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# Probability of the average monthly wind speed in Mossoró-RN, Brazil, through the probability density function of beta distribution

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***Abstract***— *The objective of this paper was to determine the expected wind speed (km/day) as a function of the daily average values, at various levels of probability, recorded during thirty-eight years (1970-2007) for the city of Mossoró-RN. Based on the Kolmogorov-Smirnov test, we found that the beta distribution can adequately describe the wind pattern, for all months of the year. We found average wind velocity values of 219.0 km/day demonstrating the great possibility of using this meteorological element as an alternative source of energy for the region.*

***Keywords*— *probability distribution, wind, beta density function, alternative energy.***

## I. INTRODUCTION

The wind was one of the first forms of energy used by man. In the past, in different situations, wind energy has been used routinely, and today the modern technology allows its use with maximum efficiency.

Due to the energy crisis in 1973, the oil price increased in the period of 1973-1986 and wind technology experienced a resurgence, which has led to the emergence of the current wind turbines capable of producing electricity at competitive prices concerning the traditional sources. Energy consumption is one of the main problems nowadays, and the largest percentage of energy consumed comes from petroleum. Several governments have been planning short- and long-term electricity supply strategies due to the rising electricity consumption in recent years. This concern justifies more effective and rigorous planning for these strategies to meet the needs of the population.

The debate over the use of the available energy sources in the country such as solar, biomass and wind energy is providing alternatives to overcome the shortcomings of the energy crisis in recent years. According to Lima (2003), about 20% of the world's energy comes from renewable resources.

Energy from wind is one of the solutions. The slight market growth in favor of wind energy is responsible by the decrease in the prices of wind turbines over the last decades, which together with the evolution of the technology and operational characteristics has become more competitive concerning other generations sources.

The zero cost of its fuel (wind), low maintenance cost, the short time required for its installation and operation, among other factors, has consolidated the space of wind energy among the potential sources of energy (Terciote, 2005).

The wind energy is one of the most important and promising technologies in the complementary generation of clean energy. Brazil has great potential for generating energy from wind. According to the Atlas of Brazilian Wind Potential, published by the Electric Energy Research Center of Eletrobrás, the Brazilian territory can generate up to 300 gigawatts, but currently, the installed capacity is 8.12 GW, that is less than 3% of the potential (Abeeólica, 2015).

To a medium and long-term energy planning, reliable information on available energy resources is needed. The lack of information on the variability, trends, and factors influencing the availability of renewable resources is the main barrier to the adoption and investment in projects of renewable energy production such as solar and wind power (Martins et al., 2005).

Knowledge of steering wind behavior and velocity, as well rainfall, temperature, relative air humidity, evaporation, global solar radiation, dew, fog, hail, frost, and snow, among others, is an essential in decision-making related to agricultural activities and the need to explore clean sources of energy. In this sense, the statistical distribution of wind speeds is an important tool for the evaluation of wind energy potential and its performance in energy conversion systems.

A theoretical distribution is an abstract mathematical form or specific format of a frequency of values of a given variable. Some of these mathematical forms appear naturally as a consequence of certain species of data generating processes, and they may concisely representing variations in a set of data. Even when there is no strong natural basis behind the choice of a particular theoretical distribution, one can empirically find that this distribution model represents a set of data very well. The specific nature of a theoretical distribution is determined by particular values of entities called distribution parameters. Theoretical distributions, also called parametric distributions, because their specific attributes depend on the numerical values of their parameters. For example, a normal or Gaussian distribution is characterized by the bell shape. However, to say that the average January temperature in a given locality is well represented by a Gaussian distribution is not very informative about the nature of the data, without specifying what Gaussian distribution represents the data. The knowledge of these distributions has important practical consequences because the methods of analysis for the observation data (random variable) that follow different theoretical distributions are different.

The random variables associated with most of the experiments can be represented by families of statistical distributions, which are mathematical models and whose properties such as mean, variance, and geometric form are a function of few parameters. Although there is an infinite diversity of families of statistical distributions, their interest is varied, and only a limited number has a broad field of application. A distribution family is a distribution that depends on one or more parameters. These parameters are classified based on their geometric or physical interpretation, and determine the location, variability, and shape of the distribution, and belong to one of the following types: i) location parameter; ii) scale parameter and iii) shape parameter (Pedrosa and Gama, 2004).

