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

goPV

June. 21-22-23

GoPV Summer School

co-organized with Università di Catania

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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goPV

June. 21st

Solar Resource & Site identification

(9:30-11:00)

co-organized with Università di Catania

GLOBAL OPTIMIZATION OF
INTEGRATED PHOTOVOLTAIC SYSTEM
FOR LOW ELECTRICITY COST

Solar Resource & Site potential

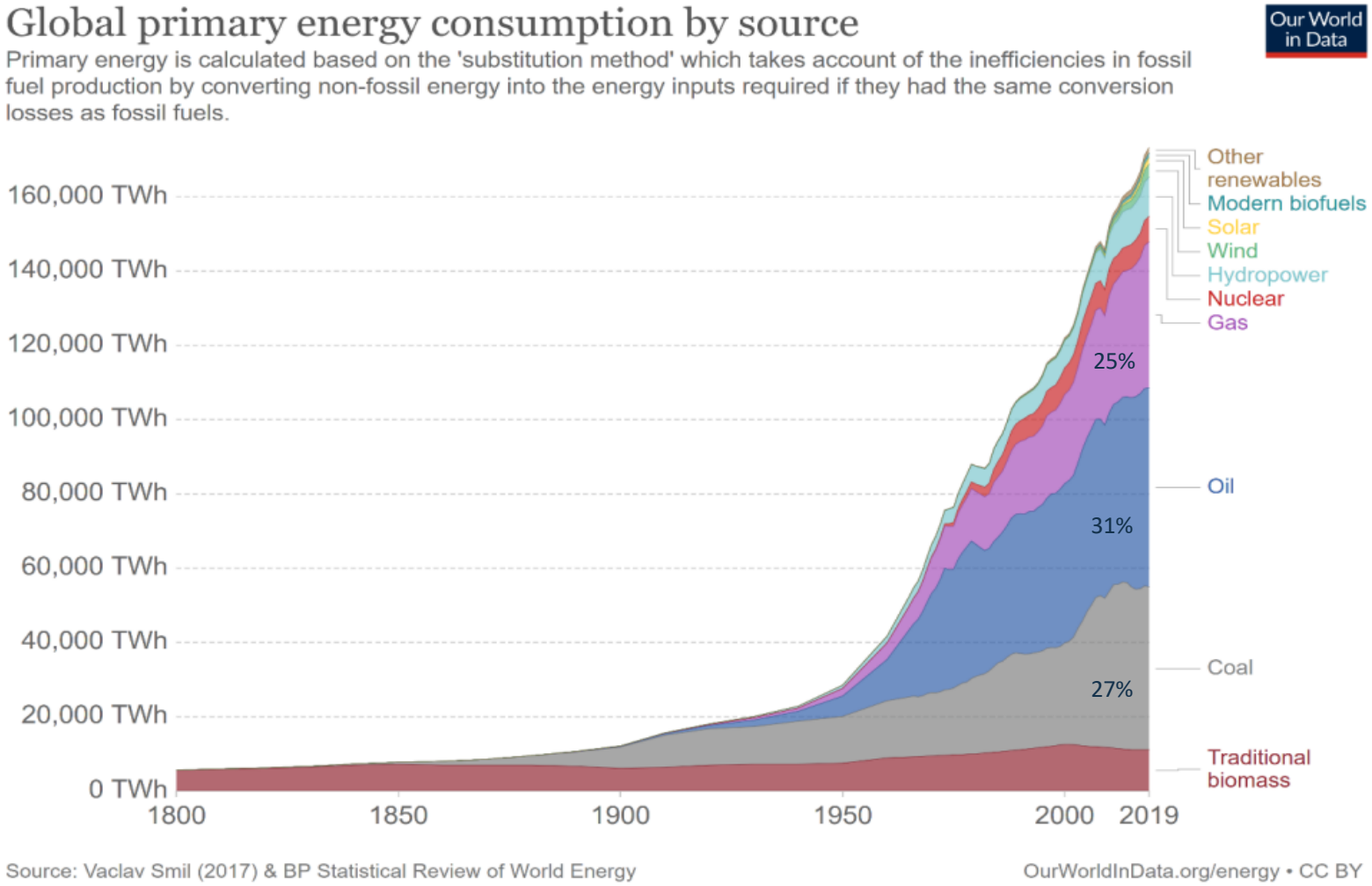
Antoine DIZIER
Solar PV Systems Engineer
antoine.dizier@ines-solaire.org

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



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

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

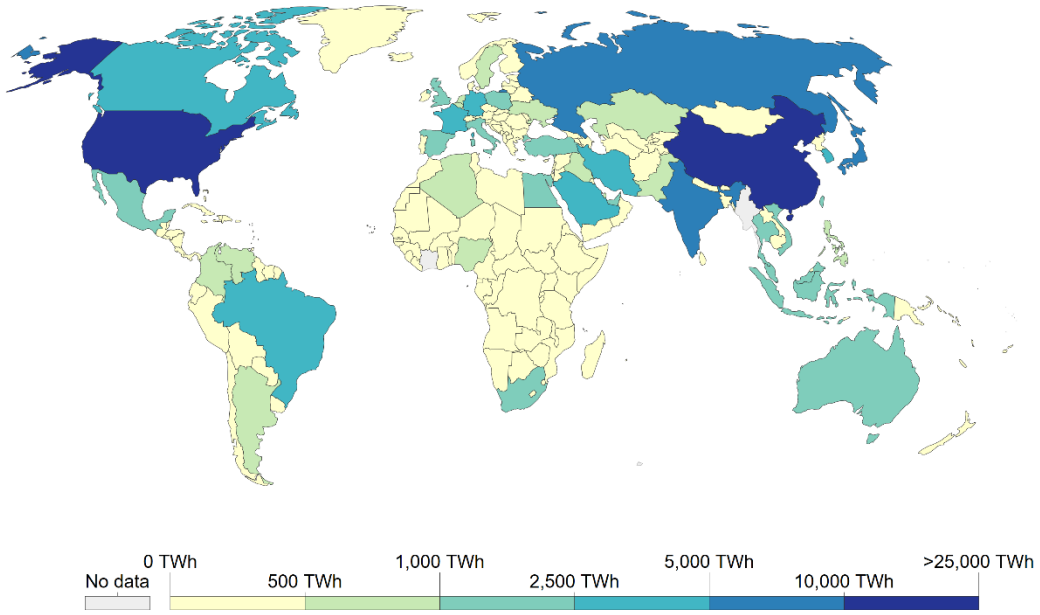
Global Energy Context

Partner logo

Primary energy consumption

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

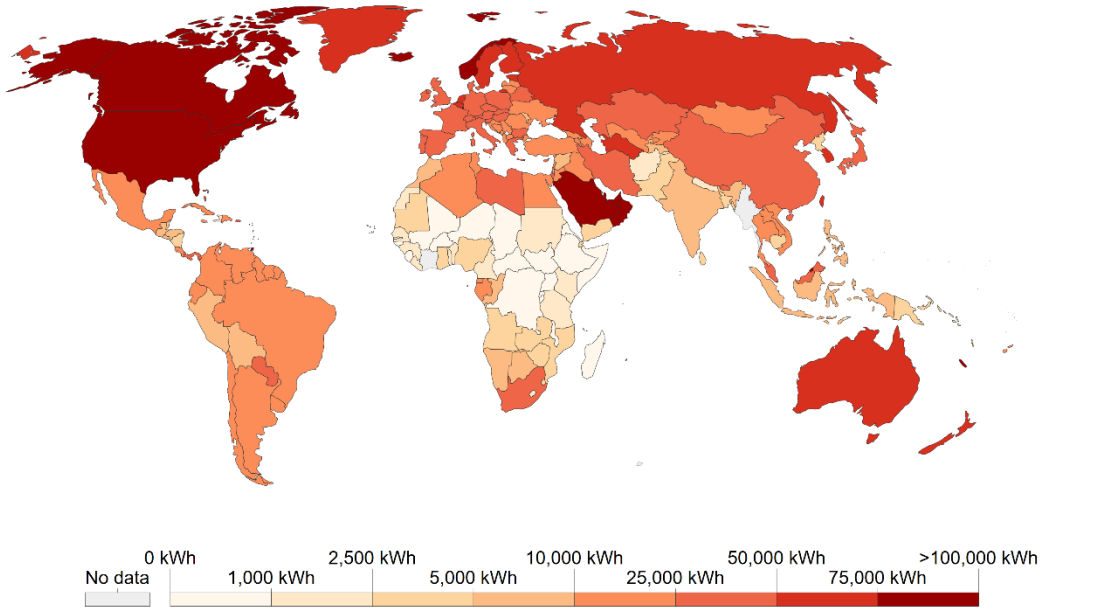
Our World in Data



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

Energy use per person

Our World in Data



Source: Our World in Data based on BP & Shift Data Portal
OurWorldInData.org/energy • CC BY
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).

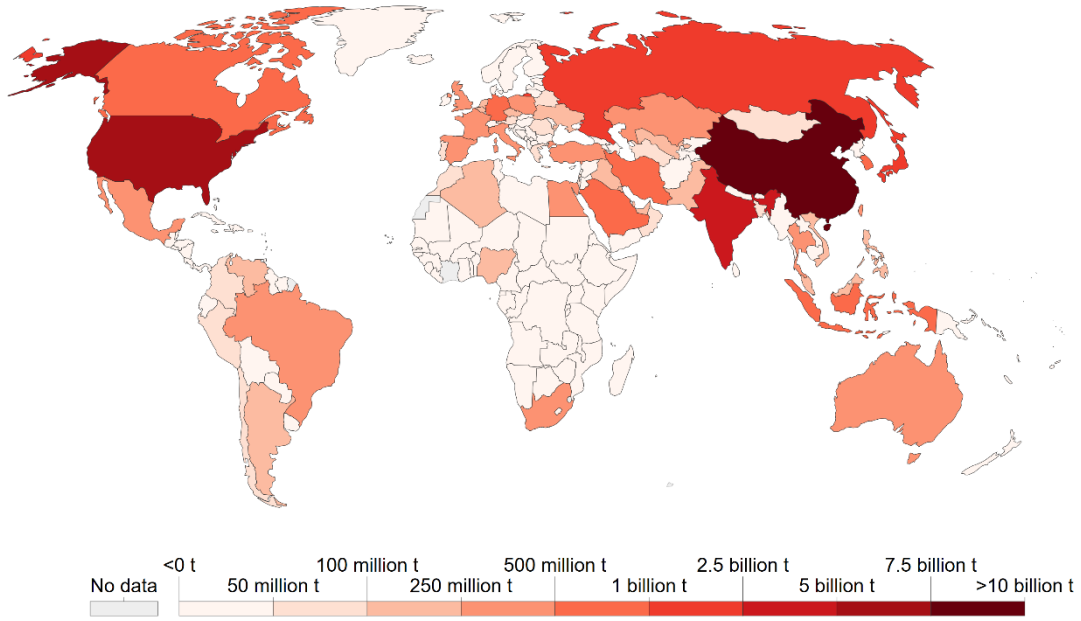
Global Energy Context

Partner logo

Annual CO_2 emissions

Carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Our World in Data

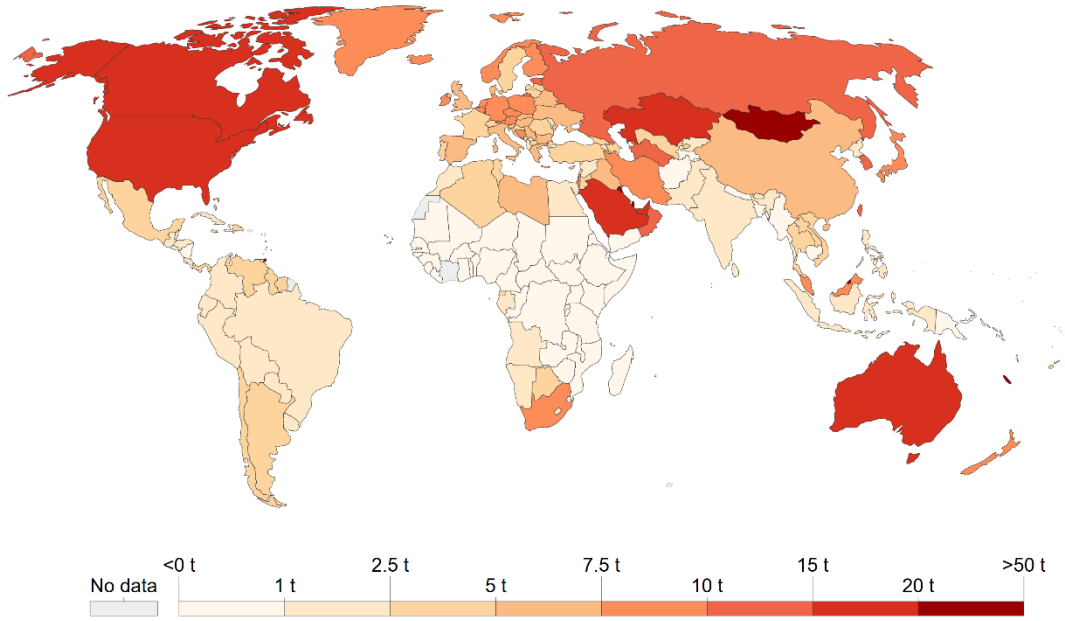


Source: Global Carbon Project; Carbon Dioxide Information Analysis Centre (CDIAC)
Note: CO_2 emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

