PV modelling 101 and some e-shape use cases

ATARRI

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Ciências ULisboa / Mines Paris
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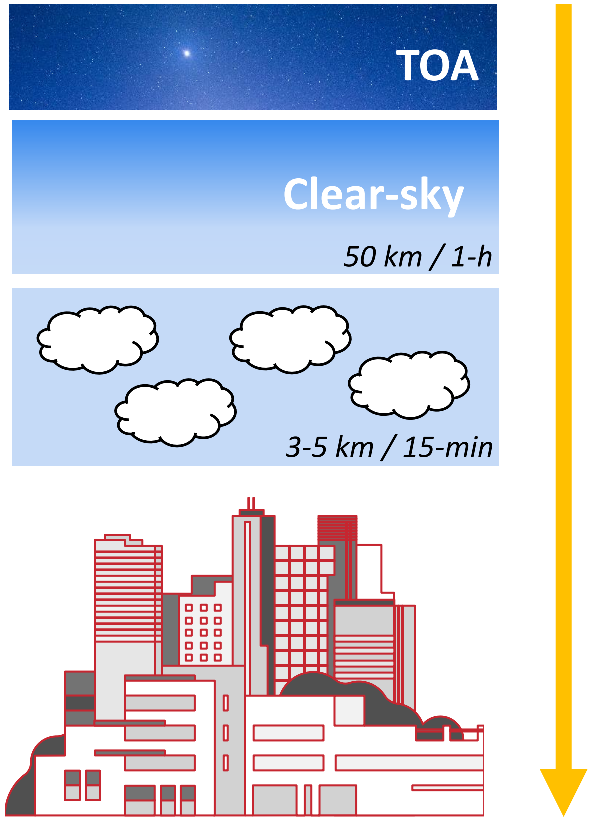
Goals for today's session

- 🎯 Introduce key photovoltaics (PV) concepts
- 🎯 Go through a typical physics-based PV modelling chain
- 🎯 Discuss urban shading and set the stage for tomorrow's demo

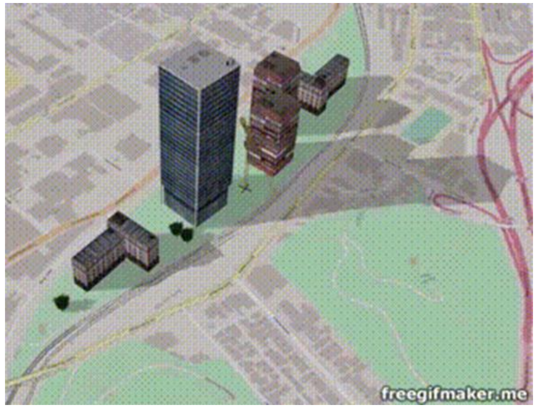
Layers of information at play

Covered by the main skills of each ATARRI partner



Layers of information at play

Receiving surface geometry



Superstructure shading

PV conversion

Layers of information at play

Dust plays two major roles

Within the atmosphere
(mostly other ATARRI partners)

And a PV counterpart
(Ulisbon/Mines Paris)

Layers of information at play

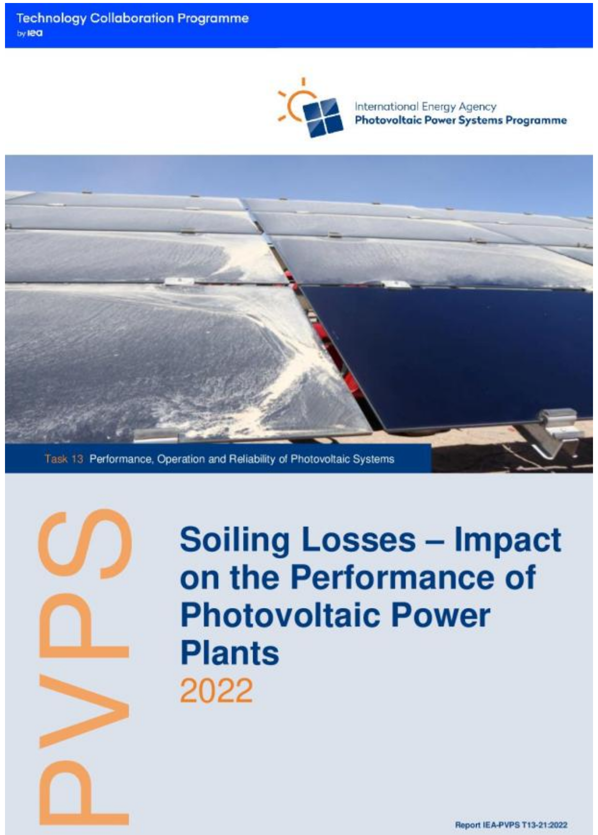
Dust plays two major roles

Solar Energy
Volume 271, 15 March 2024, 112425

A methodology for realistic estimation of the aerosol impact on the solar potential

Robert Blaga [a], Delia Calinoiu [b], Marius Paulescu [a]

https://doi.org/10.1016/j.solener.2024.112425
Get rights and content



<u>Atmosphere</u>

"Yearly losses up to 6–7% due exclusively to aerosols."

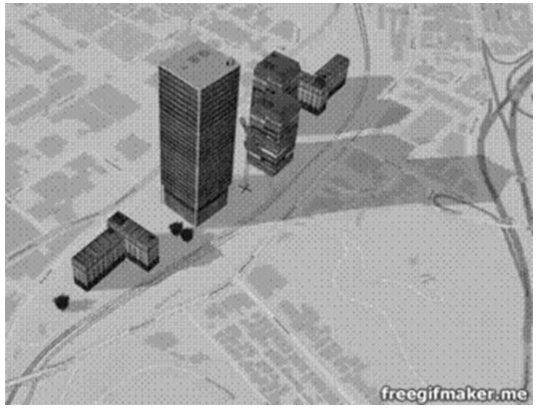
<u>Soiling</u>

"[…] estimated to cause a loss of annual PV energy […] of 3-5%, […] an economic loss […] ~3-5 b€"

To be discussed in VT

Then, let's talk about the photovoltaics

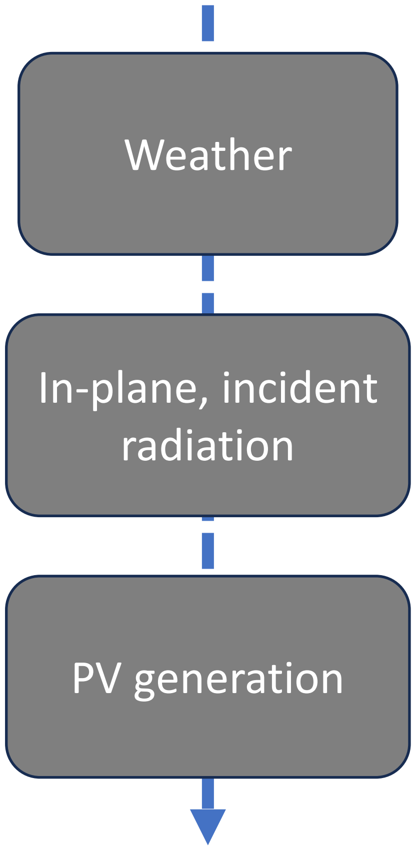
Receiving surface geometry



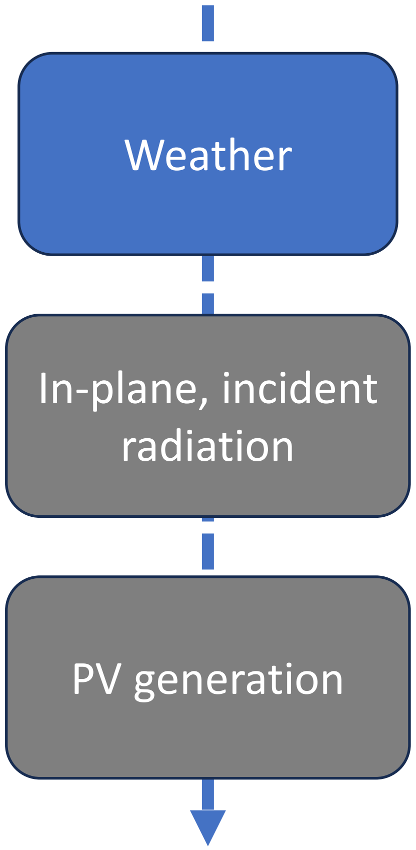
Superstructure shading

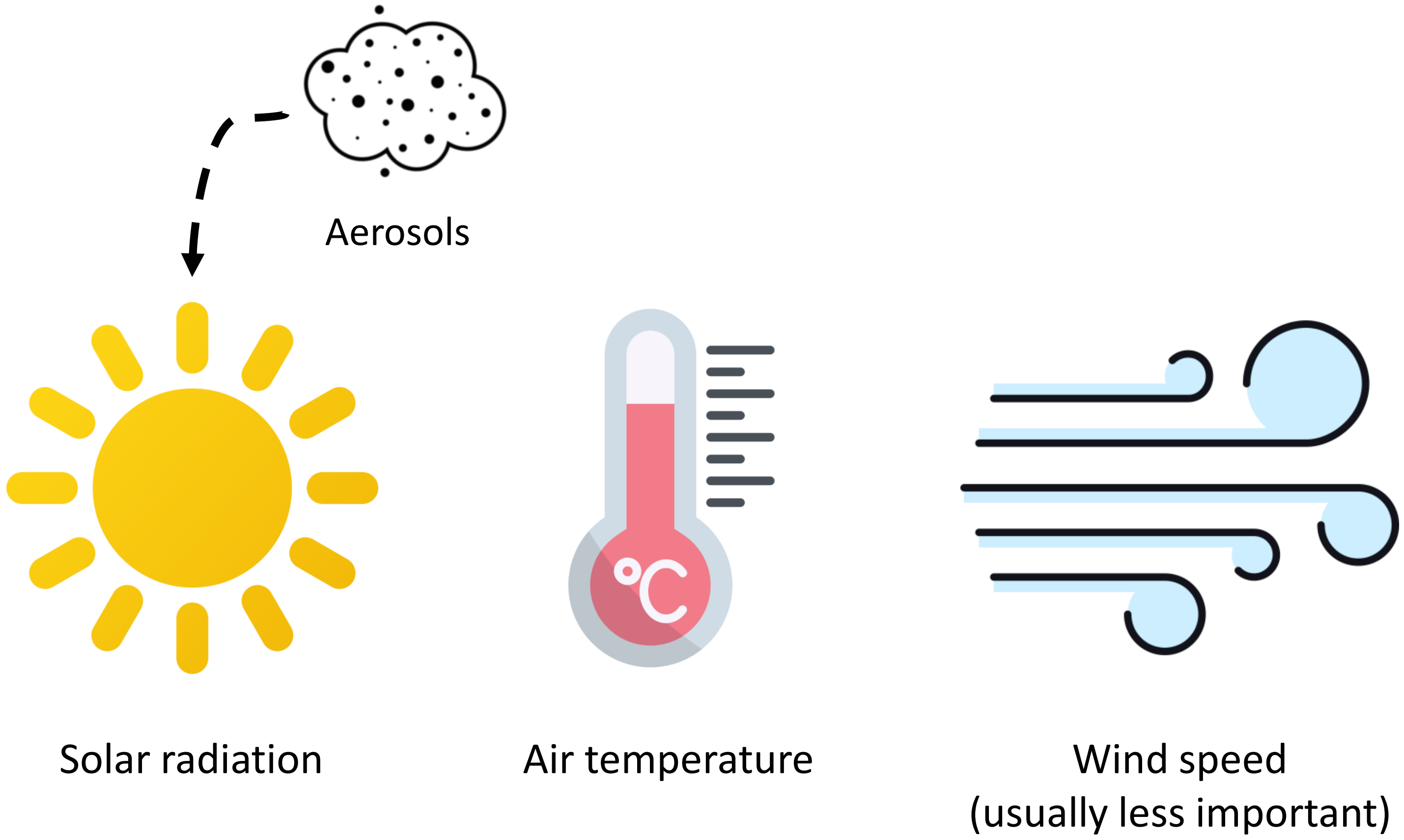
PV conversion

High-level workflow



Several variables of interest

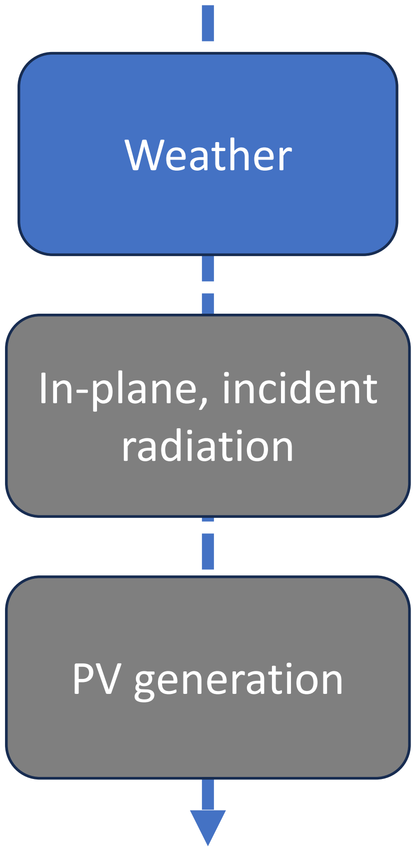


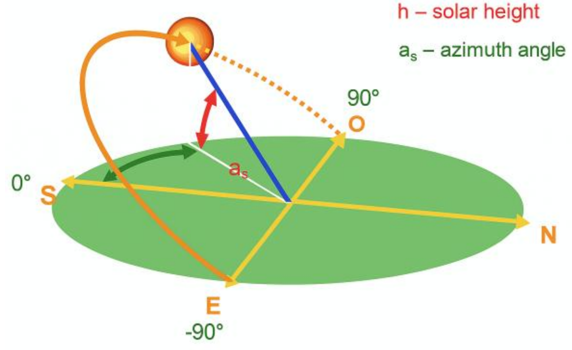


Many diferente sources for data (c.f. annex slides)