The study of the behavior of rainfall, relative humidity, evaporation, wind direction and speed, global solar radiation, dew, fog, hail, frost, and snow, among others, is an important tool in decision making related to agricultural and human activities in construction and tourism. Among these climatic variables, the global solar radiation, defined as the total energy emitted by the sun, which affects the terrestrial surface, with wavelengths between 150 and 4000 nm (Rosenberg et al., 1980; Slater, 1980; Sampaio et al., 1999; Cargnelutti Filho, 2004) is fundamental in relation to agricultural activities.

The simple construction of a histogram of frequency for the visualization of the sample data is insufficient to infer, among the several known probability density distributions, which one best fit the data under study. Therefore, it is necessary to use criteria tests and Goodness-of-Fit tests to verify if the probability distribution of the data can be represented by a certainly known probability distribution function.

There are several distributions of probability for discrete and continuous random variables. The Bernoulli, Binomial, Negative Binomial, Hypergeometric, Geometric, and Poisson are suitable for discrete data. Continuous random variables are adjusted to Uniform, Normal, Log-Normal, Gamma, Weibull, Gumbel, Exponential, Beta, Chi-square, Student's-t, Fisher-Snendecor distributions, and others.

Studies of probability distribution adjustments or probability estimates using theoretical probability distribution functions for climatic variables such as rainfall (Berlato, 1987; Botelho and Morais, 1999; Sampaio et al., 1999; Catalunha et al., 2002; Murta et al., 2005), air temperature (Mota et al., 1999; Buriol et al., 2000; Assis et al., 2004) and the solar radiation (Buriol et al., 2001; Assis et al., 2004) have benefited the planning activities, reducing probable climatic risks.

Goodness-of-fit tests such as Kolmogorov-Smirnov, Qui-square, Cramer Von-Mises, Anderson Darling, Kuiper, Lilliefors, Shapiro-Wilk and the Maximum Likelihood Logarithm (Campos, 1983; Assis et al., 1996; Moretin and Bussab, 2004; Cooke, 1993) are used to compare the empirical probabilities of a variable with the theoretical probabilities estimated by a distribution function under test. The sample values can be reasonably considered as coming from a population with that theoretical distribution. The Maximum Likelihood Logarithm shows a good quality of fit if its value is negative and the lowest possible (Cooke, 1993). In the Goodness-of-Fit tests, the null hypothesis ($H_0$) assumes that the sampled distribution does not differ from the theoretical distribution specified (Normal, Log-Normal, Beta, Range, Log-Pearson, Gumbel, Weibull and others), and the estimated parameters are based on the sample data (Assis et al., 1996; Catalunya et al., 2002).

The Log-Normal distribution has proven to be satisfactory to fit data of maximum air temperature in the city of Iguatu, Ceará, Brazil, according to the Chi-square and Kolmogorov-Smirnov Goodness-of-Fit tests (Araújo et al., 2011). For the precipitation data of Pernambuco State during the months of January to July 2015 (Lima et al., 2015), a set of distributions was adjusted (Normal, Log-normal, Gamma, Beta, Weibull 2P and Weibull 3P), and different distributions were suitable for distinct months of the year. Weibull 3P best fit the months of January February, March, May and July, while April was best fitted by a Normal function and June by a Gamma function (Lima et al., 2015). Rodrigues et al. (2014) tested the Exponential, Range, Log-normal, Pareto and Weibull probability distributions to modeling the intensity of droughts in Laranjeiras do Sul in the State of Paraná, in a historical series of 30 years. All distributions analyzed, except the Pareto distribution, presented a good fit, but Gamma and Weibull distributions were more suitable to the observed data. The corrected Akaike information criterion, the likelihood ratio, and the histogram comparison indicated that the Gamma distribution obtained better adjustment of the data, followed by the Weibull distribution (Rodrigues et al., 2014).

Kist and Virgens Filho (2015) modeling the rainfall data in the state of Paraná for a historical series of thirty-year (1980-2009) in 29 locations, found that the Mixed Exponential distribution adjusted better to the data, followed by Gamma and Weibull distributions. They conclude that if the software used to adjust the distributions does not provide the Mixed Exponential distribution, the data can be better simulated from the Gamma distribution.

