



## **Development of a Benchmarking Tool for Solar Energy Resource Datasets. A Guide for Non-Expert Users to Determine the most Appropriate Use of Solar Energy Resource Information**

Supporting Documentation

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# DEVELOPMENT OF A BENCHMARKING TOOL FOR SOLAR ENERGY RESOURCE DATASETS

## A GUIDE FOR NON-EXPERT USERS TO DETERMINE THE MOST APPROPRIATE USE OF SOLAR ENERGY RESOURCE INFORMATION

SUPPORTING DOCUMENTATION

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**SUPPORTING DOCUMENTATION**



**United Nations Environment Programme**

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PROGRAMME DES NATIONS UNIES POUR L'ENVIRONNEMENT • PROGRAMA DE LAS NACIONES UNIDAS PARA EL MEDIO AMBIENTE  
ПРОГРАММА ОРГАНИЗАЦИИ ОБЪЕДИНЕННЫХ НАЦИЙ ПО ОКРУЖАЮЩЕЙ СРЕДЕ

# DEVELOPMENT OF A BENCHMARKING TOOL FOR SOLAR ENERGY RESOURCE DATASETS

## A GUIDE FOR NON-EXPERT USERS TO DETERMINE THE MOST APPROPRIATE USE OF SOLAR ENERGY RESOURCE INFORMATION

### UNEP – ISES

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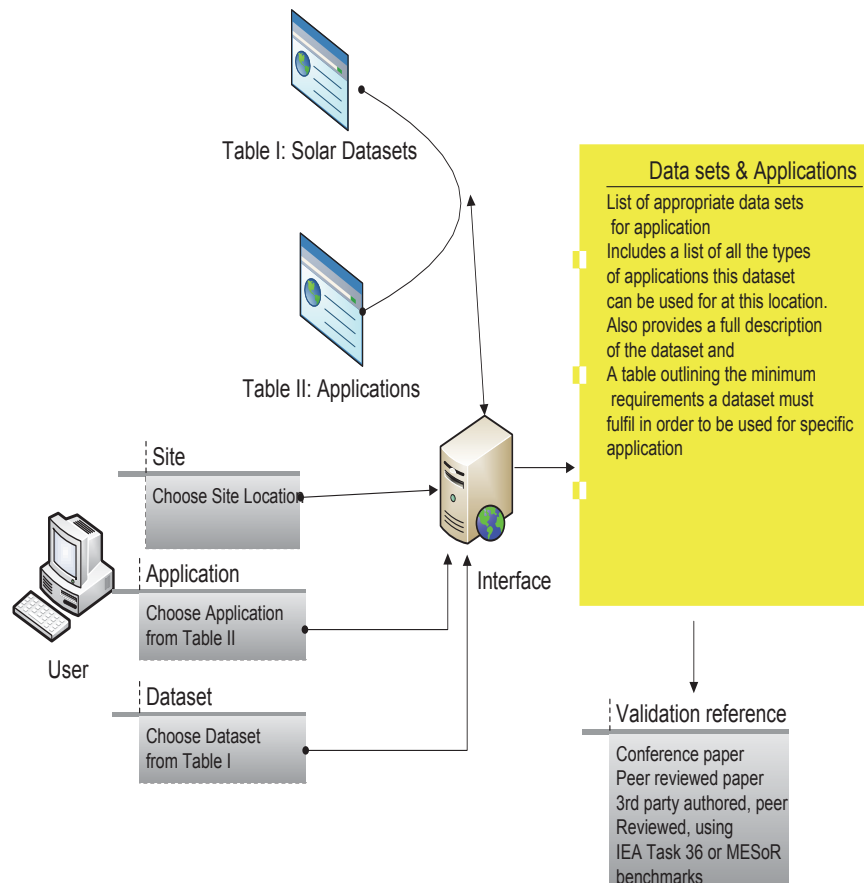
## BACKGROUND

