RENEWABLE ENERGY RESSOURCES IN BRAZIL – SWERA PRODUCTS

Fernando R. Martins
Enio B. Pereira
Brazilian Institute for Space Research
P. O. Box 515. São José dos Campos, Brazil. 12245-970
fernando@dge.inpe.br
eniobp@cptec.inpe.br

Samuel L. Abreu
Sergio Colle
Solar Energy Laboratory - University of Santa Catarina
Campus Universitário Trindade
Florianópolis, Brazil, 88040-900
samuel@emc.ufsc.br
colle@emc.ufsc.br

ABSTRACT

SWERA activities in Brazil provide general technical support, data compilation, qualification, integration and GIS formatting; and mapping activities in Brazil, extensive to the South America continental area and Caribbean region. Information on several accessible activities of solar and wind resource assessment in Brazil are reviewed, mainly for data sets and the associated data retrieval methods. All the reviewed information were organized into a metadata bank and implemented into the international SWERA website (http://swera.unep.net/swera/) for wide dissemination. This site houses the archive, act as a clearinghouse for searches, and disseminate products across the Internet. Through a collaborative effort between INPE and LABSOLAR a satellite model for solar resource assessment was implemented for operationally map the solar resources of the entire South American continent in coarse resolution (40x40 km) and in fine resolution (10x10 km) for Brazil. The implementation of GIS components of project SWERA is being made in cooperation with several national agencies such as ONS, CEPEL, IBAMA, FUNAI, ANP, ANEEL, ELETROBRÁS, LABSOLAR and others. The project has officially started in 2001 and will finish by late 2005.

1. INTRODUCTION

Modern lifestyles demand a continuous and reliable supply of energy. Energy is linked to everyday activities such as mobility, feeding habits, healthy care, leisure, education, etc. The human development is strongly related with the per capita consumption of energy and, as a consequence of improvement of the life quality in the developing countries, it is expected an annual growth of the energy demand of 4% in those countries (Goldemberg, 1998). It is possible to establish a cause/effect relation linking energy use and development with environmental damage as has been demonstrated by many researches. The third IPCC (IPCC, 2001) report confirmed that the Earth's climate is changing as a result of human activities, mainly due to fossil fuel energy use. The IPCC report stated that alternative energy sources should be implemented over the next 20 years to help reduce greenhouse gas emissions (Sims, 2004). The increase in energy demand, the high prices of conventional fuels, the political crises in producing areas of fossil fuels, and the growing concern with the preservation of the environment have stimulated the scientific survey for alternative energy resources.

Significant business opportunities will result from near term potential for renewable energy and related new industries. However, the mid and long-range energy planning require reliable information on many natural resources focusing the renewable energy policy. Investors, risk capital enterprises, and independent energy producers usually are not aware of the available renewable energy options. Besides that, potential investors tend to avoid the risk of activities dealing with the development of renewable energy projects where reliable and sufficiently detailed data are non existent. The main barriers to investments in renewable energy are:

a) the lack of reliable assessment of in-country renewable energy resource potentials,
b) the lack of long time series of ground data with adequate space distribution for studies of uncertainties and time trends,
c) the limited knowledge of the variability and confidence levels linked to several natural and non-natural variables such as climate, topography and man-made impacts in environment,
d) the need for geographically-integrated data base such as population, energy demand, grid distribution, local access, social and economic data, etc.

SWERA – Solar and Wind Energy Resource Assessment is a project financed by United Nations Environment Programme (UNEP), with co-financing by GEF in the area of renewable energies, more specifically, solar and wind energy. The project is assembling high quality information on solar and wind energy resources and ancillary data into consistent GIS (Geographic Information System) analysis tools. The project is aimed at the public and private sectors involved in the development of the energy market and it shall enable policy makers to assess the technical, economic, and environmental potential for large-scale investments in renewable and sustainable technologies. The SWERA project aims at fostering the insertion of renewable energies on the energy matrix of developing countries. There are thirteen countries involved in this pilot phase of the project and they are divided into 3 great regional groups: Africa, Latin America and Asia. In Latin America there are six countries participating in the leading phase of the project: Brazil, Cuba, El Salvador, Guatemala, Honduras and Nicaragua, Belize.

