INSTITUTO
DOM LUIZ

Introduction to energy harvesting and simulation of PV systems

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MOTIVATION

As a part of the solar energy engineering process, doing a Solar PV Simulation is necessary.

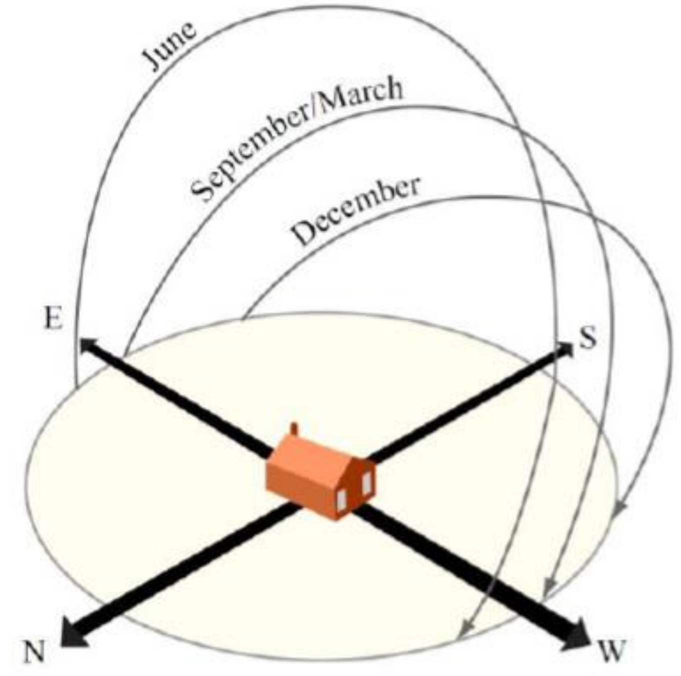
Whether it be a residential solar project, a solar PV system for building, or a grid-scale PV project, solar PV simulation is important.

OUTLINE

The solar resource
A simple and fast tool to start
Going from simple to complex simulation

Solar resource

- Earth-Sun motion
  - Solar declination: angle between line joining centres of Earth and Sun and the equatorial plane



Building orientation with the long axis facing south

$$\delta = \pi \frac{23.45}{180} \sin\left(2\pi \frac{284+n}{365}\right)$$

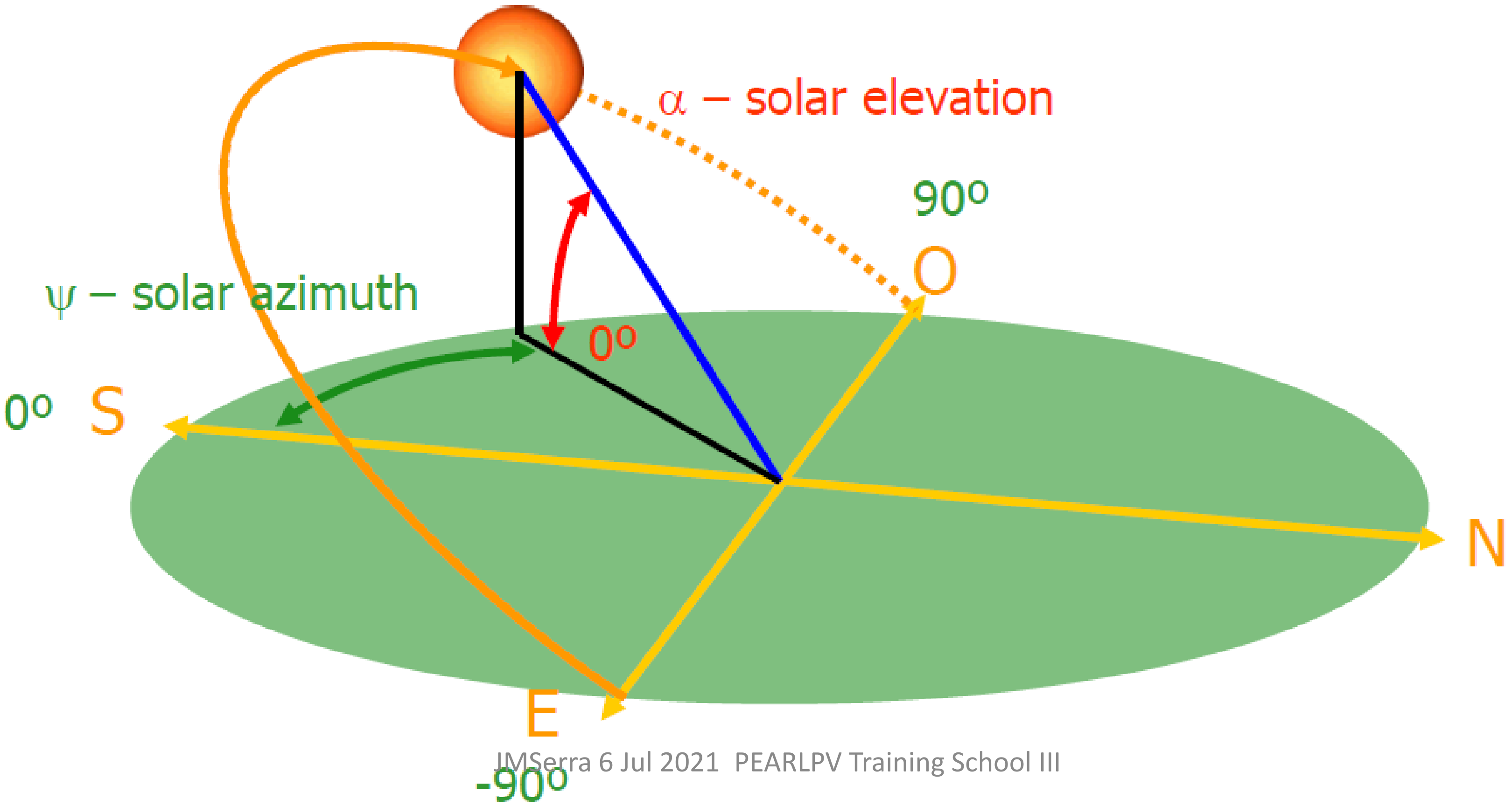
Declination in radians; n is the number of the day (Jan 1st = 1)