Knowledge of solar energy resources is essential for the planning and operation of solar energy systems. Different organizations provide several autonomous solar data covering various spatial and temporal periods with several different resolutions [1]. Understanding the quality of the datasets underlying assessments of solar energy resources requires a level of technical knowledge that only few Solar and Wind Energy Resource Assessment ([SWERA](#)) users possess. Solar data sets differ in spatial and temporal resolution, time period covered, and methodology used. Some of these datasets are available for free, while some are not, and they all may provide varying results. As a result, most users cannot verify the suitability of a given solar dataset or map based on the purpose of their assessment. This can lead users to abandon their search or make non-appropriate use of the information. A simple guide tool can help alleviate this problem, if it is developed through open and inclusive expert consultation. The results of this exercise provide guidance in data qualification and the selection of data sources for specific applications and give a better indication of the suitability of the available data sources. Therefore, aiming at developing better guidance about the energy application of solar resource information a user-friendly tool, or “guide” has been designed to help experts and non-experts make an educated decision as to which solar data sets are appropriate for use depending on the type of solar application. The tool has been developed in a joint effort between UNEP and the International Solar Energy Society (ISES) and in cooperation with principal experts in the solar radiation field (IEA/SHC Task36 [2], MESoR [3], and networks of active consultancies). The guide basically consists of two tables and relates information from each to help a user identify appropriate datasets for specific applications. The first table is a description of the data sources. The second table consists of recommendations of minimum requirements in the characteristics of the data depending on different applications.

The final result is accessible through the UNEP Energy Branch (<http://www.unep.fr/energy/>) as well as the ISES website (<http://www.ises.org>). Links are also provided from the UNEP SWERA web site, which is a natural point of inquiry for solar resource data and information worldwide (<http://swera.unep.net>) and the MESOR web site (<http://www.mesor.org>). If a solar dataset provider is interested in adding datasets to the guide, they should contact UNEP by filling in the application form on the UNEP website.

### DESCRIPTION OF THE GUIDE

The online friendly-user guide helps expert and non-expert users to decide which solar resource data sets are the most appropriate depending on a type of application that the user is interested in. Figure 1 depicts how the tool works. The programme relates information back to two information tables: one related to a compilation of a selection of existing satellite based solar datasets and their metadata and the other defines specific requirements a data set should meet for specific solar application.



**Figure 1. Scheme for the operation of the Guide to Determine the Most Appropriate Use of Solar Energy Resource Information**

#### HOW TO USE IT

1. The user selects either
  - i. Location (by country or region) AND solar data set (see Datasets in Table I)  
OR
  - ii. Location AND type of application (see classification of applications in Table II);  
OR
  - iii. Location only  
OR
  - iv. Dataset only  
OR
  - v. Type of application only

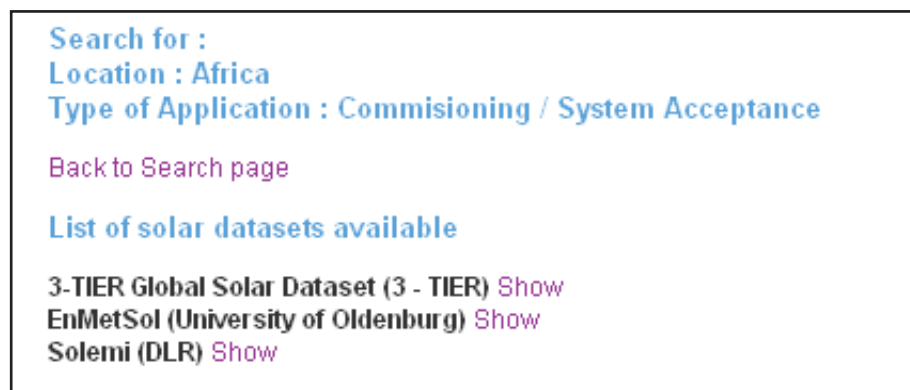
2. The interface interconnects Table I and II with the inputs given by the user
3. A list of relevant data sets is provided each listing the type of applications that the data set can be used for. The requirements for each application type are provided.
4. The data set information also includes notes on whether any of the requirements are not met completely for a specific application as well as notes on the applications specification where applicable, referring the user to examine the criteria requirements listed for each application.



The screenshot shows a search interface with three dropdown menus and a search button. The first dropdown is labeled 'Region / Country :' and contains the text 'Select a region or country'. The second dropdown is labeled 'Data Set (Providing Organisation) :' and contains the text 'Select a dataset'. The third dropdown is labeled 'Type of Application :' and contains the text 'Select a type of application'. Below the dropdowns is a button labeled 'Search'.

**Figure 2: The search menu presents the user with three different search functions.**

The guide lists only datasets as a result of the search.



The screenshot shows the search results page. It displays the search criteria entered: 'Search for : Location : Africa Type of Application : Commisioning / System Acceptance'. Below this is a link 'Back to Search page'. Then, it shows the title 'List of solar datasets available' followed by a list of three datasets: '3-TIER Global Solar Dataset (3 - TIER) Show', 'EnMetSol (University of Oldenburg) Show', and 'Solemi (DLR) Show'.