This work presents the main products of SWERA project in Brazil primarily by using the SWERA Geospatial toolkit. This toolkit is a GIS-based software package that uses ArcObjects for map-based operations that has been tested and developed for use on the Windows 2000 and XP operating systems. By use of this tool solar and aeolic energy resources can be weighted against overlapped information such as socio-economic, such as population distribution, per capita income, geographic such as navigable rivers, roads, electricity distribution lines, industry locations, power plants (nuclear, hydroelectric and others), etc. to identifying potential wind and solar energy project sites. Furthermore, this toolkit will also be used to demonstrate the long-term strategic potential of renewables by creating a number of alternative business development scenarios in energy supply business for Brazil.

2. SWERA PROJECT IN BRAZIL

The Brazilian Institute for Space Research (INPE) is coordinating the SWERA activities in Brazil which is now in its final stage. The Solar Energy Laboratory of University of Santa Catarina (LABSOLAR), the Brazilian Center of Wind Energy (CBEE) and Brazilian Centre for Research in Electricity (CEPEL) are partners involved with SWERA activities in Brazil and they are working together to develop several products and tools.

The LABSOLAR and INPE are working together to produce solar energy resources maps for Brazilian and South America territory. The national wind assessment is being provided by the CEPEL and CBEE, along with the collaboration of INPE trough the SONDA (Brazilian Depository System of Environmental Data for the energy sector) project. The SONDA project is chiefly linked to the climatic area but is strongly oriented towards providing adequate support to activities in the area of renewable energy, chiefly in the assessment of the solar and wind energy resources. More detailed description of SONDA project is presented in www.cptec.inpe.br/sonda.

Several training activities have been organized by a joint effort between CBEE, INPE and LABSOLAR for data acquisition and assimilation, including WAsP, and satellite modeling procedures for solar energy resource assessment. Test sites facilities for development of solar and wind resource assessment models, validation, and estimation of confidence levels of model estimations were set up in the northeast of Brazil.

A GIS (Geographical Information System) toolkit are been developed by NREL (National Renewable Energy Laboratory) and it aims at bringing together data from several energy resources, socio-economic, and infrastructure information for the Brazilian territory.

To conclude, in a close cooperative effort between CEPEL, INPE, CBEE, and LABSOLAR, the project will make an effort to demonstrate the long-term strategic potential of renewables by creating a number of alternative business development scenarios in energy supply business for Brazil.

2.1 Solar Energy Resource Maps

The INPE and LABSOLAR/UFSC are working together to produce solar energy resources maps for Brazil and for South America using the radiative transfer model BRASIL-SR (Martins, 2001; Colle and Pereira, 1998). The solar irradiation maps are being calculated from satellite images of geo-stationary satellites (GOES-8 and GOES-12). In addition to global solar irradiation maps, maps of direct and diffused components were also generated as well as irradiation values for tilted surfaces. All of these were validated utilizing the surface database provided by operating ground truth measurements stations (Martins et al., 2003). The surface database includes the basic climactic data (temperature, relative humidity and air pressure) needed as input data for BRASIL-SR model. The SONDA project is now improving and extending the ground measurement sites network which is essential to produce high quality input data and to provide reliable measurements to validate the radiative transfer model.

