European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Characterization of wind energy potential and availability at Beira Interior (Portugal)

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Abstract. The present work intends to evaluate and to characterize the wind potential in Beira Interior (Portugal).To do that it will be examined the installed capacity of wind energy, as well as their potential in that region. Due to the development of such systems for energy production is necessary to optimize and innovate the procedures that are related to the conversion of wind energy.

The analysis is based on meteorological data and on the characterization of the various systems of exploitation of wind energy, including the type of turbines used, their operating parameters and their relationship with the wind. This work do a comprehensive analysis in order to understand the variations of the power curve of a particular wind park, with the variability of wind speed and the influence of several variables, such as seasonal changes; effects of treadmill; the presence of obstacles, the roughness of the ground and the local altitude, in the oscillation of the transformation of wind energy.

Finally, the wind data information about Beira Interior will be integrated in the national portuguese general Framework.

Key words

Wind energy potential, Beira Interior, wind and electrical energy, wind availability

1. Introduction

Around 1 to 2% of energy from the sun is converted into wind energy. The differences in temperature lead to a consistent air circulation. The regions around the equator at 0 ° latitude, are more heated by the sun, than the areas across the globe. The hot air is lighter than cold air, so it will rise until it reaches an altitude of 10 km. Due to the rotation of the Earth, any movement in the northern hemisphere is deflected to the right when viewed from our position of the Earth (in the southern hemisphere the shift is to the left). This apparent bending force is known as the Coriolis force.

2. Coriolis Force

The Coriolis force is an inertial force with characteristic and visible effects at the Earth.

The railways wear out more quickly on one side than the other as well as at the river basins, where loose particles diverge from one bank to the other. The side is determined by the local hemisphere. In the northern hemisphere the wind tends to rotate counterclockwise, when approaching low pressure areas. For the southern hemisphere, Coriolis force has opposite direction and wind blows clockwise direction [11].

3. Global Winds

The wind rises from the equator and moves north and south in the higher layers of the atmosphere. Around 30 ° latitude in both hemispheres the Coriolis force prevents the wind move beyond. At this latitude, as a zone of high pressure, the air begins to descend again. When the wind rises from the equator appears a zone of low pressure around the ground level, which pulls the winds from north and south. At the poles, there will be high pressure due to cold air.

The troposphere, where all types of weather phenomena occur, has a thickness of approximatly 10 km, which represents 1/1200 of the diameter of the Earth. The dominant wind directions and its magnitude are important for the location of wind turbine, since the objective is to place them in an area with the least possible obstacles affecting the dominant wind directions. The local geography can influence the results of the wind energy transformation very strongly.

4. Surface Winds

The winds are much more influenced by the Earth at altitudes up to 100 meters. The wind is caught by the roughness of the surface and the obstacles. The wind directions near the surface will be slightly different from the geostrophic winds due to the rotation of the Earth and the influence of hydrodynamics boundary layers of fluids around.

5. Local Winds

Local winds are of particular importance in the case of large scale wind systems, i.e., the wind direction is influenced by the sum of the effects at global and local scales. When the large scale winds are mild, local winds may dominate the wind regime.

6. Mountain Winds

The mountain regions show very specific climate models This is the case of the valley wind is originated on the slopes of the mountain. The air density, nearby warming slopes, decreases and the air rises over the surface of the slope. During the night the air movement and wind direction is reversed, becoming a wind flowing downhill.

7. Parameters of Wind Energy

The air mass movement has kinetic energy that can be used to produce electricity. The wind blowing the blades of a wind turbine produces a mechanical work which in turn allows the generator to convert into electricity. The amount of energy that the wind must have before moving the rotor blades depends on three parameters: wind incident velocity; air density and area swept by the rotor

7.1 Wind Velocity

The velocity at which the air mass passes through the blades is crucial, since the kinetic energy power of the wind increases proportionally to the cube of the velocity at which it moves. If the velocity double, the energy power produced will be eight times greater.

7.2 Air Density

In order to understand the wind formation, is important to know the behavior of the air density that changes with the temperature.

The heating of the Earth surface warms the air layer next to it, increasing the distance between the particles that compose it. Consequently, the layer is less dense, causing a decrease in local atmospheric pressure and the formation of a center of low pressure. The cold air, in turn, stimulates the appearing of centers of high pressure. Therefore, as hot air mass rises into the atmosphere, the cold air mass takes its place. This air mass movement originates the winds that blow-over the earth's surface, from the centers of high pressure to low pressure ones.

