# Developing a Guide for Non-experts to Determine the Most Appropriate Use of Solar Energy Resource Information

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## Abstract

Knowledge of the solar energy resource is essential for the planning and operation of solar energy systems. There are a large number of different data sources available which makes it difficult for the non-expert in solar resource assessment to judge which source might be appropriate for a specific application. The United Nations Environmental Programme (UNEP) therefore supported the development of a Guide which will help users to make an educated decision about which data set to choose among several different available. The Guide basically consists of two tables. The first one 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.

## 1. Introduction

Knowledge of the solar energy resource is essential for the planning and operation of solar energy systems. Solar data sets differ in spatial and temporal resolution, time period covered, and methods used,  Some of these datasets are for available for free, while some are not, and they all may provide different results. As a result, most users cannot verify the suitability of a given solar dataset or map based on the purpose of the use of their assessment.  This can lead users to abandon their search or make non-appropriate use of the information. A simple Guide can help alleviate this problem, if it is developed through an open and inclusive consultation. The results of this study will 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 Guide 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. The first one 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.

This paper starts with a short description of the characteristics of solar resources, which may help to understand to why the tables were developed. Chapters 3 and 4 describe the two tables.

## 2. Characteristics of solar resources and resource estimates

To understand the needs for different applications, it is helpful to first provide a short insight into the characteristics of the solar resource. Solar radiation is highly variable in time and space. The variability is mainly driven by weather: Atmospheric turbidity and clouds. This variability in time and space as a function of weather patterns can be significant over short distances and short time scales. Solar radiation data for monitoring and operating solar radiation systems has to be very site-specific to capture the temporal variability due to weather patterns.

Since planning and designing solar energy systems focuses on long term time scales, the data used in the design has to represent what can be expected in the long term future of a solar energy system. The annual sum of incoming solar radiation can change significantly from year to year due to natural interannual climate variability. Everybody remembers hot or very rainy summers. Figure 1 shows the annual variability of global horizontal and direct normal radiation at two sites in Germany and the USA. The small figure on top shows a time series of annual sums of global horizontal radiation in Potsdam from 1937 to 2000. The lower graph shows the maximum deviations of moving averages from 1 to 15 years compared to the long term average of all years in the data sets. It can be seen that at least 10 years of data are necessary to stay within the limit of ±5% of the long term average. This has nothing do to with the uncertainty of measurements or models, this is just natural variability. This curve shows that if a project is based on short term measurements of only a year of two, the estimation of the resource may  differ substantially from what can be expected at this site in the long term.

