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ESMAP
Energy Sector Management Assistance Program

GLOBAL SOLAR ATLAS 2.0

TECHNICAL REPORT

November 2019

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The content of this document is the sole responsibility of the consultant authors.

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Technical Report

Global Solar Atlas 2.0

Interactive web site, solar potential data and maps

Reference 170-14/2019

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1 DESCRIPTION OF GSA 2.0 DELIVERY

The Global Solar Atlas version 2.0 ("**GSA**") is an enhancement of the online platform, originally published in 2016 in version 1.0, that offers access to data needed for preliminary assessment of solar energy projects and sites through use of GIS data layers and maps in Download section. This Technical report summarises delivery of the GSA 2.0 version and compares version 2.0 with previous version 1.0 in terms of enhancement in methodology, data layers and Solargis approach to PV electricity simulation.

GSA 2.0 provides an access to long-term averaged yearly (for selected parameters monthly) solar, air temperature, PV power potential data and map products for almost any site on Earth. All data and products are available at *https://globalsolaratlas.info* domain.

There are two main sections of the GSA 2.0:

1. **Online application** provides immediate access to data and maps from desktop or mobile devices with internet connection. The application runs on any state-of-the-art browser. Main features include (detailed specification described in Chapter 1.2):
    - **Map window** with the possibility of browsing 10+ maps of PV, solar, climate and topographic parameters globally
    - **Data access for any location**, available via a click on the map
    - **interactive PV calculator** providing a simple assessment of PV power generation potential at the specific site
    - Three tabs for selection of a) site-specific solar assessment (SITE), b) regional solar assessment (REGION) c) floating solar hydro-connected potential (HYDRO)
    - HELP and KNOWLEDGE BASE sections
    - Location sharing features, created project SAVE possibility
    - Downloadable solar and **PV assessment report** for any location in pdf format
2. **Download section** (available at *https://globalsolaratlas.info/download*), which serves data and map products on global and country level in the following forms:
    - **GIS data** - raw numeric data provided as layers in standard raster GIS formats (GeoTIFF and ESRI ASCII GRID) for global and country level in 9 arcsec (nominally 250 m) resolution for solar resource data and 30 arcsec (nominally 1 km) for PV and air-temperature data (see Chapter 1.1)
    - **Poster maps** – high quality cartographic products for three main solar parameters, optimized for a particular country, region or on a global scale. Maps are provided as press files in TIFF format, ready for poster-size printing (see Chapter 1.3)
    - **Midsize maps** – maps in medium/small scales for a country, regional or global level, suitable for on- screen presentation or document printing (e.g. format A4 or similar), provided in PNG format (see Chapter 1.3)
    - **Maps for Google Earth** – global layers (image map tiles), suitable for visualisation and analysis in Google Earth Desktop software, provided as a set of KML and PNG files (see Chapter 1.4)

GSA 2.0 is built on Solargis solar resource version 2.1 (Chapter 2). Solargis is a high-resolution global database of solar resource and meteorological parameters, developed and operated by the company Solargis. The database is computed by models, which use satellite, atmospheric and meteorological data inputs. Its geographical extent covers lands between 60° North and 55° South latitudes (in Latin America to 45°S). The primary database consists of time series of solar and meteorological data, calculated in 10/15/30-minute time step and representing years 1994/1999/2007 up to 2018 (time period and time step of available data depends on the region, see Figure 1.1). The database is systematically updated and validated. Solargis approach of PV electricity simulation is described in Chapter 3.

1.1 GIS Data

Delivered GIS data include eight parameters in the form of a raster data layers, providing the information on solar resource, photovoltaic power potential, air temperature and terrain elevation on global scale (Table 1.1).

Solar resource and PV data covers the land areas between the parallels 60°N and 55°S (in Latin America to 45°S), including approx. 10 km buffer zone towards the ocean. The data is available in two raster formats: GeoTIFF and AAIGRID (ESRI ASCII grid), suitable for use in Geographical Information Systems (GIS) to:

- Process, analyse and query data in the region
- Perform spatial analysis and expertise with other data sources
- Create custom maps or applications.

Data layers are provided in Geographical coordinate system (EPSG:4326) and calculated in 30 arc-sec (nominally 1 km) resolution. On top of this, for more detailed analysis solar resource data (GHI, DIF, GTI and DNI) is also provided in 9 arc-sec (nominally 250 m) resolution. Finally, auxiliary data layer of Optimum angle features with 2 arcmin (nominally 4 km) resolution.

Metadata is delivered with the data files in two formats, according to ISO 19115:2003/19139 standards:

- PDF - human readable
- XML - for machine-to-machine communication

Snapshots of the data are presented on the Figure 1.3 to 1.11.

Table 1.1: Description of delivered data layer

Acronym	Full name	Unit	Type of use	Values represent
GHI	Global Horizontal Irradiation	kWh/m^2	Reference information for the assessment of flat-plate PV (photovoltaic) and solar heating technologies (e.g. hot water)	Long-term yearly average of daily totals
DNI	Direct Normal Irradiation	kWh/m^2	Assessment of Concentrated PV (CPV) and Concentrated Solar Power (CSP) technologies, but also calculation of GTI for fixed mounting and sun-tracking flat plate PV	Long-term yearly average of daily totals
DIF	Diffuse Horizontal Irradiation	kWh/m^2	Complementary parameter to GHI and DNI	Long-term yearly average of daily totals
GTI	Global Irradiation at optimum tilt	kWh/m^2	Assessment of solar resource for PV technologies	Long-term yearly average of daily totals
OPTA	Optimum angle	°	Optimum tilt to maximize yearly PV production	Tilt towards the equator
PVOUT	Photovoltaic power potential of 1 kWp free-standing PV system with cSi modules inclined at optimum tilt	kWh/kWp	Assessment of power production potential for a PV power plant with free-standing fixed-mounted c-Si modules, mounted at optimum tilt to maximize yearly PV production	Long-term yearly average of daily totals
TEMP	Air Temperature at 2 m above ground level	°C	Defines operating environment of solar power plants	Long-term (diurnal) annual average
ELE	Terrain elevation	m a.s.l.	Defines limiting conditions for location of solar power plants	Elevation

Table 1.2: Raster data layers

Characteristics	Range of values
GHI, DNI, DIF	Derived by Solargis algorithms from satellite digital images and atmospheric datasets: GOES-East and GOES-West by NOAA, Meteosat PRIME and IODC by EUMESAT, MTSAT and Himawari-8 by JMA, MACC-II/CAMS atmospheric data by ECMWF, MERRA-2 atmospheric data by NASA, GFS data by NOAA.
GTI, OPTA	Calculated by Solargis algorithms. Inputs include time-series data of Global horizontal irradiation (GHI), Direct normal irradiation (DNI) and terrain horizon by Solargis
PVOUT	Calculated by Solargis algorithms. Inputs include Global irradiation at optimum tilt (GTI), air temperature (TEMP) by Solargis
TEMP	Derived from ERA5 meteorological model operated by ECMWF and post-processed by Solargis methods
ELE	Derived from SRTM v4.1, viewfinderpanoramas.org and GEBCO_2014 terrain data and post-processed by Solargis

Table 1.3: Technical specification of GIS data layers

Acronym	Description	Data type	Spatial resolution	Number of individual data files and approx. size GeoTIFF	AAIGRID
GHI	Long-term average of daily totals of global Horizontal Irradiation	Float	30 arcsec (nominally 1 km) 9 arcsec (nominally 250 m)	1 *(0.3 GB)* 8 *(2.2 GB)*	1 *(2.9 GB)* 8 *(32.6 GB)*
DNI	Long-term average of daily totals of direct Normal Irradiation	Float	30 arcsec (nominally 1 km) 9 arcsec (nominally 250 m)	1 *(0.3 BG)* 8 *(3.1 GB)*	1 *(2.9 GB)* 8 *(32.6 GB)*
DIF	Long-term average of daily totals of diffuse Horizontal Irradiation	Float	30 arcsec (nominally 1 km) 9 arcsec (nominally 250 m)	1 *(0.2 MB)* 8 *(1.6 GB)*	1 *(2.9 GB)* 8 *(32.6 GB)*
GTI	Long-term average of daily totals of global Irradiation at optimum tilt	Float	30 arcsec (nominally 1 km) 9 arcsec (nominally 250 m)	1 *(0.3 GB)* 8 *(2.6 GB)*	1 *(2.9 GB)* 8 *(32.6 GB)*
OPTA	Optimum angle	Int	2 arcmin (nominally 4 km)	1 *(0.01 GB)*	1 *(0.2 GB)*
PVOUT	Long-term average of daily totals of photovoltaic power potential	Float	30 arcsec (nominally 1 km)	1 *(0.3 GB)*	1 *(2.9 GB)*
PVOUT_*MM**	Long-term monthly averages of daily totals of photovoltaic power potential	Float	30 arcsec (nominally 1 km)	12 *(3.7 GB)*	12 *(39 GB)*
TEMP	Long-term average of air Temperature at 2 m above ground level	Float	30 arcsec (nominally 1 km)	1 *(0.1 GB)*	1 *(2.7 GB)*
ELE	Terrain elevation above/ below sea level	Int	30 arcsec (nominally 1 km)	1 *(0.8 GB)*	1 *(2.9 GB)*
			Sum	**52** ***(15.5GB)***	**52** ***(183.4GB)***

* *MM* represents month in a year (e.g. 01 = January, 02 = February … 12 = December)

Geographical coverage of data

- Entire land areas between the parallels 60°N and 55°S (in Latin America to 45°S), including approx. 10 km buffer zone towards the ocean
  West – East: 180:00:00W - 180:00:00E
  North – South: 60:00:00N - 55:00:00S
  Total area approx. 120 000 000 km^2

File formats of the delivered data:

GeoTIFF (with DEFLATE compression applied)
More information about this data format can be found at *https://en.wikipedia.org/wiki/GeoTIFF*

AAIGRID (ESRI ASCII grid)
More information about this data format can be found at *https://en.wikipedia.org/wiki/Esri_grid*

Data layers coordinate system:

EPSG:4326 (also known as GCS_WGS84, Geographical latitude/longitude map projection)

Time resolution and coverage of the solar resource and PVOUT data

Long-term yearly average of daily totals

Temporal coverage: from 1 January 1994/1999/2007 (depending on geographical region) to 31 December 2018

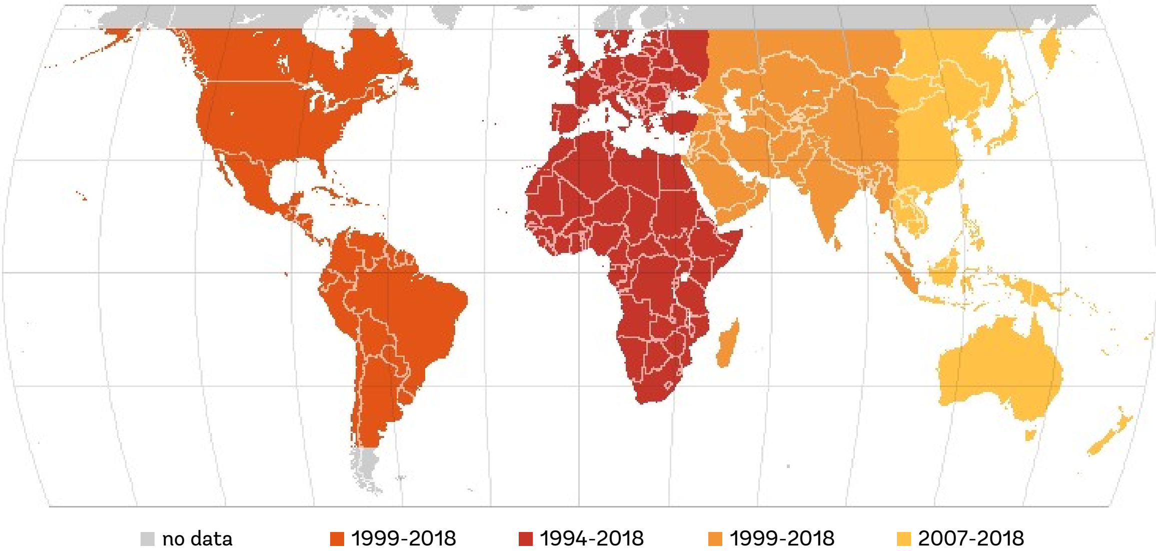

Figure 1.1: Temporal coverage of delivered solar resource data

Spatial resolution

- All data parameters (except OPTA) pixel size: **30 arcsec** (0.008333°, nominally 1 km) Data in this resolution is provided as single files (raster size is 43200x13800 pixels)
- OPTA pixel-size: **2 arc-min** (0.033333°, nominally 4 km) - OPTA
  Data in this resolution is provided as single file (raster size is 10800x3450 pixels)
- Solar resource data (GHI, DNI, GTI, DIF) in high resolution: **9 arcsec** (0.0025°, nominally 250 m) Due to large size the Globe is divided into eight segments (see Figure 1.2). The raster size of data layers in the zones of the northern hemisphere is 36000x24000, in the southern hemisphere 36000x22000 pixels.

