Evaluation of wind potential in Caraguatatuba, northern coast of Sao Paulo

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Abstract

This study aims to assess the potential for wind power generation in the town of Caraguatatuba – Sao Paulo North Coast - Brazil. The statistical analysis of wind speed will contribute to this evaluation. Data of wind speed from 2004 to 2013, corresponding to the meteorological station Caraguatatuba (code 32521) Sinda/INPE system were used. Weibull distributions for the four seasons were analyzed, and their shape and scale parameters for the wind speed data, from which an extrapolation of the vertical profile of the wind to height of 100m was performed. It was found that the average power of the wind speed is favorable to the installation of wind turbines in all seasons.

Keywords

Electric power, wind speed, statistical analysis, Weibull Distribution.

Introduction

Wind kinetic energy is the wind energy contained in moving air masses. Its use occurs through the conversion of translational kinetic energy into rotational kinetic energy, with the use of wind turbines, also called air generators to generate electricity, or windmills for mechanical works such as pumping water. For electricity generation the first attempts appeared in the late nineteenth century, but only a century later, with the international oil crisis (1970) there was interest and sufficient investments to permit the development and application of equipment in commercial scale (ANEEL, 2013).

The energy issue has a quite relevant meaning in the context of environmental issues and the pursuit of sustainable development. Thus the efficient energy supply is considered one of the basic conditions for economic and sustainable development required by society.

According to the National Electric Energy Agency – ANEEL –, the wind annual average speed at the height of 50 meters in Caraguatatuba, northern coast of Sao Paulo, is the energy class 3 (three) with values ranging from 4 m/s to 7 m/s. The coastal area is usually composed of a wide strip of sand where the wind affects predominantly towards sea-land.

Data and Method

In this study wind speed data used was obtained from the database of the Integrated Data Environment and the National Institute for Space Research – SINDA/INPE <www.sinda.crn2.inpe.br>, related to the station located in the city of Caraguatatuba (code 32521), daily measurements every six hours, at the height of 10 meters. All the measurements from 2004 to 2012 were considered covering a total period of eight years. The proportion of failures in the data series of wind speed in the period of eight years was 3%.

To obtain values of wind speed at the height of 100 m, the Hellmann's Law, or Potency Law, was used for the wind speed data extrapolation at the reference height of 10 meters (Equation 1).

$$V(f) = V(i) \left[\frac{H(f)}{H(i)} \right]^n \tag{1}$$

    V (f) = speed at the desired height;
    V (i) = speed at the measurement height of the station;
    H (i) = measurement height at the station;
    H (f)= height to be extrapolated;
    (n) = limit layer exponent.

The limit layer exponent (n) varies with the roughness of the soil as proposed by Silva (2001, apud Melo 2010). According to him, the roughness factor characterizes the soil type "low" class "surface water, agricultural areas, pastures, soils exposed" was used with a value equal to 0.143.

Wind power depends on the kinetic energy of moving air and it varies to the cube of the average wind speed. The power calculation was done to design wind turbines, E-82/2000KW, manufactured by Enercon Wobben Windpower, which features: 2.000kW rated

power, rated wind speed of 12.5 m/s, initial operation speed 2.5 m/s, tower/hub height of 98 to 108 m and area of 5.281m² (Equation 2).

$$P_{average} = \frac{(A)(V)^3(Cp, Betz)(d)}{2} \tag{2}$$

$P_{average}$ = maximum power (W);
(Cp,Betz) = Betz coefficient power, approximately (0.593);
(d) = density of dry air, worth 1,225;
(A) = scanning area of the turbine (m²);
(V) = wind speed (m/s)

According to Castro (2005), the records of probability density gain importance if they can be described by analytical expressions. Being the Weibull Distribution usually regarded as the most suitable, Equation 3 is the mathematical expression of Weibull's probability density function.

$$F(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left\{-\left[\left(\frac{u}{c}\right)^k\right]\right\} \tag{3}$$

(k) = form factor (dimensionless);
(c) = scale factor (m/s);
(V) = average wind speed.