**Figure 3: The results of the search show the relevant datasets, and include the search criteria entered.**

By clicking on “Show”, the user can view the metadata of the data sets, the appropriate application types and notes on the application requirements (see figure 4).

**Solemi**

**Dataset :** Solemi

**Providing Organisation :** DLR

**Geographical Coverage :** Europe, Africa, Middle East

**Validation Information :**

<b>Peer-reviewed or third party-validated ? :</b>	yes
<b>Validation Type <sup>(a)</sup></b>	benchmarked
<b>Database has been benchmarked according to IEA Task 36 and/or MESoR :</b>	yes
<b>Validation information available publication articles, preferably peer-reviewed &amp; third-party (primary) authored, using IEA Task 36 benchmarks :</b>	Mesor-Reports; Benchmarked within MESoR

**Source of data and further information :**

**Source :** geostationary satellites

**Availability :** for sale

**Web Sites :** <http://www.solemi.com>

**Remarks :** one year free via MESOR

**Other applications this dataset is suitable for :**

Commisioning / System Acceptance	(show results: Application requirements / Dataset values)
Due Diligence	(show results: Application requirements / Dataset values)
Feasibility	(show results: Application requirements / Dataset values)
Pre feasibility	(show results: Application requirements / Dataset values)
Site Selection	(show results: Application requirements / Dataset values)
CSP	(show results: Application requirements / Dataset values)
Daylighting	(show results: Application requirements / Dataset values)
PV Large systems	(show results: Application requirements / Dataset values)
PV Medium sized systems	(show results: Application requirements / Dataset values)
PV offgrid systems	(show results: Application requirements / Dataset values)

**Figure 4: By clicking on “Show” all the information available about the dataset will be displayed, including the applications types and additional notes on requirements, (note all the information presented is not displayed in the above screen shot). Foot notes to the metadata are also provided by scrolling the numbers.**

By clicking on "show results: Application requirements/Dataset values", under the application types listed under "Other applications this dataset can be used for", the user can view a comparison table showing the minimum requirements recommended for these applications and how the dataset fulfills these requirements .

Comparison table for Commissioning / System Acceptance			
	Application Requirement	Dataset value	Correct/not sufficient
Spatial resolution	10 km	3 km	✔
Temporal resolution	hourly	hourly	✔
Time coverage	10 years	1999-2011	✔
Radiation components	GHI+DNI	GHI, DHI, DNI	✔
Low bias <sup>(1)</sup>	yes	yes	✔
Low root mean square error <sup>(2)</sup>	no	yes	✔
Frequency distribution metrics	yes	yes	✔
Current Data Available / Near Real Time Data <sup>(3)</sup>	yes / yes	n/a / n/a <sup>(4)</sup>	✘ <sup>(*)</sup>
Validation information available	yes	no	✘ <sup>(*)</sup>

**Requirement highly recommended to be fulfilled:dataset still NOT validated**

Figure 5: The comparison table shows the minimum requirements recommended for the applications and how the dataset fulfills these requirements. Notes are included as well, below the list of applications, when for instance a dataset does not meet all the requirements for a specific application or certain clarification is required about the application, for examples by scrolling over the (\*) next to the red cross, a notice is given that this requirement is high recommended but not fulfilled.



## STRUCTURE OF THE GUIDE

Two tables form the basis for the guide:

- Table I is a compilation of solar data sources and provides metadata about each data source (see Annex I).
- Table II relates this metadata to a number of different solar applications, such as investment planning for different types and sizes of solar systems, operation of systems, policy analysis and/or scientific inquiries (see Annex II).

Both tables are interconnected; therefore Table II provides recommendations for the minimum data characteristics that should be fulfilled for each application, in terms of the metadata provided in Table I. The criteria are based on expert consultations and on existing knowledge of solar resource data and state of the art of the solar benchmarking [MESoR, IEA/SHC Task36].

## TABLE I – SOLAR DATA SETS

Table 1 gathers a selected number of the existing satellite-based solar radiation datasets as a practical sample of information and at the same time provides the features of each dataset. Table 1 does not intend to include all existing data sets, however it is open to be expanded on by the suggestions of providers, additional datasets and the respective metadata can be inserted by filling in the application form on the UNEP website. For each dataset the following information is provided:

1. Organisation providing the data
2. Geographical coverage
3. Source of data: geostationary satellites, or a combination of geostationary satellites and ground stations
4. Spatial resolution: the minimum distance between two adjacent features or the minimum size of a feature that can be detected by a remote sensing system (units in km )
5. Temporal resolution: refers to the frequency with which images of a given geographic location can be acquired (15 min, 30 min, hourly, daily, monthly, annual....).
6. Time coverage. Period of time the data have been acquired (including start and end periods)
7. Component: The solar radiation components contained in the dataset, i.e. GHI, DNI, TPI, DFI, PAR, Diffuse, Global in-plane, Global Inclined
8. Peer reviewed or third party validated: indication of validation information available
9. Database has been benchmarked according to IEA Task 36 and/or MESoR benchmarks: refers to the validation information available.
10. Validation information available: Published articles, preferably peer-reviewed & third-party (primary) authored, providing RMSE & MBE results with documented methodology, and using IEA/SHC Task 36 [2] and/or MESoR [1] benchmarks

11. Validation Type: none provided/not available, conference paper, peer reviewed paper or third party authored peer reviewed using IEA/SHC Task 36 and/or MesoR benchmarks<sup>1</sup>
12. Low Mean Bias Error (MBE): Low difference between an estimator's expectation and the true value of the solar parameter being estimated. Considered Low when: <5% GHI; <10% DNI<sup>2</sup>
13. Low root mean square error (RMSE): The root mean square error measures the differences between values predicted by a model and the values actually observed. Considered Low when: <120W/sqm hourly GHI; <160W/sqm hourly DNI
14. Frequency distribution metrics, eg KSI, OVER, available? If yes, values and link should be provided
15. Current data available / Near real time data: Yes, no or N/A
16. Availability: Free data set or for sale
17. Website: Where available
18. Remarks: any additional/relevant notes on the datasets

The information for spatial resolution, temporal coverage, time coverage and solar radiation component, as well as the validation information are the key eliminating criteria that are related back the minimal requirements of the various application types. While the tool compares all the information about the dataset with the requirements for an application, information provided on these five criteria are decisive for determining if a data set can be used for a specific application. Moreover, two of the listed requirements ("Use of multiple independent data source" and "On Site Measurements") contain information useful for the user in order to understand the requirements of each application; however, they are not listed in the characteristics of the datasets. Therefore these requirements not considered by the tool as minimum requirements, but rather as part of a detailed description of characteristics a dataset could have for a specific application.

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<sup>1</sup> Peer reviewed papers by third party author would imply higher quality work than a conference paper, but this is not necessarily always the case. Validation references not available for all datasets

<sup>2</sup> For points 12-14: When short-term, locally specific solar radiation measurements are available; these can be used to reduce the uncertainty of the satellite modelled estimates for that particular location. Doing so combines the precision of the ground measurements and the long term coverage from the satellite models. There are several methodologies to combine the short-term with the long-term data to obtain a more accurate estimate of the long-term solar resource at the site, ranging from the simple so-called ratio method (taking the model/measurement ratio over their short-term common period and applying this ratio as a model correction over the long term) to more sophisticated methods adjusting the model's underlying parameters (e.g., its turbidity settings) to better match observations, and to optimally combining multiple modelled data sets and ground measurements. These procedures have been shown to be effective as long as the satellite model to be corrected has a sound physical basis and is self-consistent over the long term (i.e., has been validated in a sufficient number of locations to properly account for long term trends and year-to-year variability).

TABLE II REQUIREMENTS FOR SOLAR ENERGY APPLICATIONS:

The second table (Table II) takes the same metadata but relates it to a number of different solar energy applications, such as investment planning for different types and sizes of systems, operation of systems, policy analysis and science. For each application Table II provides a recommendation of the minimum characteristic to be fulfilled, e.g. in terms of spatial and temporal resolutions, for a data set to be suitable for this specific application. The following is a list of the different application including examples/descriptions of each:

- **Investment Decision**
  - **Site selection:** e.g. search for sites with best resources within a given area, comparison of different sites for project development. The search usually requires a map with long term average of the available solar resource
  - **Pre feasibility:** e.g. First assessment of a project feasibility, rough assessment of investment cost, plant performance, operational cost. The initial assessment can be done with annual average values.
  - **Feasibility:** e.g. Study of plant feasibility, assessment of investment and operational cost. Simulation of plant performance and energy yield, assessment of electricity or heat cost. Feasibility studies are more detailed in the simulation of the power plant and therefore require more detailed data.
  
