SOLAR AND WIND RESOURCES DATABASE TO SUPPORT ENERGY POLICY AND INVESTIMENTS IN SOUTH AMERICA.

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ABSTRACT:

The third IPCC report mentioned that alternative energy sources should be implemented over the next 20 years to help reduce greenhouse gas emissions due to fossil fuel energy use. The mid and long-range energy planning requires reliable information on natural resources focusing the renewable energy policy and investments. Two initiatives coordinated by INPE are under development to produce reliable information on the national solar and wind energy resources. The SONDA project is financed by FINEP to assist Brazilian government at decision-level in supporting and evaluating the multiple actions in renewable energy utilization. The main task in this project is the establishment of a national network of environmental data acquisition aiming at providing high confidence data of interest to the energy sector. The SWERA project is an international project financed by GEF/UNEP funds which aims at providing a consistent and easily accessible database to increase confidence levels at decision centers in order to foster the insertion of renewable energies on the energy matrix in developing countries.

1. INTRODUCTION

Modern lifestyles demand a continuous and reliable supply of energy. It is in the heart of our prosperity and it is linked to everyday activities such as mobility, feeding habits, and our comfort (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

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quality in the developing countries, it is expected an annual growth of the energy demand of 4% in those countries, i.e. a duplication in the next 20 years [1]. 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 [2] report confirmed that the Earth's climate is changing as a result of human activities, mainly from fossil fuel energy use. The increase in energy demand, the reduction of the supply of conventional fuels caused by political crises in producing areas, and the growing concern with the preservation of the environment lead to the necessity of a sound survey for alternative energy resources. The IPCC report stated that alternative energy sources should be implemented over the next 20 years to help reduce greenhouse gas emissions [3].

Significant business opportunities will result from near term potential for renewable energy and related new industries. Investors, risk capital enterprises, and independent energy producers are not aware of the available renewable energy options. The mid and long-range energy planning require reliable information on many natural resources focusing the renewable energy policy. Without reliable information about existing resources, potential investors tend to avoid the risk of activities dealing with the development of solar and wind energy projects. The main barriers to investments in renewable energy production 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.

The Centre for Weather Forecast and Climatic Studies of Brazilian Institute for Space Research (CPTEC/INPE) are coordinating two projects which aim at providing a consistent and easily accessible climatic and renewable energy database to overcome those barriers and to foster the insertion of renewable energies on the Brazilian energy matrix.

The Solar and Wind Energy Resource Assessment project (SWERA) is a multinational project financed by United Nations Environmental Programme (UNEP), with co-financing by the Global Environmental Facility (GEF). The project includes the efforts of several countries, but is primarily directed to developing countries [4].

The second project is called SONDA (Sistema de Organização Nacional de Dados Ambientais para o setor de energia - Brazilian Depository System of Environmental Data for the energy sector) and its main objective is to provide the country with a minimum network of high quality reliable and integrated ground data acquisition sites for ground-truth in satellite and models derived assessment of solar and wind energy [5].

2. SWERA PROJECT

The "Solar and Wind Resource Assessment" (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. 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/UFSC), 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 main objectives of SWERA are:

- to provide a set of consistent, reliable, verifiable, and accessible data sets for international and in-country investors and other stakeholders such as government agencies responsible for facilitating clean energy development. In some countries, large-area high-resolution wind and solar resource mapping is expected to reveal far larger commercial wind and solar project development potential than currently thought possible;
- to reduce uncertainties associated with investment and development decisions for solar and wind projects. This will in turn decrease uncertainties in the design, cost, and performance of solar and wind systems, and should increase investor confidence, and confidence of key stakeholders;
- to increase awareness by key stakeholders and decision makers of the solar and wind resources and the relevance of the resource information to the development and deployment of various solar and wind technologies (existence of potential resource, inclusion of solar and wind energy technologies in energy planning);

- to increase capacity for making solar and wind energy plans on the local, national, and regional levels. The availability of the solar and wind resource data and training in the use of the tools to make use of the data will facilitate better planning for solar and/or wind energy development.

Table 1 shows the main SWERA activities developed under INPE's coordination. The SWERA project in Brazil is now in its final stage. The national wind assessment has been provided by the Brazilian Center for Research in Electricity (CEPEL), and the Brazilian Center for Wind Energy, along with the collaboration of INPE trough the SONDA project.

The LABSOLAR/UFSC and INPE are working together to produce solar energy resources maps for Brazil and for South America using the BRASIL-SR radiative transfer model [6,7,8]. 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 are also being 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. 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 cross validation of solar models is now completed and BRASIL-SR model has presented a performance comparable or better than other core radiative models used within the SWERA project after fine tuning to the major Brazilian environments: SUNY model, DLR model and NREL model [4,9].

