APPLICATIONS OF GEOGRAPHICAL INFORMATION SYSTEMS FOR THE OPTIMAL LOCATIONS OF WIND ENERGY ELECTRIC GENERATORS

Ignacio J. Ramírez-Rosado[1], Vladimiro Miranda[2, 3], Cláudio Monteiro[3], Luis A. Fernández-Jiménez[1], Pedro Lara-Santillan[1], Enrique Zorzano-Alba[1].

[1]Departamento de Ingeniería Eléctrica, Universidad de La Rioja, SPAIN, [2] Faculdade de Engenharia U.P., Rua dos Bragas, 4000 Porto, Portugal, [3]INESC Porto, Apartado 4433, 4007 Porto Codex, Portugal

Abstract: The shortage of conventional energy resources and the protection of the environment have promoted the installation of plants of renewable energy. But this process requires a previous planning. The planning tasks seek to achieve the optimal supply of the present and future energy demands. The development of an advanced tool, that can determine the optimal planning of plants of renewable energy, helps these planning tasks. It allows finding out optimal locations of renewable energy plants never taken into account with conventional planning techniques. In this paper, an integrated model using a geographical information system and a database with all the regional information needed in energy planning, is described and applied for the best locations of wind energy electric generators.

Keywords: Energy planning, renewable resources, GIS, optimisation.

1. INTRODUCTION.

The important economic and environmental advantages of the renewable energies have caused that the corresponding electric generating plants have proliferated in the last years. In this sense, the wind energy plants have been the most important ones, composed by small or large wind farms.

The locations of the electrical-wind conversion systems have a fundamental importance for evaluating its economic operation. Thus, for large wind farms, it is necessary to have speeds of wind above a minimum threshold during most of the year and, furthermore, it is also necessary to take into account factors like the accessibility for their installation and other auxiliary equipment, the maintenance costs, environmental limitations, etc. On the other hand, for smaller wind plants, the proximity to the consumers is a critical matter since the electric energy is usually transmitted using smaller levels of voltage.

Geographical information systems, GIS, constitute suitable tools for the optimal locations of electric wind generators (large or small wind farms), allowing to evaluate simultaneously fundamental technical, economic and environmental factors. Thus, these systems have been already used for the optimal layout of distribution lines [1], for the planning of electric substations [2], or for the renewable energy integration in remote areas [3].

In this paper, we present the methodology used for optimal planning: geographical data provided by a geographical information system, the electric power consumption in each geographical area, the electric power network of each place and past meteorological data are going to be used for determining the optimal positions of wind plants in a main research project (sponsored by the Spanish authorities and European Union funds). As a result of processing the meteorological data and the digital geographical information about orography and taking into account the type of vegetation in the whole studied area, a map of wind resources is created. This map enables to find out the places with the best potential of electric energy production. This approach for the energy resources combined with the sites of the electric power consumers (according to the population and industry characteristics of each area) and the existing electric power networks, is going to lead to the final selection of the appropriate places for the optimal locations of electric wind generators. A module for the forecasting of electric loads is also used to establish the electric demand growth in the future. Furthermore, the criteria applied for deciding these optimal locations are the minimization of the installation costs and the maximization of the profitability in the operation of the wind plants according to the expected annual wind electric energy production.

2. THE PLANNING RESEARCH PROJECT.

The above mentioned project was born as an intent of integrating all the necessary data on a support of geographical information system in order to be able to carry out a regional energy planning. The region under study is La Rioja, Spain, a region with a surface of 5045 km^2 and about 263000 habitants. The system used in this project consists of:

- One server computer with the geographical information system.
- Several workstations used by the operators to give the information needed, or to obtain the results.
- A complex database composed by maps and historical information on energy consumptions, population, energy infrastructures, etc.

The construction of the database constitutes one of the most laborious tasks in the project. Historical information should be extracted from certain indexes of the region for the energy planning. The population evolution in each town or village along the last years can facilitate information for forecasting its value for a short, medium and long future. The spatial energy consumptions can give information useful for a suitable location of new energy plants. The properties of the existing infrastructures (electric power networks) and the economical costs of new equipments or the expansion of the existing ones, are the bases for the optimal planning of new electric power networks.

The energy sources taken into account in the project are wind, photovoltaic, small hydro and biomass. The competitiveness between electricity and natural gas as source of energy supply for domestic, industrial and commercial sectors, according to their geographical localisation, is also considered.

At the present time the optimal zones with the best wind and photovoltaic resources (geographical maps of energy resources) have been achieved, and are going to be included in future scenarios of study of competitiveness between the these two technologies. The forecast of geographical evolution of energy consumptions, according to the population foreseen evolution, is used for these scenarios.