Gumbel probability density distribution model was used for data of absolute minimum monthly and annual temperatures (May to September) and frost incidence, for a series of thirty years referring to twenty locations in the State of São Paulo. The parameters of the probability density function of the distribution were estimated for all locations and periods analyzed and showed a good fit between the observed frequencies and the Gumbel distribution, independently of the time of occurrence and locality. Using suitable probabilistic or stochastic models, the risk levels of absolute minimum temperatures and frosts can be estimated at different periods of the year using the calculated parameters (a and p), based on historical series of this information.

Some papers use empirical classification employing the relative frequency of occurrence of minimum temperatures to estimate the unconditional probabilities. The problem, according to Soares and Dias (1986), is the sample size, which may be insufficient to obtain stable probability values. Conrad and Pollak (1950) recommend series of at least thirty years to obtain representative results. For example, Camargo (1977), in a study of the occurrence of low temperatures in Campinas (SP), for the period from 1890 to 1975, considered temperatures under a meteorological shelter below 2.5 °C as representative of frost. Ortolani et al. (1981), found 2ºC as a predictor of frost, using the historical series from 1962 to 1980, in eight localities of São Paulo. The adoption of 2 ° C as the limit was based on the average difference between the air temperature in the meteorological shelter and the grass temperature in frost nights, which is of the order of 5.6 ° C (Fagnani and Pinto, 1981). Considering the air temperature of 2 ° C, therefore, the leaf has a temperature of -3.6 ° C, close to the value found by Camargo and Salati (1967) and Pinto et al. (1977, 1978) as the limit for the appearance of damages in coffee trees. Using a relative frequency, with a series of twenty years of data, Soares and Dias (1986) defined for the city of São Paulo the probability of occurrence of daily minimum temperatures, at monthly level, lower than 10 and 15 ° C.

The use of suitable probabilistic models introduces mathematical precision, allowing for more consistent studies of historical data series. Arruda et al. (1981) tested the Extreme Values and Normal distributions for absolute minimum temperature in a series of 50 years for the regions of Campinas for June and July. The authors found concluded that both distributions are recommended to describe minimum temperature data. Silva et al. (1986) in a series of 69 years of daily minimum temperature data for April to September in the city of Lavras (MG), found that the Extreme values distribution best fit the data. By using the model of extreme values for annual absolute minimum temperatures, referring to several locations in the State of São Paulo and Mato Grosso do Sul, Camargo et al. (1990) identified areas of frost risk, observing large gradients of probability values.

The climate is a factor of great influence in the control of the growth of the plants. Moreover, agricultural productivities are probabilistic elements (random variables), in the sense that they depend on climatic variables, such as temperature and global solar radiation of the region during the growing season of a crop. Dallacort et al. (2011), for example, found that the probability of precipitation in Tangará da Serra is between 40 and 50% probability for the rainy months and between 30 and 40% for the months without rainfall, using the Incomplete Gamma distribution. Based on the results, this type of research assists in the elaboration of irrigation projects for the municipality of Tangará da Serra in the State of Mato Grosso, Brazil.

The use of probability density functions is directly linked to the nature of the data. Some functions have good estimation capacity for small numbers of data; others require a large number of observations. Due to the number of parameters of your equation, some can take different forms, suitable for a larger number of cases, being more flexible. Respecting the representativeness aspect of the data, the estimates of the function parameters for a given region can be established without prejudice to the precision in the estimation of probability (Catalunha et al., 2002).

The adjustment of probabilistic models to daily rainfall data, plant growth productivity and a summary of these data represents an efficient technique for the analysis of this information. Each frequency distribution can be approximated through the use of probability density equations with some parameters extracted from the sample in question. The use or not of a distribution resides in its capacity to estimate the observed data, based on its parameters, and this capacity is measured through Goodness-of-Fit tests (Almeida, 1995).

Some previous papers have described the wind patterns to suggest control practices such as the use of windbreaks and also to identify sites with wind potential for energy (Munhoz and Garcia 2008; Pereira et al., 2009; Beruski et al., 2009). Pereira et al. (2009), for example, conclude that in the winter and spring, the winds blow with intensity higher than the average, with September having the highest values. According to the authors, in the summer and autumn, the winds have values below the average. The mean wind velocity data indicate that the wind potential can be exploited in the municipalities of Cascavel, Ponta Grossa and Clevelândia among the analyzed sites, which are also the most outstanding areas for the implementation of windbreaks. Beruski et al. (2009) concluded that the gamma distribution was better at adjusting the mean wind speed data, considered a good model to represent the data of the region of Lapa, PR.