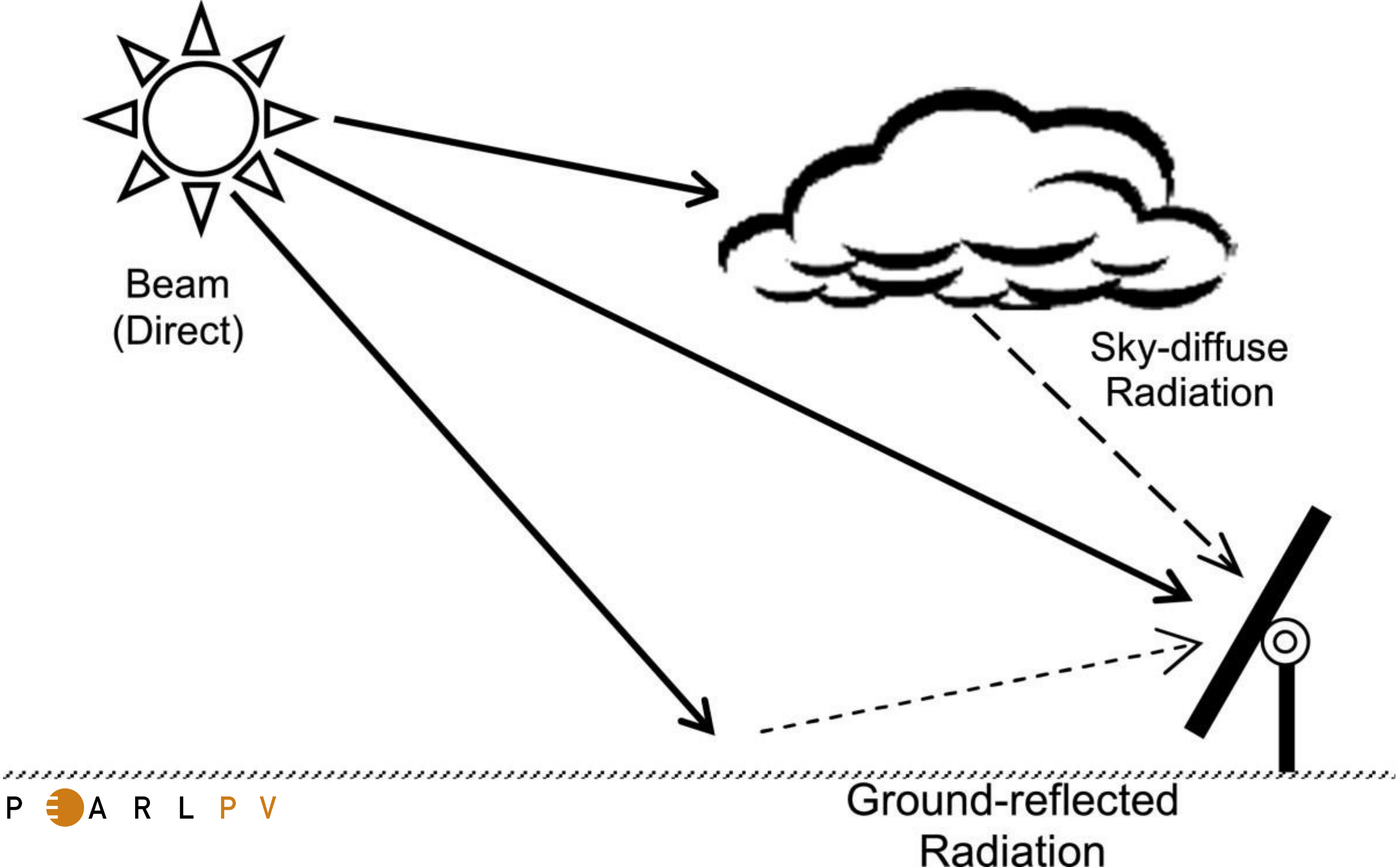
Solar resource

- Earth-Sun motion

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi$$

$$\cos\psi = \frac{\sin\alpha\sin\phi - \sin\delta}{\cos\alpha\cos\phi}$$

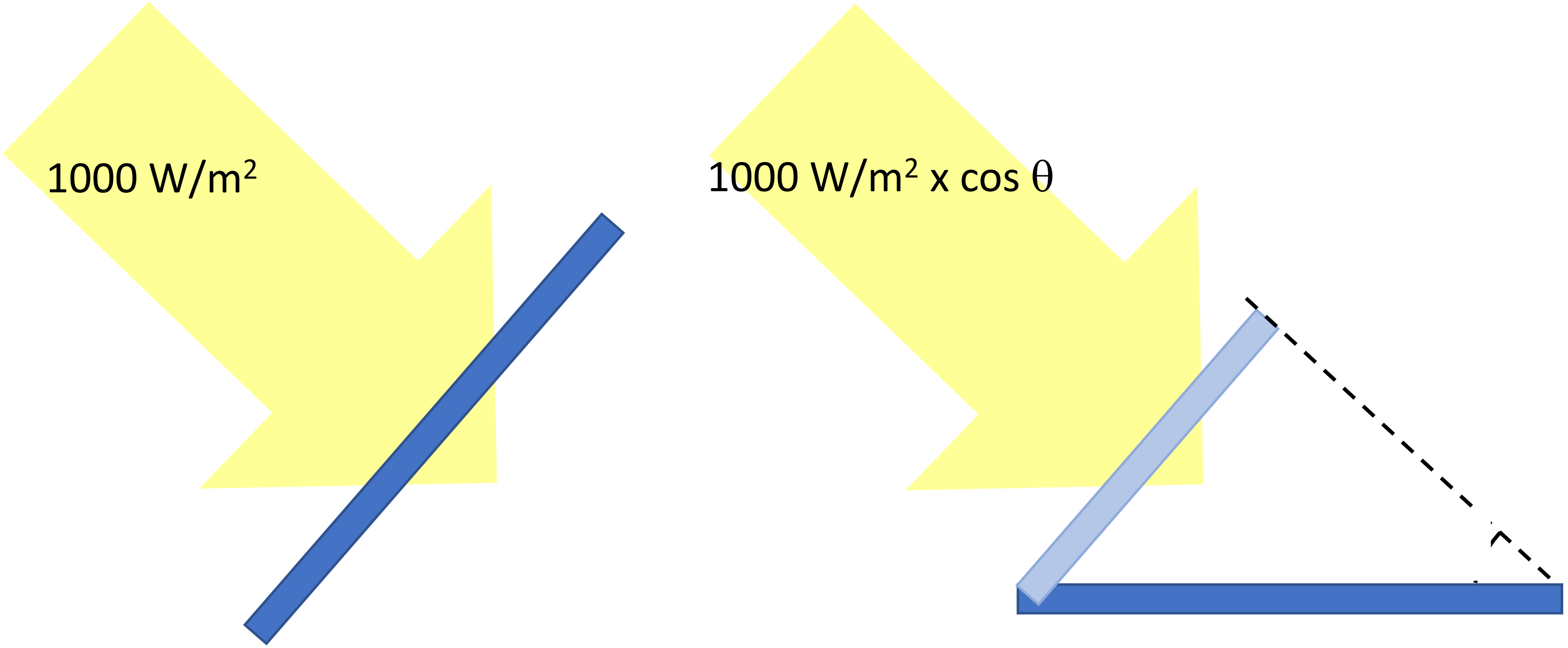



Beam
(Direct)
Sky-diffuse
Radiation
Ground-reflected
Radiation

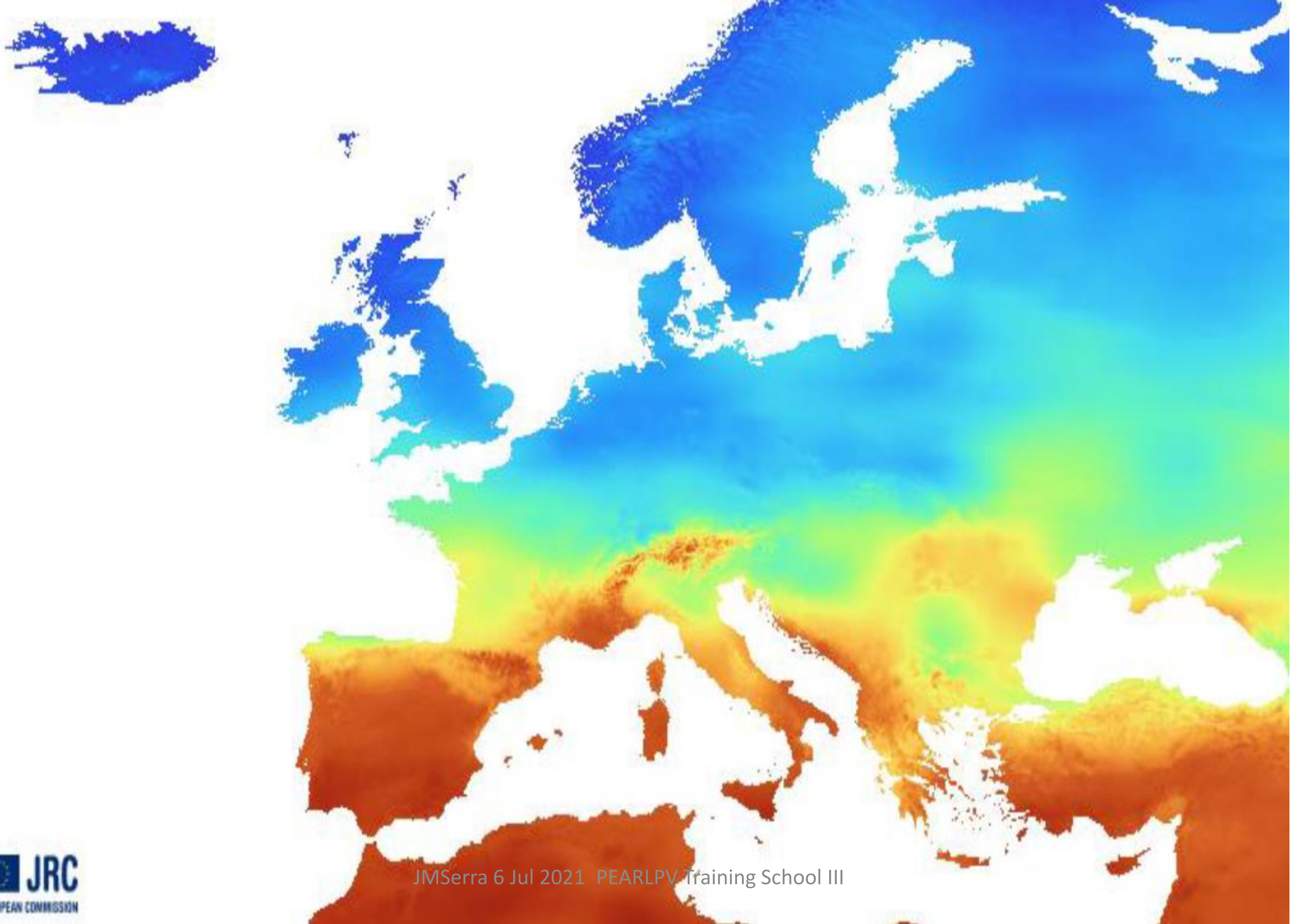
P A R L P V

PV MODULE TILT

Energy generation depends on the angle of incidence



Yearly sum of global irradiation on optimally-inclined surface (kWh/m²)
period 1981-1990



JRC
EUROPEAN COMMISSION

Some facts about PV in cities

- Most of the consumption happens in cities
- 2% of the area but 75% resource consumption
- Local generation avoids transport losses
- Lower investments in the transport grid
- More reliable because the system is tolerant to system faillures

P EARL PV

Role of photovoltaics in cities - Architectural aspects

Architecture in cities are a big driver for innovation and boosting the energy transition

- Solar skins Increasing renovation rates in cities,
- new buildings with BIPV

- For example, the EU Smart Cities Lighthouse Projects are striving towards Positive Energy Districts (PEDs).

- These projects bring together various stakeholders, such as real estate developers, construction companies, network operators, utility companies and many others, that will play a vital role as solution providers

- For example, Groningen’s approach to the energy transition has served the city to be appointed the title 'Lighthouse City' by the European Commission.

Small scale

- Urban furniture
- Social sharing/interaction points

Larger scale

- PV Facades

Even larger scale

BIPV and large power plants

SOLAR POTENTIAL SIMULATION

Basic: Indicates irradiation levels and their categorisation (e.g. high, medium, low irradiation values).

Medium: Indicates irradiation levels, solar system outputs, categorisation of suitable area for solar production and system effect.

Advanced: Indicates irradiation levels, system (PV, thermal) output, categorisation of suitable area for solar production, system effect, monthly output, financial considerations, information about installers and data regarding solar energy.

PV SYSTEMS SIMULATION GENERAL CHARACTERISTICS

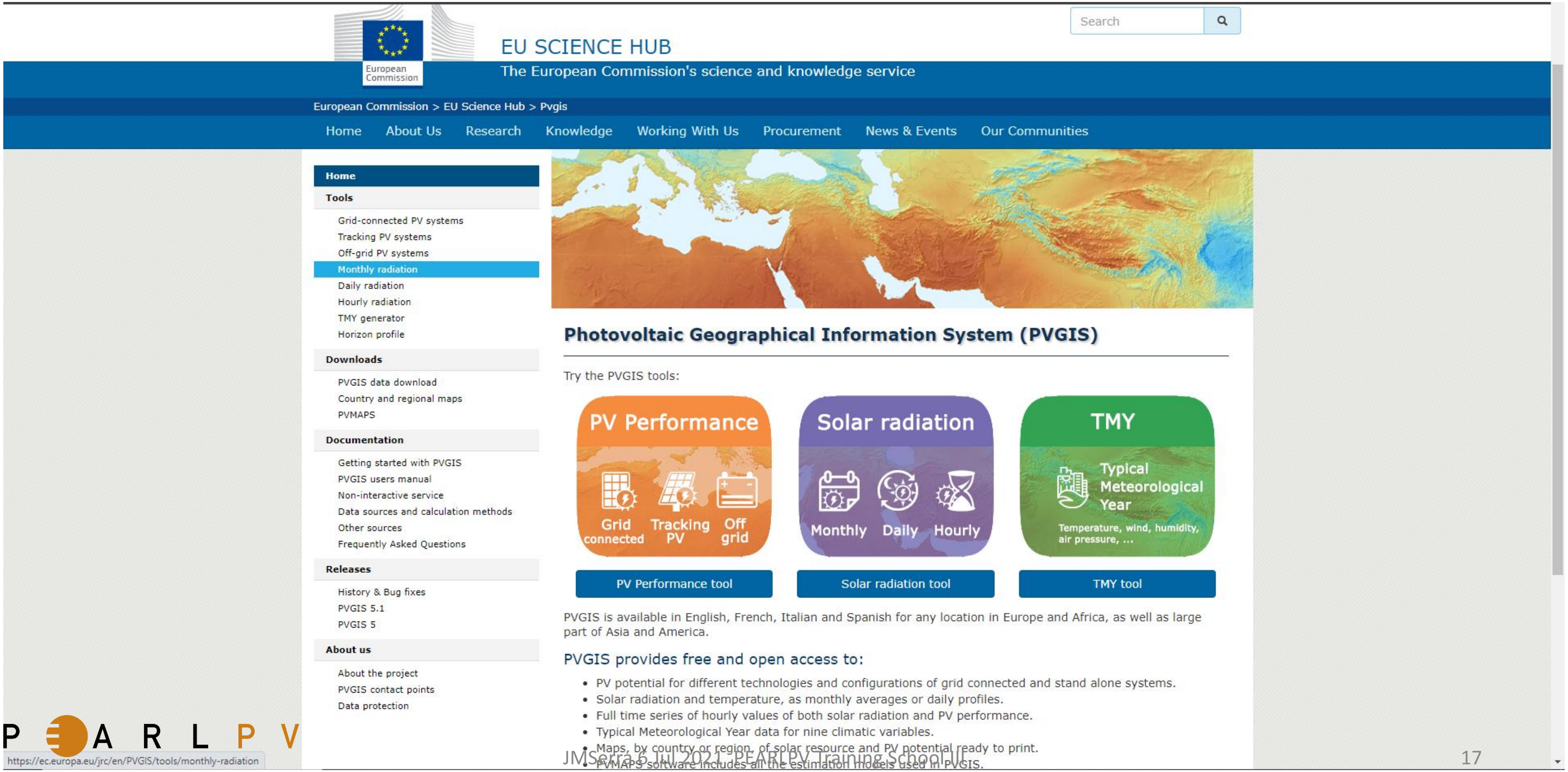
Solar PV Software Inputs:
Project/site location
Quantity, specifications of solar PV modules and inverters
Configuration of solar PV Strings
Solar PV tilt angle and azimuth
Total cost of the project
Electricity costs/tariff from utilities
Battery/electrical storage specifications and others