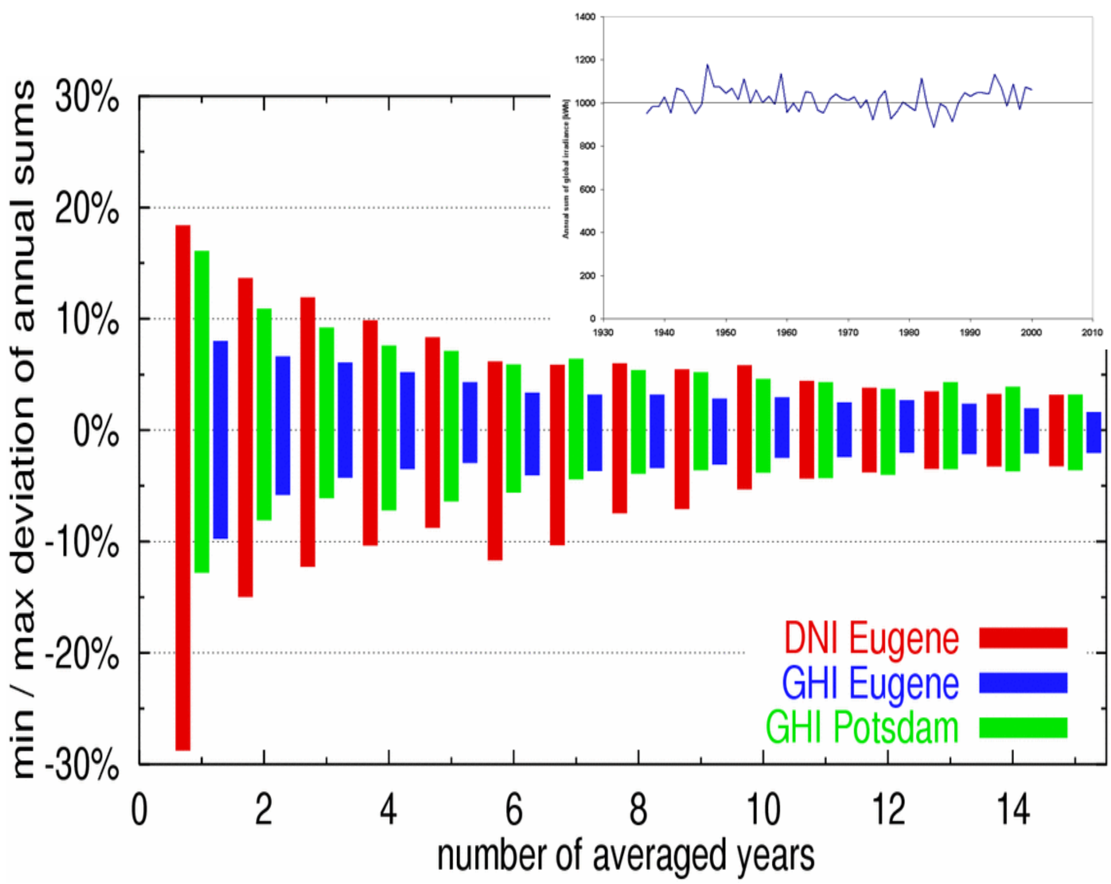


Figure 1: Annual variability of solar radiation.  The top right figure shows the annual sum of global horizontal radiation in Potsdam for 63 years from 1937 to 2000. The graph shows the maximum and minimum deviation. The graph shows that in order to stay within a margin of ±5% at least a ten year average is needed.

Figure 2 is an example of the spatial variability of solar radiation. The left figure is a five year average of direct normal radiation in Spain. The right figure shows the annual differences in each year to this five year average. The patterns are quite different each year and the deviation and values change over short distance. This means that if one knows the deviation of data for the current year to a long term average on one site, one cannot transfer this result to the next site. Resource assessments have to be site specific.

