Analysis of wind power potential of a region of Aveiro, Portugal

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Abstract: - This work intends to characterize the wind and evaluate the wind power potential of a region in the western coast of Portugal which geographical coordinates are 40º 38' of latitude and 8º 40' of longitude, being 5m above sea level. An algorithm which allows obtaining data from wind and making the project of a wind turbine into a horizontal rotation axis in a perspective of optimization was built and used. The results obtained allow the knowledge of the characteristics of wind and the wind power potential in the area of study. The Weibull distribution has indicted that the winds frequently experiencing slow speeds.

Key-Words: - Wind characteristics; logarithmic law, power law, atmospheric stability, Weibull law, wind power.

1 Introduction

Development and adoption of reliable source of renewable energy is major challenge being faced by most of the parts of this planet. Most of research work under the caption of renewable energy encompasses around the limited models of adoption for this form of energy. Renewable energy technologies can bring a revolution in the life style and living standards of people in remote areas. However to introduce and implement this form of energy, there is a need to take certain promotional measures like practical demonstration, education of masses through outreach programs and pilot projects [1].

Nowadays, humanity is faced with the possibility of enormous environmental problems in the near future. Climate Change and Global Warming are problematic issues, to politics as well as to researchers [2-3].

With the price of petrol industry and charcoal so low, the investment in renewable sources of energy hasn't been taken in account for many years. As a result, with the anxiety of economic prosperity and urban growth, the increase of the number of vehicles without any type of clean energy, complete electrical networks working from centrals on basis of charcoal fire, have been scattering all over the world.

The outcome of new world market economies and the improvement of human kind lifestyle, improved the necessity of energy as well.

Nowadays, in several countries that are paying attention to this issue and which have natural resources, it is being developed and refined some alternative ways to obtain "greener" energy that provides a cleaner environment to the planet Earth. Although being apparently more expensive, renewable sources of energy are a good option. The literature shows the importance in the use of renewable energy [4-9].

Most renewable energy sources have their origin in cycles caused by solar radiation or directly in the sun's radiation. This makes the renewable energy sources practically inexhaustible.

By using them and promoting their increase, Portugal can be considered a country of forefront. Additionally, the geographical localization of Portugal gives excellent performances in order to the dynamics and implementation of usage of renewable sources of energy (wind, solar, hydroelectric, geothermal, and tidal and waves).

As Portugal is situated in a zone with favourable conditions respect the winds, in this work, we are particularly interested in a better knowledge of the wind power potential in the Santiago's University campus of Aveiro University, located in the western offshore coast, close to Atlantic Ocean.

Available information from 2007 showed that Portugal had installed till the end of 2006, 1716W of wind power and that situation allowed Portugal to be in the ninth place in the world in absolute terms and is per capita quarter (right after Denmark, Germany and Spain). In March 2007, it was indicated to have a wind power capacity of 1839MW in 142 wind park with 1035 wind turbines; with production of wind electricity increased 60% over the same month of 2006.

Are licensed 3273MW which may increase the production of electricity from wind turbines to over 20% of total consumption.

It is expected that Portugal will soon be running more than 3000 wind turbines on land. Installation requirements for offshore wind farms do not seem easy because of the gross offshore platform and the high costs involved. In practice, we are saying that the water of the Portuguese coast is relatively deep in some areas. Moreover, as the coast is "hit" by a strong and continuous north winds throughout the year, suggests ideal conditions

Portugal has an Industrial Cluster Wind. The area that has been licensed to the shipyard in Viana do Castelo, located in northern Portugal, had an area of about 200000m^2 that almost hadn't been used and that has been licensed to about 106000m^2 ENEOP - Wind of Portugal. This land has a platform, managed by shipyards, which facilitates the quick flow of production, giving this complex, unique and highly competitive. In November 2007, opened the first Portuguese factory of rotor blades, deployed in the Praia Norte and occupying an area of 25000m^2. This factory is producing 4 to 5 blades per week, with 40m of long (using fibreglass, balsa wood and foam that are shaped in moulds). It is estimated that it will produce 12 blades per week. The production of the first four years is intended to meet national needs (150 to 200 towers per year, equivalent to about 600 blades per year). From the fourth year and beyond, it is expected to export to southern Europe, notably in Spain, France, Greece, Italy and other countries. Interestingly, it will be installed two wind turbines in the park that will produce energy and allow pumping rainwater to feed the mixed concrete plant that started its activities in July 2008. A large reservoir of water, for the purpose of any fire, will also be operated by energy from two wind turbines [10].

