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CHARACTERISATION OF THE WIND ENERGY POTENTIAL FOR ENERGETIC PURPOSES THE PORTUGUESE CASE – 10 YEARS OF ACTIVITIES

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Abstract *Following and, simultaneously, encouraging the growing interest for wind energy in Portugal along last decade, the Engineering Faculty of the University of Porto (F.E.U.P.) and its interface institutions (INEGI, IDMEC) have been deeply involved in several actions related to the topic, mainly planing and conducting measuring campaigns and performing resource assessment studies, but also in developing and improving numerical simulation models of atmospheric flow. INEGI, in particular, has dedicated an important effort to the identification of potentially interesting sites. More than 80 meteorological stations have been operated, covering an area of about 40 000 km^2, in the scope of R&D projects, as well as under contracts and protocols established with promoters. The volume of data gathered is the equivalent of 2 complete years in 55 measuring points, being one of the most important wind date base in the country. Three 10 MW wind farms were already built after measuring campaigns and resource assessment studies conducted by INEGI and several others are now in course of project. A site big enough to allocate about 100 MW was also identified and characterised. The experience acquired in these institutions, briefly described on this communication, can be of interest for the study of zones with similar characteristics, as is the case of several regions of the South American Continent, where significant resources are expected to exist that would be important to characterise.*

Keywords: Wind energy, Measuring campaigns, Resource assessment

1. INTRODUCTION

Wind energy has conquered along the last ten years a relevant place among renewables, being pointed as an important source of primary energy for the next century. Among other applications wind is an attractive source of primary energy for electricity production, with a great global availability and low environmental impact, presenting very low external and social costs. In particularly windy sites, wind can be competitive with fossil fuels, in an economic way, even without counting on those external and social costs. When taking into

account those costs, the comparison can be favourable to wind energy in an extension big enough to permit a rapid development of the market.

Some estimations, maybe optimistic, indicate that, with the available resource and after considering the technical and environmental constraints, Europe can fulfil around 25% of its electricity needs, by using wind energy installations. In other parts of the world, with less known and still unexplored potential, wind resources are equally wide.

In any case, the predictions made in the last years have always been surpassed by the reality. By 1991, European Wind Energy Association expected to reach 4000 MW installed by the year 2000, which has been overcome in 50% by 1998. The expectations for the first years of the next century are, though, very high, as can be observed in figure 1 (EWEA, 1997).

The interest with the diversification of energy sources has been object of some important decisions, from which can be noticed the setting of a target for the reduction of the emissions of some greenhouse gases by 5,2% in relation to 1990 levels, for the developed countries, taken in Kyoto. Also recently (European Commission, 1997), the European Union adopted well defined targets for the contribution of renewable sources of energy. For wind energy, in particular, a target of 40 GW of installed capacity by 2010 was approved.

As an economic activity, wind energy reached, in some countries, an importance probably unimagined a few years ago, being a very consistent industry and presenting very high growth rates In Denmark, nowadays, there is more people working in wind energy industry and related activities, than in the traditional fishing sector.

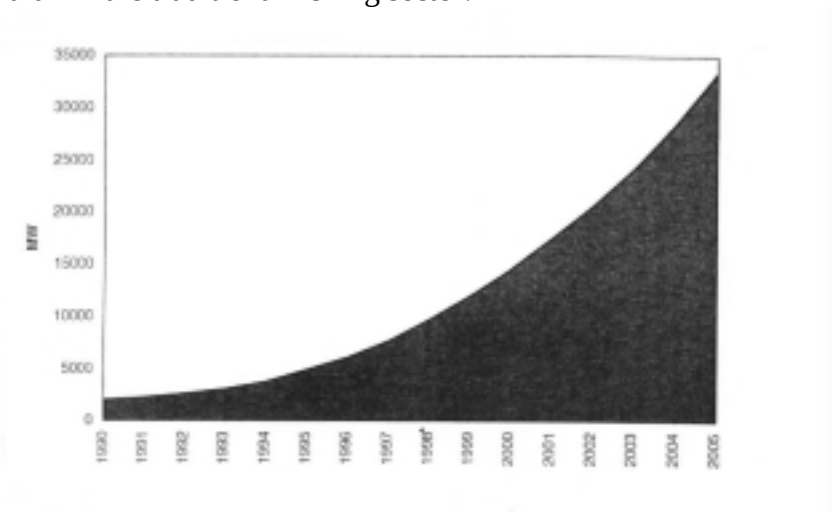

Figure 1 – Wind energy development prediction until 2005

Despite of its general availability and other advantages, some barriers to the dissemination of the technology still exist that have to be overcome. Without going to discuss this topic in detail, the unfair prices that most countries pay for renewables has to be referred. There are restrictions, varying from one country to another, and technical conditions that not all sites fulfil but, among all, the resource assessment is of major importance for the evaluation of the feasibility of any project, due to the above mentioned fact.

