COMPUTER TOOL TO IDENTIFY PROMISING AREAS FOR WIND FARM, PHOTOVOLTAIC AND BIOMASS PROJECTS AND ESTIMATE ENERGY PRODUCTION

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Abstract. *The objective of this article is to present the computer tool that is the result of a project originally acommplished to aid in the preliminary phase of identifying promising areas to develop wind farm projects. Moreover, this tool is going to give support to CHESF (Companhia Hidro Elétrica do São Francisco) in the activities of planning and operating the electric system concerning the integration of wind power generation inserts into its grid.*
This computer tool is based on a GIS (Geographic Information System) platform and it uses the ARCGis 8.X software, with Brazilian geographic information database (wind, roughness, topography, districts, main roads, land use, soil and electric power substations localization, economical activities). The results are obtained through crossing database information and the outputs are presented in form of polygons, which includes the size of each area, amount of wind turbines, the energy production estimation, the communities enclosed by the polygon, closest substations, the economical activities of the area etc. Each identified area (polygon) can be turned into a project, by a customized function (developed with Visual Basic for Applications), for the development of the complementary studies. Therefore, the tool presents, also, a customized function designed to assist the projects management.
Besides aiding in the searching phase, administration of projects and operation, it's already able to predict the energy production of wind farms installed, 72 hours ahead, using results from wind forecast models supplied by the brazillian meteorological center INPE (Instituto Nacional de Pesquisas Espaciais). This function is capable of predicting the amount of energy that can be generated three days ahead in order of planning the energy dispatch to the grid.
The tool already includes customized functions to accomplish the same studies with photovoltaic and biomass systems. The function concerning biomass systems is in the phase of supplying the database with information like biomass type, necessary equipment and their characteristics to energy production estimation, waste management etc.

Keywords*: Wind power, photovoltaic system, biomass system, wind forecast, energy prediction*

1. INTRODUCTION

The use of the wind energy presents some aspects that make it extremely attractive as an alternative source of energy. The possibility of application in wide scales, from isolated systems of a few kW to extensive wind farms of hundreds of MW, and the well or enough developed technology, turn its application possible to immediate use. That is not always true with other alternative sources, which its technology still demands additional developments to be competitive. Besides, the wind energy is one of the types of energy that is less harmful to the environment. Several countries have been implanting incentive programs for developing its utilization. In Brazil, the PROINFA - Alternative Energy Sources Incentive Program - has been recently launched and it reflects the crescent interest in the renewable energy development in Brazil. PROINFA is an important instrument for the national energy resources diversification. It intends to guarantee the reliability and the safety of the Brazilian electric provisioning. This Program, coordinated by the Ministry of Mines and Energy (MME), establishes the recruiting of 3.300 MW of energy through projects connected to the National Interconnected System (SIN), producing 1,100 MW of energy each, by wind power sources, biomass and small hydroelectric plants. In the case of the wind energy, PROINFA is in implantation phase, but future plants have already been selected. Important information on wind resources, for a preliminary selection of promising areas, destined to the implantation of wind farms, are in "BRAZILIAN WIND ATLAS" which elaboration was coordinated by CEPEL. The ATLAS embraces the whole Brazilian national territory and its development became possible through the use of the MesoMap model (Amarante *et al.*, 2001). The ATLAS is composed by thematic maps that present the behavior of wind, annual and associated to the seasons (wind speed, wind directions and Weibull statistical), at 50m height, 1 km x 1km resolution, for most of the areas of the country. According to the "BRAZILIAN WIND ATLAS", Brazil presents a promising potential, mainly in isolated areas where other energy sources are not well suited or are not

available, as in some places in Northern and Northeastern coasts of Brazil, that present wind speeds in the order of 7 m/s (at 10 meters height). For this reason an expressive mobilization was verified to turn viable the use of this energy source.

The objective of this project is to give support to the preliminary phase of searching promising areas for the development of wind farms, starting from Brazilian geographic information database (wind, roughness, topography, districts, main roads, land use, soil and electric power substations localization, economical activities). Besides, it will be able to establish the capacity of electric power production of up to 72 hours in advance or to forecast.

This tool also presents functionalities for photovoltaic systems and biomass, that will be presented in this work.

2. CHARACTERISTICS OF THE TOOL

The tool presents two sets of operation. The first one seeks to identify promising areas for the accomplishment of studies on implantation of wind farms, taking into consideration the wind characteristics, the orography, the roughness and the type of socioeconomic occupation of the soil. The second set seeks to accomplish prognostics of electric power production based on data of wind forecast, generated by official meteorological centers, where prognostics are accomplished with up to 72 hours of antecedence, allowing to predict the amount of energy that can be generated in the three subsequent days.