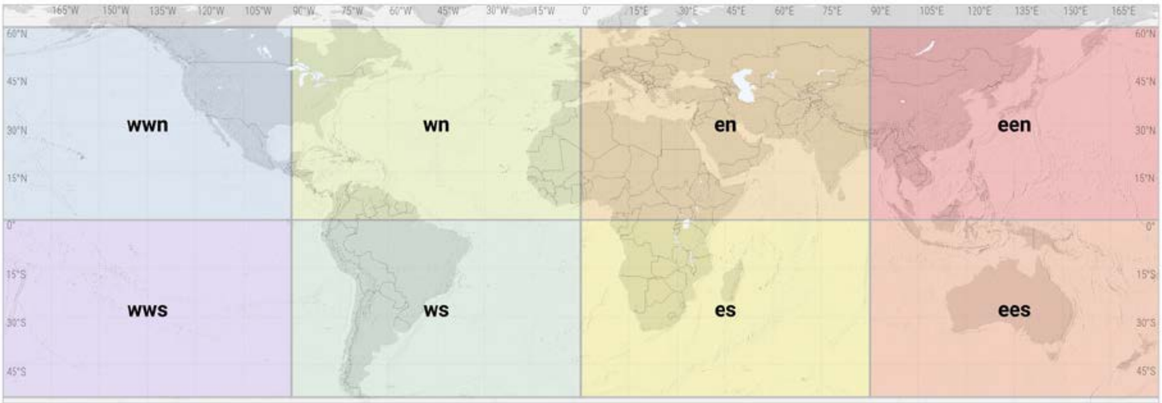

Figure 1.2: Segmentation of the Globe for high resolution (9 arcsec) solar resource data.
wwn – West-West-North, wn – West-North, en – East-North, een – East-East-North
wws – West-West-South, ws – West-South, es – East-South, ees – East-East-South

Filename convention of data layers

Examples of filenames:

GeoTIFF data

- *GHI.tif* – GeoTIFF with yearly long-term average values of GHI
- *GHI.tif.xml* – metadata for provided AAIGRID
- *GHI.tif.pdf* – human readable metadata provided for AAIGRID

AAIGrid data

- *GHI.asc* – AAIGRID with yearly long-term average values of GHI
- *GHI.prj* – project file to AAIGRID, containing information about spatial reference system
- *GHI.asc.xml* – metadata for provided AAIGRID
- *GHI.asc.pdf* – human readable metadata provided for AAIGRID

GeoTIFF with long-term monthly averages of PVOUT daily totals

PVOUT_01.tif - PVOUT for January
PVOUT_02.tif - PVOUT for February
- ...

PVOUT_12.tif - PVOUT for December

High resolution (9 arcsec): GeoTIFF with long-term average of daily DNI totals

DNI_wwn.tif - segment West-West-North
DNI_wn.tif - segment West-North
DNI_en.tif -, segment East-North
DNI_een.tif -, segment East-East-North
DNI_wws.tif -, segment West-West-South
DNI_ws.tif -, segment West-South
DNI_es.tif -, segment East-South
DNI_ees.tif -, segment East-East-South

Data Access

Data layers are downloadable from https://globalsolaratlas.info/download/world. Note that processing of such large volume data requires sufficient software and hardware equipment.

Therefore, the data extracts were created, allowing to work with smaller datasets on the level of countries. Data is accessible within a *country* section on *http://globalsolaratlas.info/download. There are 187* countries included in the downloadable map section

For selected countries (Zambia, Malawi, Pakistan, Maldives, Nepal, etc.), customised mapping has been done. In such cases, more detailed data layers are provided, accompanied by a separate documentation.

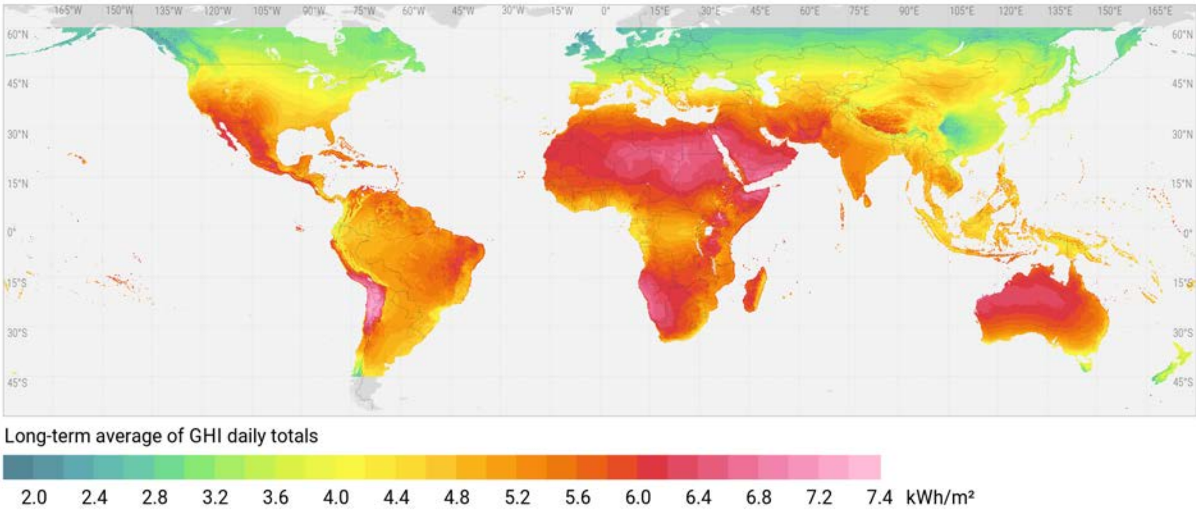

Figure 1.3: Long-term yearly average of daily totals of global horizontal irradiation (GHI)

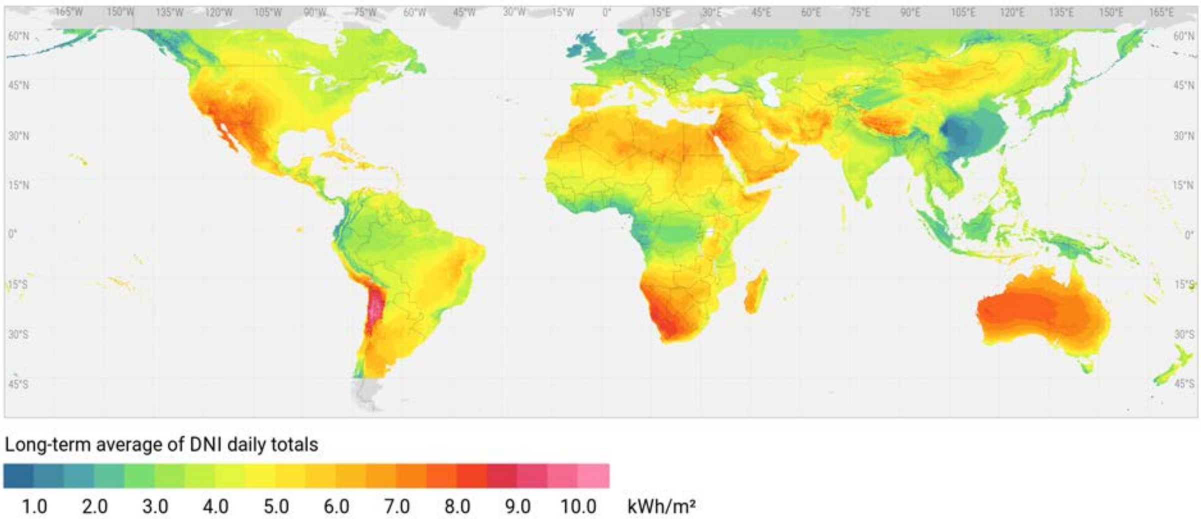

Figure 1.4: Long-term yearly average of daily totals of direct normal irradiation (DNI)

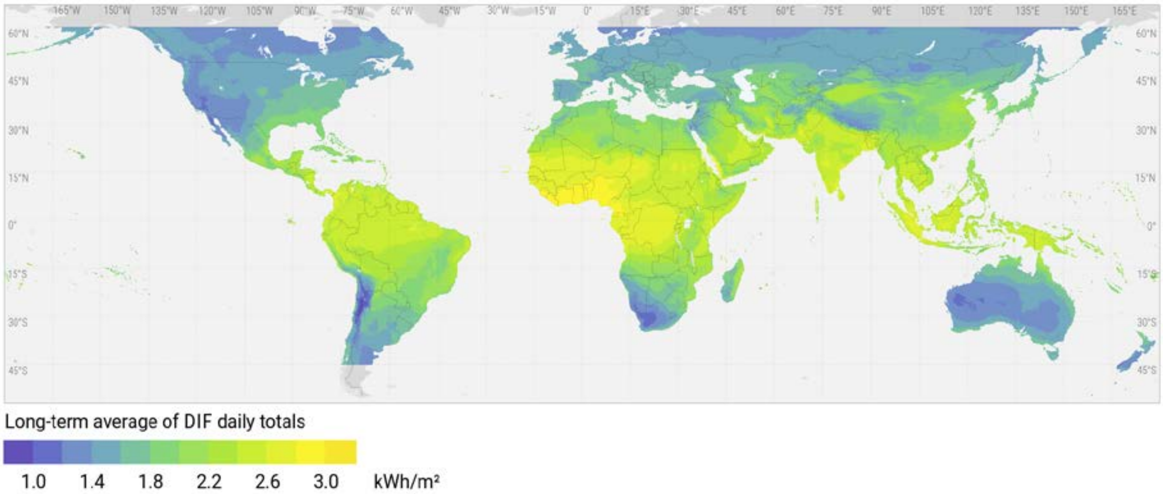

Figure 1.5: Long-term yearly average of daily totals of diffuse horizontal irradiation (DIF)

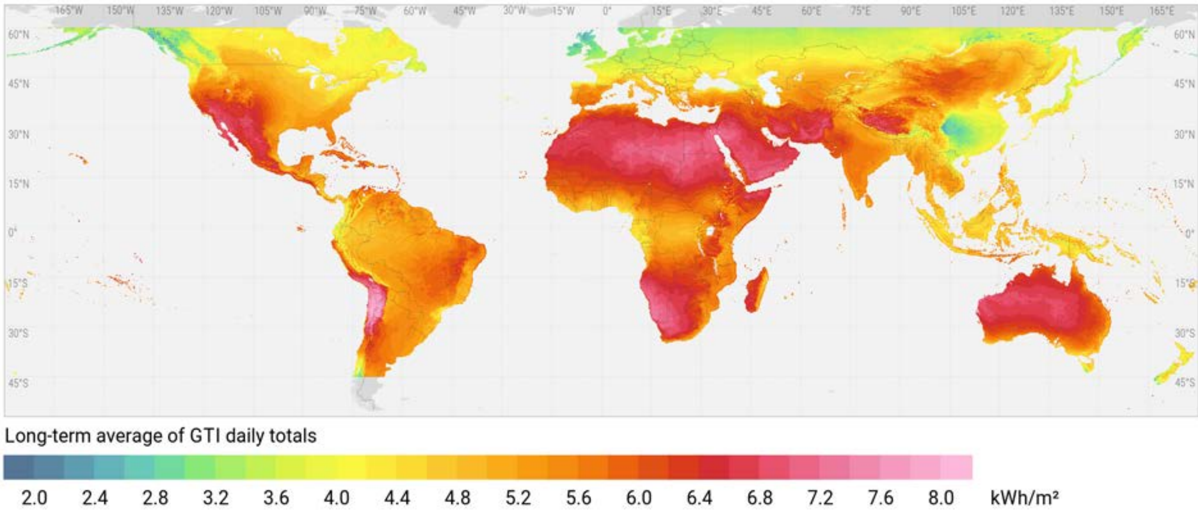

Figure 1.6: Long-term yearly average of daily totals of global irradiation on optimally tilted surface (GTI)

