



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792059



June. 21-22-23

GoPV Summer School

co-organized with



GLOBAL OPTIMIZATION OF
INTEGRATED **PHOTOVOLTAIC** SYSTEM
FOR LOW ELECTRICITY COST





Summer School Agenda



June 21st 2022 – Catania Univ.

9:00 – 9:30 → Presentation of program

9:30 – 11:00 → Global Energy Context / Solar Resource

AM Break

11:30 – 12:30 → PV modules (part. 1)

Lunch Break

14:00 – 15:00 → PV modules (part. 2)

PM Break

15:30 – 17:30 → PV systems components / PV inverters



Summer School Agenda



June 22nd 2022 – Catania Univ.

9:00 – 11:00 → Electrical characteristics of modules / Case study

AM Break

11:30 – 12:30 → Structures and Trackers (part. 1)

Lunch Break

14:00 – 15:00 → Structures and Trackers (part. 2)

PM Break

15:30 – 17:30 → Yield simulation and PV performance





Summer School Agenda



June 23rd – Passo Martino (ENEL)

9:00 – 10:00 → LCOE and economic analysis

10:00 – 11:00 → LCA and environmental analysis (remotely)

AM Break —————

11:30 – 13:30 → EGP visit at Passo Martino

Lunch Break —————

END of GoPV Summer School



GoPV project



Objectives

Targeting a **0.02 €/kWh LCOE** (50% reduction vs. present reference PV system)

- High energy efficiency = HJT + bifacial + trackers + string inverters
- Long lifetime = architecture and material innovation at component and system levels
- Low costs = CAPEX and OPEX reduction





GoPV project



Partners

Leading european industrial companies + internationally recognized R&D institutes





GoPV project



INES – French National Institute of Solar Energy



Research & innovation

INES is a world leader in research and development for advanced photovoltaic solar technologies, their integration into electrical systems and intelligent energy management.



Capacity Building

INES Formation & Evaluation's mission is to support territories and companies to strengthen their capacities in the field of solar energy.



Shine

A key player in the solar industry worldwide, INES represents the French solar industry in different regional, national, European and international organizations.





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June. 21st

Solar Resource & Site identification

(9:30-11:00)

co-organized with



GLOBAL OPTIMIZATION OF
INTEGRATED **PHOTOVOLTAIC** SYSTEM
FOR LOW ELECTRICITY COST





Solar Resource & Site potential



Antoine DIZIER

Solar PV Systems Engineer

antoine.dizier@ines-solaire.org

Agenda

1. **Global Energy Context**
2. Introduction to solar resource
3. Solar databases, uncertainties, TMY
4. Sun path, far and near shadings estimation



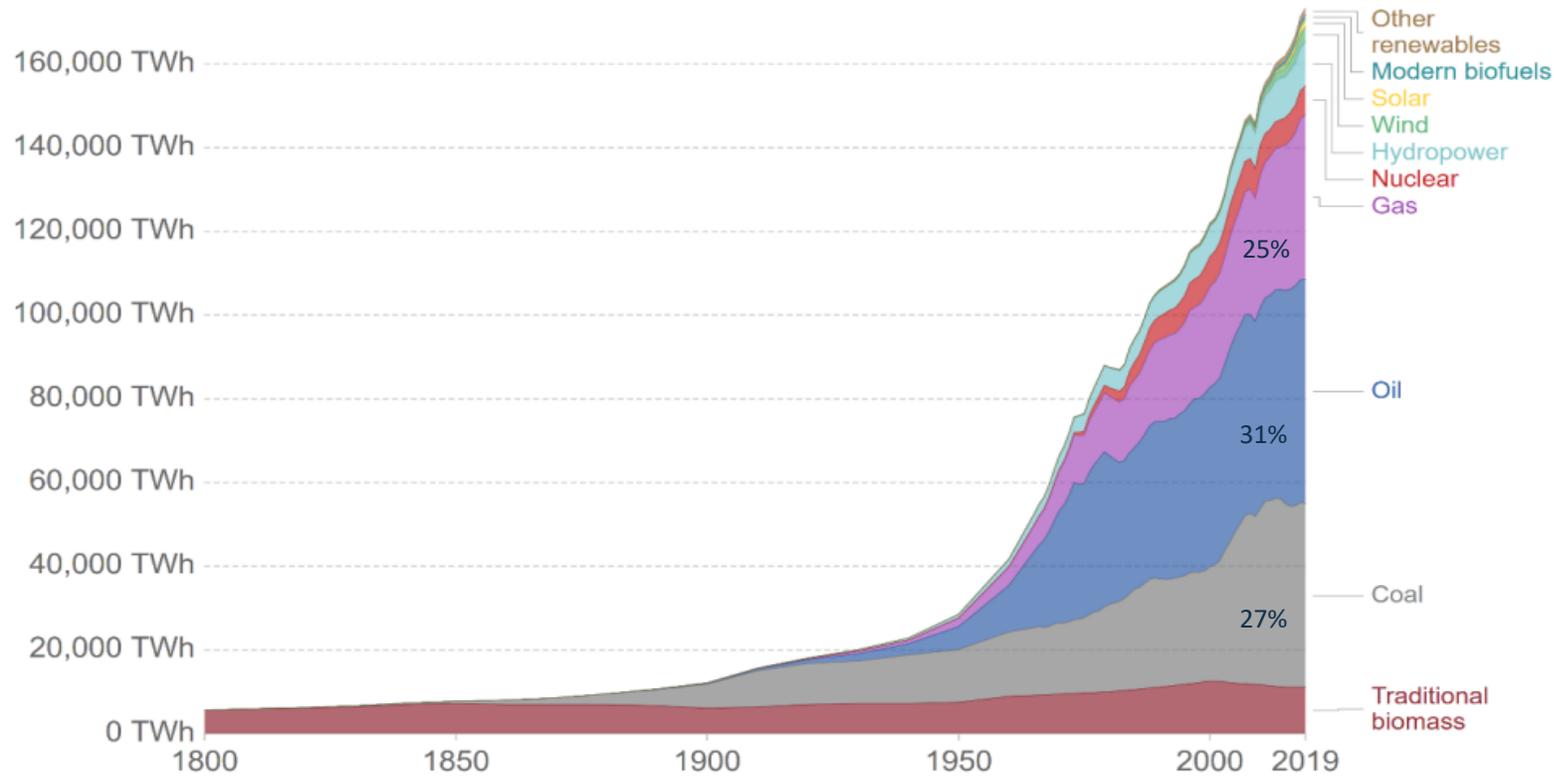


Global Energy Context

Partner logo

Global primary energy consumption by source

Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.



Part of **fossil fuels** in global primary energy source:

1970 = 94%
 2009 = 84%
2020 = 83%

Source: Vaclav Smil (2017) & BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY

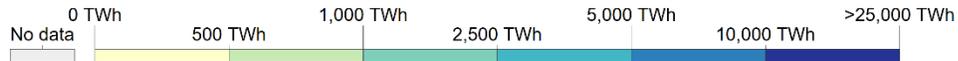
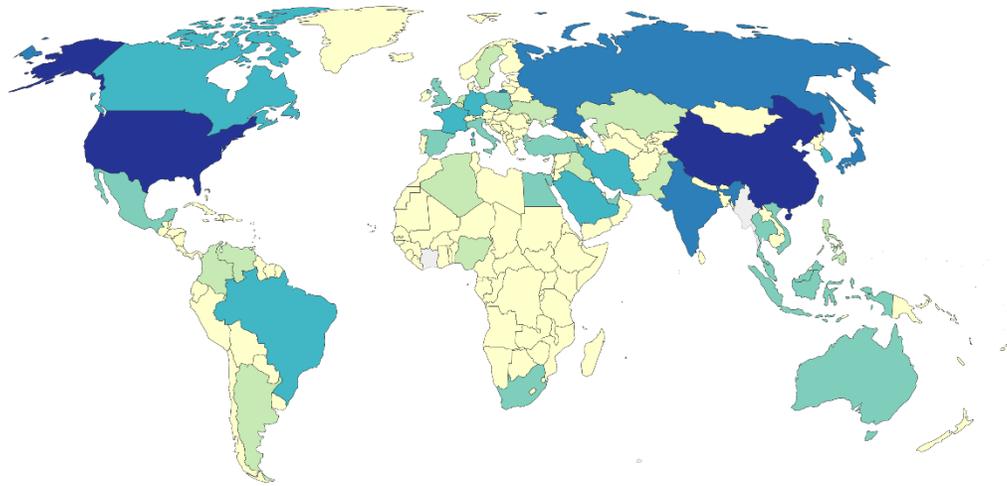


Global Energy Context

Partner logo

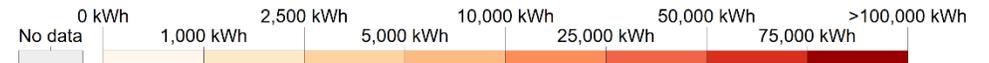
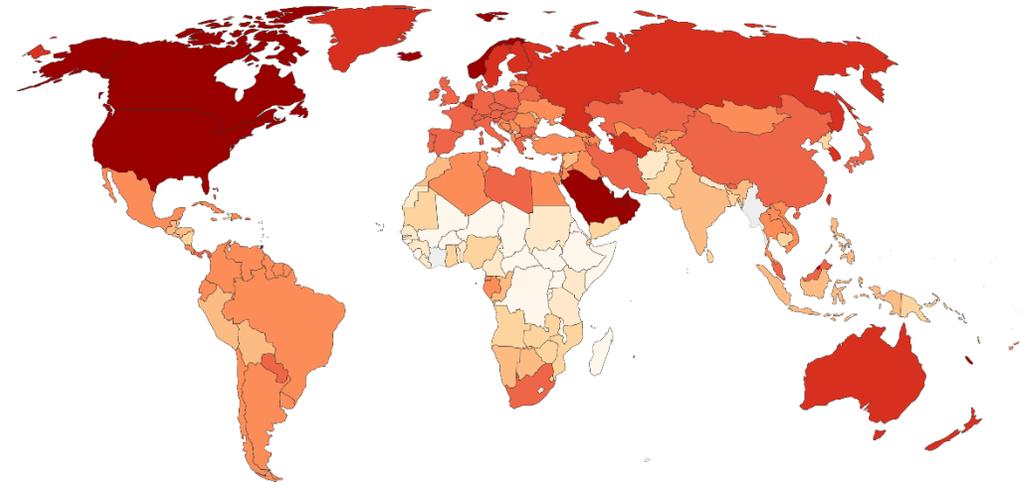
Primary energy consumption

Primary energy consumption is measured in terawatt-hours (TWh).



Source: BP Statistical Review of Global Energy
Note: Data includes only commercially-traded fuels (coal, oil, gas), nuclear and modern renewables. It does not include traditional biomass.
OurWorldInData.org/energy • CC BY

Energy use per person



Source: Our World in Data based on BP & Shift Data Portal
Note: Energy refers to primary energy – the energy input before the transformation to forms of energy for end-use (such as electricity or petrol for transport).
OurWorldInData.org/energy • CC BY

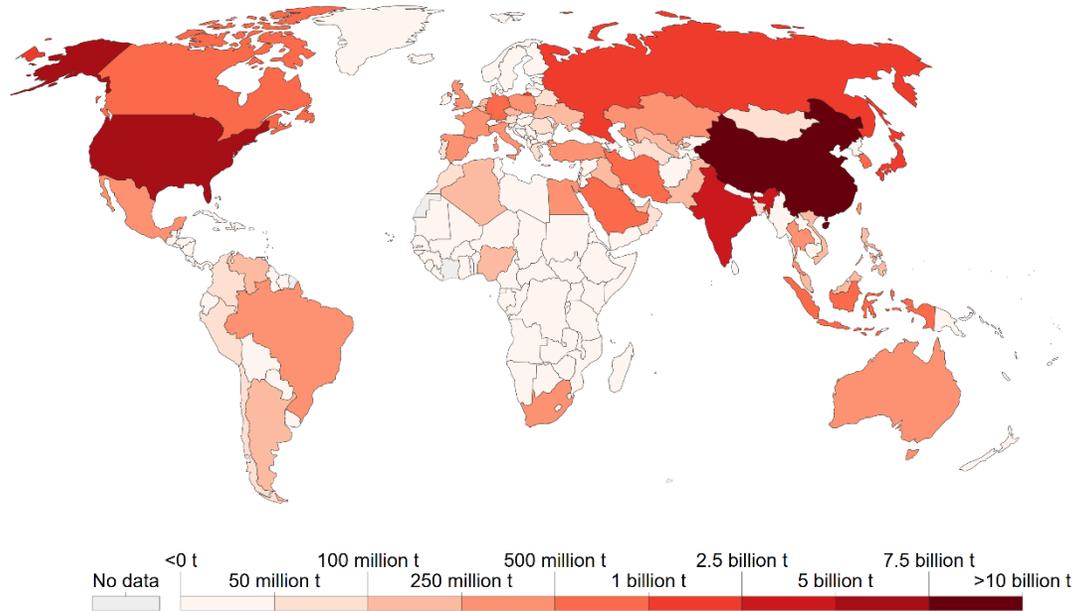


Global Energy Context

Partner logo

Annual CO₂ emissions

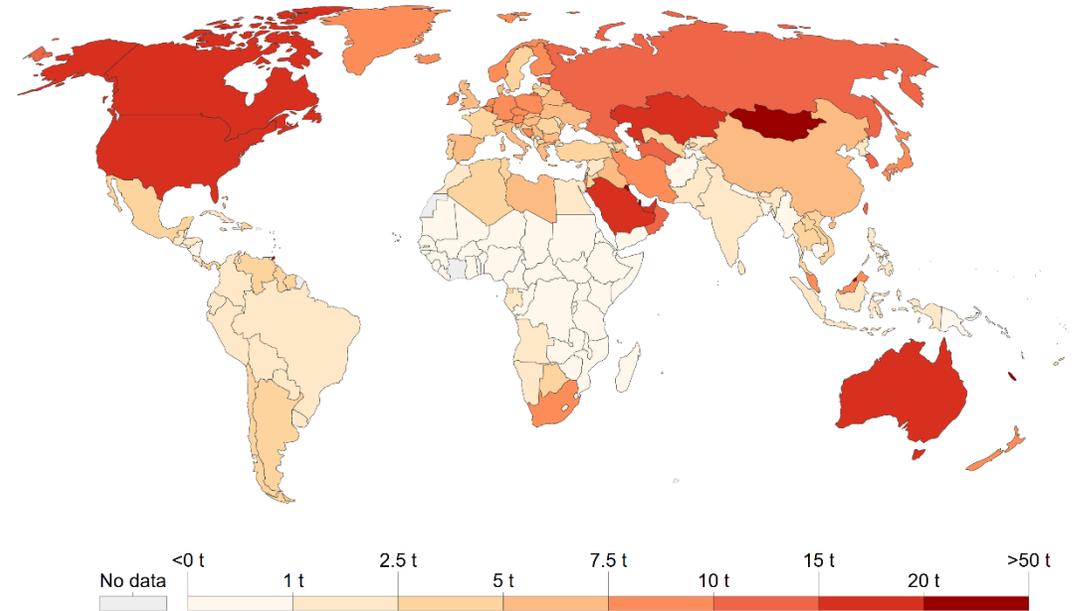
Carbon dioxide (CO₂) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.