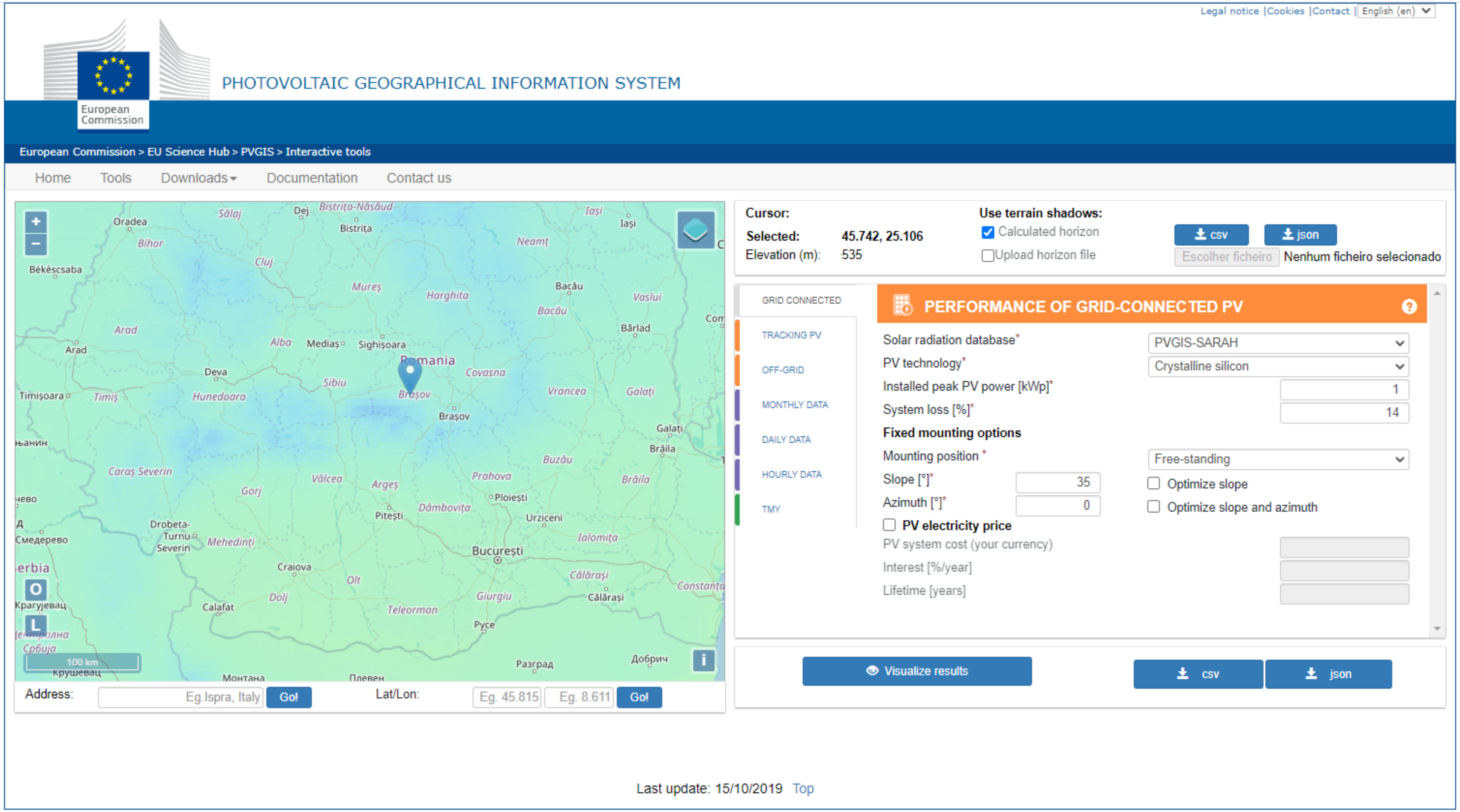
Solar PV Software Outputs:
Solar energy yield in kWh
Financial analysis
Technical reports

Examples of PV simulation software (alphabetic order)
Aurora Solar
Helioscope
Homer
PVSol Premium
PVSyst
Solar Pro by Laplace Systems
SAM
PVLib

And more...

A simple and fast tool to start





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European Commission
PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM
European Commission > EU Science Hub > PVGIS > Interactive tools
Home
Tools
Downloads
Documentation
Contact us
Cursor:
Selected: 45.742, 25.106
Elevation (m): 535
Use terrain shadows:
Calculated horizon
Upload horizon file
csv
json
Escolher ficheiro
Nenhum ficheiro selecionado
GRID CONNECTED
TRACKING PV
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY
PERFORMANCE OF GRID-CONNECTED PV
Solar radiation database* PVGIS-SARAH
PV technology* Crystalline silicon
Installed peak PV power [kWp]* 1
System loss [%]* 14
Fixed mounting options
Mounting position * Free-standing
Slope [°]* 35
Optimize slope
Azimuth [°]* 0
Optimize slope and azimuth
PV electricity price
PV system cost (your currency)
Interest [%/year]
Lifetime [years]
Visualize results
csv
json
Address: Eg.Ispra, Italy Go!
Lat/Lon: Eg. 45.815 Eg. 8.611 Go!
Last update: 15/10/2019 Top

PERFORMANCE OF GRID-CONNECTED PV: RESULTS

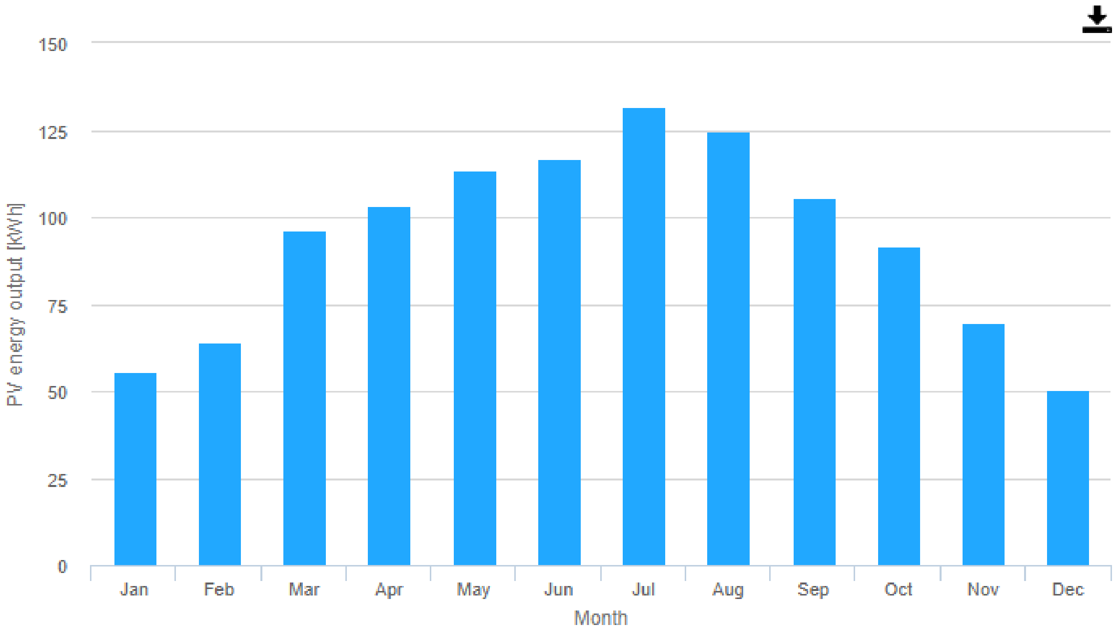
PV output | Radiation | Info | PDF

Summary

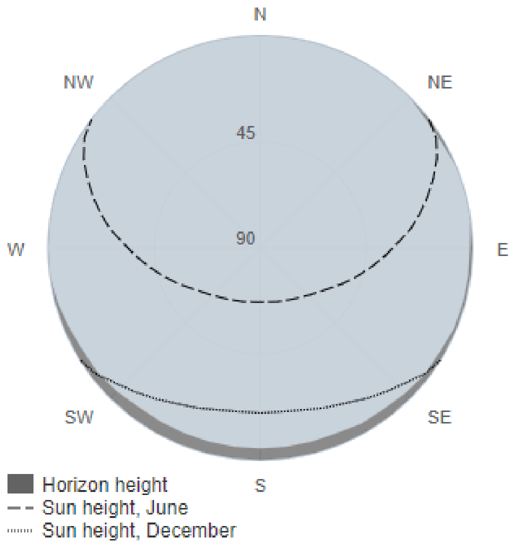
Provided inputs:	
Location [Lat/Lon]:	45.742, 25.106
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14

Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	1122.85
Yearly in-plane irradiation [kWh/m²]:	1409.41
Year-to-year variability [kWh]:	58.93
Changes in output due to:	
Angle of incidence [%]:	-2.96
Spectral effects [%]:	1.45
Temperature and low irradiance [%]:	-5.9
Total loss [%]:	-20.33