Per capita CO_2 emissions

Carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

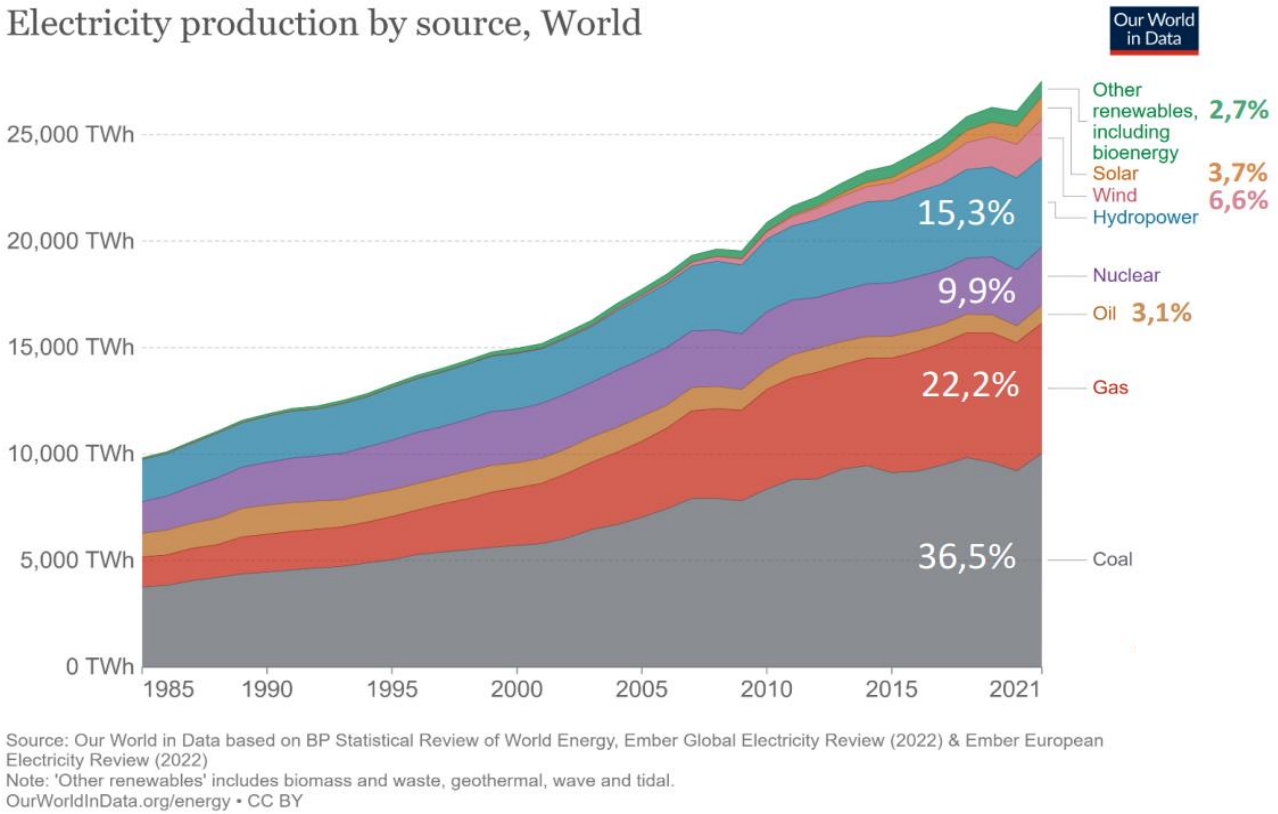
Our World in Data

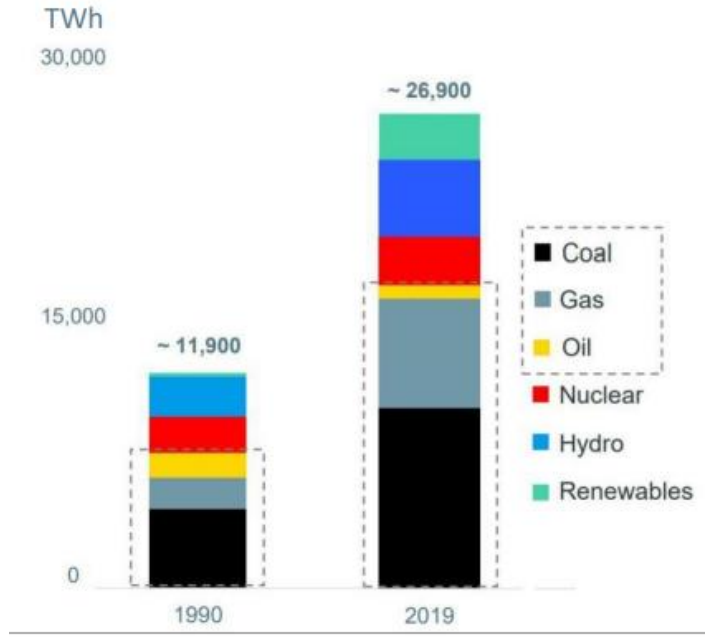


Source: Our World in Data based on the Global Carbon Project; Gapminder & UN
Note: CO_2 emissions are measured on a production basis, meaning they do not correct for emissions embedded in traded goods.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

Global Energy Context

Partner logo

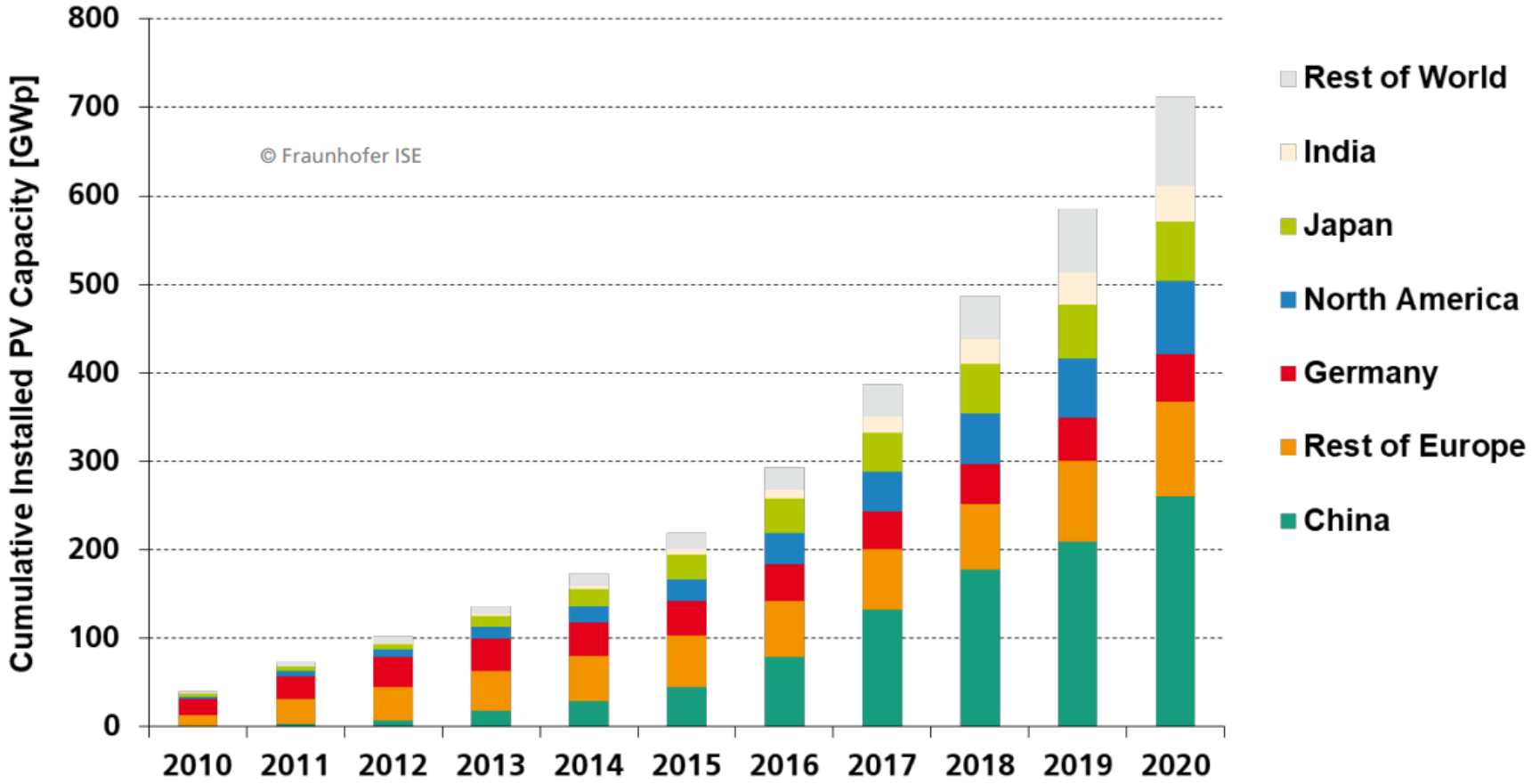




62% of global electricity production is based on non-renewables (fossil fuels + nuclear)
+ 28% of global electricity is now based of renewables (only 19% in 2010)

Global PV Market

Partner logo



+175 GWp
in 2021

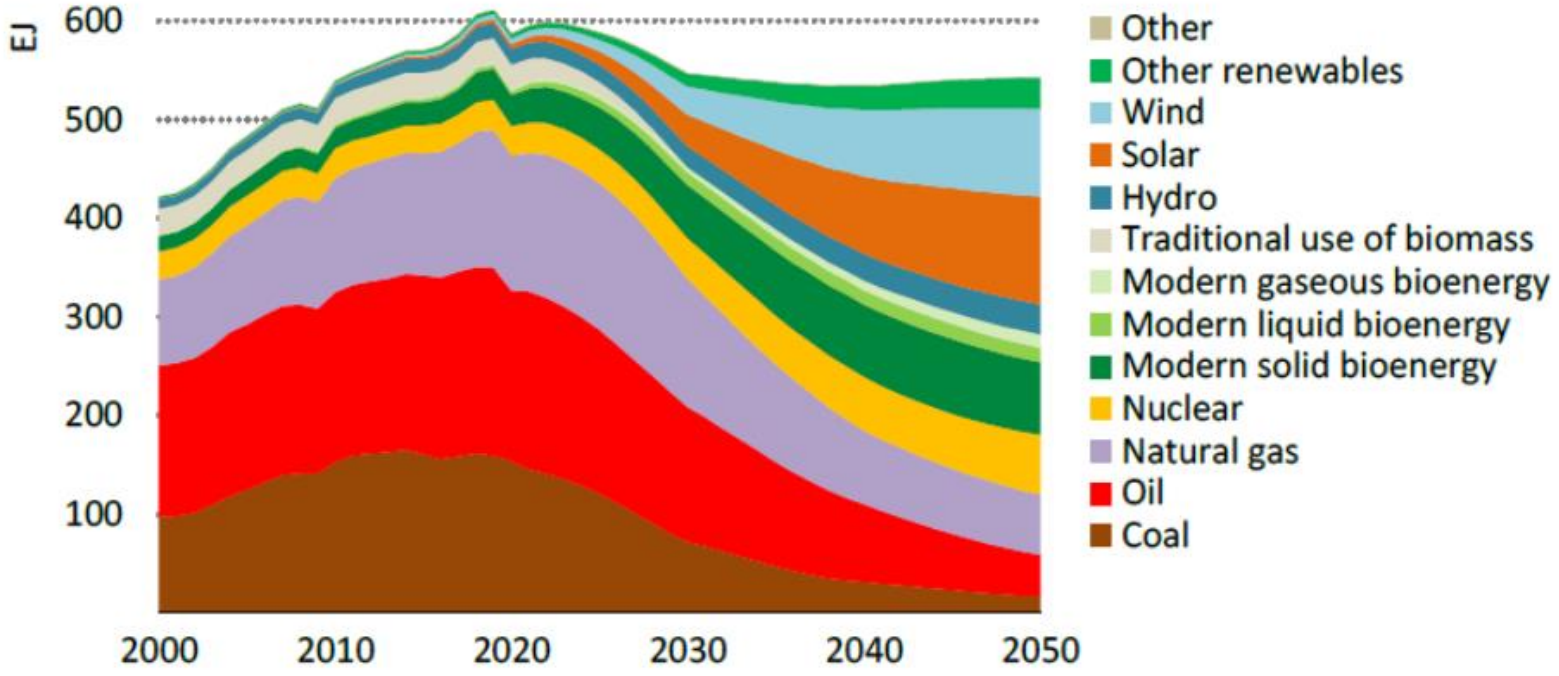
Today
> 1000 GWp installed

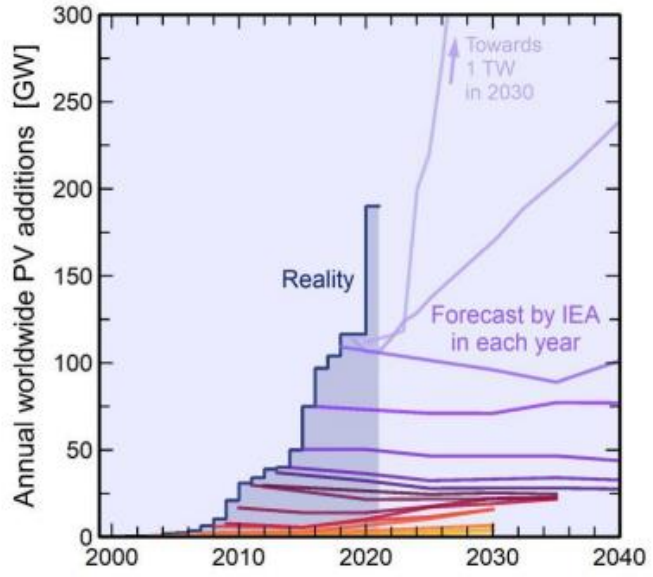
Data: IRENA 2021. Graph: PSE Projects GmbH 2021

Global PV Market

Partner logo

IEA Net Zero Roadmap (oct 2021)