Starting in flat coastal areas, with emphasis in the northern European countries (Denmark Netherlands), wind energy progressively spread to zones of higher topographic complexity, due to some advantages that mountainous regions can present: interesting resource levels, higher availability of land, less restrictive legislation (noise, visual impact), among others.

The effort that has to be dedicated to the characterisation of the wind regime is as more important as the complexity of the terrain increases, due to the high variability of resource that can be found, even between relatively close sites.

The Portuguese case is a good example of this type of orography, where the complexity of the terrain imposes a careful strategy of combination between field measuring and the use of simulation codes. Without significant resources at the coastal area, with the exception of a narrow strip in the Centre and South of the country [1],the attention of promoters and specialists concentrated in the North and Centre mountainous regions where some very interesting sites have already been identified.

Most of the measuring campaigns have been conducted or participated by INEGI that also performed several resource assessment studies. The participation of F.E.U.P., INEGI and IDMEC in several European and national research projects has also been of major importance in the characterisation of the wind regime and in the evaluation of the potential of that zones.

From the 1.8 MW installed until 1996, Portugal (mainland) reached already the 45 MW by 1998, being several projects under way at this moment. The potential is, however, far to be fully exploited. After the knowledge acquired during last years and providing some barriers are removed (problems with grid connections, unfair tariff schemes) a penetration of about 3% in the national electricity productive system, which means about 240 MW of installed capacity, can be assumed as a target to be reached before the year 2005.

2. WIND RESOURCE ASSESSMENT IN COMPLEX TERRAIN

Wind energy started its development in the European continent in countries like Denmark, the Netherlands and Germany, taking advantage of the favourable winds coming from the North Sea. The flat terrains and open plains that characterise those areas have been occupied by a large number of wind turbines in the last decade.

In flat terrains the resource distribution varies according to factors, like terrain roughness and sheltering caused by buildings or trees, which the commercially available software codes are able to deal with, enabling wind data collected in one point to characterise the resource over large areas. This fact and the existence of meteorological information of good quality facilitated the evaluation of the potential of the different sites, without significant efforts in the conduction in new measuring campaigns.

To cope with the ambitious targets that have been defined, the wind energy promoters faced the need to switch from these traditional coastal sites to less friendly areas, as is the case of mountainous sites. These are normally characterised by a very complex orography that poses a whole new type of difficulties, not only from the resource assessment side but also from the point of view of the construction of the plants as well as problems of loads over the components of the turbines.

Among these difficulties, a very important one is the uncertainty in the prediction of the wind characteristics extrapolating data from one site to another. In fact, the simulation of the atmospheric flow over hills and valleys in its full extension is a very difficult task, demanding sophisticated computational means and large computational times, in order to obtain reliable results. The application of the commercially available software, making use of simplified flow models, to complex orography sites, demands for a careful analysis and a very good local measuring support. This kind of software, normally developed for use in flat terrain, has some difficulties in dealing with unattached flows originated by the steep slopes and sequences of hills and valleys typical of mountainous areas, which can easily lead to significant errors when using inadequate sets of data.

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[1] Madeira and Azores islands are also exceptions to this observation that only applies to mainland.

Wind measuring campaigns are, thus, an indispensable instrument for a good evaluation of a given site potential. Care needs to be taken in choosing the correct location for measuring, being important to select a site as much representative of the available area as possible. Making use of cross predictions, using data from as much measuring stations as possible is also extremely important, by permitting to improve the coverage of an area thus minimising the risk of possible errors associated to the limitations use of the computer models.

Correlations are also very useful. Measuring campaigns are expensive and time consuming, delaying, beyond the promoters' will, the timing of the project. A good grid of meteorological stations to support, for long term extrapolation, the measuring performed on the sites where projects are to be developed, is a very useful tool that permits, by the adequate use of correlation methodologies, to reduce the time needs for local measuring.

3. THE PORTUGUESE CASE

3.1. Wind regime and type of terrain

Portugal is located in a region of the globe that is not characterised by high geostrophic winds. As can be seen in figure 2 (Petersen *et al*, 1998), the United Kingdom, Denmark and the Northwest of Spain are the zones of Europe where the higher wind potential is expected.