Concerning the problem of greenhouse gas emissions in January 2008, the European Commission proposed the following objectives for 2020: 20% reduction in emissions of greenhouse gases, increasing the contribution of renewable energy sources (RES) in 20%, improve energy efficiency by 20%.

So, due to Climate Change, there are obligations of "shared responsibility" and are assigned to Portugal to a maximum of an additional 27% of emissions of greenhouse gases between 1990 and 2010. There are environmental objectives of the EU: Kyoto Protocol directive of energy - reducing emissions of greenhouse gases by 8% between 1990 and 2010, Directive of renewable - increased production of electricity from RES from 14% in 1997 to 22% in 2010. Commitment Portugal: Kyoto Protocol directive of sources - GHG emissions to 78Mt CO_2 equivalent (an increase of 27% between 1990 and 2010), Directive of energy - energy produced from RES representing about 39% of the electricity in 2010 (8.8TWh in 2006 ~ 18%). There is a new target of 25TWh in 2010 ~ 45%. The new capacity installed between 2005 and 2010 will provide additional 10TWh/year, the equivalent of a nuclear power plant. The Table 1 shows the evolution of installed power in Portugal (2007-2008).

Table 1 - Evolution of installed power in Portugal

Installed power (MW)	up to 2008	2007-2008
Hydroelectric	4578	-
Thermal	5820	-
Thermal (RES)	1463	98
Mini-Hydric	379	5
Wind	2624	576
Solar/ photovoltaic	50	37
Waves	2	2
TOTAL	14916	718

The Fig. 1 shows the evolution of electricity production from RES (Renewable Energy).

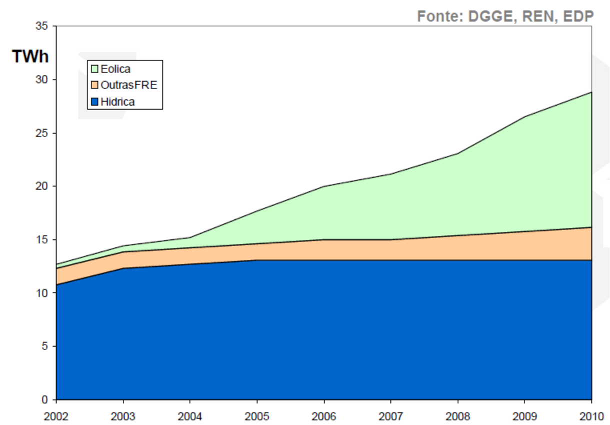

Fig. 1 - Production of electricity from RES

Thus, the sustained growth of wind power is the realization of a target of 5100MW until 2012. With an upgrade of equipment is expected to get an additional 600MW of power. As a target, Portugal is expected to register 45% of gross consumption by producing electricity from renewable energy sources. However, as illustrated in Figure 4, the volatility of wind power versus daily potential change should be valued. It is necessary that the operating reserve will increase in parallel with the wind component of the system [11].

In Europe in 1989 was created the European Wind Atlas data obtained from meteorological stations that have been processed and extrapolated to other areas [12], as shown in the Figure 2. The observation of the figure indicates to the study site, the sea coast, a wind resource available to 50m above ground level from 6.0 to 7.0 ms^{-1}.

To know the performance of a site in terms of renewable wind energy is essential to characterize the wind. This may blow in all directions, has no definite direction. The variation of wind speed and direction above the soil surface does not follow a template set (no influence local and global).

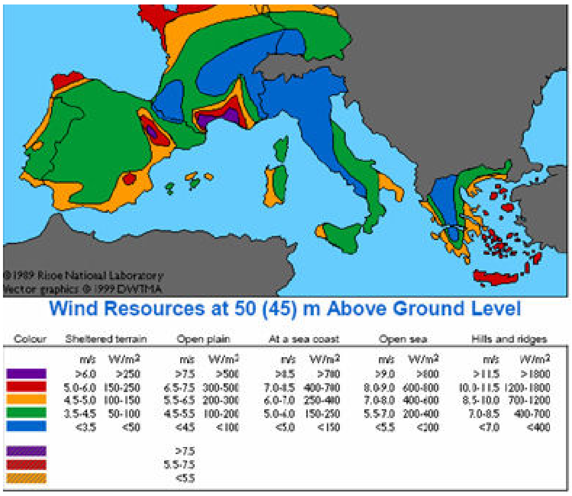

Fig. 2 - European Wind Atlas

The wind is a variable resource (in time and space). Since we can not control these variations, the wind turbine or the turbine must be selected within the parameters compatible.
The variations in wind speed in time can be divided into intra-annual, annual, daily and short periods.
To get all the annual cycles and obtain an annual average wind speed that can be considered reliable in a particular place is important to consider historical values of at least one year.
For the recorded data we investigate the behavior of the winds.
We considered the scenario of installing a wind turbine at a level of 60m (horizontal axis wind turbine).