3. GEOGRAPHIC MAPS OF WIND ENERGY RESOURCES.

A detailed assessment of the wind resources is a difficult work dependent on orography, terrain roughness, obstacles and historical values of wind speeds and directions measured on meteorological stations. A commercial software was used in the achievement of the wind energy resources. The software selected was the WA^{S}P from RISØ National Laboratory, Denmark. This software uses complex models for the vertical and horizontal extrapolation of wind data. WA^{S}P software is based on a dynamical model for wind and its accuracy has been tested even in the worst conditions [4].

The WA^{S}P software manipulates wind data using its probability density distribution. The function of this type, with the best description of the wind speed variations, is the Weibull distribution. This distribution varies from place to place, changing its parameters according on local climate, the orography and the roughness of the terrain. This roughness gives an idea of the influence of the vegetation or any possible obstacle that slow the wind down in their proximity.

The Weibull distribution has two parameters: the parameter of scale, A, and the form parameter, k. This distribution presents two particular cases: one when k=1 that is known as the exponential distribution, and the other one when k=2 that is known as the Rayleigh distribution, which is also very useful in wind studies.

The wind resources calculated by WA^{S}P have significant errors in the borders of the orographic map. This is specially important if we have to fragment, in several pieces, all the map of the region under study. In this work, we have had to fragment the orography map of the region in six superimposed pieces, each one covering about 1/3 of the total surface. The valid results for the wind resources are obtained when the six output resources calculated by WA^{S}P are transferred to the GIS in the form of ASCII files, and are interpolated in order to get the required accuracy in all the points.

The models of wind (for the determination of the wind resources by the WA^{S}P software) use as inputs the following data:

- Orography, with level lines or a digital model of the land.
- Maps of ruggedness of the land built with the GIS, starting from maps of vegetation and maps of use of the land.
- Time series of speeds and direction of the wind measured in the meteorological stations.
- Obstacles surrounding the meteorological stations.

and the obtained results are:

- One grid with the wind resources, with a resolution of 10^4 m^2. The total number of points calculated is over $5\ 10^5$.
- The calculated results correspond to a height of 30 m, that is assumed for the rotor position of the wind turbine.
- Each point of the grid is classified according to its Weibull parameters A and k.

After the calculation of the valid results for the wind resources, the GIS is used to achieve a filtering process over these data in order to exclude every place where the installation of an electric aerogenerator is not feasible. The excluded areas are:

- Areas with a minimum wind speed at the height of the rotor of the electric aerogenerator fixed by the user (5 m/s in this work).
- Areas with a terrain slope over a maximum permitted (10% in this work).
- Natural parks.
- Areas around 150 meters from any inhabited place.
- Areas with electromagnetic interferences, as the areas of proximity to radio or television repeaters.
- Any other protected or restricted area such as airports, military zones, etc.

After the mentioned process, a map with all the available places for the installation of wind turbines is obtained. Later, economical considerations are used for selecting the optimal locations for these wind energy conversion systems. In order to this economical selection, we define the load factor, the annual energy supplied and the levelled energy cost [5]. This last index is used for the final selection, not only of wind turbines, but all types of energy generating systems (photovoltaics, small-hydroelectric, etc).

The selection between wind farms or isolated generators is carried out considering the areas for the possible location, and their proximity to centres of large energy consumption.

The load factor, $LF(A)$, represents the quotient between the mean power generated and the maximum power of the wind energy electric generator, P_{max}. It is calculated integrating the product of the power curve of the generator, $PC(v)$, and the speed of the wind, expressed as its Weibull distribution, $f_{A,k}(v)$. The power curve of the generator expresses the power generated depending on the wind speed.

$$LF_k(A) = \frac{\int PC(v)\, f_{A,k}(v)\, dv}{P_{max}} \qquad (1)$$

$$AES = P_{max}\ LF(v)\ 8760 \qquad (2)$$

The annual energy supplied (*AES*) is calculated as the product between the maximum power, the load factor and the number of hours per year.

The levelled energy cost (*LEC*), in \$/kWh, is the ratio between the annualised cost and the energy received at the interconnection point to the electric power network.

$$LEC = \frac{C_{\text{int}} + C_{ext} + C_{con} + C_{road} + C_{land} + C_{inst}}{AES} \qquad (3)$$

The parameter C_{int} involves the economical cost of all the equipment for wind farms or isolated electric aerogenerators. Its depends on equipment economical costs and financing conditions, not on geographical characteristics.

The parameter C_{ext} corresponds to the costs derived from connecting the wind farms or isolated electric aerogenerators to the electric power network. If the required connection is carried out to the high voltage network, then this parameter is significantly larger than the one of the connection by low voltage networks without power transformers.

The parameter C_{con} is computed directly by an optimisation model available in the GIS software. It corresponds to the economical cost of an electric interconnection line. The optimisation model finds out a minimal cost path for this line. This cost is very geographically influenced: C_{con} depends on the terrain slope, the presence of obstacles as water zones or buildings, the accessibility or distance from the electric power network and the nearest road.