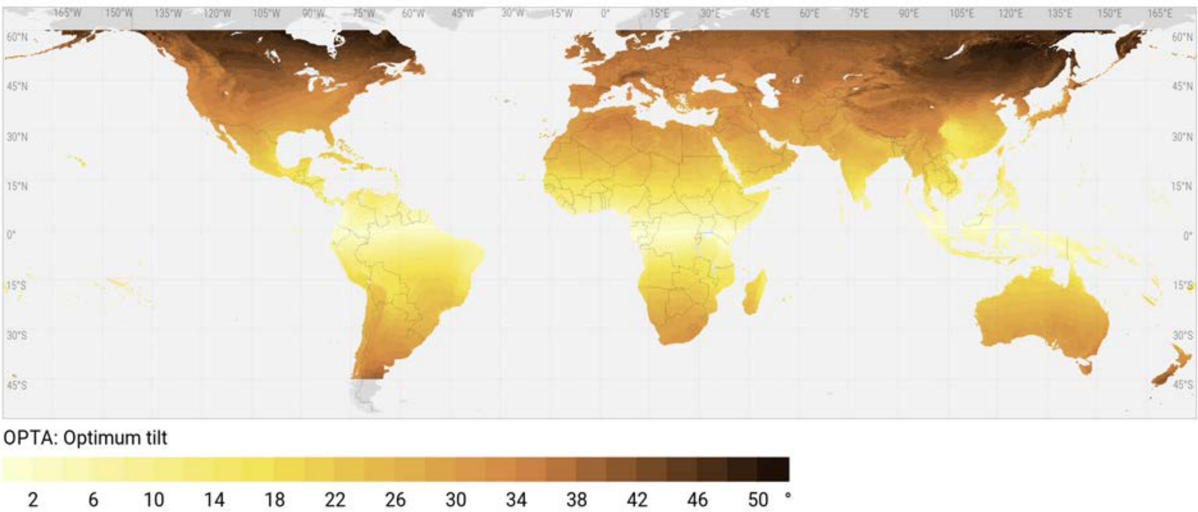

Figure 1.7: Optimum tilt (OPTA) of the modules to maximize PV yield

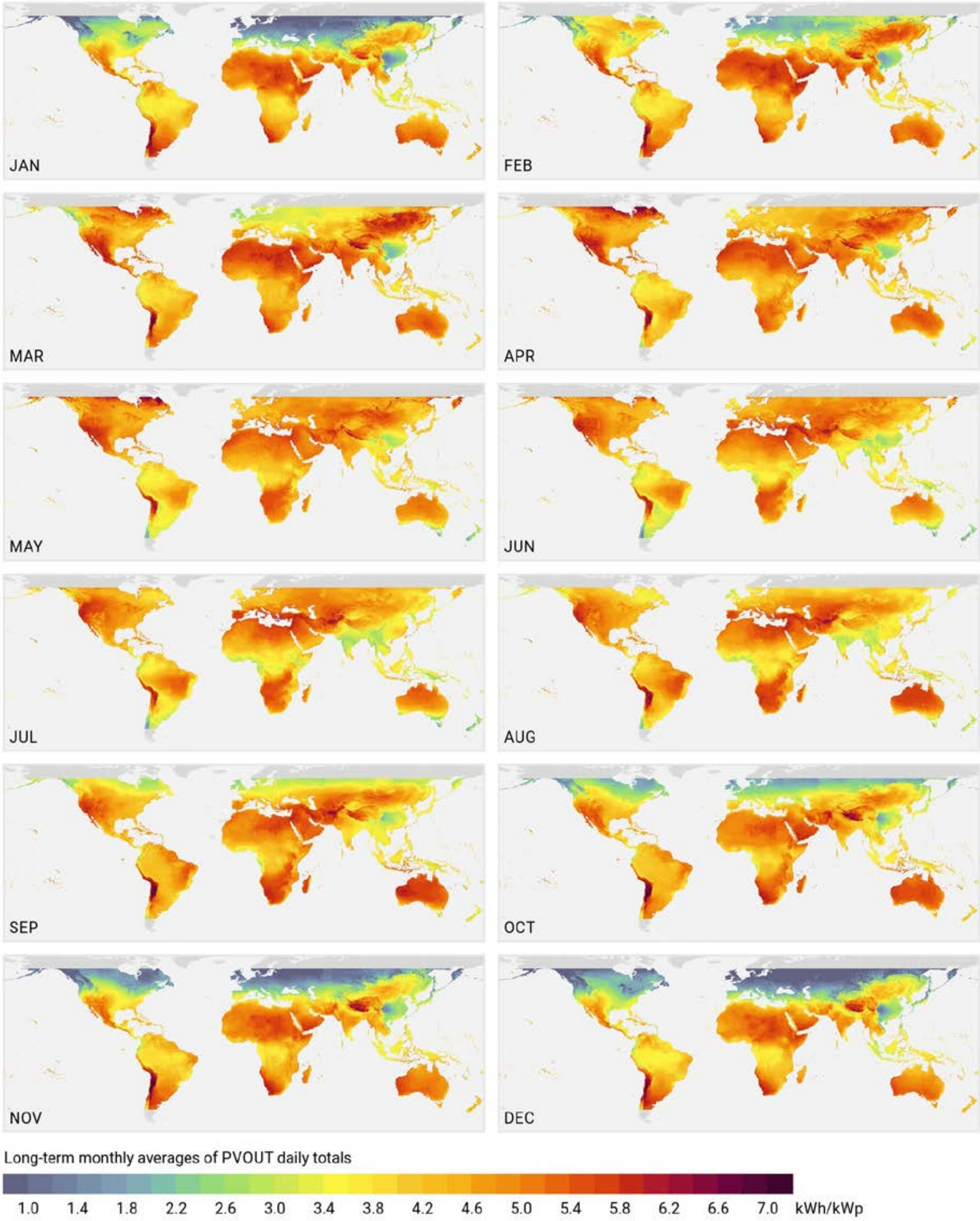

Figure 1.8: Long-term monthly averages of daily totals of photovoltaic power potential (PVOUT)

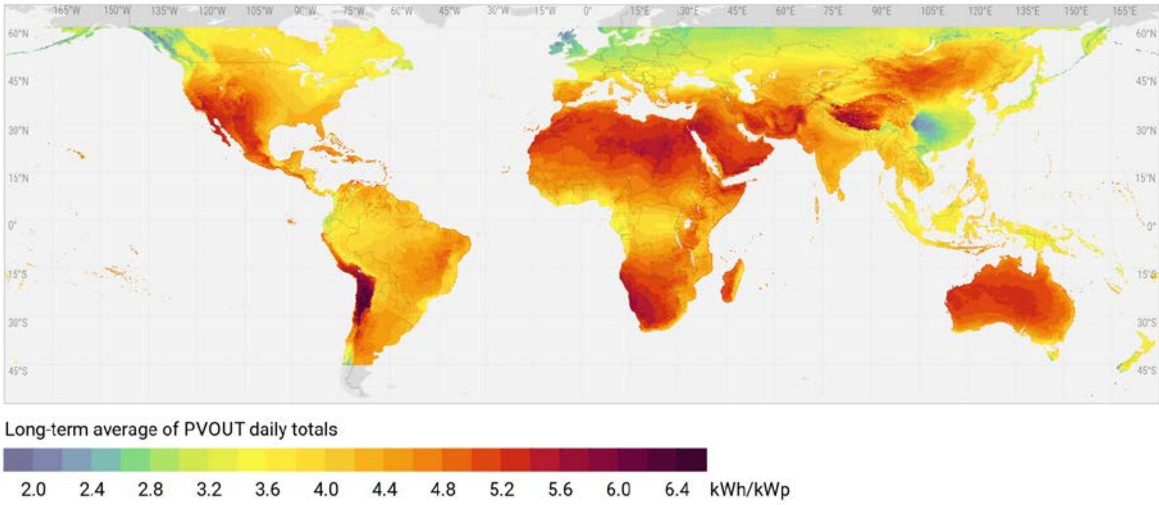

Figure 1.9: Long-term yearly average of daily totals of photovoltaic power potential (PVOUT)

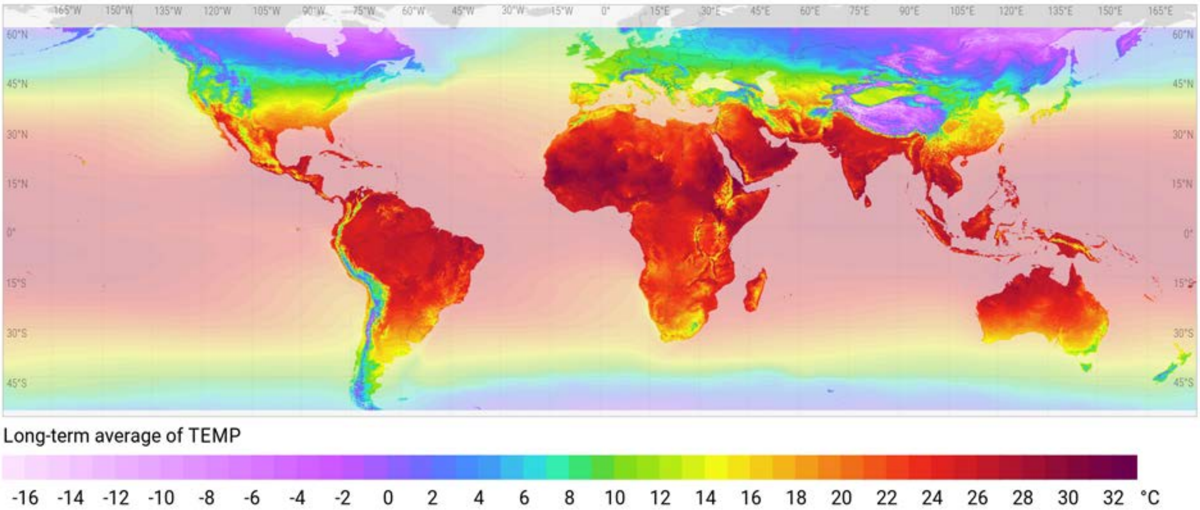

Figure 1.10: Long-term average of air temperature (TEMP)

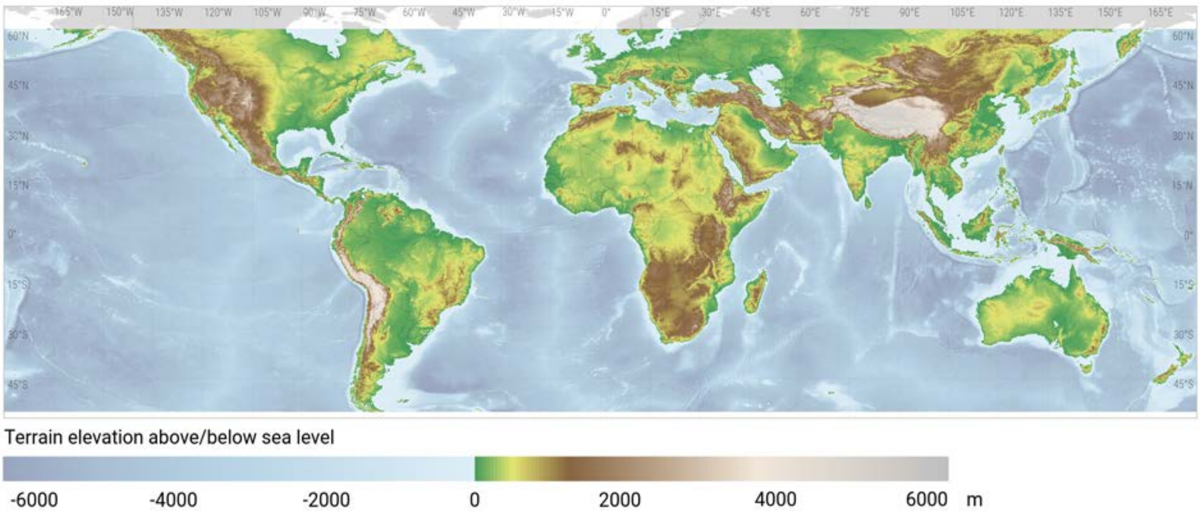

Figure 1.11: Terrain Elevation above sea level (ELE)

1.2 Features of online software application

A software designed for fast and comfortable access, visualisation and analysis by clicking on the map or searching for the site. The functionality of the GSA v2 includes:

- Visualization of the pre-computed data from the Solargis database
- Flexible calculation of PVOUT values

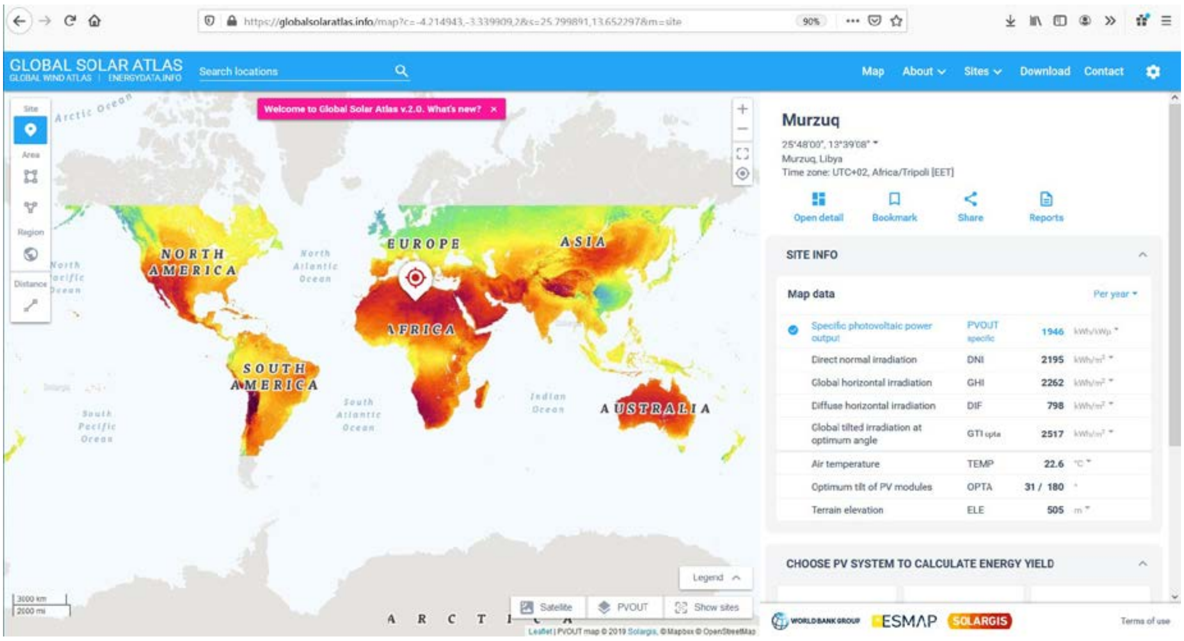

Figure 1.12: Screenshot of the web application

Operational environment

- Cloud-based system (Amazon Web Services)
- Implemented service that uses Solargis internal PV calculator and database to calculate PV output (more information about PV simulation software in Chapter 3).
- Accurate management and display of latitude/longitude position (up to 1 arc-second or 6 decimal degrees)
- Intelligent parser of user inputs for latitude/longitude coordinates
- Intelligent parser of user inputs for geographical name
- Map based applications:
  - o Map based application based on Leaflet engine with some services from Google Maps
  - o Complementary, fully functional application based on interactive maps
- Geocoding services to identify geographical names and address for a map position