The energy of the wind increases in proportion to the mass per unit volume of air, which under normal conditions (at sea level, at a pressure of 1013 bar and a temperature of 15 ° C) is 1,225 kg m^{-3}. This means that when the air cools, becomes more dense and it will therefore transfer more energy to the turbine.

7.3 Area swept by the rotor

Concerning the swept area, the more air kinetic energy a wind turbine is able to capture, more energy is passing through. Following the example of a rotor of a turbine of 1 MW of nominal power, the rotor having a diameter of about 54 meters, it sweeps approximately an area of 2300 m^2.

8. Betz Limit

The power coefficient of a wind turbine was introduced by the theory of Betz. Betz limit shows that, the best wind turbine, of 2 or 3 blades and horizontal axis, can convert a maximum of 59% of wind energy that reaches the rotor. Nowadays, due to losses in the process of transformation of energy, a wind turbine takes about 40% of the kinetic energy of the wind.

Betz theory modelizes the air passage before and after the turbine, like the stream tube presented in Figure 1.

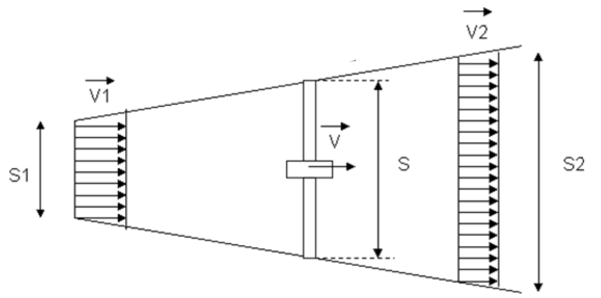

Figure 1 – Schematic representation of the stream tube of the air before and after the passage through the turbine, beeing S, the cross sectional area of the rotor blades and *V*, the wind velocity.

9. Wind Rugosity

Approximately one kilometer height from the soil surface, there is still some influence on the wind perturbation. In the lower layers of the atmosphere, the wind velocity is affected by the friction with the surface.

So it is crucial to know the topography of the area in which one wants the implementation of wind turbines. Thus, one can distinguish the concepts of roughness of the ground, the influences of obstacles and of the boundaries of the terrain.

Those factors point to the height of about 70/80 m for wind towers, since it can mitigate some of the refered problems.

The region of Beira Interior is not so much urbanized and industrialized, as other regions of the coast. The region of Beira Interior has a very important mountainous profile of different size and altitude, being also characterized by its high altitude patamars which, therefore, makes this region (especially in the north) one of cooler environment, where the tunnel and hill effects are very influential.

9.1 Tunnel Effect

In a close zone between mountains or high buildings, the “tunnel effect” is observed, since the air is forced to pinch itself to cross between the mountains and hence its velocity increases considerably. This process is knowed as "tunnel effect”. Having a normal wind velocity in open environment of 6 $m.s^{-1}$, in a natural tunnel effect the wind velocity can reach 9 $m.s^{-1}$.Installing a wind turbine in a tunnel of this type is a smart way to get wind speeds higher [11].

For the case of high hill slopes, there may be undesirable turbulence in this area, once the wind have different directions.

9.2 Hill Effect

A common way of implementing wind turbines is to place them on the top of the hills. The advantage is to have a perspective, as broad as posible, for the direction of the prevailing wind in this area. On the top of the hills, the wind velocity is higher compared to surrounding areas. This happens because the wind is compressed against the mountain, and the air reaching the top of the hill can be re-expanded to areas of low pressure.

10. Areas of environmental impact

There are, however, some increased precautions to take into account when one wants to install a wind park in a region with endangered species or near the movement of migratory corridors, especially during the installation of the machines.
The use of land classified as national ecological reserve for the installation of wind parks requires an environmental impact study in order to preserve the natural habitats.