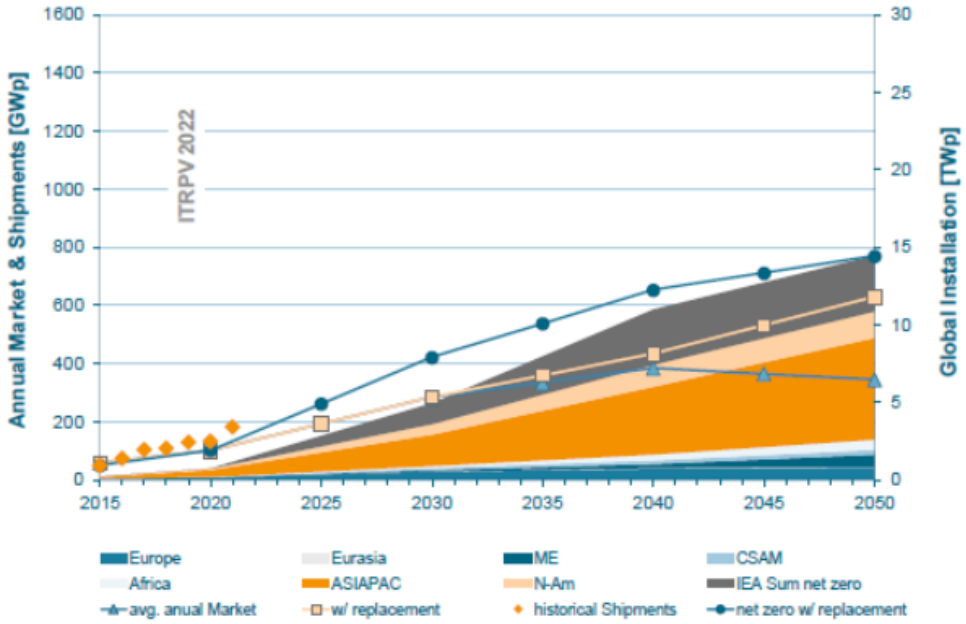
Global PV Market

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



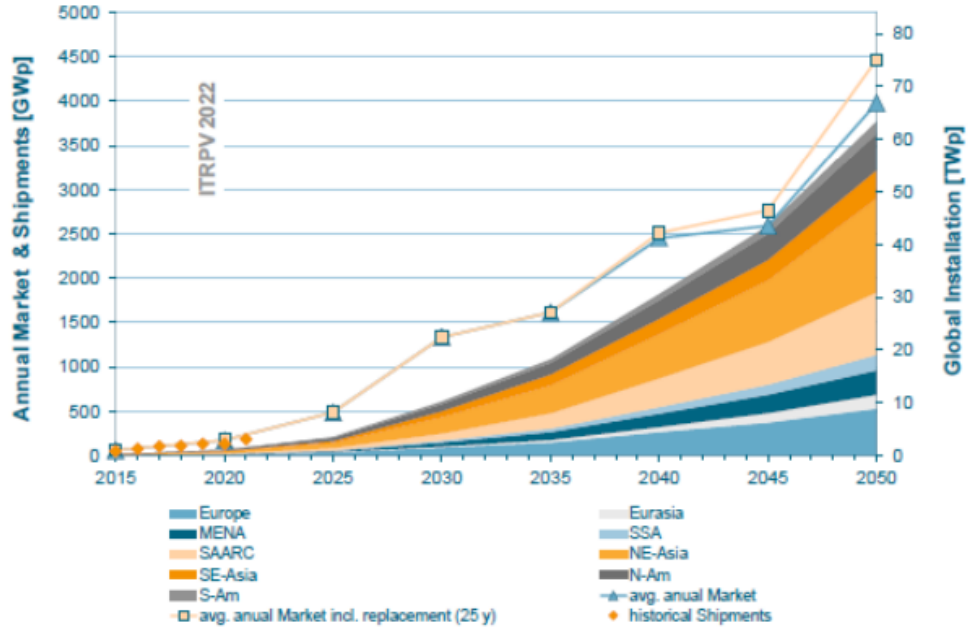
33% of global electricity in 2050

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
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Agenda

1. Global Energy Context
2. **Introduction to solar resource**
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Solar Resource

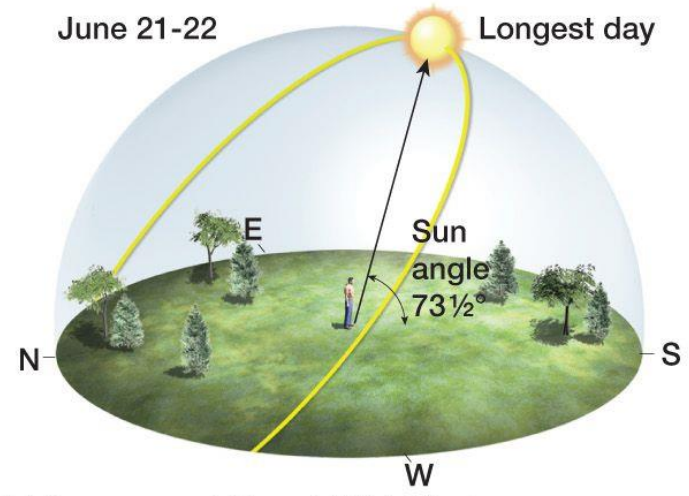
Partner logo

Solar energy depends on:

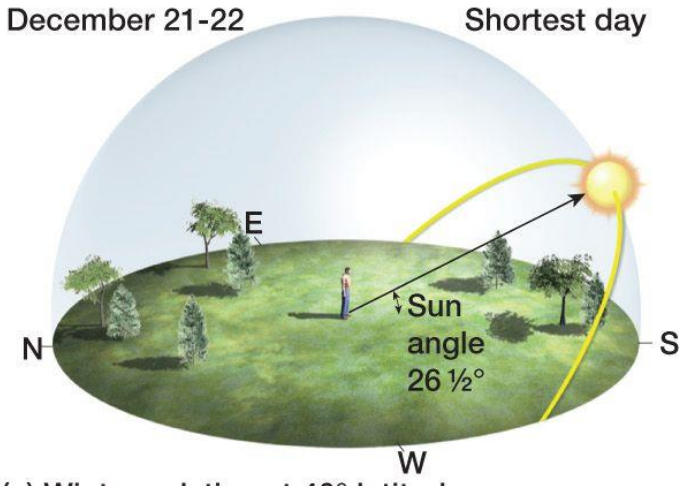
- Earth rotation (night & day)
- Seasons (declination of 23.45°)
- Latitude of site

… in brief… on sun path in the sky

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



(a) Summer solstice at 40° latitude



(c) Winter solstice at 40° latitude

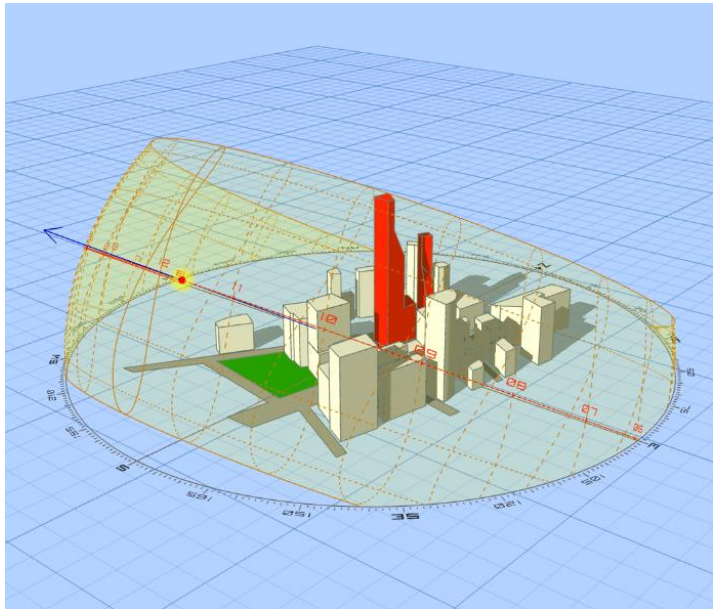
Solar Resource

Partner logo

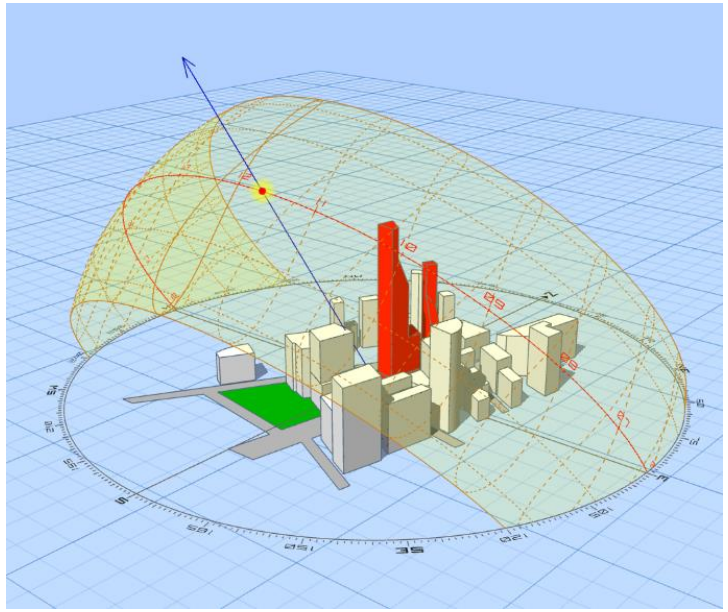
1. Sun Azimut = angular position relative to South -180° to 180°

2. Sun Elevation = angular position relative to the ground 0° to 90°

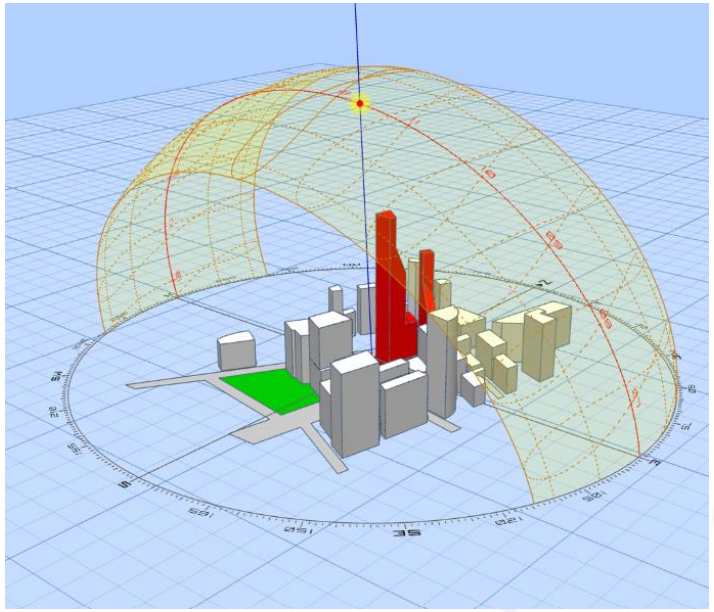
STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



DAKAR
Latitude = 14°

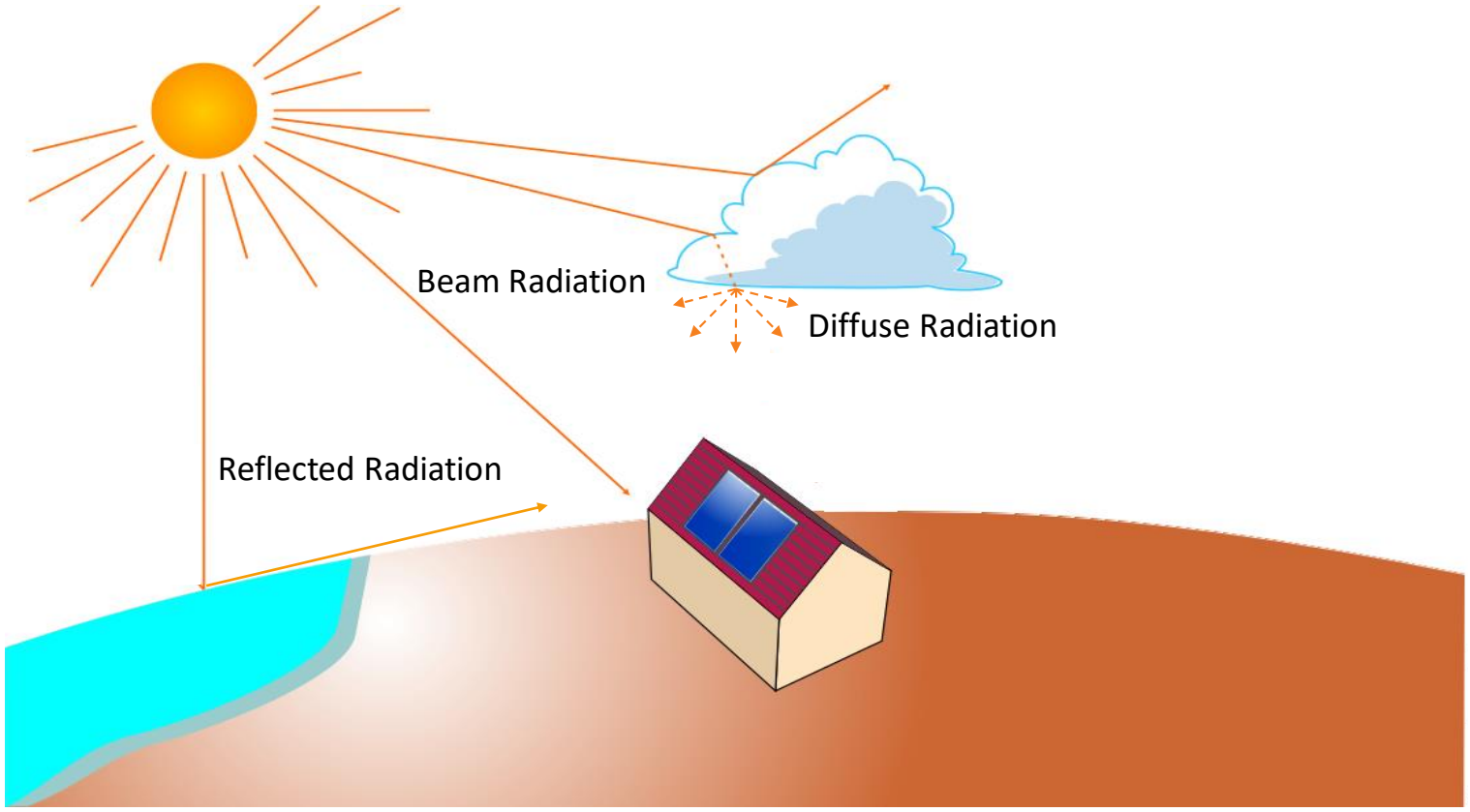


Source : http://andrewmarsh.com/apps/staging/sunpath3d.html

Solar Resource – Components

Partner logo

Global Irradiation = Beam Irradiation + Diffuse Irradiation + Reflected Irradiation



