Results of Solar Resource Assessments in the UNEP/SWERA Project

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ABSTRACT

This paper provides a summary of the solar resource information that has been developed to date for the 13 countries participating in the United Nations Environment Programme's (UNEP's) Solar and Wind Energy Resource Assessment (SWERA) project. The solar assessments include country-specific maps as well as maps of large regions encompassing these countries. In addition, solar time series and Typical Meteorological Year (TMY) data sets are developed for selected stations within each country.

Besides these solar resource products developed by the SWERA international technical team, information on validation of the results, and intercomparison of the various approaches, has been done in collaboration with country partners working with the international team. These products are being used by government and industry to facilitate the development of renewable energy technologies in these developing countries.

1. INTRODUCTION

The United Nations Environment Programme (UNEP), through funding from the Global Environment Facility (GEF), has been supporting the Solar and Wind Energy Resource Assessment Project for 13 countries around the world, shown in Fig. 1. The countries are Guatemala, Nicaragua, El Salvador, Honduras, Cuba, Brazil, Ghana, Ethiopia, Kenya, Sri Lanka, Bangladesh, Nepal, and China. SWERA is providing high quality wind and solar resource information in Geographic Information Systems (GIS) format for these 13 countries, a Geospatial Toolkit to allow users to analyze the resource data in context with other geospatial data sets (such as roads, transmission lines, protected areas, demographic centers, etc.), and a web-based data archive that makes the information available to the entire world. An international technical team has been assembled to develop

the resource information, and country partners have been identified to work with the team and assist in the development and validation of the resource data sets. The project began in 2002, and will be completed by the end of 2005.

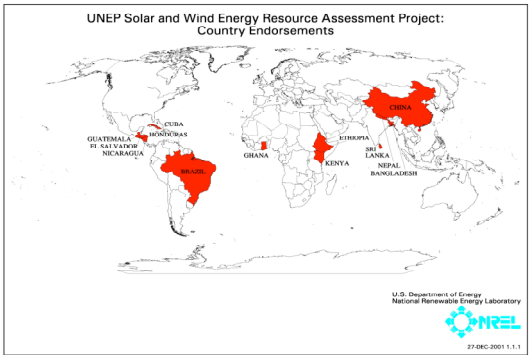

Fig. 1: Location of the 13 SWERA participating countries

Several members of the SWERA international team have been conducting solar resource assessments. These include the National Renewable Energy Laboratory (NREL), and the Atmospheric Sciences Research Center at the State University of New York (SUNY)/Albany in the U.S., the German Aerospace Center (DLR) in Germany, The Energy Resources Institute (TERI) in New Delhi, India, the Instituto Nacional de Pesquisas Espaciais (INPE) in Sao Jose dos Campos, Brazil, and LABSOLAR at the University of Santa Catarina (UFSC) in Florianópolis, Brazil. An overview of their respective approaches for producing solar resource data was published in 2002 (1).

In the following sections, preliminary results of the various solar resource assessment approaches are provided. A robust set of products, along with validation and cross-model intercomparison studies, will be made available. SUNY/Albany, DLR, INPE/LABSOLAR, and TERI are developing high resolution (approx. 10 km x 10 km) data sets for specific countries or smaller regions, while NREL and INPE/LABSOLAR are producing medium-resolution data sets (approx. 40 km x 40 km) for large regions. The U.S. National Aeronautics and Space Administration's (NASA's) Surface Solar Energy (SSE) "Low Resolution" (1^0 x 1^0) global solar energy data set represents an overlay for the entire project; these data are on the NASA web site http://eosweb.larc.nasa.gov/sse/. All data are archived at the UNEP GRID (Global Resource Information Database) Sioux Falls facility in South Dakota, USA, and will ultimately be available on the SWERA archive through the site http://swera.unep.net.

2. MEDIUM-RESOLUTION REGIONAL SOLAR MAPS

NREL has developed medium-resolution (40-km) climatological (1985-1991) solar data sets for four regions around the world: Central America/Cuba and the Caribbean region, Asia/South Asia, Africa, and South America. The technique uses the 40-km resolution gridded cloud cover data (Real-Time Nephanalysis) provided by the U.S. National Climatic Data Center (NCDC) as input to NREL's Climatological Solar Radiation (CSR) model (2). The model uses an updated gridded aerosol optical depth data set developed specifically for this project (3). This aerosol data set is based on a combination of various satellite-derived datasets and ground-based sun photometric spectral measurements. The CSR model outputs monthly and annual average daily total solar radiation values for fixed flat plate collectors oriented at latitude tilt (for photovoltaic systems), direct normal values (for concentrators) and diffuse sky values (for daylighting analysis).

At the time of this writing, results for Central America and for the Asia/south Asia region are completed. The regional analyses for Africa and for South America will be completed by summer, 2005.