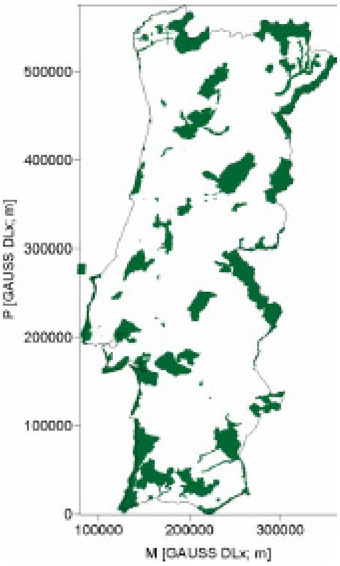

Figure 2 – Map that shows the collected data about the areas classified as preserve environment [10]

Usually it is required to developers of wind parks, a study of incidence and/or environmental impacts (depending on the classification of region) to be included in the design and licensing of them. Thus, in order to introduce this type of limitation, information about the mapping of classified areas as ecological reserves must be presented (Figure 2).

11. **Production of Electrical Energy**

The descentralized systems for the production of electrical energy need to improve the distribution network of electricity.
There are other potentially useful applications in terms of the promoters of wind parks, such as: calculating distances between points of connection to the network transmission; detection of areas with potential for the installation of wind farms and identification of regions of interconnection capacity available. This methodology should be implemented for the region.

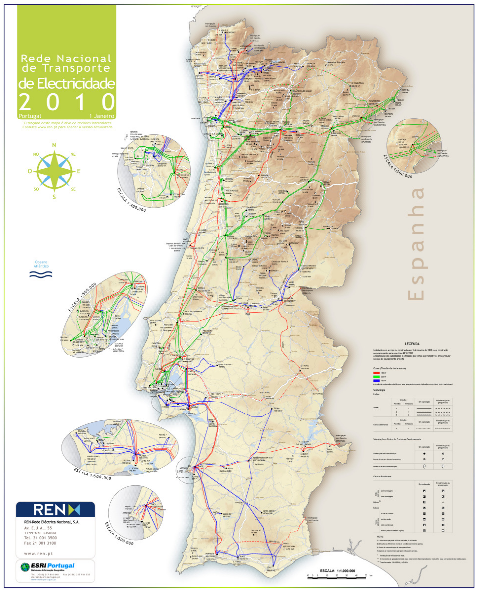

Figure 3 – The figure presents the points of connection to the network published [12]

The Portuguese territory presents a great inequality in the distribution of population and of the industrial and other activities related to the energy consumption. Because of higher population densities in the coastline regions there is a concentration of transmission lines and distribution of electricity in the area. For the interior regions and other remote areas there is a reduced number and capacity of transmission lines.
This situation means that in most cases there is a need to build lines of large length and economic cost to connect the substation to the existing network of wind parks. The economic costs associated with the instalation of the lines are currently supported, mostly, by the promoters, (in addition to incentives from the government). These costs are very high, and can call into question many projects.
Figure 3 presents the points of connection to the network published by DGGE (Direcção Geral de Geologia e Energia) and their relative connection available in 2010 and planned to 2013.

12. Characterization of wind parks in Beira Interior

Acording the Faculty of Engineering of the Oporto University (FEUP), the district of Castelo Branco has 425 MW of installed capacity and the district of Guarda has 152 MW, approximatly. So the region of Beira Interior has 577MW of 3338 MW of wind energy installed in Portuguese territory, which means, about 20%.

12.1 Guarda District

Some characteristics of the wind parks at Beira Interior, district of Guarda, will be pointed out:
Videmonte, belonging to the company Parque Eólico Serra do Ralo SA. Its production started in 2006 and currently has 16 wind turbines that make up 32 MW of installed capacity. It is located in Serra do Ralo, Cadafaz, county of Celorico da Beira [17].

Guarda, belonging to the company Vento Central Reunidas - CENTEOL SA. Its production started in 2007 and currently has 4 wind turbines that makes up 8 MW of installed capacity. Among these turbines only 2 entered service in 2008 (4 MW). It is located in Zambito, S. Vicente, district of Guarda [14].

Mosteiro, belonging to the company Molds - Wind Energy SA. Its production started in 2004 and currently has 7 turbines which make up 9,1 MW of installed capacity. It is located in Serra do Mosteiro Santa Catarina, county of Sabugal [15].

Terreiro das Bruxas, belonging to the company SOLTAVENTOS – Produção de Energia do Vento. It production started in 2006, with 1 that makes wind turbine 1 MW of installed capacity. It is located in Serra do Mosteiro, Casteleiro, county of Sabugal [14].

Dirão da Rua, belonging to the company SOLTAVENTOS – Produção de Energia do Vento. It started the production in 2004, with 2 turbines which make up 2.6 MW of installed capacity. It is located in the place Cabeço do Castanheiro, Sortelha, county of Sabugal [14].