The parameter (k) determines the curve shape (amplitude) distribution related to the standard deviation, while the parameter (c) defines the range of the distribution related to the average speed. In this work they were estimated by maximum likelihood method.

Castro (2005) shows that one of the most used methods to calculate the parameters (k) and (c) uses a linear regression. The function F(x), accumulated probability, is the probability of a random variable (x) to exceed the value (x0), given by Equation 4.

$$F(x) = 1 - \int_{-\infty}^{x0} f(x)dx \tag{4}$$

Running the relationship (Equation 5):

$$f(x) = -\frac{dF(x)}{dx} \tag{5}$$

The application to the case of Weibull distribution leads to F(u) expression (Equation 6):

$$F(u) = \exp\left\{-\left[\left(\frac{u}{c}\right)^k\right]\right\} \tag{6}$$

Which may be expressed as a linear function of the typified (Equation 7):

$$Y = AX + B \tag{7}$$

Y = ln[-ln(1-F(u))];
X = ln(u)

The parameters k and c are related to A and B by the expressions:

$$k = A \quad \text{and} \quad c = \exp^{\left(-\frac{B}{A}\right)}$$

According to Castro(2005), the function Gamma relates the parameters c and k of the Weibull Distribution to the characteristics of the average wind speed (u) and the standard deviation (σ), by the following Equations 8 and 9:

$$u_{average} = cr^{\left(1+\frac{1}{k}\right)} \tag{8}$$

$$\sigma^2 = c^2\left[r\left(1+\frac{2}{k}\right)-\left(\left(r\left(1+\frac{1}{k}\right)\right)^2\right)\right] \tag{9}$$

Results

Figures 1 to 4 illustrate the relative frequency of occurrence in the four seasons for the height of 100 m.
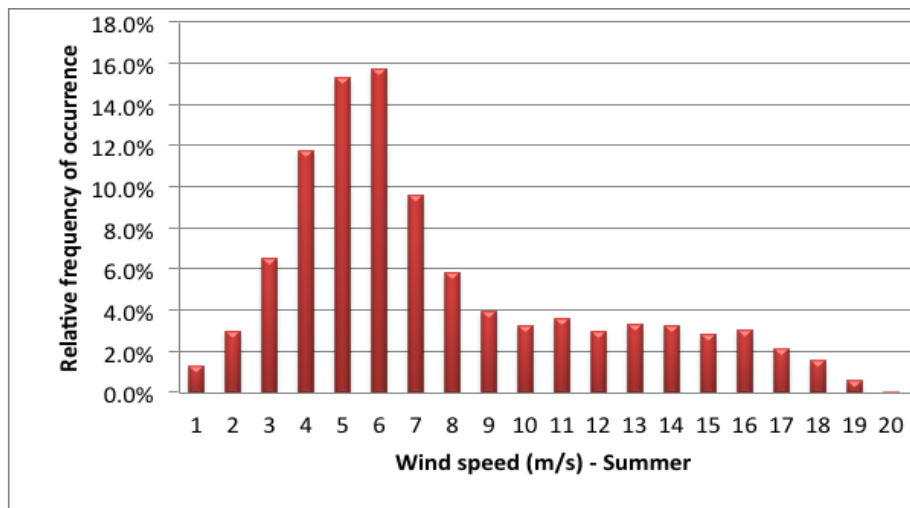
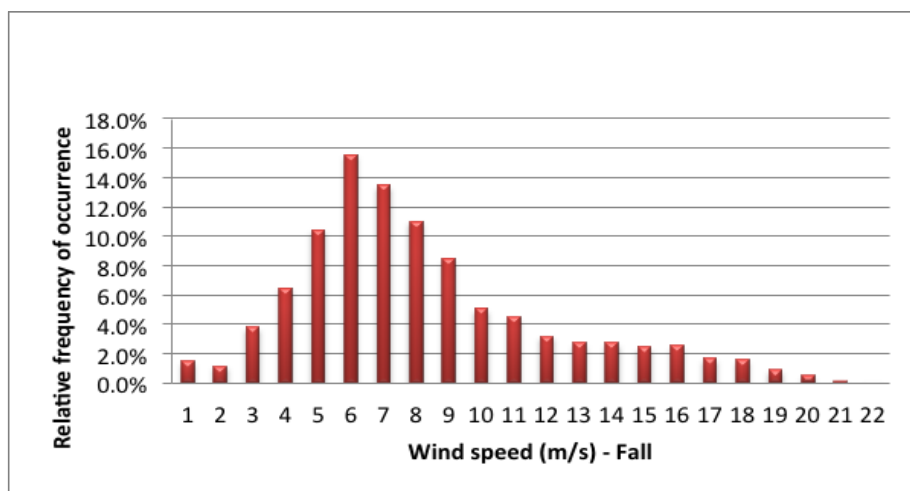**Figure 1.** Relative frequency of occurrence – summer.