- **Design and construction:** Designing of solar energy system is usually done simulating the system. The different components (Number of panels or collectors, interconnections, field layout, inverter, storage size, etc.) are modified until optimal plant performance is achieved. The detail of the simulation depends on the type of the system, larger systems usually call for a more detailed simulation. The level of detailed simulation determines the necessary detail in the solar radiation data. The following are typical examples of different applications presented in the exercise:
  - PV off-grid systems
  - PV Small systems
  - PV medium sized systems
  - PV Large Systems
  - Tracking/Concentrating PV
  - Solar Hot Water
  - Solar cooling
  - CSP
  - Daylighting
  - Solar Process Heat
  
- **Due diligence:** A review process by an independent expert of the project development documents used to acquire project financing. The needs are therefore the same as in the design phase.
  
- **Commissioning:** The commissioning phase requires solar data for the validation of the performance of the solar components.
  
- **Operation**
  - **Performance monitoring** (does the system work correctly?): The operation of solar energy systems needs current data to monitor the performance, e.g. are all strings working correctly in a PV-system or does the inverter work with the expected efficiency?
  - **Performance improvement** (how to improve system performance): Records of plant performance and solar data can be used to model the actual system performance and find improvements in operation or system layout.

- **Forecasting:** Can be used to optimize performance within the electricity grid by reducing necessary back up power, optimize the use of storage or market participation in the energy markets.
- **Energy policy**
  - **Potential assessment:** Assessment of the technical and economical potential of an energy technology is the first step in the market introduction. This assessment shows if it is worthwhile to introduce a technology into a market and which share of the market it can reach. Long term average values are needed for the assessment.
  - **Design of support instruments, e.g. levels of tariffs, incentives:** It is usually the aim of a support instrument to make investments successful. Incentives therefore have to be at a level which gives the investors a reasonable return on investment. The amount of the incentive depends on the locally available resource. A too low incentive will not level the investment, a too high incentive will waste funding and give the investors an unnecessary high return.
  - **Policy monitoring:** Monitoring and evaluation of policies also needs resource data to level monitoring data of a particular time frame to the long term averages.
- **Climate policy:** Solar radiation is one of the main parameters within climate modeling.
  - Climate models
  - Impact assessment models
  - Climate monitoring
- **Science/technology:** The application of solar radiation data within science and technology is a very wide field. The named applications are just a few but common ones.
  - Energy system analysis (Systems, components)
  - System simulations
  - Grid integration studies

## EXPERT CONSULTATION

To support the validity of the information presented a consultation with solar resource experts has been undertaken to expand and up-date the metadata presented in the Table I as well as to review the requirements presented in Table II.

## ACCESS

The tool is accessible from the UNEP Energy Branch and ISES web sites, and links are available from the SWERA and MESOR web sites.

## AUTHORS AND ACKNOWLEDGMENTS

Prof. Richard Perez of the State University of New York at Albany, Carsten Hoyer-Klick of the German Aerospace Centre, Dr. David Renné of the United States National Renewable Energy Laboratory (NREL), Dr. Magda Moner-Girona and Daniel Puig from UNEP, and Jennifer McIntosh from ISES have worked together to define the nature and scope of the tool and develop the main elements of the tables and tools.

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- Prof. Dr. A. David Pozo Vázquez, University of Jaen, Spain
- Dr. Enio B. Pereira, INPE, Brazil
- Dr. Lourdes Ramírez, CENER, Spain

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- [2] Task 36 under the International Energy Agency’s ‘Implementing Agreement’ – <http://www.iea-shc.org/task36/index.html>
- [3] European Commission-funded MESOR ‘Management and exploitation of solar resource knowledge’ - <http://www.mesor.org/>
- [4] “Developing a Guide for Non-Experts to Determine the Most Appropriate Use of Solar Energy Resource Information”, C. Hoyer et al., EuroSun 2010