Solar Resource – Terminology

Partner logo

Irradiance = **POWER** Unit → **W/m²**

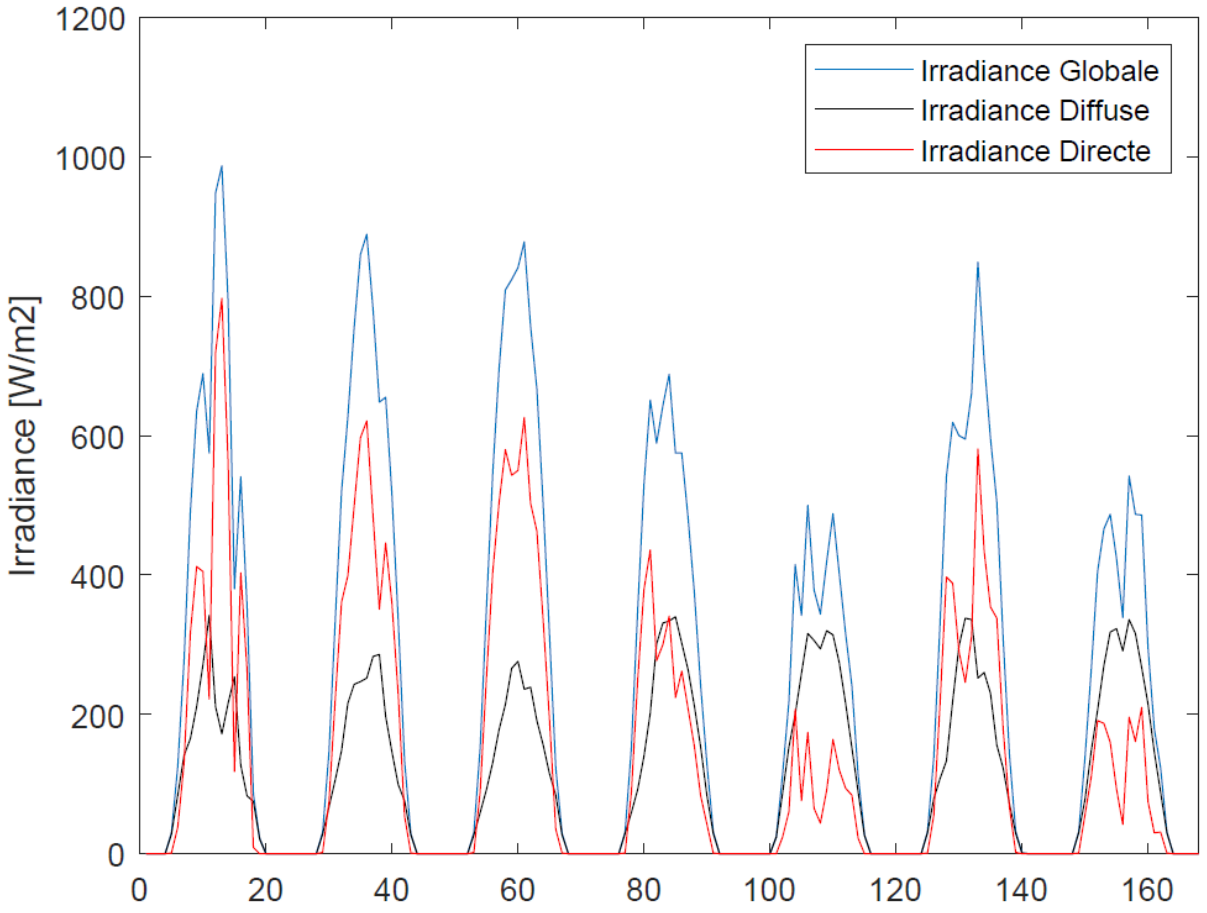
Irradiation = **ENERGY** Unit → **kWh/m²**

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

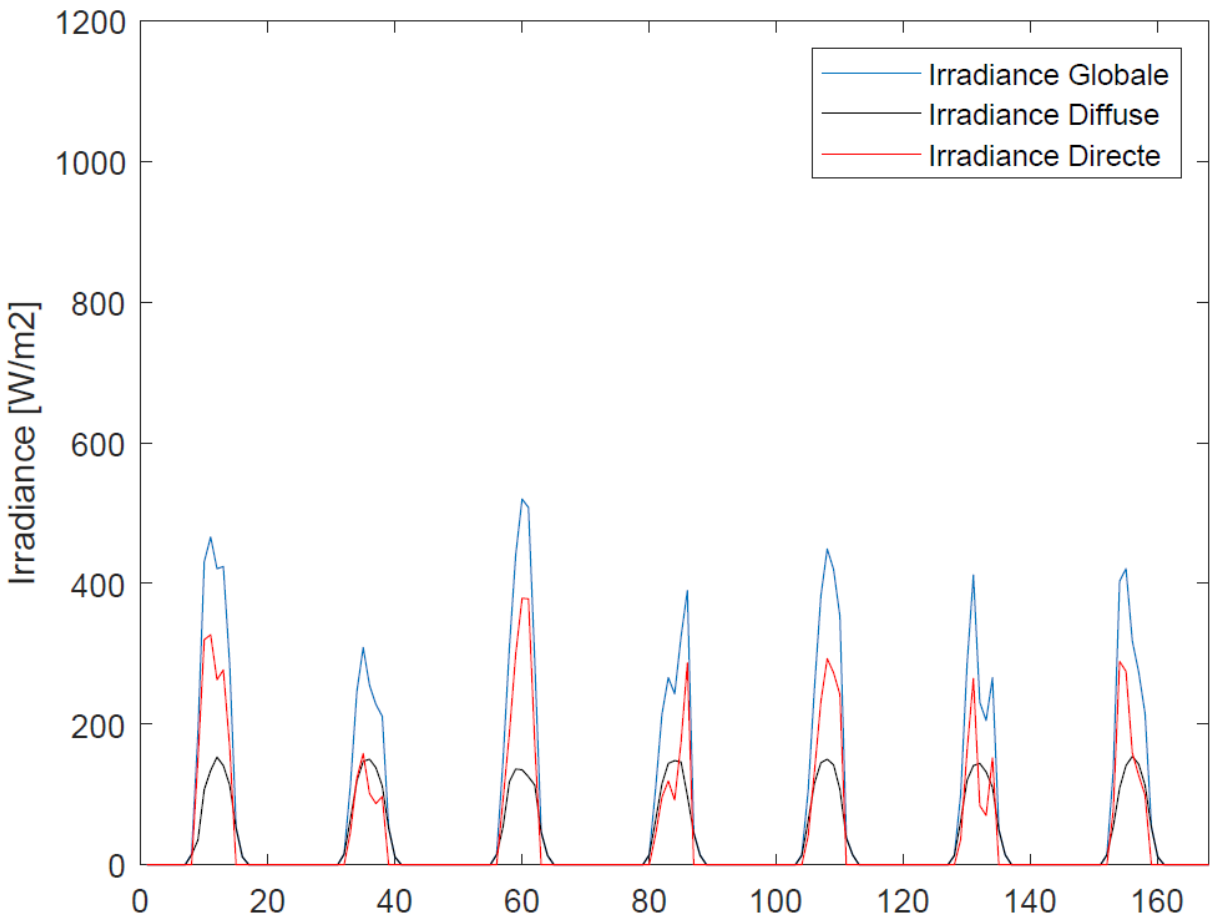
Solar Resource – Irradiance

Partner logo

Summer Week

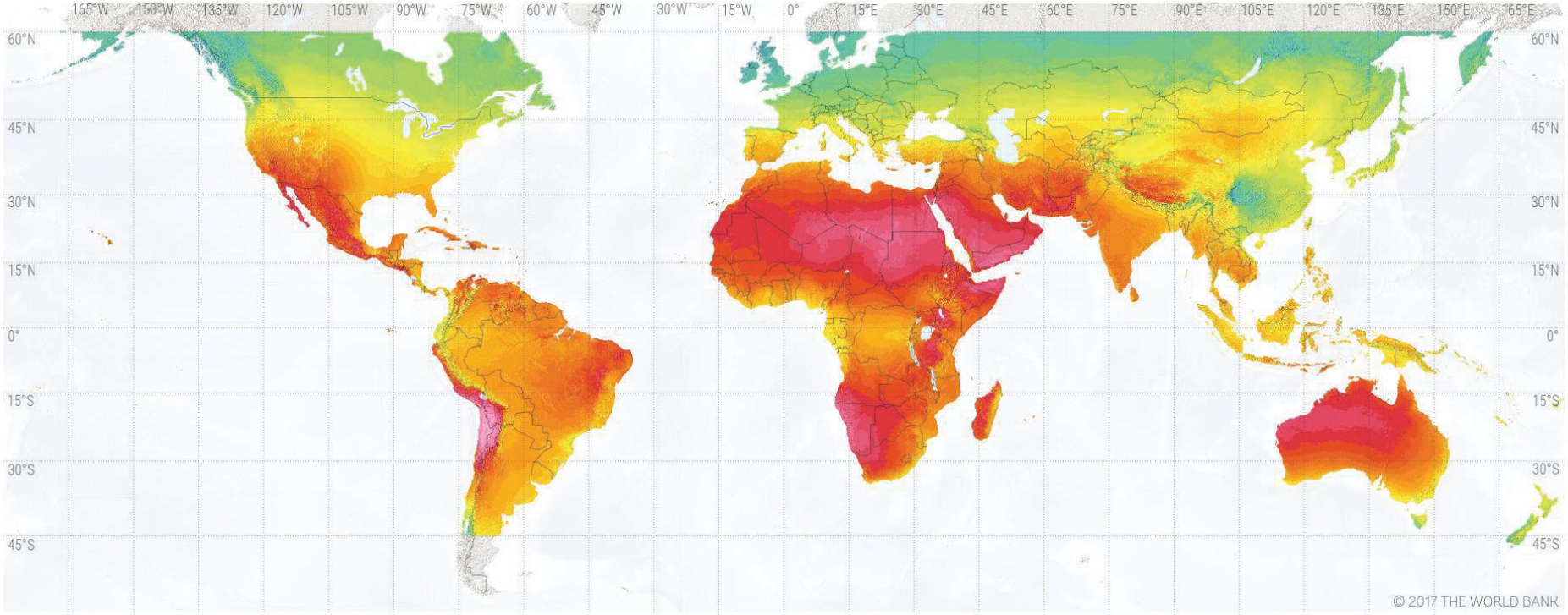


Winter Week



Solar Resource – Irradiation

Partner logo



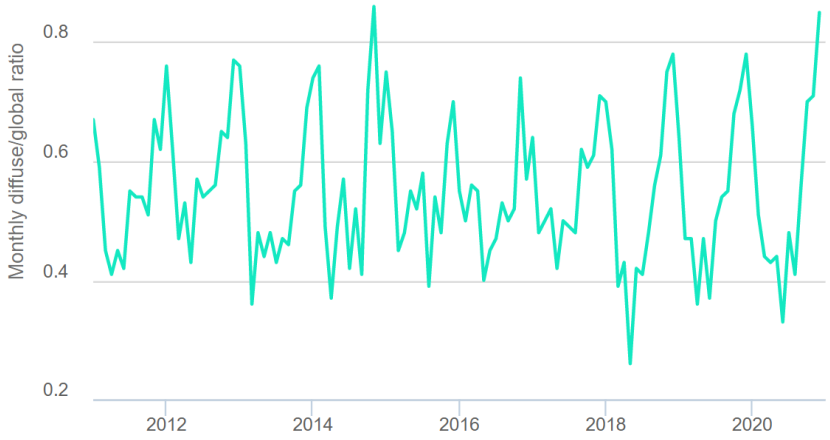
Solar Resource

Partner logo

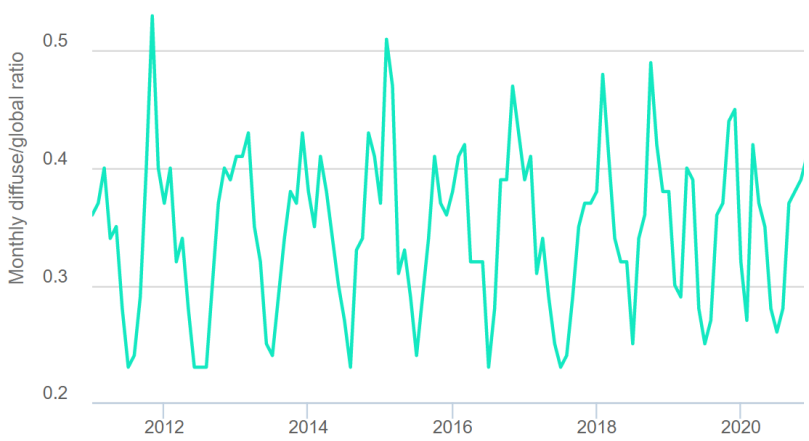
Diffuse / Global Ratio

What do you think?