Based on the given information and in the absence of studies using probability distribution functions to describe the wind pattern for Rio Grande do Norte, this work has the objective of determining the monthly average values assumed by the wind speed in the city of Mossoró, RN, through the Beta probability density distribution, analyzing the potential for generating energy.

## II. MATERIAL METHODS

The average wind speed data in km/day were obtained from a series of 38 years (1970 to 2007) of the data records of the UFERSA Meteorological Station (Federal Rural Semi-Arid University) in Mossoró. The data was sampled at 10m, coordinates 5°11' S e 37°20' W, 18m of altitude, average annual temperature of around 27.5 °C and relative humidity of 68.9% (Carmo filho et al., 1991). According to Köppen's climatic classification, the climate of Mossoró is of the type BSwh ', that is, hot and dry.

In each month of the year, the data of the series were adjusted to the beta probability distribution model. The beta density function can be expressed as follows (Falls, 1973; Haan and barfield, 1973):

$$B(x) = \frac{1}{(b-a)}\frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)}\left(\frac{x-a}{b-a}\right)^{p-1}.\left(1-\frac{x-a}{b-a}\right)^{q-1}$$

a and b correspond to the smallest and highest value of the data series, respectively, Γ is the symbol of the gamma function of the respective variables, p and q are parameters of the beta distribution and x is the value of the variable under analysis. The estimation of the parameters p and q is done from the moment’s method (Pearson, 1934). The density function of the beta distribution takes the following form:

$$B(x') = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)}.\left(x'\right)^{p-1}.\left(1-x'\right)^{q-1}$$

In which, $0 < x' < 1$, for $p > 1$ and $q > 1$. The numerical integration of this equation configures the probability of values occurrence to any value of x within the considered interval.

The main method to estimate its parameters is the maximum likelihood method, whose estimators have the four desirable properties of a good estimator which are: non-biased or non-addictive, consistent or coherent, efficient as well as sufficient, which must satisfy the condition $\alpha > 0$ (by definition) (Thom, 1958 e 1966; Catalunha et al., 2002; Bussab and Morettin, 2017; Casella and Berger, 2018).

The moment’s method is a statistical inference tool to obtain estimates of population parameters, being one of the simplest and oldest to obtain estimators of one or more parameters of a distribution. The estimators are obtained by replacing the moments of the sample in the expressions representing the moments in the population, i.e., the basic idea is to use the moments of the sample to estimate the corresponding moments of the population, and, from there, to estimate the parameters of interest (Murteira et al., 2001). Let $X_1, X_2, ..., X_n$ be a random sample of a given population with probability function (density) f.d.p,: $f(x; \theta_1, \theta_2, ...., \theta_k)$ that depends on k parameters. Assuming that there are ordinary moments of population x, these are functions of k parameters. The method of the moments consider that the estimators of the ordinary moments are given by ordinary sampling moments, that is, $\hat{\mu}'_r = m'_r, r = 1,...,k.$ Some forms of estimating the parameters of the Beta distribution were developed, contributing, along with their flexibility of forms, to their use in several areas.

We used the Kolmogorov-Smirnov test to evaluate the fit of the mean values of monthly wind speed to the beta probability density function. This test uses the values estimated through a specific and known theoretical (or real) distribution of the event F(x), which in the case of this study corresponds to the values determined by the

Beta density function, to data coming from an empirical distribution estimated with the observed values S(x). As a way of characterizing the study area, the present work estimated the wind speed values at the following probability levels: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 and 95%. The analysis was performed in the free statistical program VTFIT (Cooke, 1993; Campos, 1983; Siegel, 2006).

## III. RESULTS AND DISCUSSION

We observed that the highest wind speed was verified in October and November, and the lowest values in the months of March to May (Table 1 and Figure 1).