2 Data

The data used in this work was recorded in the automatically meteorological station of the University of Aveiro (2006 and 2007).
Data of mean air temperature at 1.5m, average wind direction and intensity mean wind at 10m. The data file was filtered and was eliminated data without physical meaning (eg, failing to record the sensor). The records of 360º were converted to 0º.

3 Description of the algorithm

It isn't an objective of the study neither the analysis nor forecasts of wind power generation based on a particular model of turbine.

The wind speed was designed for the level of the axis of rotation of the turbine using a power law [13], given by

$$v_z = v_{z_0}\left(\frac{z}{z_0}\right)^{\alpha} \qquad (1)$$

In which v_z represents the wind speed at z level, v_{z_0} the speed registered at z_0 level and α coefficient that depends from both roughness of the surface and the atmospheric stability. It was used a value $\alpha = 0{,}15$ having in mind that the region to be studied was flat, not only topographically, but also due to the nearness of the river and the sea. These factors make the wind similar to a deserted region.
The algorithm allows the evaluation of α when it is known the stability of the local atmosphere. Depending on both the type of surface and the value of the vertical gradient of potential temperature it can be known the value of applying.
The algorithm lets the selection of the law power or logarithmic law. In this case, when there is a two leveled data record, the algorithm determines the surface roughness and cutting speed and compares with typical tabulated values.
It is considered that the distribution of velocities follows the model of the Weibull distribution [14-16], given by the expression

$$f(x;k,\lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(x/\lambda\right)^{k}} \qquad (2)$$

where x represents the wind speed, k the shape parameter and λ scale parameter, with positive values.
The speed value for which is the maximum of the curve was evaluated according to the application of the term,

$$v_{\max} = \lambda\left(\frac{k-1}{k}\right)^{1/k} \qquad k > 1 \qquad (3)$$

The energy per unit time and per unit area or power per unit area produced by the wind is given by

$$P = \frac{1}{2}\rho v^3 \qquad (4)$$

where ρ is the air density and v is the wind speed. The density of air is determined using the equation of state, the hydrostatic equation and the equation of the temperature variation in altitude from the vertical gradient of air temperature.
Multiplying the power generated by each wind speed by the probability of each speed the distribution of speeds Weibull, we obtained the distribution of wind energy for the different speeds, which are called the power density.

To estimate the atmospheric pressure, it was used the barometric formula. The values of air temperature and air pressure to the projected level of 60m to calculate the average density of air and power density. The usable power is given by

$$P = c_p \frac{1}{2} \rho v^3 \quad (5)$$

The greater the length of the blades of the wind energy, the larger the area it covers and thus more mechanical energy can be extracted from the wind. However, we must take into account two factors: the turbines normally operate only when the wind speed is above the 3-5ms^{-1} and below the 25ms^{-1} and the wind generators are constrained by their income. Also, normally the efficiency recorded and used is considered to be 20%.

The expression (5) determines the maximum power extracted from a given wind speed.

The developed algorithm grants the power to model the parameter c_p. An assessment was made for different turbines available on the market. Although the results were very close, there were exceptions for some types of turbines and stop booting at different wind speeds. In the algorithm, we assumed to accept an average value for the calculation of power.

The density function for probability of the wind, not only allows the analysis of the distribution of winds, but also to calculate the energy produced at a certain time, and thus shaped by the expression

$$E_{annual} = t \int_{v_i}^{v_f} F_D F_p \, dv \quad (6)$$

where t represents the time in hours when the turbine is in operation, F_D the probability density function of wind and F_p power function.

However, assuming that the wind speed is expressed in discrete steps, the expression (6) can be written as

$$E_{annual} = t \sum_{v=v_i}^{v=v_f} F_D F_p \quad (7)$$

4 Results and discussions

It was made a physical interpretation of the characteristics of wind and wind power annual and for seasons (Spring, Summer, Autumn and Winter).

The Figures 3 to 10 shows the behavior of the weighted average wind speed, the distribution of wind (histogram), the distribution of wind (wind rose), the distribution of wind speed (Weibull), the distribution of energy, average wind speed - when there is wind (histogram and wind rose) and its distribution angle annual.