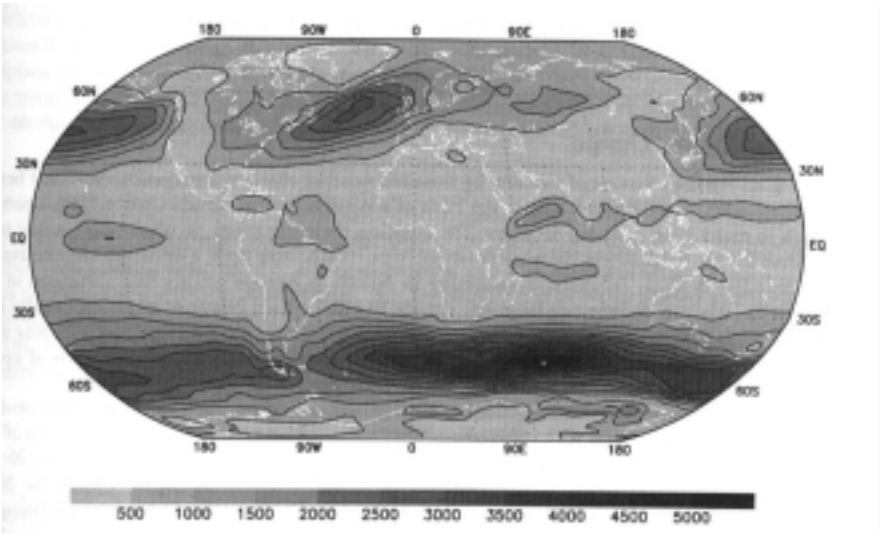
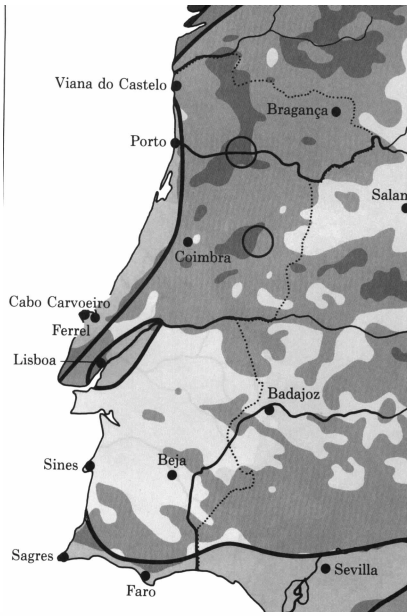


Figure 2 – Energy flux of the wind at 1500 m above sea level in W/m^2

The conclusions of the studies performed for the European Wind Atlas (Troen & Petersen, 1989) confirmed the belief that only in areas with particular characteristics would be possible to find sites with good conditions for the exploitation of wind energy for electricity production in Portugal. Near the coast, only a narrow strip of land near Cabo Carvoeiro and the Western Algarve coast present wind speeds interesting for wind energy applications. Figure 3 shows the results presented in the European Wind Atlas for Portugal.

Being so, the look for accelerating and concentrating effects over the wind flow become of special importance, in order to find the best sites for the installation of wind farms for electricity production. The speed-up factor induced on the wind flow by the steep slopes of some of the mountainous areas of the country were thought to be capable gathering the necessary conditions to make possible the installation of wind turbines.



Wind resources at 50 metres above ground level for five different topographic conditions*										
	Sheltered terrain		Open plain		At a sea coast		Open sea		Hills and ridges	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400
○	Regions where local concentration effects may occur								* see Fig. 2.3 for full explanation	

Figure 3 – Wind resource distribution in Portugal

The North and Centre of Portugal are characterised by the existence of areas with significant altitude, just a few tenths of kilometres from the sea coast, with North-South orientation. Furthermore, important rivers flow in deep valleys West-East oriented, driving the prevailing winds that normally come from the sea, with a strong incidence of West and Northwest directions, towards the mountain hills. This geographic conditions permitted to expect that wind could be concentrated through the river valleys being then accelerated over the hills with more important slopes.

At higher elevations, typically above 1000 meters, significant areas were identified gathering the preliminary conditions required for the installation of wind farms. However the lack of local meteorological information did not allow, at a first stage, the quantification of the potential of the sites, leading to the need of designing and implementing new methodologies, including the planning and running of measuring campaigns.

3.2. Legislation and public support

Since 1975 until the late eighties, electricity production was almost a monopoly of the national utility, as for transportation and distribution. The opening of the market to small independent producers, from 1988, gave to mini-hydraulic, wind, biomass and co-generation exploitations the possibility to be integrated in the electricity production system. Special conditions are offered to the producers, namely preventing the depreciation of electricity prices in the first years of exploitation. In any case a technical limit of 5% of the short circuit power in the connection point should be observed.