The excellence and reliability of solar estimates provided by BRASIL-SR model were checked out in the cross-validation step of radiative transfer models used in SWERA project. The DLR model, NREL model, SUNY model were adopted in the project to produce solar maps for Central America, Africa and Asia. The cross-validation step was completed and BRASIL-SR model has presented a performance comparable to the other three core radiative models (Martins et al, 2003; Martins, 2003; Beyer et al., 2004). The ground data used for the validation were provided by Caicó, Balbina and Florianópolis site. The last two sites are BSRN stations located in Amazonian region and in the South of Brazil, respectively. Caicó site was implemented in the Northeast of Brazil by the SWERA project to provide high quality ground data where a large number of clear sky days occur due to climatological characteristics of the location. Figure 1 shows annual mean and seasonal maps for global horizontal solar irradiation. It is interesting to observe that the South region are subject the larger irradiance during the summer season due to climate characteristics of Amazon region – large precipitation and persistent cloud cover all along the summer months. Even in the dry season, the Northwest of Brazilian Amazonian presents a large precipitation (around 1200mm) as a result of ITCZ displacement into North Hemisphere and incursion of Trade wind from Atlantic ocean. This climate feature is responsible by the lower solar irradiation in coastal area of North region and in western area of Brazilian Amazonian.

The north and central region of Brazil will receive largest solar irradiance during the dry season from July till September when precipitation is low and large number of clear sky days occurs in the region.

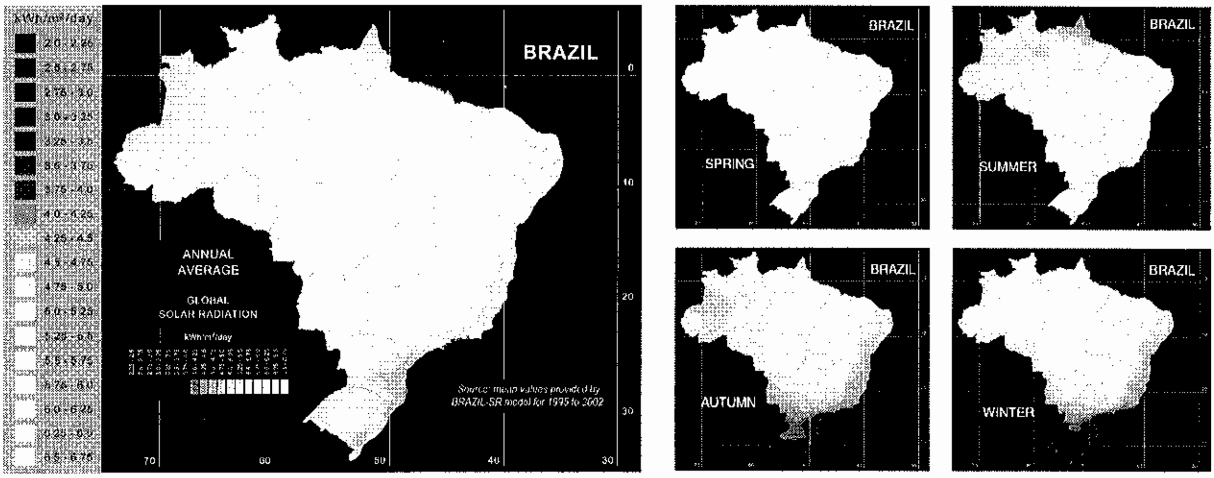


Fig. 1: Annual mean and seasonal maps for daily global solar irradiation. Spring map was prepared using data from October/November/December period. Summer map was prepared using data from January/February/March. The months April/May/June were used to prepare Autumn map and July/August/September were employed for Winter map.

It is important to mention that the annual mean of the estimated global horizontal solar irradiation is larger than $4.5 kWh/m^2$ for any location around Brazil. Brazilian territory receives higher solar irradiation than most of the European countries where solar energy has been wide used. Information about European solar maps can be retrieved from www.satel-light.com.

2.2 <u>Wind Energy Resource maps</u>

CEPEL have produced the first aeolic resource maps for Brazil using the MESOMAP system. The MESOMAP consist in an integrated set of computational models, meteorological database. The model MASS (Mesoscale Atmospheric Simulation System) is the core model of MESOMAP. It is similar to other models like Eta and Mm5 used in weather forecast. The model MASS parameterize the major processes related to atmospheric circulation. The model MASS works together with WINDMAP model to generate wind data in an useful format to a high resolution geographical information system (GIS). The meteorological input data were provided by National Centre for Atmospheric Research (NCAR). Topography and soil use data were provided by US Geological Survey. Physical parameters like roughness, surface albedo, and emissivity were obtained from NDVI (Normalized Difference Vegetation Index) and soil usage data provided by US Geological Survey (USGS), University of Nebraska and Joint Research Centre (JRC). The spatial resolution of the input dataset is 1km.