Map browsing features

- Browse and zoom high detailed map
- Search by geographical name or coordinates
- Query coordinates and name, query data values
- For GHI, DNI, GTI, DIF and PVOUT a user can switch between values shown as average daily total or average yearly total
- Export PV calculation results to report in PDF formats

- Location sharing features,
- SAVE feature of created project

Knowledge base information pages with background information about the interactive tools:

- Technical description of underlying solar, meteo, PV and ancillary data
- Links to GIS data and maps repository
- Description of solar validation sites and accuracy of the database
- Global Solar Atlas user guide
- Frequently asked question
- Terms of use and copyright section
- Links to other projects (ESMAP, IRENA, etc.) and to selected public software tools

Application monitoring

- Based on Google Analytics
- Yearly reporting of key performance parameters

Language version of the user interface and PDF reports

- English

1.3 Map products

Understanding the regional context of solar, climate and geographic data is important in planning of solar power plants. Maps are an effective way of visualisation Solargis data. Delivered map products are the result of GIS data processing and digital cartography. The maps can be characterized by:

Coverage

- **Regional** – six geographic regions (defined by The World Bank) and global maps (Figure 1.13).
- **Country** – 145 ODA eligible countries (in DAC list) were updated with the recent data, see Figure 1.14). Other countries (not eligible for ODA) are being gradually added into the download section, resulting in total number of 187 country maps.

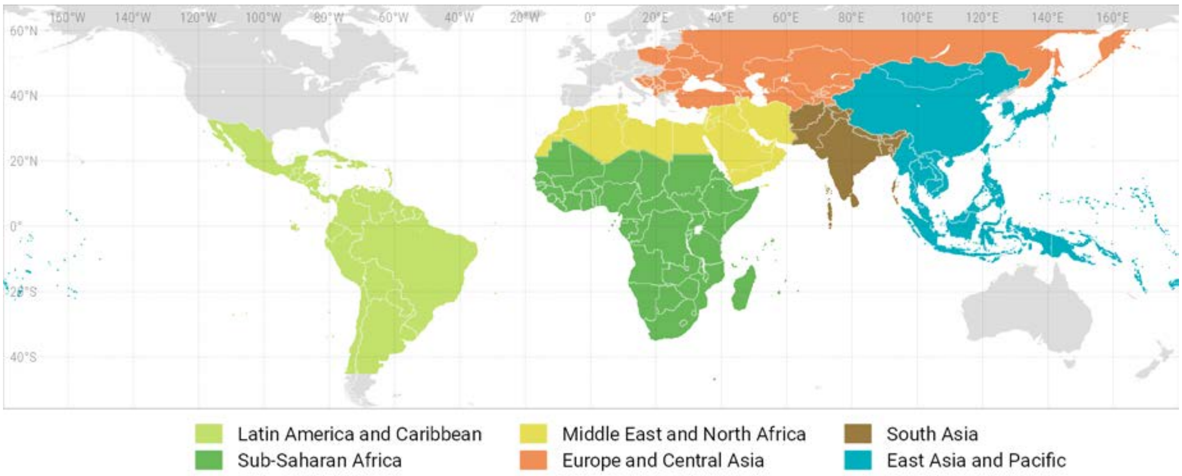

Figure 1.13: Regional maps according to the World Bank classification

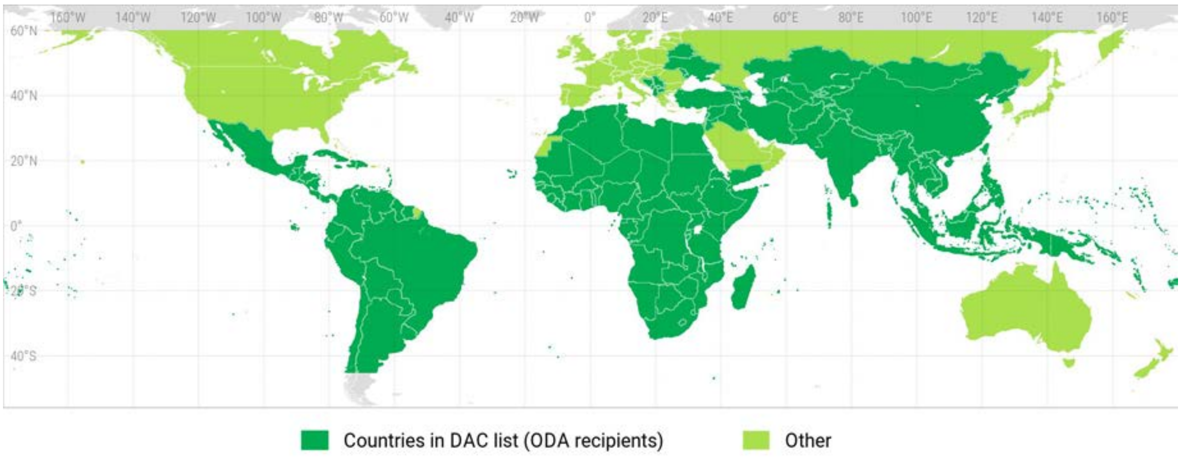

Figure 1.14: Area covered by country maps

Map scale (print/view size)

- **Poster size** – large-scale, high resolution maps, provided as ready-to-print image files (TIFF, typical size approx. 100 Mpix). The typical size is approximately 1 m^2. For optimum results we recommend the print on fine-art machines or high-quality plotter printing on semi-glossy paper. Alternatively, consult your printing company for other options and materials (foam boards, solid boards, stickers, canvas, elastic materials, etc.).
- **Mid-size** – medium and small-scale maps. They are prepared for the width up to 160 mm (height is calculated according the shape of the country) and thus suitable for standard office printers (format A4 or similar) and for on-screen presentations. The images are provided in PNG format (typical size approx. 1 to 4 MPix).

Data type

- **Photovoltaic power potential** (PVOUT)
  PVOUT provides a summary of estimated solar photovoltaic (PV) power generation potential of electricity production from a 1 kW-peak grid-connected solar PV power plant with cSi modules optimally tilted towards the equator (detailed information in Chapter 3)
- **Global horizontal irradiation** (GHI)
  GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies.
- **Direct normal irradiation** (DNI)
  DNI is the most important parameter for energy yield calculation and performance assessment of concentrating solar power (CSP) and concentrator solar photovoltaic (CPV) technologies. DNI is also important for the calculation of global irradiation received by tilted or sun-tracking photovoltaic modules.

Altogether more than a thousand individual map files can be downloaded from the Global Solar Atlas *Download* section. A typical download section screen is described in Figure 1.15.

Figure 1.15: An example of maps and GIS data available in the download section
See https:/globalsolaratlas.com/downloads/ (status: November 2019)

For illustration, the snapshots of various map types are shown in Figures 1.16 to 1.20.

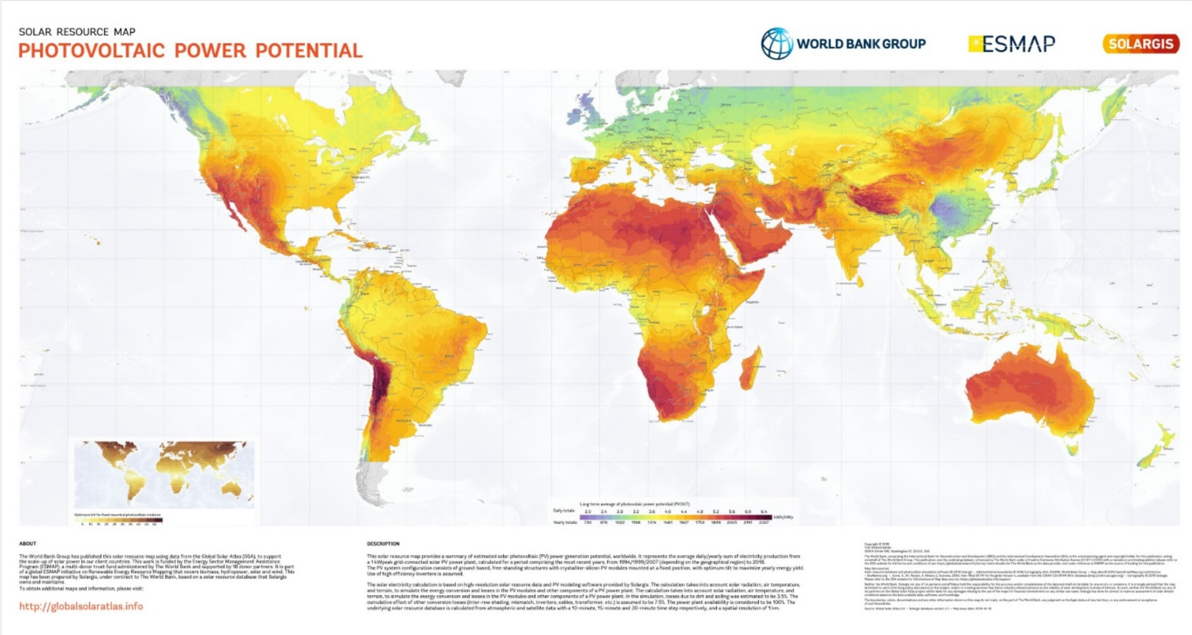

Figure 1.16: An example of PVOUT world poster map (original size 150 x 80 cm)

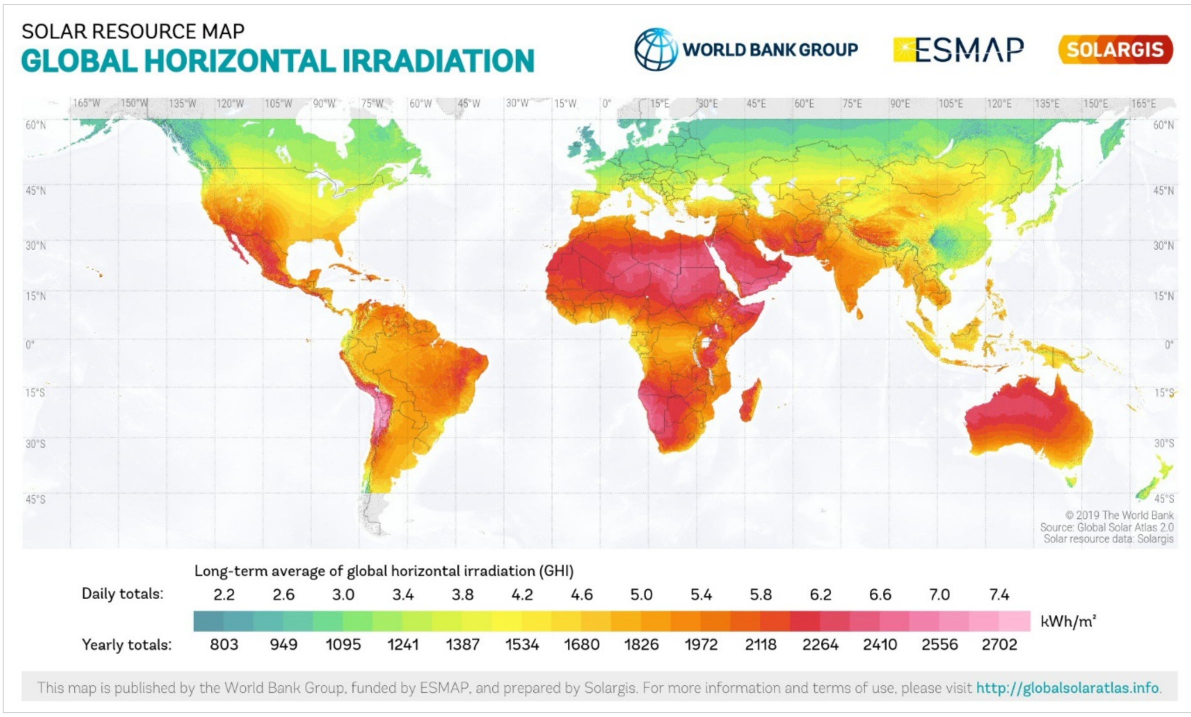

Figure 1.17: An example of GHI midsize world map (original size 16 x 9.5 cm)