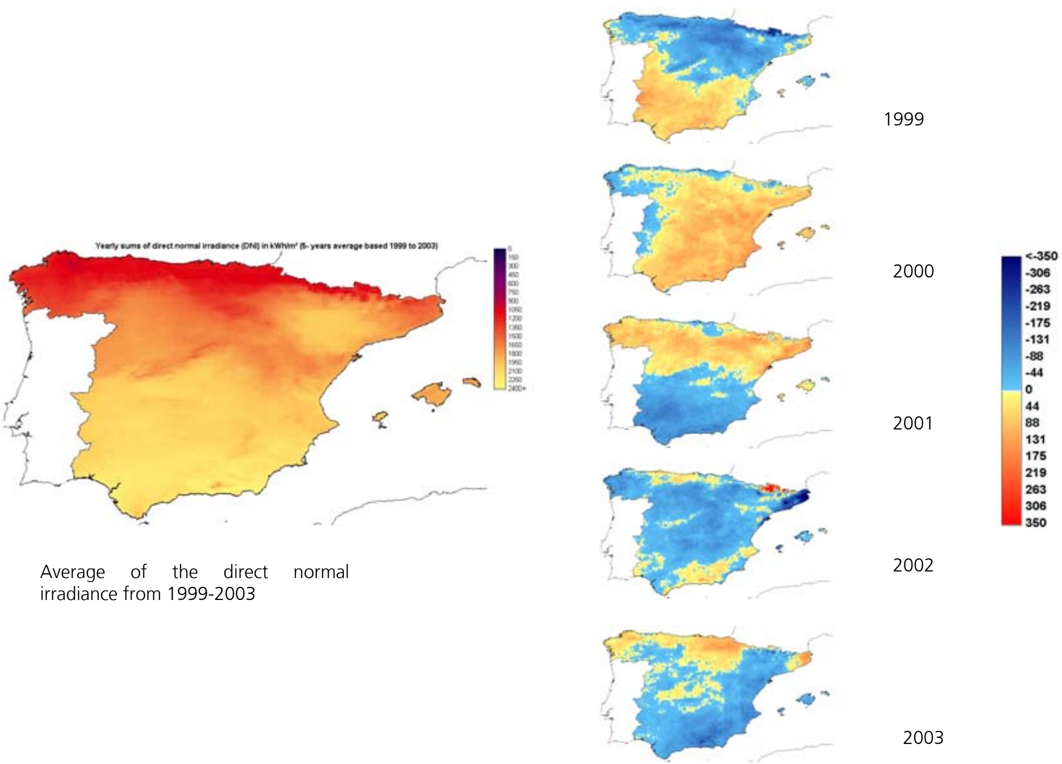


Figure 2: Spatial variability of the solar radiation, five year average (left figure) and annual differences to the average (right figure).

These two examples show two important features of a good resource assessment: it needs to be based on long term data (at least 10 years) and must have a high spatial resolution of a few kilometres. Satellite based resource assessments can provide both: satellite raw data is archived for many years and data from meteorological satellites in geostationary orbits has a very high spatial resolution.

But satellite data have limitations in temporal resolutions and therefore it is generally not possible to model all local effects. In addition, some of the input data sets (e.g. currently aerosols) are not available in high spatial resolutions. Ground measurements are therefore a necessary and helpful addition to satellite-based resource assessments. A major advantage of the inclusion of ground-based instruments is that they can register the solar radiation at very high temporal sampling rates of 1 min or even less. Such data are very useful for modelling transient effects in solar thermal systems e.g. at sunrise and sunset or the passage of a cloud.

### 3. Information about data sources

Table I 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 contacting the UNEP officer in charge of this Guide. 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 components contained in the dataset, i.e. GHI, DNI, TPI, DFI, PAR, Diffuse, Global in-plane, Global Tilt
8. 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
9. Validation Type – none provided, conference paper, or third party authored peer reviewed using IEA Task 26 and/or MESoR benchmarks[i]:
10. 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 [ii]
11. 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
12. Frequency distribution metrics, eg KSI, OVER, available? If yes, values and link should be provided
13. Current data available / Near real time data
14. Availability: Free data sets or for sale
15. Website (where available)

See Table 1 below

## 4. Recommendations on minimum characteristics

The second table (Table 2 in the Guide) takes the same metadata but relates it to a number of different applications, such as investment planning for different types and sizes of systems, operation of systems, policy analysis and science. For each application Table 2 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.