Several variables of interest

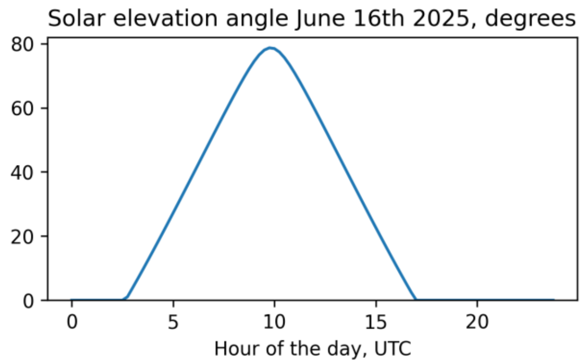
Solar apparent position

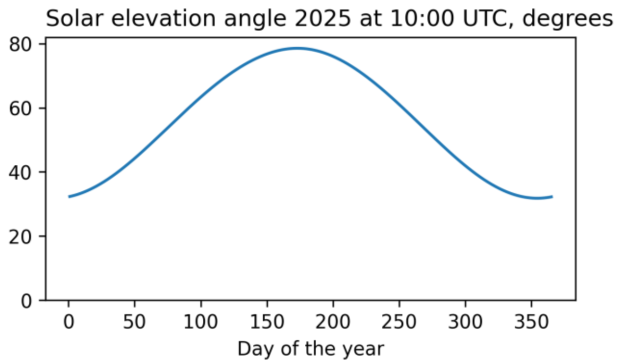




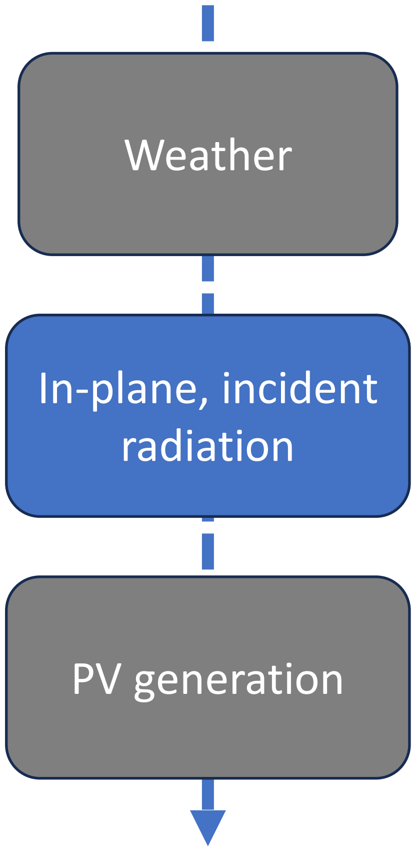
SG2 algorithm:

- Blanc and Wald (2012)
- doi: 10.1016/j.solener.2012.07.018
- @https://github.com/gschwind/sg2





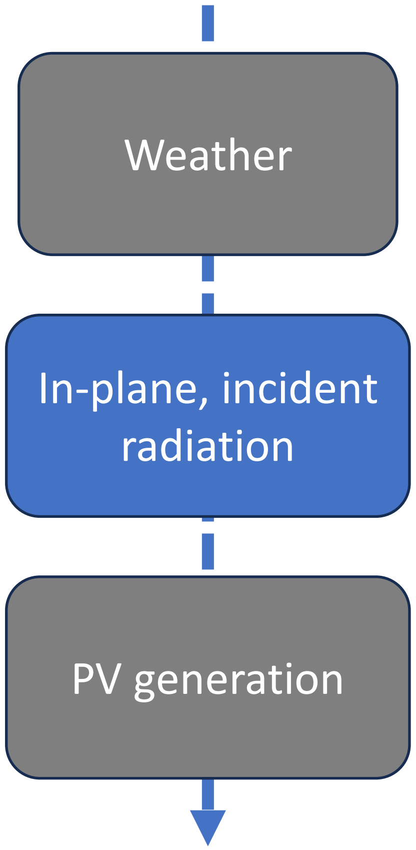
PV modules are not horizontal

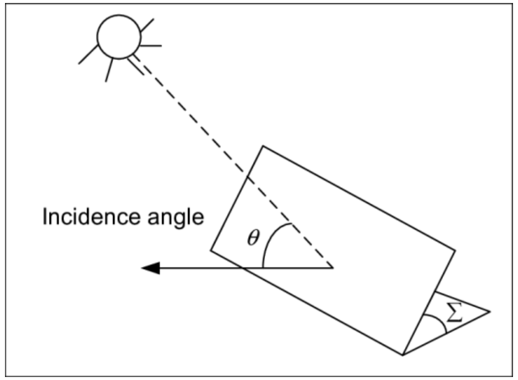


Utility-scale power plant

Lisbon rooftops

PV modules are not horizontal





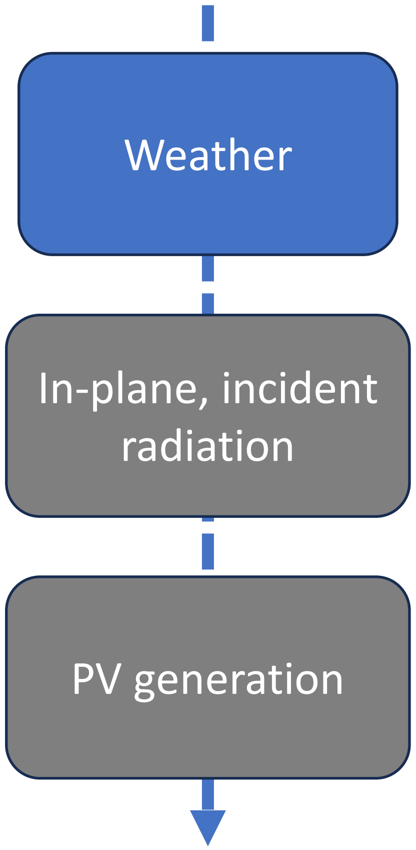
Need to account for modules inclination and azimuth (e.g. 30°S)

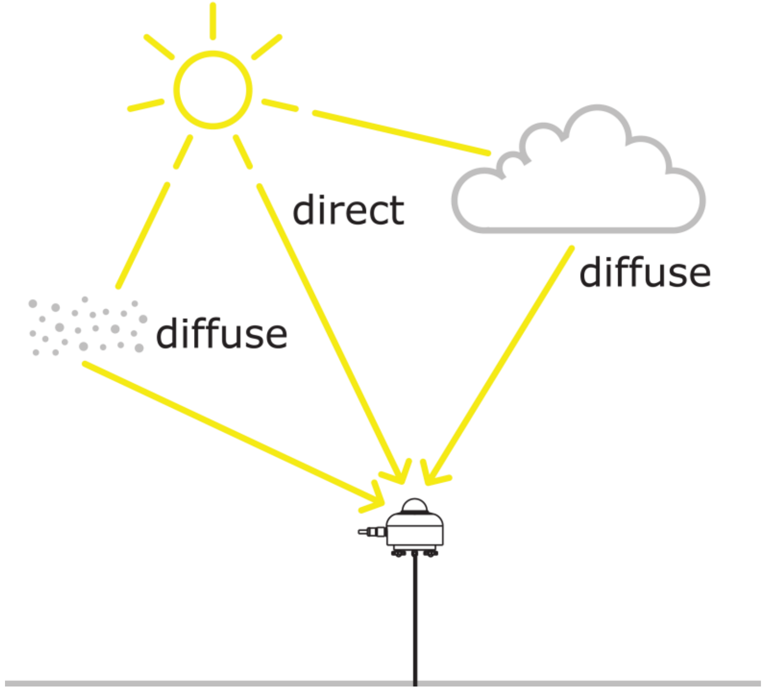
Most likely our base radiation data will not match this geometry

- **Transposition** models (transposing from one angle to another)

The many sides of solar radiation

Solar radiation, e.g. for horizontal surface





Beam horizontal irradiance (**BHI**)

Diffuse… (**DHI**)

Global … (GHI = BHI + **DHI**)

The many sides of solar radiation

Weather

In-plane, incident radiation

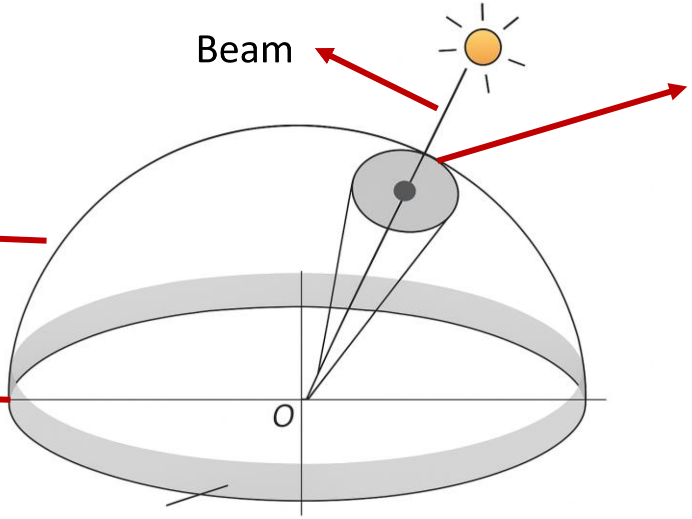
PV generation

Ideally, a transposition model should address each irradiance component separately (more in annex)

Sky dome

Horizon brightening

Beam



Circumsolar

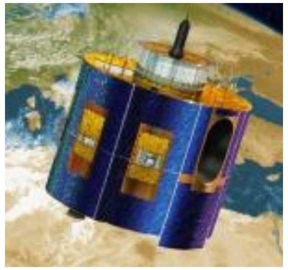
And sometimes we have very limited information

Weather

In-plane, incident radiation

PV generation

Sometimes, only GHI data is available



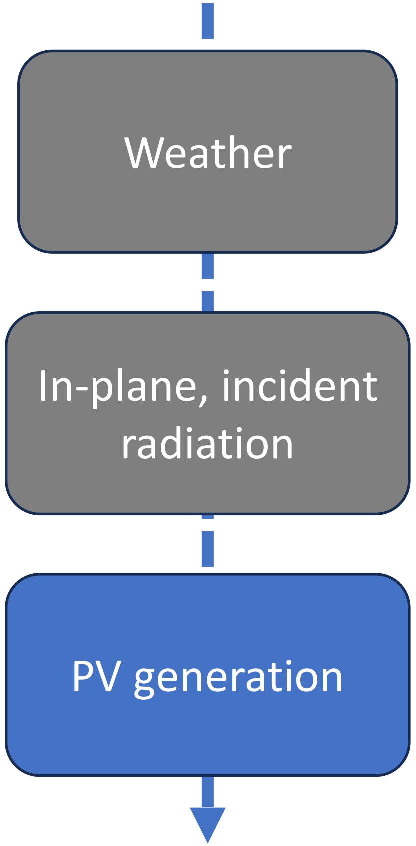
So, in this context, we also need a **decomposition** model

GHI → Diffuse and Beam Horizontal (DHI, BHI) → Global **Tilted** Irradiance

Decomposition model

More in annex

Conversion efficiency



PV efficiency in standard test conditions (STC)

Specifications (STC)

Maximum Power – Pmax [Wp]
Maximum Power Voltage – Vmp [V]
Maximum Power Current – Imp [A]
Open-circuit Voltage – Voc [V]
Short-circuit Current – Isc [A]
Module Efficiency STC [%]
Power Tolerance
Temperature Coefficients of Pmax
Temperature Coefficients of Voc
Temperature Coefficients of Isc