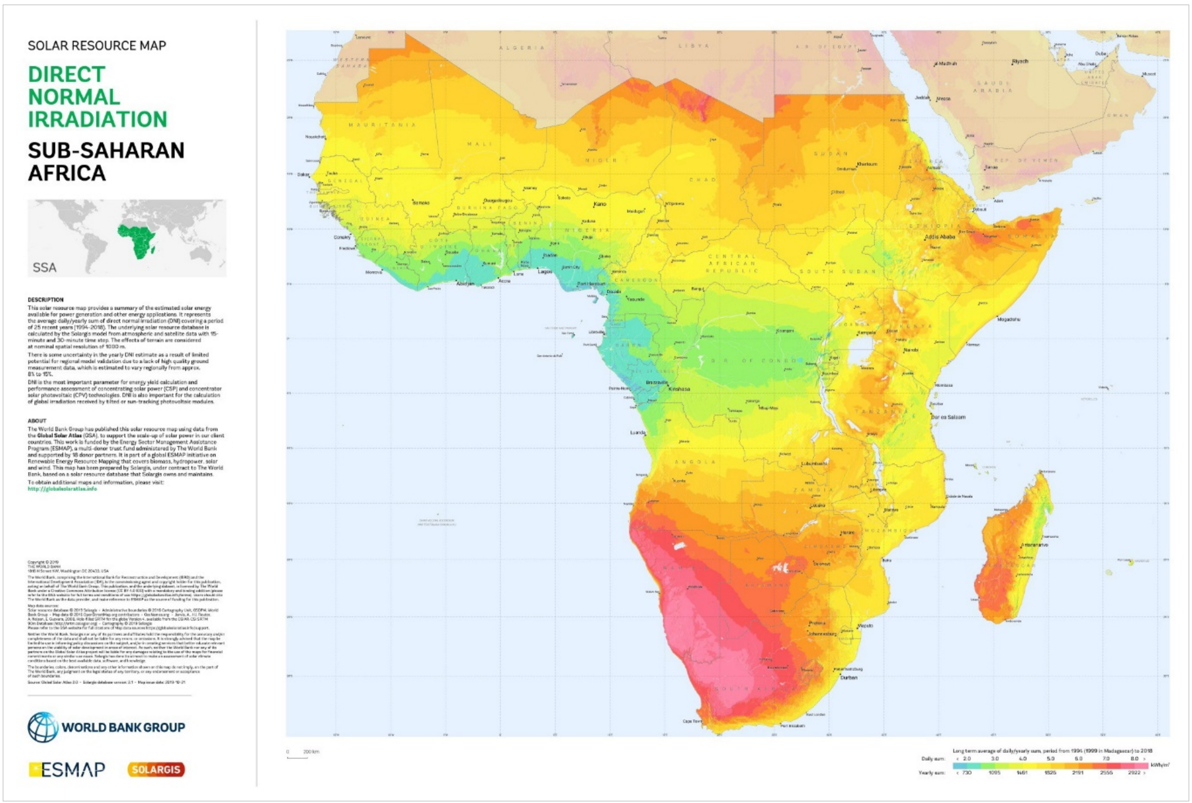

Figure 1.18: An example of DNI poster map of the Sub-Saharan Africa region (original size 120x80 cm)

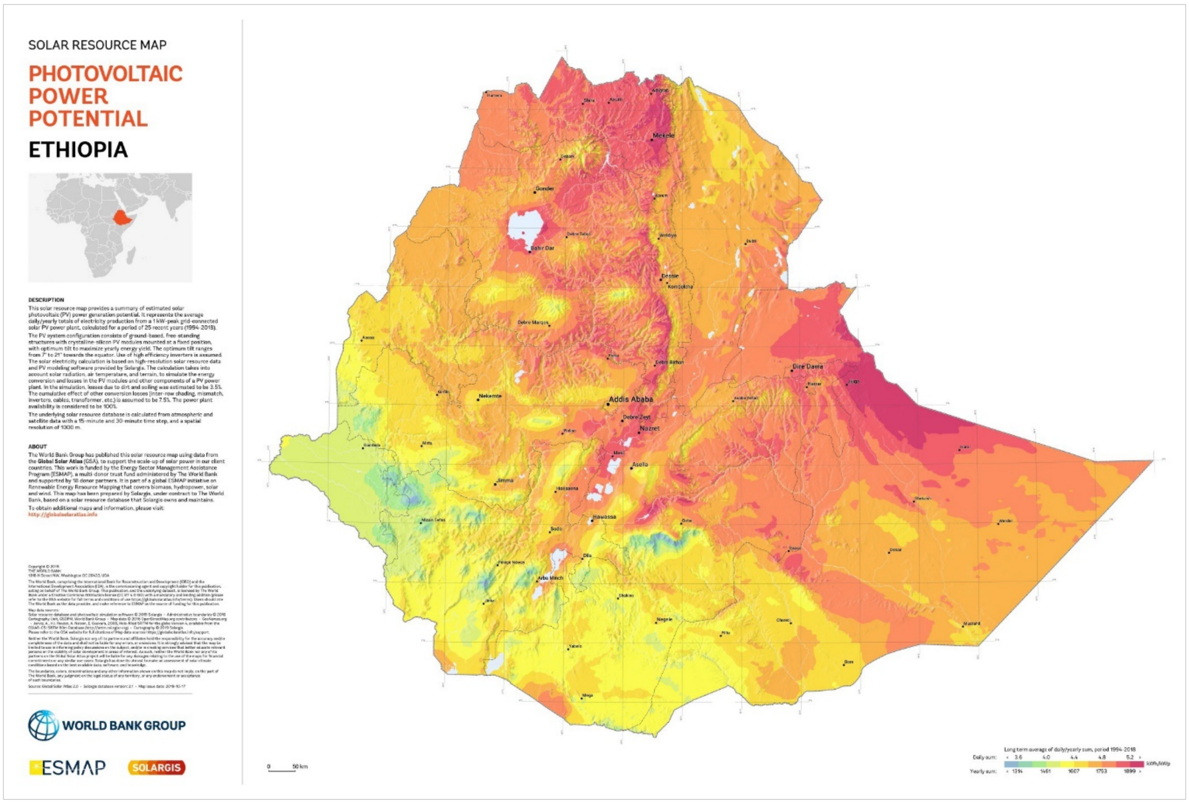

Figure 1.19: An example of country PVOUT poster map (Ethiopia, original size 120x80 cm)

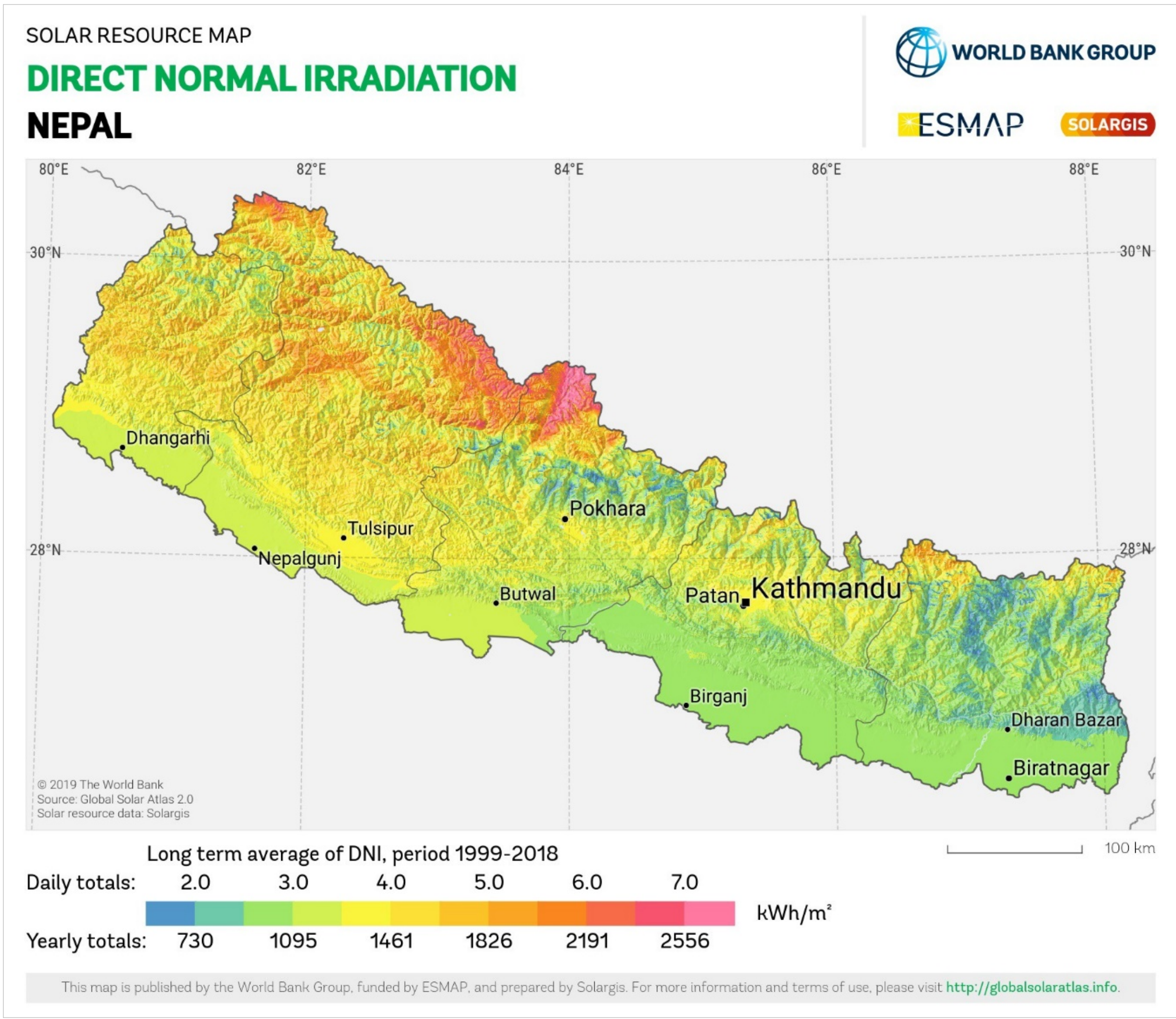

Figure 1.20: An example of DNI midsize country map (Nepal)

1.4 Maps for Google Earth

Visualisation and analyses of data in Google Earth Desktop is essential working tool, attractive for presentation and efficient for collaboration. Therefore, the map layers are provided in the specific format to be easily used with Google Earth, Open Layers or other GIS software.

Delivered GIS data for PVOUT, GHI and DNI (layers with the nominal resolution in 30 arcsec, described in Chapter 1.1) are presented as image layers, segmented into large number of geo-positioned square images – ***map tiles***. For faster loading and smoother browsing, tiles are specially processed for various zoom levels. Colour legend is included to each map layer; the value can be identified according to the colour code. "No-data" values are transparent.

Note on file delivered formats

Map tiles and additional files are provided as a single ZIP file. To start the job:

- Unpack the ZIP file, keep the complete directory on your computer
- Locate and import the KML file to Google Earth application on your computer.

Map layers for Google Earth Desktop are prepared as a mesh of KML, HTML, geo-referenced JPG or PNG files, which are shown in the Google Earth browser in the correct position. Provided map tiles can be also used with other GIS software or Earth browsers and thus to create customised cartographical product.