Monthly energy output from fix-angle PV system

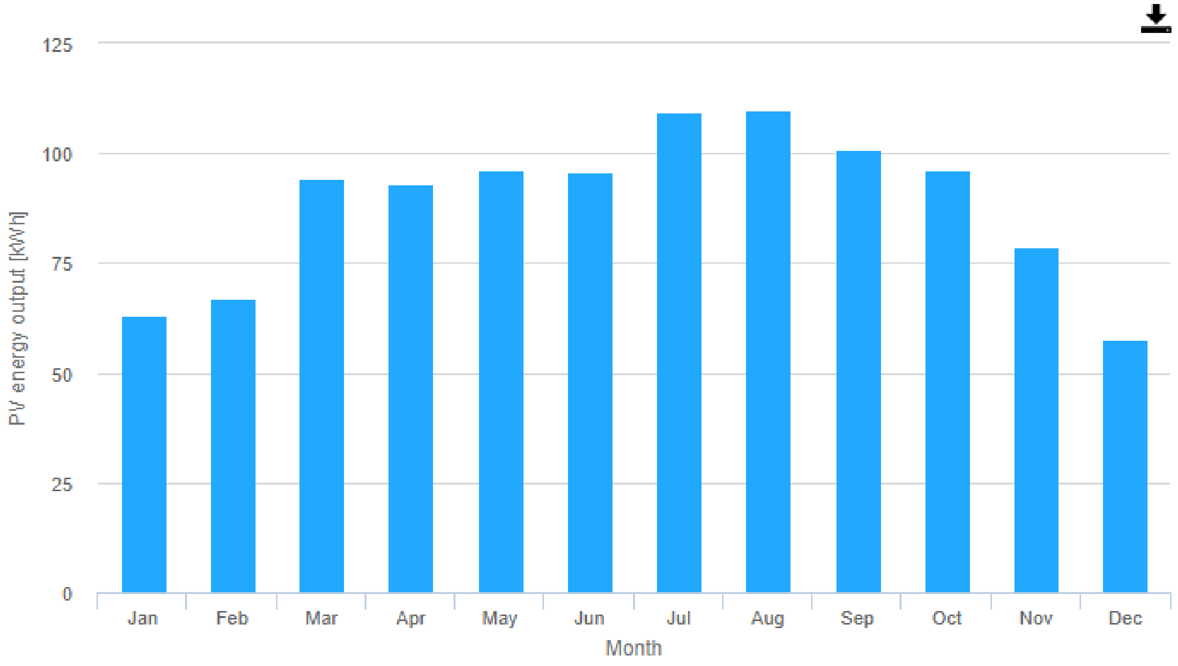


Outline of horizon

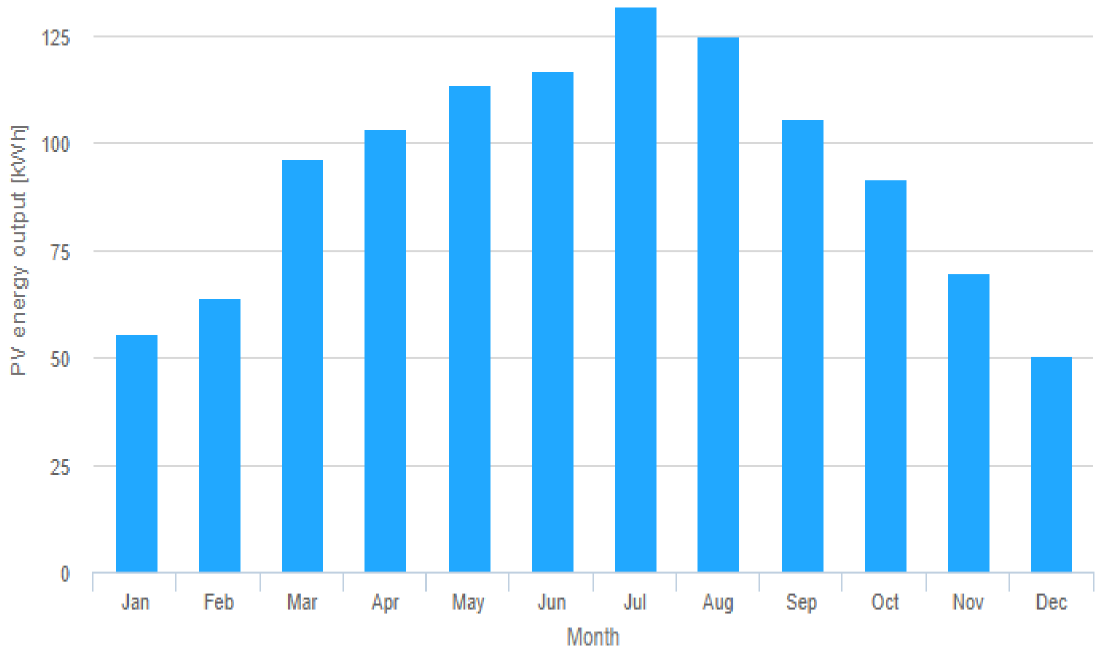


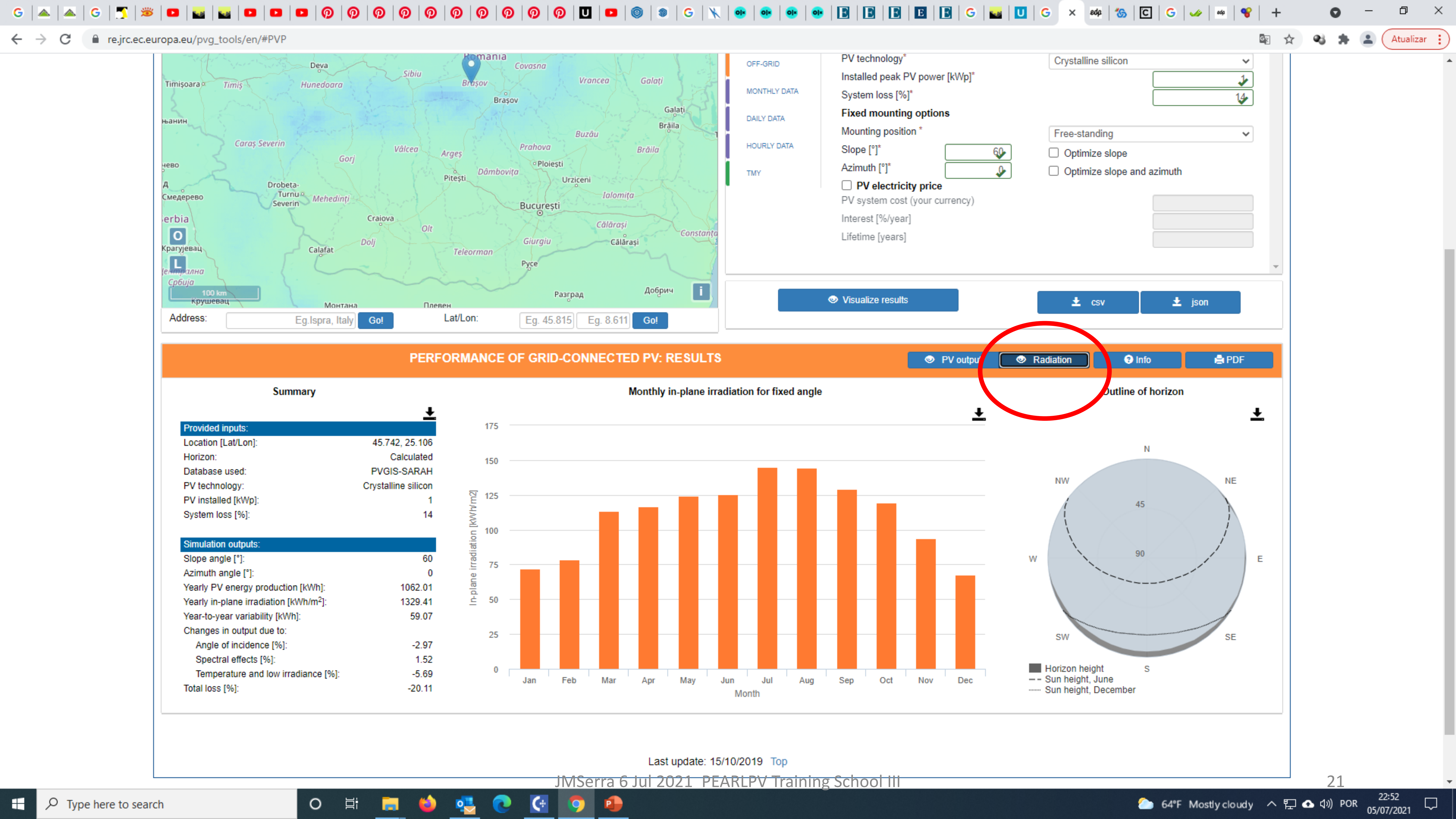
Last update: 15/10/2019 Top

Slope: 60º



Slope: 35º




re.jrc.ec.europa.eu/pvg_tools/en/#PVP
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY
PV technology*
Crystalline silicon
Installed peak PV power [kWp]*
1
System loss [%]*
14
Fixed mounting options
Mounting position *
Free-standing
Slope [°]*
60
Optimize slope
Azimuth [°]*
0
Optimize slope and azimuth
PV electricity price
PV system cost (your currency)
Interest [%/year]
Lifetime [years]
Visualize results
csv
json
Address:
Eg.Ispra, Italy
Go!
Lat/Lon:
Eg. 45.815
Eg. 8.611
Go!
PERFORMANCE OF GRID-CONNECTED PV: RESULTS
PV output
Radiation
Info
PDF
Summary
Provided inputs:
Location [Lat/Lon]: 45.742, 25.106
Horizon: Calculated
Database used: PVGIS-SARAH
PV technology: Crystalline silicon
PV installed [kWp]: 1
System loss [%]: 14
Simulation outputs:
Slope angle [°]: 60
Azimuth angle [°]: 0
Yearly PV energy production [kWh]: 1062.01
Yearly in-plane irradiation [kWh/m²]: 1329.41
Year-to-year variability [kWh]: 59.07
Changes in output due to:
Angle of incidence [%]: -2.97
Spectral effects [%]: 1.52
Temperature and low irradiance [%]: -5.69
Total loss [%]: -20.11
Monthly in-plane irradiation for fixed angle
In-plane irradiation [kWh/m2]
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Outline of horizon
N
NE
E
SE
S
SW
W
NW
Horizon height
Sun height, June
Sun height, December
Last update: 15/10/2019
Top

Building integrated PV

- BIPV issues
  - Inclination
  - Orientation
  - Shading
  - Temperature
  - Design
- PV & architecture
- Categories of BIPV
- PV integrated in public spaces

Buil

- Optimal inc etically it may not make sen
- Optimal orie region prone t

Building integrated PV

- Importance of shading – crucial during system & building design

  (micro-inverters make PV system more tolerant to shading mistakes)

Building integrated PV

- Importance of temperature: (ventilated) air gap behind module to keep ‘low’ module temperature (extra: insulating function!)
- Design!
  - ‘High-tech’ or ‘Green’ look
  - Replacement for other facade materials (e.g. office building)

Building integrated PV

- Importance of shading – crucial during system & building design (micro-inverters make PV system more tolerant to shading mistakes)
- Notice that high surrounding buildings may also alter (i.e. usually block!) diffusive light

ROOFTOPS SOLAR POTENTI

Why is it important?

- ❑ It is a urban planning tool
- ❑ It is a dissemination tool for cit

  What energy can I produce?