The production is to be paid with reference to mean voltage prices. For wind farms bigger than 10 MW, only the energy equivalent to the production of a 10 MW facility operating at

full capacity, in a monthly basis, is considered. Above this limit the energy will be paid according to avoided costs which, due to Portuguese strong hydraulic component, is a very unfavourable situation. Wind farm promoters have chosen, up to now, to limit the installed power to 10 MW. Nevertheless, some bigger projects are being planned taking into account that only in a few months the load factors are expected to exceed 60%, making believe that wind farms up to around 15MW could fall into the best tariff scheme the most of their operating time.

For an initial period of 8 years, it is guaranteed that the differential between the raise in electricity prices and the inflation tax is covered by the state. This intends to protect the independent producer from a political decrease of the electricity prices on the final consumer, as has been happening in the last few years.

Even so, the still important specific costs of these projects and the decreasing trend for electricity prices (almost 20%, nominally, since 1995), are factors that strongly condition new projects. Recently, the Portuguese Government has issued a new differentiated tariff scheme for wind, mini-hydraulic and biomass, that slightly improves the conditions, by increasing the price paid for the produced kWh and by raising from 8 to 12 years the period of price guarantee. Furthermore, the limit of the short circuit power is to be raised to 10%.

The political will for supporting the use of renewables gave birth to several programs directed not only to electricity production but also for a more rational use of energy resources. "Programa Energia" in its chapter devoted to electricity production, the adequate field for wind energy penetration, concedes a not negligible support for the initial investment of an independent producer.

The support is in the form of a long term loan under no interest and can reach up to 55% of eligible costs. The loan is to be returned in 9 years, starting the 3rd year of the project. This can be, of course, of big significance in the economical viability of a project.

Projects with an investment up to 750 000 EURO [*] are very interesting applications as they can be supported with lost funds up to 50% of the investment.

Projects submitted to the "Program Energia" are to be evaluated both from the company profile and project feasibility point of view. Economic calculations based on technical data from the manufacturers, resource assessment studies and electrical grid connection permission are imperative to be presented with the appliance.

4. TEN YEARS OF ACTIVITIES IN WIND MEASURING AND STUDIES

Since 1989 that researchers from F.E.U.P. and from its interface institutions INEGI and IDMEC, develop a series of activities related to the wind energy field, planing and conducting measuring campaigns and performing resource assessment studies, but also developing and improving numerical simulation models of atmospheric flow.

Field activities concentrated in the assessment of the wind potential in the mountainous areas of the North and Centre of Portugal due to the belief that it should be possible, in those areas, to find sites gathering good conditions for the use of wind energy for electricity production.

The National Meteorology Institute operates a very important grid of meteorological stations, which, however, do not permit to perform an adequate characterisation of the wind potential, due to the fact that it was not planned for that purpose. Among several limitation that put in doubt the reliability of the collected data, the location of most of that stations is

[*] Typically one machine of 500 kW represents an investment of 570 000 EURO.

within village or city limits, thus making very difficult the use of the information to perform the wind analysis in the top of hills or mountains, a dozen of kilometres far from the station.

By these reasons it was thought that the research community could play a role in trying to find and characterise the wind regime at the potentially interesting areas. With that target, a methodology was defined at F.E.U.P. and INEGI, considering the following main steps:

- Identification of potentially interesting sites from the point of view of the available energy density, accessibility and possibilities for the land use, compatibility with other activities and with protected landscape areas and natural reserves, local verification of the orographic characteristics and type of vegetation.
- Installation of measuring stations, equipped with reliable instruments for measuring and recording the wind speed and direction, and conduction of measuring and data processing programmes for as long as possible.
- Creation of a computerised database containing the results of the measures undertaken, the topography of the terrain and its superficial roughness, as well as other complementary climatological data considered as relevant.
- Development of methodologies, based on the one defined on the European Wind Atlas, comprising numerical predictions, collected data and correlations, for the quantification of the wind resource.
- Making use of the developed instruments, and of the collected information, elaborate maps of the distribution of the wind velocity and energy density trying to identify sites that could possibly suit for the installation of wind farms on the studied regions.

The beginning of a series of field measurings and resource assessment actions started with a campaign carried out in the scope of an European Community Joule project. The measuring campaign started in June 1991 and was carried on until the beginning of 1995. For that project 10 measuring masts were installed and a lot of wind data were collected.