The tool was elaborated on a GIS platform (Geographic Information System), ArcGis 8.x, and a database containing high-resolution information, composed of:
° Brazilian Wind Atlas;
° Brazilian Solar Atlas;
° Regional Biomass Atlas;
° Electric diagram of the Northeastern region of Brazil;
° Information of electric substations;
° Hydropower data;
° Thermo-electrical plants data;
° Municipal base of the Northeastern region;
° Orography and roughness models;
° Highways database;
° Conservation units database (indigenous and nature protection areas);
° Demographic occupation;
° Economical activities.

For operation, it is necessary to inform to the tool the necessary parameters for it, in order to identify the best location for the construction of a wind farm, such as annual wind speed average, the State to accomplish the study, the turbines etc. With those data, the tool accomplishes the calculations; it looks for the closest substations and it presents results in the report form, containing, besides other information:
° Location of the site that presents demanded characteristics;
° Useful area of the polygon;
° Amount of possible turbines, in agreement with the chosen manufacturer (wind energy case);
° Annual energy to be produced;
° The Closest substations and their distances;
° The Closest highways to the polygon;
° Economical activity of the area;
° Surrounding roughness diagram.

Once identified the most appropriate place, to start the renewable source (photovoltaic, biomass or wind) project, the measurement should be developed, as well as appropriate calculation models. In the case of a wind energy project, a second operation tool set is used after installation of the measurement system in the selected area. The results obtained during the measurement campaign will be compared with the accomplished forecasts of the local meteorological centers, in order to reduce uncertainties in the case of missing data during the measurement campaign, for example. Later, after the wind farm installed in the site, the tool will be able to accomplish the forecast calculations, in order to identify the energy generation with up to 72 hours of antecedence, with low degree of uncertainties. Those calculations are accomplished starting from wind forecasts emitted by the meteorological center. During the measurement phase the tool will learn the climatic behavior of the site and provide a possibility to adjust the prognostics that comes from the meteorological center. This mechanism is very important for planning the energy dispatch.

3. DESCRIPTION OF THE ARCHITECTURE

In a simplified way, the function of GIS is to combine layers of a site to obtain a space vision of the features and the tabulated data. In this study case, a hypothetical wind farm, the objective is to identify the annual energy production, the

capacity factor, the name of the municipal district of the site, population size, roughness, highways that pass through the area and closest electric substations. The selection of the layers depends on what the study needs. The Fig. 1 presents the simplified diagram of the modules of the tool.

Besides, the database gathers information, including technical characteristics of the equipments (turbines, photovoltaic systems, etc), substations and transmission lines, basic cartography, orography and roughness models, wind data, solar radiation and renewable energy from forests - biomass.

The analysis module is responsible for processing the information and for parameters entrance, besides the reports elaboration. The analyses are accomplished taking in consideration the cities and conservation units – indigenous areas, biological reserves, natural lakes, rivers etc.
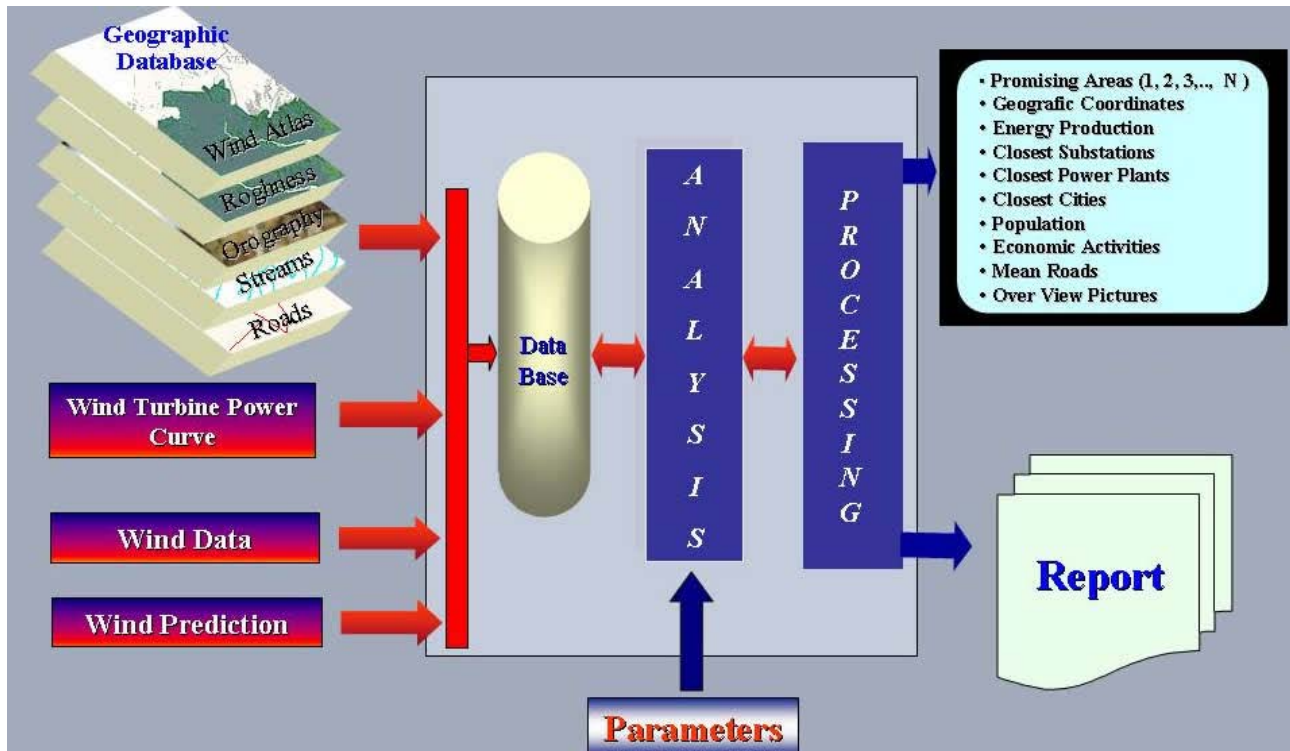