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 will be generated for a few selected points. These series, known as TMY's (Typical Meteorological Year), will be developed in partnership with NREL (National Renewable Energy Laboratory). Long-term series of surface data supplied by NREL will be associated with short-term series of satellite images, thus creating the possibility to generate TMY's for any location.

Regional data files containing model input GIS formatted data necessary for the implementation of national and regional charts of solar and wind energy resources are being assembled and processed. A GIS toolkit has been developed by the SWERA partners from 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. It is a GIS tool where solar and aeolic energy resources maps can be compared or overlapped with all sort of socio-economic information like population distribution, per capita income, maps of railroads, rivers, roads, distribution lines of electricity, industry locations, power plants (nuclear, hydroelectric and others), most of it of restricted distribution.

The GIS toolkit will allow the study and delineation of possible scenarios for solar and wind energy utilization to illustrate the benefits of renewable energy in our energy matrix. It will also be useful to develop methodologies in order to retrieve useful information for devising incentive policies for renewable energy usage.

Table 1. Activities developed by Regional Agency for Latin America in SWERA Project.

Task	Short description
Develop maps and receive incremental capacity building in assessment techniques in partnership with SWERA's team	Develop BRASIL-SR radiative transfer model, generate solar and wind high resolution maps derived from satellite data, generate time-series data for TMY, relate short-term satellite-derived solar with long-term ground-based data sets, coordinate regional review of existing national solar and wind surveys and assessment methods, cross-model and model validation for wind and solar
Assist SWERA team in developing geospatial datasets	Identify in-country partners based on the ability to implement the GIS component of the project
Dissemination of SWERA products and outreach to investors	Assist UNEP and SWERA team in establishing of global archives data sets and technical notes/reviews, assist UNEP/GRID in establishing of an Internet site and help distributing SWERA's products
Provide capacity building in use of resource maps and tools	Work with partners to put forward case studies in energy planning, assist UNEP in marketing and presentation of the alternative energy development projections to investors

Figure 1 is an example of two outputs of the GIS tool developed in SWERA project. Figure 1 (A) shows the annual mean wind power density in Brazilian territory. Areas with highest potential are located mainly in northeast coastal region, the South and Central region of the country. The areas more than 100km far from electricity transmission lines and wind power density larger than 200W/m^2 are presented in Figure 1(B). The global solar irradiation map for November 2000 is shown in Figure 1(C). The colored areas presented in Figure 1(D) represent the regions with solar irradiation larger than 5.5kWh/m^2/day and distant more than 100km far from major roads.

Queries like these examples above are suitable for decision makers in defining national policies for investments in new energy projects since they are distant of the highways raising the costs or hindering of the fossil fuel transport. The toolkit will provide the government and the private investor with an uncomplicated and easily available tool to perform otherwise intricate queries on the potential use of solar and wind energy resources.

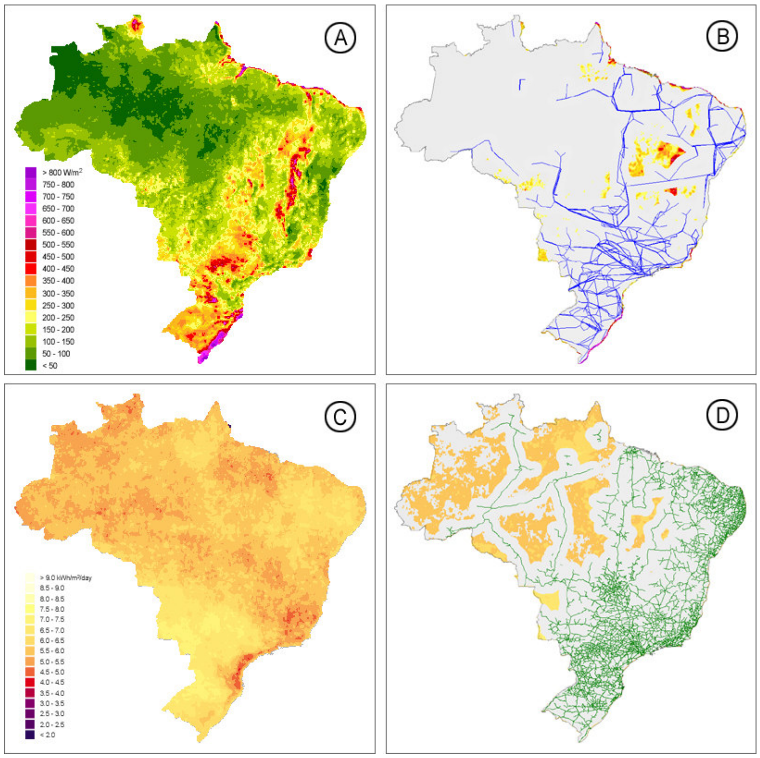

Figure 1. (A) Map of annual mean of the wind power density; (B) Output provided by GIS tool presenting areas distant more than 100km far from electricity transmission lines and with wind power density larger than $200 W/m^2$; (C) global solar irradiance map for November 2000; and (D) Output provided by GIS tool presenting areas distant more than 100km from major Brazilian highways and having solar irradiation larger then $5.5 kWh/m^2$/day.