STC: Irradiance 1000W/m^2, Cell Temperature 25°C, AM=1.5

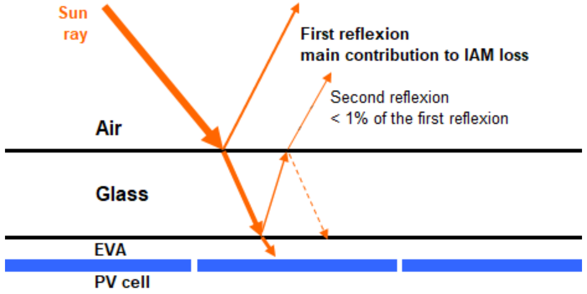
Varies from module to module

Conversion efficiency

Weather

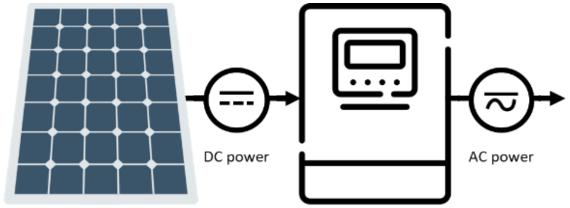
In-plane, incident radiation

PV generation

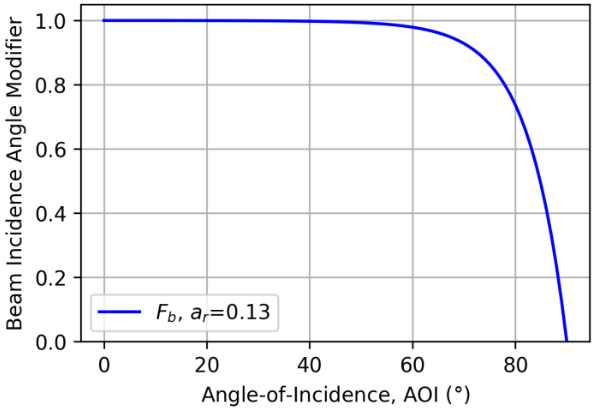


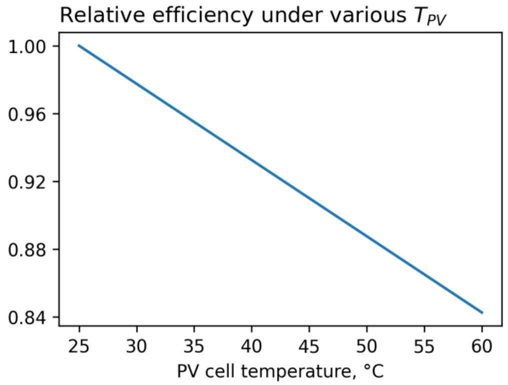
Optical losses

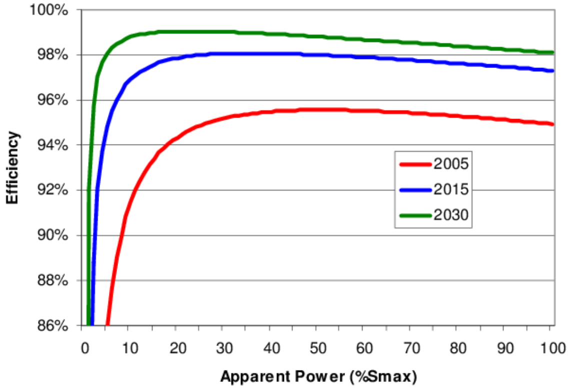
Thermal losses



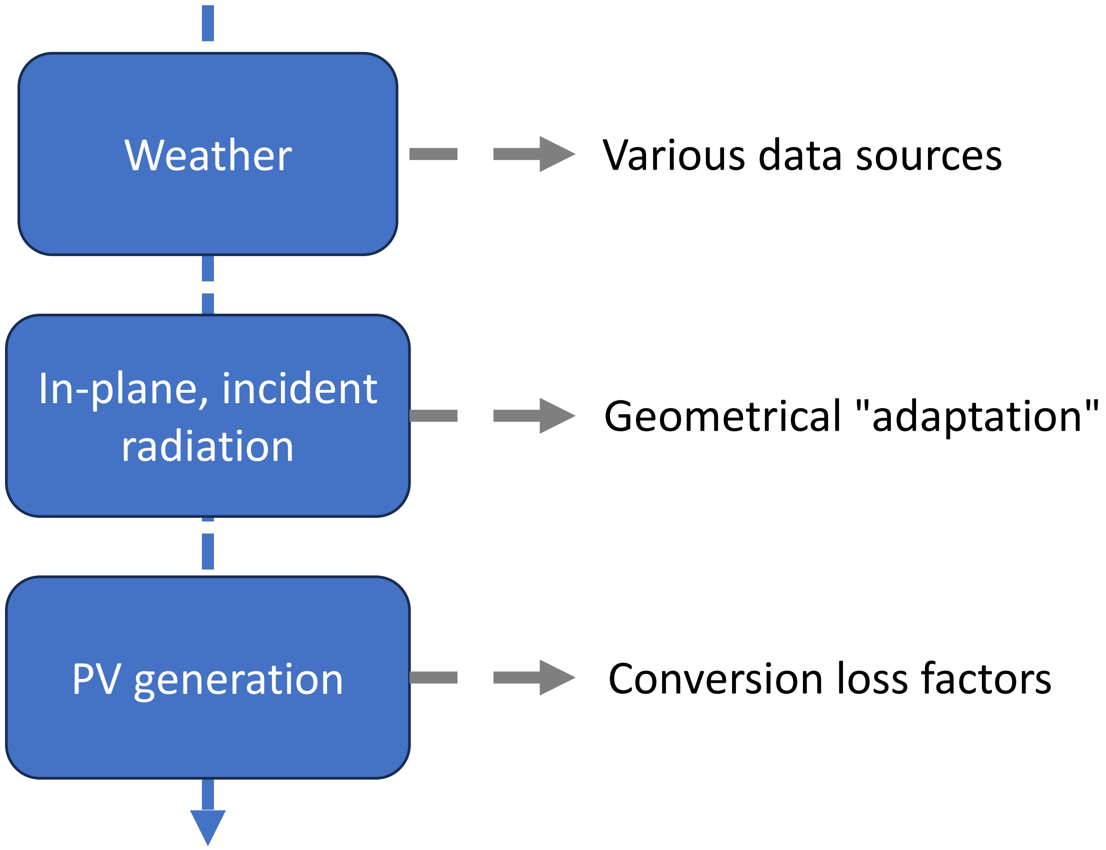
Electric losses







In a nutshell



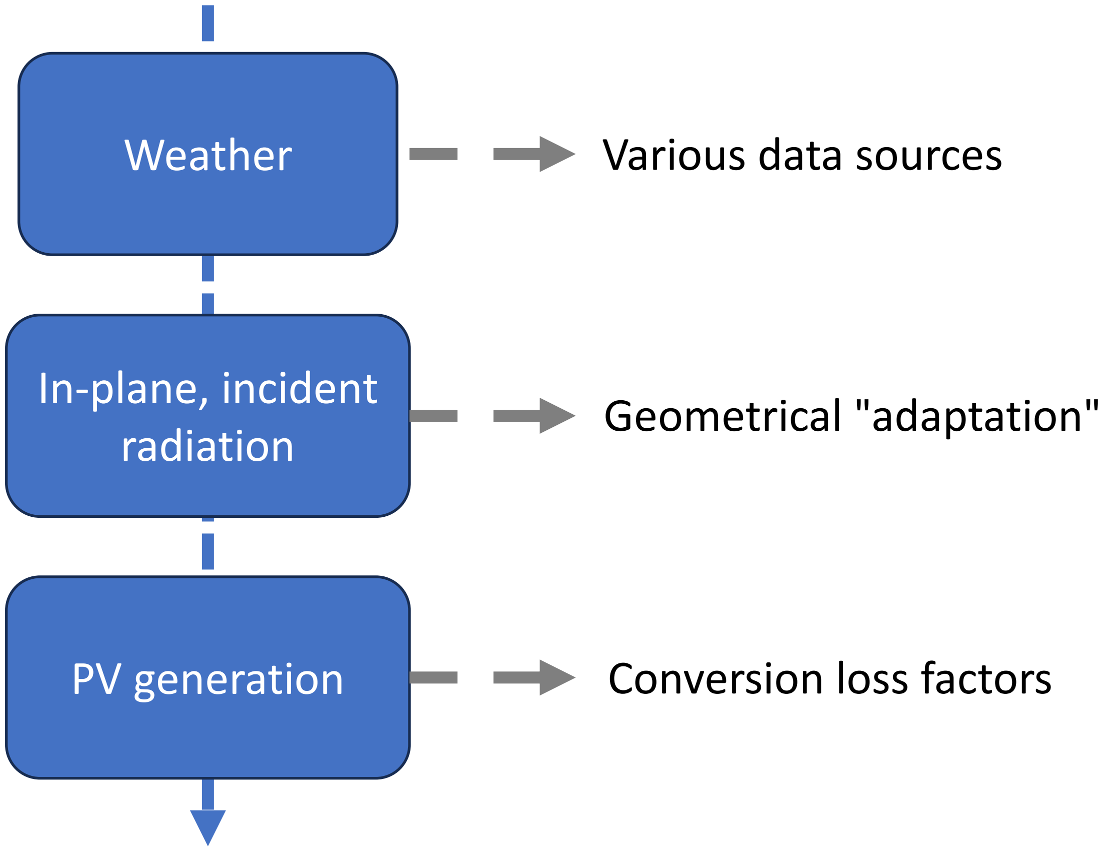
<u>PV conversion</u>

$$PV = GTI \times A \times \eta$$

<u>Overall efficiency</u>

$$\eta = F_{optics} \times \eta_{STC} \times F_{low-rad} \times F_{thermal} \times F_{electric}$$

In a nutshell



The modelling choices depend greatly on:

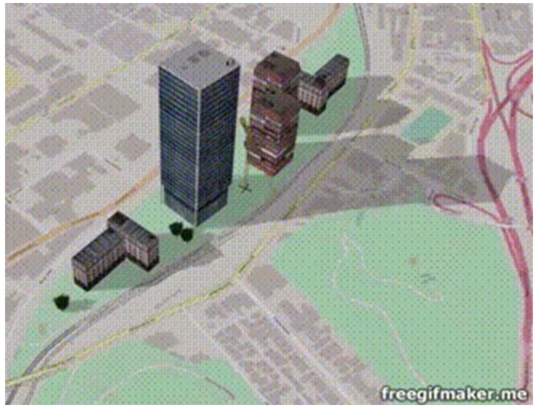
- the available data, and
- the geography of interest

Just testing these and the influence of dust for the Cypriot context is already interesting

And now, the urbanistics…

And now, the urbanistics

Receiving surface geometry



Superstructure shading

PV conversion

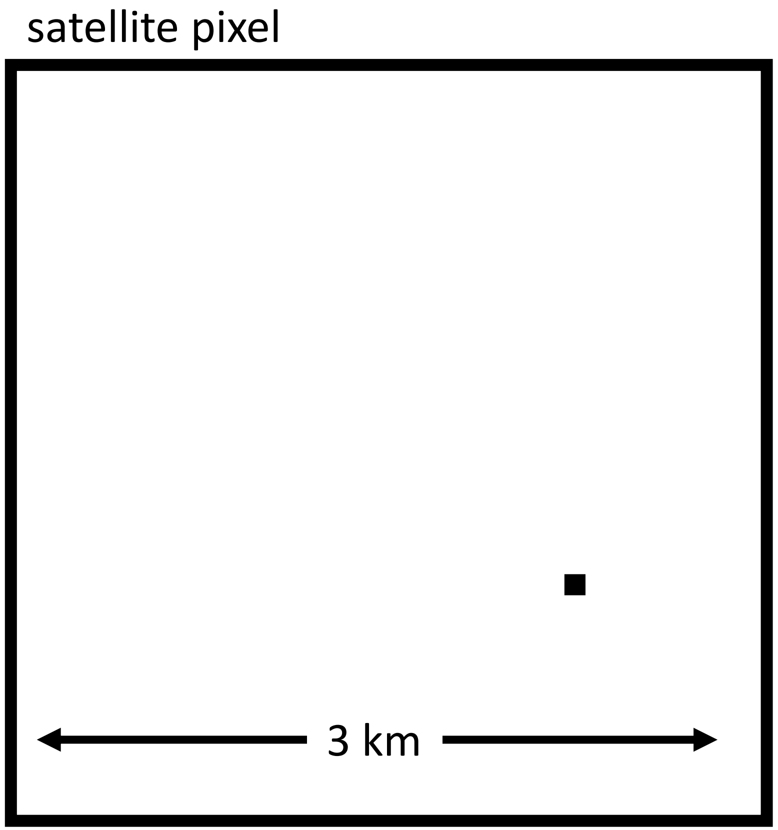
Sources of shading

Trees and vegetation

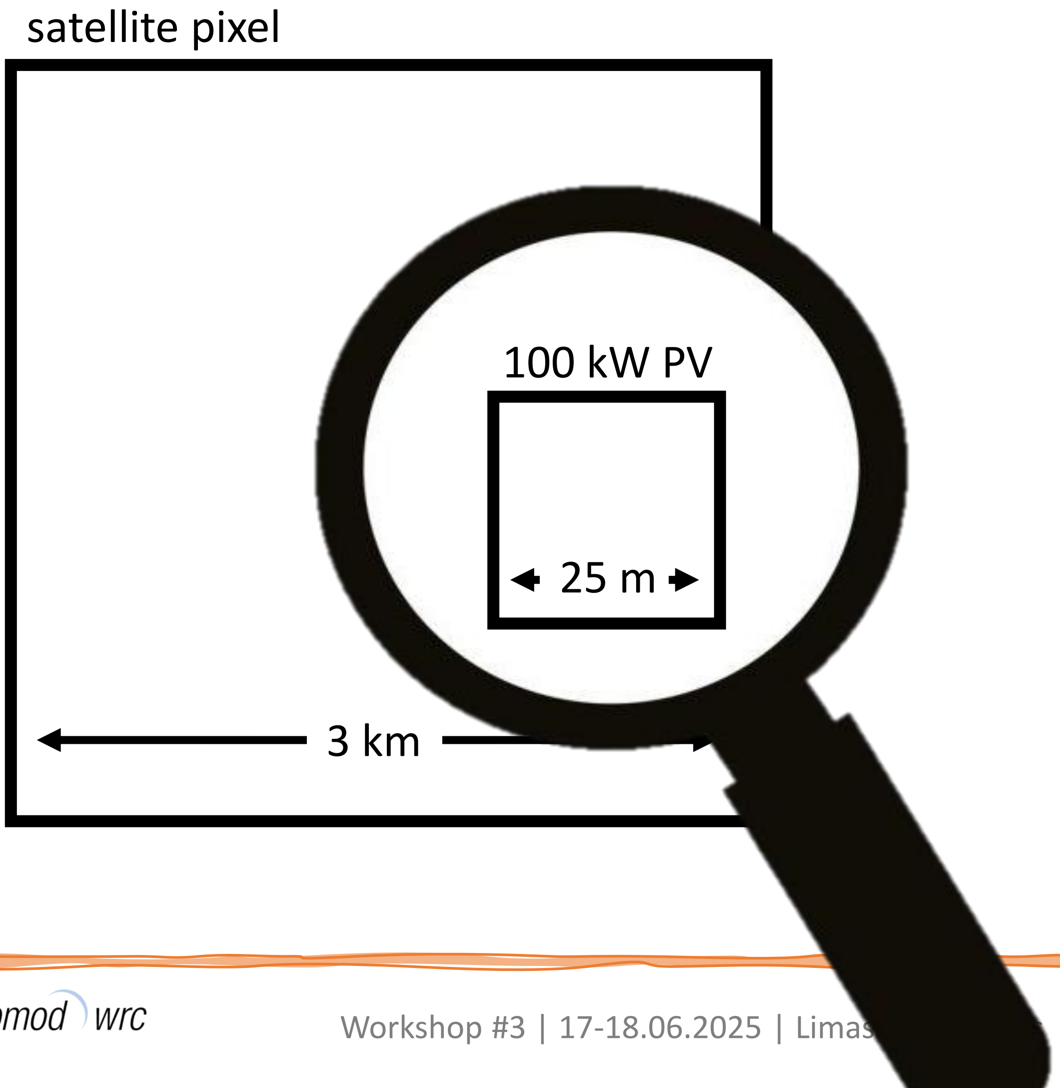
Nearby obstructions

Obstructions in the rooftop itself

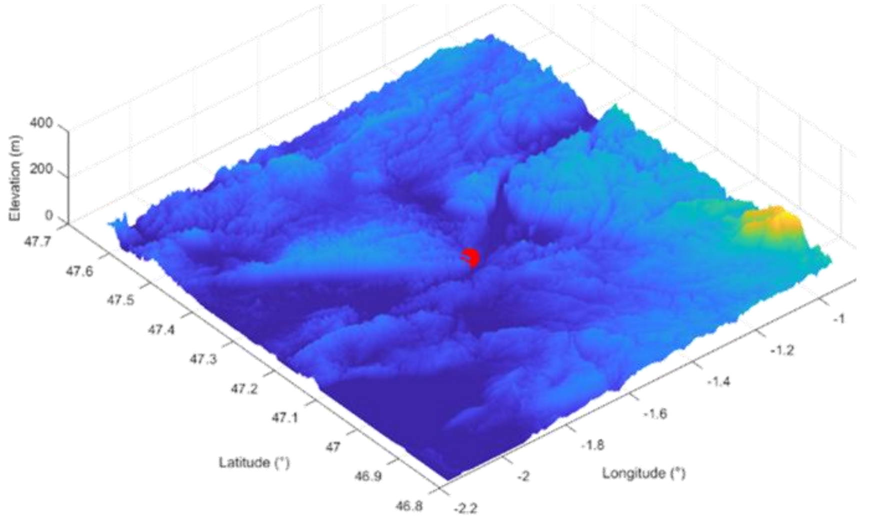
Blind satellites: it's all a matter of scale



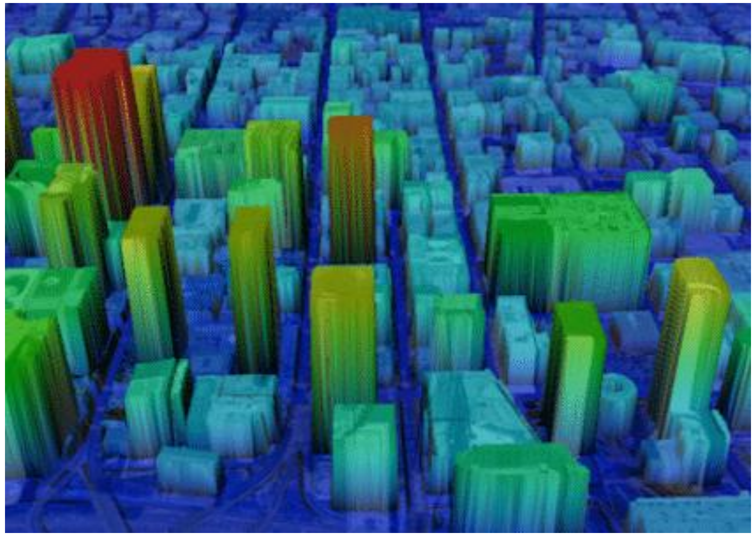
Blind satellites: it’s all a matter of scale



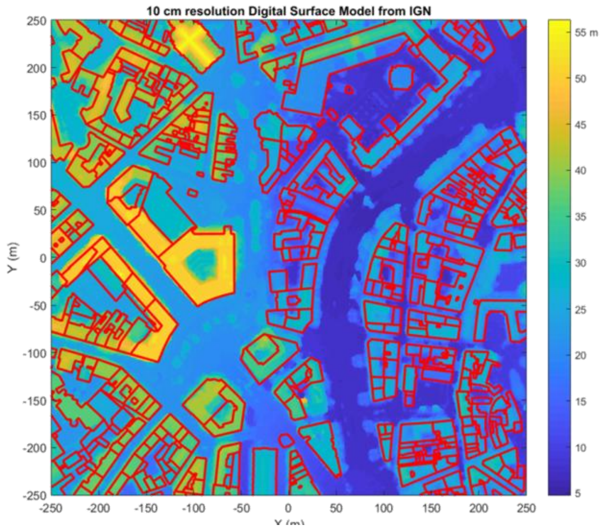
Main inputs



Digital Terrain model (DTM)
decametric
(e.g. SRTM, ASTER)