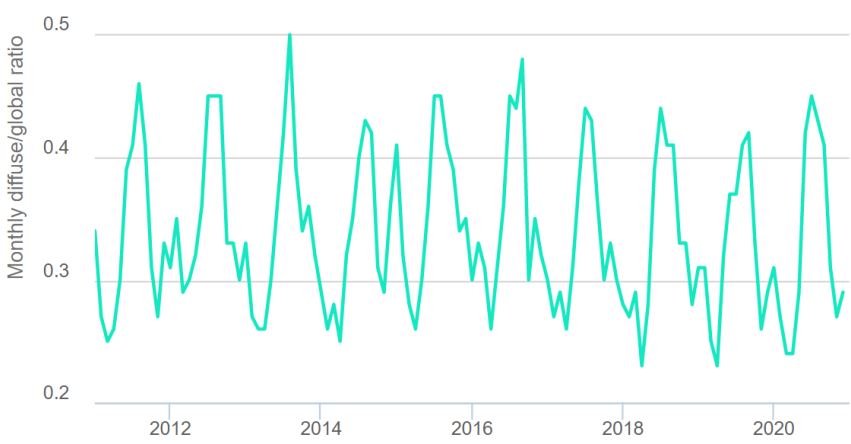
STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



DAKAR
Latitude = 14°



Solar Resource & Site potential

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1. Global Energy Context
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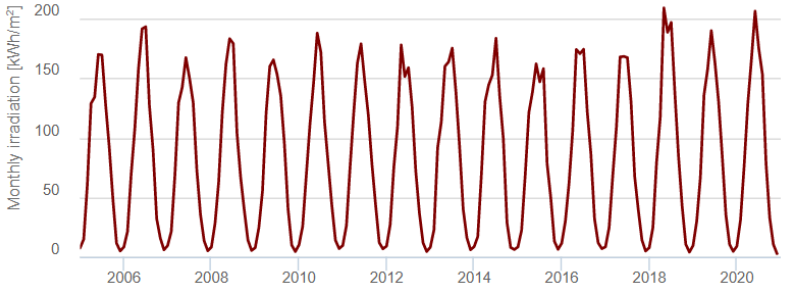
Solar Resource – Variability

Partner logo

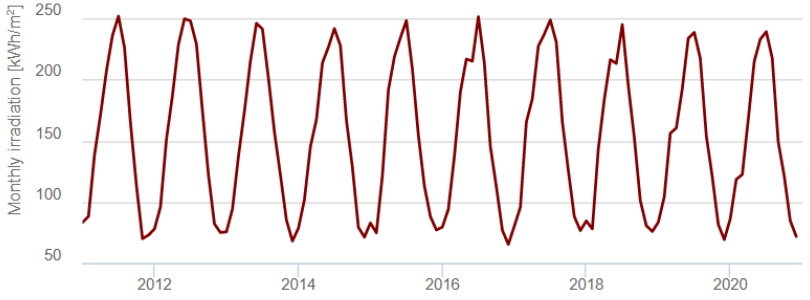
Year-to-year variability in terms of GHI

What do you think?

STOCKHOLM
Latitude = 59°



CATANIA
Latitude = 37°



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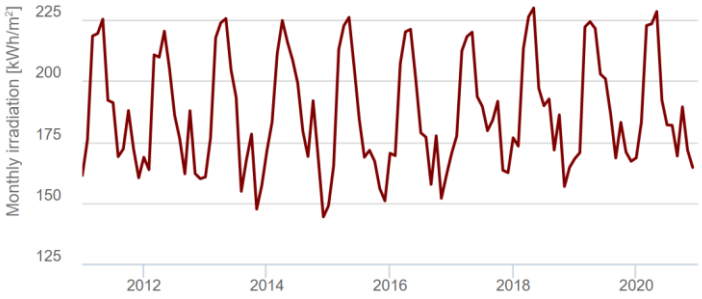
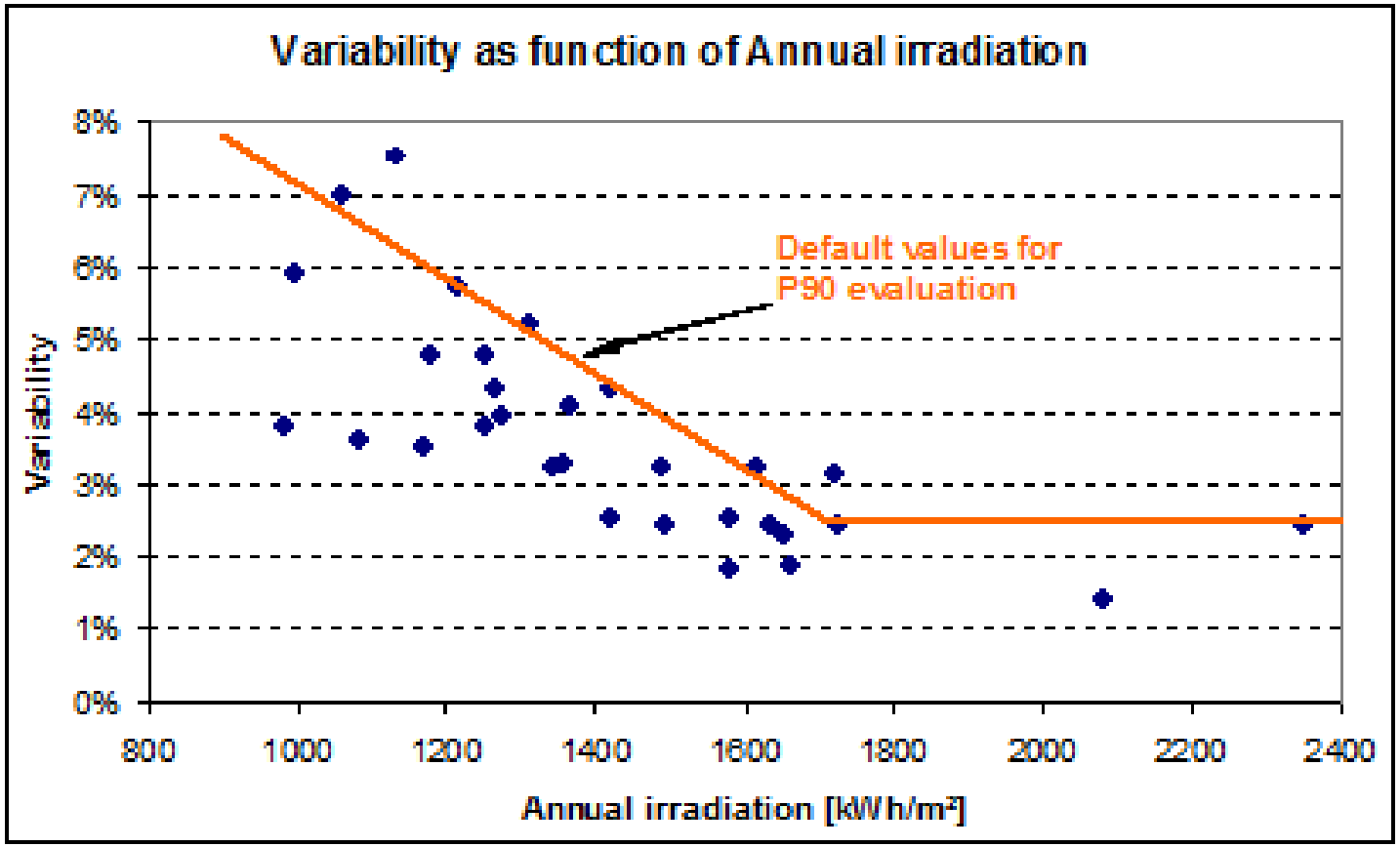


Solar Resource – Variability

Partner logo



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

Solar Resource – Measurement

Partner logo

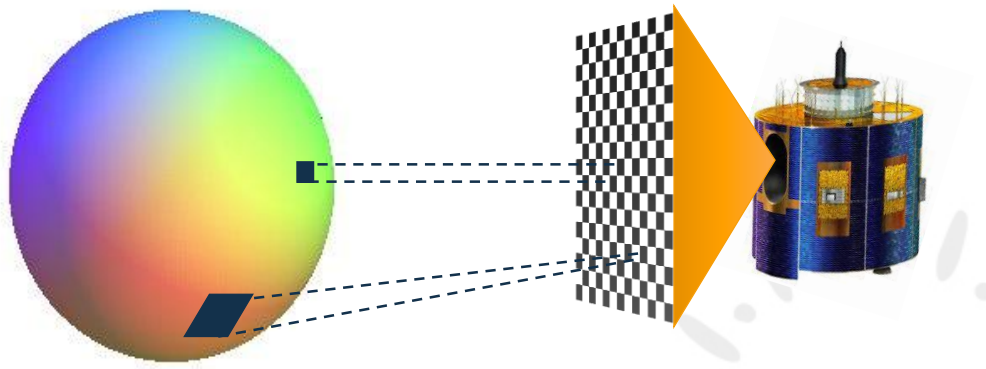
On-site measurement

+ 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 ≈3-5 km for one site)
+ Long-term series available
- Higher uncertainties due to calculations / aggregation