3. SONDA PROJECT

The "Sistema de Organização Nacional de Dados Ambientais para o setor de energia" (Brazilian Depository System of Environmental Data for the energy sector) 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. The CPTEC/INPE devised the project to help the government in supporting and evaluating the multiple actions of renewable energy resources assessments in Brazil, such as that of SWERA. It has been granted by FINEP (Brazilian National Foundation for Project Development) since 2001.

The project aims to provide the country with a minimum network of high quality reliable and integrated ground data acquisition sites for ground-truth in satellite and models derived assessment of solar and wind energy. Besides that, the database provided by SONDA network will provide capacity building for the study of climate impacts on solar and energy resources (variability, uncertainty, trends, regional and microclimate, manmade effects, etc.) and will build up human resources through technical training and formal academic activities such as those leading to MSc. and PhD.

Figure 2 shows the location map of all measurement sites. Table 2 presents a brief description of these locations. The sites are divided into 4 different classes: (a) reference sites, (b) complete solar sites, (c) basic solar sites and (d) aeolic sites. Table 3 presents the minimum set up for each site category.

Five reference sites are planned to be part of network. Their locations were chosen to represent the major climatic areas of Brazil: the northeast, the Amazon, the central plateau, and the south. Two of them are in operation now and other two are in test to become operational in a few weeks. The data provided by these reference data will be used to validate satellite models developed to estimate renewable energy resources, mainly solar and wind energy.

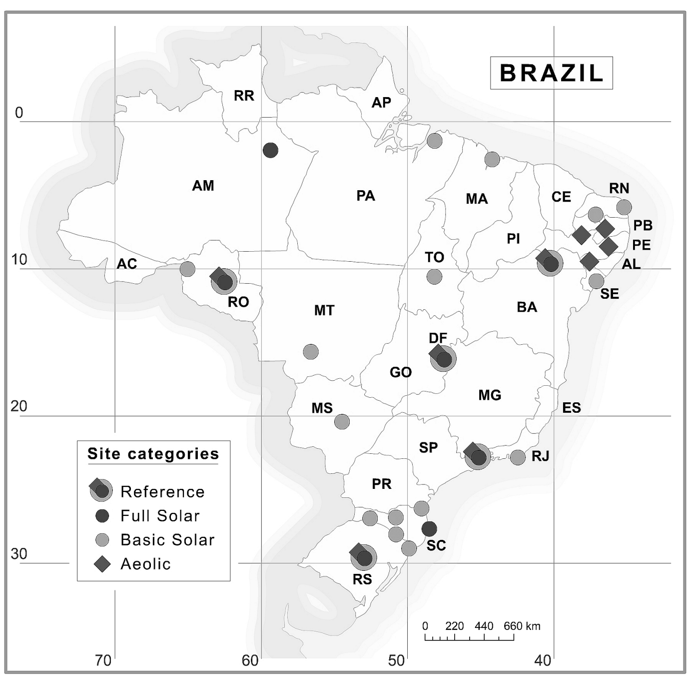

Figure 2. Location of all measurement sites of SONDA network.

Table 2. Basic information of all SONDA measurement sites.

Category	Site Location	ID	Latitude	Longitude	Altitude (m)	Situation
Reference	Brasília/DF	BRB	15°36" S	47°42' O	1023	in operation since 06/2004
	São Martinho da Serra/RS	SMS	29°26" S	53°49' O	489	in operation since 01/2004
	Ouro Preto d'Oeste/RO	OPO	10°52' S	61°58' O	200	in test since 07/2004
	Petrolina/PE	PTR	09°04' S	40°19' O	387	in test since 07/2004
	Cachoeira Paulista/SP	CPA	22°39' S	45°00' O	574	projected
Full Solar	Florianópolis/SC	FLN	27° 36' S	48°30' O	12	in operation since 01/2004
	Balbina /AM	BAB	01°55' S	59°25' O	230	in operation
Basic Solar	Aracaju/SE	AJU	10°54' S	37°04' O	4	projected
	Caicó /RN	CAI	06°28' S	37°05' O	176	in operation
	Campo Grande/MS	CGR	20°26' S	54°32' O	677	in operation since 01/2004
	Campos Novos/SC	CPN	not allocated	not allocated	not available	in project
	Chapecó/SC	XAP	27°04' S	52°36' O	700	in test
	Cuiabá/MT	CBA	15°33' S	56°04' O	185	in operation since 01/2004
	Joinville/SC	JOI	26°15' S	48°51' O	48	in operation since 05/2004
	Lebon Regis/SC	LEB	26°59' S	50°42' O	1036	in operation since 05/2004
	Palmas/TO	PMA	10°10' S	48°21' O	216	projected
	São Luiz/MA	SLZ	02°35' S	44°12' O	40	projected
	Sombrio/SC	SBR	29°05' S	49°48' O	15	in test
	Belém/PA	BEL	01°28' S	48°27' O		in project
	Natal/RN	NAT	05°50' S	35°12' O	50	in project
	Nova Mamoré/RO	NOM	10°18' S	65°11' O	91	in project
	Região dos Lagos/RJ		not allocated	not allocated	not available	in project
Aeolic	Piranhas/PE	PIR	9° 37' S	37° 46' O	203	in test
	Belo Jardim/PE	BJD	8° 22' S	36° 25' O	718	in test
	Triunfo/PE	TRI	7° 49' S	38° 07' O	1123	in test
	São João do Cariri/PB	SCR	7° 22' S	36° 31' O	486	in test