Another parameter, C_{road}, involves the cost of a new road, when there are no roads, to access to the selected possible location for the wind farm or isolated aerogenerator. It is computed in a similar manner as the parameter C_{con}. The optimisation model finds out the minimal cost path, taking into account the different types of each piece of land crossed by the new road (rocky, muddy, etc).

The parameter C_{land} corresponds, as its name indicates, to the cost of the necessary land for the installation of wind farms or isolated aerogenerators and their auxiliary equipment. Its depends on the usage of each piece of terrain and the conditioning works needed.

The last parameter, C_{inst}, is the economic cost for carrying out that selected project. It depends on the total power installed, the complexity of the necessary auxiliary equipment, etc.

Most of the parameters depends on the type of the wind turbine to be installed, the auxiliary equipment needed, and their availability in the region.

4. COMPUTATIONAL RESULTS.

The maps of wind resources were computed for all the studied region obtaining the Weibull distribution parameters A and k. The mean wind speed obtained in the region is about 5.5 m/s with 50% of calm (wind speed lower than 1 m/s).

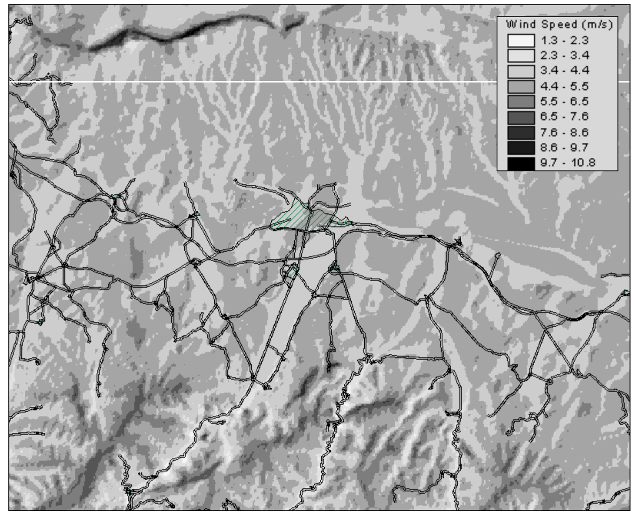

Figure 1 – Map representing the anual mean wind speed. Dark zones represent higher values for mean wind speed.

Based on this map of wind resources (Figure 1), the load factors (1) were computed, obtaining values between 0.1 and 0.5. The annual energy supplied was computed based on equation (2), taking into account the “calm” time (we have wind in approximately 4300 hours per year).

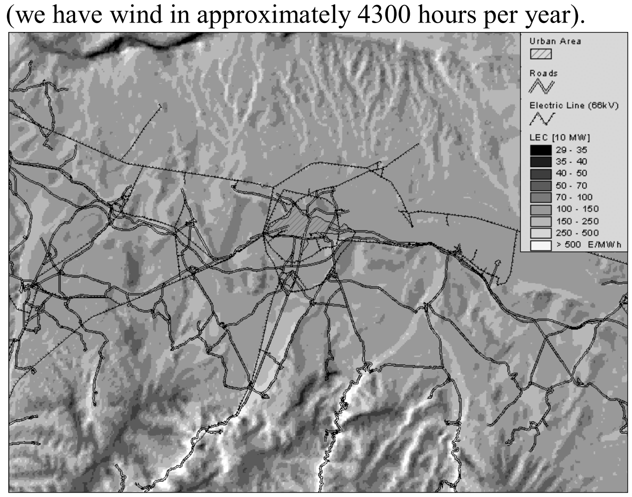

Figure 2– Map showing the LEC (Levelled Electric Cost). The dark zones represent the locations with high potential to install 10 MW wind farms.

The second step of the process consists in calculating the costs associated with the wind farm installation. We have used a set of illustrative cost values in order to test our planning models. These values have been: 650 euro/kW for the wind farm equipment, 30 euro/kW for O&M, 2.8 M Euro for fix cost to connect the wind farms to the 66 kV electric network, 2.4 M euro/km^2 for cost of terrain, 70 euro/m for new roads and 40 euro/m for electric lines necessary to interconnect the wind farms to the 66 kV network. For each location on the studied region, the GIS computes the minimal distance to the electric networks and to the road infrastructures. These maps of distances are used to estimate the cost associated to infrastructures and electric lines. Finally, it is computed the Levelled Electric Cost, LEC, presented on the Figure 2.