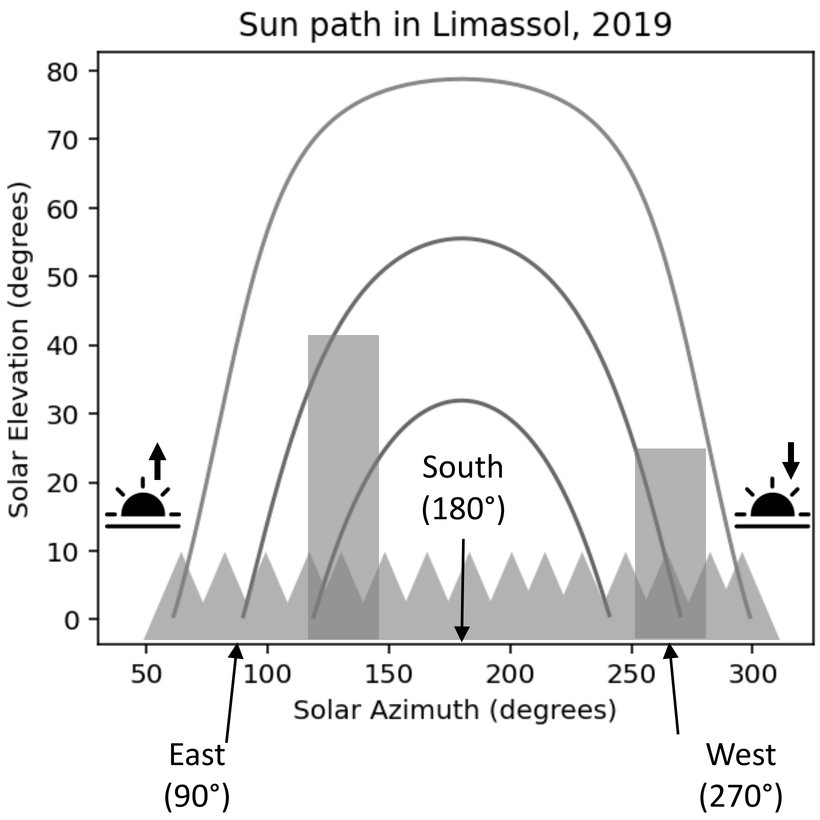


Digital Surface Model (DSM)
Higher resolution
(Google Earth, IGN@FR, DLS@CY)



Rooftop cadaster
high-resolution
(OpenStreetMap, BDTOPO)

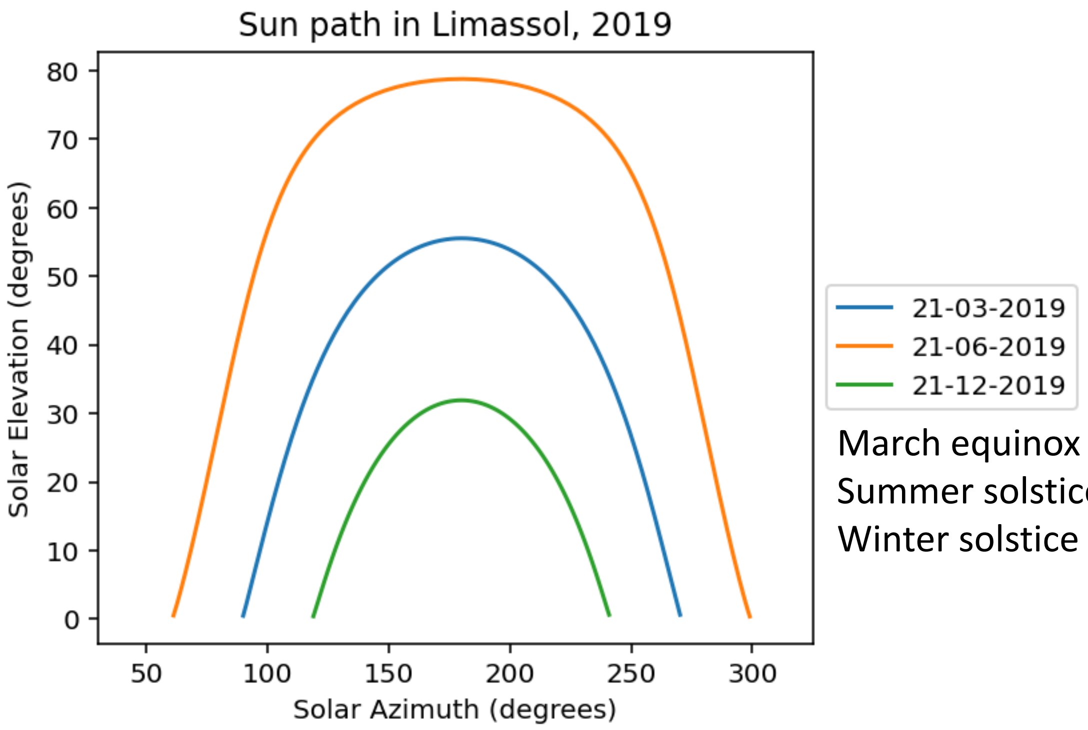
The horizon profile



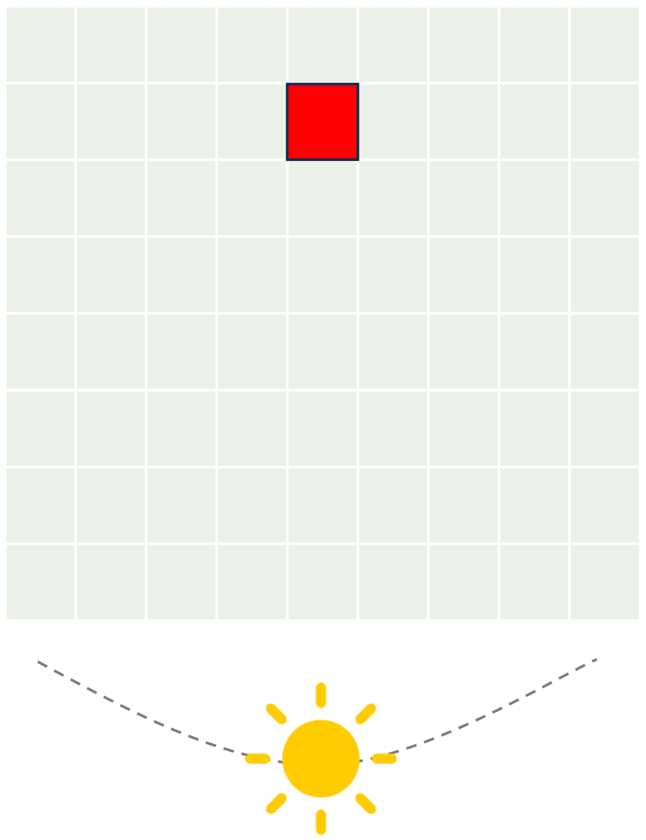
X- and Y-axis represent the angles surrounding the location of interest

Shaded area represents when a certain obstruction shades that same location

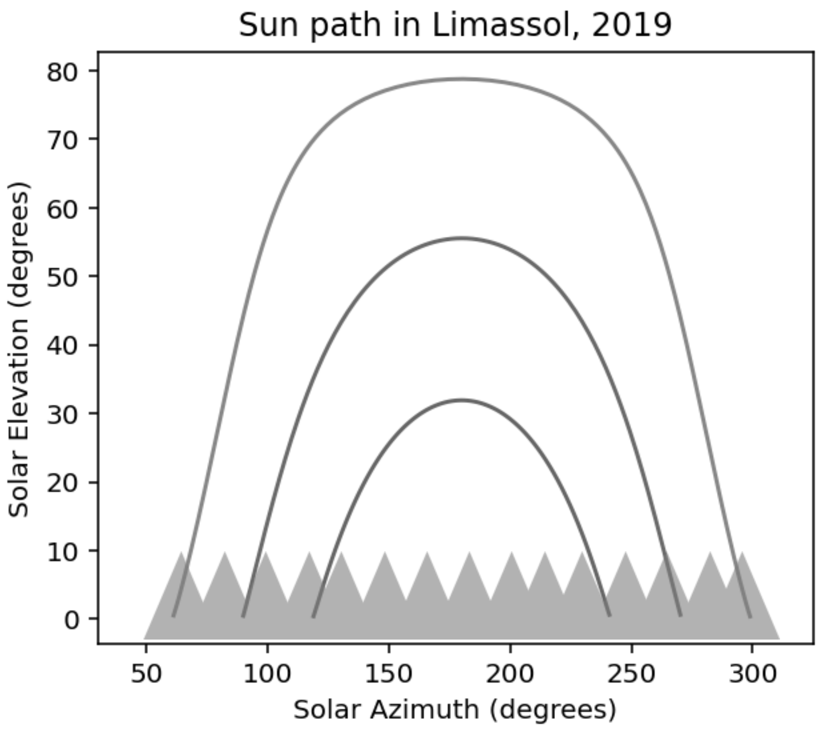
Let's start from scratch

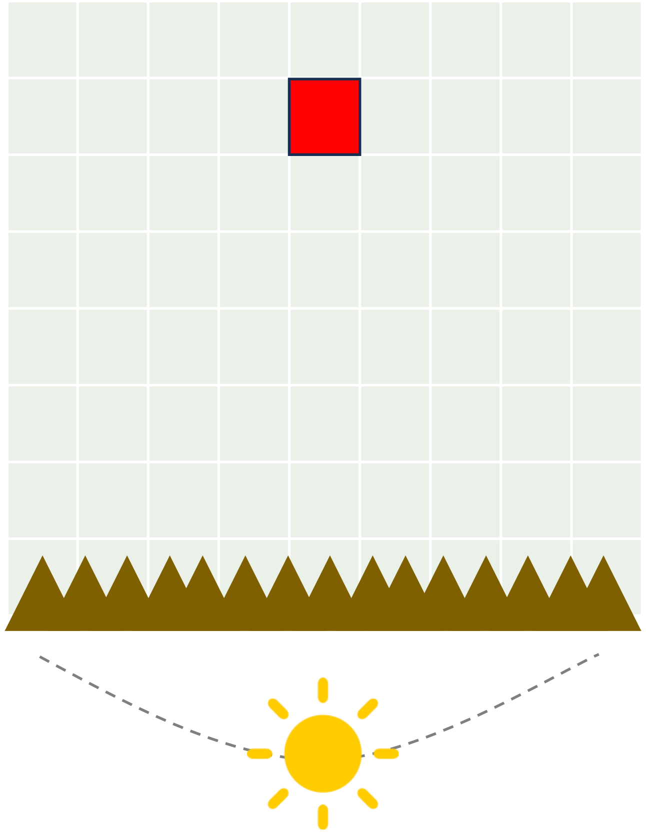


March equinox
Summer solstice
Winter solstice



Let’s start from scratch

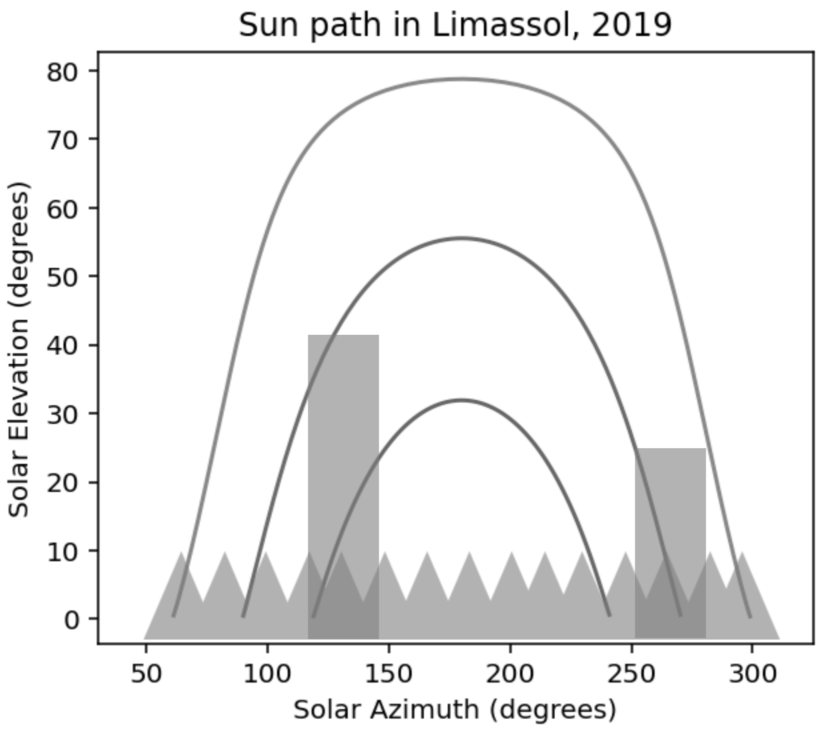


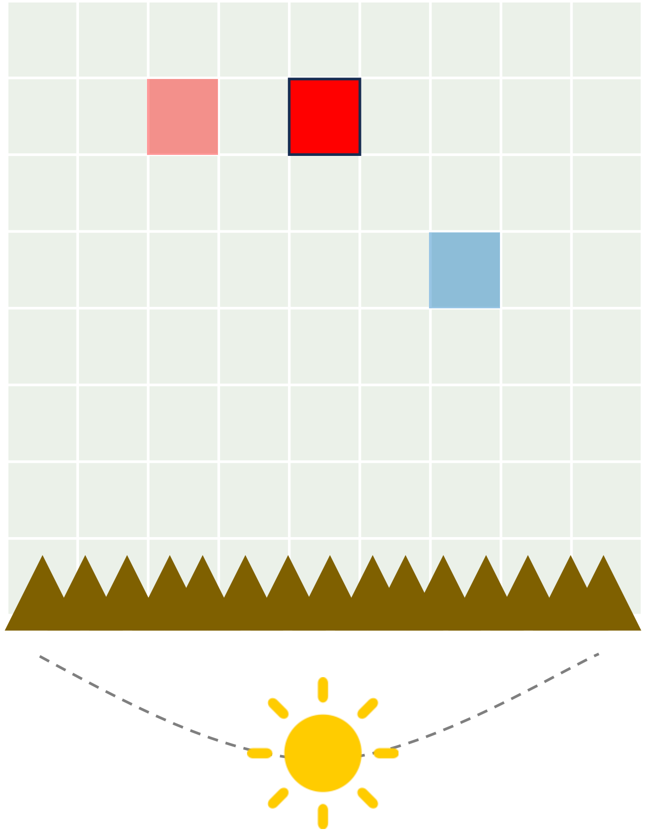


There is a mountain chain far away in the South

For each grid cell around us, we check the azimuth and calculate the obstruction elevation

Let’s start from scratch



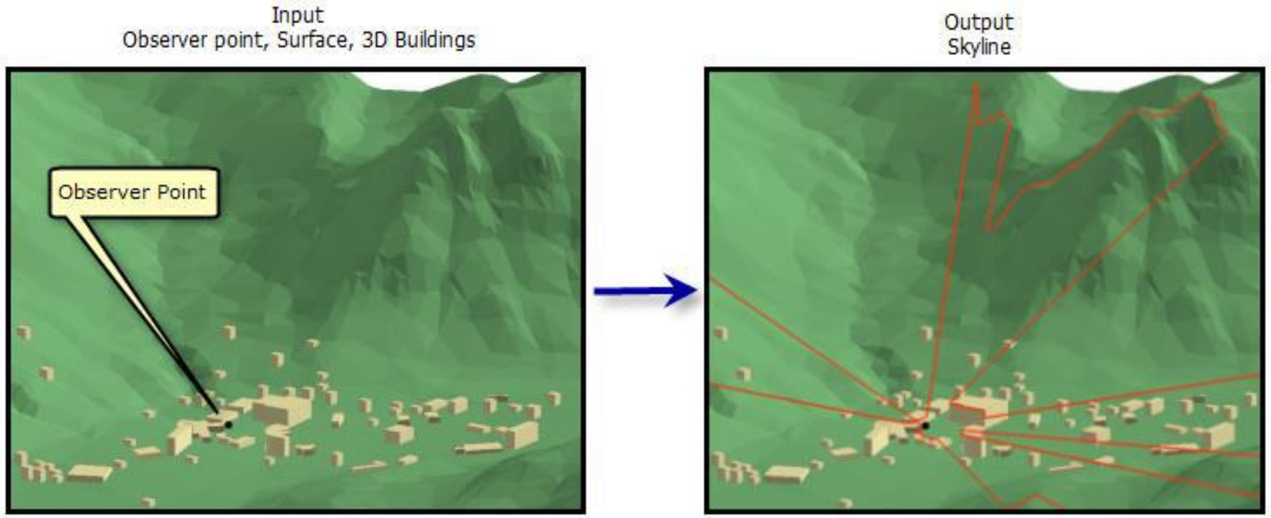


When there are several obstructions for the same azimuth We record only the highest elevation.