Resources → PVGIS / SoDa / SolarGIS / Meteonorm / NASA

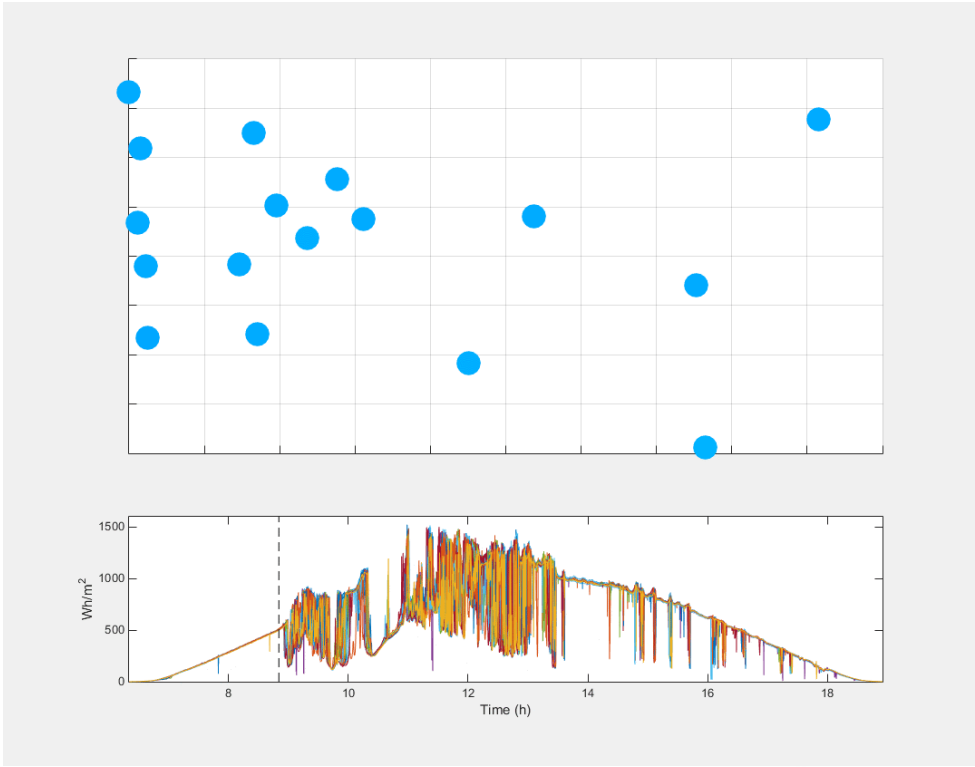


Solar Resource – On-site

Partner logo

1 km

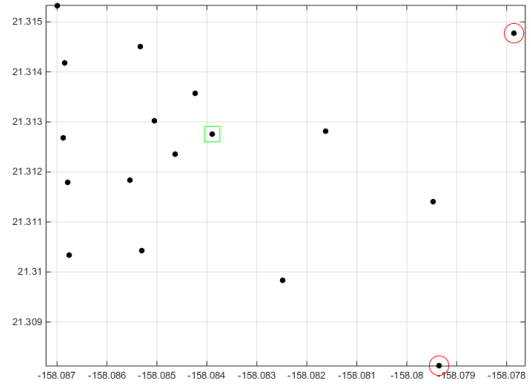
- Pyranometric sensors



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

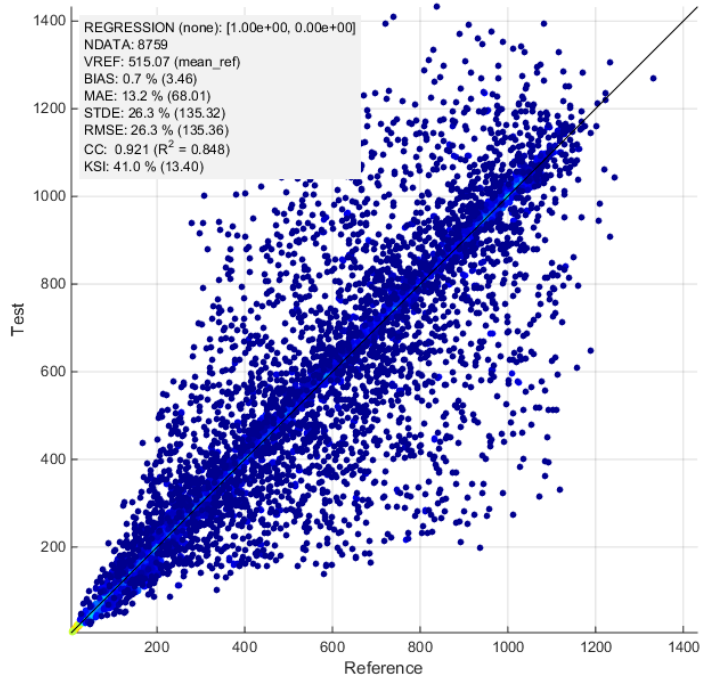
Solar Resource – On-site

Partner logo

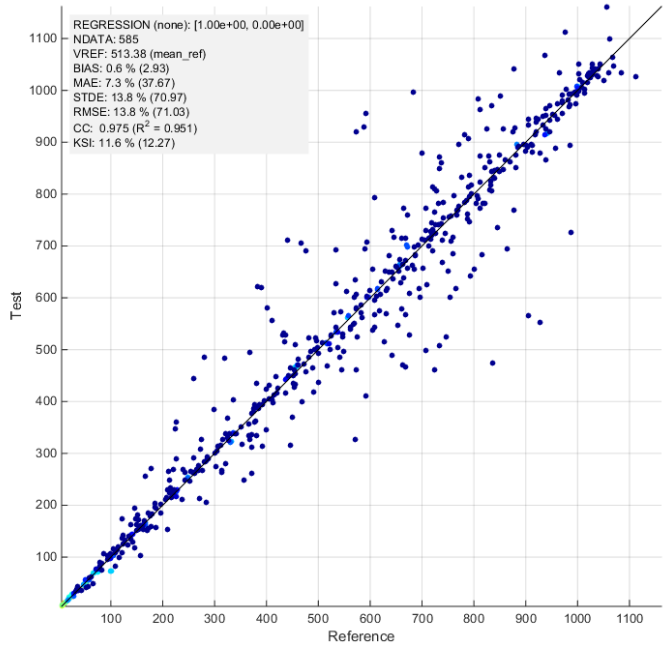


Comparison of GHI over several days with regards to a reference pyranometer

Comparison 1 min



Comparison 15 min

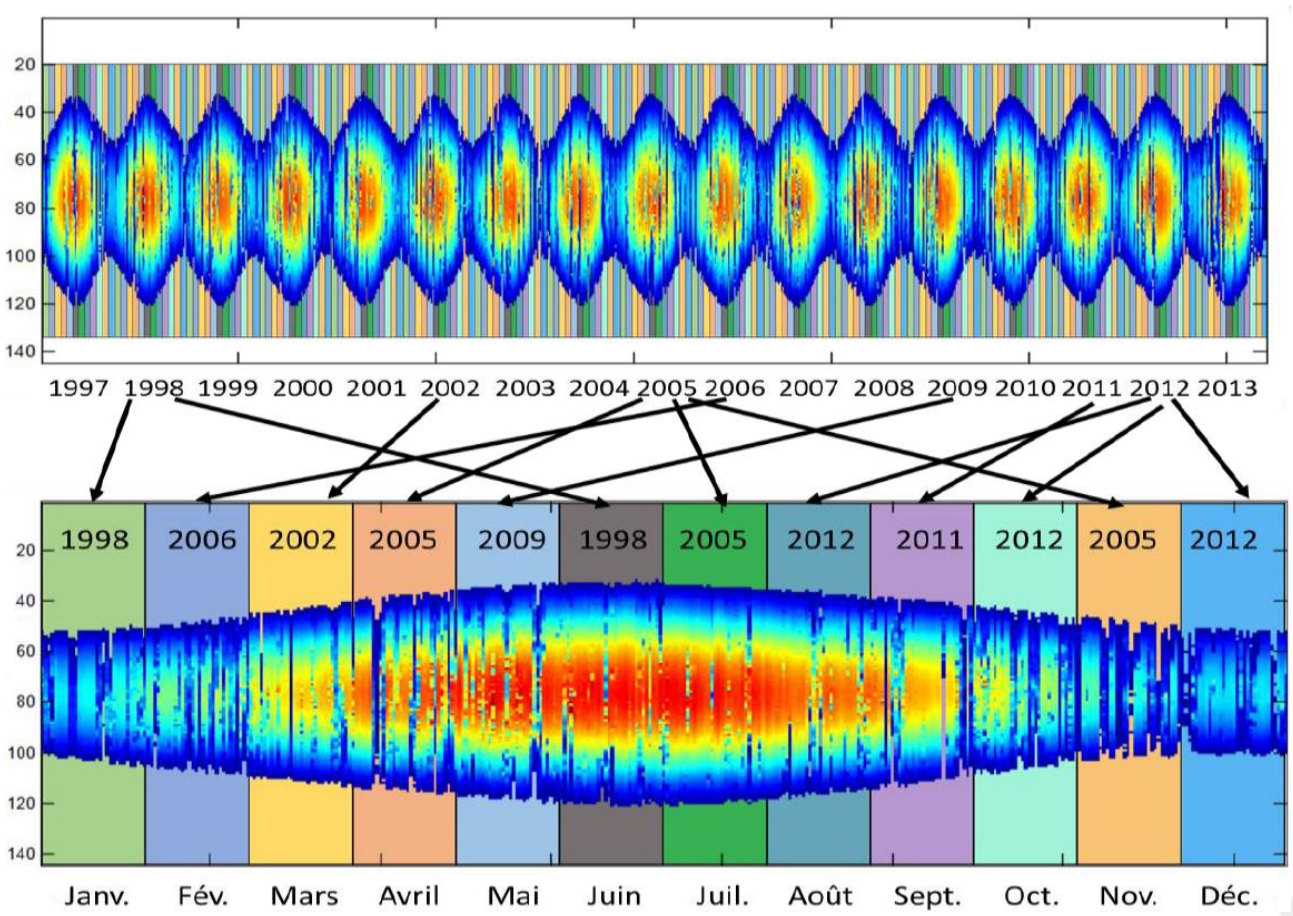


Solar Resource – TMY

Partner logo

Long-term time series
of 17 years

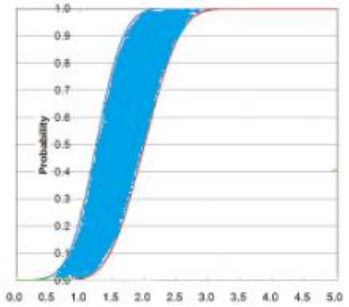
Monthly selection with real data
with regards to statistical analysis



Solar Resource – TMY

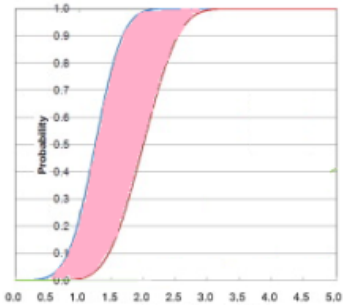
Partner logo

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



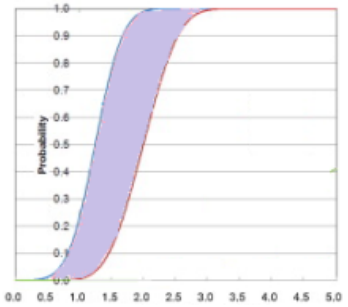
δ(GHI)

Global Horizontal Irradiance



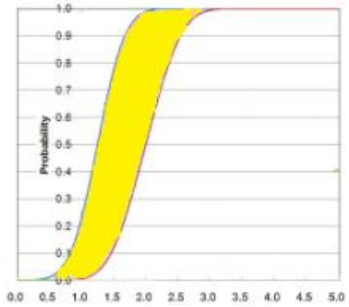
δ(BNI)

Beam Normal Irradiance



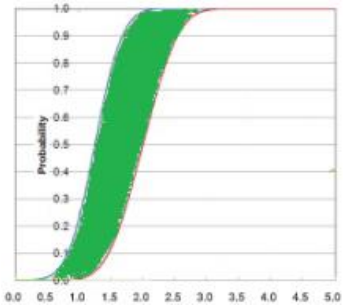
δ(T2)

Air Temperature



δ(WS)

Wind speed



δ(RH)

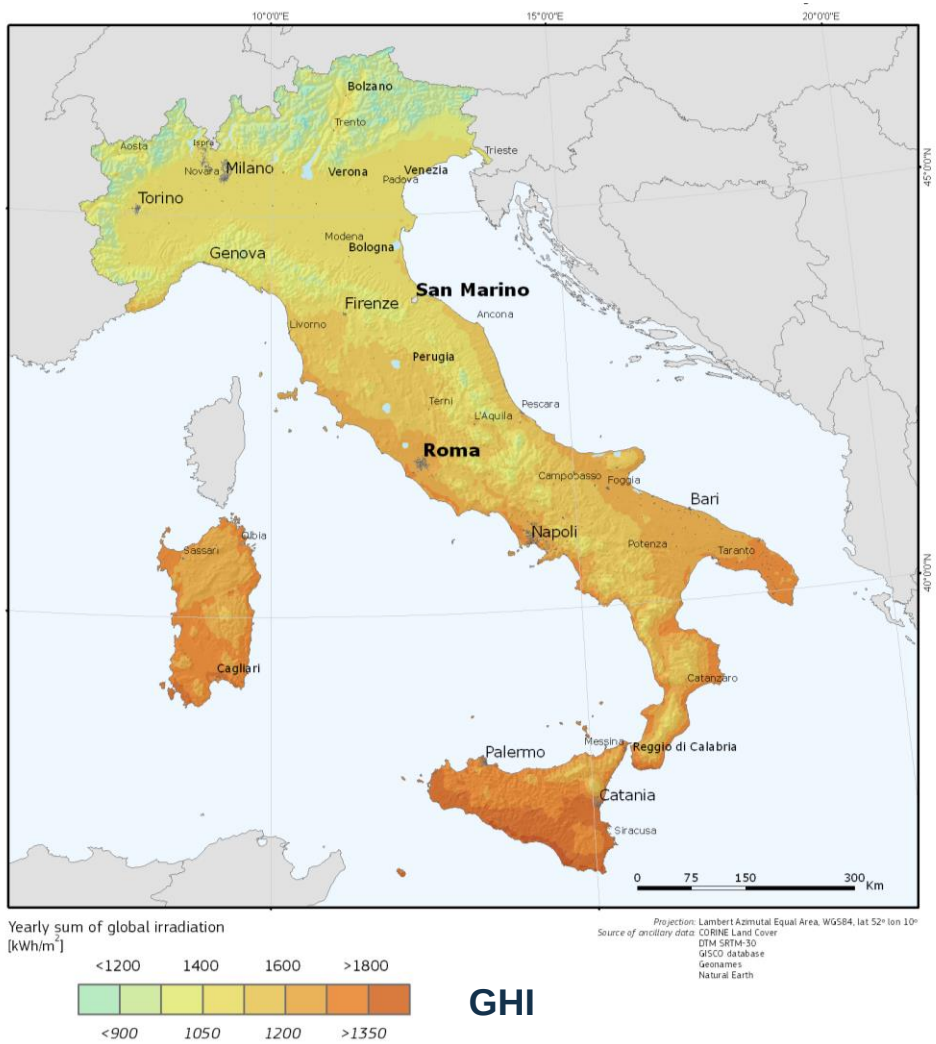
Relative Humidity

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

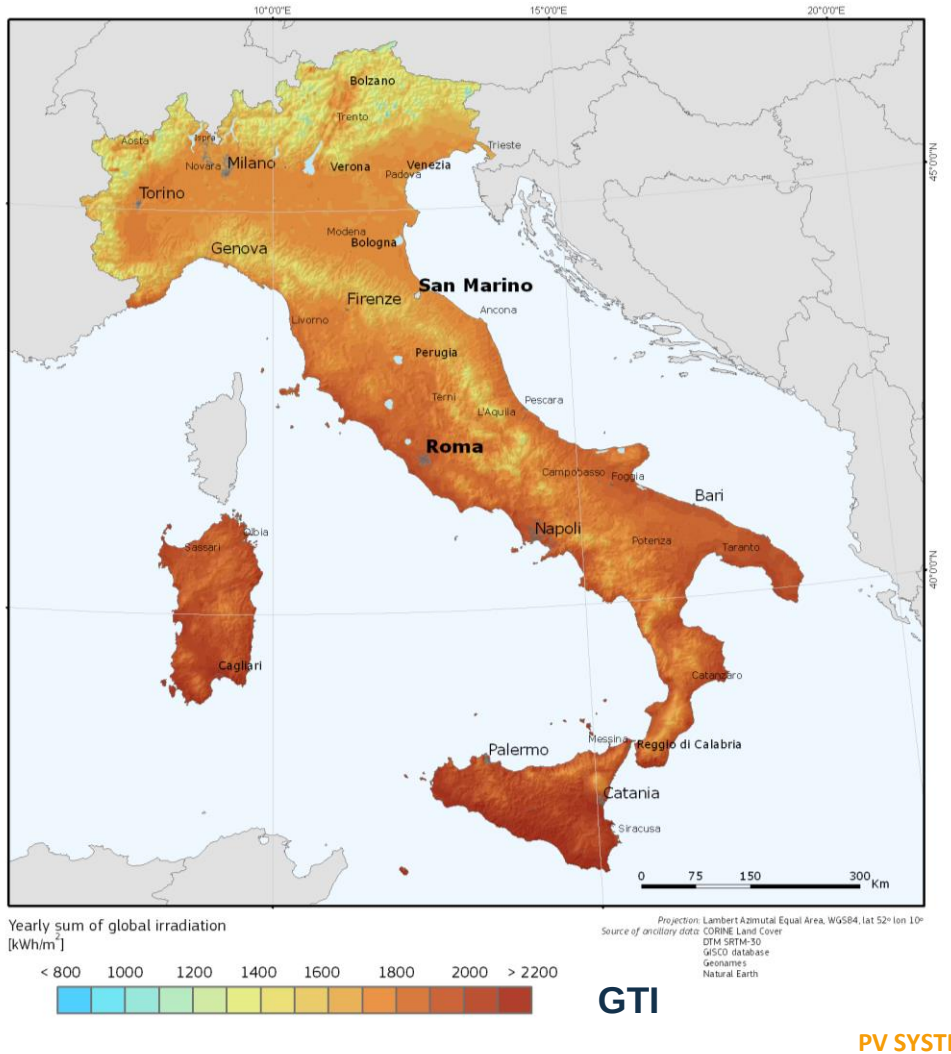
Example → $\min \{ 10\,\delta(GHI) + 1\,\delta(BNI) + 2\,\delta(T2) + 1\,\delta(WS) + 1\,\delta(RH) \}$