## ANNEXES

ANNEX I: TABLE I SOLAR DATASETS (EXTRACT ONLY) – SEE THE FULL TABLE I ON WEBSITE

DATA SET	Providing organisation	Geographical coverage	Source	Spatial resolution (km) node 1 degree	Temporal resolution	Time coverage	Component	Peer-reviewed or third party-validated?	Database has been benchmarked according to IEA Task 36 and/or MESOR	Validation information available - publication articles, conference, peer-reviewed, using IEA Task 36 benchmarks	Validation Type (1)	Low Bias (<5% for GHI and <10% for W/m <sup>2</sup> )	Low root mean square error (< 125 W/m <sup>2</sup> for hourly GHI and < 160 W/m <sup>2</sup> for hourly DNI) (2)	Frequency distribution OVER, available? (2)	Current data available / Near real time data	Availability	Website	REMARKS
NASA-SSE	NASA	World	multiple satellites	100 km	Daily	1983-2008	GHI-DNI*	yes	yes	Link to NASA sites: Literature and Conference, Benchmarked within IEA Task 36	bench marked	yes*	n/a	no	no	free	eosweb.larc.nasa.gov/isa	*DNI available only on a monthly basis, DNI bias exceeds 10% poleward of 60 degrees
Swera-40k	NREL	Asia (excluding Japan), South	US-Airforce cloud cover	40 km	Monthly	1985-1991	GHI-DNI	yes	no	SWERA website	NA	yes	n/a	no	no	free	swera.unep.org	**Model based on histogram of 1985-1991 RTNEPH data, not updated by NREL
Swera 40k	INPE	Brazil and South America	satellites	40 km	Monthly	1995-2005	GHI, DNI, TPI, DFI, PAR	yes	no	MARTINS, Fernando Ramos; PEREIRA, E. B.; ABREU, Samuel Luna de. Satellite-Derived	peer reviewed	Yes	Yes	Yes	No	Free	swera.unep.org	* DNI only for Brazil
Swera-10k	SUNY	Bangladesh, Brazil, China, Cuba, FL	geostationary satellites	10 km	hourly	1998-2005	GHI-DNI	yes	no	Conference articles, independent review	conference paper	yes	yes	n/a	no	free	swera.unep.org	** only selected sites are hourly
Swera 10k	INPE	Brazil	satellites	10 km	Monthly	1995-2005	GHI, DNI, TPI, DFI, PAR	yes	no	MARTINS, Fernando Ramos; PEREIRA, E. B.; ABREU, Samuel Luna de. Satellite-Derived	peer reviewed	Yes	Yes	Yes	No	Free	swera.unep.org	
Swera 10k	DLR	Ghana, Ethiopia, Kenya, Bangladesh	geostationary satellites	10km	annual *	2000-2003	GHI-DNI	yes	no	Solar Energy Article	peer reviewed	yes	yes	n/a	no	free	swera.unep.org	few sites available in annual resolution
Solemi	DLR	Europe Africa Middle East	geostationary satellites	5 km	hourly	1991-2005	GHI-DNI	yes	yes	Mesor-Reports; Benchmarked within MESOR	bench marked	yes	yes	yes	no	for sale***	www.solemi.com	***one year free via MESOR
EnMetSol	University of Oldenburg	Europe Africa	geostationary satellites	5 km	hourly	1995-present	GHI-DNI	yes	yes	Mesor-Reports; Benchmarked within MESOR	bench marked	yes	yes	yes	yes	for sale***	www.enmet-solar.com/en/telemetry/index.html	Spain resolution changes in 2005 to 0.025°, on request 15 or 30 min values are
Helioclim-1	Mines ParisTec	Europe Africa	geostationary satellites	30 km	monthly (DNI), daily (GHI)	1995-2005	GHI-DNI	yes	yes	Solar Energy Article; Benchmarked within MESOR	Peer reviewed	N/A	N/A	N/A	no	for sale*** 1989 free	http://www.solemi.com/en/telemetry/index.html	***one year free via MESOR
Helioclim-3	Mines ParisTec	Europe Africa	geostationary satellites	5 km	1/4 hourly	2004 - present	GHI-DNI	yes	yes	Mesor-Reports & Solar Energy; Benchmarked within MESOR	bench marked	yes	yes	yes	yes	for sale***	http://www.solemi.com/en/telemetry/index.html	***one year free via MESOR
Satel-Light	ENTPE	Europe	geostationary satellites	5 km	1/2 hourly	1998-2000	GHI-DHI**	yes	yes	Mesor-Reports; Benchmarked within MESOR	bench marked	yes	yes	yes	no	free	http://www.satel-light.com/	DNI must be calculated from horizontal direct DHI
NSRDB-SUNY	NREL	USA northern Mexico	geostationary satellites	10 km	hourly	1998-2007	GHI-DNI	yes	no	NREL-Report	Peer reviewed	yes	yes	yes	no	free	http://ftp.nrel.gov/pub/istat/srbs-solar	
Solar Anywhere	Clean Power Research	USA northern Mexico	geostationary satellites	10 km	hourly	1988-present	GHI-DNI	yes	no	Solar Energy Article	peer reviewed	yes	yes	yes	yes	for sale	www.solaranywhere.com	
NRC-SUNY	Natural Resource Canada	Canada below 60degrees	geostationary satellites	10 km	hourly	1998-2008	GHI-DNI	yes	no	Ongoing Validation by CanMet	NA	yes*	yes*	N/A	no	free	http://re.jrc.ec.europa.eu/bug	increased bias in winter due to prevalence of snow
PVGIS	EU-JRC	Europe, Africa	ground stations, satellite (Africa)	on of variable density stations	monthly	1981-1990 (EU), 1985-2004 (Africa)	GHI, G inclined	yes	yes	Benchmarked within MESOR	bench marked	yes	N/A	N/A	no	free	http://re.jrc.ec.europa.eu/bug	
CM-SAF	DWD/Meteosat	Europe, Africa	Satellite (MSG)	15 km	daily averages	2005-2010	GHI, direct horizontal	no	no	not available at this time	NA	yes	N/A	N/A	yes*	free		* 6 weeks delayed