Figure 1. Simplified diagram of the tool

4. DESCRIPTION OF THE OPERATION

The tool has a quite friendly operation. The system presents a main screen, with several menu commands: "Wind Energy", "Photovoltaic Energy" and "Biomass Energy. Each one has several options for calculations.

In the case of the wind search approach, one must choose the "Wind Energy" option menu. It begins with the choice of the area that one wants to accomplish the study. To begin, it is necessary to choose the variables that one wants to establish as initials conditions (for instance, the wind speed). The three options in "Wind Energy" option menu are:

°   "Modeling of Promising Sites / Modelagem de Sítios Promissores": it accomplishes the crossing of the chosen information by the user;

°   "Wind Potential Report / Relatório de Potencial Eólico": it presents the result of the research requested by the user;

°   "Energy Forecast / Previsão de Energia Eólica": it allows the user to verify the production of future energy in wind farms installed, with up to 72 hours of antecedence, starting from forecasted wind velocities from local meteorological centers.

Selecting the functions "Modeling of Promising Sites" and right after the button "To Analyse / Análise", it is possible to insert the desired wind speed to accomplish the search and to continue with the entrance of new parameters. The State of interest should be selected and, if it is necessary, to establish the class of roughness and the altitude that one want to accomplish the research.

When the modeling is concluded, the tool presents in the screen all the areas that present the previously established conditions by the user, in form of polygons, as shown in the Fig. 2. The user can choose the polygon that wants to elaborate the complete report, through the commands that appear on the screen, which can be found on bottom "Prognostic/ Prognóstico" in the corner of the dialog box in Fig. 2 (encircled by the blue line). The tool models the polygon and presents the following results:

° Neighborhood data: It presents the municipal districts contained inside the polygon;

° Wind data: It presents the annual wind speed average, *C & k* parameters and roughness;

° Energy prognostic data (based in the wind velocities of the BRAZILIAN WIND ATLAS): it presents the identification and the amount of wind turbines used in the modeling (the relationship used is 10diameters x 5diameters), the capacity factor; the power [W], the annual energy [kWh] and the amount of assisted families (considering 250 kWh/month per family);

° Area data: total area, altimetry and economical activity;

° Substations data: Name of electric substations, the operation voltage and the distances, in relation to the studied place;

° Transmission lines data: Operation voltage and the distances in relation to the studied place;

° Hydropower data: Name of the hydropower plant, the utility responsible, the rate power [MW] and the distances (km) in relation to the studied place;

° Thermo-electrical plants data: Name of thermo-electrical; fuel type; utility responsible; the power [W] and the distances [km] in relation to the studied place;

° Cities data: Name of the cities and the respective distances in relation to the studied place;

° Roads data: Identification of the highways; type (paved or not paved) and the distances in relation to the studied place;