Source: Global Carbon Project; Carbon Dioxide Information Analysis Centre (CDIAC)
Note: CO₂ emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

Per capita CO₂ emissions

Carbon dioxide (CO₂) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.



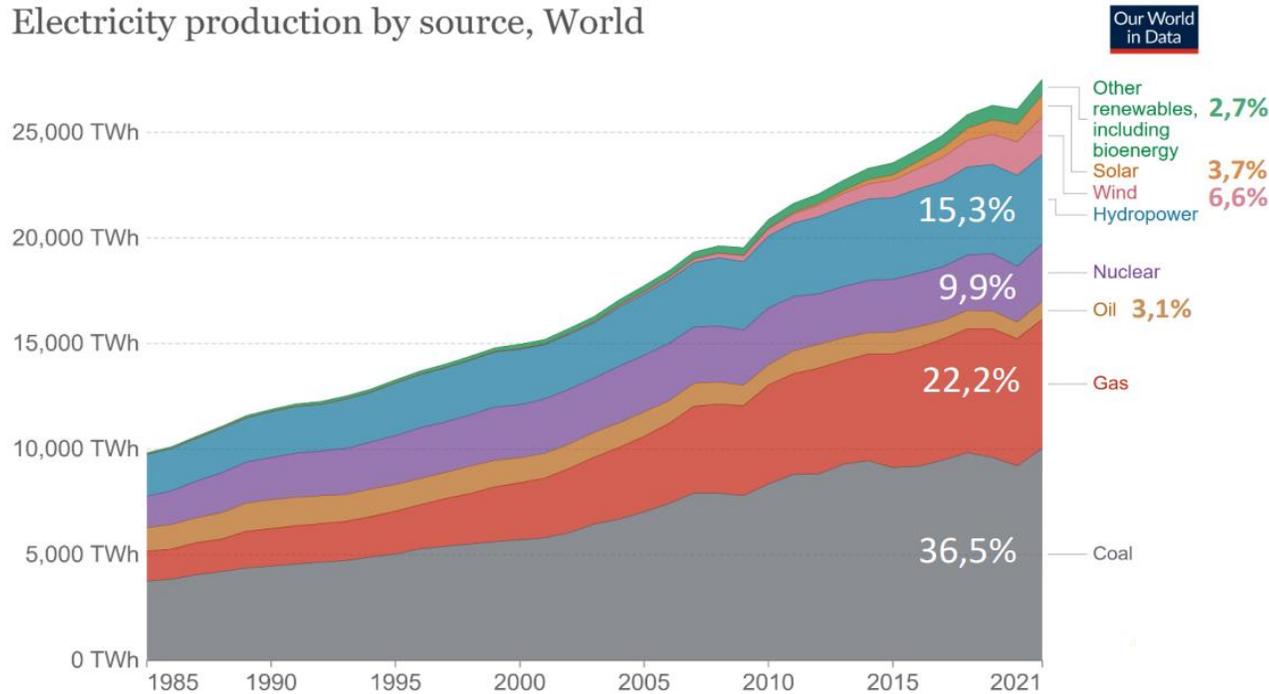
Source: Our World in Data based on the Global Carbon Project; Gapminder & UN
Note: CO₂ emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY



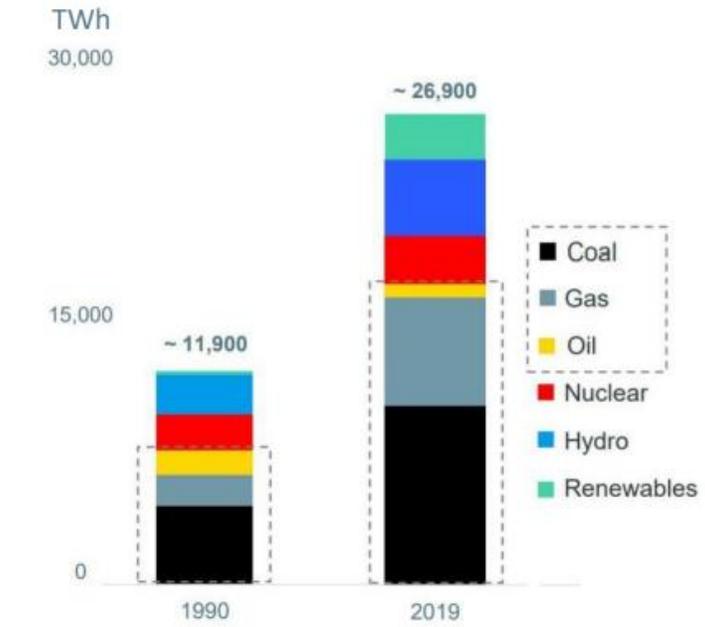
Global Energy Context

Partner logo

Electricity production by source, World



Source: Our World in Data based on BP Statistical Review of World Energy, Ember Global Electricity Review (2022) & Ember European Electricity Review (2022)
 Note: 'Other renewables' includes biomass and waste, geothermal, wave and tidal.
 OurWorldInData.org/energy • CC BY

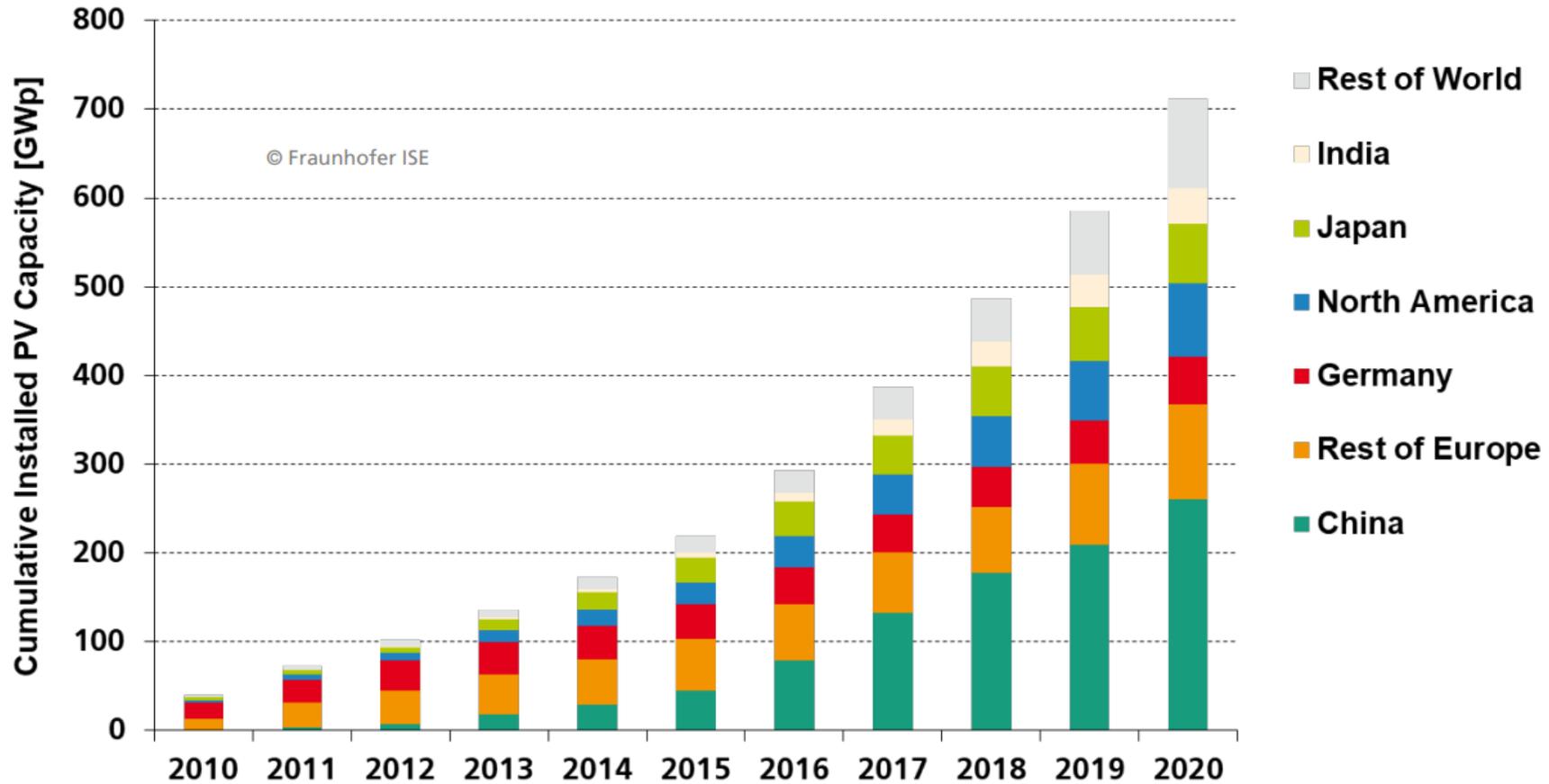


62% of global electricity production is based on non-renewables (fossil fuels + nuclear)
 + 28% of global electricity is now based of renewables (only 19% in 2010)



Global PV Market

Partner logo



+175 GWp
in 2021

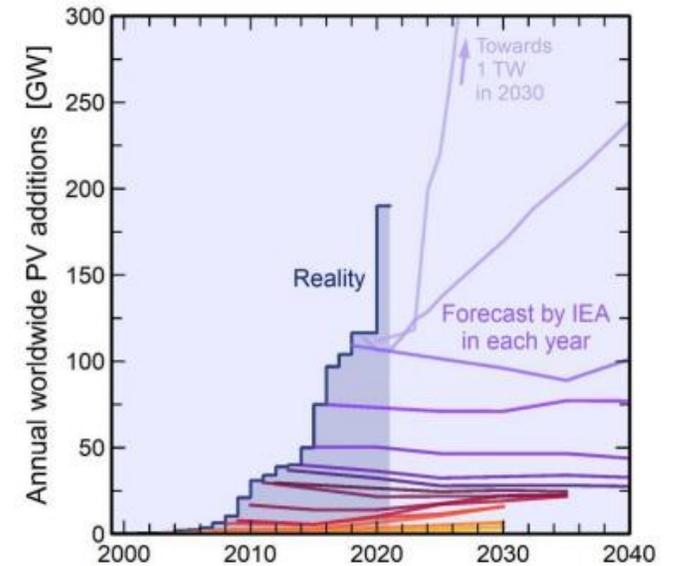
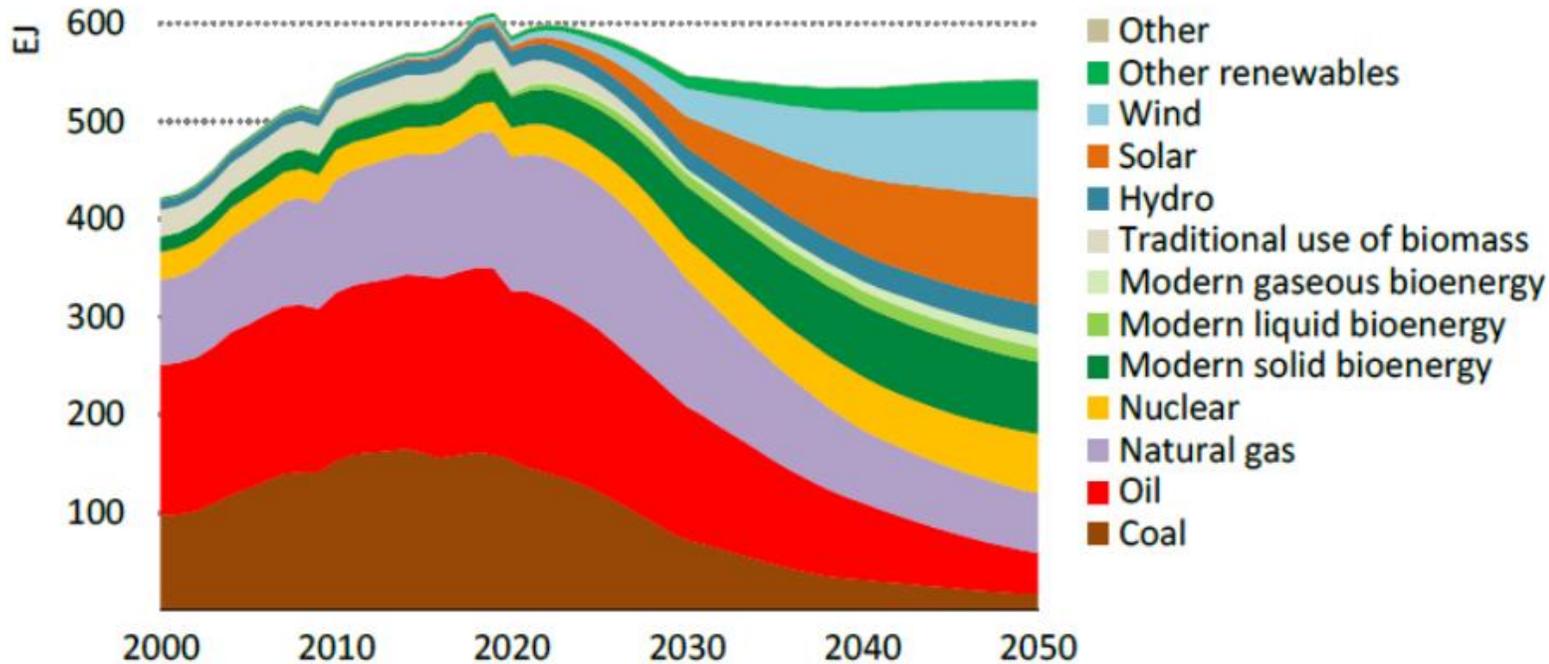
Today
> 1000 GWp installed



Global PV Market

Partner logo

IEA Net Zero Roadmap (oct 2021)



IEA. All rights reserved.