ANNEX II: TABLE II APPLICATIONS

	Minimum spatial resolution (km) (note 1 degree roughly equals 100 km)	Minimum temporal resolution	Minimum time coverage [years]	Solar radiation components	Peer-reviewed or third party-validated?	Database has been benchmarked according to IEA Task 36 and/or MESOR	Low Bias (<5% for DNI) (1)	Low root mean square error (< 125 Wsqm for hourly GHI and > 160 W/sq.m for hourly DNI) (1)	Frequency distribution metrics, e.g., KSI, OVER, available? (1)	Use of multiple independent data source	On site measurement	Current data available / Near real time data
Investment Decision										recommended always	recommended always	No with the accuracy needed
Site selection	10 (map)	annual long-term	10	GHI or DNI	yes	no	yes	n/a		yes	no	no
Pre feasibility	100	annual long-term	5	GHI or DNI	yes	no	yes	no		yes	no	no
Feasibility	10	hourly	10	DHI or DNI	yes	yes	yes	no		yes	no	no
Design and construction												
PV offgrid systems	100	hourly	10	GHI	yes	yes	yes	no		yes	yes	yes
PV Small systems	100	monthly	5	GHI incl.	yes	no	yes	no		no	no	no
PV Medium sized systems	10	hourly	5	GHI + DNI, in	yes	yes	yes	yes		yes	yes	yes/no
PV Large systems	10	hourly	10	GHI + DNI, in	yes	yes	yes	no		yes	yes	yes
Tracking / concentrating PV	10	hourly	10	GHI + DNI, in	yes	yes	yes	yes		yes	yes	yes
Solar hot water	100	monthly	5	GHI incl.	yes	no	yes	no		no	no	no
Solar cooling	10	monthly	5	GHI incl.	yes	no	yes	no		no	no	no
CSP	10	hourly	10	DNI	yes	yes	yes	yes		yes	yes	yes
Daylighting	100	hourly	5	illuminance	yes	no	yes	no		no	no	no
Solar Process Heat	10	hourly	10	GHI	yes	yes	yes	no		yes	yes	yes
Due diligence	10	hourly	10	GHI + DNI	yes	yes	yes	no		yes	yes	yes
Commissioning / System Acceptance	10	hourly	10	GHI + DNI	yes	yes	yes	no		yes	yes	yes
Operation										recommended always	recommended always	No with the accuracy needed
Performance monitoring (does the system work correct?)										recommended always	recommended always	YES
Performance improvement (how to improve system performance)										recommended always	recommended always	YES
Forecasting										recommended always	recommended always	YES
Energy policy										recommended always	recommended always	YES
Potential assessment	10	annual long-term	5	GHI	yes	yes	yes	n/a		yes	no	no
Design of support instruments, e.g. levels of tariffs, incentives,	10	annual long-term	10	GHI	yes	yes	yes	n/a		yes	no	no
Climate policy										recommended always	recommended always	No with the accuracy needed
Climate models	25	daily	20	GHI	yes	yes	yes	no		no	no	no
Impact assessment models	10	daily	10	GHI+DNI	yes	yes	yes	no		no	no	no
Climate monitoring	25	annual	20	GHI+DNI	yes	yes	yes	no		yes	yes	yes
Science										recommended always	recommended always	No with the accuracy needed
Energy system analysis (Systems, components)	10	hourly	n/a	GHI+DNI	yes	yes	yes	no		no	no	no
System simulations	10	hourly	n/a	GHI+DNI	yes	yes	yes	yes		no	no	no
Grid integration studies	10	hourly	5	GHI	yes	yes	yes	yes		no	no	no