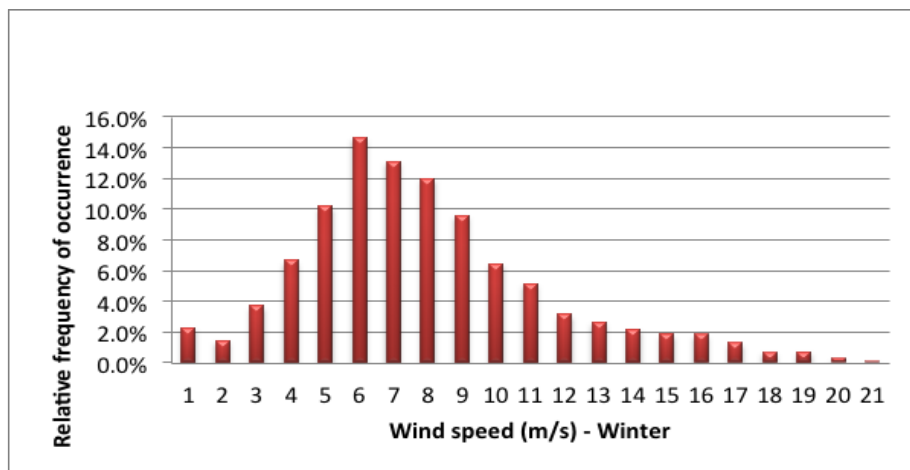**Figure 2.** Relative frequency of occurrence – fall.

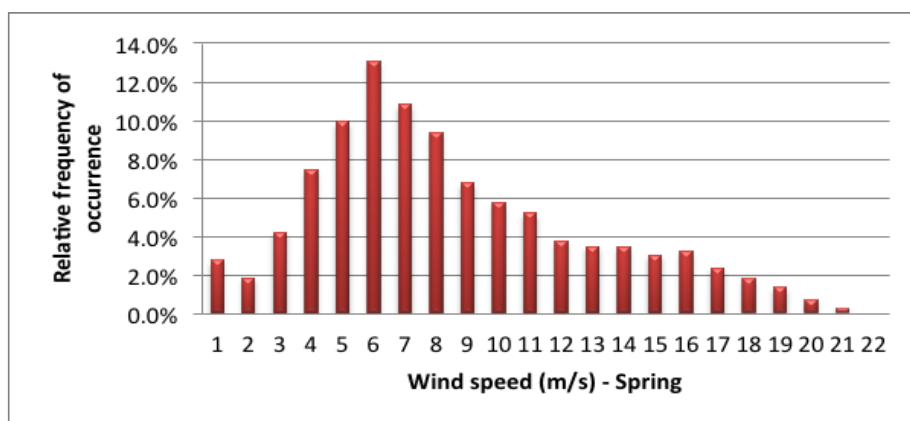**Figure 3.** Relative frequency of occurrence – winter.

Figure 4. Relative frequency of occurrence – spring.

Table 1 shows the calculation results obtained for Weibull parameters, average speed and standard deviation per season of the year.

Table 1. Weibull parameters (k and c), average speed and standard deviation per season.