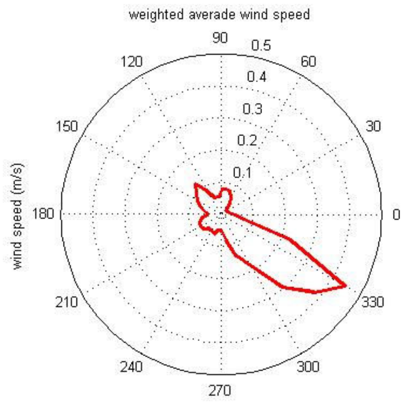

Fig. 3 - Weighted average wind speed (annual)

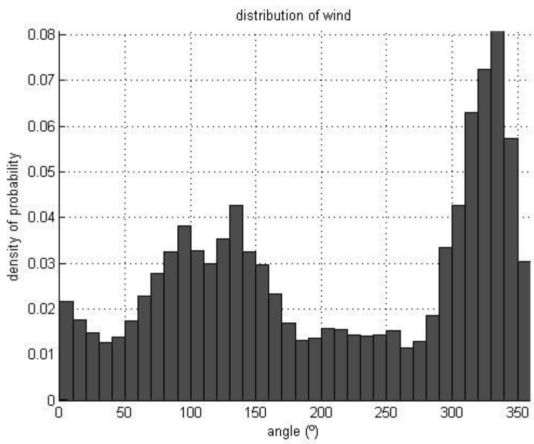

Fig. 4 – Distribution of wind (annual)

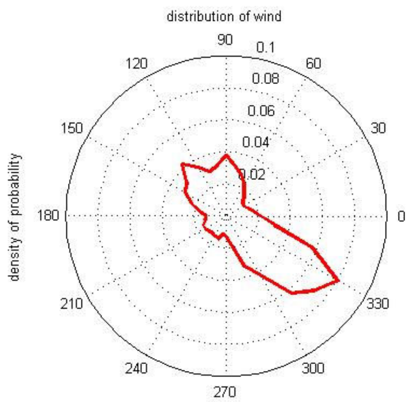

Fig. 5 –Wind rose – distribution of wind (annual)

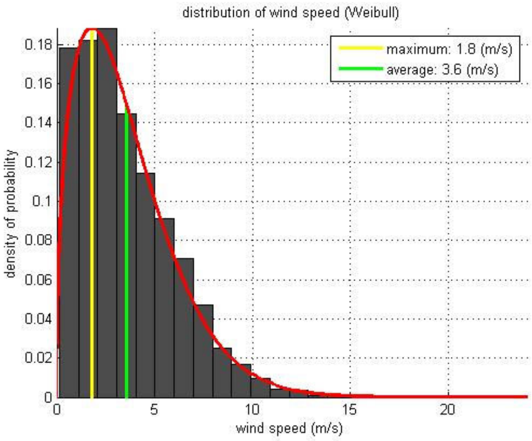

Fig. 6 – Distribution of wind – Weibull (annual)

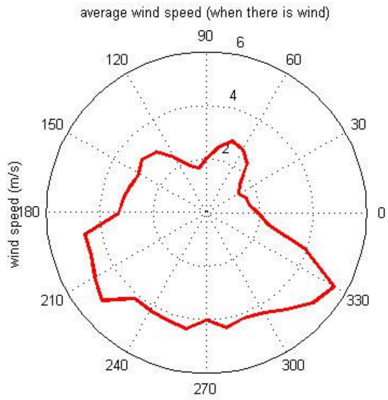

Fig. 9 –Wind rose – when there is wind (annual)

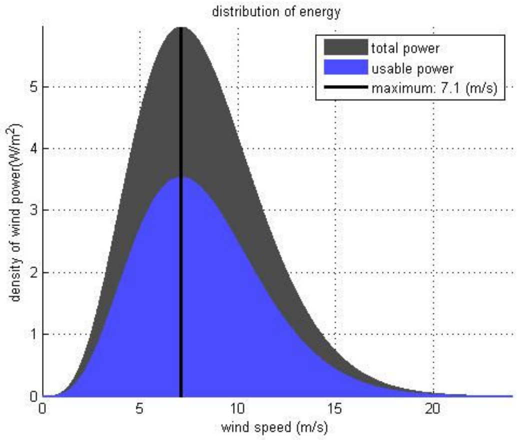

Fig. 7 – Distribution of energy (annual)