Alvoaça, belonging to the company ENERNOVA - Novas Energias SA. It started the production in 2007. The wind park of Serra da ALVOAÇA consists of 10 wind turbines of 2 MW of power unit, which corresponds to an installed power of 20 MW. It is located in Serra da ALVOAÇA, Alvoco da Serra, county of Seia [16].

Pedras Lavradas, belonging to the company ENERNOVA - Novas Energias SA. It started the production in 2007, with 7 turbines that make up (14) 16.1 MW of installed capacity. It is located at Teixeira, county of Seia [14].

Mosqueiros, belonging to the company GENERG – Gestão de Projectos e Energia. It started the production in 2008 with 4 wind turbines of 2 MW each, which offers 8MW of installed capacity. It covers the municipality of Guarda – Seixo Amarelo e João Joanes. The expected production is 22 GW.h / year average [14].

Trancoso, belonging to the company GENERG –Gestão de Projectos e Energia. It started the production in March 2008 with 14 turbines (2MW each) which make up 28 MW of installed capacity. It is located in the municipality of Trancoso. Expected annual production is 81 GW.h/year average [14].

Sabugal, belonging to the company TECNEIRA – Tecnologias de Energia. It is currently under construction and should begin production in 2008 with 19 turbines for a total of 39,9 MW of installed capacity. It is situated in Sabugal Velho, county of Sabugal. It is expected an average annual energy production of 109,2 GW.h [18].

The district of Guarda has currently 23 power stations in operation, which account for a combined output of approximately 426,5 MW. Almost four-fifths of the installed capacity energy prooduction in this district is coming from water (79,3%), and the central Pocinho has a significant role in the weight of this type of energy [14]. Furthermore, one fifth of the installed power in the region (20,6%) is provided by wind farms, among which stands out Videmonte due to their size [14].

12.2 Castelo Branco District

Some characteristics of the wind parks at Beira Interior, district of Castelo Branco, will be pointed out:

Pinhal Interior, belonging to the company GENERG - Ventos do Pinhal Interior – Energias Renováveis. The production started in 2005 and currently has 63 turbines that make up 144 MW of installed capacity. The wind park is divided into several subparks spread over several counties in the district of Castelo Branco. The expected annual production is 336 GW.h/year average. [19]

It's one of the 3 largest wind farms in Portugal. The production of clean electricity, at the wind farm of Pinhal Interior, will bring environmental benefits, reducing import of petrol in the order of 110 thousand tonnes per year, preventing from being released into the atmosphere about 194 thousand tons/year of CO_2. [19]

Cabeço da Rainha I, belonging to the company ENERNOVA - Novas Energias SA. The production started in 2000 and currently has 20 wind turbines that make up 16 MW of installed capacity (3 of them having ~~3~~ a power of 2 MW, unit). It is situated in the Cabeço da Rainha – Serra de Alvelos, near the place João Porco, county of Oleiros [19].

Penamacor, belonging to the company LESTENERGIA – Operação de Parque Eólicos SA. The production started in 2006 and currently has 39 turbines that make up approximately 80 MW of installed capacity. This wind farm came into operation in two phases of 40 MW each, with the subparks Penamacor I and III (a) starting the production in 2006, while subpark Penamacor II (b) has entered into the network in 2007. It is located in the place of Monte Santo Estevão, Meimão, municipality of Belmonte [19].

Vergão, belonging to the company GENERG - Ventos de Proença-a-Nova – Energias Renováveis. The production started in 2003 and currently has 10 turbines that make up 13 MW of installed capacity. It is situated in the place of Vergão in the municipality of Proença-a-Nova. Its annual production is 27,7 GWh/year, average [19].

Perdigão, belonging to the company GENERG - Ventos do Pinhal Interior – Energias Renováveis. The production started in 2007 and currently has 1 turbine that makes 2 MW of installed capacity. Has only one wind turbine of 78 meters high. Located in the place of Perdigao Fratel, municipality of Castelo Branco. The expected annual production is 3,6 GW.h / year, average [19].

Cabeço da Rainha II, belonging to the company ENERNOVA - Novas Energias SA. The project is under consideration since 2006 and is expected to have 17 turbines in order to obtain 26 MW of installed capacity. It is situated in Cabeço da Rainha - Serra de Alvelos, near the place of João Porco, county of Oleiros [19].