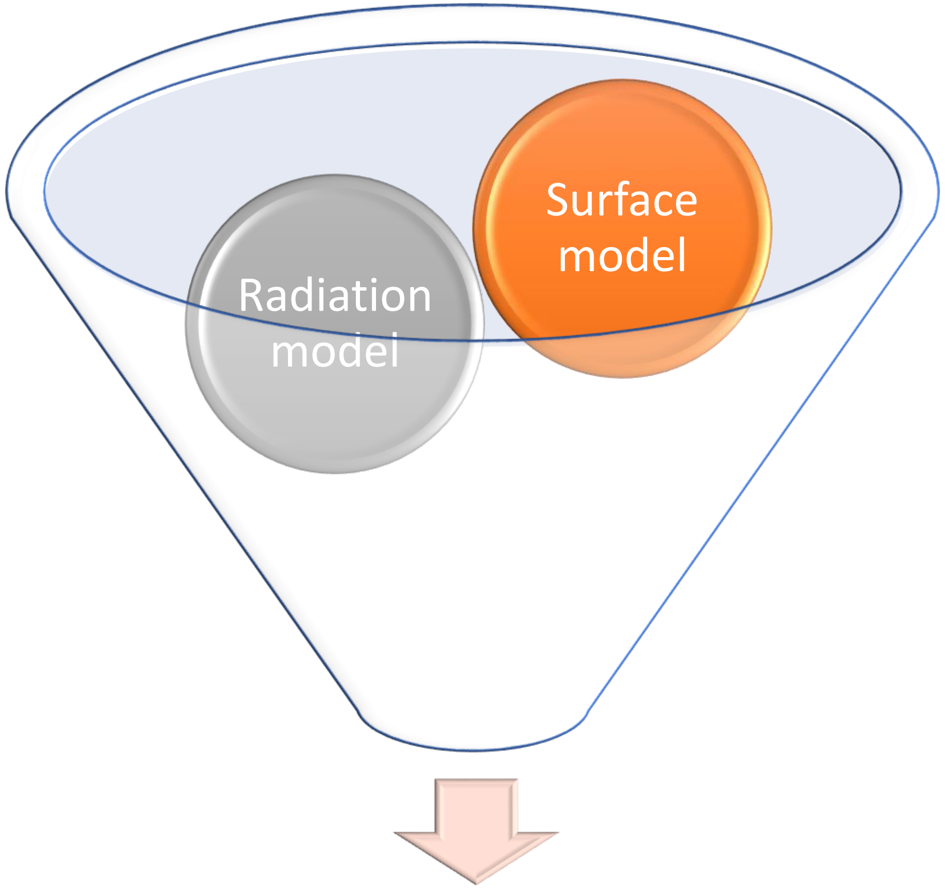
  How much will it cost?

  What is the payback time?

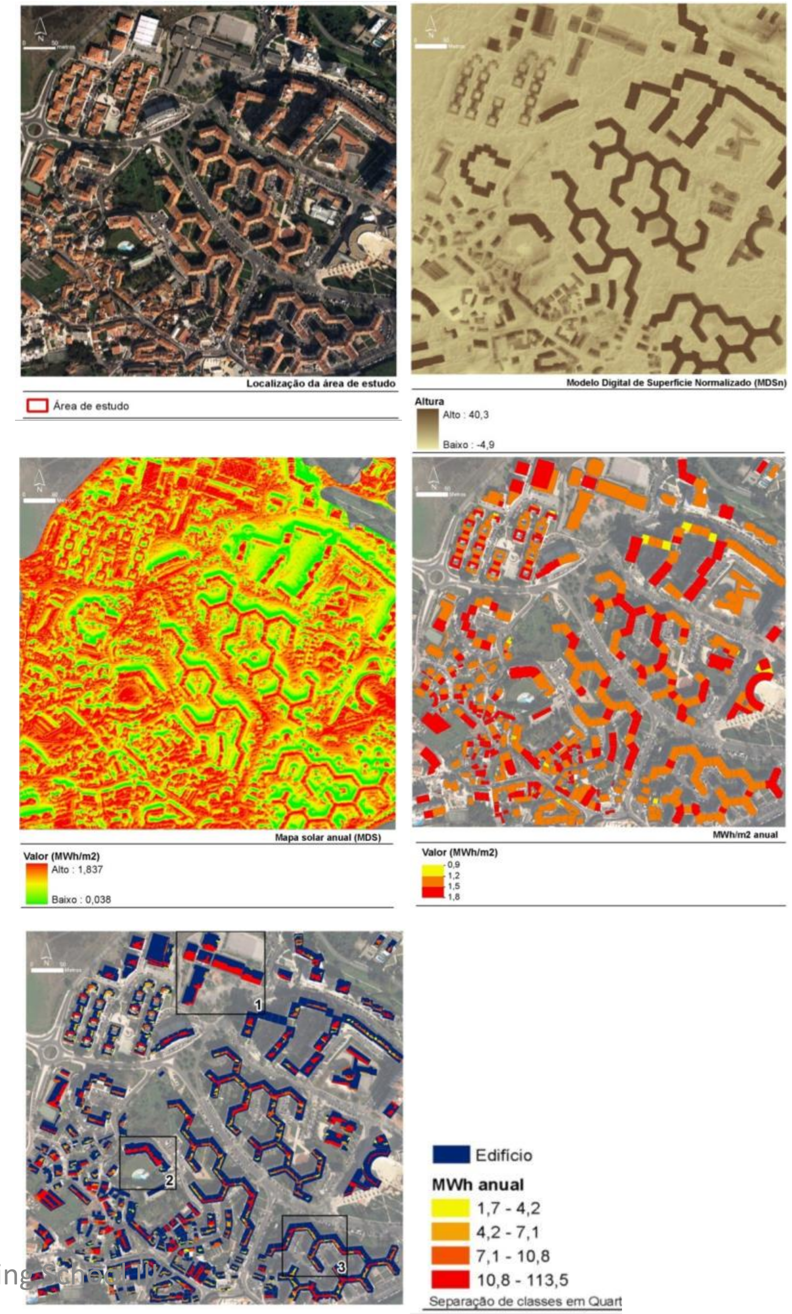
But this is not trivial because one must consider