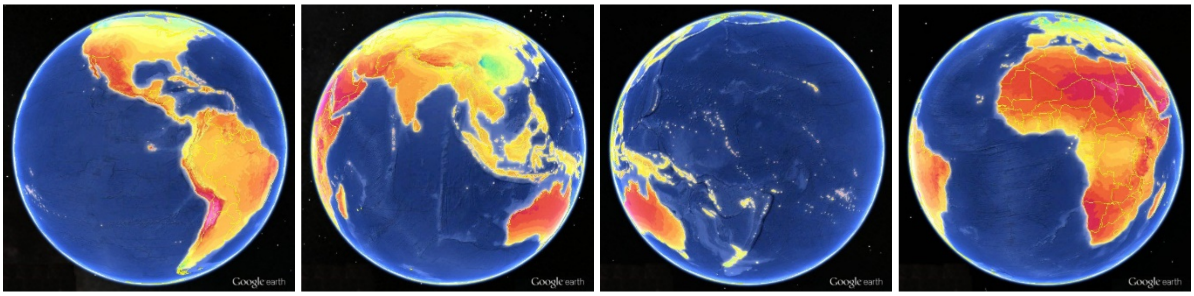

Figure 1.21: Snapshots of GHI map layer in Google Earth Desktop in global scale

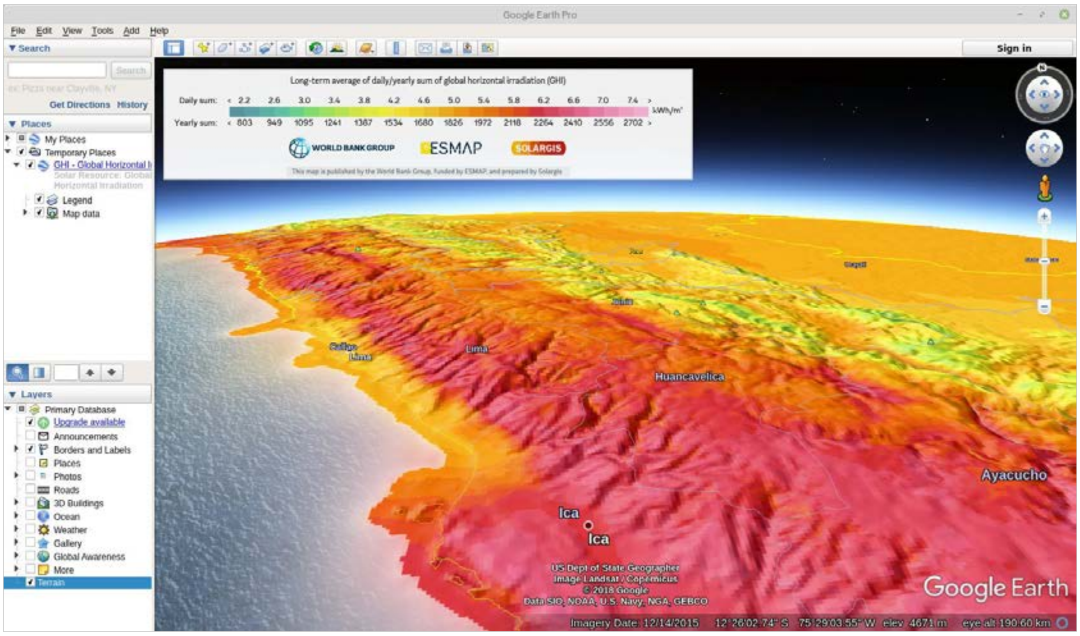

Figure 1.22: Snapshots of GHI map layer in Google Earth Desktop in detail

2 SOLARGIS DATABASE

Solargis is high-resolution global database of solar resource and meteorological parameters, operated by company Solargis. Its geographical extent covers most of the land surface between 60° North and 55°S (in Latin America to 45°S).

2.1 Satellite-derived solar radiation

Solar radiation is calculated by numerical models, which are parameterized by a set of inputs characterizing the cloud transmittance, state of the atmosphere and terrain conditions. A comprehensive **overview of the Solargis model** is made available in the recent book publication [1]. The methodology is also described in [2, 3]. The related uncertainty and requirements for bankability are discussed in [4, 5].

In Solargis approach, the **clear-sky irradiance** is calculated by the simplified SOLIS model [6]. This model allows fast calculation of clear-sky irradiance from the set of input parameters. Sun position is deterministic parameter, and it is described by the algorithms with satisfactory accuracy. Stochastic variability of clear-sky atmospheric conditions is determined by changing concentrations of atmospheric constituents, namely aerosols, water vapour and ozone. In Solargis, the global atmospheric data, representing these constituents, are routinely calculated by world atmospheric data centres:

- In Solargis, the new generation **aerosol data set** representing Atmospheric Optical Depth (AOD) is used. This data set is developed and regularly updated by MACC-II/CAMS project (© ECMWF) [7, 8]), and delivered at a spatial resolution of about 45, 75 km and 125 km. Important feature of this AOD data set is that it captures daily variability of aerosols and allows simulating more precisely the events with extreme atmospheric load of aerosol particles. Thus it reduces uncertainty of instantaneous estimates of GHI and especially DNI and allows for improved statistical distribution of irradiance values [9, 10].
- **Water vapour** is also highly variable in space and time, but it has lower impact on the values of solar radiation, compared to aerosols. The daily GFS and CFSR values (© NOAA NCEP) are used in Solargis, thus representing the daily variability from 1994 to the present [11, 12, 13].
- **Ozone** absorbs solar radiation at wavelengths shorter than 0.3 μm, thus having negligible influence on the broadband solar radiation.

The **clouds** are the most influencing factor, modulating clear-sky irradiance. Effect of clouds is calculated from the satellite data in the form of cloud index (cloud transmittance). The cloud index is derived by relating irradiance recorded by the satellite in three spectral channels and surface albedo to the cloud optical properties. Depending on a region, satellites have a time step of 10/15/30 minutes

- Spatial resolution of Meteosat MSG and MFG (Prime satellite, © EUMETSAT) data used in Solargis is about 2.6 to 4.6 km in the region and the time step is 30 minutes for a period from 1994 to 2005 and 15 minutes, for a period from 2005 onwards [14].
- Spatial resolution of Meteosat MSG IODC and MFG IODC (Indian Ocean position, © EUMETSAT) data used in Solargis is about 2.6 to 3.5 km in the region and the time step is 30 minutes for a period from 01/1999 to 01/2017 and 15 minutes, for a period from 02/2017 onwards [15].
- Spatial resolution of data from the Pacific satellite mission (MTSAT and Himawari 8 satellite (JMA)) is 4.0 to 8.0 km and 2.0 to 5.0 km and available from 2007 to 2015 (MTSAT) in a time step of 30 minutes, and for a period 2016 onwards in a time step of 10 minutes [16].
- Spatial resolution of GOES East (© NOAA) satellite data used in Solargis is about 4.1 to 4.4 km and the time step 30 minutes, for a period from 1999 onwards [17].
- Spatial resolution of GOES West (© NOAA) satellite data used in Solargis is about 4.1 to 4.4 km and the time step 30 minutes, for a period from 1999 onwards [17].

In Solargis, the modified calculation scheme by Cano has been adopted to retrieve cloud optical properties from the satellite data [18]. A number of improvements have been introduced to better cope with specific situations such as snow, ice, or high albedo areas (arid zones and deserts), and also with complex terrain.

To calculate **all-sky irradiance** in each time step, the clear-sky global horizontal irradiance is coupled with cloud index.

Direct Normal Irradiance (DNI) is calculated from Global Horizontal Irradiance (GHI) using modified Dirindex model [19]. Diffuse irradiance for tilted surfaces, which is calculated by Perez model [20]. The calculation procedure included also terrain disaggregation model for enhancing spatial representation – from the resolution of satellite to the resolution of digital terrain model (250 meters) [21].

Solargis model version 2.1 has been used for computing the data. Table 2.1 summarizes technical parameters of the model inputs and of the primary outputs. Figure 2.1 shows coverage of satellite's regions used in Solargis database.

Table 2.1: Input data used in the Solargis solar radiation model and related GHI and DNI output

Inputs into the Solargis model	Source of input data	Time representation	Original time step	Approx. grid resolution at sub-satellite point
Cloud index	Meteosat MFG Meteosat MSG (EUMETSAT)	1994 to 2004 2005 to date	30 minutes 15 minutes	2.5 km 3.0 km
	Meteosat MFG (IODC) Meteosat MSG (IODC) (EUMETSAT)	1999 to 01/2017 02/2017 to date	30minutes 15 minutes	2.5 km 3.0 km
	MTSAT (JMA) Himawari 8 (JMA)	2007 to 2015 2016 to date	30 minutes 10 minutes	4.0 km 2. 0 km
	GOES East (NOAA) GOES-R EAST (NOAA)	1999 to 2017 2018 to present	30 minutes 15 minutes	4.0 km 2.0 km
	GOES West (NOAA)	1999 to date	30 minutes	4.0 km
Atmospheric optical depth (aerosols)*	MACC/CAMS* (ECMWF) MERRA-2 (NASA)	2003 to date 1999 to 2002	3 hours 1 hour	75 km and 125 km 45 km (since June 2016) 50 km
Water vapour	CFSR/GFS (NOAA)	1994 to date	1 hour	35 and 55 km 13 km (since Feb. 2015)
Elevation and horizon	SRTM-3 (SRTM)	-	-	250 m
Solargis primary data outputs (GHI and DNI)	-	1994 to date	15 minutes	250 m

** Aerosol data for 2003-2012 come from the reanalysis database; the data representing years 2013-present are derived from near-real time operational model*

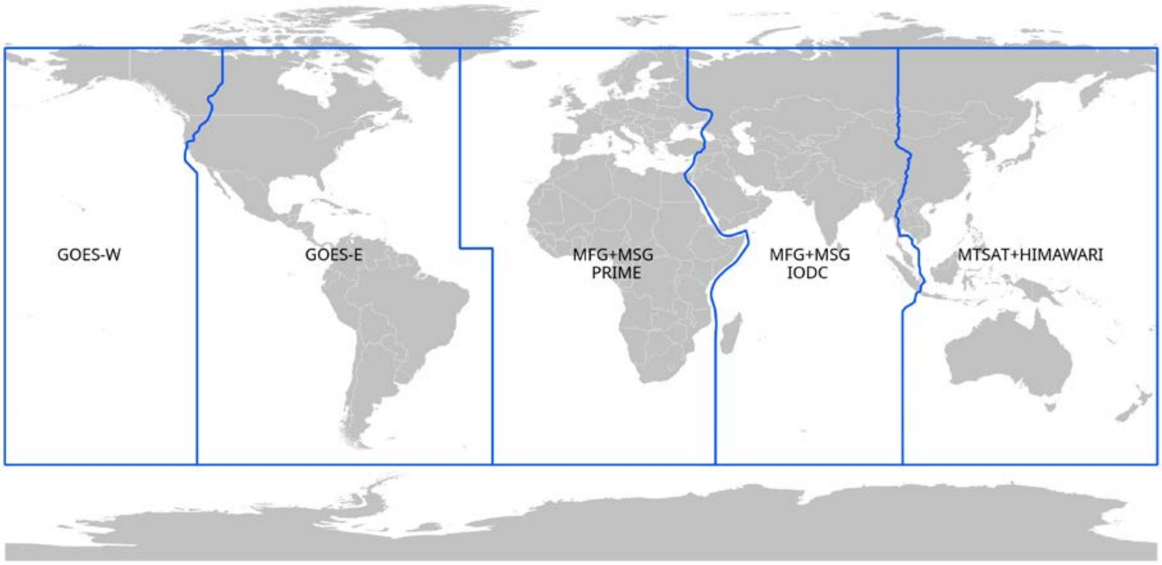

Figure 2.1: Borders of satellite coverage (used by Solargis)

2.2 Meteorological data

In Solargis, the model-based historical meteorological data from the ERA5 climate reanalysis produced by ECMWF is available globally since 1994/1999/2007 (depending on the geographical region to match the time period of solar radiation data) within 3 months of real time. The period of last 3 months to the present time is covered by coupled forecast system model version 2, CFSv2 produced by NCEP as summarised in Table 2.2.

Table 2.2: Original source of Solargis historical meteorological data.

	Climate reanalysis ERA5	Climate Forecast System CFSv2
Time period	1994/1999/2007 - within 3 months of real time	3 months of real time to the present time
Original spatial resolution	0.25°	0.2045°
Original time resolution	1 hour	1 hour

In this delivery, the long term hourly average air temperature is derived from the ERA5, for the whole time period 1994 to 2018 with global coverage (without differentiation between geographical regions) Table 2.3.

Table 2.3: Solargis meteorological parameters delivered within the GSA

Meteorological parameter	Acronym	Unit	Period	Time resolution	Spatial representation
Air temperature at 2 metres (dry bulb temperature)	TEMP	°C	1994-2018	Long-term hourly average	Spatially interpolated to 2-arc minutes

The accuracy of the meteorological model depends on the underlying model equations, on the input data and its spatial and time resolution. Being a mathematical representation of dynamic processes, the meteorological model is based on a complex system of partial differential equations, solution of which strongly depends on initial and boundary conditions. The initialisation parameters come from meteorological measurements at different levels of atmosphere. The accuracy in the lowest layer of the atmosphere (2 m for air temperature, relative humidity and atmospheric pressure, and 10 m for wind speed and wind direction) depends on spatial distribution and quality of measurements from the meteorological observation networks. Thus, the accuracy of the meteorological output

Table 2.4: Comparing data from meteorological stations and weather models

	Meteorological station data	Data from meteorological models
Availability/ accessibility	Available only for selected sites. Data may cover various periods of time	Data are available for any location Data cover long period of time (decades)
Original spatial resolution	Local measurement representing microclimate with all local weather occurrences	Regional simulation, representing regional weather patterns with relatively coarse grid resolution. Therefore the local values may be smoothed, especially extreme values.
Original time resolution	From 1 minute to 1 hour	1 hour
Quality	Data need to go through rigorous quality control, gap filling and cross-comparison.	No need of special quality control. No gaps Relatively stable outputs if data processing systematically controlled.
Stability	Sensors, measuring practices, maintenance and calibration may change over time. Thus long-term stability is often a challenge.	In case of reanalysis, long history of data is calculated with one single stable model. Data for operational forecast model may slightly change over time, as model development evolves
Uncertainty	Uncertainty is related to the quality and maintenance of sensors and measurement practices, usually sufficient for solar energy applications.	Uncertainty is given by the resolution and accuracy of the model. Uncertainty of meteorological models is higher than high quality local measurements. The data may not exactly represent the local microclimate but are usually sufficient for solar energy applications.