Gardunha, belonging to the company GENERG - Winds of Gardunha – Energias Renováveis. The production staretd in December 2006 and currently has 57 wind turbines of 2 MW each, in order to get 114 MW of installed capacity. It is located in the municipalities of Castelo Branco, Fundão and Oleiros. The expected annual production is 277 GWh / year, average [19].

13. Caracterization of Wind Farm of Gardunha

The Figure 4 presents anemometric stations installed in the database INETI, and some other stations of the same instituation that are relevant to the characterization of the wind energy resource in Portugal.
Anemometric station designated "IN_32", is located in Gardunha, inside in the wind park mentioned above.

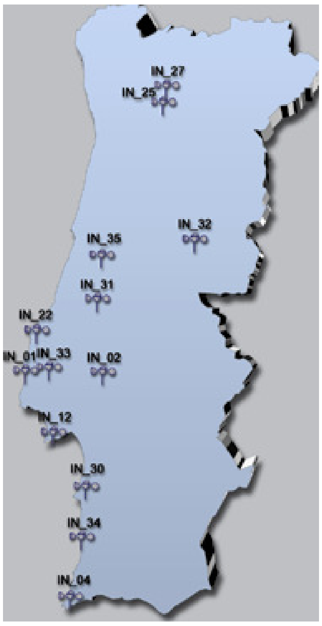

Figure 4 –The figure represents anemometric stations installed in the database INETI [4]

This anemometric station from INETI, is situated in a mountainous zone at 1220 meters altitude and coordinates (m) (625750, 4437825). The land surrounding the mast is essentially characterized by low vegetation. In the surrounding area there are installations of telecommunications and satellite retransmission of television [4].

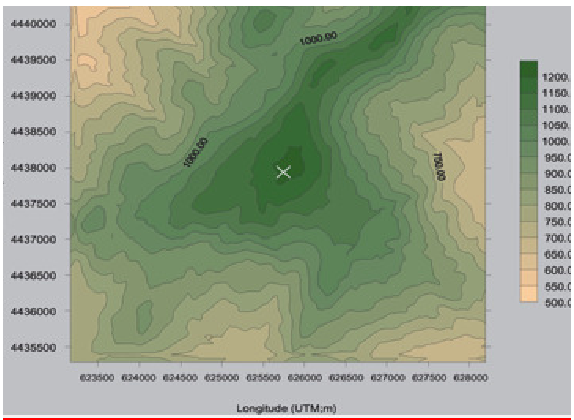

Figure 5 - Map of contour lines representative of the anemometric station IN_32 – Gardunha [4]

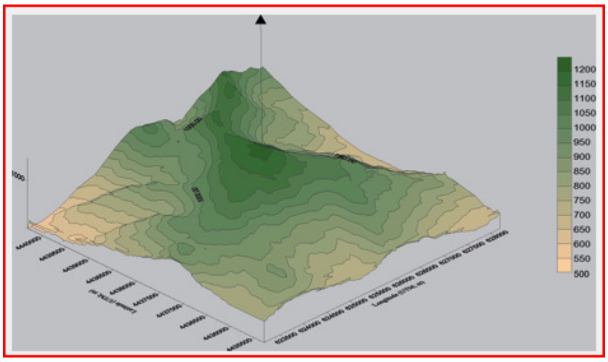

Figure 6 - Three-dimensional model representative of the anemometric station Gardunha [4]

At Gardunha wind farm is installed an anemometric mast type telescope instrumented at two levels: level of 10 m - anemometers cups; level of 20 m anemometer cups and heading sensor.
At the base of the anemometric mast is installed a system of data acquisition and storage.
Figure 6 presents also the orography of this mountainous region of Gardunha. The orographic shape contributes for the hill and tunnel effects, as referred previously.