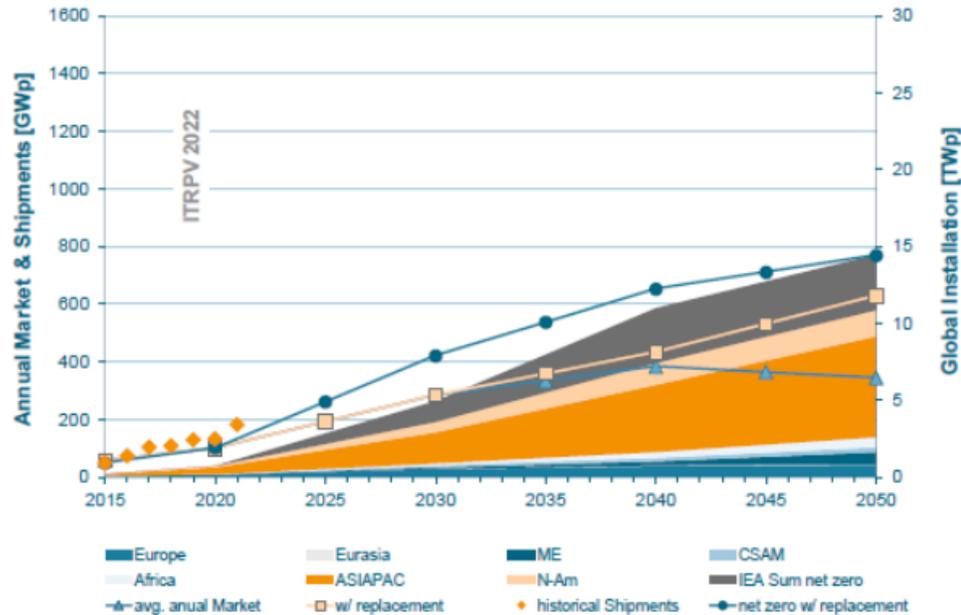
Global PV Market

Partner logo

Low scenario: IEA World Energy outlook 2021

Global PV Installation and corresponding PV market

IEA 2021: Sustainable Development Scenario + Net Zero Emission by 2050 Scenario



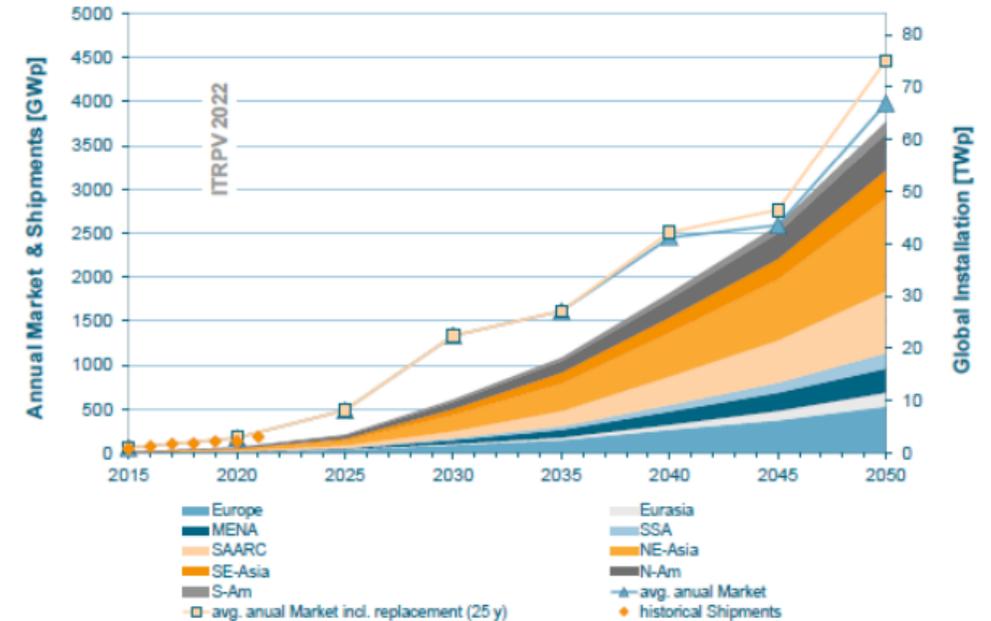
33% of global electricity in 2050

High scenario: Broad electrification

[Bogdanov et al., Energy 227 (2021)]

Global PV Installation and corresponding PV market

PV based energy mix scenario



69% of global primary energy demand in 2050



Solar Resource & Site potential



Antoine DIZIER

Solar PV Systems Engineer

antoine.dizier@ines-solaire.org

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- 2. Introduction to solar resource**
3. Solar databases, uncertainties, TMY
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Solar Resource

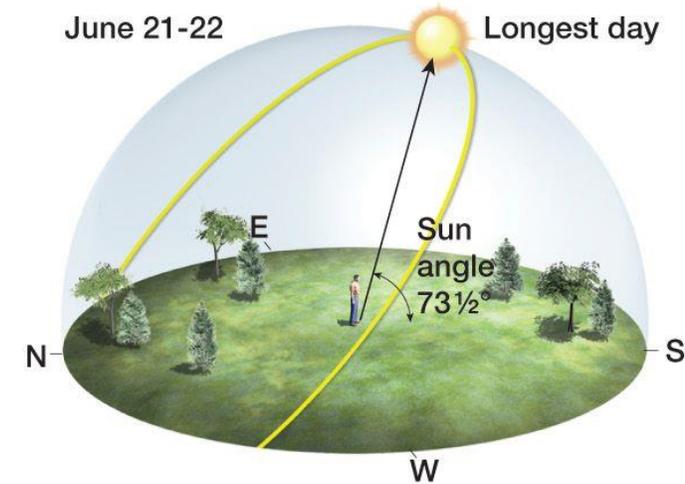
Partner logo

Solar energy depends on:

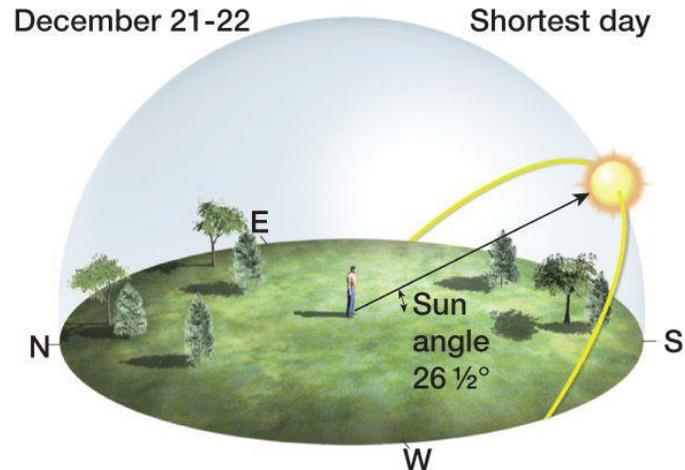
- Earth rotation (night & day)
- Seasons (declination of 23.45°)
- Latitude of site

... in brief... on sun path in the sky

1. **Sun Azimut** from -180° to $+180^\circ$
 - South = 0°
 - East = -90°
 - West = $+90^\circ$
2. **Sun Elevation** from 0 to $+90^\circ$



(a) Summer solstice at 40° latitude



(c) Winter solstice at 40° latitude





Solar Resource

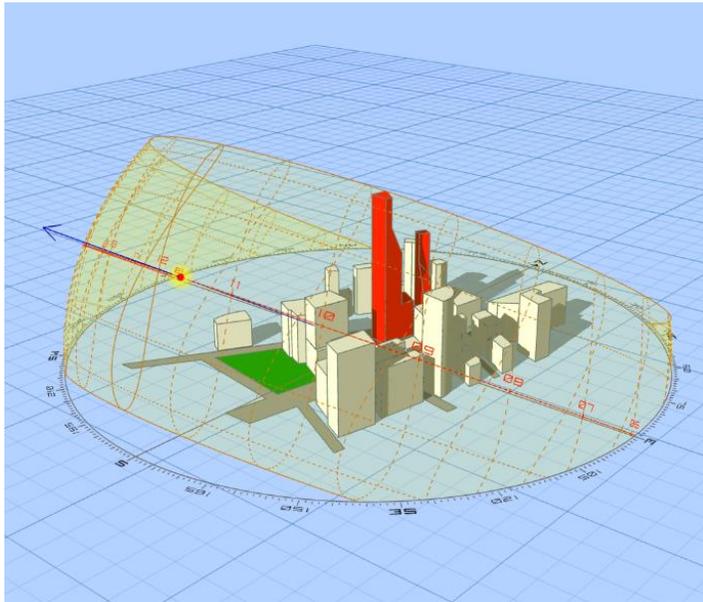
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1. **Sun Azimut** = angular position relative to South
2. **Sun Elevation** = angular position relative to the ground

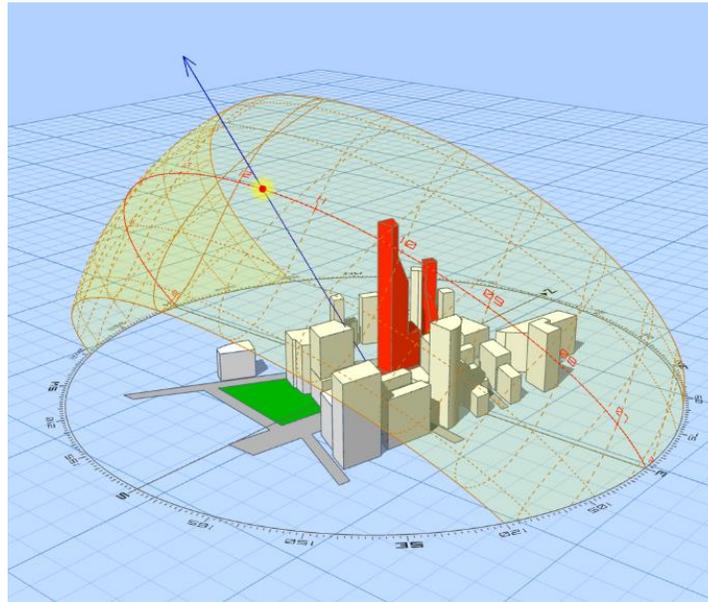
-180° to 180°

0° to 90°

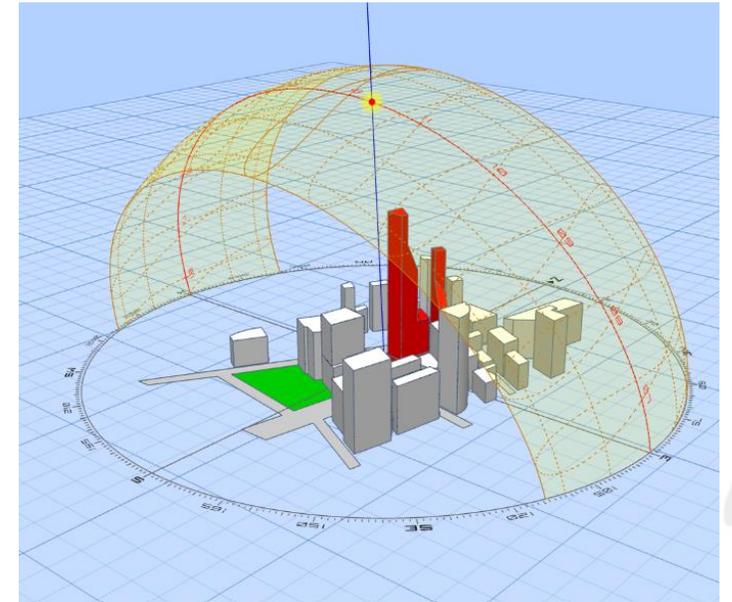
STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