° Conservation units data: Identification of the areas, biological priority; type of the area and distances in relation to the studied place.
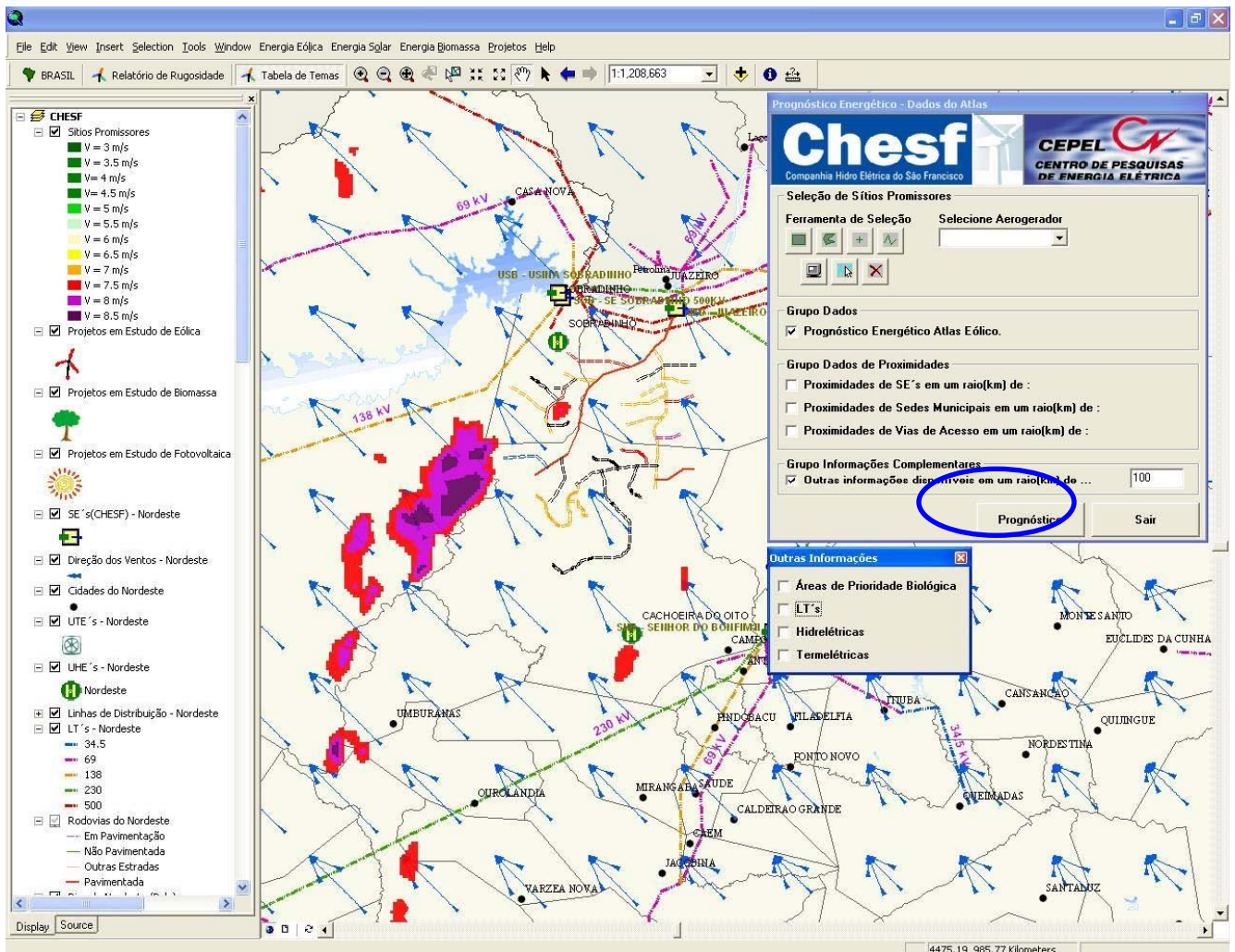

Figure 2. The sites identified by the tool.

The annual energy produced by a certain turbine is obtained from

$$E_{Wind} = 8760h \sum f_i P_i \qquad \text{[kWh per year]} \qquad (1)$$

where P_i is the turbine power obtained from the power curve and $f_i = \dfrac{k}{C}\left(\dfrac{V_i}{C}\right)^{k-1} exp\left[-\left(\dfrac{V_i}{C}\right)^{k}\right]$. Weibull parameters C

and k can be calculated as $C = \dfrac{\overline{V}}{\Gamma\left(1+\left(\dfrac{1}{k}\right)\right)}$ e $k = \left(\dfrac{\sigma}{\overline{V}}\right)^{-1,086}$ where $\overline{V}$ is the average velocity and σ is the velocity

standard deviation.

Besides, it presents a comparative report with the simulation of the capacity factor of each turbine available in the databank and chosen during the modeling phase.

The second item of the dialog box the button "Old Cases / Análises Existentes", allows the user to know the behavior of winds in projects registered in the system database, as well as, the power generation capacity, making possible to identify:

° Wind average, standard deviation and the C & k parameters;

° The amount of wind turbines that will fit in the identified area, the capacity factor of the site, the power [W] and the total energy [W/h]. Those values depend on the selected wind turbine. Therefore, it is recommended to identify the wind turbine that better adapts to the profile of the winds of the site.