If an obstruction is beyond the azimuth of the solar path, it is not relevant.

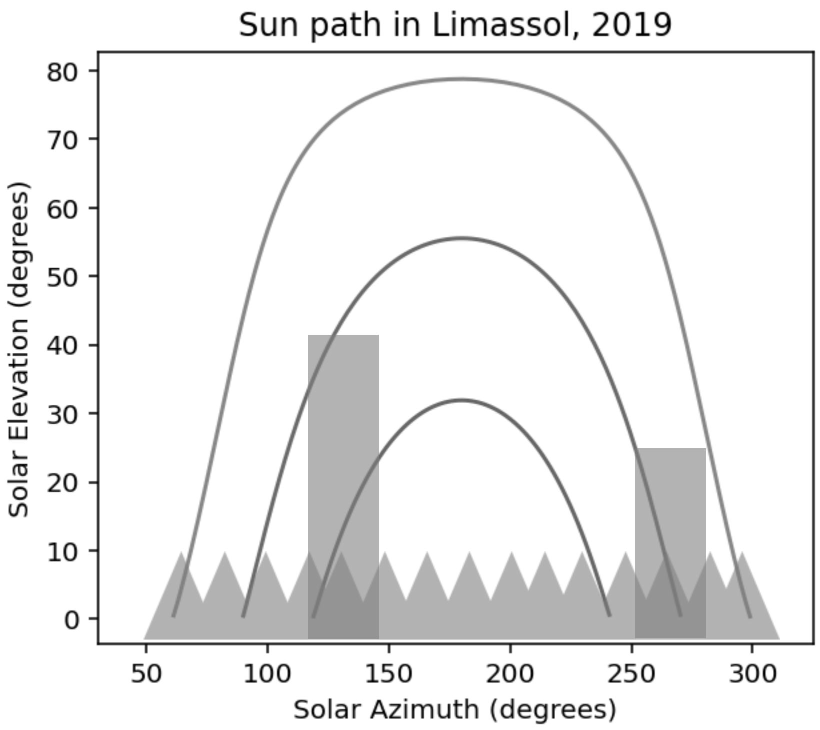
Let's start from scratch

A 3D perspective



Mapping the horizon around each pixel
(both from terrain and urban orography)

Let’s start from scratch



We end up with a binary mask:

- obstruction(azim,elev) = 1 or 0

So, for each time *t* we:

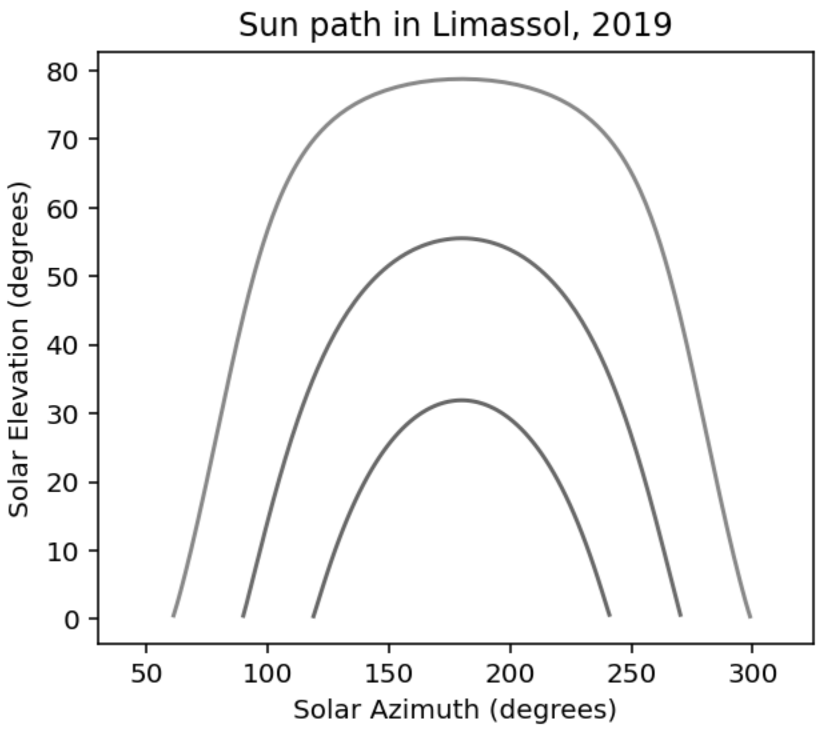
- calculate sun position (azim’,elev’)
- If obstruction(azim’,elev’) =1, beam radiation = 0

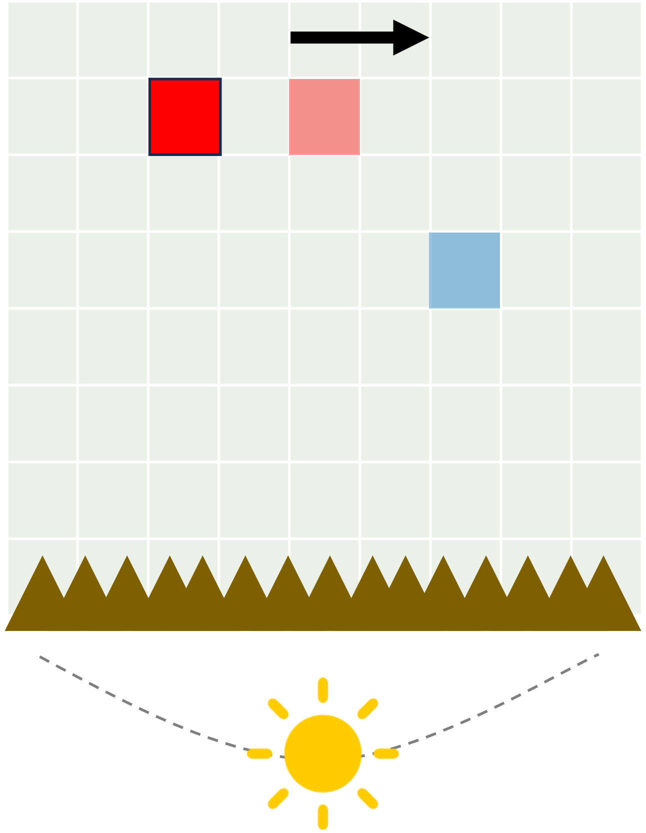
We also compute a sky-view factor:

- % of sky dome visible
- for dome-related diffuse radiation

Figure from Liang et al. (2017)

Influencing factors: location

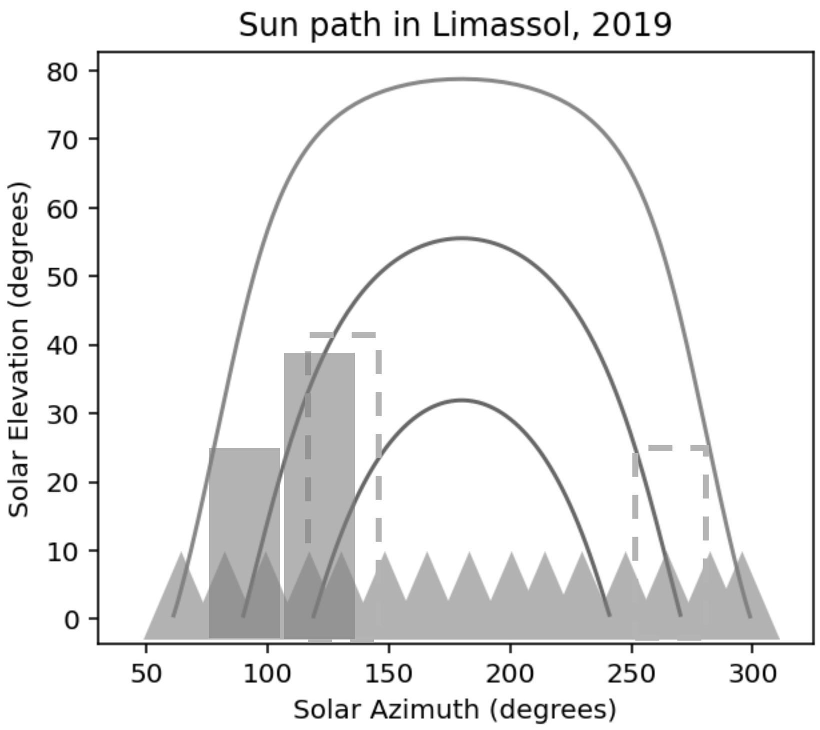


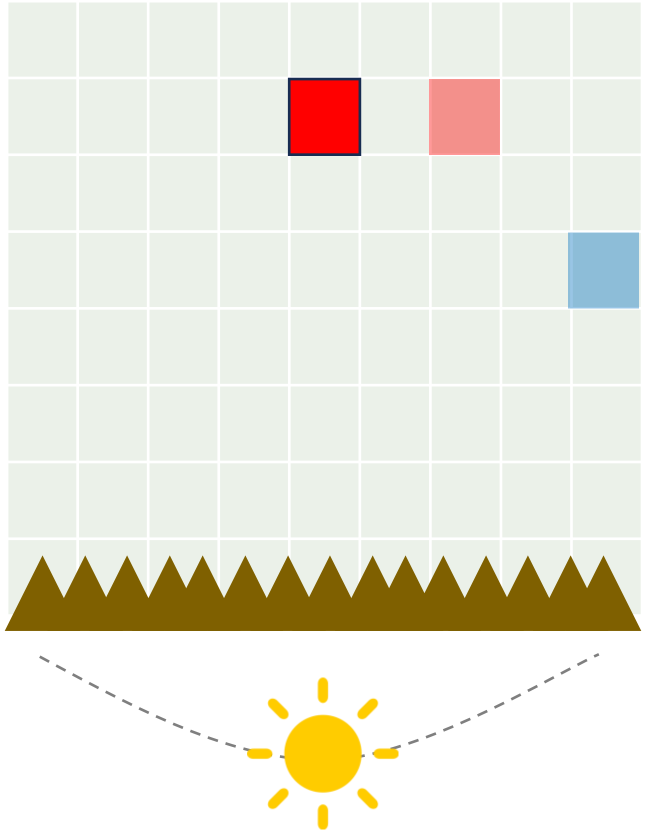


If we consider the other rooftop two grid cells to the left

We then need to recenter the grid and recompute the horizon profile

Influencing factors: location



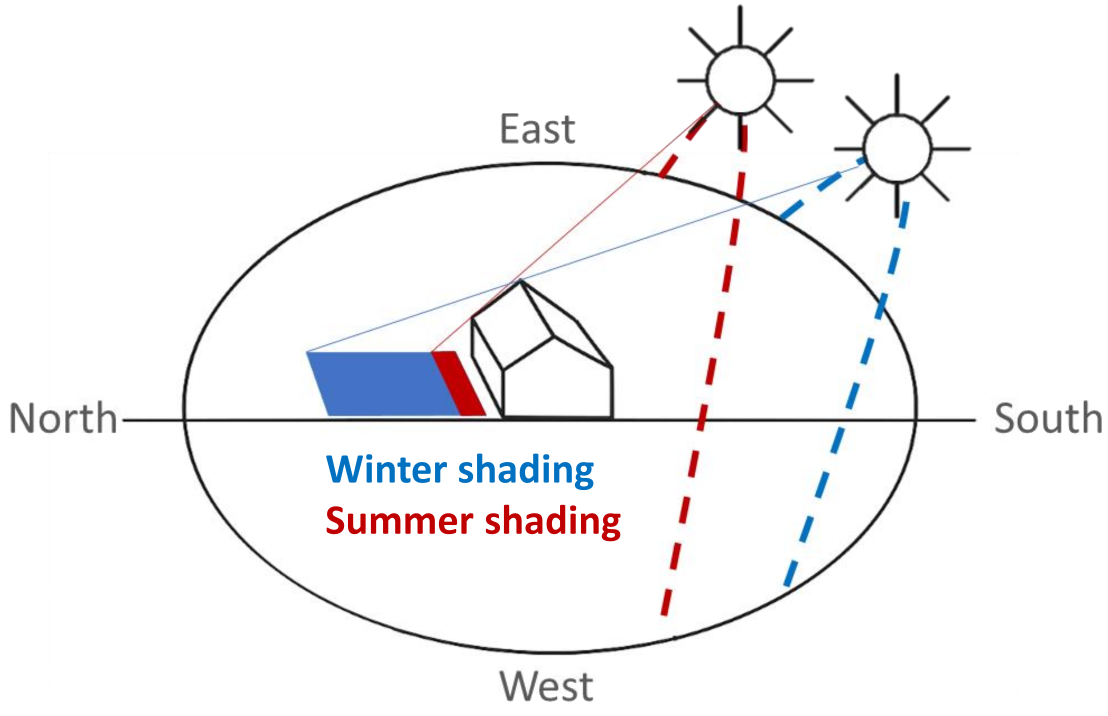


So, in this case, both obstructions are Eastward

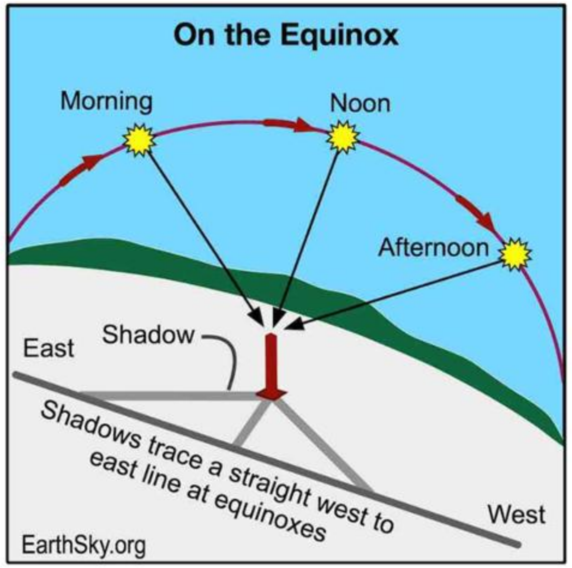
The blue building is farther away, so it leads to a shorter shadow