Solar Resource – Maps

Partner logo



GHI

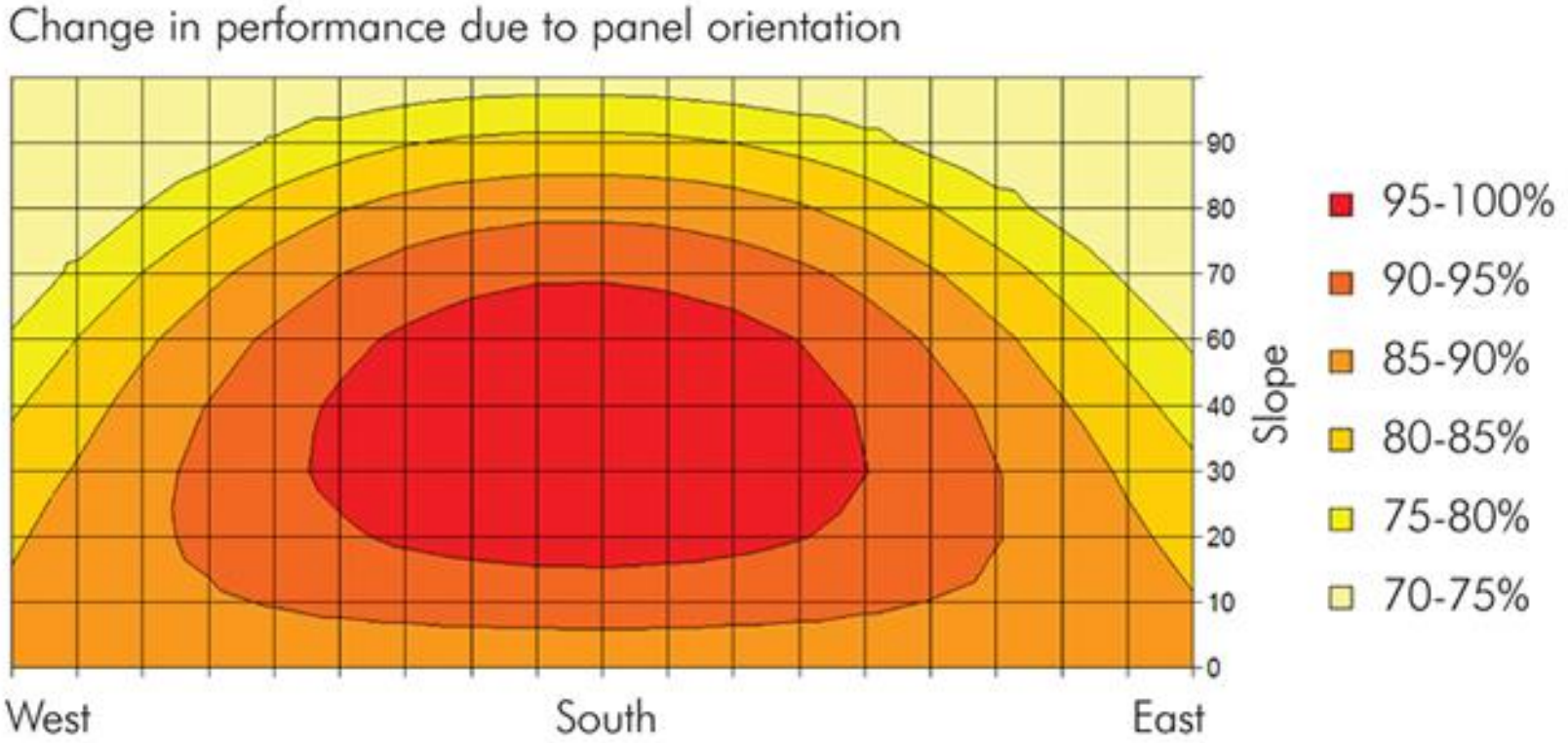


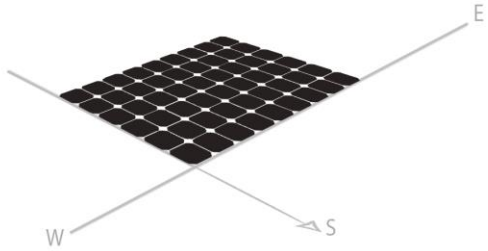
GTI

Solar Resource – In-plane choice

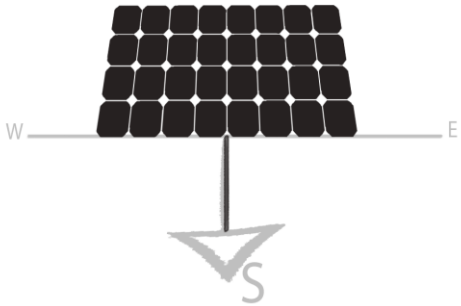
Partner logo

Tilt and Azimut impact on GTI





Tilt angle



Azimut angle

Solar Resource – Case Study

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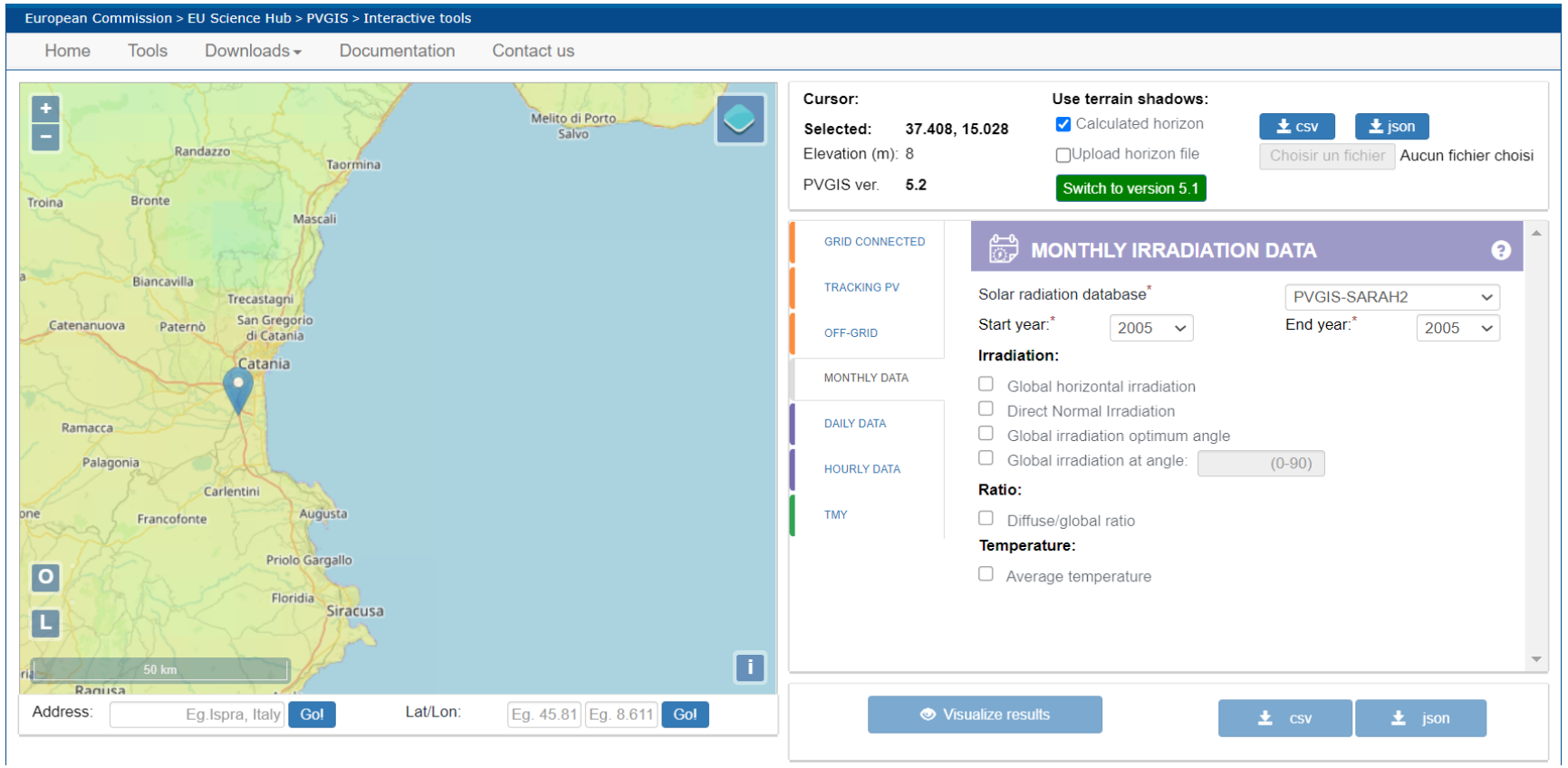
https://re.jrc.ec.europa.eu/pvg_tools/en/



Solar Resource & Site potential

Antoine DIZIER
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Agenda

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

Solar Resource – Shadings

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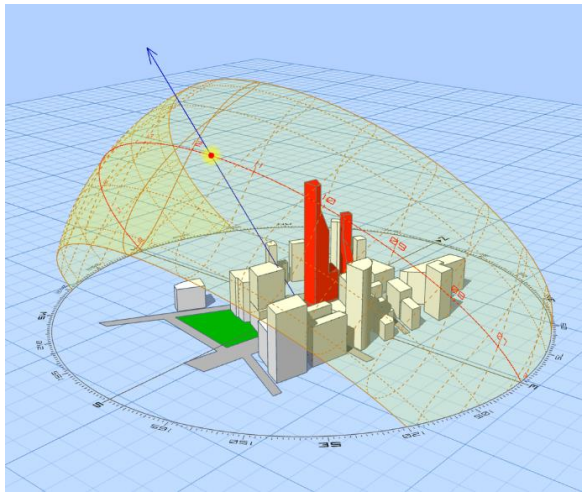
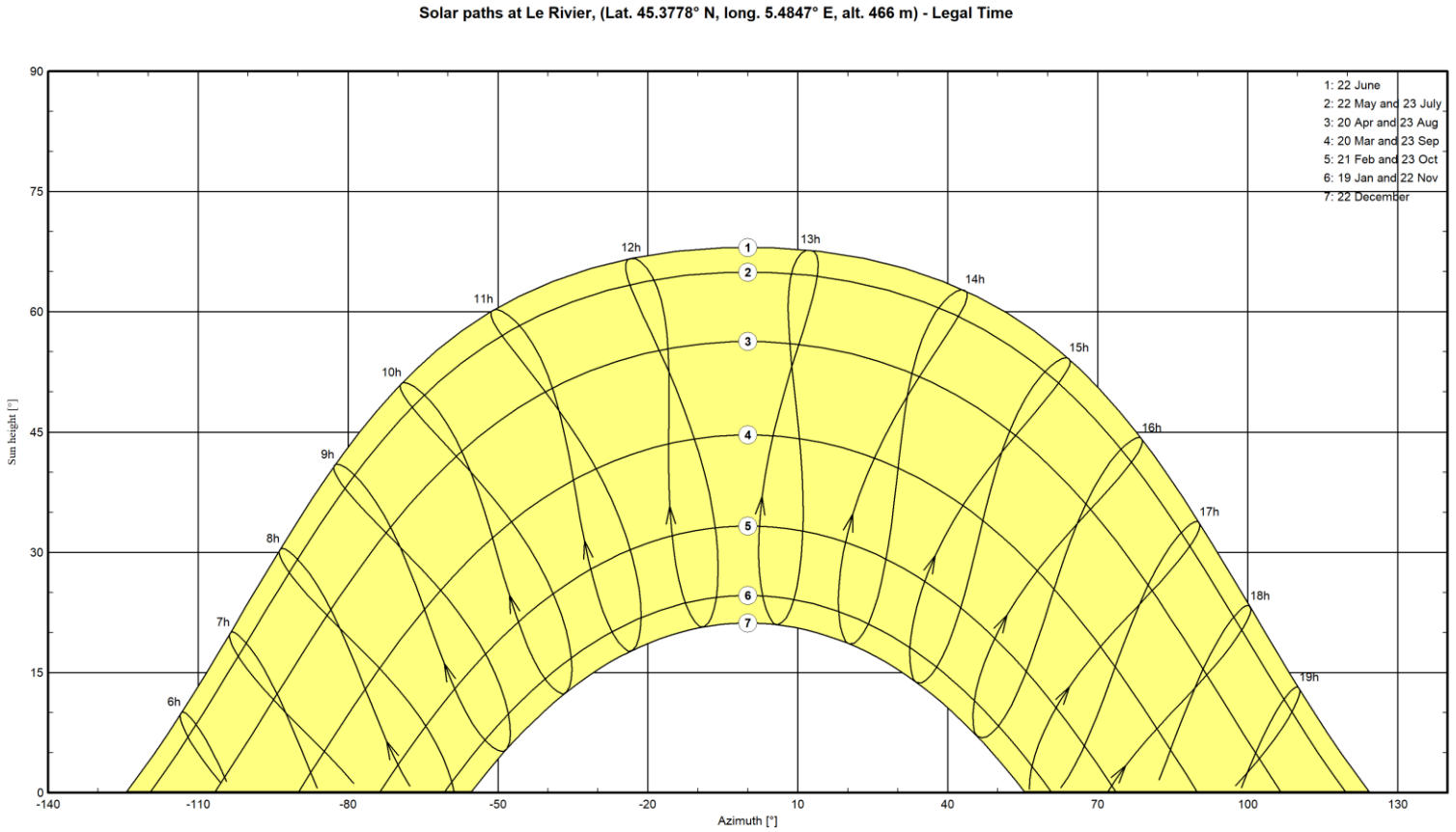
Shading analysis → Sun Path Diagram