DAKAR
Latitude = 14°



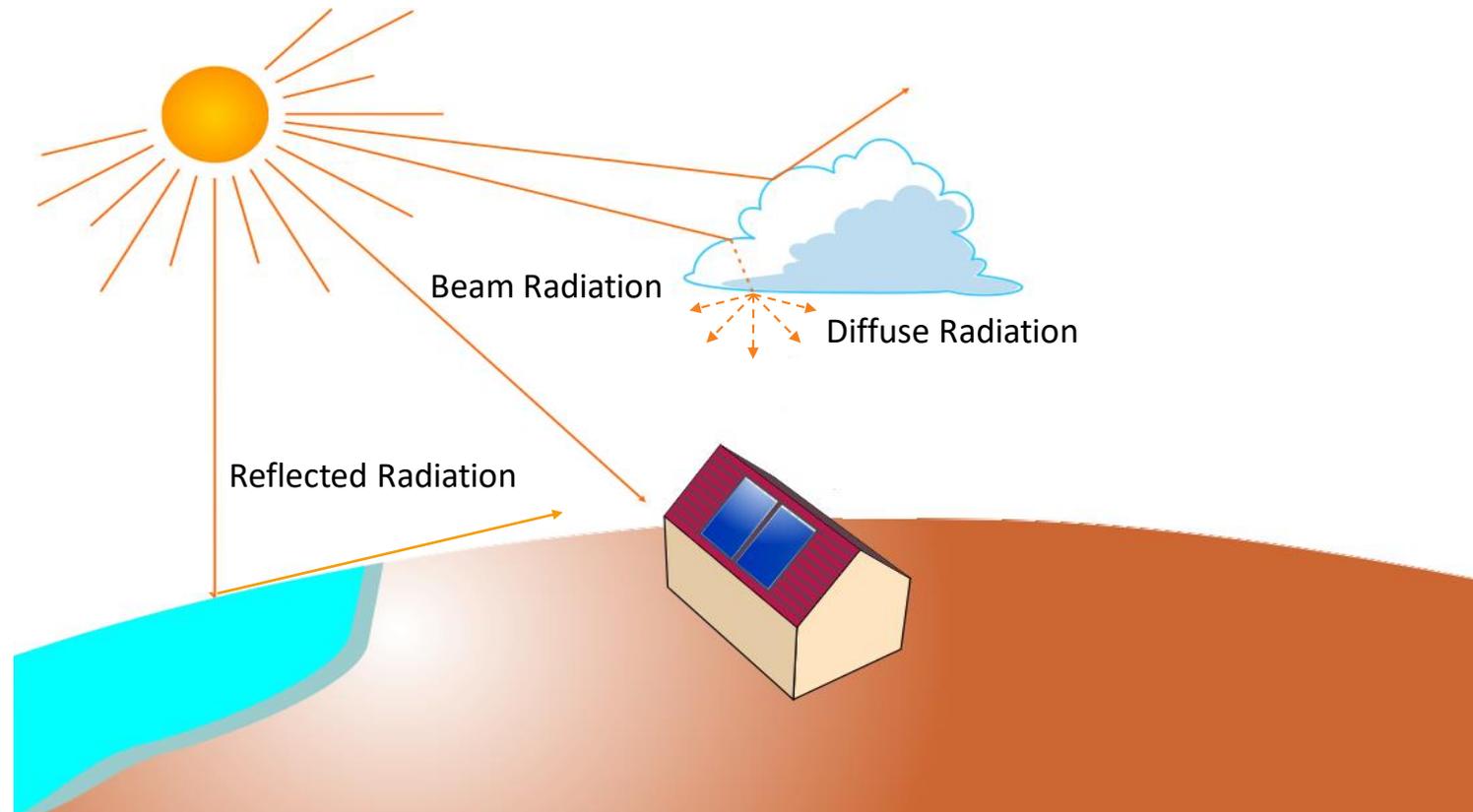
Source : <http://andrewmarsh.com/apps/staging/sunpath3d.html>



Solar Resource – Components

Partner logo

Global Irradiation = Beam Irradiation + Diffuse Irradiation + Reflected Irradiation





Solar Resource – Terminology

Partner logo

Irradiance = POWER Unit → W/m^2

Irradiation = ENERGY Unit → kWh/m^2

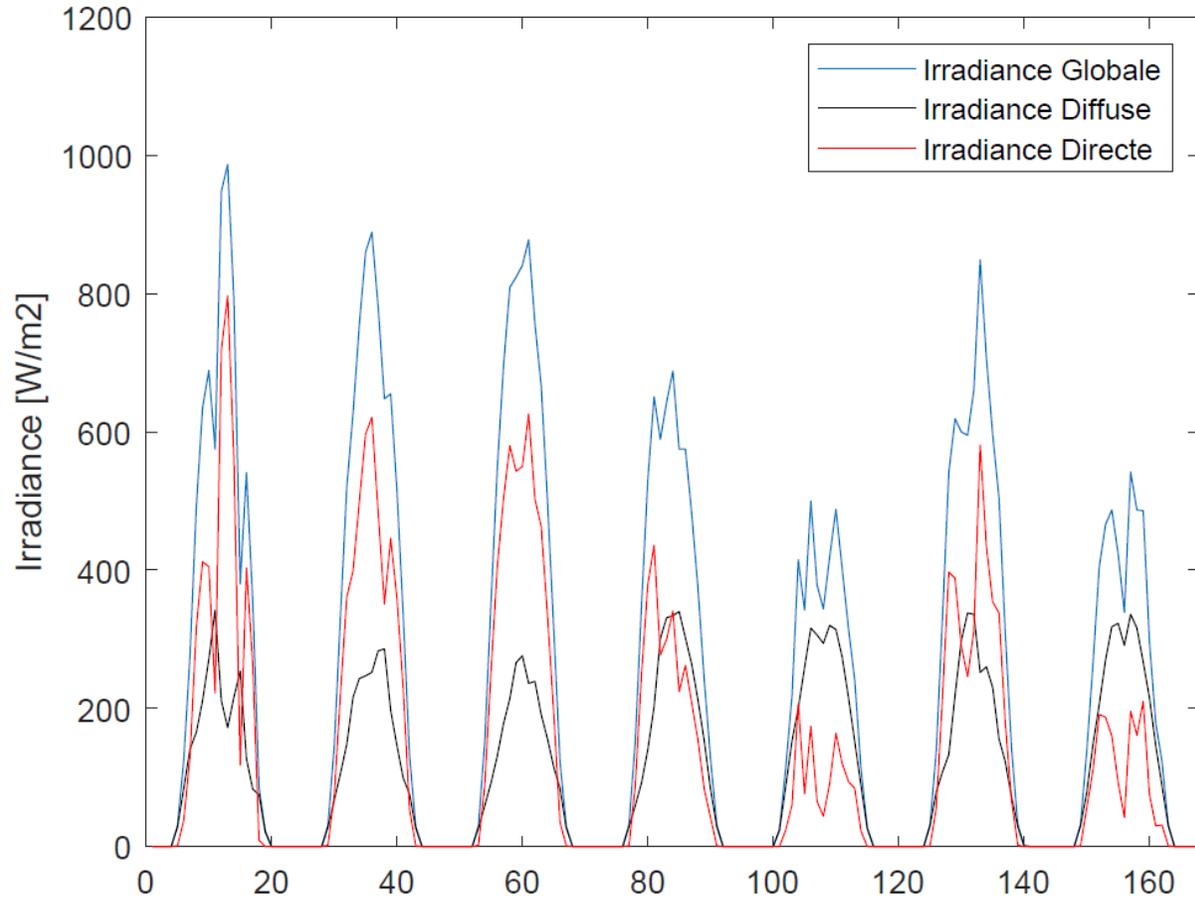
GHI	Global Horizontal Irradiance / Irradiation
GTI	Global Tilted (or in Plane) Irradiation / Irradiance
DHI	Diffuse Horizontal Irradiation / Irradiance
BNI	Beam Normal Irradiation / Irradiance



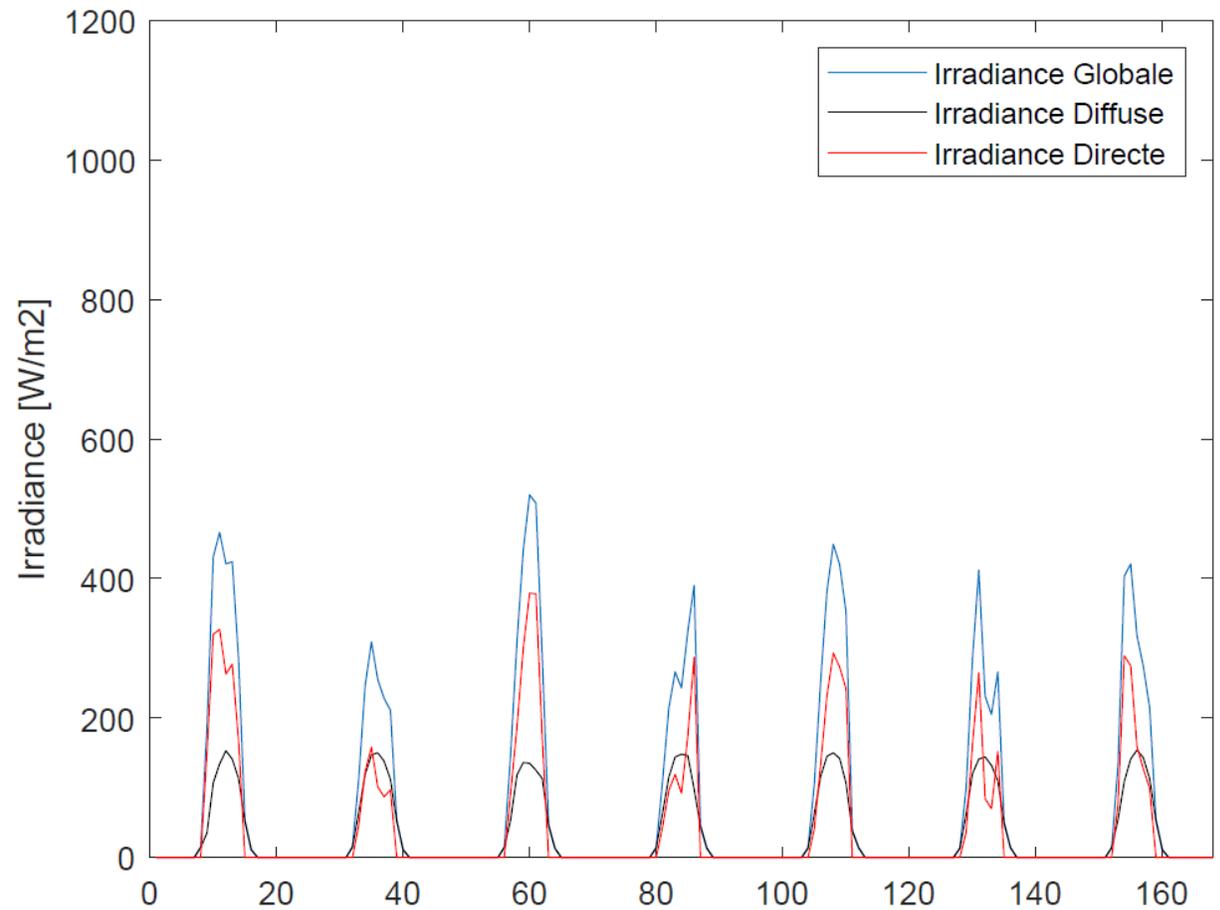
Solar Resource – Irradiance

Partner logo

Summer Week



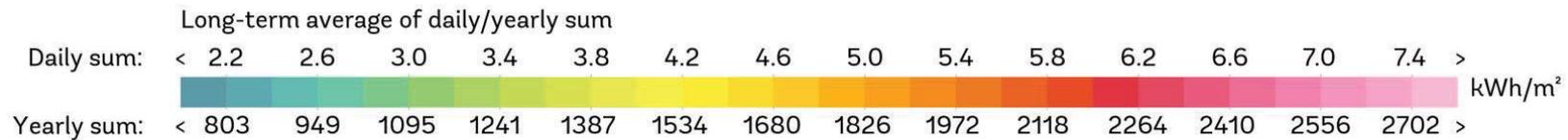
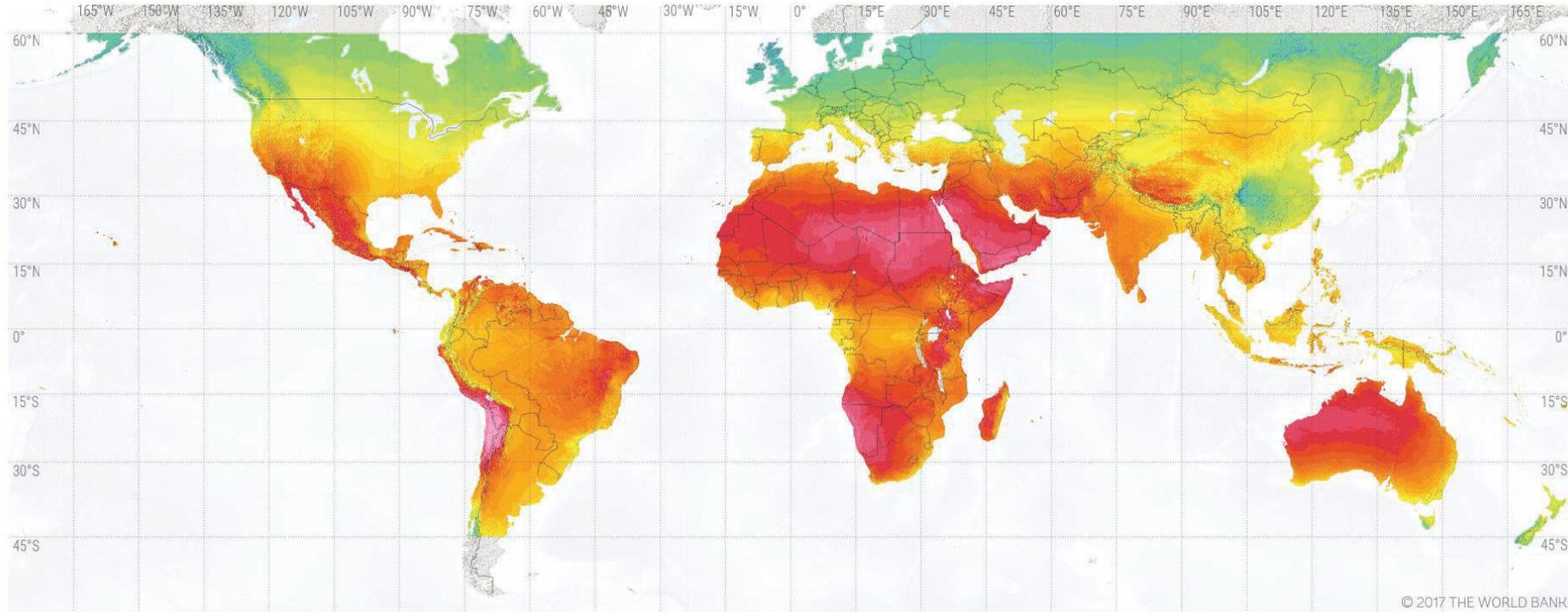
Winter Week