Influencing factors: time

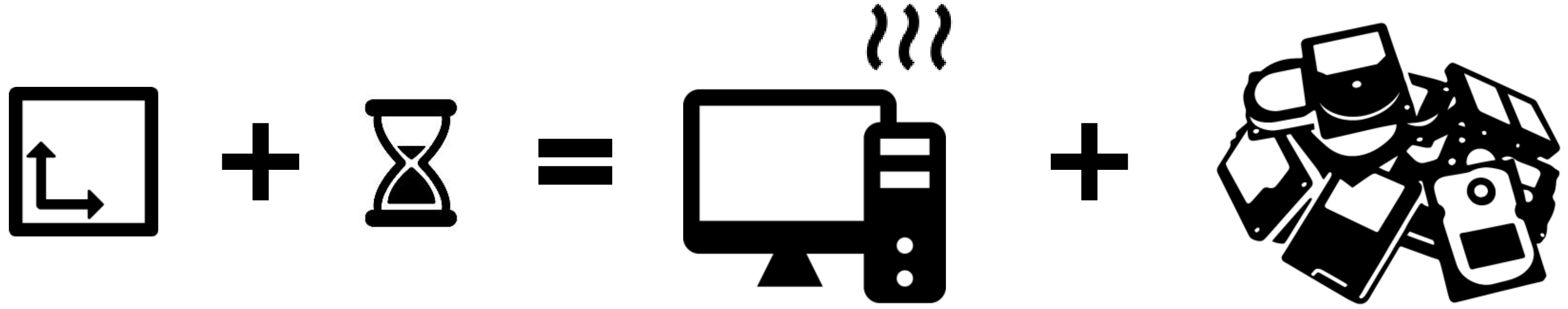
Also depends on day of year and time of day



North Hemisphere perspective



The urban calculation conundrum



10 x 10 cm^2 pixels + 15 min timesteps = Heavy computations! + Too much data!

COMPROMISE

- smaller regions of interest
- store only aggregate values
- avoid repetitions/improvements

Revisiting e-shape

e-shape
EuroGEO Showcases: Applications Powered by Europe

https://e-shape.eu/

EuroGEO Showcases Applications Powered by Europe
4 years grant (2019-2023)

60 partners, 7 showcases

agriculture · health · renewable energy · ecosystem · water · disaster · climate

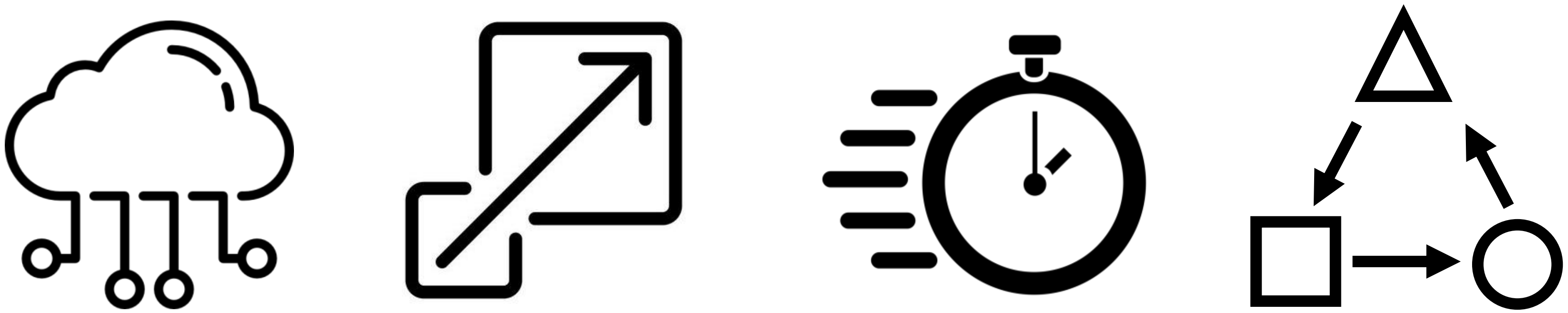
Promoting **users' uptake** of European Earth Observation resources

Development of **co-design pilots** (**33!**) to deliver **economic**, **social** and **policy value** to European citizens

EuroGEO · GEO GROUP ON EARTH OBSERVATIONS · Copernicus
The e-shape project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 820852

Our solution: the SAaF-aaS

Solar Assessment and Forecasting as a Service



Cloud-based

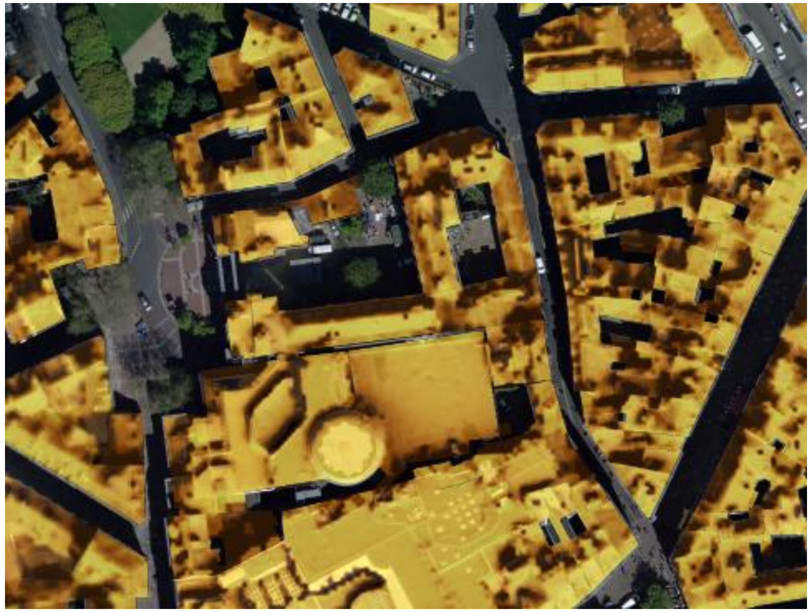
Scalable

ON- demand / the-fly

Interoperable

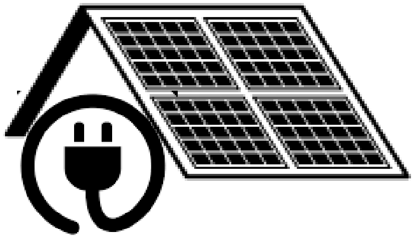
A teaser for tomorrow

Agile urban PV modelling unlocks many applications



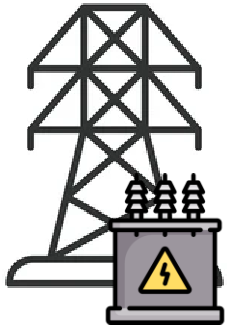
Classic solar cadaster

Urbanism



Self-consumption

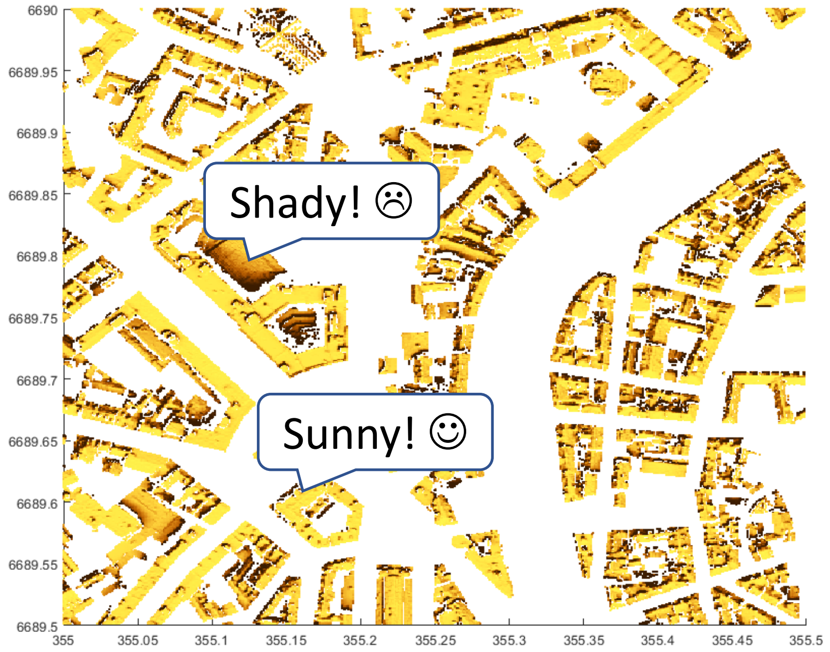
Solar forecasting



Grid integration

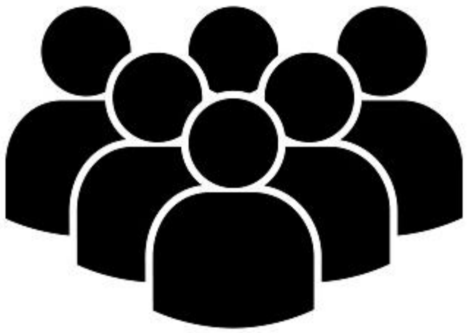
#1: Static solar cadasters

A classic output, great for feed-in tariff



Part of a neighborhood in Nantes, France.
Resolution: 1 meter, long-term anual mean.

Policymakers

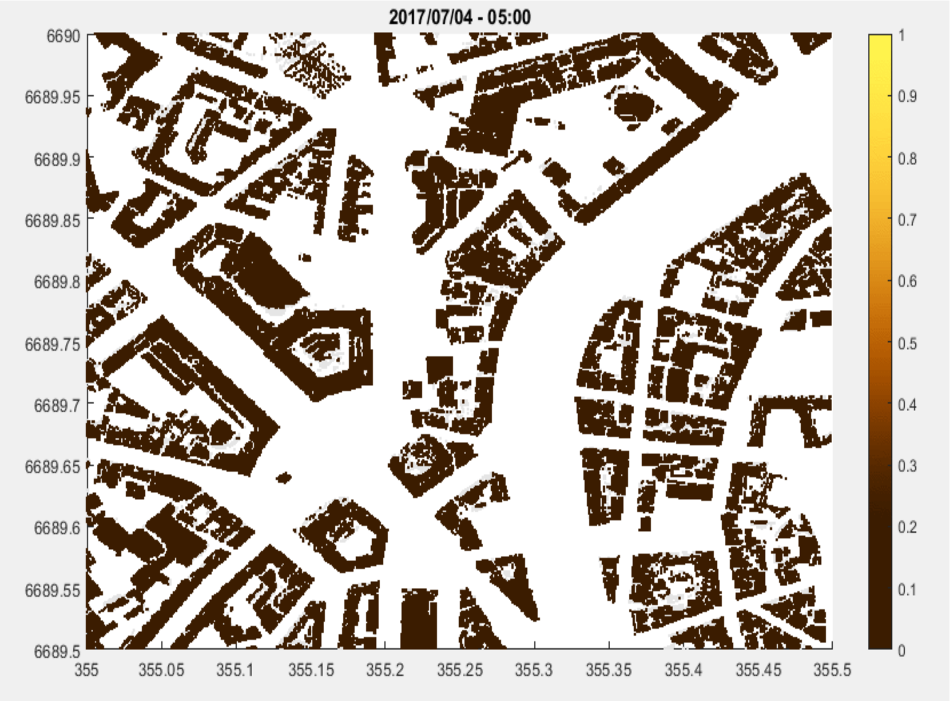


Civil society

PV industry

#2: Urban self-consumption sizing

Self-consumption: the need to temporally matching PV-demand



Requires similar product but with much higher temporal resolution (15-60 min)

#3: Urban planning (the right to light)

In 2019, a 18-floor building project in Lisbon was rejected by locals

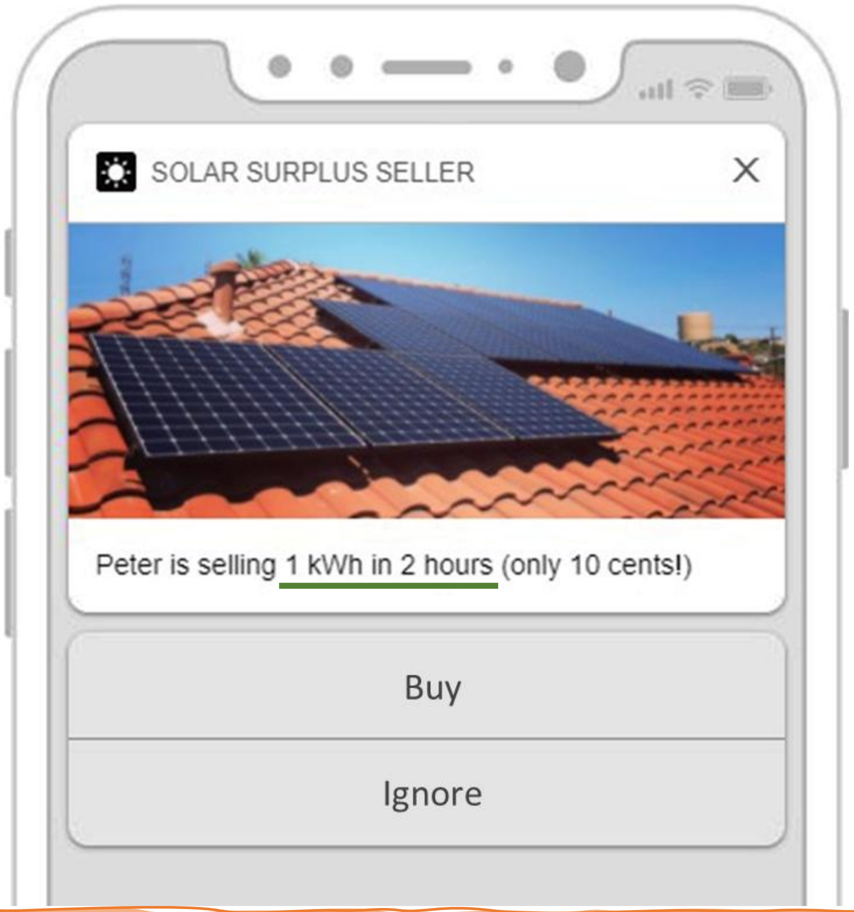
- Would block natural light for buildings behind, but also “kill” PV

Assessed only with few snapshot/visual simulations (qualitative!)