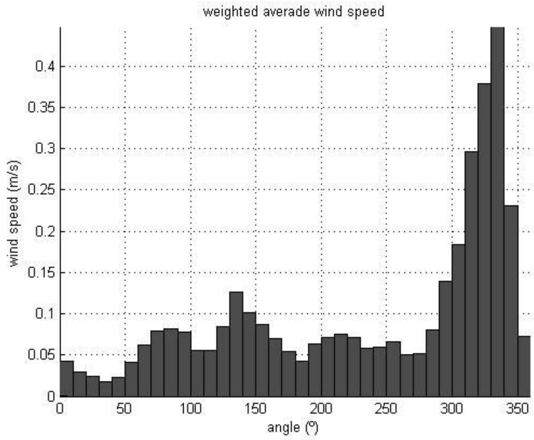

Fig. 10 –Histogram weighed average wind (annual)

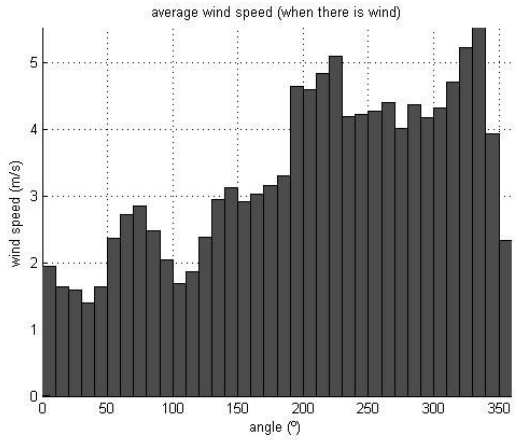

Fig. 8 –Histogram - when there is wind (annual)

The research for each month in the year (include all data series investigated for the same month) show that from March to September the predominant wind direction is well marked (NW). January, February and October show a predominance of opposite directions. Interesting are the results of November and December showing of predominance opposite direction (SE and NW). One explanation for this change in prevalence is basically the synoptic change that influences the Iberian Peninsula.

It is known that the knowledge of a climatic region for a sufficiently long period allows us to know the wind regime. In the case of the Iberian Peninsula because of the location and semi-permanent anticyclone of the Azores can be said that the wind regime was predominantly in the North-South direction. The index of NAO (North Atlantic Oscillation) is a good indicator to determine the trend of the annual wind regimes in the Iberian Peninsula. The results shows that the winds recorded in the study area are from NW, which validates the influence of the anticyclone of Azores.

Also, it was considered important, evaluated the wind potential for each of the seasons. Figures 11 to 22 shows different graphs where we can collect information for the design of intervention strategies.

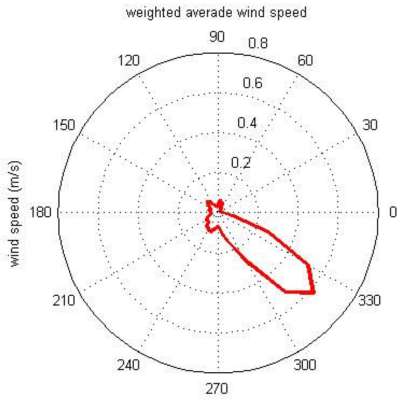

Fig. 11 – Weighted average wind speed (Spring)

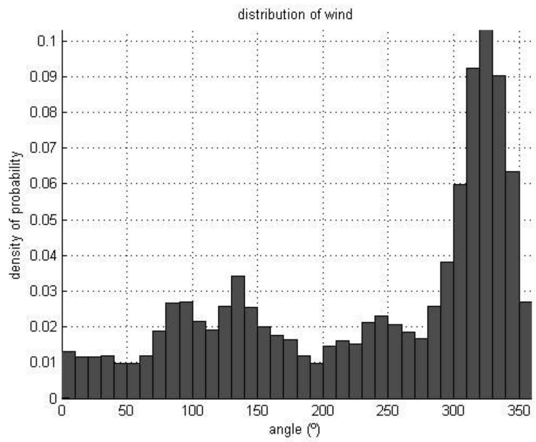

Fig. 12 – Distribution of wind (Spring)

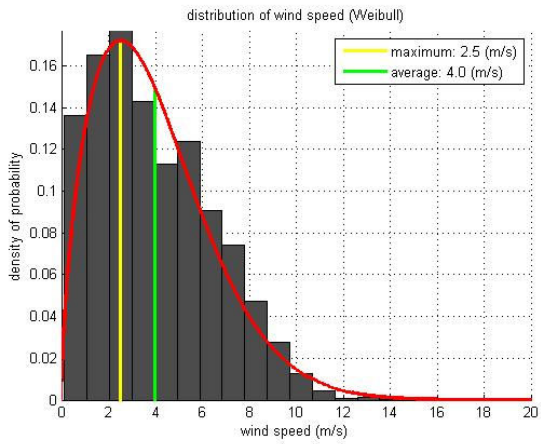

Fig. 13 –Density of probability – Weibull (Spring)