- ❑ Shadowing between buildings
- ❑ Available rooftop area

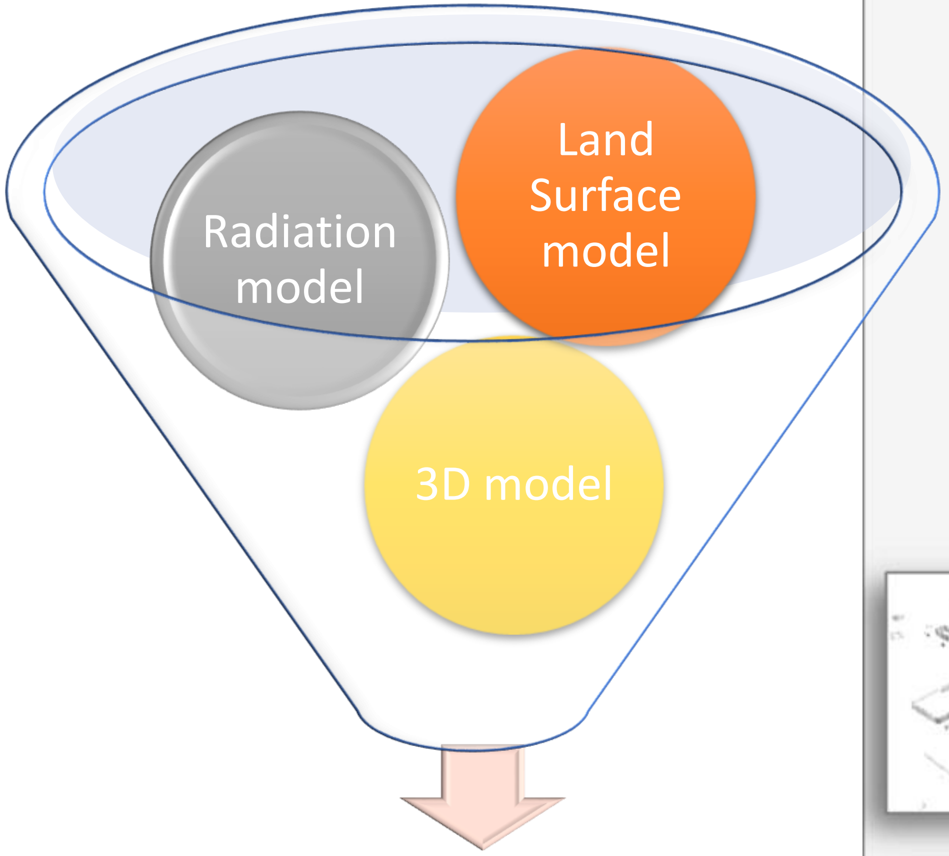
Role of photovoltaics in cities



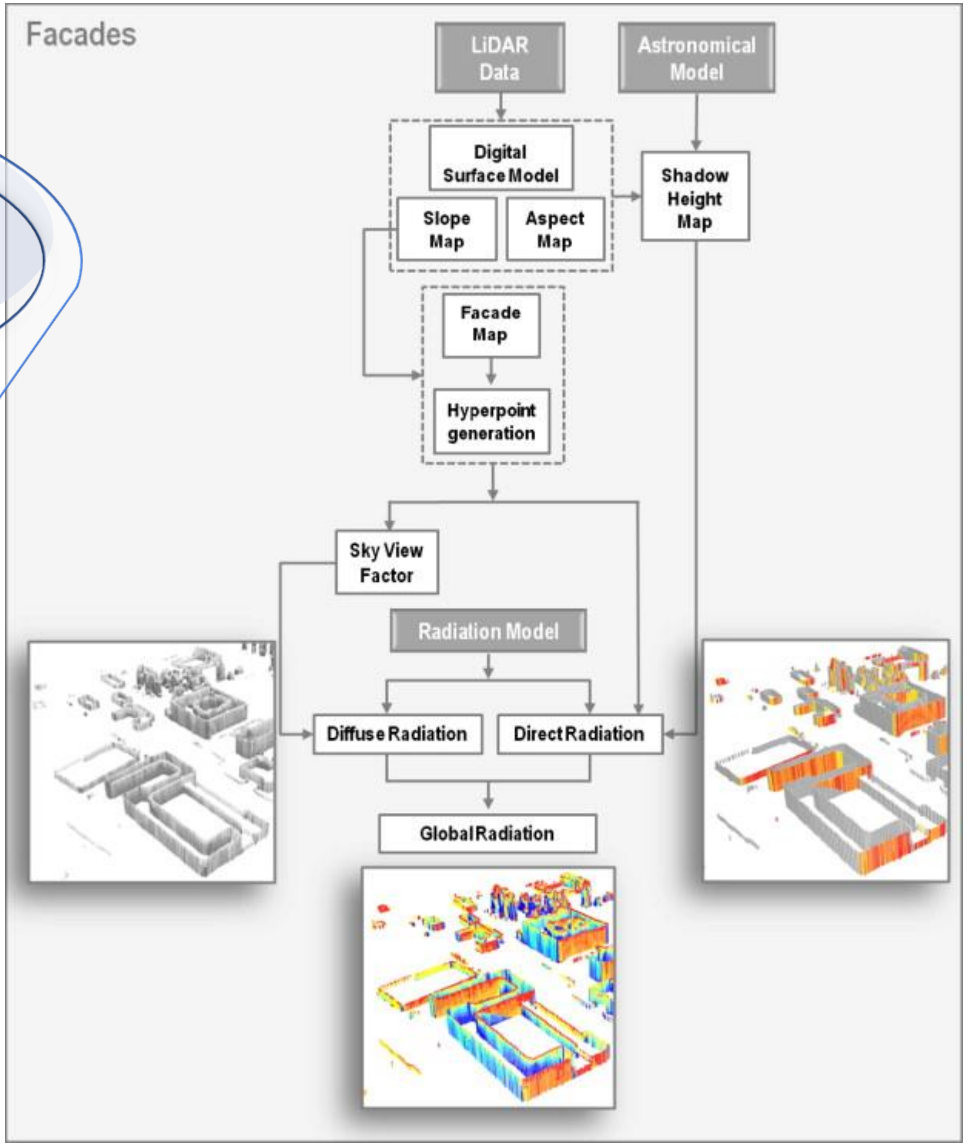
Solar potential map



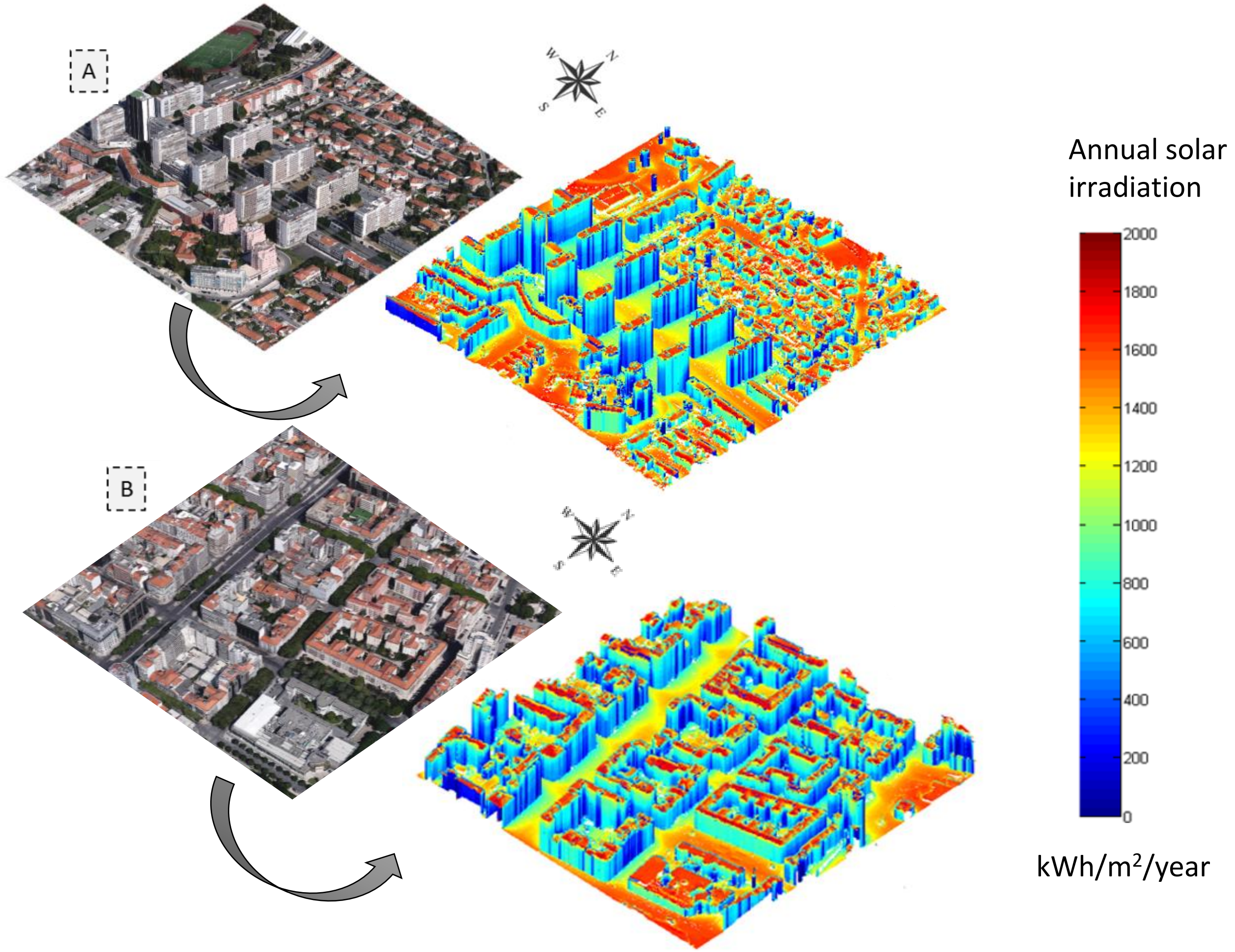
Role of photovoltaics in cities



Solar potential map

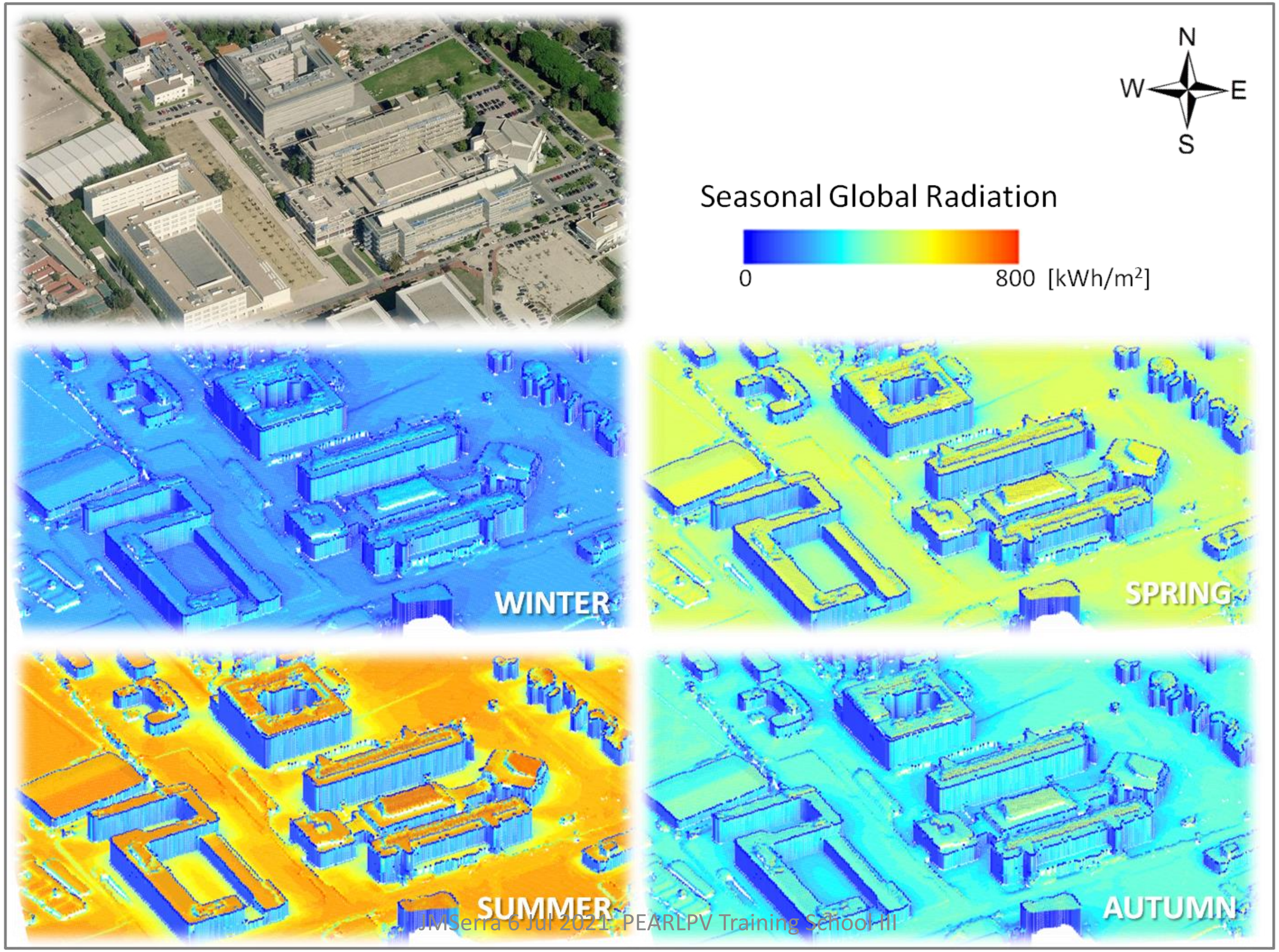


PV FACADES



A
B
Annual solar irradiation
2000
1800
1600
1400
1200
1000
800
600
400
200
0
kWh/m²/year

Role of photovoltaics in cities



Role of photovoltaics in cities

Solar radiation may be coupled with Augmented Reality tools:

Solar radiation on the facades – android application

SOLAR FAÇADES

We must distinguish several different situations with increasing complexity

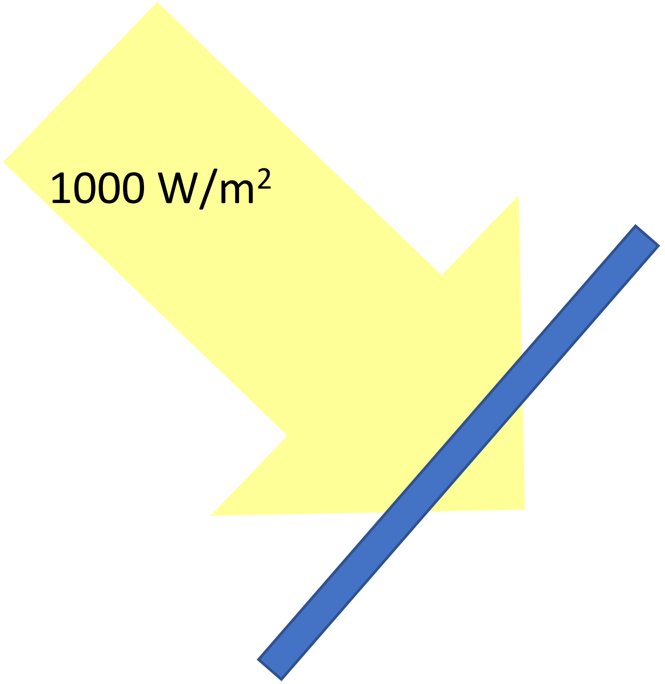
Pure flat surfaces

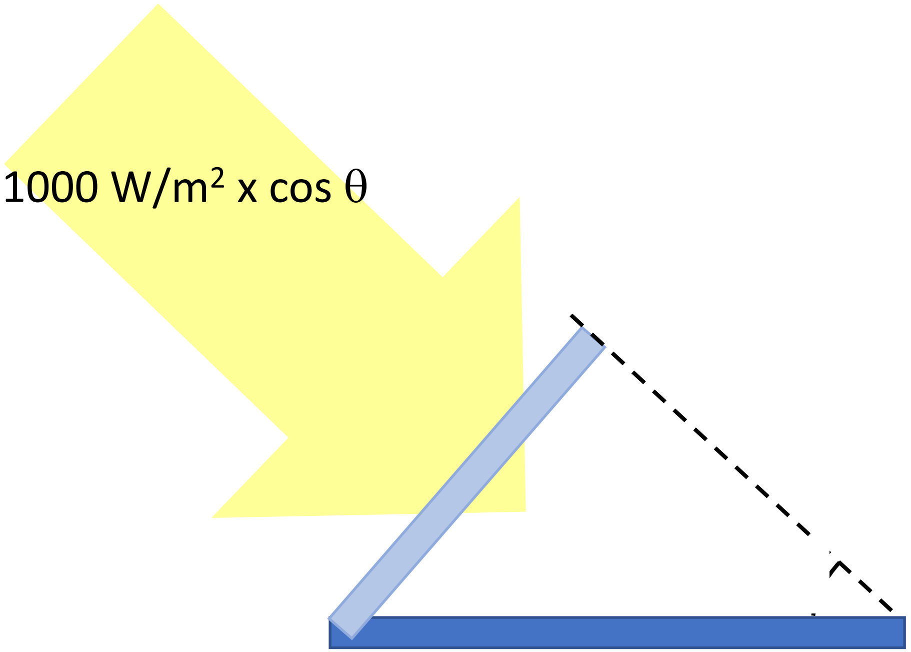
Flat surfaces with different orientations on a complex structure

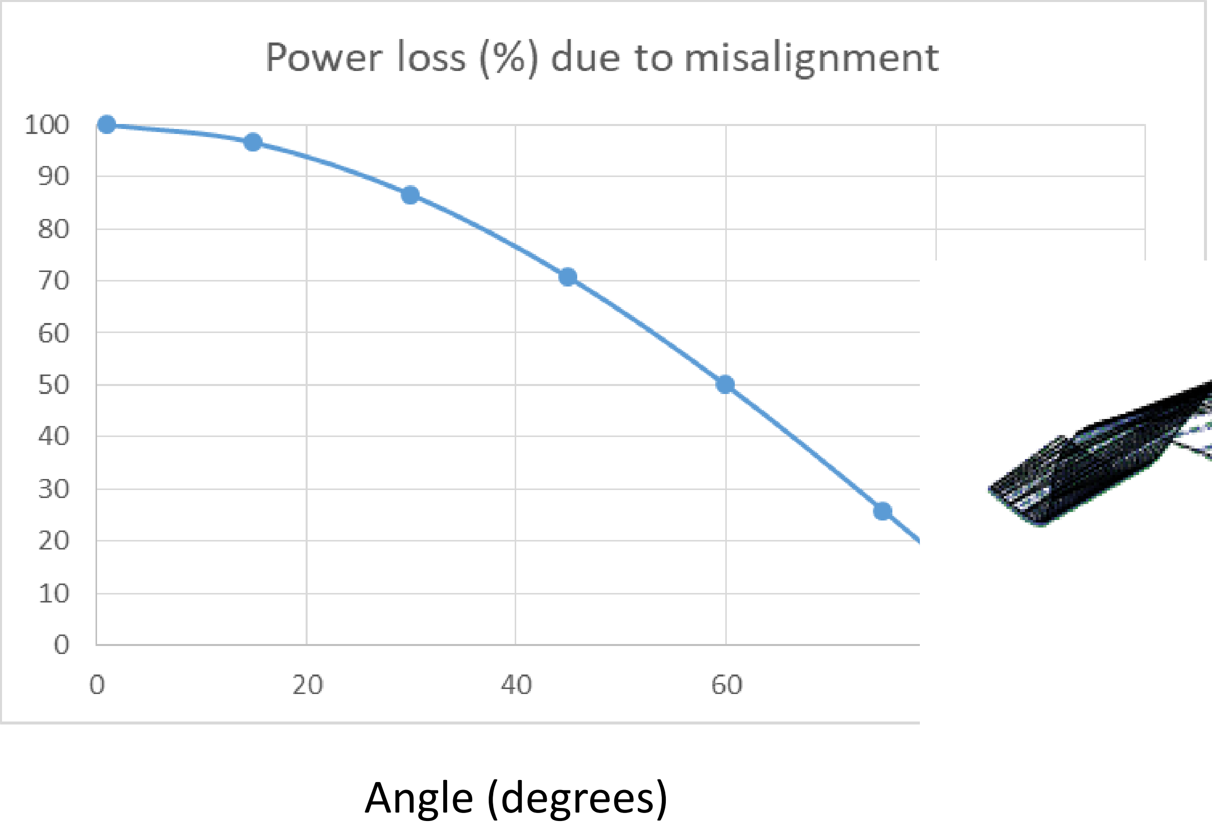
Partial shading

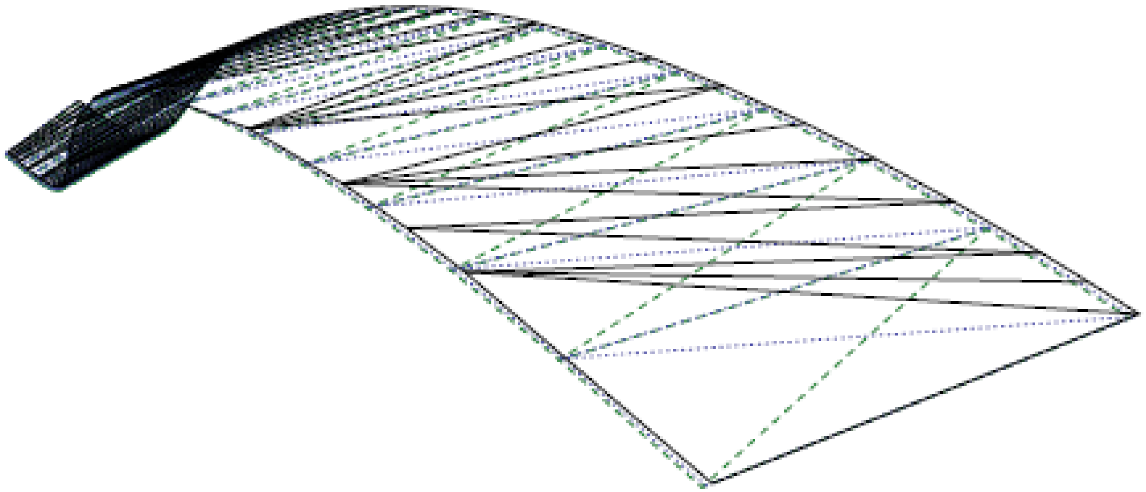
PV ENERGY

Energy generation depends on the angle of incidence

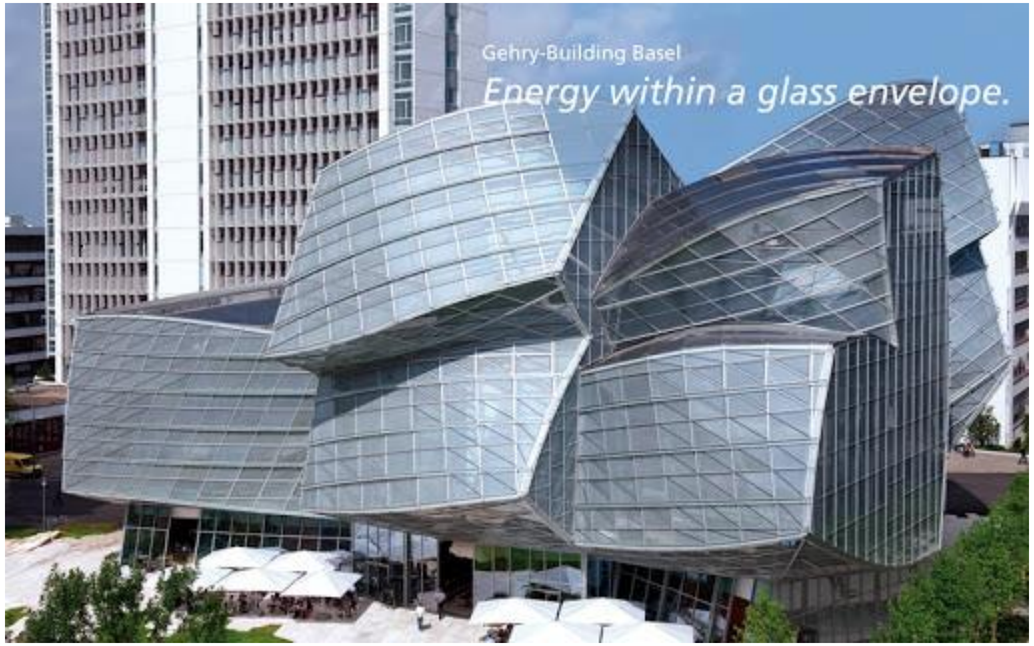





Power loss (%) due to misalignment
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
Angle (degrees)




UniCredit

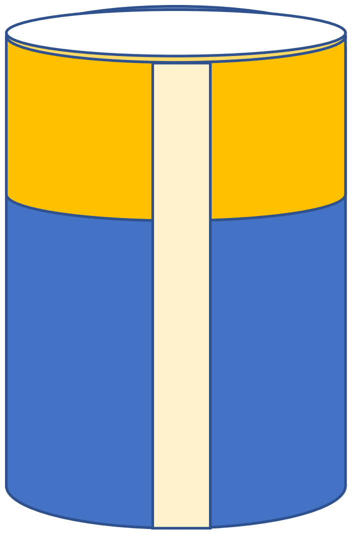

Gehry-Building Basel
Energy within a glass envelope.

PV systems working with curved surfaces

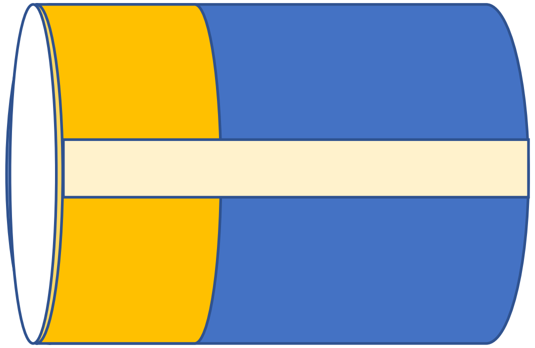
Even when we know to calculate the irradiance in a module, it does not translate easily into a power conversion in a straightforward way

Variable irradiance on curved surfaces can be alleviated by choosing a specific string connection that is adapted for the irradiance; for example.