Quantitative studies would be more comprehensive and support compensations when such projects are implemented

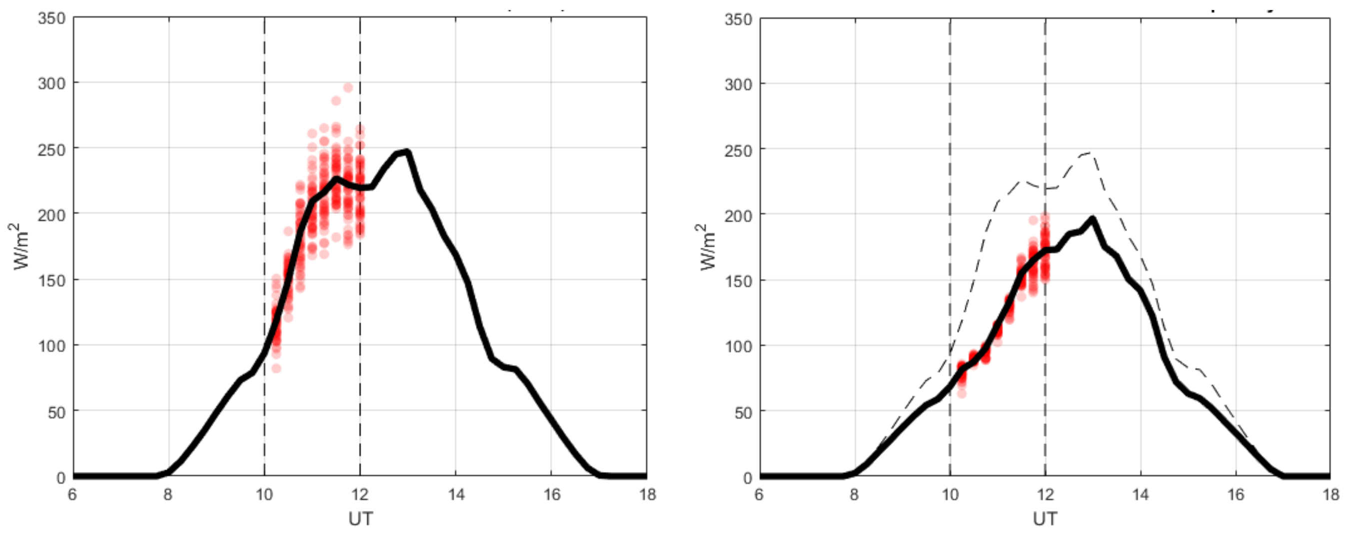
#4: Urban PV forecasting

In a not so futuristic vision, we may see



Forecasting = <u>business enabler</u>

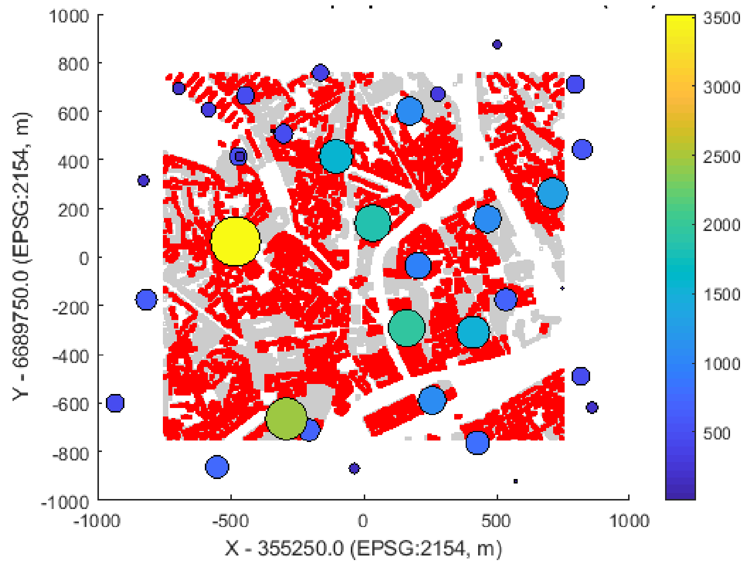
Upgrading a naive satelite-based forecasting



#5: Distribution grid studies

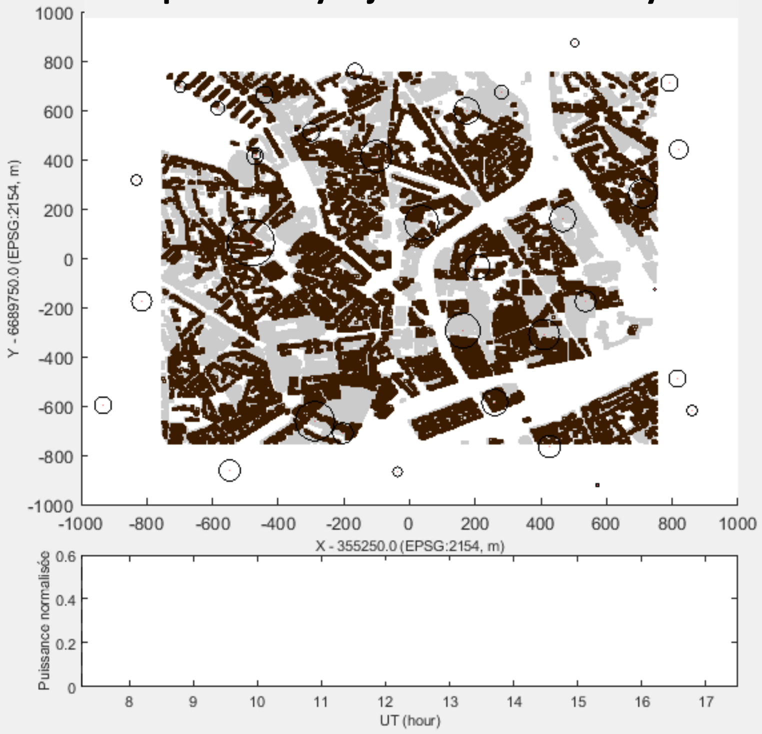
Distribution grid operators need to know how much energy is injected

Example: urban area of of 1.5 km x 1.5 km
35 feeders of ENEDIS (French DSO)
14 ha of PV rooftop systems (~20 MWp)



Nameplate PV power injected in the source points

Temporal evolution of PV power potentially injected within a day



ATARRI

Funded by the European Union

THANK YOU

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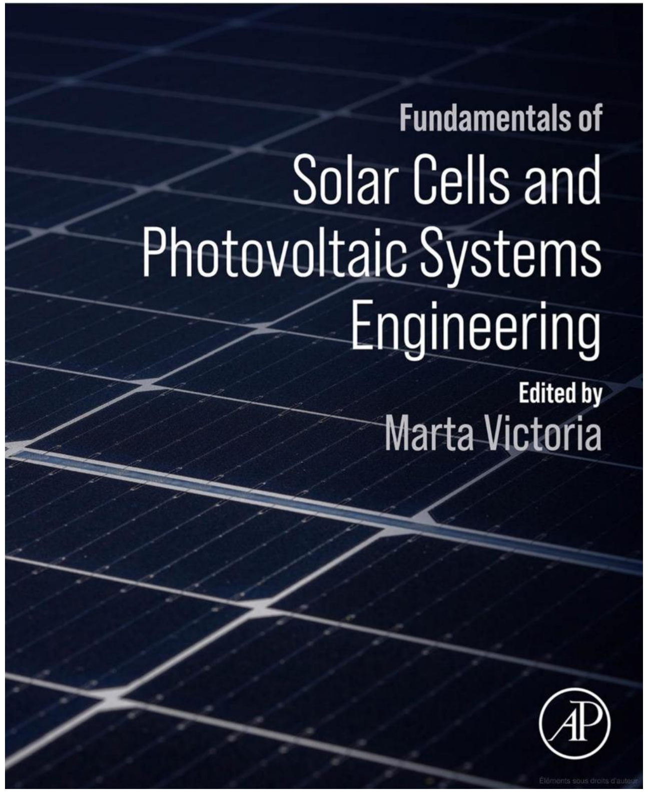
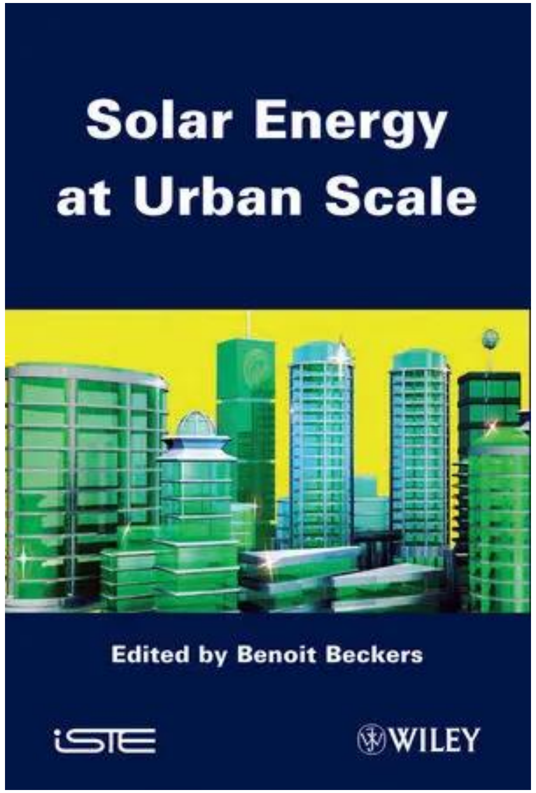
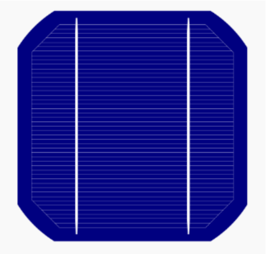
Suggested materials