Data from the two sources described above have their advantages and disadvantages (Table 2.4). Air temperature retrieved from the meteorological models has lower spatial and temporal resolution compared to on- site meteorological measurements, and they have lower accuracy. Thus, modelled parameters may characterize only regional climate patterns rather than local microclimate; especially extreme values may be smoothed and not well represented. Local microclimate may deviate from the values derived from the Solargis global database.

Important note: meteorological parameters derived from the numerical weather model outputs have lower spatial and temporal resolution. Thus, they do not represent the same accuracy as the solar resource data. Especially wind speed data has higher uncertainty, and it provides only overview information for solar energy projects. The local microclimate of the site may deviate from the values derived from the Solargis global database.

3 SOLARGIS PV ELECTRICITY SIMULATION

PV energy simulations in the GSA are based on software, solar resource and meteorological data developed by Solargis. This chapter summarizes key elements of the simulation chain. In the text below, losses and uncertainties incorporated in the calculation steps are estimated, summary of parameters used in GIS layers calculations is listed and the example of the calculation for a selected site is shown.

3.1 Solargis PV electricity simulation

Electrical energy produced by a photovoltaic (PV) system depends on several external factors. First and the most important of them is the amount of solar radiation impinging on the surface of the PV modules, which in turn depends on the local climatic conditions as well as the mounting of the modules, e.g. fixed, tracking or floating on the water body, inclination angle, etc. If solar radiation was the only parameter influencing the PV module power, the task of estimating the long-term energy performance of a system would be reduced to finding the average global in-plane irradiation. However other factors also contribute to the final PV power output and air temperature is the most important of them.

The Solargis PV software has implemented scientifically verified methods [22 to 31]. The data and model quality are checked against field tests and ground measurements. The database is updated in real time. The software implementation makes it possible to use historical, near-real time and also forecast data.

Two types of inputs must be available for PV simulation at a selected site:

- **Site parameters** are provided by Solargis database (solar radiation, air temperature, terrain) and algorithms implemented in the Solargis system, including the sun path geometry.
- **Technical parameters** of the PV power system (installed power, mounting system, type of modules, DC and AC losses, inverter efficiency and PV system availability). These parameters are reflected in the simulation steps as losses with amplitude related to the characteristics and quality of components used in the PV installation.

Site and technical parameters are implemented in the computation process in eight steps.

- **Global irradiation impinging on a tilted plane of PV modules** (Global Tilted Irradiation, GTI) - **STEP 1** - is calculated from Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), terrain albedo, and instantaneous sun position. Then following PV energy simulation chain assumes several energy losses occurring at the individual steps of energy conversion
- **Losses due to terrain shading (STEP 2)**

  Shading by terrain features is calculated using the Shuttle Radar Topography Mission (SRTM) digital elevation model and computed horizon. Shading from local features such as from the nearby buildings, structures or vegetation is not considered at this stage of calculation.

  Water level in reservoirs is subjected to change during seasons of year or during hydroelectric power generation stations operation. The change can be up to tens of meters, thus local horizon at point of PV floating installation may be affected. These changes are also not considered at this stage of calculation.

  For the open space systems installed in the flat areas the uncertainty of this estimate is very low (lower than 0.1%) [21] and increases with the increasing complexity of terrain. For the urban areas, an additional analysis should be undertaken to account for the shading by urban structures (Step 5).
- **Losses due to angular reflectivity (STEP 3)**

  These loses depend on instantaneous incidence angle (the relative position of the sun and the plane of PV module), what in turn depends on the geographical position of the PV installation and PV modules tilt and orientation. For this calculation the model developed by Martin and Ruiz is used [22, 23]. The losses at this stage depend also on the module surface type and cleanness. In the calculation, a typical low iron float glass and "small" effect of dirt and dust are assumed (commercial clean crystalline silicon modules). With the increasing surface soiling and dirtiness, angular losses also increase, but at this stage this effect is not considered.

- **Losses due to performance of PV modules outside of STC conditions (STEP 4)**

  Relative change of produced energy at this stage of conversion depends on the geographical location, modules tilt and azimuth and mounting of the modules. Typically, for crystalline silicon modules, these losses are higher when modules mounted on a tracker rather than at a fixed position [24 to 27].

  Special case occurs for PV modules mounted on pontoons floating on a water surface. Depending on construction, additional cooling of modules due to water evaporation is considered and may results in higher gains in PV production in comparison to the same system mounted on a ground [32].

- **Losses due to external shading (**in the group of **Other DC losses, STEP 5)**

  External shading is caused by external obstacles situated close to PV system and casting shadows on the modules surface. Shadows can appear during a particular season of the year when the sun azimuth and elevation reaches specific direction of external obstacle, or may reduce the output power during the entire year. For example, typical shading objects are trees, poles, fences, buildings, chimneys or adjacent roofs when considering a roof or façade system. The most sensitive systems are small roof PV installations, where shading losses can easily reach up to 50 percent, especially when objects obstruct the modules during midday (when the sun's elevation as well as electricity generation is the highest). This type of shading losses is not included in the general calculation scheme. It can be included in detailed local PV performance study.

- **Losses due to dirt and soiling (**in the group of **Other DC losses, STEP 5)**

  Losses of solar radiation at the level of surface of PV modules depend on the environmental factors and cleaning of the PV modules surface as well on the inclination of the modules (highest for the horizontal surface, lowest for vertical). For PV modules mounted on a water additional source of soiling are birds' droppings.

- **Losses due to inter-row shading (**in the group of **Other DC losses, STEP 5)**

  Row spacing leads to electricity losses due to short-distance shading. These losses are specific, depending on a type of PV system installation, strings organization and PV modules technology. No inter-row shading occurs on roof installations with flat laying PV modules. Roofs with rack systems or ground-mounted (or floating) structures creating shadows on next rows, which lead to shading losses. This can be avoided by optimising tilt and distance between rows of modules.

- **Power tolerance of the modules (**in the group of **Other DC losses, STEP 5)**

  PV modules are connected in strings, and power tolerance of modules determines mismatch losses for these connections. If PV modules with higher power tolerance are connected in series, the losses are higher as result of higher probability of connecting in one-string modules with different characteristics. Gain due to higher real installed power than nominal "label" power is compensated by possible losses due to higher mismatch. The higher power tolerance of the modules increases uncertainty of the power output estimation.

- **Mismatch and DC cabling losses (**in the group of **Other DC losses, STEP 5)**

  Mismatch due to different MPP operating points of the modules connected to inverter and heat losses in the interconnections and cables depend on the design and used components of PV power plant. If classification of PV modules is considered according to the performance measurements of the nominal power performed by the manufacturer, grouping the modules from the same class is an effective measure to minimize the mismatch losses of the modules connected within one string. Losses due to different illumination levels of different strings due to near shading results in mismatch losses and the magnitude will depend on the near-shading situation.

  In case of the floating PV installations, additional mismatch losses need to be considered. Waves cause movements of whole construction or separate pontoons; thus optimum tilt of PV modules is not guaranteed during operation. According to type of construction and local microclimatic conditions (type of water body, wind speed) wave induced mismatch may reach values up to 9% [33] or more.

  Cable losses in DC circuits are influenced mainly by PV power plant topology. Connections from the modules into string inverters in decentralized systems (what is typical configuration for roof systems) are shorter, have smaller currents flow and result in smaller losses. Centralized systems with high-power inverters, typical for large-scale installations, have longer current paths, usually with combiner boxes, work with high currents thus creating higher losses.

- **Inverter losses, conversion of DC to AC (STEP 6)**

  Although the efficiency of PV inverter is high, each inverter introduces additional losses to the system. Losses due to performance of inverters can be estimated using the inverter power curve or using the less accurate pre-calculated value given by the manufacturer. It can be found in the technical data sheet of the inverter as Euro or CEC efficiency (e.g. Euro Efficiency of 97.5% corresponds to losses of 2.5%). Lowest efficiencies have low-performance inverters with built-in isolation transformer (capacities of tens of kVA). Highest-weighted efficiencies of up to 98.5% are reached by very high-performance inverters (usually hundreds of kVA).

- **AC and transformer losses (STEP 7)**

  These losses apply mainly for large-scale open space systems, where the inverter output is connected to the grid through the transformer. The additional AC losses reduce the final system output by a combination of cabling and transformer losses. For a PV roof system these losses are optional and depend on the system size. Small PV system can be directly connected to the grid without output transformer. Then only AC cable losses are applied. Similar to DC cabling losses, AC cabling paths, length of cables and currents in AC circuits are influencing the amount of loss.

- **Availability (Downtime losses, STEP 8)**

  This empirical parameter quantifies electricity losses incurred by shutdown of a PV power plant due to maintenance or failures, including issues in the power grid. Availability of well-operated PV system is approximately 99%, but easily can drop down to 90% if PV system does not produce electricity for more than a month due to a system failure. Especially in case of instable grid, the losses can be higher, as the PV system has to be switched-off in case of grid outage.

The result of Solargis energy simulation is provided as theoretical DC electricity output excluding some losses mentioned above. All additional losses are to be defined as percentage of value calculated at previous simulation stage, (it is not possible to simply sum up all losses). The following formula will be used for calculation of losses (example, Loss1, Loss2, Loss3 are in %):

$$PV_{considering\ Loss1} = PV * (100\% - Loss1)$$

$$PV_{considering\ Loss1\ and\ Loss2} = PV_{considering\ Loss1} * (100\% - Loss2) = PV * (100\% - Loss1) * (100\% - Loss2)$$

$$PV_{considering\ Loss1,\ Loss2\ and\ Loss3} = PV * (100\% - Loss1) * (100\% - Loss2) * (100\% - Loss3)$$

etc.

Table 3.1 shows summary of simulation steps and possible loss ranges. It has to be noted, that each installation has its own working conditions, which in extreme cases may be over mentioned limits.

Table 3.1: Summary of Solargis simulation steps and possible loss ranges

Simulation step	Loss type	Range [%]	
		Min	Max
1	Global Tilted Irradiation (model estimate)	-	-
2	Losses due to terrain shading	0.0	10.0
3	Losses due to angular reflectivity	2.5	7.5
4	Losses due to performance of PV modules outside of STC conditions	1.0	16.0
5	Losses due to external shading	0.0	50.0
5	Losses due to dirt and soiling	1.1	57.5
5	Losses by inter-row shading	0.0	7.0
5	Power tolerance of modules	0.0	0.0
5	Mismatch and DC cabling losses	0.5	15.0
6	Inverter losses from conversion of DC to AC	2.0	7.0
7	AC and transformer losses	0.2	3.5
8	Availability (Downtime losses)	0.0	10.0
Total		7.1	90.5

Note on long-term performance degradation

Many years of operation of PV power systems is the ultimate test for all components. Currently produced modules represent a mature technology, and low degradation can be assumed. However, it has been observed that performance degradation rate of PV modules is higher at the beginning of the exposure, and then stabilizes at a lower level, Initial degradation may be close to value of 0.8% for the first year and 0.5% or less for the next years [29]. Degradation is not considered in the calculations.

3.2 PV simulation uncertainty

Table 3.2 shows expected uncertainties for each step of simulation, presented in Chapter 3.1. The values are considering the long-term annual average value and are not the values for one single year, as this would need the interannual variability analysis from the full-time series of data. It has to be noted, that in extreme cases limits may be exceeded.

The calculation of uncertainty is simplified and assumes that all losses are independent from each other and also normal distribution of uncertainty at each step. A simple error propagation formula is used in the calculations:

$$TotalUncertainty = \sqrt{UncLoss1^2 + UncLoss2^2 + UncLoss3^2 + \cdots}$$

Table 3.2: Solargis simulation steps and uncertainties estimate

Simulation step	Loss type	Uncertainty [%]	
		Min	Max
1	Global Tilted Irradiation (model estimate)	5.0	15.0
2	Losses due to terrain shading	0.1	5.0
3	Losses due to angular reflectivity	2.0	2.0
4	Losses due to performance of PV modules outside of STC conditions	2.0	8.0
5	Losses due to external shading	0.1	20.0
5	Losses due to dirt and soiling	1.0	30.0
5	Losses by inter-row shading	0.0	3.0
5	Power tolerance of modules *	0.0	0.0
5	Mismatch and DC cabling losses **	0.5	10.0
6	Inverter losses from conversion of DC to AC	1.0	1.0
7	AC and transformer losses	0.5	0.5
8	Availability (Downtime losses)	1.0	1.0
Total		6.0	41.6

** Only positive module power tolerance is considered*

*** Depends strongly on the near shading and mounting type (ground/roof mounted or floating PV)*

3.3 Types of PV system configuration used in GSA

Solargis simulation chain allows knowing the expected PV yield for solar PV systems in the long-term at the early stage of the project, before designing and constructing. Interpreting Solargis simulation results involves the understanding of related uncertainties, including solar radiation, theoretical models for PV yield simulations and the user's estimate of the losses.