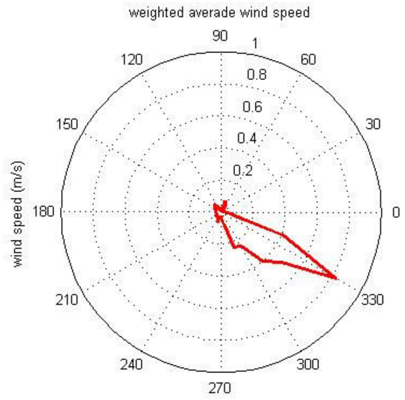

Fig. 14 – Weighted average wind speed (Summer)

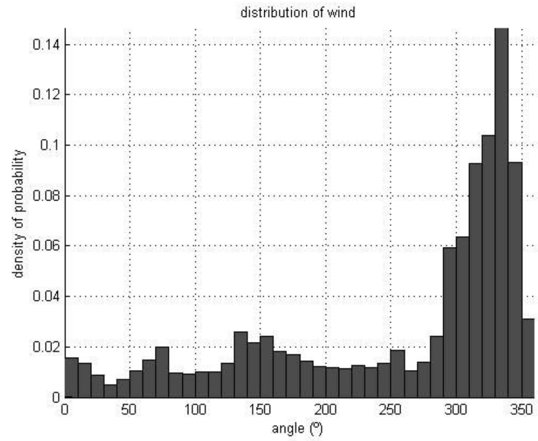

Fig. 15 – Distribution of wind (Summer)

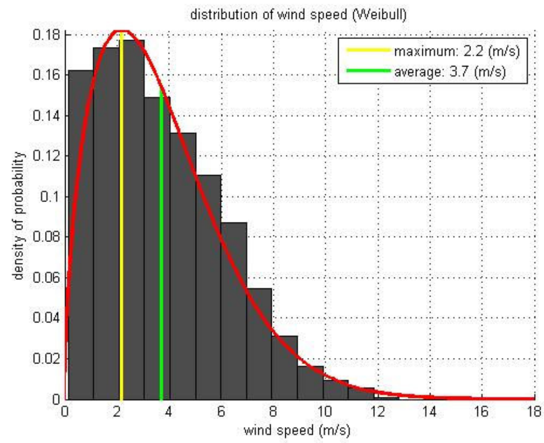

Fig. 16 –Density of probability – Weibull (Summer)

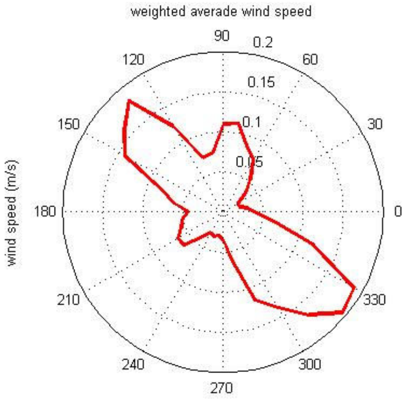

Fig. 17 – Weighted average wind speed (Autumn)

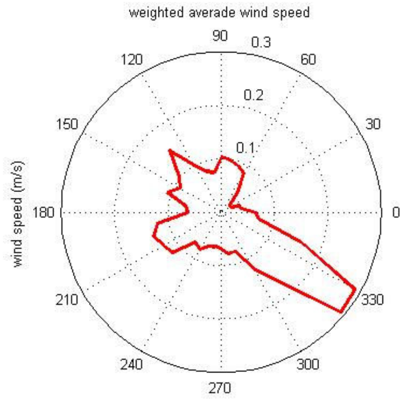

Fig. 20 – Weighted average wind speed (Winter)

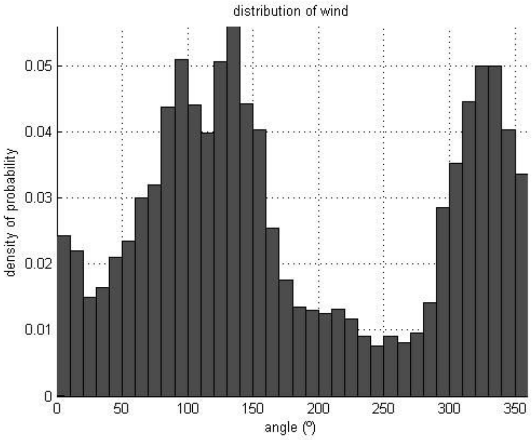

Fig. 18 – Distribution of wind (Autumn)