See Table 2 below

## Table 1: Extract from the Data sets:

| DATA SET | Providing organisation | Geographical coverage | Source | spatial resolution (km) | temporal resolution | Time coverage | Component | Validation information available: publication articles, preferably peer-reviewed & third-party (primary) authored, using IEA Task 36 benchmarks | Validation Type (1) | Low Bias (<5% for GHI and <10% for DNI) (2) | Low root mean square error (< 125 W/m for hourly GHI and < 160 W/m for hourly DNI) (2) | Frequency distribution metrics e.g. KSI, 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* | Link to NASA sites; Literature and Conference, Benchmarked within IEA | bench marked | yes* | n/a | no | no | free | eosweb.larc.nasa.gov/sse | *DNI available only on a monthly basis; DNI bias exceeds 10% poleward of 60 degrees |
| Swera 40k | NREL | 13 countries | US-Airforce cloud cover | 40 km | Monthly | 1985-1991 | GHI-DNI | SWERA website | | 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 | MARTINS, Fernando Ramos ; PEREIRA, E. B. ; ABREU, Samuel Luna de . Satellite- | peer reviewed | Yes | Yes | Yes | No | Free | swera.unep.org | * DNI only for Brazil |
| Swera-10k | SUNY | 13 countries | geostationary satellites | 10 km | hourly | 1999-2005 | GHI-DNI | Conference articles | 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 | MARTINS, Fernando Ramos ; PEREIRA, E. B. ; ABREU, Samuel Luna de . Satellite- | peer reviewed | Yes | Yes | Yes | No | Free | swera.unep.org | |
| Swera 10k | DLR | Ghana, Ethopia, Keyna, Banglades | geostationary satellites | 10km | annual | 3 years out of 2000-2003 | GHI, DNI | Solar Energy Article | peer reviewed | yes | yes | n/a | no | free | swera.unep.org | |
| Solemi | DLR | Europe Africa Middle East | geostationary satellites | 5 km | hourly | 1991-2005 | GHI-DNI | 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 | Mesor-Reports, Benchmarked within MESoR | bench marked | yes | yes | yes | yes | for sale*** | www.energiemeteorologie.de | spatial resolution changes in 2006 to 0.025o, on request 15 or 30min values are avalabel |
| Helioclim-1 | Mines ParisTec | Europe Africa | geostationary satellites | 30 km | monthly (DNI), daily (GHI) | 1985-2005 | GHI-DNI | Solar Energy Article; Benchmarked within MESoR | Peer reviewed | | | | no | for sale*** 1985-1989 free | http://www.soda-is.com/eng/help/index.html | |
| Helioclim-3 | Mines ParisTec | Europe Africa | geostationary satellites | 5 km | 1/4 hourly | 2004 - present | GHI-DNI | Mesor-Reports & Solar Energy, Benchmarked within MESoR | bench marked | yes | yes | yes | yes | for sale*** | http://www.soda-is.com/eng/help/index.h | ***one year free via MESOR |
| Satel-Light | ENTPE | Europe | geostationary satellites | 5 km | 1/2 hourly | 1996-2000 | GHI-DHI** | 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 | NREL-Report | Peer reviewed | yes | yes | yes | no | free | ftp://ftp.ncdc.noaa.gov/pub/data/nsrdb-solar | |
| Solar Anywhere | Clean Power Research | USA northern Mexico | geostationary satellites | 10 km | hourly | 1998-present | GHI-DNI | Solar Energy Article | peer reviewed | yes | yes | yes | yes | for sale | www.solaranywhere.com | |
| NRC-SUNY | Natural Resouce Canada | Canada, below 60degrees | geostationary satellites | 10 km | hourly | 1998-2008 | GHI-DNI | Ongoing Validation by CanMet | | yes* | yes* | | no | free | | increased bias in winter due to prevalence of snow |
| PVGIS | EU-JRC | Europe, Africa | ground stations, satellite (Africa) | Interpolation of variable density stations | monthly | 1981-1990 (EU), 1985-2004 (Africa) | GHI, G inclined | Benchmarked within MESoR | bench marked | yes | N/A | N/A | no | free | http://re.jrc.ec.europa.eu/pvgis/ | |
| SolarGIS | GeoModel | Europe, North Africa, Middle | geostationary satellites | 4 km disagregated to 0.2 km | 1/4 hourly | 2004-2010 | GHI, DNI, Diffuse, Global in-plane, Air | paper: Cebecauer et al. ASES SOLAR 2010 Conference | conference paper | yes | yes | yes | yes | for sale | http://solargis.info | Online shop for variety of data sets, including air temperature. PV planning tools |
| Meteonorm | Meteotest | World | combo measurements, met models | Interpolation of variable density | hourly, minute | typical years (climatology 1981-2000) | GHI-DNI, incl. | Mesor-Reports, Meteonorm-Reports; Benchmarked within MESoR | bench marked | yes | | | | for sale | www.meteonorm.com | |
| IrSOLaV | IrSOLaV - CIEMAT | Europe North Africa | geostationary satellites | 5 km | hourly | 1994-2009 | GHI-DNI | Solar Energy Article | peer reviewed | yes | yes | | no | for sale | | |
| LTS | CENER | EUROPE, MENA, Australia | NWM, combo measuremts | 3 km to 9 km | hourly | typical | GHI-DNI | Renewable Energy article and Solarpaces congress | peer reviewed | yes | yes | yes | yes | for sale | no*** | ***Site specific |