The wind energy resource maps were achieved in three steps: a) mesoscale simulation using MASS for Brazilian territory in a 15km resolution; b) a second mesoscale simulation in a 3.6km resolution for all regions identified in earlier step as higher wind energy potential; and c) use of WINDMAP for improve final resolution for 1km. The second step was applied to all coastal region to get more reliability in modeling sea breezes and the influence of complex terrain orography. Besides the coastal area, the second step was used on South region and on the semiarid area of Northeast region where higher wind velocities were obtained in the first step. Figure 2 presents the wind power density in Brazil. It can be noted the areas with highest potential to make use of the wind energy are in northeast coastal region, the South and Central region of the country.

2.3 Typical Meteorological Year (TMY) data

In various situations, only the monthly averages of daily totals may not be sufficient to obtain the desired results in the proposed application, therefore, hourly series of solar irradiation and wind velocity data are being generated for a few selected points. These series, known as TMY's (Typical Meteorological Year), are being developed in partnership with NREL (National Renewable Energy Laboratory). Data acquired in twenty measurement sites managed by universities, research institutes and airports are being used to generate the long term TMY series. Figure 3 shows the location of the twenty cities selected to characterize the different climate regimes observed in Brazil. Table 1 presents a short description of each site including the time period used to the TMY generation. Long-term series of surface data will be associated with short-term series of satellite images, thus creating the possibility to generate TMY's for any location.

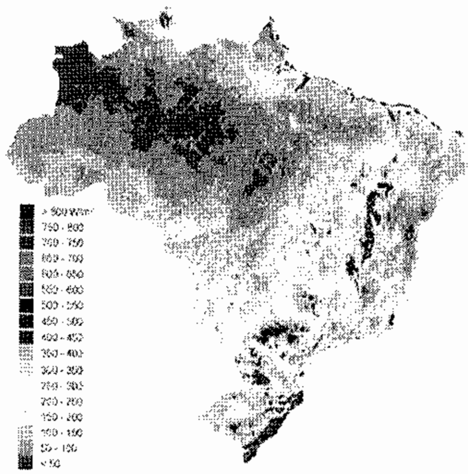


Fig.2: Wind power density map produced by Research Centre for Electric Energy (CEPEL).

TABLE 1: SHORT DESCRIPTION OF SITES USED TO GENERATE "TYPICAL METEOROLOGICAL YEAR" SERIES.

ID	*altitude (m)*	*Location*	*Time (months)*
1	556	Campo Grande	354
2	908	Curitiba	352
3	5	Florianopolis	342
4	25	Fortaleza	311
5	19	Recife	288
6	182	Cuiaba	281
7	375	Petrolina	277
8	785	Belo Horizonte	277
9	290	Porto Nacional	264
10	140	Boa Vista	261
11	803	Sao Paulo	227
12	1061	Brasilia	224
13	3	Rio de Janeiro	211
14	16	Belém	210
15	88	Porto Velho	205
16	98	Jacareacanga	194
17	51	Salvador	193
18	458	Bom Jesus da Lapa	162
19	72	Manaus	148
20	114	Santa Maria	135

2.4 GIS Toolkit

A GIS toolkit has been developed by the SWERA partners and it aims at bringing together data from several energy resources, socio-economic and infrastructure information for the Brazilian territory. It is a GIS tool where solar and wind energy resources maps can be compared or overlapped with all sort of socio-economic information. Table 2 presents a short description of all available information to be use in GIS components of the SWERA project. The database available for implementation of GIS tools is being made in cooperation with several national agencies such as ONS, CEPEL, IBAMA, FUNAI, ANP, ANEEL, ELETROBRÁS, LABSOLAR and others.