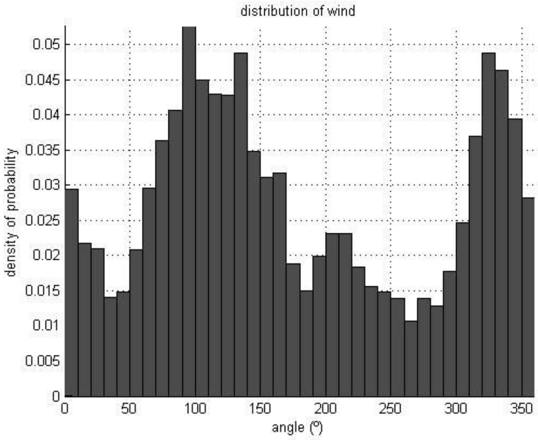

Fig. 21 – Distribution of wind (Winter)

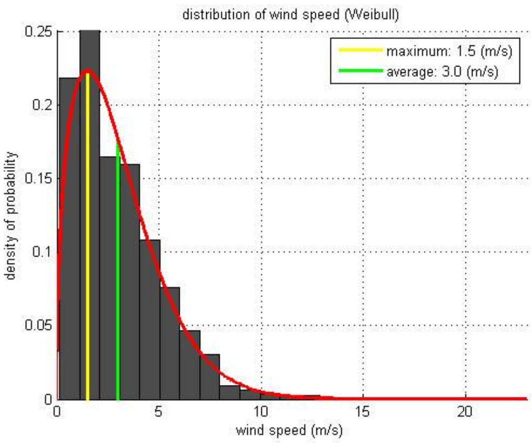

Fig. 19 –Density of probability – Weibull (Autumn)

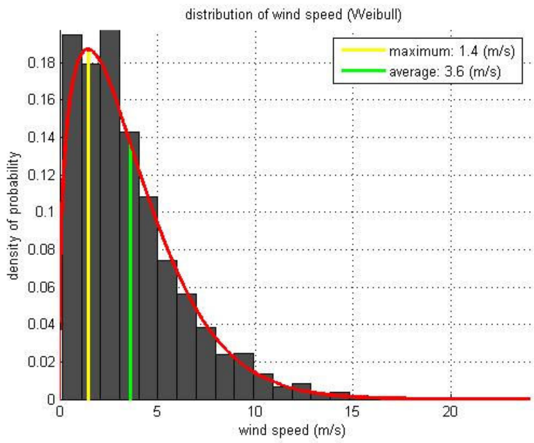

Fig. 22 –Density of probability – Weibull (Winter)

The results shows that the Spring and Winter are the seasons that features the best position to record the best wind potential and therefore better energy available.

A comparative analysis between months shows clearly that the month of March and May are what provides the best conditions for wind energy potential.

The density of probability (Weibull distribution) to

March and May are shows in Figures 23 and 24.

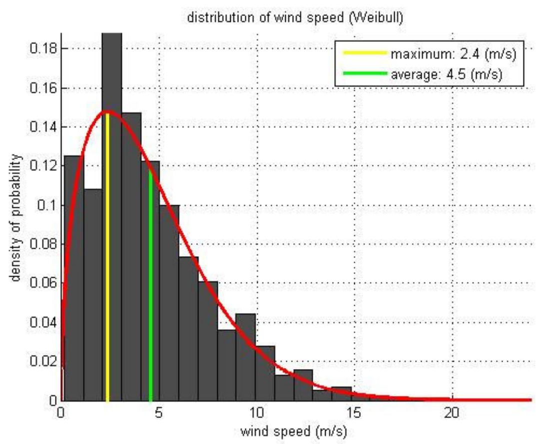

Fig. 23 –Density of probability – Weibull (March)

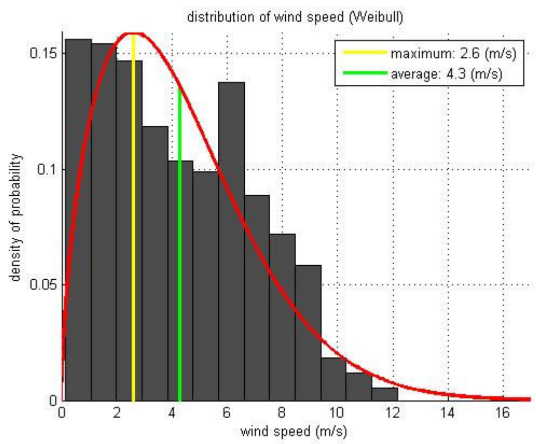

Fig. 24 –Density of probability – Weibull (May)

The observation of Table 2 indicates that Spring and Winter record best values. The worst results are recorded during the Autumn. The nomenclature AN, SP, SU, AU, WI, mc, my indicates annual, Spring, Summer, Autumn, Winter, March and May respectively.