## Table 2: Minimum requirements for different applications[iii]

| See below for explanation of input and changes (km) | 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 | Low Bias (<5% for GHI and <10% for DNI) (1) | Low root mean square error (< 125 W/swm 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 | annual long-term (map) | 10 | GHI or DNI | yes | no | yes | n/a | n/a | yes | no | no |
| Pre feasibility | 100 | annual long-term | 5 | GHI or DNI | yes | no | yes | no | no | yes | no | no |
| Feasibility | 10 | hourly | 10 | DHI or DNI | yes | yes | yes | no | no | yes | no | no |
| Design and construction | | | | | | | | | | | | |
| PV offgrid systems (4) | 10 | hourly | 10 | GHI | yes | yes | yes | no | yes | yes | yes | yes |
| PV Small systems | 10 | monthly | 5 | GHI incl. | yes | no | yes | no | no | no | no | no |
| PV Medium sized systems | 10 | hourly | 5 | GHI + DNI, in | yes | yes | yes | no | yes | yes | yes | yes/no |
| PV Large systems | 10 | hourly | 10 | GHI + DNI, in | yes | yes | yes | no | yes | yes | yes | yes |
| Tracking / concentrating PV | 10 | hourly | 10 | GHI + DNI, in | yes | yes | yes | no | yes | yes | yes | yes |
| Solar hot water | 100 | monthly | 5 | GHI incl. | yes | no | yes | no | no | no | no | no |
| Solar cooling | 100 | monthly | 5 | GHI incl. | yes | no | yes | no | no | no | no | no |
| CSP | 10 | hourly | 10 | DNI | yes | yes | yes | no | yes | yes | yes | yes |
| Daylighting | | hourly | 5 | Illuminance | yes | no | yes | no | no | no | no | no |
| Solar Process Heat | 10 | hourly | 10 | GHI | yes | yes | yes | no | yes | yes | yes | yes |
| Due diligence | 10 | hourly | 10 | GHI + DNI | yes | yes | yes | no | yes | yes | yes | yes |
| Commissioning / System Acceptance | 10 | hourly | 10 | GHI + DNI | yes | yes | yes | no | yes | yes | yes | yes |
| Operation | | | | | | | | | | **recommended always** | **recommended always** | **No with the accuracy needed** |
| Performance monitoring (does the system work correct?) | 10 | hourly | n/a | GHI + DNI | yes | | yes | yes | less important | no | no | yes |
| Performance improvement (how to improve system performance) | 10 | hourly | n/a | GHI + DNI | yes | | yes | yes | less important | no | no | yes |
| Forecasting | 10 | hourly | n/a | GHI | yes | | yes | yes | less important | no | no | yes |
| Energy policy | | | | | | | | | | **recommended always** | **recommended always** | **YES** |
| Potential assessment | 10 | annual long-term (map) | 5 | GHI | yes | yes | yes | n/a | n/a | yes | no | no |
| Design of support instruments, e.g. levels of tariffs, incentives, | 10 | annual long-term (map) | 10 | GHI | yes | yes | yes | n/a | n/a | yes | no | no |
| Climate policy | | | | | | | | | | **recommended always** | **recommended always** | **No with the accuracy needed** |
| Climate models | 25 | daily | VARIABLE | GHI | yes | yes | yes | no | no | no | no | no |
| Impact assessment models | 10 | daily | 10 | GHI+DNI | yes | yes | yes | no | no | no | no | no |
| Climate monitoring | 25 | annual | 20 | GHI+DNI | yes | yes | yes | no | 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 (5) | yes | yes | yes | no | yes | no | no | no |
| System simulations | 10 | hourly | n/a | GHI + DNI (5) | yes | yes | yes | yes | yes | no | no | no |
| [iv] Grid integration studies | 10 | hourly | 5 | GHI | yes | yes | yes | yes | yes | no | no | no |

## 5. Operation of the Guide

The online user-friendly 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. Figure 3 depicts how the Guide works. The Guide relates information back to Tables 1 and 2 above.