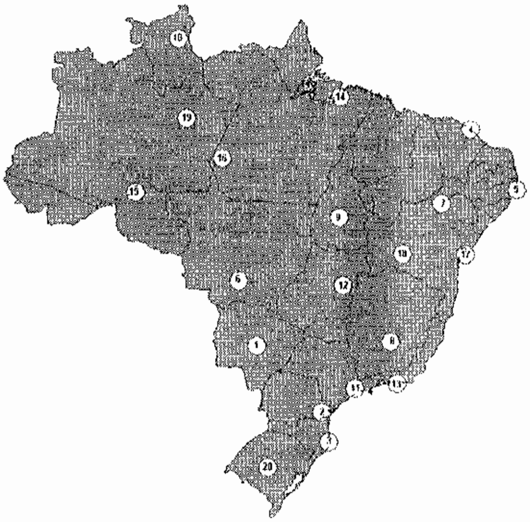


Fig.3: Location map of the measurement sites used to generate TMY series.

The toolkit aims to provide the government and the private investor with an uncomplicated and easily available tool to perform otherwise intricate queries to evaluate the risk and benefits of the potential use of solar and wind energy resources. Several possible scenarios of exploitation of these renewable energy sources can be studied using the query capabilities of the GIS toolkit in order to provide quality information for energy planning authorities and to illustrate the benefits of renewable energy for investors and stakeholders. It will also be useful to develop methodologies in order to retrieve useful information for devising incentive policies for renewable energy usage. The energy resource maps put together with socio-economic and infrastructure data consent to investigate the pros and cons of the employment of solar and wind energy in Brazilian energy matrix.

Figure 4 shows two examples of queries output provided by the GIS tool. Figure 4(A) presents the areas more than 100km far from electricity transmission lines that presents wind power density larger than 200W/m2. These areas would be considered for investments to exploit the wind energy resources to supply electricity for areas not connected to the distribution grid. Figure 4(B) shows the Brazilian regions with solar irradiation larger than 5.5kWh/m^2/day and distant more than 100km far from roads. These locations would be considered in decisions and policies for energy investments since they are distant of the highways raising the costs or hindering of the fossil fuel transport. Most of the areas are located in Amazon region where the use of solar energy would reduce the expected environmental impact due to hydroelectric power plants planed to the region.

4. CONCLUSIONS

The project SWERA aims at providing reliable and high quality information to decision makers, politicians, investors and stakeholders for facilitating clean energy development. It is the first time that such a great amount of reliable information and high quality ground data will be put together to produce a complete image of the solar and wind energy resources in Brazil and South America. Solar irradiance maps for Brazil were obtained by using climatological and satellite data as input to the model BRAZIL-SR. The solar and wind maps demonstrate the great potential available to use this renewable source of energy in Brazil, even in the South region where annual mean of solar irradiation is comparable to the estimated for Amazonian region.

5. ACKNOWLEDGMENTS

The SWERA project was possible thanks to the UNEP/GEF project no. GFL-232827214364 - SWERA. The SONDA project was possible thanks to the FINEP project no. 22.01.0569.00. Thanks are due to the following colleagues: Silvia V. Pereira, Mariza P. S. Echer, Cristina Yamashita, Sheila A. B. Silva, Hugo Corrá, Rafael Chagas, Chou Sin Chan. The following institutional acknowledgment is due to Centre for Weather Forecast and Climatic Studies (CPTEC/INPE). The author was supported by a grant from CNPq (No. 381072/2002-9)..

5. REFERENCES

(1) Beyer H. G.; Pereira,E. B.; Martins, F. R.; Abreu, S. L.; Colle, S.; Perez, R.; Schillings, C.; Mannstein, H.; Meyer, R., Assessing satellite derived irradiance information for South America within the UNEP resource assessment project SWERA. Proceedings of 5th ISES Europe Solar Conference in Freiburg, Germany, September, 2004

(2) Colle, S.; Pereira, E. B. Atlas de irradiação solar do Brasil. Brasília: INMET, 1998 (In Portuguese)

(3) Goldemberg, J., Energia, meio ambiente e desenvolvimento. São Paulo: EDUSP, Brazil, 1998

(4) IPCC, Climate Change 2001 (3 vols). United Nations Intergovernmental Panel in Climate Change.