Solar Resource – Irradiation

Partner logo



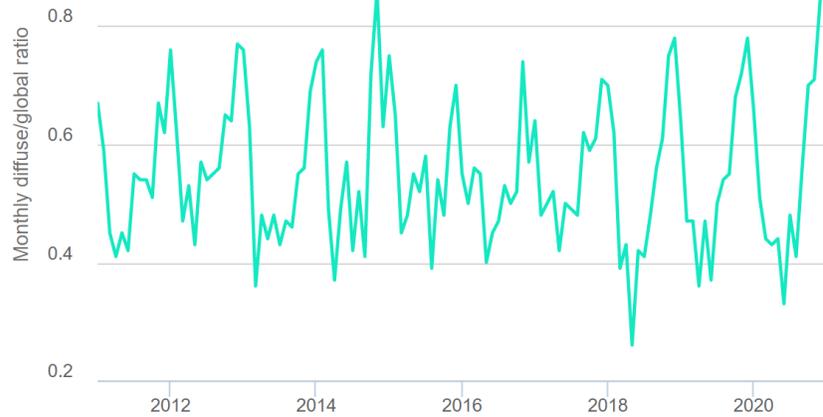
This map is published by the World Bank Group, funded by ESMAP, and prepared by Solargis. For more information and terms of use, please visit <http://globalsolaratlas.info>.



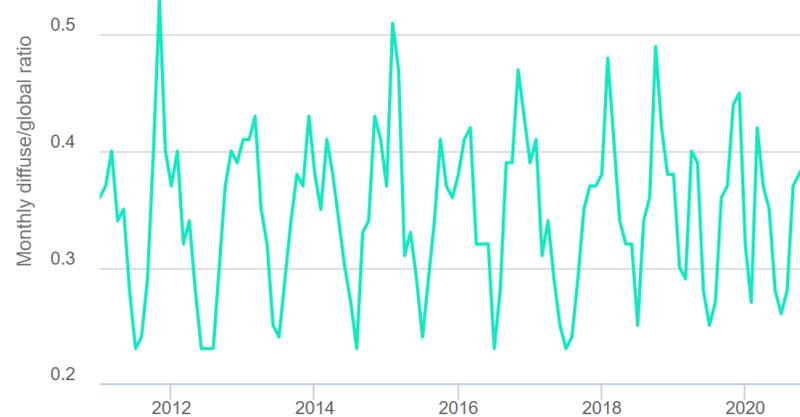
Diffuse / Global Ratio

What do you think?

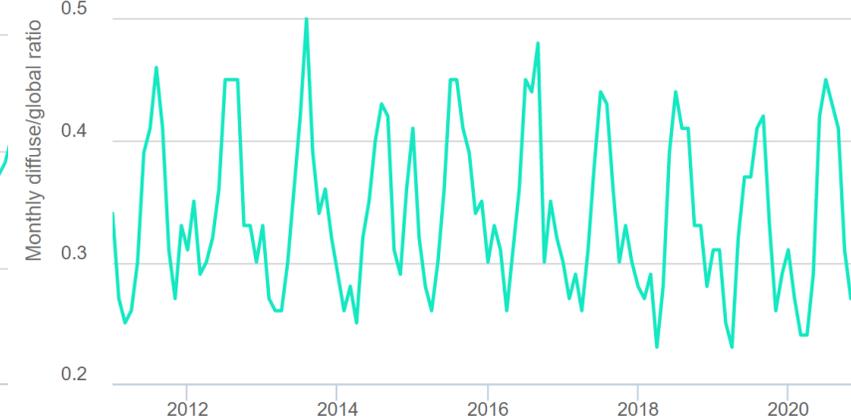
STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



DAKAR
Latitude = 14°





Solar Resource & Site potential



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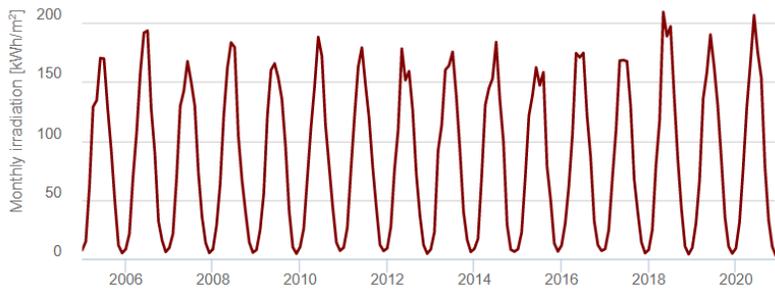
Solar Resource – Variability

Partner logo

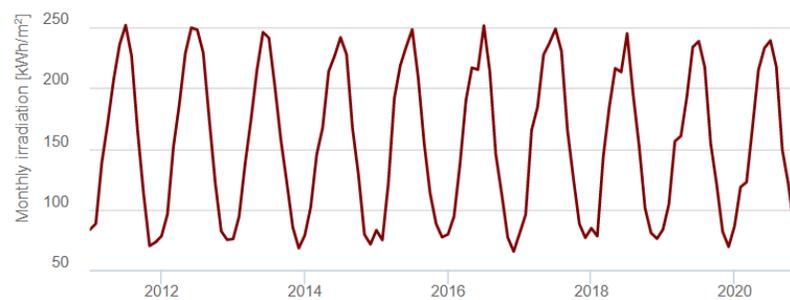
Year-to-year variability in terms of GHI

What do you think?

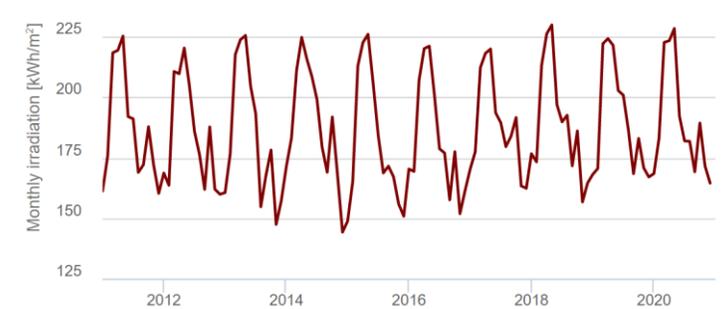
STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



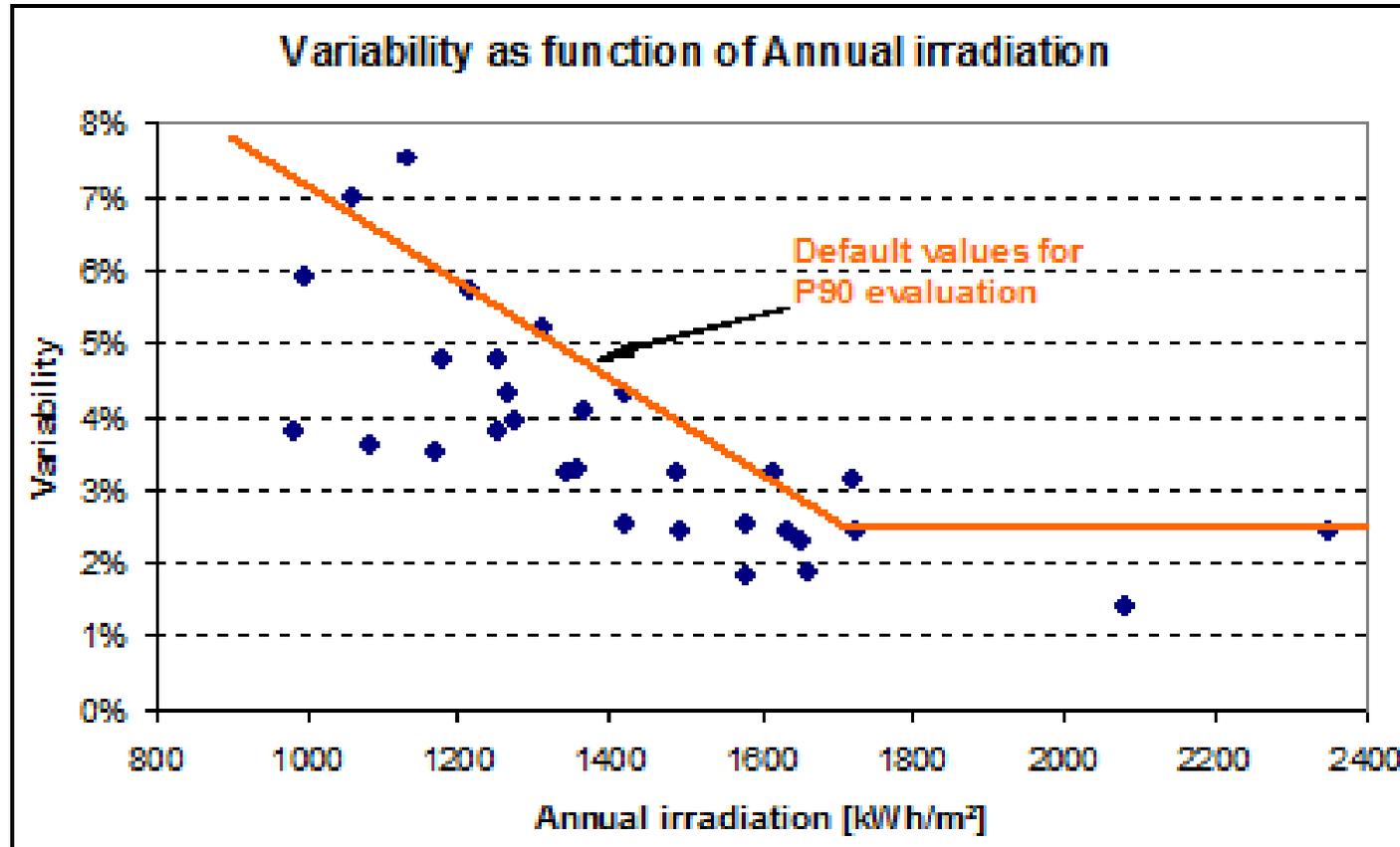
DAKAR
Latitude = 14°





Solar Resource – Variability

Partner logo



P. Ineichen – *Global irradiation: average and typical year, and year-to-year variability* (2011)



Solar Resource – Measurement

Partner logo

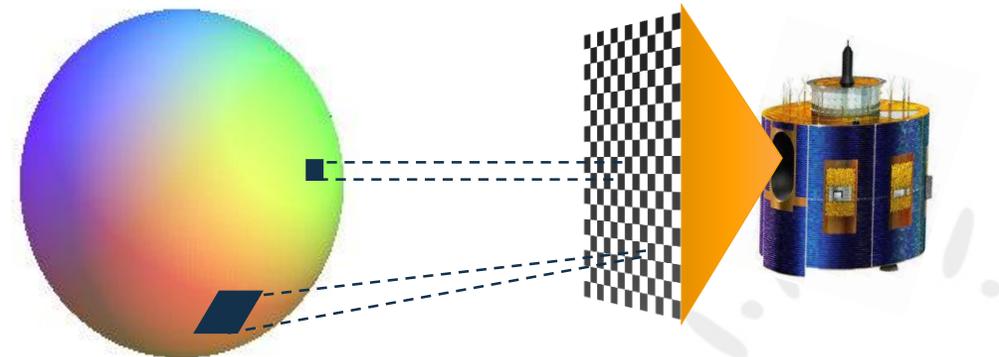
On-site measurement

- + High quality and site-specific data
- + Very high precision / Low uncertainties
- Long-term measurement is needed
- Very good calibration is needed / Lack of data



Satellite measurement

- + Global coverage (with $\approx 3-5$ km for one site)
- + Long-term series available
- Higher uncertainties due to calculations / aggregation