The two sites in Full Solar category in operation are part of "Baseline Solar Radiation Network". They provide ground measurements of global, diffuse and direct solar radiation; photosynthetic active radiation (PAR); illuminance (LUX) data; and basic meteorological data (temperature, pressure, humidity and precipitation). These sites are submitted a very strict procedures of standardization, maintenance and data qualification to accomplish the requirements of the BSRN network. Their high quality data will be very useful to validate radiative transfer models used to estimate solar irradiation at surface. The Basic Solar sites will be helpful to validate radiative transfer models in special atmospheric and environmental conditions like those encountered in Northeast or Amazon region where persistent clear or cloud sky, respectively, make difficult to get cloud cover index from satellite data.

The aeolic category aims at providing wind data to be used in comparisons with climate models and validate wind maps. They consist of vertical towers of 50m eight, with first grade wind (speed and direction) and temperature meters at 25m and 50m, along with data logger and data transmission system. They are collocated with the five complete solar stations to constitute the sites denominated of "reference sites". Wind data are acquired every second and averaged for 10minutes along with having the maximum and minimum calculated before data transmission.

All data are received in the base data collection facility located at CPTEC, in Cachoeira Paulista. The qualified ground measurements database generated by whole SONDA network will be archived following specific procedures to provide control quality and reliability. The archive database will be available for public access by several media (website, ftp, cd, or other required media).

Table 3. Minimum setup for each site category in SONDA network.

Sensors	**Site Category**			
	Reference	**Full Solar**	**Basic Solar**	**Aeolic**
Solar Photometer	X			
Sky Imager	X			
Solar Tracker	X	X		
Global Irradiation	X	X	X	
Diffuse	X	X	X	
Direct	X	X		
Long Wave	X	X		
PAR	X	X	X	
LUX	X	X	X	
Temperature	X	X	X	
Relative Humidity	X	X	X	
Pressure	X	X	X	
Rain Gauge	X	X	X	
Anemometer at 10m	X	X	X	
Anemometer at 25m	X			X
Anemometer at 50m	X			X
Temperature at 1m	X			
Temperature at 25m	X			X
Temperature at 50m	X			X

4. CONCLUSIONS

Both SWERA and SONDA projects in development under CPTEC/INPE coordination 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. The SWERA and SONDA databases will also allow for a better understanding on how renewable energy and climate are related to each other in Brazil, and how climate changes would impact on these renewable energy resources.

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References

1. Goldemberg, J., 1998. **Energia, meio ambiente e desenvolvimento**. São Paulo: EDUSP, Brazil.
2. IPCC, 2001. **Climate Change 2001** (3 vols). United Nations Intergovernmental Panel in Climate Change. Cambridge University Press, UK. (available from www.ipcc.ch).
3. Sims, R. E. H., 2004. **Renewable Energy: a response to climate change**. Solar Energy, 76, 9-17.
4. SWERA Latin Amarica – Model Validation Website, http://www.cptec.inpe.br/swera, 2004.
5. SONDA Website, http://www.cptec.inpe.br/sonda, 2004.
6. 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)
7. Colle, S.; Pereira, E. B. **Atlas de irradiação solar do Brasil (primeira versão para irradiação global derivada de satélite e validada na superfície)**. Brasília: INMET, 1998.
8. Pereira, E. B.; Colle, S. **A energia que vem do Sol.** Revista Ciência Hoje, 22, 130, 25-35, 1997.
9. H. G. Beyer, E. B. Pereira, F. R. Martins, S. L. Abreu, S. Colle, R. Perez, C. Schillings, H. Mannstein, R. Meyer. **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.