Note: for evaluation effect, the minimum default area cell is of 1 km², and at distances among wind turbines is of four for eight rotor diameters.

The computer tool also contains a functionality called "Report of Roughness / Classificação de Rugosidade" (see Fig. 3) that presents the analysis of the roughness in any selected geographical coordinate based on the information from the databank. For analysis effect, the calculations are accomplished for the rays of, 2, 4, 6, 8, 10 km, divided in angles of 22.5º.

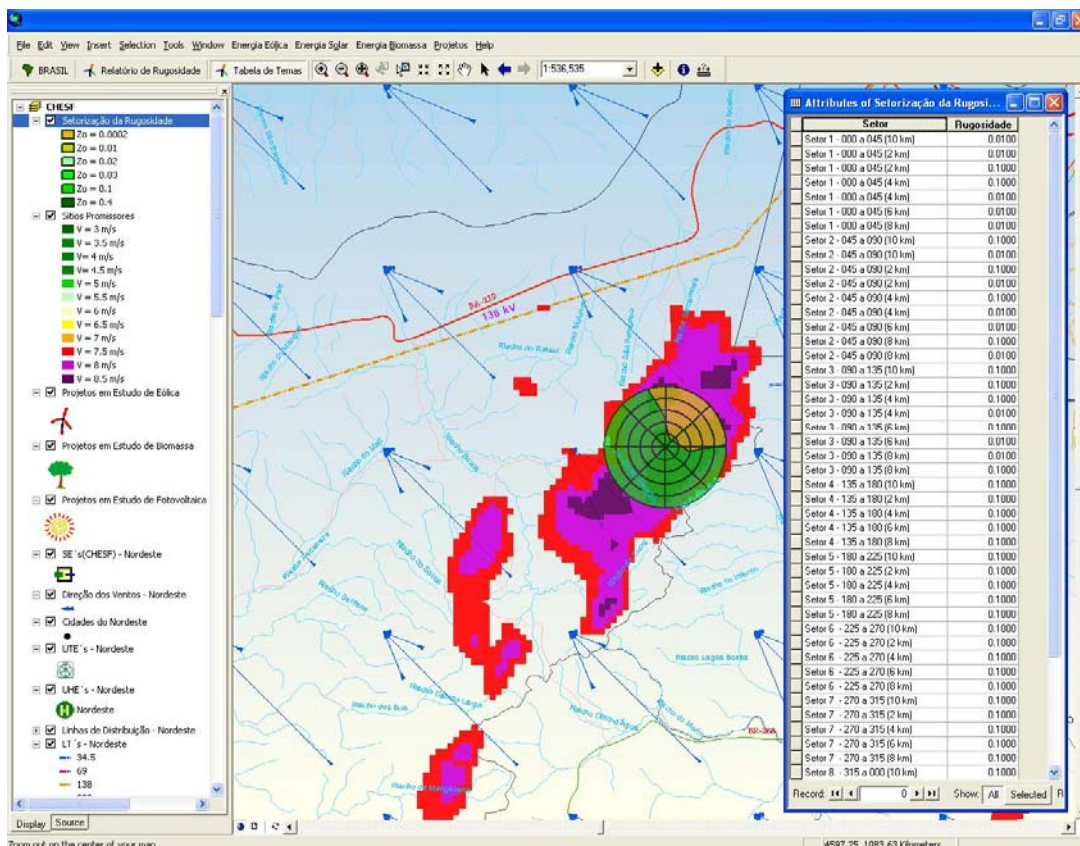
Figure 3. Roughness tool

4.1. Wind Energy Forecast Tool

This tool allows one to calculate the electric power production in pre-established places, with up to 76 hours of antecedence, starting from data bases supplied by Brasilian Forecast Center, obtained through mesoscale modellings on the established places coordinates (Figs. 4, 5, 6 and 7). Based on the amount of wind turbines that fit in the identified area, this tool is enabled to model:

° The wind average, the standard deviation and the *C & k* parameters ;

° The rate power [MW], the capacity factor of the place and the total energy production [MW/h], for different wind turbines.

The advantages in using this methodology during the study phase of the site are:

° It facilitates one to obtain wind data series before the installation of the meteorological mast;

° It allows one to confirm if the site presents the conditions foreseen in the BRAZILIAN WIND ATLAS;

° It facilitates the decision of use of the site.

The advantages in using this methodology after the installation of meteorological mast:

° It supplies wind forecast in advance of 72 hours. So, it allows one to program the dispatch of wind energy (Fig.4);

° It allows one to update the modeling in function of the alteration of the landscape. So, it allows the continuous correction of the forecast of winds (Fig. 6).