13.1 Windrose and Weibull distribution

The information presented comes from data obtained at 20 meters high, inside the installation. In Figure 8, A and k represent, respectively, the scale parameter and shape parameter of Weibull distribution

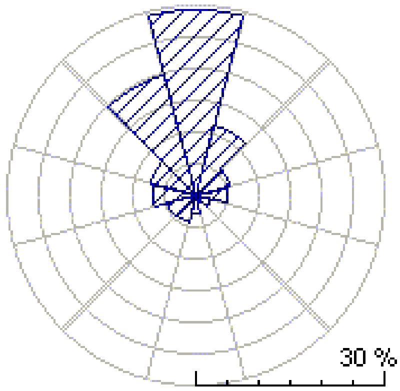

Figure 7 – Windrose feature of the anemometric station IN_32 – Gardunha [4]

To understand the distribution of wind velocities and frequency of variation of the directions, you can draw the so-called Windrose, based on weather observations.These representations are extremely useful to decide the placement of the wind turbines, in order to have the largest wind energy with respect to a particular direction, to find the fewest possible obstacles for that angle, and to choose an area, as smooth as possible.
The figure 7 shows the windrose characteristic of an anemometric station IN_32–Gardunha. Most of the energy comes from the Nort so it is not necessary great concern about the obstacles. The most convenient in these cases is to perform observations during several years in order to obtain a reliable wind data and average values.

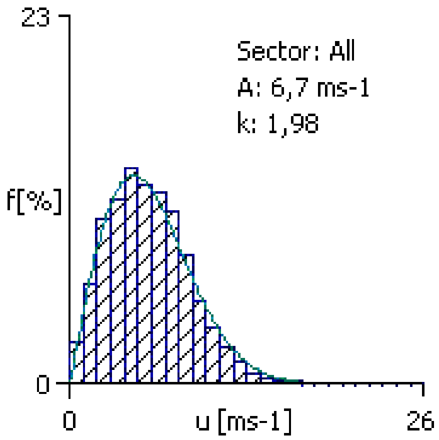

Figure 8 - Weibull distribution characteristic of the anemometric station IN_32 – Gardunha [4].

The figure 8 shows the Weibull distribution of the wind velocities for the anemometric station of Gardunha, whose scale (A) factors and shape (k) are 1,98 and 6,7, respectively. The annual average wind velocity measured, was approximately 5,9 $m.s^{-1}$. The combination of these values for wind velocity and k (shape factor) value, of around 2, gives to Gardunha good conditions to host wind turbines, according Weibull distribution. When the slopes, and the air nearby, is warming, air density decreases, and the air rises over the surface of the slope. During the night the air movement and wind direction is reversed, becoming a wind flowing downhill. Table 1 presents the data of the average velocities at 10 m and 20 m above the ground, the power flux, shape parameter (k), scale parameter (A), obtained at the anemometric station IN_32 – Gardunha, between the months of April (1999) and May (2000).

Table 1 – Data values of anemometric station IN_32 – Gardunha (1999/00), with an average velocity at 10 and 20 meters above the ground, power flux, shape parameter (k), scale parameter (A) [4].

mês	vel. Média (10m) [m/s]	vel. Média (20m) [m/s]	Fluxo de potência (20m) (W/m2)	A (20m) [m/s]	K (20m)
Abril (1999)	7.0	7.7	551	8.7	1.94
Maio	5.8	6.4	227	7.1	2.85
Junho	5.4	5.9	207	6.6	2.32
Julho	4.7	4.9	123	5.5	2.26
Agosto	4.6	4.9	135	5.6	2.08
Setembro	5.4	5.9	297	6.6	1.70
Outubro	6.5	7.0	435	7.9	1.88
Novembro	7.3	8.3	581	9.4	2.30
Dezembro	7.9	8.4	743	9.4	1.85
Janeiro(2000)	5.1	5.4	218	6.0	1.69
Fevereiro	4.8	5.3	187	6.0	1.87
Março	5.4	6.0	275	6.7	1.83
Abril	8.8	9.6	735	10.7	3.17
Maio	3.9	4.3	106	4.8	1.77

Since 2000 Gardunha region had good conditions to accommodate wind parks. However this wind models can change from year to year. So it is necessary to obtain wind data of over several years, so we can obtain reliable information and confidence for many working years.
For the designers of wind parks usually the data available is concerning to one year of measurements and ideal weather observations. There is a need for using long-term sustainability of the stations in order to obtain an average data from the most reliable way.

13.2 Daily profile of Wind Speed

In figure 9, the continuous line represents the velocity of the wind for 20 m above the ground; the discontinuous line represents the wind velocity profile for 10 m. There is a difference which may be due to the presence of obstacles such as vegetation that don´t allow higher wind speeds. This requires a high height of wind turbine.

