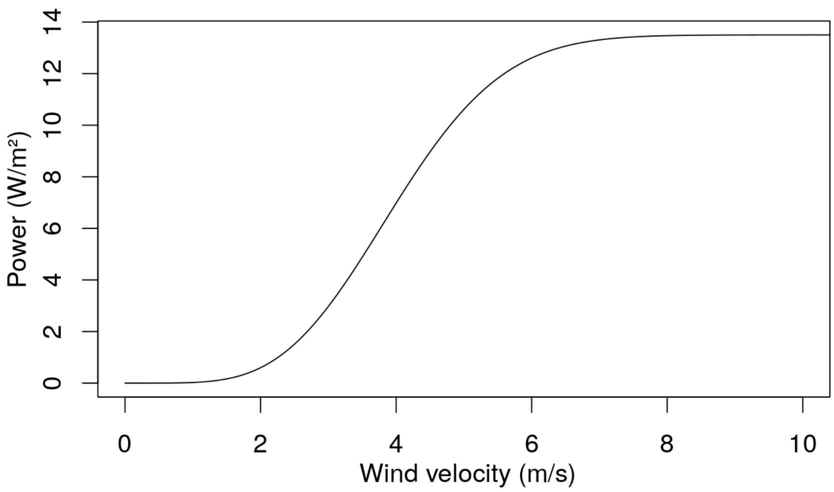


Figure 10. Cumulative power as a function of velocities

Weibull distribution of the wind was also studied, allowing for the construction of a graph and an equation that expresses the behavior of these data, with a shape and scale factor corresponding to 2.0959 and 2.7717, respectively. The Q-Q plot showed a very satisfactory correlation between experimental and theoretical data.

The graphs of accumulated distributions showed that in the range of winds, up to 10 m/s, stabilizes for 6 m/s and 7 m/s for the probability and the power per unit area respectively, being the total wind potential of 13.50 $W/m^2$.

Brasília has sufficient wind potential for low demands, depending on the area of the rotor to be used in the turbine. The study can be complemented by attaching the behavior of the winds as a function of altitude.

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