The first results and studies of that and other research projects and the identified potential (Rodrigues, 1994), together with the growing interest for the environmental aspects of the energy market, led to the interest of several promoters that contacted INEGI, in order to seek for sites with the intention of installing wind farms. From 1994 INEGI has performed measuring campaigns, wind resource assessment and several consultancy works for wind energy promoters, both Portuguese and foreigner, that plan to erect wind turbines in the Portuguese territory.

Since the first project circa 80 wind measuring stations have been regularly operated by F.E.U.P. and INEGI in the Centre and North of Portugal. About 50 of these stations are still working, under private or public contracts. Some other stations (10 to 20) have been operated by other institutions, covering part of the Centre region and Algarve. The volume of data gathered by INEGI is the equivalent of 2 complete years in 55 measuring sites, being one of the most important wind database in the country, and certainly the most valuable when looking for wind energy applications.

In figure 3, the circles represent the wind potential identified so far, being bigger as the available area is also wider, permitting more turbine installation. In 1996, the first 10 MW wind farm was installed, more than doubling the installed capacity at that time. Until the end of 1998, Portugal passed 50 MW of installed wind power with INEGI being involved in the studies that leaded to 30 MW.

After the results of a couple of technical-economical feasibility studies being performed, it seems that a production of about 2750 hours of full capacity per year is, with the actual conditions (electricity price, cost of the investment, etc.), the limit for a project to be feasible, depending, naturally, on its size. According to the results of a study performed by INEGI to

E.D.P. (Electricity of Portugal) a total of 92 km^2 of terrain fulfil that requirement in the Northern half of Portugal (Restivo *et al,* 1993).

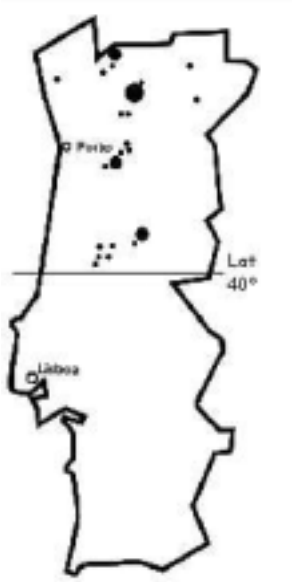


Figure 3 - Zones with identified potential in the Northern part of Portugal

Estimating, after the experience already acquired and the knowledge of the terrain, that about 20% of the mountainous area with interesting potential, 18.4 km^2, exhibit all the conditions for the installation of wind turbines, considering a power density of 10 MW/km^2, and assuming that other 50 MW can be installed outside the zones covered by the study performed by INEGI, the final figure is a total capacity between 230 MW and 240 MW, so close to the 3 % of penetration of electricity production from wind.

More than an estimate, we think that this 3 % should be looked as a target that can be reached without significant environmental and social conflicts (Rodrigues & Ferreira, 1997).

5. CONCLUSIONS

Wind energy presents a huge potential for the development of electricity production using alternative sources. The growth has been enormous in the last few years, leading to the establishment of very ambitious targets for the first decade of the 21st century.. A growing number of persons are now working in the subject. It is estimated that, the target of 40 GW by 2010 being achieved, it would represent more than half a million jobs created by the wind energy field (EWEA, 1997).

Despite of the very interesting figures, the reality shows that most of the installed capacity is concentrated in a small number of countries. This means that very wide areas are still unexplored and that the growth potential is still very high.

Portugal is among the countries where interesting perspectives for the technology are expected. From 1.8 MW in 1996, the installed capacity (mainland) reached about 45 MW by the end of 1998. Far to be exhausted the estimated potential indicates that the target of 3% penetration in the national electricity productive scheme, meaning about 240 MW of installed capacity, can be reached during next decade.

The complexity of the terrains where the most important potential is expected, together with the lack of meteorological information, led to the need of an important effort of field

work, namely by performing measuring campaigns to collect representative and reliable data. Since the very beginning F.E.U.P. and its interface institutions, namely INEGI, were involved in the actions that contributed for a better characterisation of the resource in the Northern half of country.

First under publicly financed projects and afterwards at the expenses of private developers, INEGI installed and operated around 80 meteorological stations in the North and Centre of Portugal, collecting the equivalent to more than two years in 55 measuring points. This is the biggest wind database gathered in Portugal for the purpose of evaluating the wind potential, in order to install wind turbines. Also important is the knowledge of the terrain (topography, restrictions and constraints, accessibility and so on) acquired along these 10 years of activities.

More than just operating the meteorological stations, INEGI has developed a methodology for the resource assessment, making use not only of commercial software but also to own developed tools, that justify its presence, as a consultant, in most of the wind energy projects implemented or under course of project, for the last few years.

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