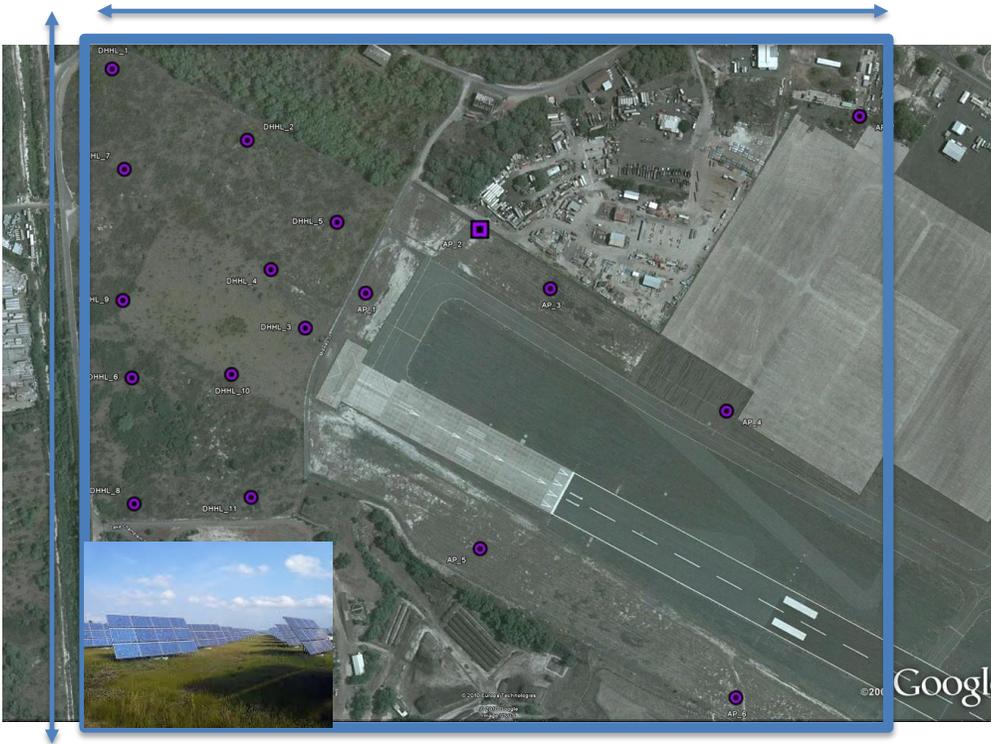
Resources → PVGIS / SoDa / SolarGIS / Meteonorm / NASA



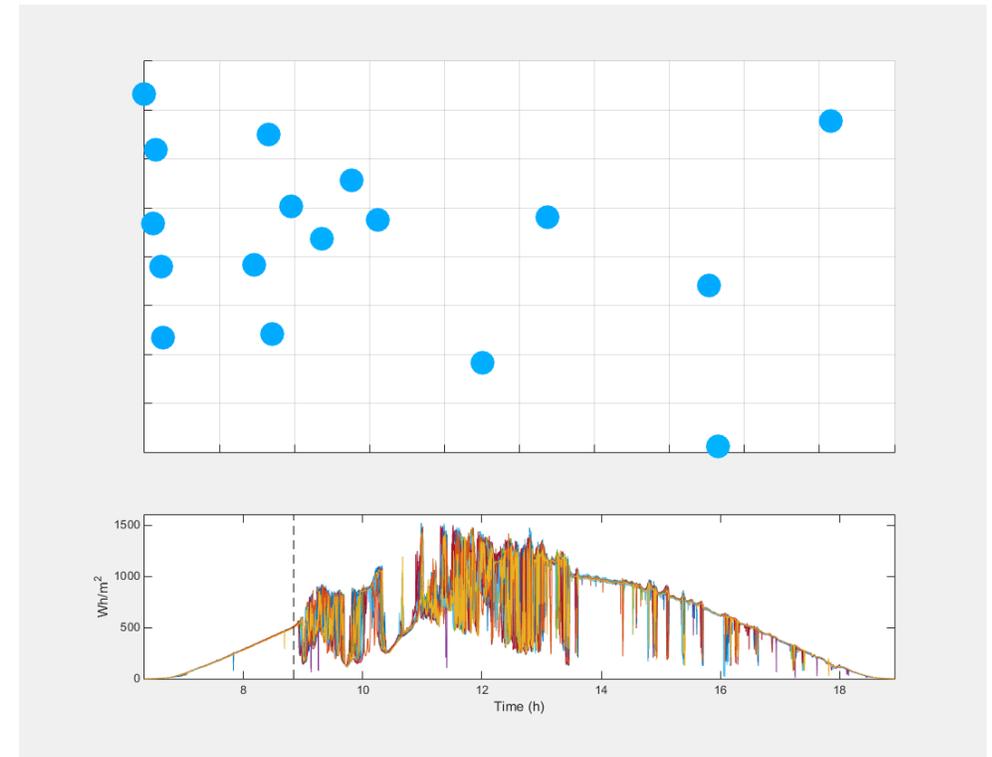
Solar Resource – On-site

Partner logo

1 km



● Pyranometric sensors



NREL Solar Measurement grid at Oahu : 1-s solar measurements from 17 photodiode pyranometers (Data available at: www.nrel.gov/midc/oahu_archive)

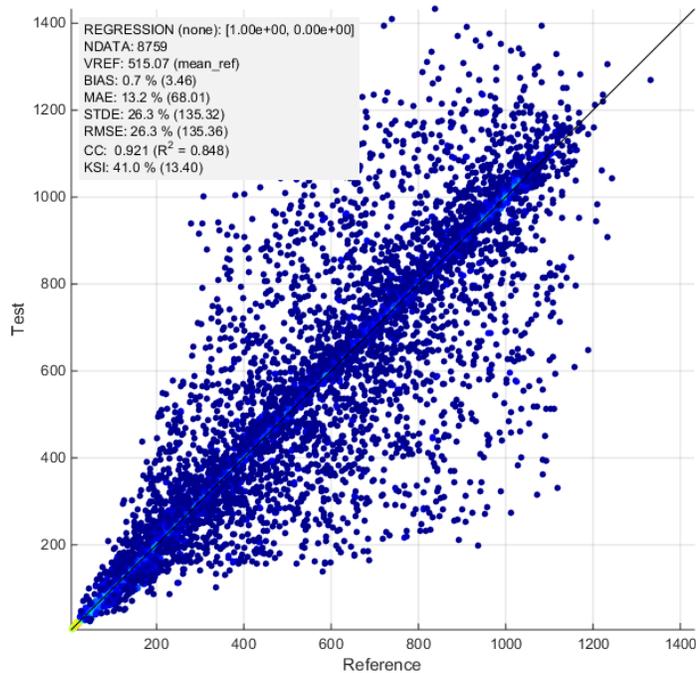


Solar Resource – On-site

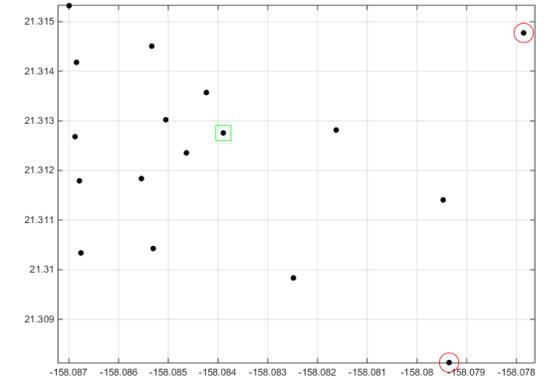
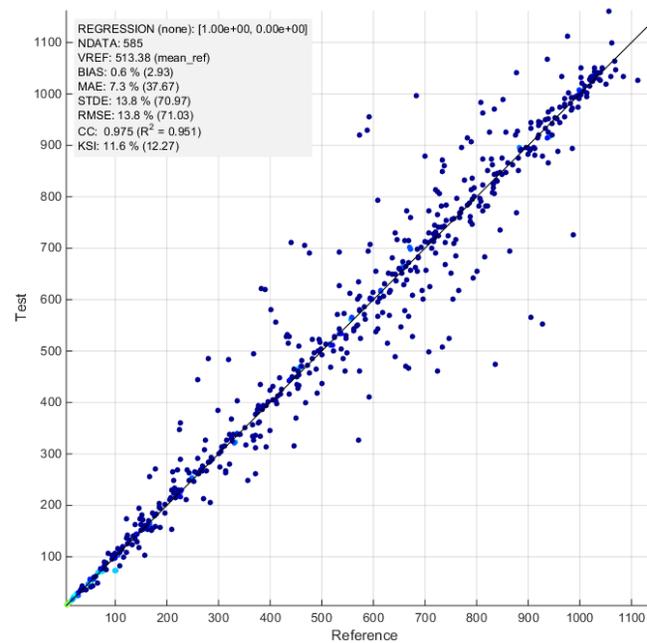
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Comparison of GHI over several days with regards to a reference pyranometer

Comparison 1 min



Comparison 15 min





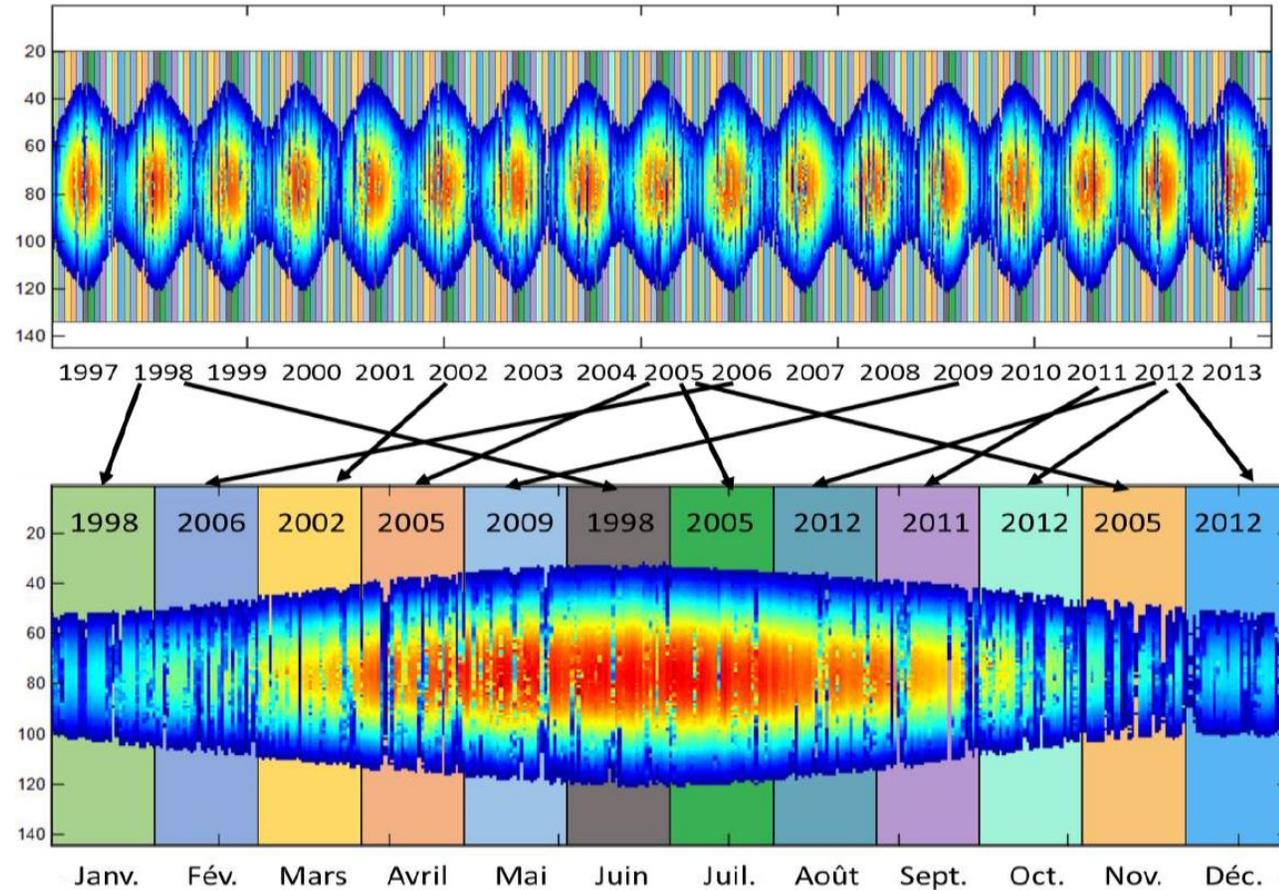
Solar Resource – TMY

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Long-term time series
of 17 years



Monthly selection with real data
with regards to statistical analysis

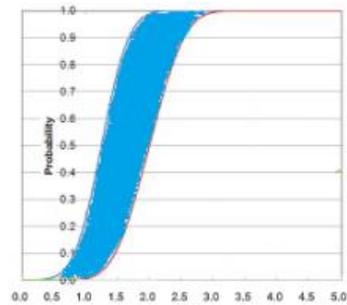




Solar Resource – TMY

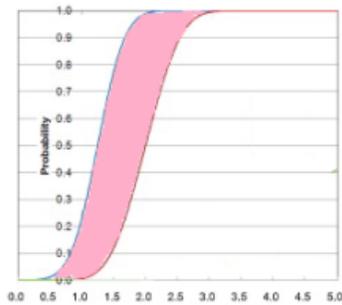
Partner logo

Comparison of 2 cumulative distribution functions for different meteo variables for each month:



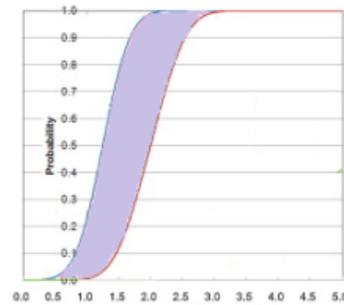
$\delta(\text{GHI})$

Global Horizontal Irradiance



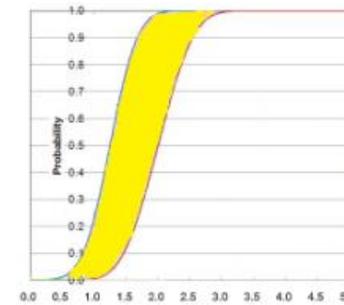
$\delta(\text{BNI})$

Beam Normal Irradiance



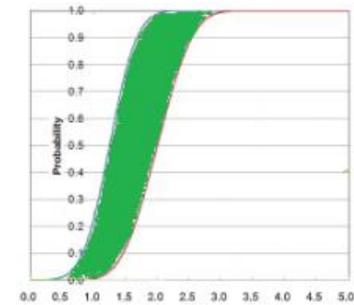
$\delta(\text{T2})$

Air Temperature



$\delta(\text{WS})$

Wind speed



$\delta(\text{RH})$

Relative Humidity

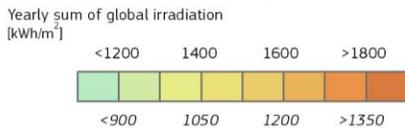
Final TMY is built with « best month » considering weighted variable selection (depending of TMY methods)

$$\text{Example} \rightarrow \min \{ 10 \delta(\text{GHI}) + 1 \delta(\text{BNI}) + 2 \delta(\text{T2}) + 1 \delta(\text{WS}) + 1 \delta(\text{RH}) \}$$