As shown above, there are multiple simulation steps in the standard calculation of PV power potential. Table 3.3 provides a list of default settings applied in the calculator for the pre-selected type of PV power systems. The setting in the GSA user interface have been simplified to a great deal so that a user can select only the most important ones:

- PV system type: theoretical (map-based PVOUT calculation), small residential, medium size commercial, ground-mounted large scale, hydro-mounted large scale
- Installed capacity
- Azimuth of PV modules
- Tilt of PV modules

Parameters listed in Chapter 3.1 are used as inputs for energy simulation in Solargis web application and also for generating the GIS data layer pf PV theoretical potential. For GSA, several type of PV systems are considered. Description of the system types is shown in Table 3.3 and simulation assumptions are summarised in Table 3.4.

Table 3.3: Simulation options considered in Global Solar Atlas

Variant	Description
Theoretical	Used for map-based calculation with generalized theoretical settings for a quick assessment of PV power potential.
Small residential	Used for [site-specific simulation of roof-mounted PV systems. It considers bad ventilation of PV modules mounted on rooftops, with sub-optimal inclination and harder access for cleaning.
Medium-size commercial	Used for site-specific simulation of larger roof-mounted PV systems, installed for commercial production of electricity into distribution grid, or as support of own consumption of a building.
Large-scale ground mounted	Used for site-specific simulation of grid-connected free-standing large PV systems with modules assembled on fixed tilted constructions. Power is delivered to the distribution grid through step-up medium voltage distribution transformer.
Large-scale hydro- mounted	Used for site-specific simulation of large floating solar PV installations with modules assembled on tilted plastic floating pontoons, oriented towards equator. Modules have lower operational temperature, higher mismatch between modules in string and higher soiling. Installation is connected to the distribution grid through step-up medium voltage distribution transformer.

Table 3.4: Configuration of a photovoltaic system considered in the calculations

Feature	Description
Nominal capacity	Scaled to 1 kWp, so the numbers represent specific PV power output per installed capacity of 1 kilowatt-peak
Modules	Generic high efficiency crystalline silicon modules with positive only power tolerance. Modules surface reflectance is 0.16. **NOCT for PV system types:** • Theoretical: 46.2°C • Small residential: 51.2°C • Medium-size commercial: 49.2°C • Large-scale ground mounted: 46.2°C • Large-scale hydro- mounted: 46.2°C ± modification by water evaporation **Temperature coefficients of P_{max}:** • Theoretical: -0.45 %/°C • Small residential, Medium-size commercial, Large-scale ground mounted, Large-scale hydro-mounted: -0.43 %/°C
Losses	Typical losses representing simulation steps from 5 to 8 in Chapter 3.1. Losses are selected according to typical local condition in which selected system type is operated. **Losses for PV system types:** • Theoretical: 8.9 % • Small residential: 12.9 % • Medium-size commercial: 11.9 % • Large-scale ground mounted: 9.5 % • Large-scale hydro- mounted: 21.5 %

Detailed description of all settings for the system types is available on web page of the Global Solar Atlas: https://globalsolaratlas.info/support/methodology.

Table 3.5 summarizes default losses used for calculation of different installation types. The values are representing typical use case (best guess), but not covering whole possible ranges, because each installation is unique. It has to be noted, that in extreme cases limits may be exceeded.

Table 3.5: Default values of losses used in PV calculator for GSA 2.0 [%]

Loss type	Installation type and expected losses [%]				
	Theoretical	Small residential	Medium-size commercial	Large-scale ground mounted	Large-scale hydro-mounted
Losses due to dirt and soiling	3.5	4.5	4.0	3.5	6.0
DC cabling losses	2.0	1.0	1.0	2.0	2.5
Mismatch losses	0.3	0.8	0.5	0.3	6.5
Losses in inverter (conversion of DC to AC)	2.0	4.1	3.6	2.2	3.6
Transformer losses	0.9	0.0	1.0	0.9	1.0
AC cabling losses	0.5	0.2	0.4	0.5	2.0
Availability (Downtime losses)	0.0	3.0	2.0	0.5	2.0
Total	**8.9**	**12.9**	**11.9**	**9.5**	**21.5**

4 ENHANCEMENTS OF VERSION GSA 2.0 COMPARED TO GSA 1.0

In this chapter we present comparison of the enhanced version of the Global Solar Atlas version 2.0 with the previous version 1.0, which has been published in 2017. In the present version, apart from longer period of data included in the database, we bring more user-friendly features in online application, new sections functionalities (floating hydro etc.) and more country maps, language versions of maps, higher resolution.

The major highlights of the upgraded version GSA 2.0 are:

- **Data analysis beyond annual aggregated values.** A more detailed analysis of the energy variability is possible in the new version. Besides the annual averages, the user of Global Solar Atlas can now see photovoltaic (PV) power generation and Direct Normal Irradiation data as monthly summaries, and also as 12 x 24 average hourly profiles. At the regional level, solar potential statistics are now available together with the country maps and GIS data.
- **More accurate calculations with updated periods of data.** The GSA uses more accurate algorithms, higher resolution inputs and updated periods for calculating the averages (it includes the historical period up to the year 2018). We have validated the solar radiation data models again with more weather stations (now more than 220 public reference locations, worldwide). Ground reference data from new sites coming from ESMAP and IFC campaigns have been added too.
- **Other solar technologies besides ground and roof mounted PV included.** Besides photovoltaics, some users may be interested in evaluating other solar technologies. For instance, a first approximation to solar thermal electricity potential is now possible by looking at the values of direct normal irradiation (DNI). On the other hand, we included also more information about hydro-power generation sites for those looking at the potential of floating PV systems.
- **Better management of personal sites and results.** With the new version of the GSA, saving the information of projects is easier by using personal bookmarks. Download the results in xls besides pdf is possible in the newer version and makes easier to run further analyses with the data.

Main features and improvements are summarised in Table 4.1.

Table 4.1: Comparison of versions GSA 2.0 and GSA 1.0

	GSA version 2.0	GSA version 1.0
Basic information		
Launch date	October 2019	January 2017
Database version	2.1	1.0
Parameters	GHI, DIF, DNI, GTI, PVOUT,	GHI, DIF, DNI, GTI, PVOUT,
	TEMP, ELE, OPTA	TEMP, ELE, OPTA
1. Online application GSA		
Spatial resolution GHI, DIF, DNI, GTI	250 x 250 meters	1 x 1 km
Digital elevation model resolution	250 x 250 meters	1 x 1 km
Terrain horizon resolution	250 x 250 meters	1 x 1 km
Temporal coverage	1994/1999/2007 up to 12/2018	1994/1999/2007 up to 12/2015
Time step of average annual values	GHI, DIF, DNI, GTI, TEMP, ELE, OPTA	GHI, DIF, DNI, GTI TEMP, ELE, OPTA -
Time step of average hourly values (24 x 12 graphs)	PVOUT, DNI	NO
Integration of HELP feature	YES	-
Re-design for optimalization	YES	NO
Implemented project saving feature	YES	NO
Implemented regional solar assessment Implemented	YES	NO
floating-solar hydro-connected potential Deployment of	YES	NO
floating/hydro-connected query tab Deployment of	YES	NO
custom region query tab Customized map generation	YES	-
	GHI, DNI, PVOUT, TEMP	
2. Download section		
2.1 GIS data		
Parameters	GHI, DIF, DNI, GTI, PVOUT, OPTA	GHI, DIF, DNI, GTI, PVOUT, OPTA
Global and country GIS data time resolution	1994/1999/2007 up to 12/2018	1994/1999/2007 up to 12/2015
2.2 Maps		
Parameters	GHI, DNI, PVOUT	GHI, DNI, PVOUT
Number of countries	187	146
Language version	148 in English + 58 countries in second language	148 countries in English language
World and 6 regional poster maps time resolution	1994/1999/2007 up to 12/2018	1994/1999/2007 up to 12/2015
Country poster and mid-sized maps time resolution **2.3**	1994/1999/2007 up to 12/2018	1994/1999/2007 up to 12/2015
Statistics and other		
Solar potential country/regional GHI, DNI, PVOUT,	Average, Min, Max, Percentile 10 and 90	-
TEMP Average hourly profiles (24 x 12 graphs) of	YES	-
PVOUT, DNI Customized regional statitstics	GHI, DNI, PVOUT, TEMP	-
Global solar potential country comparison	YES	-
LCOE calculation per copuntry	YES	-

5 GSA 2.0 SOFTWARE ARCHITECTURE

Online application is built on the Angular framework, providing interactive map, responsive design and reactive state management. The infrastructure as code is used to describe and manage the cloud infrastructure for the serverless application backend, which is deployed to Amazon Web Services in an automated flow. The serverless API backed by Lambda functions is robust and scalable with virtually no limits.

Cloud infrastructure components:

- AWS API Gateway: Cloud API management
- AWS DynamoDB: Cloud document database
- AWS Lambda: Serverless compute service and runtime
- AWS CloudFront: Global Content Delivery Network service

- AWS CloudFormation: Cloud infrastructure management
- AWS CDK: Cloud Infrastructure as code
- AWS S3: Cloud storage service

External dependencies:

- MapBox: Customized basemap tiles and geocoding provider
- Bing: Satellite map provider
- TimezoneDB: Service to query timezone for latitude/longitude position
- ButterCMS: Headless CMS system for serving static content
- energydata.info: Source for hydro-connected solar PV potential sites and solar measurement sites
- Google Analytics: Tracking page views, events and timings in interactive
- Google reCaptcha: application Protecting contact form against bots
- Mandrill: Email sending service

PDF reports are generated using headless browser, displaying and printing the print-version of the online page.

Backend technologies: AWS SDK, Node.js, Puppeteer, Chromium, Nunjucks, excel4node, moment

Client technologies: Angular, Material Design, Bootstrap, NGXS, RxJS, Flexbox, D3, Highcharts, Leaflet

Tools: AWS CDK, Webpack, Serverless, TypeScript

Programming language is TypeScript, with Node.js runtime on the backend side and compiled to JavaScript on the client side.

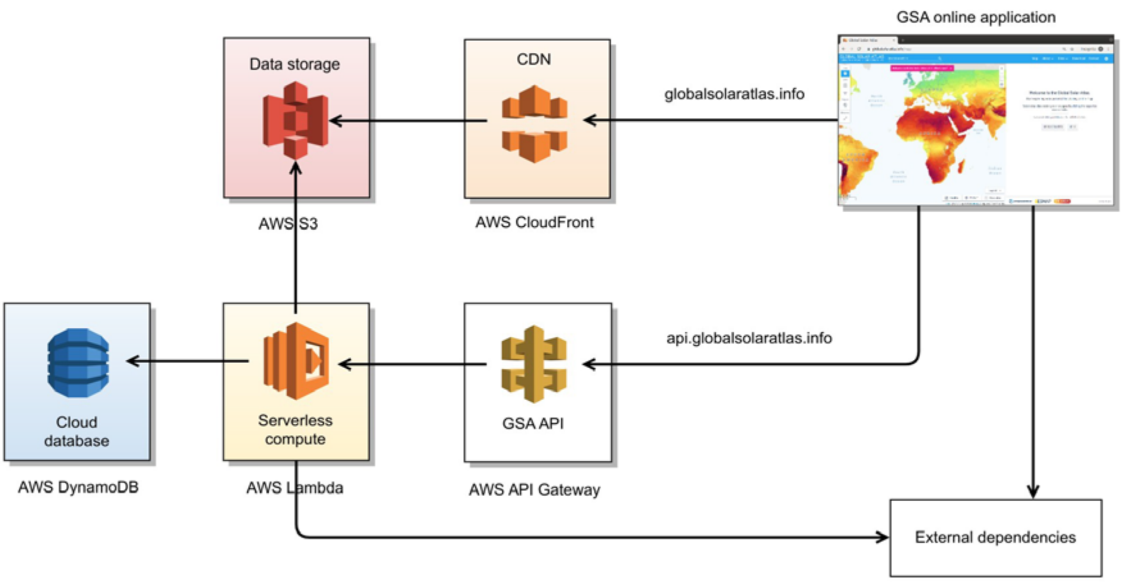

Figure 5.1: GSA 2.0 simplified software architecture

6 LIST OF FIGURES

7 LIST OF TABLES

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9 BACKGROUND ON SOLARGIS

About Solargis

Solargis is a technology company offering energy-related meteorological data, software and consultancy services to solar energy. We support industry in the site qualification, planning, financing and operation of solar energy systems for more than 19 years. We develop and operate a new generation high-resolution global database and applications integrated within Solargis® information system. Accurate, standardised and validated data help to reduce the weather-related risks and costs in system planning, performance assessment, forecasting and management of distributed solar power.

Legal information

Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainty of measurements and calculations, the company Solargis cannot take guarantee of the accuracy of estimates. The company Solargis has done maximum possible for the assessment of climate conditions based on the best available data, software and knowledge. Solargis® is the registered trademark of Solargis s.r.o. Other brand names and trademarks that may appear in this study are the ownership of their respective owners.

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Solargis is ISO 9001:2015 certified company for quality management.

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