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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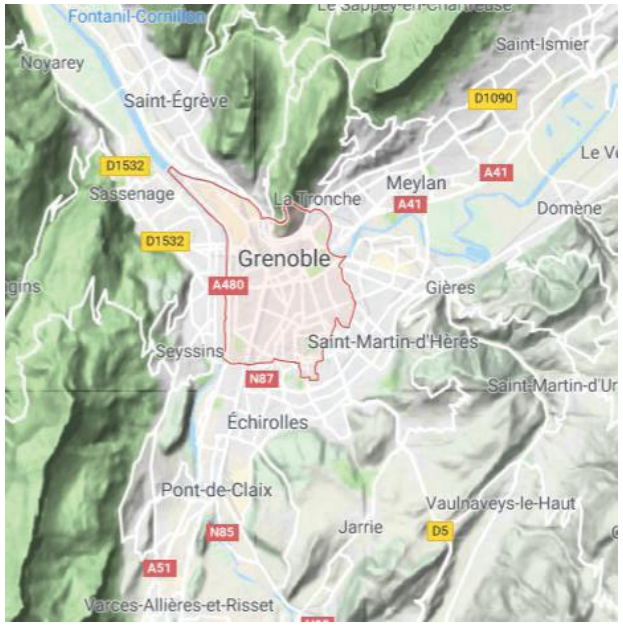
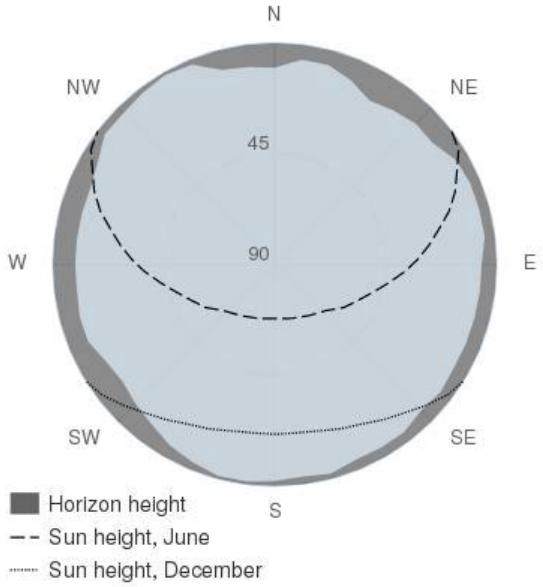
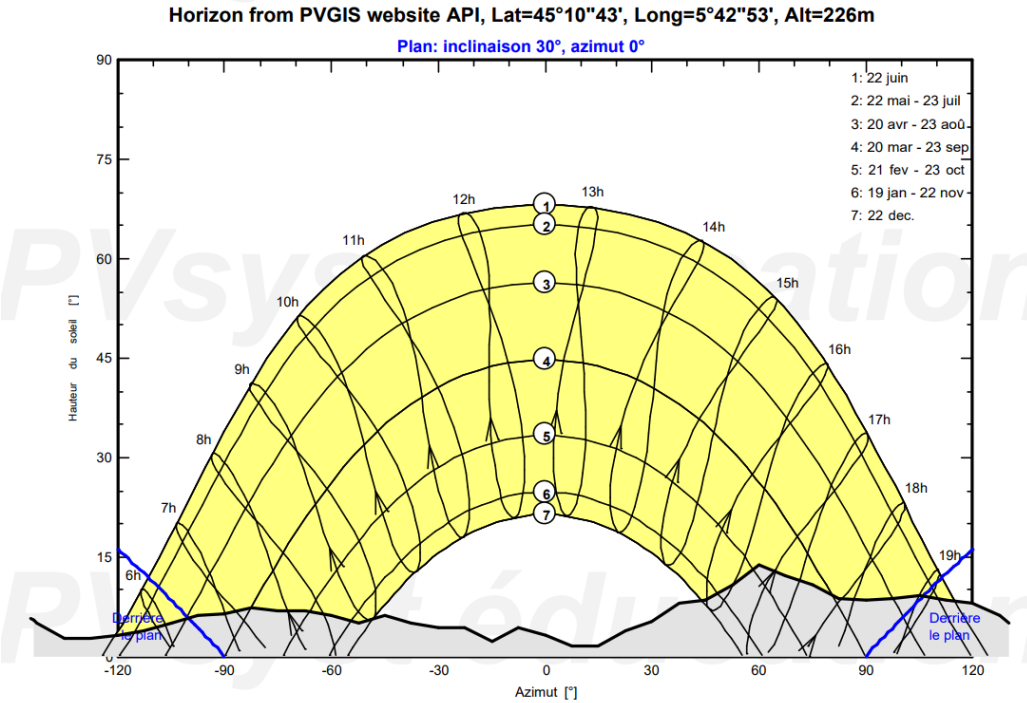
Far shadings can be analysed with satellite data







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

Solar Resource – Shadings

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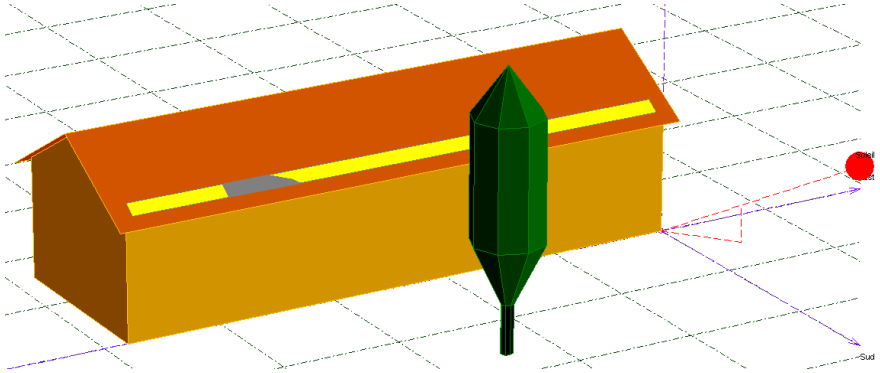
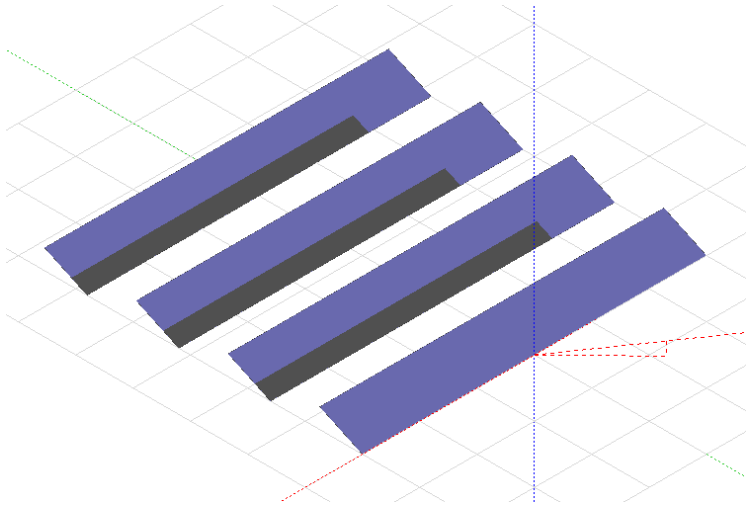
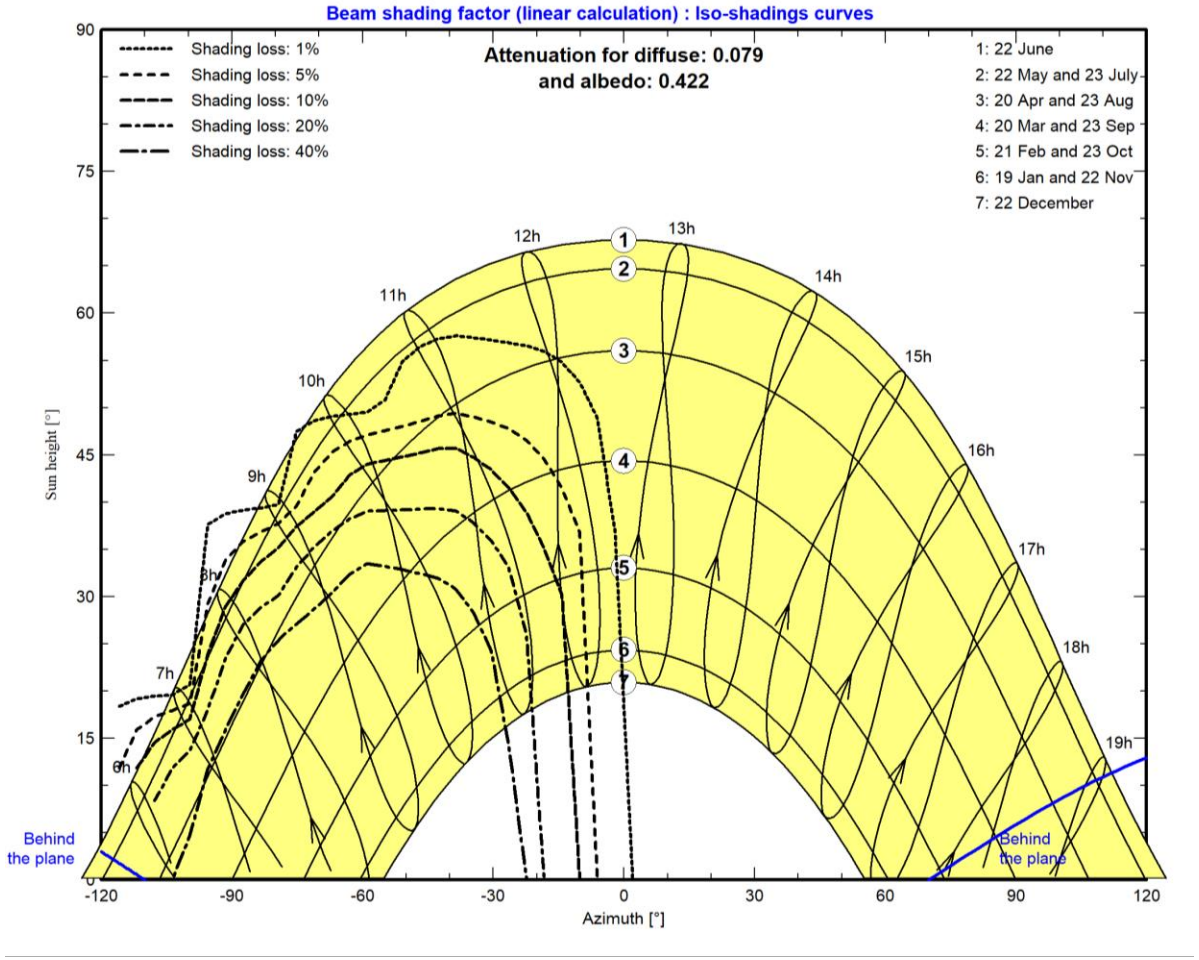
Near shadings have to be designed with a 3D modelling software







Solar Resource – Shadings

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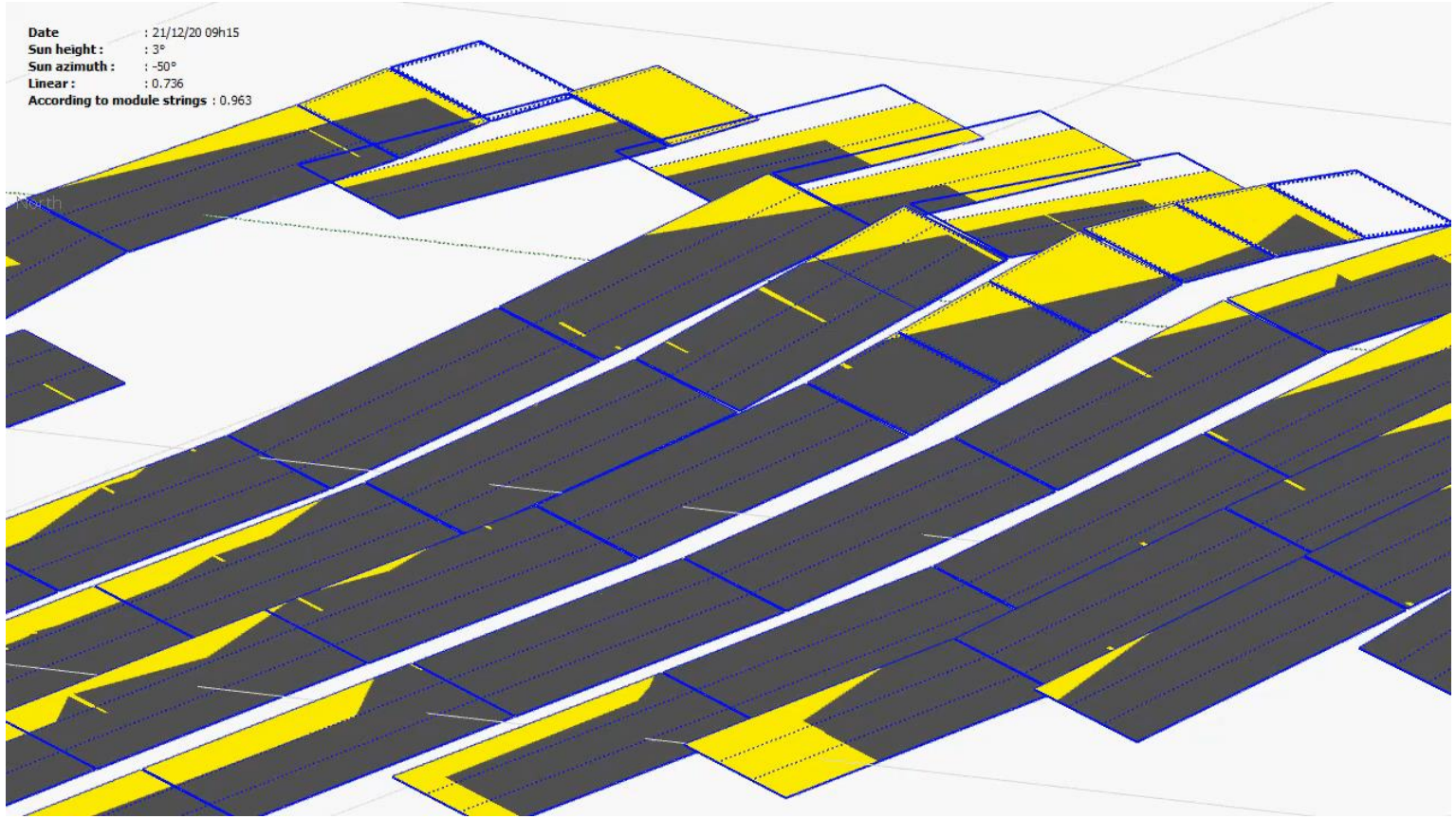
Near shadings have to be designed with a 3D modelling software



GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

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Thank you for your attention!

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