Table 2 – Values determined for different situations (Wind turbine with 80m diameter)

	average wind speed	total wind power	usable wind power	wind to maximum power	electric power estimated	electric energy estimated
	m/s	W/m^2	W/m^2	m/s	W	GWh/year
AN	3.6	46.8	27.7	7.1	39399.4	0.345
SP	4.0	53.1	31.5	7.3	45626.1	0.400
SU	3.7	43.5	25.8	7.0	36385.8	0.319
AU	3.0	30.0	17.8	6.0	22350.6	0.196
WI	3.6	58.5	34.6	7.7	51209.7	0.449
mc	4.5	95.9	56.8	9.0	89061.1	0.780
my	4.3	65.0	38.5	7.9	58042.5	0.508

The Table 2 show the estimated annual electric energy. Unequivocally Spring and Winter offers the best result, which are conditioned by the value recorded for May and March. Also, are showed values the average wind speed, total wind power, usable wind power, wind to maximum power, electric power estimated and electric energy estimated.

It is good to note that the data given in Tables 1 and 2 are designed in terms of annual values, e.g., the data for each month or season of the year are projected in terms of 365 days in order to be comparable with the value of number of years representing the 365 days of the year.

In Figure 25, it is shown a picture of the program evaluation of wind power, where the options menu is. It is represented the direction of the winds, the evolution of winds during the year, some statistics about taking strategies (annual energy the height of 10m, the annual energy level is chosen, the maximum energy from the speed of the turbine inlet turbine, better days the year, worst day of the year, and other information).

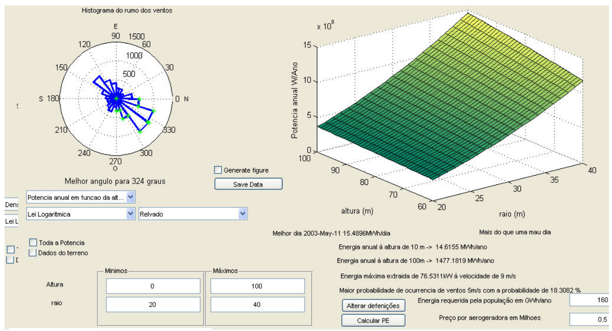

Fig. 25 - Panel: program evaluation of wind power

The algorithm also allows considering the characteristics of wind turbines available on the market and maximizing the energy extracted from the turbine. It is also determined the distribution of winds (probability density versus angle probability density versus speed, maximum and average speed through the Weibull distribution, energy distribution, mean wind speed (when no wind and when there is no wind), total power, usable power and speed to the maximum density power.

Additionally, there is a need to understand the relationship between breezes and wind power potential [17].

5 Conclusions

Today, the issue of climate change is addressed by different policy areas, including research, social, economic, political.

Global warming is influenced by the emission of greenhouse gases is a major challenge both at the country level and globally. The World Conferences held in Bali and now more recently in Copenhagen were more an attempt to alert about the use of fossil fuels.

Renewable sources of energy are an excellent alternative to minimize the problematic issues and energy policy and social distress that lies ahead.

Technical studies are important for economic and financial know the wind potential of a site.

We consider it of utmost importance to perform an economic analysis about the goals of the Government, cost of technology, global investment in wind farms already installed, assessing profitability of wind farms installed and assessment rates.

This research evaluated the characteristics of the wind with annual data recorded during two years.

The results obtained allow the knowledge of the characteristics of wind in the area of study and experiencing the energy extracted from a wind turbine.

The knowledge of the distribution statistics to evaluate and select a wind turbine that provides the best efficiency was very important.

The Weibull distribution has indicted that the winds frequently experiencing slow speeds. There are wind turbines on the market are beginning to work with winds whose intensity is above $3ms^{-1}$, reaching a maximum power with intensities of $11.2ms^{-1}$ and block system for winds whose intensity are greater than $24ms^{-1}$. There is currently being investigated the influence of wind in wind power potential.

The algorithm is being modified to be able to indicate the number of turbines to be installed in the study.

Additionally, a parallel study is underway to exploit wind up to 4m/s (usually negligible in most turbines available on the market)

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