Wind Energy Resource Map of the State of Paraná, Brazil

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Summary
An assessment of the wind energy resource available in the Brazilian State of Paraná was conducted by the local state utility COPEL, from 1994 to 1998. The methodology and resulting Wind Resource Map are presented and discussed.

1. Introduction

The State of Paraná is located in the Southern region of Brazil. The state area is about 200 thousand km^2. With a narrow coastline, close to a barrier of mountains ranging from 900 m up to 1800 m, its inner territory alternates highlands and river valleys.

Brazil has an installed electricity generation capacity of about 65 GW, of which presently 92 % comes from hydro. The State of Paraná is rich in hydro resources, including the largest hydro powerplant of the world – at the western border to Paraguay.

COPEL, the local electricity generation, transmission and distribution utility, predominantly owned by the government of the State of Paraná, has a long tradition of large, low cost hydro power plants: 3.3 GW installed capacity that keeps expanding, through the construction of another 1.3 GW hydro power plant to be fully operational in 2000. Nevertheless, the State of Paraná is going through a recent process of industrial expansion, and COPEL has been strategically investigating all possible energy resources for future generation expansion.

2. The State of Paraná Wind Energy Resource Assessment

Started in 1994, named "Projeto Ventar", the project was a further development of prior studies COPEL conducted to evaluate the use of wind energy to improve the electricity supply to Mel Island, where diesel power plants were in use for isolated villages. Following the awareness about wind energy suitability to large-scale grid connection, the company decided to investigate the available resources in its concession area, mostly addressed at investigating the best sites.

3. The Strategy of the Project

The existing information on the wind energy potential available, from prior assessments in Refs. [1, 2], showed disappointingly low wind speeds in Paraná: the best mean annual values were 3.5 to 3.7 m/s at 10 m height, in southern and northeastern sites respectively - both from meteorological stations operated by IAPAR, the State of Paraná Institute for scientific support to agriculture. Even optimistic extrapolations didn't show promising figures for other tentative sites, at the beginning. GIS-based wind mapping tools and a full model of the State (orography and roughness) were not available at that time.

Due to these limitations, the strategy adopted for the assessment was to maximize the number of monitoring stations covering all different regions of the State of Paraná, while keeping the cost of the project as low as possible. The trade-off led to the acquisition of 25 monitoring systems from NRG (anemometers, wind vanes and data loggers), and the borrowing and adaptation of common concrete poles promptly available at COPEL - with a tubular extension to a maximum of 18-20 m measuring height. Wherever possible and adequate, existing telecommunication towers were also used.

For area selection, a large collection of aero photos from other COPEL studies were used for analysis, together with contour maps (1:50 000 and 1:100 000) and a LANDSAT mosaic image of the State of Paraná, channels 3, 4, 5, supplied by IAP - Instituto Ambiental do Paraná - the State environmental institute.
In large areas or with more difficult access by car, the site inspection process used some hours of helicopter flight, "borrowed" as an optimized insertion in the scheduled biennial inspection the Company carries on its main power transmission lines. Most areas were normally inspected by car, through access roads.

4. Area Selection

A combined set of actions were taken to identify the most suitable areas for wind monitoring campaigns:

- development of computer models of orography/roughness;
- questionnaires to regional maintenance teams;
- analysis of existing data and modeling of selected meteorological stations;
- area inspection;

Computer models of orography/roughness: although GIS models of the State of Paraná weren't available or known at the beginning of the project, efforts were made to develop a systematic evaluation of combined orography/roughness of areas. A big help forward, at this phase of the project, was supplied both by the digital elevation data file with 1 minute resolution, from CEHPAR - Center of Hydraulics maintained by COPEL and the Federal University of Paraná, and the LANDSAT mosaic from IAP. An overview of the general features of the territory was produced at this stage, through a 3D computer model, shown in Fig. 2.

Questionnaires to regional maintenance personnel: utilities usually have maintenance staff for their power distribution lines, including small towns. Since maintenance is usually provided to rural areas, personnel involved are a very rich source of information on existing open, windy areas. A questionnaire was prepared and distributed to all the regional offices of the Company, with special emphasis on the search for windy sites with a minimum of 1 km^2 of open area, to avoid indication of mountain peaks - not suitable for larger wind energy projects. The response formed a mapped data bank, to be crosschecked with other models and data, to orient the site inspection phase.

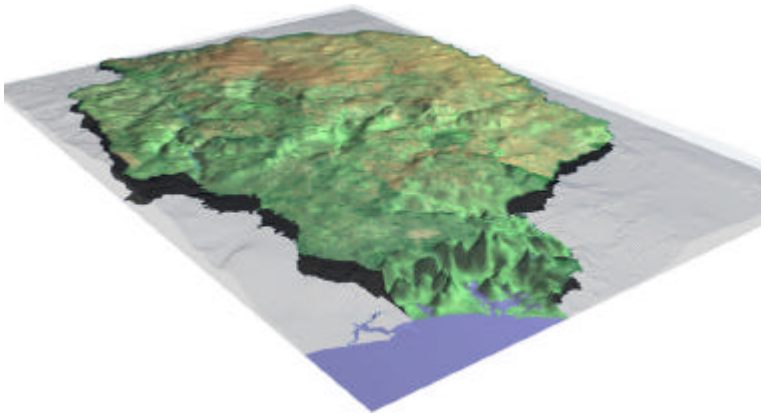

Fig. 2: 3D computer visualization model of topography/roughness of the State of Paraná.

Besides the valuable information from the questionnaire, the maintenance personnel were very helpful guides in the site inspection phase, as well as in the process of getting permission from the landowners to install monitoring masts.