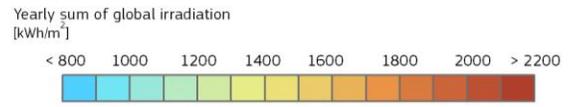
Solar Resource – Maps

Partner logo



GHI

Projection: Lambert Azimuthal Equal Area, WGS84, lat 52° lon 10°
 Source of ancillary data: CORINE Land Cover, DTM SRTM 30, GISC0 database, Geonames, Natural Earth



GTI

Projection: Lambert Azimuthal Equal Area, WGS84, lat 52° lon 10°
 Source of ancillary data: CORINE Land Cover, DTM SRTM 30, GISC0 database, Geonames, Natural Earth



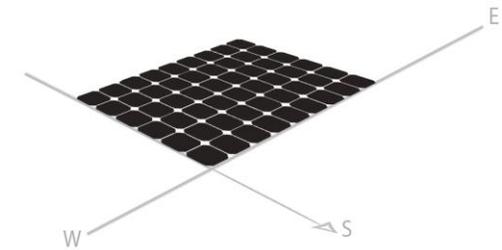
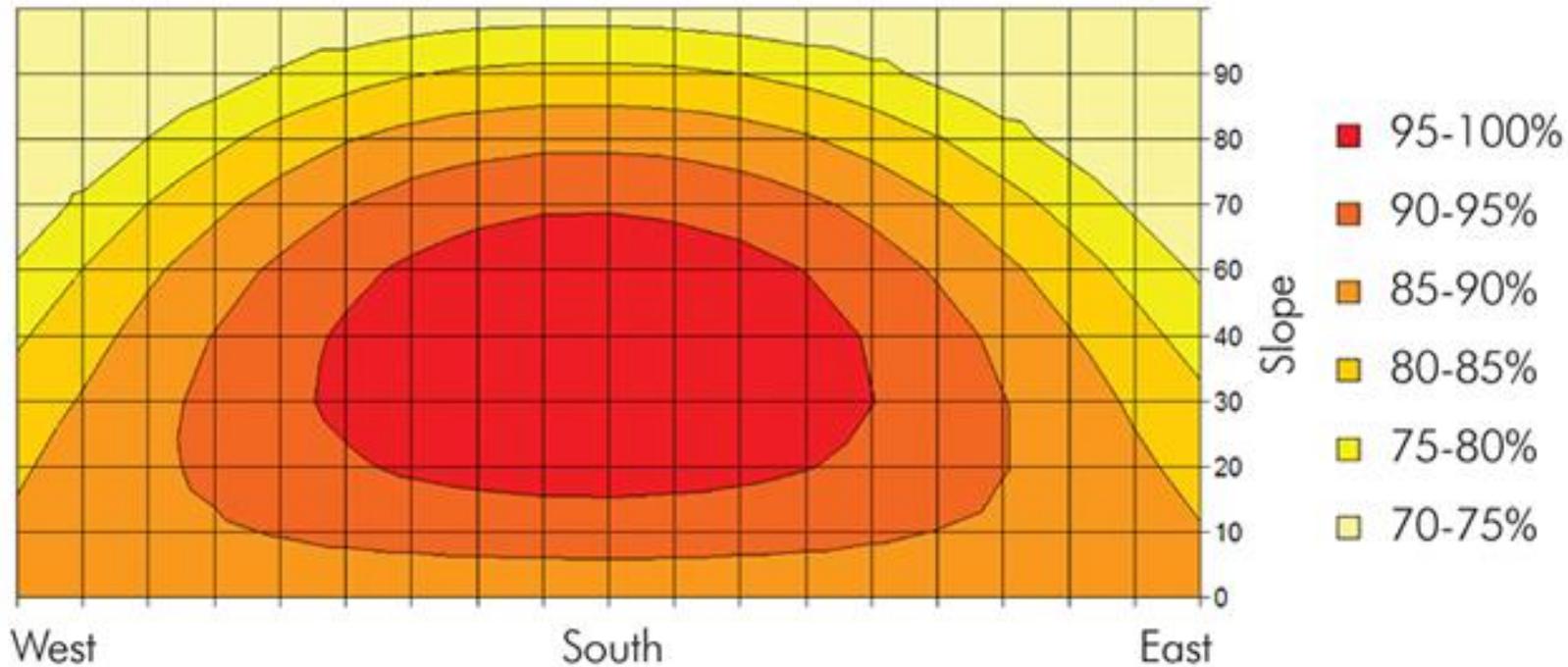


Solar Resource – In-plane choice

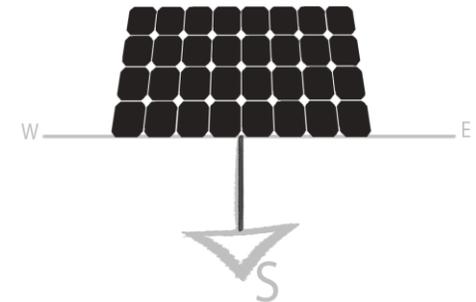
Partner logo

Tilt and Azimut impact on GTI

Change in performance due to panel orientation



Tilt angle



Azimut angle



Solar Resource – Case Study

Partner logo

https://re.jrc.ec.europa.eu/pvg_tools/en/

The screenshot displays the PVGIS web application interface. At the top, there is a navigation bar with the text "European Commission > EU Science Hub > PVGIS > Interactive tools" and a menu with "Home", "Tools", "Downloads", "Documentation", and "Contact us".

The main interface is divided into several sections:

- Map:** A map of the Catania region in Sicily, Italy, with a blue location pin over Catania. The map includes a scale bar (50 km) and a search bar at the bottom with the address "Eg. Ispra, Italy" and "Go!" button. Below the map, the coordinates "Lat/Lon: Eg. 45.81 Eg. 8.611" are shown with "Go!" buttons.
- Cursor:** Displays "Selected: 37.408, 15.028", "Elevation (m): 8", and "PVGIS ver. 5.2".
- Use terrain shadows:** Includes a checked "Calculated horizon" option with "csv" and "json" download buttons, and an unchecked "Upload horizon file" option with a "Choisir un fichier" button and "Aucun fichier choisi" text. A "Switch to version 5.1" button is also present.
- MONTHLY IRRADIATION DATA:** A section with a question mark icon. It includes a "Solar radiation database*" dropdown set to "PVGIS-SARAH2", "Start year*" and "End year*" dropdowns both set to "2005". Under "Irradiation:", there are checkboxes for "Global horizontal irradiation", "Direct Normal Irradiation", "Global irradiation optimum angle", and "Global irradiation at angle:" (with a "(0-90)" input field). Under "Ratio:", there is a checkbox for "Diffuse/global ratio". Under "Temperature:", there is a checkbox for "Average temperature".
- Left sidebar:** A vertical menu with options: "GRID CONNECTED", "TRACKING PV", "OFF-GRID", "MONTHLY DATA" (highlighted in purple), "DAILY DATA", "HOURLY DATA", and "TMY".
- Bottom:** A "Visualize results" button and "csv" and "json" download buttons.



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3. Solar databases, uncertainties, TMY
4. **Sun path, far and near shadings estimation**

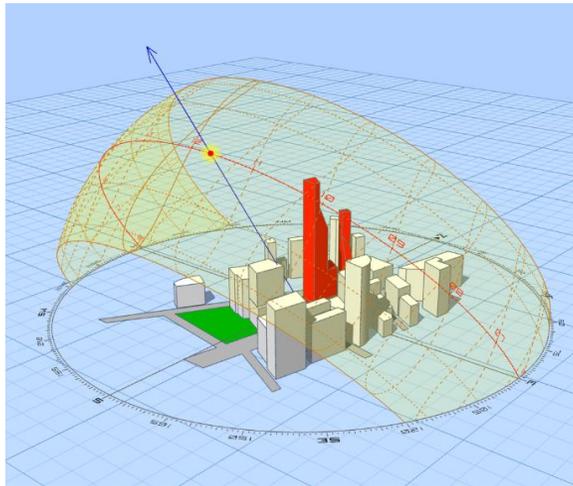




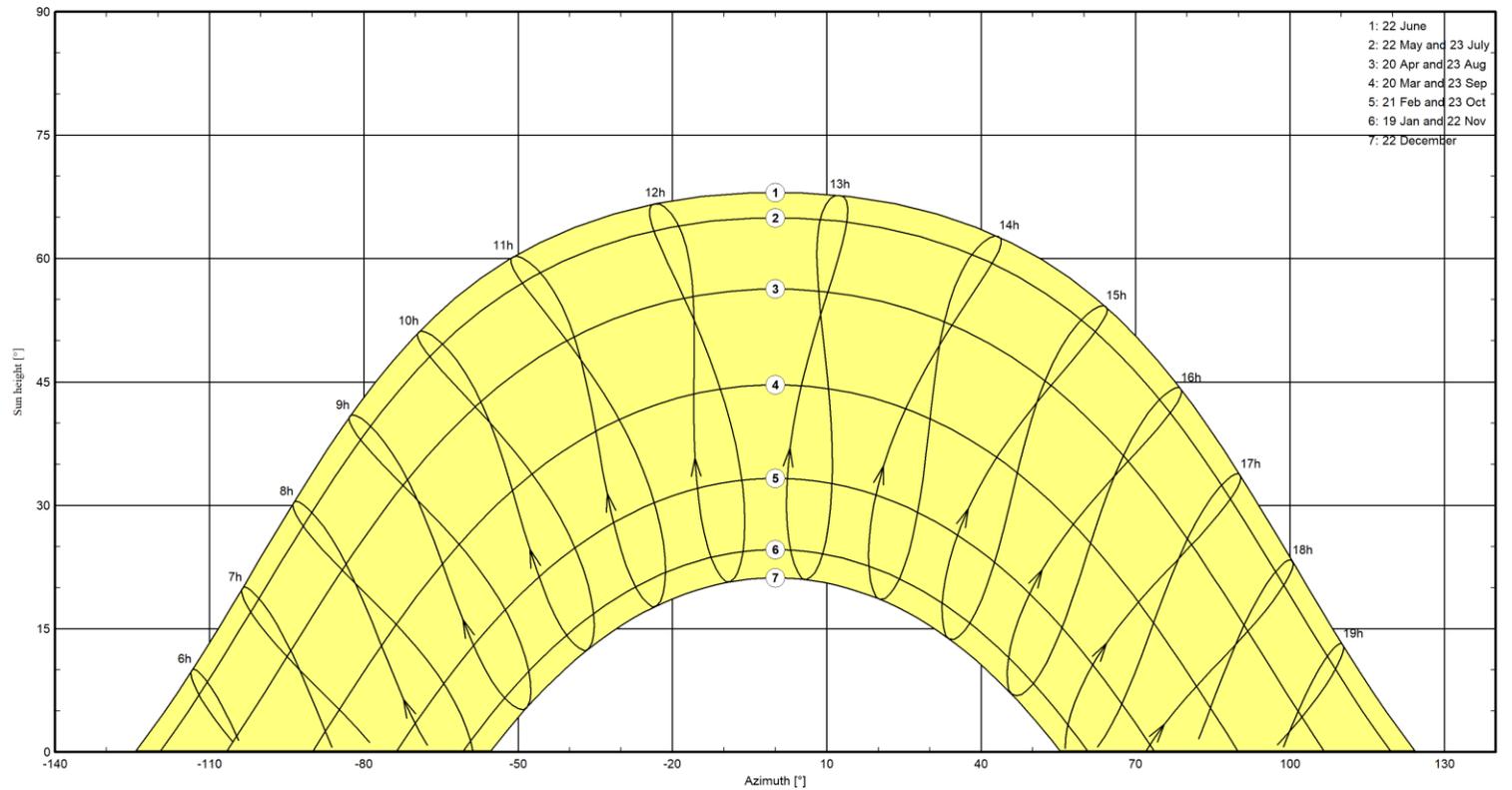
Solar Resource – Shadings

Partner logo

Shading analysis → Sun Path Diagram



Solar paths at Le Rivier, (Lat. 45.3778° N, long. 5.4847° E, alt. 466 m) - Legal Time





Solar Resource – Shadings

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There are **two types of shadings** for solar PV plants

Far Shadings

All PV plant is shadowed

Terrain Horizon (mountains, etc.)



Near Shading

PV Plant is partially shadowed

Close objects (trees, buildings, etc.)