*Table.1: Estimated average values of wind speed (Km/day) in function of probability level [p(x ≤X)] for the city of Mossoró-RN, 2018.*

| PROBABILITY LEVEL | JAN | FEV | MAR | ABR | MAI | JUN | JUL | AGO | SET | OUT | NOV | DEZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 615.57 | 530.08 | 419.14 | 519.49 | 383.04 | 400.02 | 476.46 | 546.28 | 574.01 | 636.22 | 638.95 | 628.65 |
| 10 | 583.41 | 505.79 | 380.98 | 439.08 | 343.72 | 368.89 | 434.18 | 504.36 | 553.42 | 603.61 | 609.52 | 593.00 |
| 15 | 557.26 | 484.01 | 355.87 | 385.42 | 318.04 | 345.57 | 404.11 | 474.92 | 536.84 | 579.75 | 587.21 | 565.89 |
| 20 | 534.14 | 463.53 | 336.41 | 344.04 | 298.24 | 326.08 | 379.85 | 451.42 | 522.27 | 560.05 | 568.34 | 543.04 |
| 25 | 512.89 | 443.85 | 320.11 | 309.88 | 281.75 | 308.91 | 359.07 | 431.48 | 508.90 | 542.83 | 551.57 | 522.85 |
| 30 | 492.88 | 424.66 | 305.84 | 280.56 | 267.36 | 293.31 | 340.65 | 413.95 | 496.34 | 527.27 | 536.19 | 504.50 |
| 35 | 473.73 | 405.78 | 292.95 | 254.72 | 254.42 | 278.85 | 323.94 | 398.18 | 484.32 | 512.88 | 521.79 | 487.49 |
| 40 | 455.21 | 387.04 | 281.03 | 231.53 | 242.51 | 265.24 | 308.51 | 383.74 | 472.68 | 499.34 | 508.10 | 471.51 |
| 45 | 437.07 | 368.34 | 269.81 | 210.42 | 231.32 | 252.27 | 294.08 | 370.36 | 461.27 | 486.44 | 494.93 | 456.34 |
| 50 | 419.16 | 349.58 | 259.12 | 191.01 | 220.70 | 239.79 | 280.45 | 357.82 | 449.99 | 474.00 | 482.12 | 441.80 |
| 55 | 401.33 | 330.62 | 248.71 | 172.99 | 210.41 | 227.67 | 267.44 | 345.98 | 438.74 | 461.89 | 469.55 | 427.77 |
| 60 | 383.46 | 311.36 | 238.49 | 156.16 | 200.34 | 215.80 | 254.93 | 334.71 | 427.42 | 449.99 | 457.08 | 414.13 |
| 65 | 365.41 | 291.68 | 228.30 | 140.33 | 190.34 | 204.09 | 242.81 | 323.91 | 415.94 | 438.16 | 444.62 | 400.78 |
| 70 | 346.97 | 271.41 | 218.00 | 125.37 | 180.28 | 192.42 | 230.99 | 313.49 | 404.14 | 426.31 | 432.02 | 387.65 |
| 75 | 327.92 | 250.34 | 207.38 | 111.17 | 169.97 | 180.69 | 219.33 | 303.38 | 391.89 | 414.26 | 419.13 | 374.60 |
| 80 | 307.97 | 228.16 | 196.19 | 97.63 | 159.14 | 168.74 | 207.73 | 293.49 | 378.93 | 401.83 | 405.74 | 361.53 |
| 85 | 286.59 | 204.38 | 183.98 | 84.67 | 147.42 | 156.33 | 196.05 | 283.72 | 364.93 | 388.70 | 391.50 | 348.29 |
| 90 | 262.90 | 178.09 | 169.95 | 72.25 | 134.06 | 143.12 | 184.02 | 273.96 | 349.15 | 374.36 | 375.83 | 334.62 |
| 95 | 234.58 | 147.10 | 151.74 | 60.22 | 116.96 | 128.18 | 171.11 | 263.94 | 329.83 | 357.46 | 357.15 | 319.93 |