Cambridge University Press, UK., [online] www.ipcc.ch, 2001

(5) Martins, F. R., Influência do processo de determinação da cobertura de nuvens e dos aerossóis de queimada no modelo físico de radiação BRASIL-SR, Tese de doutoramento, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 330pp , 2001

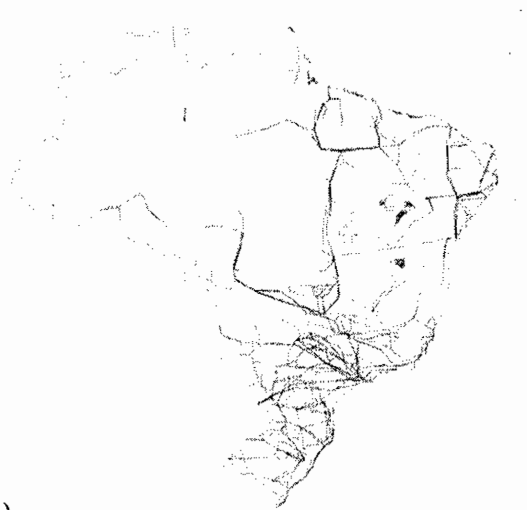
(6) Martins, F. R.; Souza, M. P.; Pereira, E. B., Comparative study of satellite and ground techniques for cloud cover determination. Advances in Space Research, 32, 11, p. 2275-2280, 2003

(7) Martins, F. R. Cross validation of SWERA's core radiative transfer models – First and Second Reports. SWERA Latin America – Model Validation Website, http://www.cptec.inpe.br/swera/EN/bdd/bdd_pub.html, 2003

(8) Sims, R. E. H., Renewable Energy: a response to climate change. Solar Energy, 76, 9-17, 2004

TABLE 2: SHORT DESCRIPTION OF SOCIO-ECONOMIC AND INFRASTRUCTURE DATA AVAILABLE IN GIS COMPONENTS OF SWERA PROJECT.

Category	Data Content	Source of Information
Environment	Climatological data (Relative Humidity, Surface Albedo, Temperature, Visibility)	INPE (Brazilian Institute for Space Research)
Protected Areas	Environmental Protection Areas, National Parks, Ecological Reserve and others	IBAMA (Brazilian Institute for the Environment and Natural Renewable Resources)
Hydrology	Rivers, flooding areas, lakes, lagoons, reservoirs	INPE (Brazilian Institute for Space Research)
Transportation	Railroads in use and planned	Ministry of Transportation
Transportation	Gravel Roads, Roads in pave process, Roads paved and Roads planned and in construction	Ministry of Transportation
Transportation	Airports	Department of Air Space Control
Infra-structure	Gaslines, Oil pipelines, Gas and oil refineries and terminals and Natural Gas Processing Unit	ANP (National Agency of Oil)
Infra-structure	Transmission lines and Sub-stations	ELETROBRÁS (Brazilian Electric Central Inc.)
Infra-structure	Power plants	ONS (National Operator of the Electric System) and ANEEL (National Agency of Electric Energy)
Facilities	Hospitals, Schools	Ministry of Education and Culture and Ministry of Health
Settlements	Cities/Population	INPE (Brazilian Institute for Space Research) and IBGE (Brazilian Institute of Geography and Statistics)



(A)

(B)

Fig. 4: GIS toolkit allow to make overlap energy resource maps and infra-structure information: (A) Query output showing areas with wind power density larger than 200W/m^2 and distant more than 100km far from electricity transmission lines (blue lines are the transmission lines); (B) Query output showing the Brazilian regions with solar irradiation larger than 5.5kWh/m^2/day and distant more than 100km far from roads (green lines are the major Brazilian roads).