Fig. 2 provides an example of a regional analysis, showing the annual average daily total solar resource for fixed flat plate collectors oriented at latitude tilt for the Central America/Caribbean region. Fig. 3 provides the same information for the four Central American countries in SWERA.

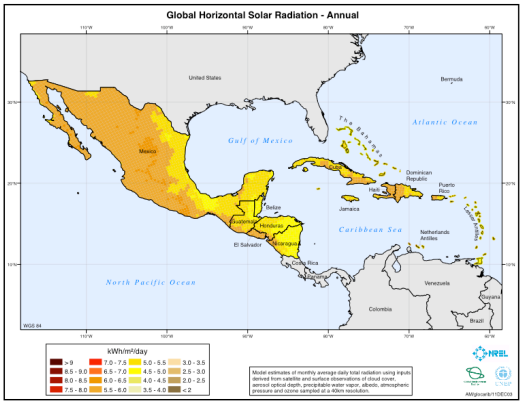

Fig. 2: Solar resource for fixed plate collectors at latitude tilt (NREL's CSR model); Central America/Caribbean region.

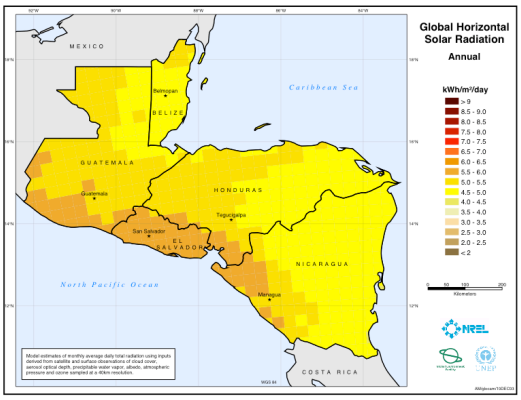

Fig. 3: Solar resource for fixed plate collectors at latitude tilt (NREL's CSR model); SWERA Central America countries.

INPE/LABSOLAR have also developed 40-km regional solar data sets for South America, using the BRASIL-SR model. The BRASIL-SR model is a spectral physical model that combines the utilization of the "two-stream" method to solve the radiative transfer equation using satellite data and climatological information. It was developed first in Germany (GKSS, Geesthacht) and, later, adapted and improved in Brazil by means of an agreement between LABSOLAR and INPE (4). This information has been incorporated into a solar atlas for Brazil.

3. HIGH-RESOLUTION SOLAR MAPS

High resolution (10-km) site-time specific solar data covering a 4 or 5-year period has been developed by the State University of New York (Albany) for Central America, Cuba and portions of Brazil, using imagery from two Geostationary Operational Environmental Satellites (GOES 8 and 10) positioned over the equator in two western Hemisphere locations (5). Fig 4. provides DNI information derived fromthe application of this methodology in Central America.

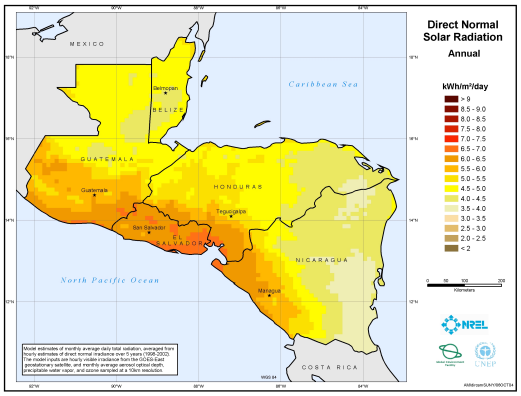

Fig 4: High-resolution DNI for Central America (SUNY/Albany method)

DLR (Germany) has developed similar data sets for the countries of Ghana, Kenya, Ethiopia, Sri Lanka, Bangladesh, Nepal, and western China covering a 3-year period. In addition, hourly time series for selected sites for each country are provided. The DLR-method is based on data from two METEOSAT geostationary satellites, both located over the equator, one at 0^0 Longitude, and one at 69^0E Longitude. The method calculates accurate hourly solar direct normal irradiance (DNI) with high spatial resolution independently from ground measurements (6). Fig. 5 is an example of a high-resolution map for western China using the DLR method.

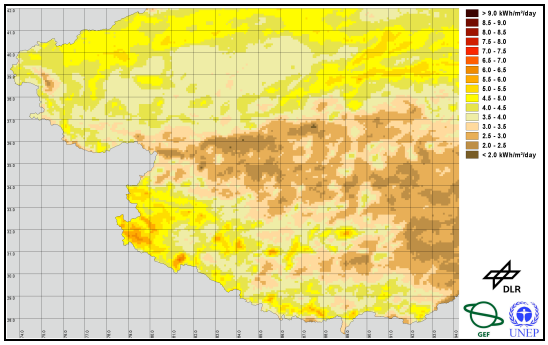

Fig. 5: High-resolution (10-km) map of annual average daily total sum of direct normal irradiance (DNI) in kWh/m_/day for western China (year 2000) based on DLR-methodology.