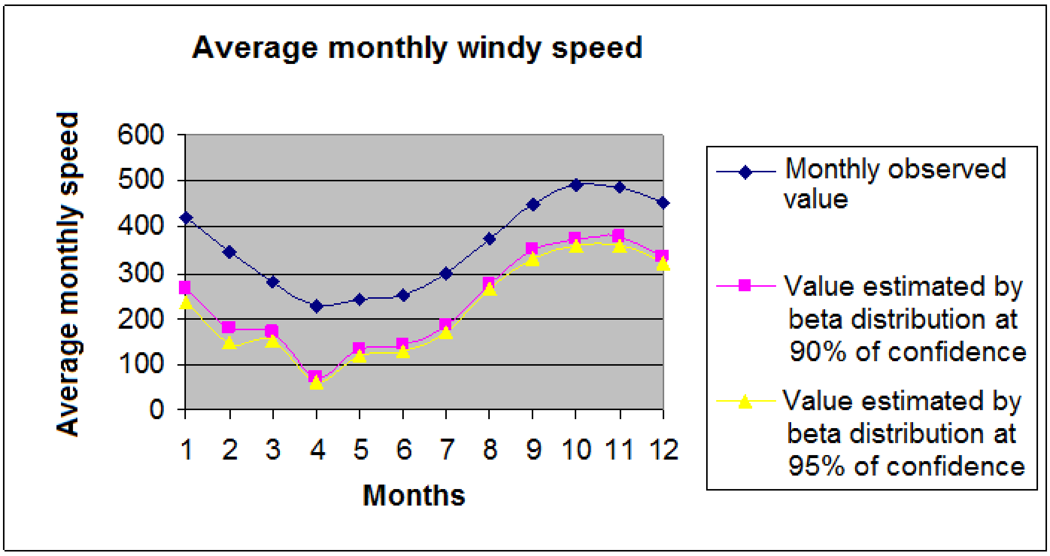

*Fig.1: Average values of wind speed of the Mossoró city, RN, Brazil, 2018.*

The wind speed varies depending on the region and the season. In general, in Brazil, the strongest winds occur in early spring and the weakest in early summer (Bíscaro, 2007), this fact confirms the analysis of the data in Table 1 and Figure 1. It should be verified that the highest value of the average wind speed for Mossoró, RN, occurred in October and November. Similar results were obtained by Leite and Filho (2006) in Ponta Grossa, PR.

The period of highest average wind velocity occurred in the spring, from September to December; and the lowest average speed occurs in March to May. The wind speed is directly proportional to the values of the radiation balance. Therefore, it explains the low values of wind speed in late summer and early fall (Bíscaro, 2007).

The present study provided subsidies for the use of this available energy to guide energy engineering studies, as well as in related areas. It was verified that the region of Mossoró, RN, constitutes a possible region for obtaining wind energy, this is because the North and Northeast regions of Brazil have the highest wind power, which seen occur in and November. The highest wind speed values were 357.46 Km/day and 357.15 Km/day (95% of probability), respectively (Table 1), and that the lowest values were found from March to May, with an average 100 km/day (Figure 1).

The maximum value, therefore, presents a small probability of occurrence. We can verify that the probability of occurring a value less or equal to this event would be greater than 95% (Table 1). It is also noted from Table 1 that at a 95% probability level, the estimated wind speed is 116.96 km/day for May. Similar results were obtained by Martins (1993), Marques Júnior et al. (1995) and Silva et al. (1997) for other regions. In these studies, all the authors were unanimous about the local possibilities for using this climatic element as an alternative energy source. The average speed in Mossoró is higher (486.91 km/day) than the found by the authors (220.37 km/day), showing to be a region of high potential for the rational and directed exploration of wind energy.

The estimated theoretical and calculated probabilities by the beta function for the wind speed data were all adjusted to the 10% probability level according to the Kolmogorov-Smirnov Goodness-of-Fit test. The results indicate that the meteorological event discussed can be adequately represented through the distribution of beta probability density function when analyzed monthly average periods. Thus, the adjusted model for this random climate variable can be used by researchers in general to perform probabilistic forecasts, estimate wind speed values, make comparisons between phenomena of the same nature, and analyze the location of historical series and study variability or scale of this variable. Also is possible to analyze the asymmetry and kurtosis or flattening of frequency distributions of the variable under investigation, as well as to make statistical inferences, through the construction of confidence intervals and the application of hypothesis tests or of significance, among other types of statistical analysis.

## IV. CONCLUSIONS

The mean velocity data of the winds indicates a possible wind potential to be used in the region of Mossoró, RN, and should be evaluated by complementary studies.

The beta probability density distribution showed a good fit for all months of the year, and is therefore adequate for this type of study, in this locality and evaluated times.

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