Analysis of existing data and modeling of selected meteorological stations: existing data was extensively discussed with SIMEPAR - Sistema Meteorológico do Paraná, a meteorological institution maintained by COPEL, IAPAR and the Federal University of Paraná - to form a comprehensive view of wind climatology and dynamics over the territory. Regarding the meteorological stations from IAPAR, only the ones that showed the most promising annual wind speeds were inspected and modeled in roughness. The stations of Clevelândia and Ponta Grossa proved to be suitable for long-term climatological corrections for the monitoring phase: flat installation site, no obstacles, and adequate maintenance schedule.

The area inspection is a very time-consuming phase. The use of helicopter helped in accelerating the inspection and preliminary site selection on some large open areas, as well as on the mountains. Another big advantage of the helicopter: it helped to discard a lot of candidate areas that seemed promising from the existing mapped data bank. Many difficult access areas would have consumed a lot of time, with disappointing results.

5. Wind Monitoring Campaign

First monitoring stations were installed in January 1995, with 25 stations installed until 1998. For the most representative areas, collected data covers more than 2 years.

Of the 25 stations, 10 were installed in existing telecommunication towers, with heights ranging from 20 to 77 meters. In all these cases, the anemometers and wind vane were adapted to the top of the tower, slightly below and in front of the lightning protection system, related to prevailing northeastern winds; special care was taken to install sensors free from obstacles of tower structures. Towers with parabolic antennas close to the top were discarded, to avoid obstacle interference. In this case, the owners of the towers, companies TELEPAR, EMBRATEL and ENERSUL, gave a helpful permission.

On 15 stations, common concrete poles were adapted with a steel tubular extension on top, and measuring heights of 18 - 20 meters were achieved. This was a very low cost solution for COPEL, since the poles exist in quantities at the Company, and were taken for temporary use. The adapted steel tube already had a widespread use to support radio antennas in many of the company's offices in the State. Anemometers were installed at 18-20 meters and also at the intermediate height of 10 m, to supply information on wind shear parameters.

The height of about 20 m and the relatively close 10 m intermediate anemometer certainly lead to inaccuracy for extrapolations to current wind turbine hub heights, e.g. 50 m. Nevertheless, this solution proved to be a low cost, effective solution within the existing limitations. Later on, when wind farm fea-

sibility studies were conducted on the best revealed area (Palmas), 50m towers were installed while keeping the existing adapted pole/tube monitoring tower as a long-term reference.

Data collection and analysis were centered at the COPEL office in Curitiba.

6. The Wind Energy Resource Map of the State of Paraná

The wind model was prepared on the second half of 1998, through extensive analysis of collected data. Extrapolations to 50m height were performed using WAsP (Risoe) and orography and roughness models in a 10 x 10 km region around all monitoring stations. Climatological adjustments to the Clevelândia and Ponta Grossa simultaneous and long term (15 years) data was done, although differences to the long term mean values were lower than –3 %.

The roughness model was developed from a detailed GIS-based map of the Land Use in the State of Paraná, made available by SEMA - Secretaria de Meio Ambiente do Paraná. Roughness length z_o values were assigned to the several classes of land use and vegetation classes.

The orography model of the State of Paraná was produced from the elevation data already supplied by CEHPAR, using a gridded resolution of 2 x 2 km.

For wind mapping and extrapolation of results to the territory of Paraná, WindMap^{TM} from Brower & Co (USA), a much improved mass-consistent, GIS based software was used. Optimization runs were performed, in order for the resulting map to reflect all actual measurement data.

The resulting map, shown in Fig. 3, was printed in a 1 m x 0.7 m format, scale 1: 1 000 000. Annual mean wind speeds at 50m height are presented in a continuous scale of 255 levels of colors, interpolated pixels. Information on the most important measured parameters for all site locations is included, as well as on the orography and roughness models used.

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Also included in the map are basic information on the wind dynamics over the Paraná territory, and the mean diurnal-, seasonal- and interannual mean wind speed behavior.

An example of the meaning of the 2 x 2 km is presented through a comparison with the Mel Island wind map, produced in a 100 x 100 m grid.

General information is also added on the characteristics of wind farms, sharing pasture and agricultural land, its suitability to GW-scale, fast installation rate, industrial production of wind turbines and associated consequences on generating jobs.

Last but not least, the gridded area of the GIS map was integrated for some classes of wind speeds, and assuming a mean wind farm installable density of 2 MW/km^2 (under topography, land use, obstacles and other limitations), a table with the total estimated usable energy (in GW and GWh) available from wind in the State of Paraná is also presented.

7. Conclusions

Regarding the methodology, the COPEL project is representative of a pioneering effort in Brazil. The advances in GIS tools, resources and software have resulted in much faster and lower costs for tasks like identifying and preliminary quantifying promising areas, although the lack of reliable specific wind data still persists in large areas of Brazil.

Specific wind measurements and mapping of wind resources are a necessary step for the development of wind-generated electricity in a country like Brazil. "Projeto Ventar", conducted by COPEL, may be regarded as an example. Projeto Ventar also made possible the first wind farm in southern Brazil, already commissioned: the Palmas Phase I: 2.5 MW, with Enercon E-40 wind turbines operated by a private company in the windy pastures of the State highlands.

8. References

[1] Atlas do Potencial Eólico Nacional; ELETROBRÁS, 1988

[2] Atualização do Levantamento Anemo-Solarimétrico do Estado do Paraná; COPEL-ISAM/PUC-PR, 1993

[3] Mapa de Uso do Solo do Estado do Paraná 1980-1990; SEMA/Liserp, 1995

Abb. 3: Wind potential map of the State ofParaná