Season	Linear Function	k	c	Average Speed	Standard Deviation
Summer	Y = 2.2113X – 4.8359	2.21	8.91	7.89	3.77
Fall	Y = 2.2958X – 5.1943	2.30	9.60	8.50	3.93
Winter	Y = 2.2235X – 4.9113	2.22	9.10	8.06	3.83
Spring	Y = 2.0336X – 4.6150	2.03	9.67	8.57	4.41

Figures 5 to 8 illustrate the frequency histograms of the Weibull Distribution for wind speed (m/s) related to the seasons of the year, considering (January-February-March, summer), (April-May-June, fall), (July-August-September, winter) and (October-November-December, spring).

The representation of wind speed data through a statistical distribution theory, in this case the Weibull Distribution, has the advantage to represent the distribution over two parameter settings, which generally is defined as the statistical probability distribution of wind speeds.
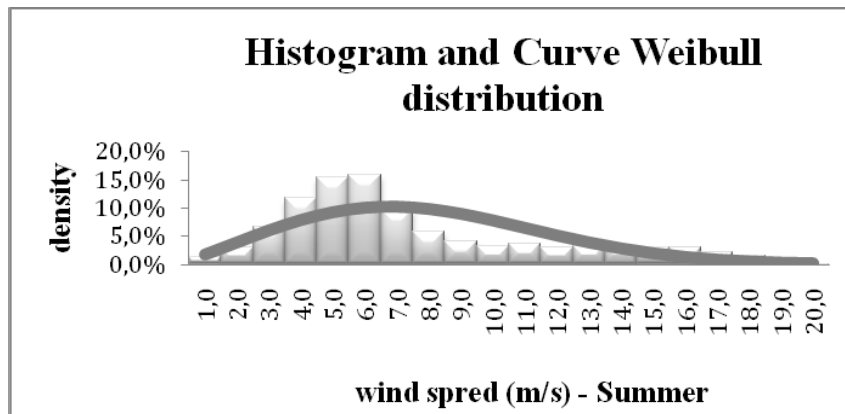
Figure 5. Histogram and Weibull Distribution curve (summer). Parameters (k = 2.21 e c = 8.91).
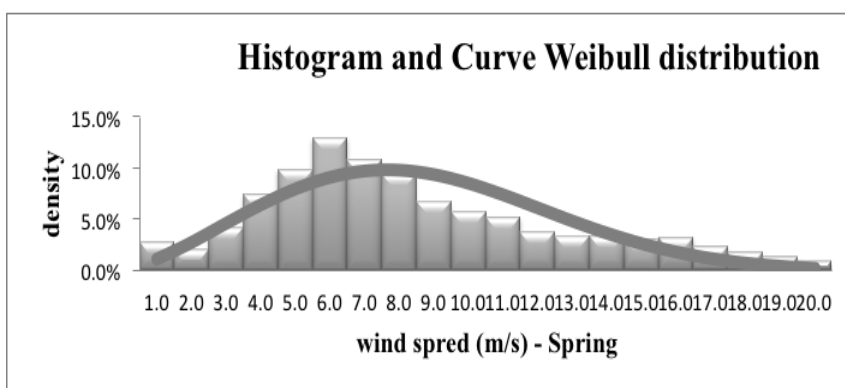

Figure 6. Histogram and Weibull Distribution curve (spring). Parameters (k = 2.34 and c = 9.67).
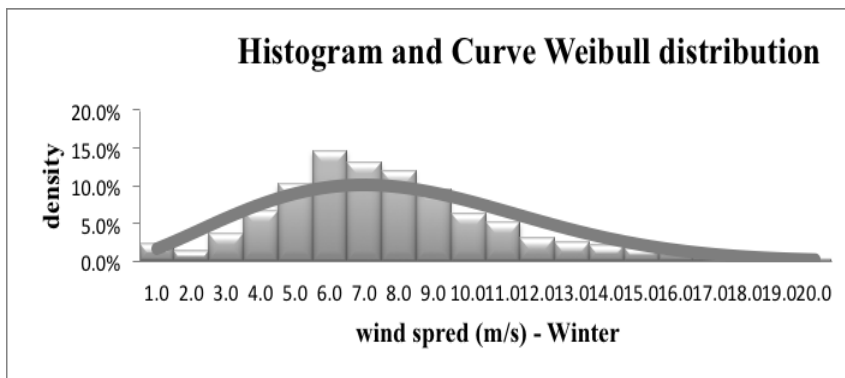