ANNEX III: SOLAR RESOURCE PARAMETER- SOLAR TECHNOLOGY

Solar Resource Parameter		Solar Technology
Direct Normal Irradiance-DNI	Principal component of sunshine, directly from the sun	Concentrating solar thermal installations.
		Installations that track the position of the sun. Concentrating PV
Diffuse Horizontal Irradiance- DHI	Amount of radiation received per unit area by a surface scattered by molecules and particles in the atmosphere	Building climatology (daylighting)
Global Horizontal Irradiance-GHI	Total amount of solar radiation ( sum of direct, diffuse, and ground-reflected radiation on a horizontal surface)	Photovoltaic installations
Global Inclined	Total amount of solar radiation on tilted or tracking surfaces	Photovoltaic
		Solar water heating Passive solar



## ANNEX IV GLOSSARY OF TERMS

### *Azimuth Angle*

Angle between the horizontal direction (of the sun) and a reference direction (usually North, although some solar scientists measure the solar azimuth angle from due South).

### *Bias Limit*

An indication of the average deviation of the predicted, values, from the measured (i.e., true) values. typically expressed as mean bias error (MBE).

$$MBE = \sum_{i=1}^N (y_i - x_i) / N$$

where:

$y_i$  is the  $i^{\text{th}}$  predicted, or true value

$x_i$  is the  $i^{\text{th}}$  measured value

$N$  is the number of observations.

### *DHI or Diffuse Sky Radiation*

Diffuse Horizontal Irradiance is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions. In the absence of atmosphere, there should be almost no diffuse sky radiation. High values are produced by an unclear atmosphere or reflections from clouds.

### *DNI*

Direct Normal Irradiance is the amount of solar radiation from the direction of the sun received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun.

### *GHI*

Global Horizontal Irradiance is the total amount of solar radiation received from above by a horizontal surface the sum of direct, diffuse, and ground-reflected radiation because ground reflected radiation is usually insignificant compared to direct and diffuse includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF). This value is of particular interest to photovoltaic installations.

### *Irradiance*

Rate at which radiant energy arrives at a specific area of surface during a specific time interval. This is known as radiant flux density. A typical unit is  $W/m^2$ .

*Root Mean Square Error*

Square root of the mean square error, which makes it a more easily interpreted statistic since it shares the same units as the quantity being graphed. The mean squared error is the resulting value from measuring the distance between every data point and a simulated curve, squaring each distance, and taking the average of all the squared distance values.

## ANNEX V: UNEP & ISES

### UNEP

The United Nations Environment Programme (UNEP) is an intergovernmental agency created in 1972 to provide governments with technical assistance in the area of natural resource management. It serves both developed and developing country governments, with a clear focus on the latter. Most of its work is funded by developed countries, often from development aid budgets.

UNEP's work is organised around six priority areas – climate change, disasters and conflicts, ecosystem management, environmental governance, harmful substances and resource efficiency. As a part of its efforts to curb climate change, UNEP promotes the deployment of solar and wind energy technologies. This includes assessments of solar and wind energy technology potentials.

To date UNEP has initiated several assessments of solar and wind energy potentials – by matching the needs expressed by developing countries with the resources made available by certain developed countries. In addition, UNEP works with bilateral donors and recipient countries to integrate the findings of related bilateral aid projects into a more robust consolidated output.

More recently UNEP is helping develop training courses on solar and wind energy resource assessment, and facilitating closer cooperation between selected developing and developed country centres of excellence in this area. As a complement to this work, UNEP will convene selected experts in solar energy resource assessment to develop a benchmarking tool for use by non-experts.

### About ISES

Since 1954, the International Solar Energy Society (ISES) has been actively engaged in advancing the science, technology, policy and education needed for the efficient use of renewable energy and its practical applications. As a UN accredited non-profit and non-governmental organisation (NGO), ISES represents scientists, technical experts, industry delegates and related professionals all committed to advancing renewable energy solutions to global climate change and world poverty. The ISES vision is simple and urgent: Rapid Transition to a Renewable Energy World.

The ISES mission is to provide current, scientifically credible renewable energy and energy efficiency information and networking opportunities to the global communities of scientists, educators, practitioners, industries, policy makers, and to the general public. The underlying core values of ISES are sustainable development, scientific methodology and participative decision making. Based on these values, ISES aims to achieve its vision and mission through scientific, popular and policy publications and through conferences, strategic alliances and projects globally.

ISES project activities address issues that affect global climate change and the advancement of renewable energies – by bringing together local and international perspectives, by encouraging the transfer of information and good practices, by promoting interaction and learning. The Society helps raise awareness, promote good policy, stimulate industry, improve quality and development and generally promote the wider use of renewable energy sources.

The Society's long history and extensive technical and scientific expertise provided by its members are what distinguish ISES as a unique and innovative organization.