The results obtained by the developed wind forecasting model are presented in Fig. 8. It uses the Mesoscale Eta Model (Black, 1994, Chou *et al.*, 2002, Chou *et al.*, 2005). Three simulations of wind velocities [m/s] at 10m height, from day September 13 to September 27, 2005, are presented in function of the orography database resolution (5km, 10km e 40km). In Fig. 8, the black line represents the wind velocity measured at the site; the green line represents the wind velocities estimated with a 5km resolution orography model; the blue line represents the wind velocities estimated with a 10km resolution orography model, and finally, the red line represents the wind velocities estimated with a 40km resolution orography model. It's observed that a good agreement was accomplished between measured velocities and the estimated velocities with a 5km resolution orography model.
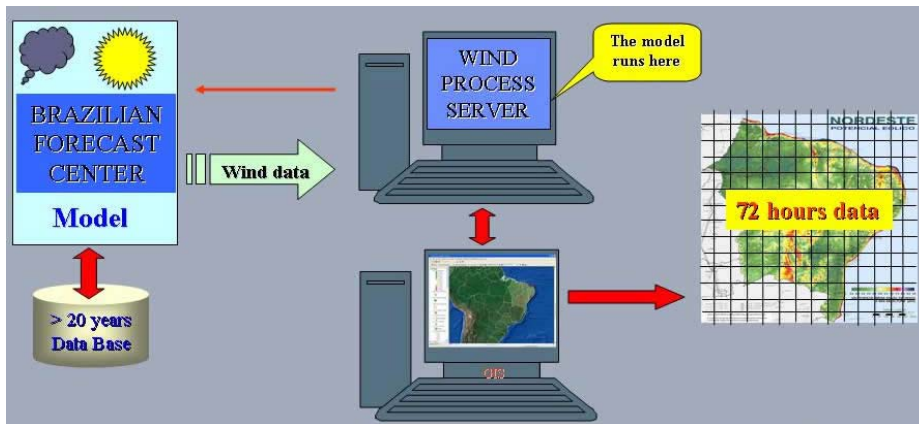
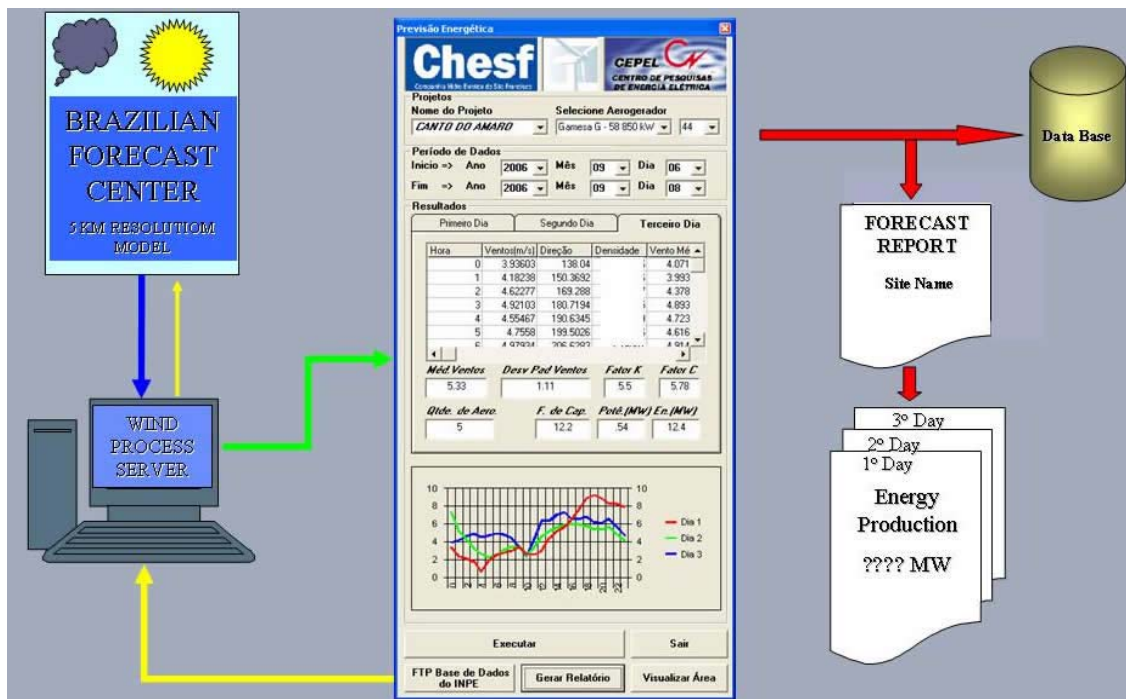