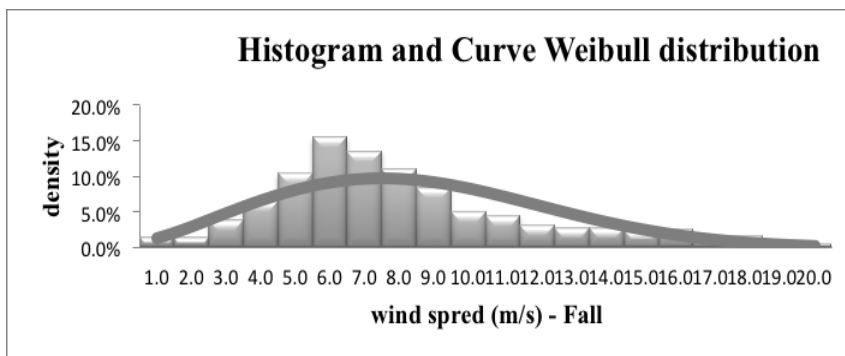**Figure 7.** Histogram and Weibull Distribution curve (winter). Parameters (k = 2.22 and c = 9.10).

Figure 8. Histogram and Weibull Distribution curve (fall). Parameters (k = 2.29 and c = 9.60).

The parameter settings of the Weibull Distribution provides the assessment of the wind persistence in terms of average speed – the scale factor and form factor (Brackmann, 2009 apud Schumacher et al. 2012).

Conclusion

Through the analyzed data from February 2004 to August 2013, the wind speed at the height of 100 meters registered in the city of Caraguatatuba, verified that the municipality has considerable values of average power wind, considerable scale and shape parameters of Weibull in addition to values of viable average speed (Table 2).

However, a more detailed analysis should be performed to ensure more safety to energy sector projects that might be installed in this region.

Table 2. Average speed and average wind power for Caraguatatuba, Sao Paulo Northern Coast.

Height (m)	Season	Average speed (m/s)	Average power (watts)
100	Summer	7.32	752,333.15
100	Fall	8.03	993,169.99
100	Winter	7.77	899,787.61
100	Spring	8.38	1,128,779.23

References

BRACKMANN, R. et al. Evaluation of the wind potential at the central region of Rio Grande do Sul. In: CONGRESSO BRASILEIRO DE ENGENHARIA QUÍMICA, 8., 2009, Minas Gerais. **Anais…** Minas Gerais, [s.n.], 2009.

CASTRO R. M. G. **Renewable energies and decentralized production – Introduction to wind energy**. Ed. 2.1. Lisbon, Portugal: Lisbon Technical University – Technical Superior Institute – DEEC/Energy Section, 2005.

ELECTRIC ENERGY NATIONAL AGENCY. **Brazil's Electrical Energy Atlas**. Brasilia: ANNEL. Available in: <http://www.aneel.gov.br/aplicacoes/atlas/pdf/06-energia_eolica(3).pdf>. Accessed in: 14 aug. 2013.

MELO, S. C. Methodology for evaluating the attractiveness for wind potential study. SPECIALIZATION COURSE IN GEOPROCESSING, 12., 2010, Belo Horizonte, MG. **[work paper].** Belo Horizonte, MG: [s.n.], 2010.

SCHUMACHER, V. et al. Evaluation of the potential of wind power generation on the south coast of the state of Rio Grande do Sul. **[on line]**. 2012. Available in: <http://www.congremet.prmarg.org/upload/schumachervanucia.pdf>. Accessed in 14 jul. 2013.