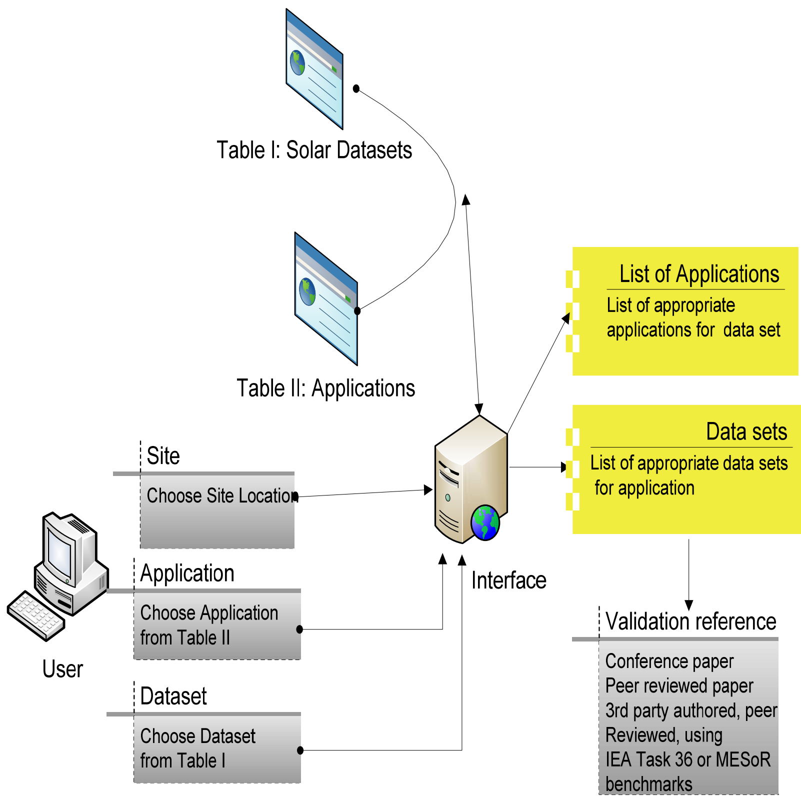


Figure 3. Scheme for the operation of the Guide to determine the most appropriate Uue of solar energy resource information

The user selects one of the three entry types that are possible: application of the user (see classification of applications in Table 1) and/or location of the site or the solar data of interest. The interface interconnects Table 1 and 2 with the inputs given by the user. As a final output, the Guide provides either a list of relevant datasets for specific purpose or a list of applications a dataset can be used for.

To support the validity of the information presented in both tables, a consultation with experts was undertaken. The experts are members of the IEA/SHC Task 36. They provided input to expand and up-date the metadata in Table 1 and review the requirements in Table 2.

The final Guide will be available on the UNEP Energy Branch website, with links available from the ISES, Task 36, and MESOR websites as well as the SWERA (Solar and Wind Energy Resource Assessment) website, unep.swera.net, where many of the listed data sets can be found.

## References


[1] C.Hoyer-Klick et al, “Management and Exploitation of Solar Resource Knowledge”, EuroSun 2008

[2] Task 36 “Solar Resource Knowledge Management” under the International Energy Agency’s (IEA’s) Solar Heating and Cooling 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/


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[i] Peer reviewed papers by third party author would imply higher quality work than a conference paper, but this is not necessarily always the case.

[ii] For points 10 -12: 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 procedure 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).

[iii] For low Mean Bias Error (MBE), low Root Mean Square Error (RMSE) and frequency distribution columns, see end note above.

[iv] On site measurements should encompass at least one years worth of ground measurements