Figure 4. Forecast Consult Tool
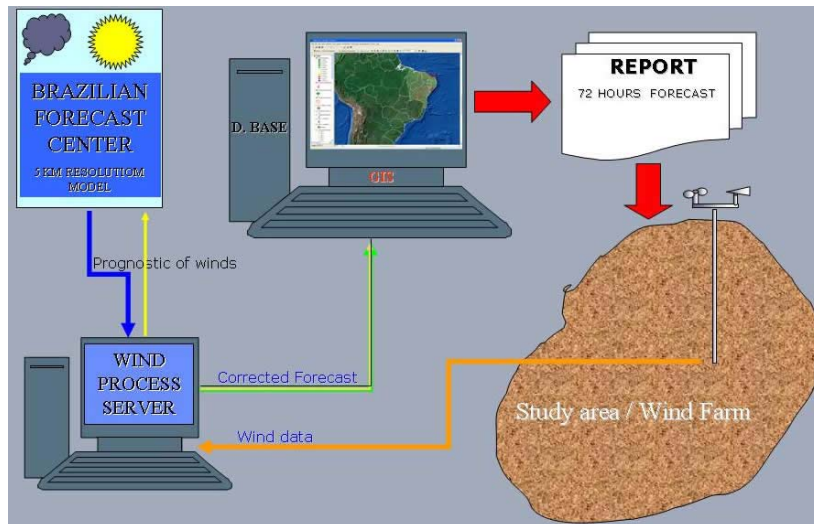

Figure 5. Forecast Report Tool

Figure 6. Energy Forecast Tool - With wind measurement to adjust the prediction
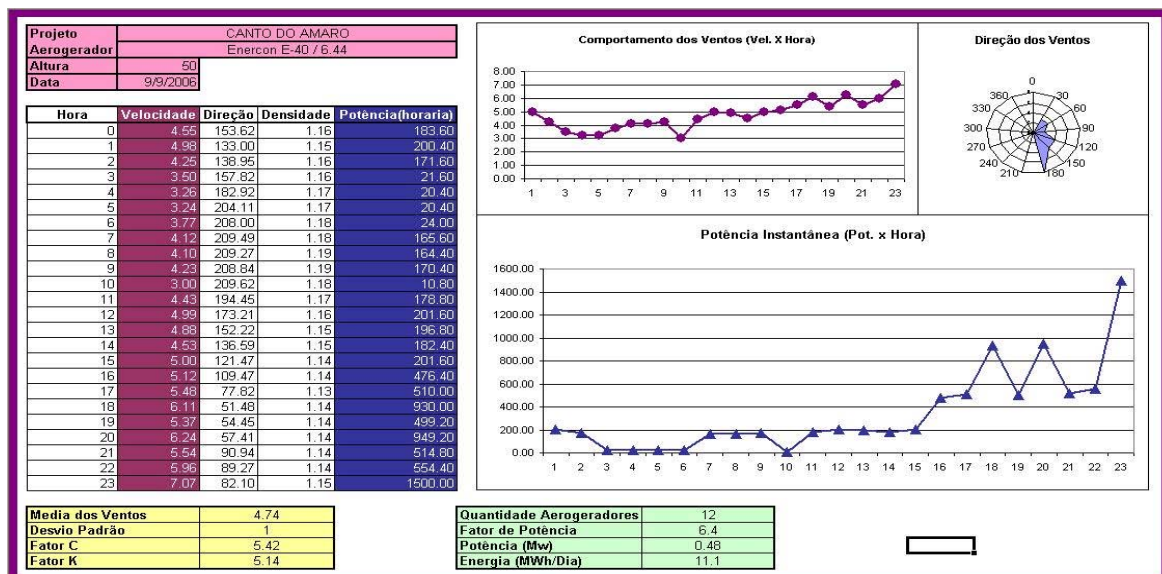
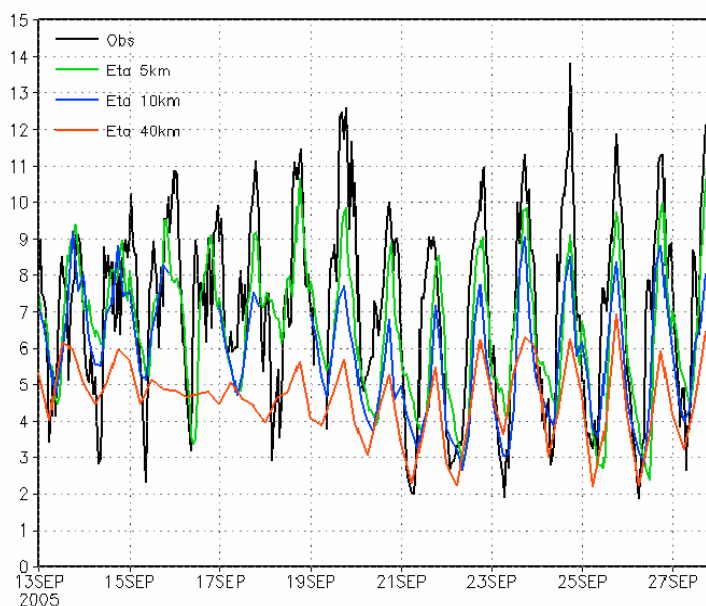

Figure 7. Forecast Report

Figure 8. Forecast results.