The SUNY/Albany method was originally designed to produce global horizontal irradiance (GHI) values, while DLR's method originally focused on DNI (for Concentrating Solar Power applications). The two organizations are now working in collaboration through SWERA so that each has the capability to provide both GHI and DNI resource information from their respective methodologies.

In addition to their 40-km methodology, INPE/LABSOLAR have developed high-resolution solar resource data for Brazil using their physically-based BRASIL-SR model for GHI and DNI. Fig. 6 shows an example of a GHI map using this approach.

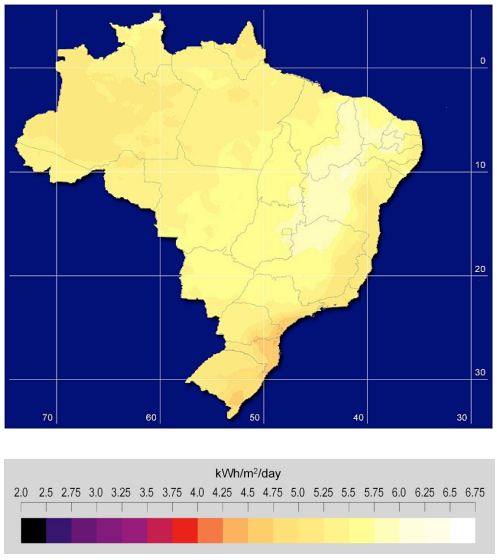

Fig. 6: Annual average global horizontal solar resource, BRASIL-SR high-resolution (10-km) model

Because the data record available to the SWERA team from the geostationary satellites covers only a few years, tools will also be developed to allow the user to generate longer-term time series data at any location based on adjusting time-series solar data, either measured or estimated from weather observations at ground stations, to that specific point.

TERI (India) is also engaged in the high-resolution solar resource work for countries covered by the Indian Geostationary Satellite (INSAT). They have recently adapted the BRASIL-SR model to the Indian subcontinent, and will post the results to the SWERA archive by the end of the project.

4. SOLAR TIME SERIES AND TMY DATA

Using the methods developed in (7) and (8), NREL is providing solar resource time series and TMY data for a number of select ground stations within each of the 13 countries. The methodology incorporates the reported cloud cover observations from national weather services in each country into the METSTAT model. These cloud cover observations, along with other key meteorological parameters, are available from NCDC's DATSAV3 global weather archive. The period of record for most of the stations in this data set typically exceeds 20 years; however, careful screening of the data is required in order to determine if sufficient data are available to produce a reliable TMY. In some countries, only a few stations ultimately were available for the analyses, while in others (such as China) nearly 50 stations were available. All of the time series and TMY data sets are available through the SWERA archive.

5. MODEL CROSS-COMPARISON AND VALIDATION STUDIES

NREL, SUNY, DLR and INPE/LABSOLAR are engaged in a model cross-comparison study over northeastern Brazil to establish the relative uncertainties of the various approaches. This region is unique because it is "seen" by both the eastern GOES and the western METEOSAT geostationary satellites. A ground solar measurement station has been installed by INPE near the city of Caicó in northeast Brazil, and intercomparisons among the various modeling techniques are being conducted relative to this reference station. Additional intercomparisons of the BRAZIL-SR and the NREL CSR models

will be conducted at the Florianopolis and Balbina (Amazon region) Baseline Surface Radiation Network (BSRN) stations. In all cases the NASA SSE data set is also incorporated as a reference data set to the intercomparisons.

Partners from the 13 countries are also engaged in model validation exercises, using independent data sets available from within their countries. For example, in Managua, Nicaragua data from a high quality solar measurement station at the University of Central America (UCA), Managua, and maintained by Padre Lopez de la Fuentes, was made available to the SWERA team for their model validation activities in the region. A preliminary result of the comparisons of the models with the surface data for the cells immediately over Managua is shown in Table 1. Data from the NASA SSE dataset for the Managua region is included in the table. The results show that all the models compare to within 1-5% on an annual average basis.

TABLE 1: COMPARISON OF MODELED ANNUAL AVERAGE GHI WITH OBSERVATIONS AT UCA, MANAGUA, NICARAGUA

Method	**Period**	**W-h-m^{-2}-day^{-1}**
SUNY/A	1998-2002	5506
UCA (MEAS.)	1998-2002	5547
NREL	1985-1991	5477
UCA (MEAS.)	1985-1991	5378
NASA/SSE	1985-1991	5688

5. SUMMARY

The UNEP/SWERA project represents one of the first attempts ever to conduct a combined wind and solar resource assessment for multiple regions around the world, and to incorporate this information into a GIS framework and make the data available through a well-established global archive. This project serves to remove key information barriers and greatly facilitate the development of renewable energy technologies worldwide. As more and more countries see the value that the SWERA products offer the original 13 endorsing countries, other countries are also expected to seek funding to have a similar set of data products developed for their own use.

6. REFERENCES

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