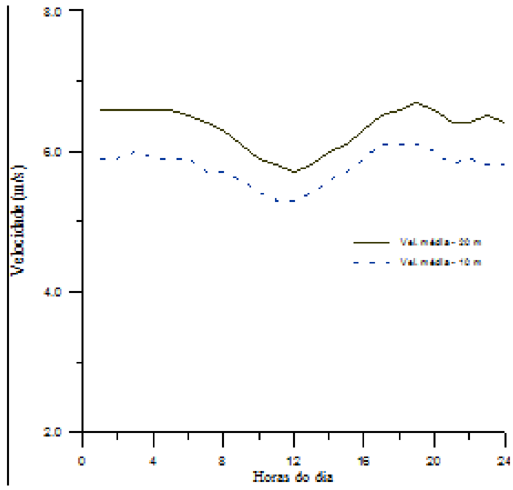

Figure 9 - Daily profile of wind velocity at the anemometric station IN_32 - Gardunha (h = 10; h = 20m) [4].

14.Environmental Impact

Despite the strong human intervention, Gardunha is still an area with great potential for preservation. However, it is an area vulnerable to agricultural activities, forest fires, and destruction of natural vegetation.
The anemometric station of Serra da Gardunha (see figure 10) is located within an area covered by the Natura 2000. It covers an area of 5892 ha, with a maximum altitude of 1227 m and a minimum of 450 m. The coordinates of the center of this area are: longitude W7º 29' 44''and latitude N40° 7' 1'' (see figure 10) [4].

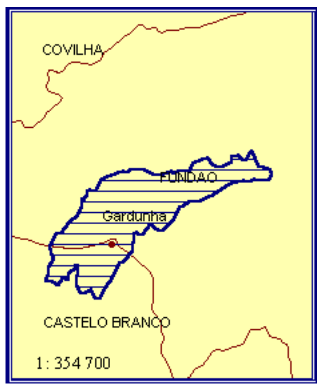

Figure 10 – The figure represents the localization of the anemometric station of Serra da Gardunha [4].

Concerning noise impact, the following figure represents a study in Gardunha where it can be observed the noise level contour (see figure 11). This shows and demonstrates how the registration of the noise can inform us about the impact that the wind conversion systems can cause in the region.

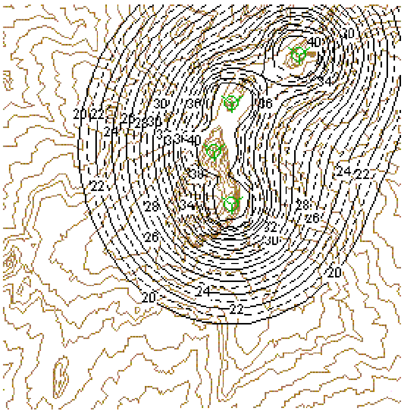

Figure 11 - The figure represents a study in Gardunha where it can be observed the level of noise impact [4]

15. Discussions and Conclusions

The results obtained and presented here show that, despite the high potential in Portugal for the exploitation of wind energy, the main limitations can be the high percentage of the total land area with some type of environmental classification. However this does not mean a barrier to the development areas of wind conversion systems. The major hindrance to the wind development conversion systems can be the limited capacity of the regional electricity grid and as a consequence a freezing in licensing processes.

The unequal distribution of capacity of the power system and its concentration in populated regions near the coast is an added difficulty of making full use of wind power in Portugal. Now the wind potential is converted only in the interior and mountainous regions of Portugal.

A "redistribution" of the network planned capacity would be a good solution to this problem and would contribute to the increased reliability and expansion of the service.

The wind project in Gardunha is undoubtedly the largest wind conversion investment in the mountains and meets the proposed objectives like, the production of electricity, the approaching between the two or three counties covered by the upgrading of some infrastructure and accessibility to the mountain and the contribution to an integrated plan for prevention and firefighting.

In this study the data used was obtained from the wind park of Gardunha, overlooking and only 14 months between the years 99 and 2000. In the future, the goal is to do a more extensive analysis of the wind parks of the region of Beira Interior, taking into account several years in order to get mixed and reliable results, allowing higher quality in the characterization of wind power at Beira Interior of Potugal.

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[19]http://wikienergia.com/~edp/index.php?title=Centrais_el%C3%A9ctricas_no_Distrito_de_Castelo_Branco

[1] INETI is the largest public sector R&D institution in Portugal, focused on providing services to the private sector.
[2] INEGI is recognised by the Portuguese Institute for Quality as an Organism of Sectorial Standardisation of technical design.