As observed on the Figure 3, the costs of electricity produced by the 10 MW wind farms are lower than the ones for the scenario of 5 MW wind farms, with lower difference on high wind potential sites. This is consequence of the lower influence of the infrastructure costs for larger wind farms. For 10 MW wind farms, the distance to roads and the distance to electric network have a lower influence. However when considered a small wind farm, 5 MW, the component of infrastructure costs becomes more relevant on the overall costs and the influence of the distances is more evident. This is observable on the white contour lines of Figure 3, which represent the difference in percentage between the two scenarios. Considering the 10 MW scenario, the locations near to the infrastructures present approximately a 7% lower impact with respect to the locations far from the infrastructures.

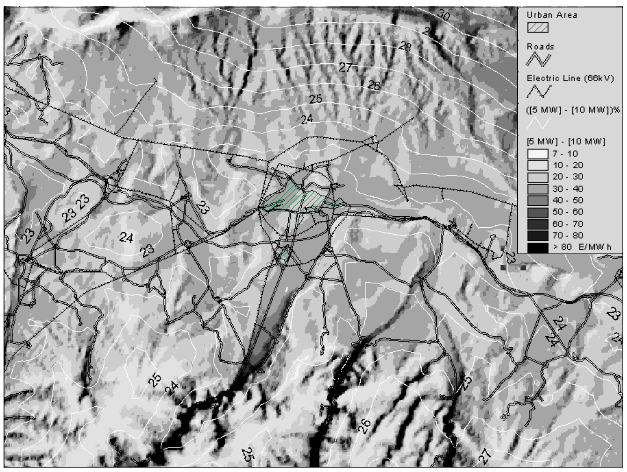

Figure 3 – Map comparing the scenario of 5 MW with 10 MW wind farms. The dark zones represent locations with higher differences for LEC, between the two scenarios. Locations with higher wind potential have lower differences.

Based on the results of the LEC map, it is possible to study some statistics about the available areas with high wind potential. The Table I shows these statistics for the area shown in Figure 2, covering about 2560 km^2.

TABLE I. AVAILABLE AREAS

Euro/MWh	Area %	Km^2
< 50	0.75%	18
< 100	18.5%	456
< 125	41.9%	1034
< 150	74,4 %	1838

From Table I, only the 0.75% of the 2560 km^2 have associated LEC values lower than 50 euro/MWh, corresponding to a limited value of 144 MW for wind plants installations. However, for values of LEC lower than 100 euro/MWh, there are 456 km^2 for building wind farms.

5. CONCLUSIONS.

In this paper, a methodology was presented, based on GIS, to optimise the investment cost for new wind farms. This optimisation is carried out mapping and ranking geographically the best locations to built new wind farms.

The evaluation of the areas with high wind potential is carried out by the calculation of all the costs involved and by the estimation of the wind farm annual energy production. Some of the costs considered are geographical dependent (e.g. costs of roads, costs of electric lines, costs of lands, etc.). On other hand, the wind farm annual energy production is highly dependent on the location due to the local wind speed behaviour.

From the computer results we observe that, for regions with good roads and electric power networks, the best locations are mainly dependent on the availability of wind resources.

Two different scenarios were compared: wind farms with 10 MW and wind farms with 5 MW. From this comparison we concluded that the proximity to the roads and electric networks are more important for lower capacity wind farms.

Finally, several spatial statistics were obtained by ranking the locations ordered by its class of wind potential. From the statistics, the area available for wind farms building growths exponentially when increasing the levelled energy costs.

ACKNOWLEDGEMENTS

The authors would like to thank to the European Union, the “Ministerio de Ciencia y Tecnología” (CICYT) and the “Ministerio de Asuntos Exteriores” of Spain, for supporting this research under the Projects 2FD97-1514 and HP1999-0005, and the “Confederación Hidrográfica del Ebro”, as well as the “Dirección General del Medio Natural de La Rioja”, for its collaboration in this work.

REFERENCES

[1] E.C. Yeh, Z. Sumic, S.S. Venkata, APR: A geographic Information System Based Primary Route for Underground Residential Distribution Design, *IEEE Transactions on Power Systems*, Vol. 10, No. 1, 1995, pp. 400-406

[2] W.M. Lin, M.T. Tsay, S.W. Wu, Application of geographical information system for substation and feeder planning, *Electric Power & Energy Systems*, Vol. 18, No. 3, 1996, pp. 175-183

[3] M. Muselli, G. Notton, A. Louche, Computer-aided analysis of the integration of renewable-energy systems in remote areas using a geographical-information system, *Applied Energy*, Vol. 63, No. 3, 1999, pp. 141-160

[4] N.G. Mortesen, E.L. Petersen, Influence of topographical input data on the accuracy of wind flow modelling in complex terrain, Proceedings of the 1997 European Wind Energy Conference, Dublin, Ireland, 1997, pp. 317-320.

[5] The SOLARGIS Handbook – Guidelines for the elaboration of regional integration plans for decentralised electricity production with renewable energies. SOLARGIS Consortium, JOULE2 Program, Contract JOU2-CT94-04309, 1996.