Or choosing a string connection according to the dominating shadow we have in a façade.



The same technique can be applied in a curved surface on a large rooftop or large power plant



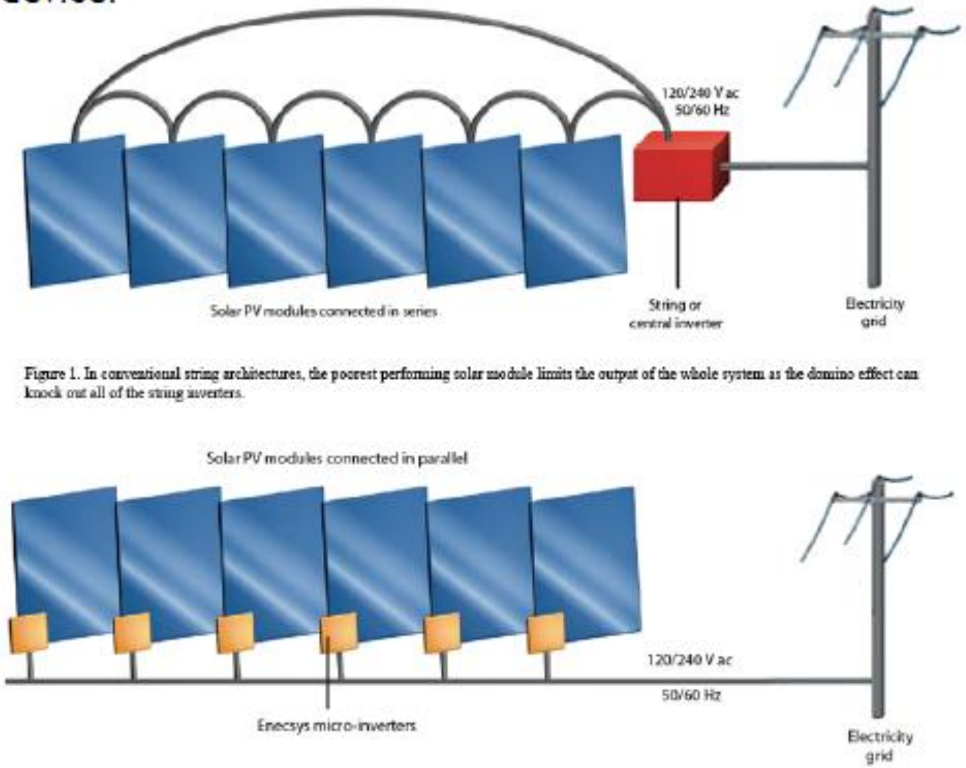
or by using individual micro inverters

SMART MODULES

Micro-inverters

PV module becomes AC device.

Easier installation.

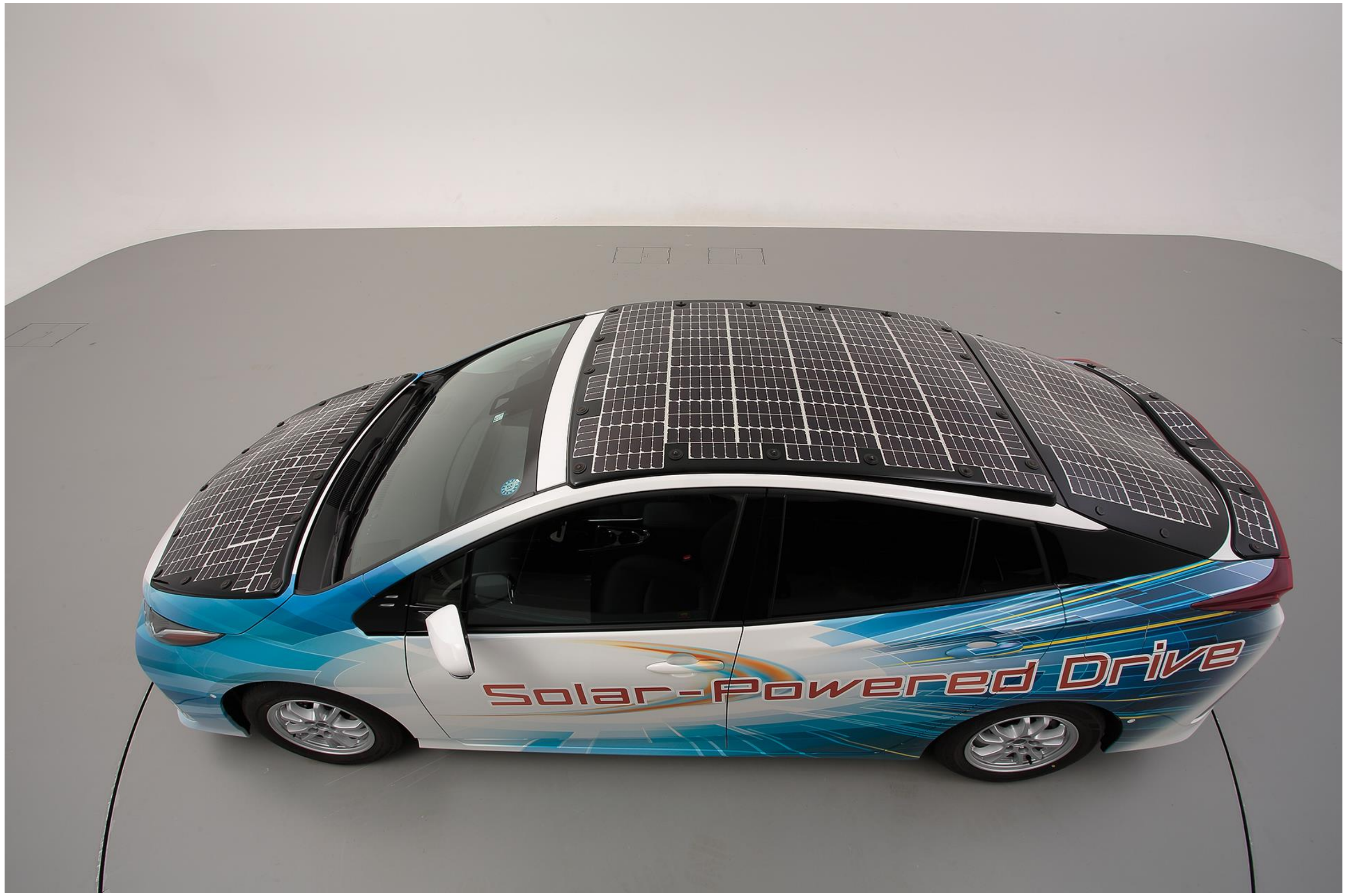


www.enecsys.com

Things get more complicated when you find this...

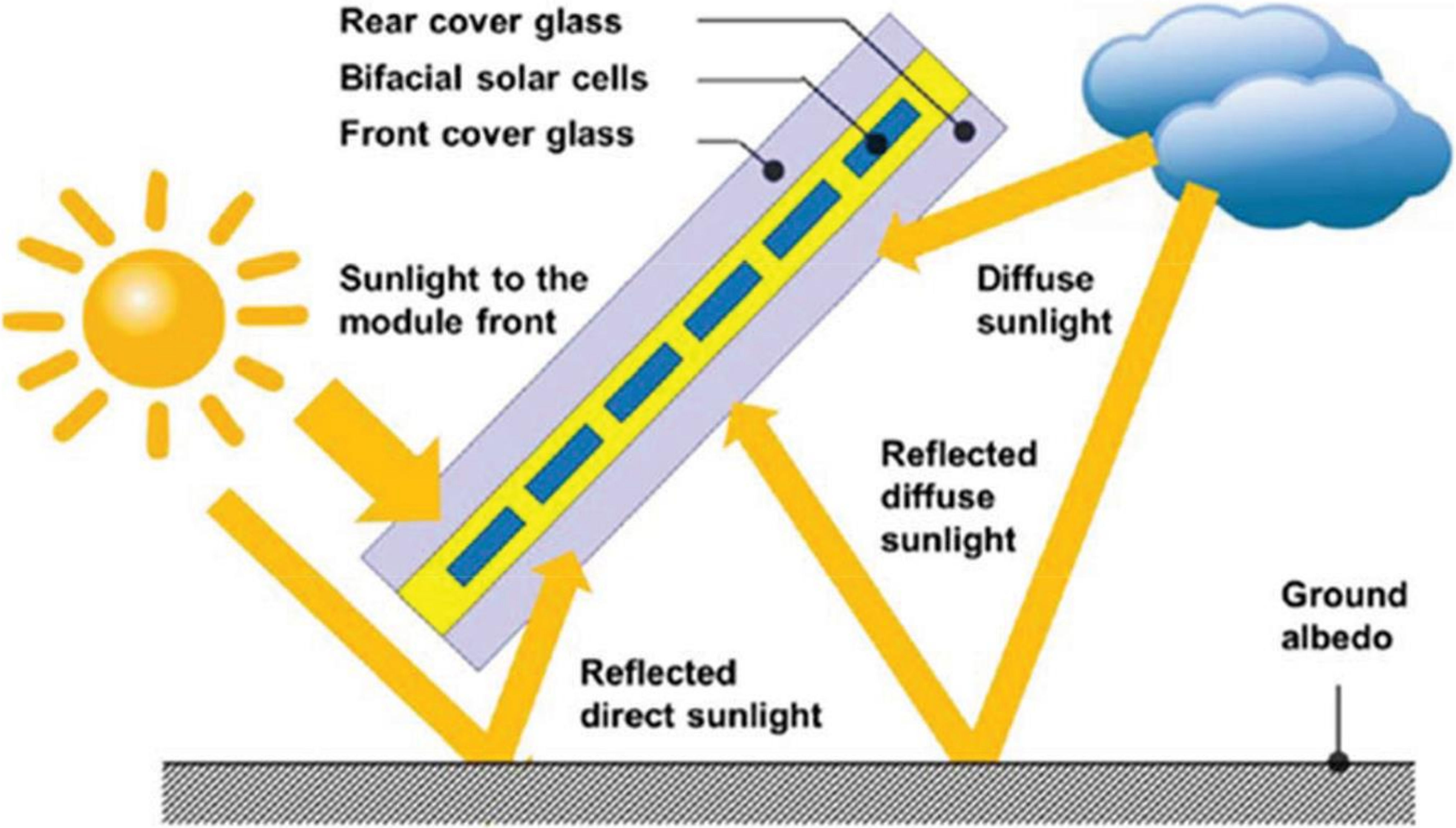
Or this...

Or this...



Because here we have a curved surface and a moving car in a city environment

Or this...


Rear cover glass
Bifacial solar cells
Front cover glass
Sunlight to the module front
Diffuse sunlight
Reflected diffuse sunlight
Ground albedo
Reflected direct sunlight

During this summer school you will have the chance to deal with different challenges in terms of PV simulation

THANK YOU