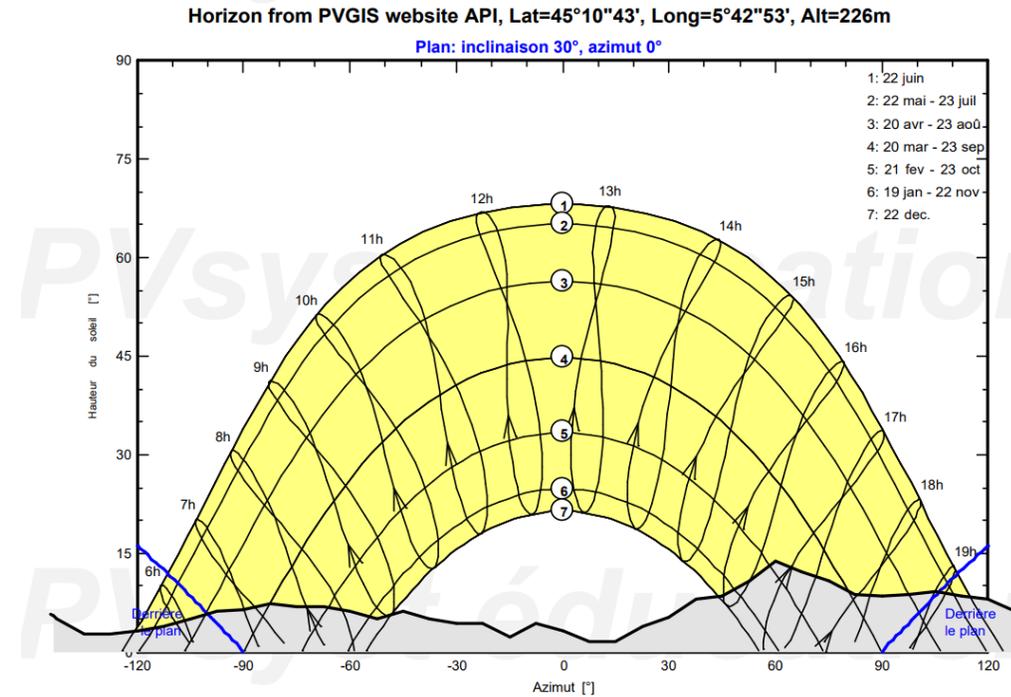
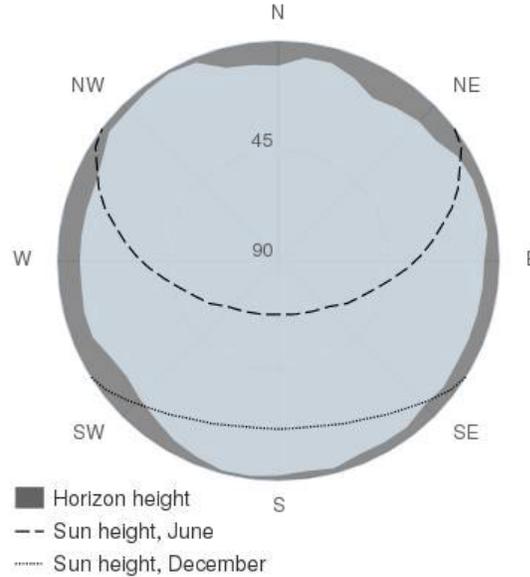
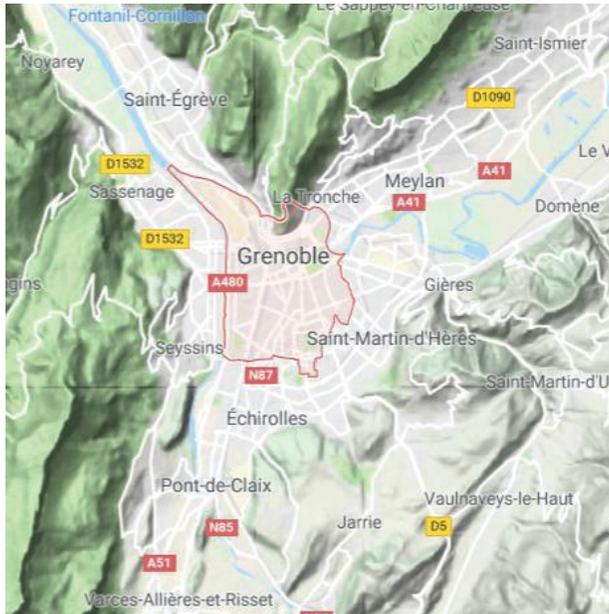




Solar Resource – Shadings

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Far shadings can be analysed with satellite data



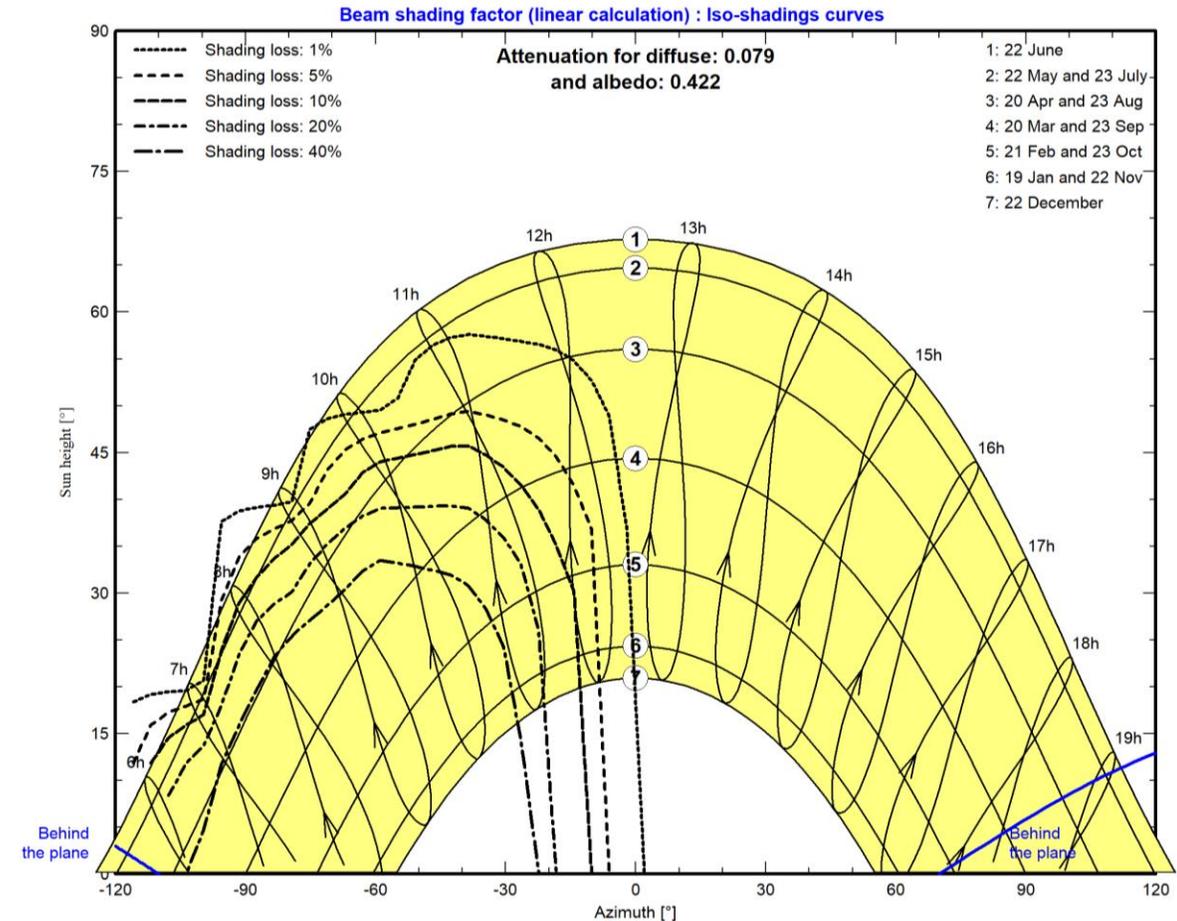
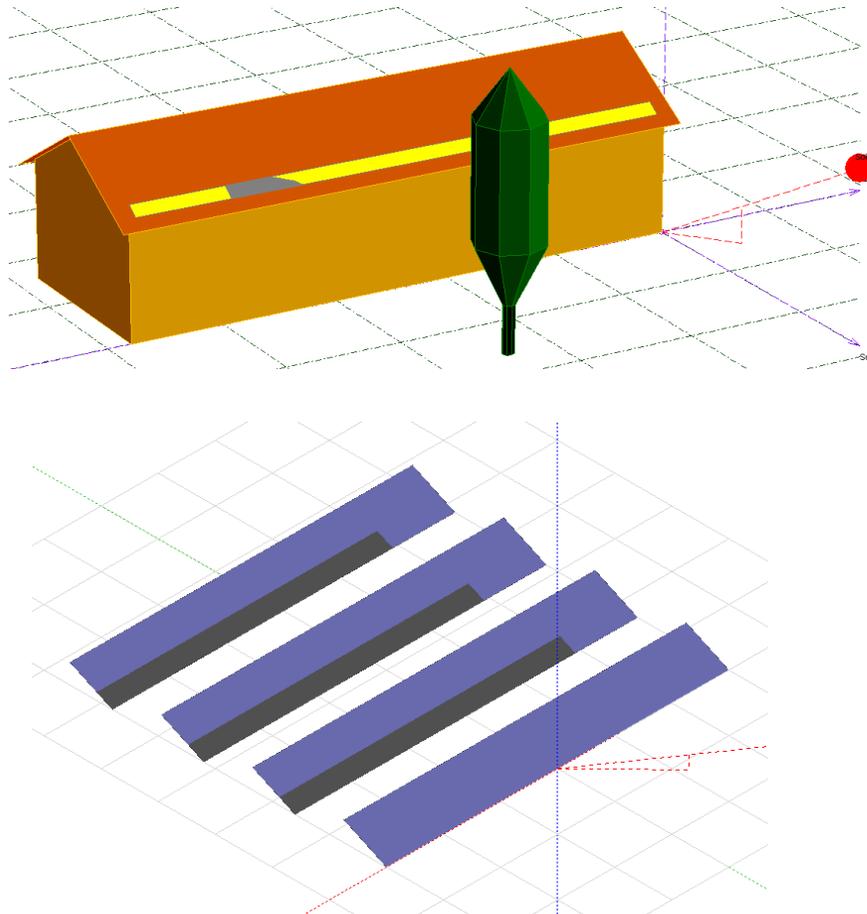
Source : PVGIS – http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP



Solar Resource – Shadings

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Near shadings have to be designed with a 3D modelling software

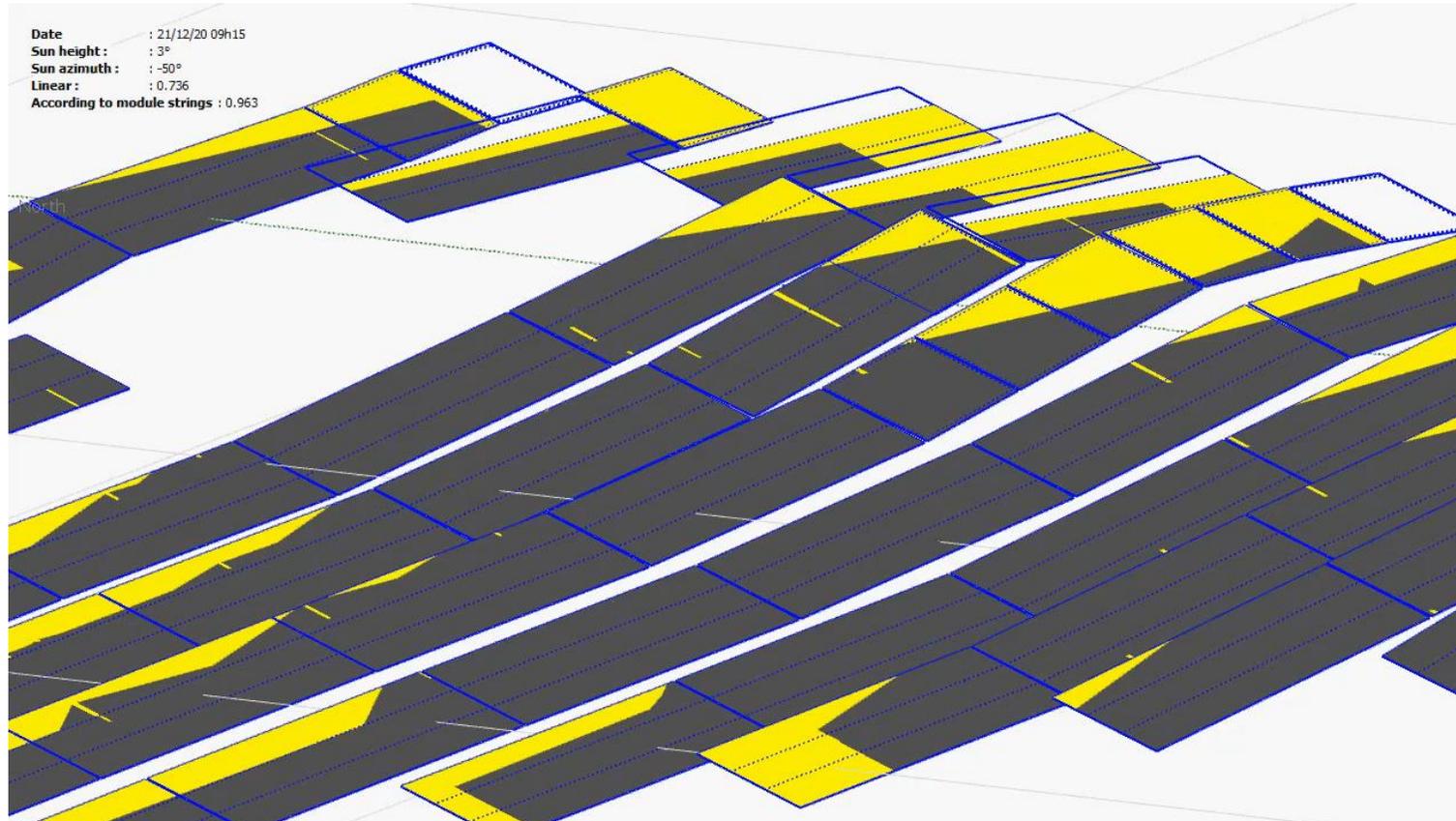




Solar Resource – Shadings

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Near shadings have to be designed with a 3D modelling software





GLOBAL OPTIMIZATION OF
INTEGRATED PHOTOVOLTAIC SYSTEM
FOR LOW ELECTRICITY COST



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Thank you for your attention!

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