4.2. Photovoltaic Tool

This tool allows one to calculate the electric power production produced by photovoltaic systems, (Fig. 9), in order to assist off-grid communities, starting from SOLAR ATLAS database. The energy produced by photovoltaic systems can be written in the form (GTES, 2004):

$$E_{Photovoltaic} = P \times FHS \times \eta_{total} \times 365 \qquad [kWh/m^2/day] \qquad (2)$$

where P is the power capacity of the photovoltaic system; FHS is the average number of full hours of sunshine per day at $1kw/m^2$ of intensity; η_{total} is the system efficiency that comprises battery efficiency (0.95), wiring efficiency (0.98), inverter efficiency (0.80) and a correction factor for dust, dirty, system malfunction, damaged system (0.9). These values are given in GTES, 2004.

The average number of full hours of sunshine per day is given by

$$FHS = \frac{Irradiation \; [kWh/m^2]}{1.0 \, kW/m^2} \qquad (3)$$

and the Irradiation is obtained from the SOLAR ATLAS database (Pereira *et al.*, 2006).

The results are presented in report form, containing the following information:

° Communities data: Name of the communities and the respective distances in relation to the studied place;
° Economic data: Mean Activities
° Roads data: Identification of the access roads; type (paved or not paved) and the distances in relation to the studied place;
° Conservation units data: Identification of the areas, biological priority; type of the area and distances in relation to the studied place.

Figure 9. Photovoltaic Tool screen and commands

4.3. Biomass Tool

This tool allows one to calculate the amount of electric power produced by burns of renewable biomass (Fig. 10), available in each place. The energy produced biomass systems can be written in the form

$$E_{Biomass} = \frac{NBP \times \eta \times \rho \times LHV \times A}{860} \qquad (4)$$

where *NBP*[1] is the net biomass productivity [m³/ha/year] which is the difference between gross productivity (production of plant material by photosynthesis) and respiration and it represents the amount of organic material produced by a plant; η is the chosen thermal cycle (40% for the combined cycle; 27% for the steam cycle; 32% for the gas cycle and 30% for the diesel cycle); ρ is the material density [ton/m³]; *LHV* is the lower heating value [Mcal/ton] and *A* is the area [ha].

The calculations are accomplished starting from the REGIONAL BIOMASS ATLAS database and the results are presented in form of reports, containing the following information:

° Substations data: Name of electric substations, the operation voltage and the distances, in relation to the studied place;

° Transmission lines data: Operation voltage and the distances in relation to the studied place;

° Hydropower data: Name of the nearest hydropower plants, the utility responsible, the rate power (MW) and the distances (km) in relation to the studied place;

° Thermo-electrical plants data: Name of the nearest thermo-electrical power plants; fuel type; utility responsible; the rate power (MW) and the distances (km) in relation to the studied place;

° Cities data: Name of the cities and the respective distances in relation to the studied place;

° Roads data: Identification of the highways; type (paved or not paved) and the distances in relation to the studied place;

° Conservation units data: Identification of the areas, biological priority; type of the area and distances in relation to the studied place.

Figure 10. Biomass tool

5. Conclusions

Nowadays, the importance of developing and spreading the use of alternative sources of energy has been proven worldwide. In the last two years, The Renewable Energy Incentive Program - PROINFRA has provoked an increase of 730% in the renewable sources connected to the grid. Considering the wide extension of our country, the opportunities for renewable energy and the part of population that lives out of grid, the use of Geographic Information System tools

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[1] http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/biogeography/biomass_productivity.html

designed to give support into the prospecting of promising sites for energy production using alternative sources, can be a powerful aid in the development and dissemination of these technologies.

The fast access to the information in the databank and the possibility of crossing several of these information is a great advantage. The tool quickly provides an initial guess to the searching of potential sites for electric power from alternative sources of energy. This initial guess can be used in the observation of satellite pictures in order to identify the promising areas to be visited.

Another important aspect of that tool is it possibility to present a forecasts of generated electric energy starting from forecasts of winds, automatically acquired from national meteorological centers.

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