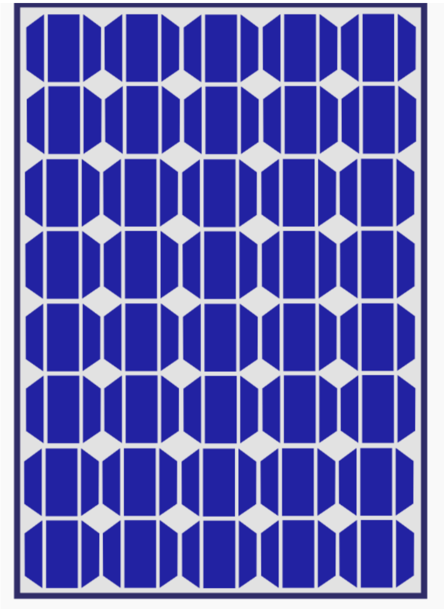


Then, the photovoltaics

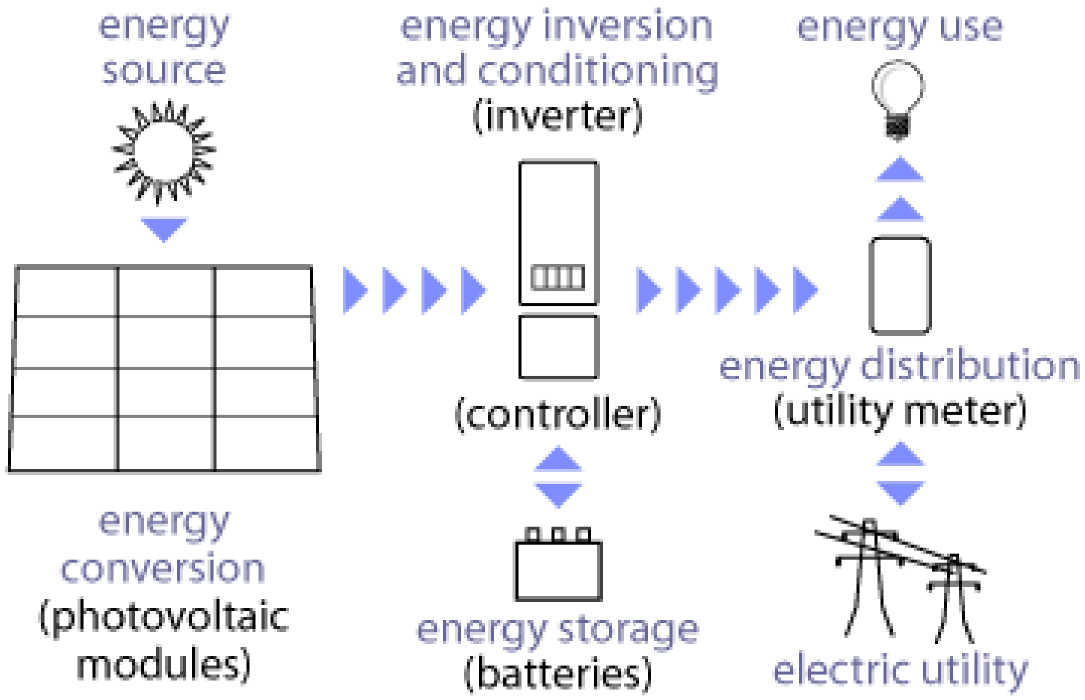
Solar Cell



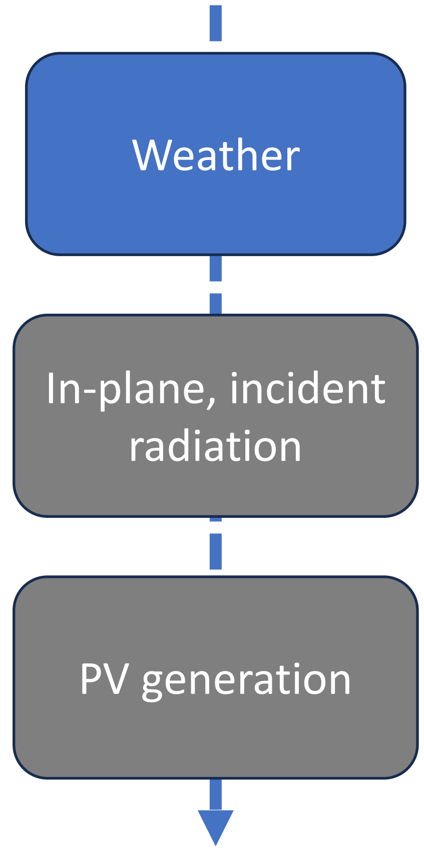
Solar Module



Solar system



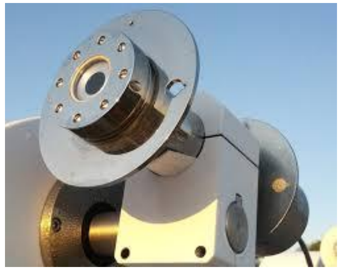
Many types of data sources



In-situ

Pyranometer

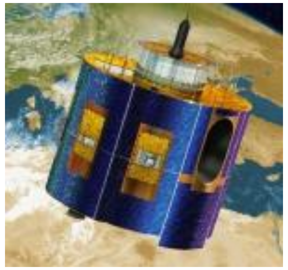
+ shadowband



Pyrheliometer

Weather station

Cloud radar



Satellite

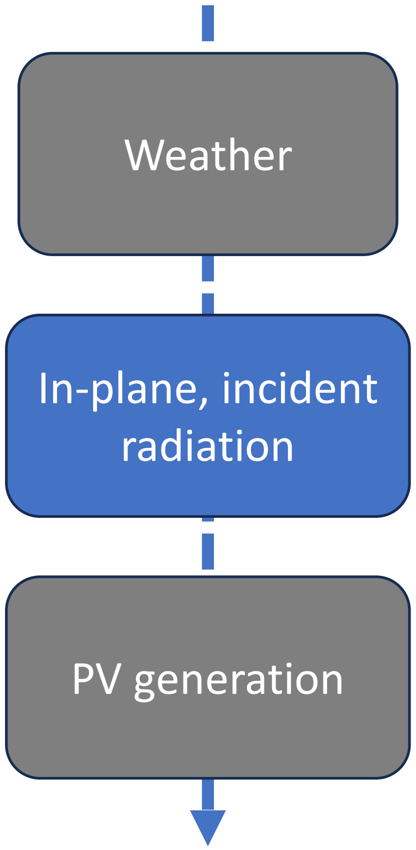
Airborne data

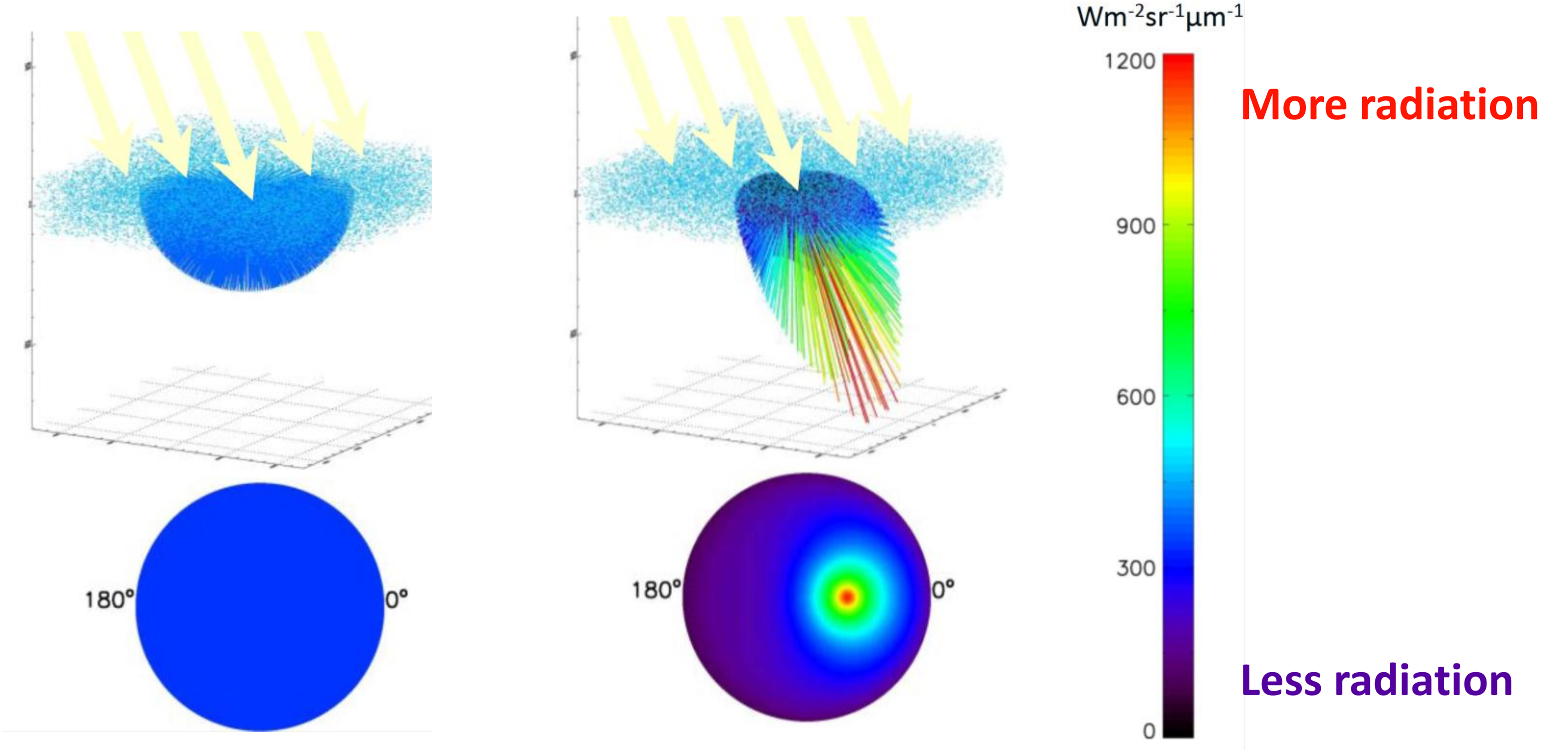
Remote sensing

Numerical Weather Model

Models

Radiation is far from being isotropic

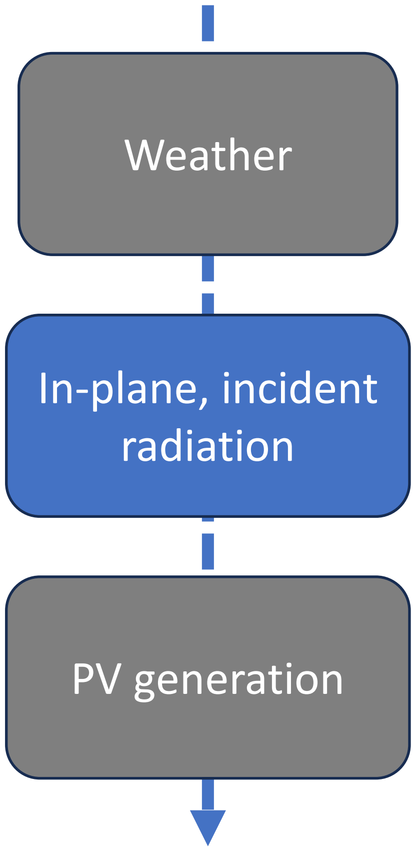




Isotropic assumption

Anisotropic reality

Transposition models



Beam/direct is isotropic, so it's mainly geometric:

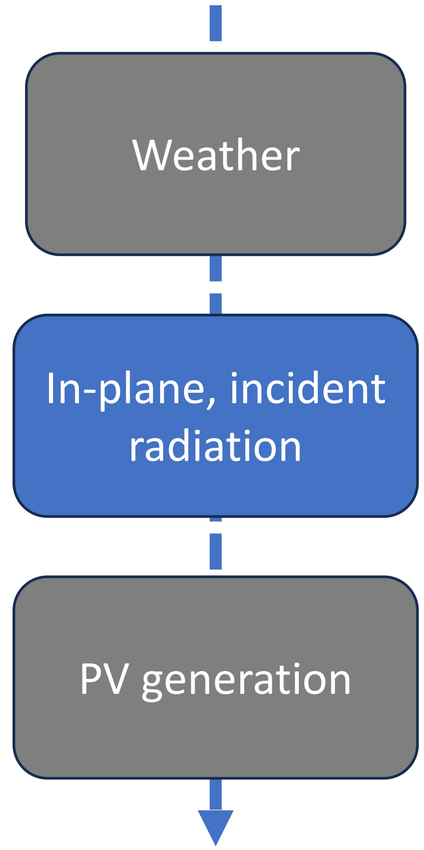
$$BTI = BNI \times \cos(AOI)$$

For diffuse, there are many approaches:

Model	Considers	Good for
Liu-Jordan	Full isotropy	Very cloudy skies
Temps-Coulson	Full anisotropy, near-horizon and circumsolar	Clear skies
Klucher	Tries to merge previous two	All skies
Perez	Both (an)isotropy, more detailed modelling	All skies

pvlib: a great Python package for this
https://pvlib-python.readthedocs.io/en/stable/reference/irradiance/transposition.html

Decomposition models

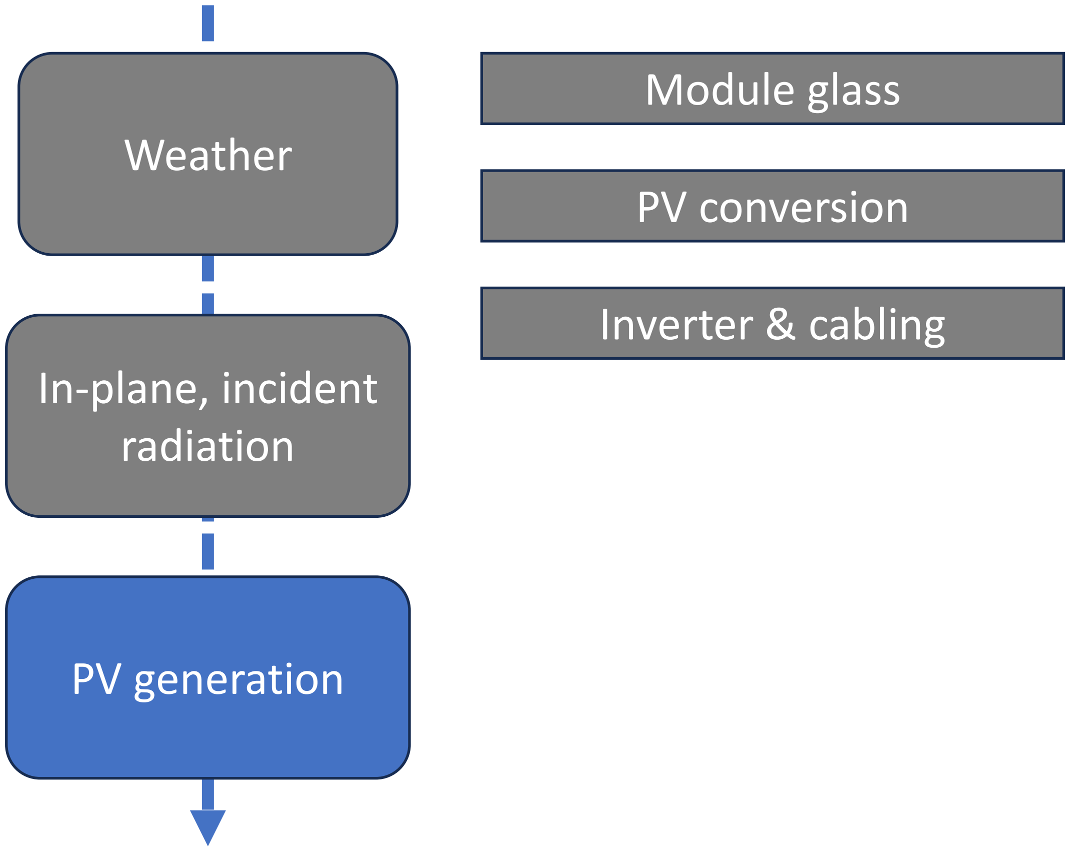


Transposition: we know total diffuse, but how is it distributed in the sky?

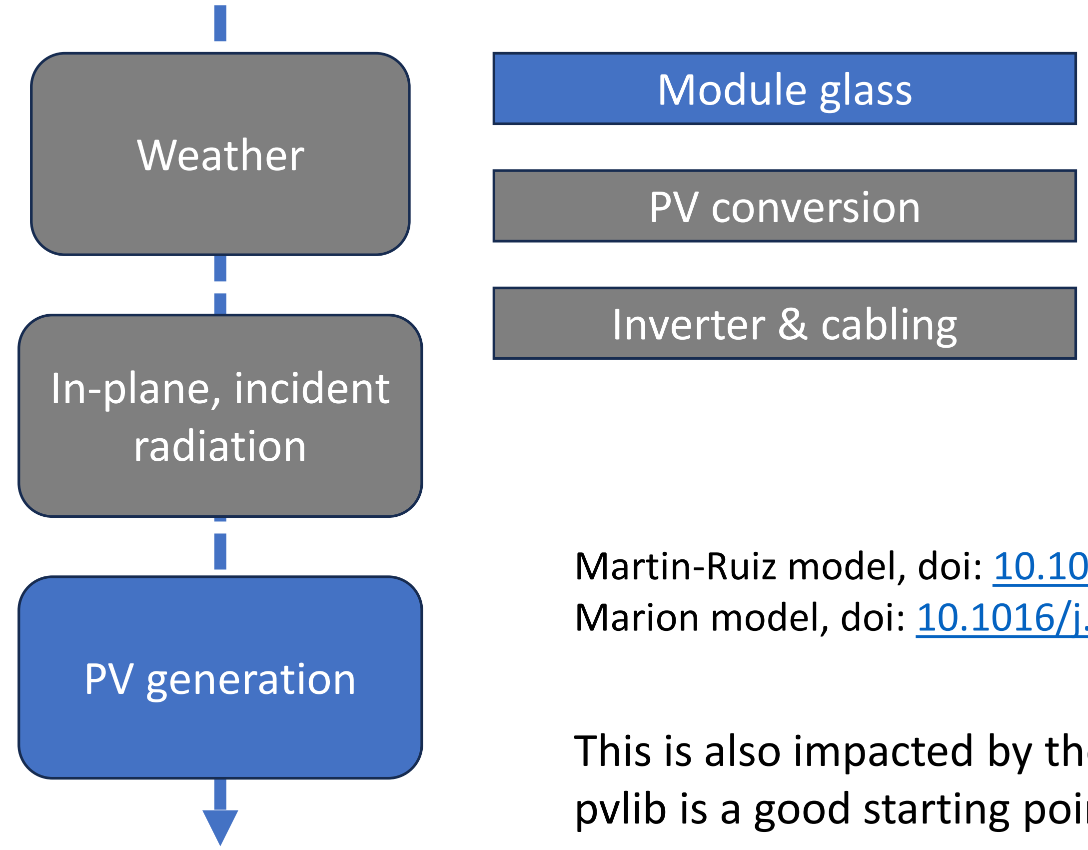
Decomposition: how much is total diffuse even?

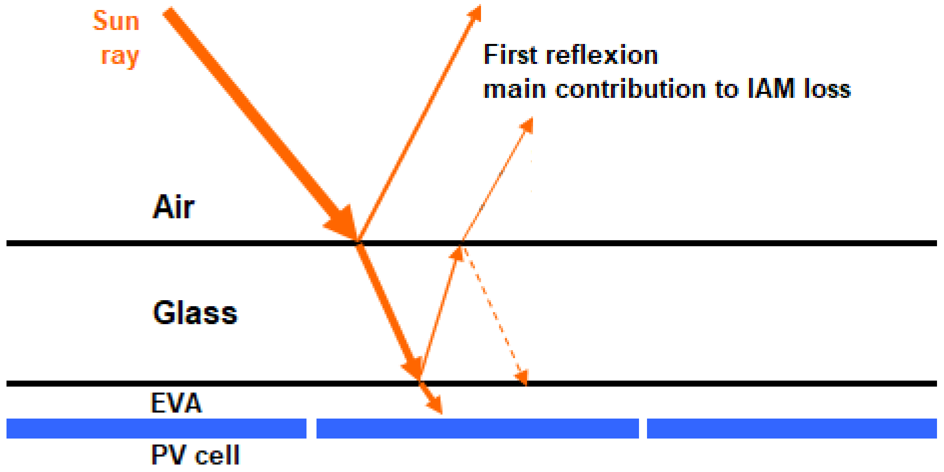
Model	Considers
Erbs	Empirical linear correlation between **diffuse fraction** and clearness index. Based on observations from the USA.
Orgill & Hollands	Similar as Erbs but considers piece-wise linear correlation.
Reindl	Includes solar zenith angle as input (as a kind of proxy to AOD)
DIRINT	Semi-empirical, derives direct irradiance and adds air mass to inputs.
de Miguel	Similar to Orgill & Hollands, but adjusted to North Mediterranean Belt

PV performance losses



Optical losses



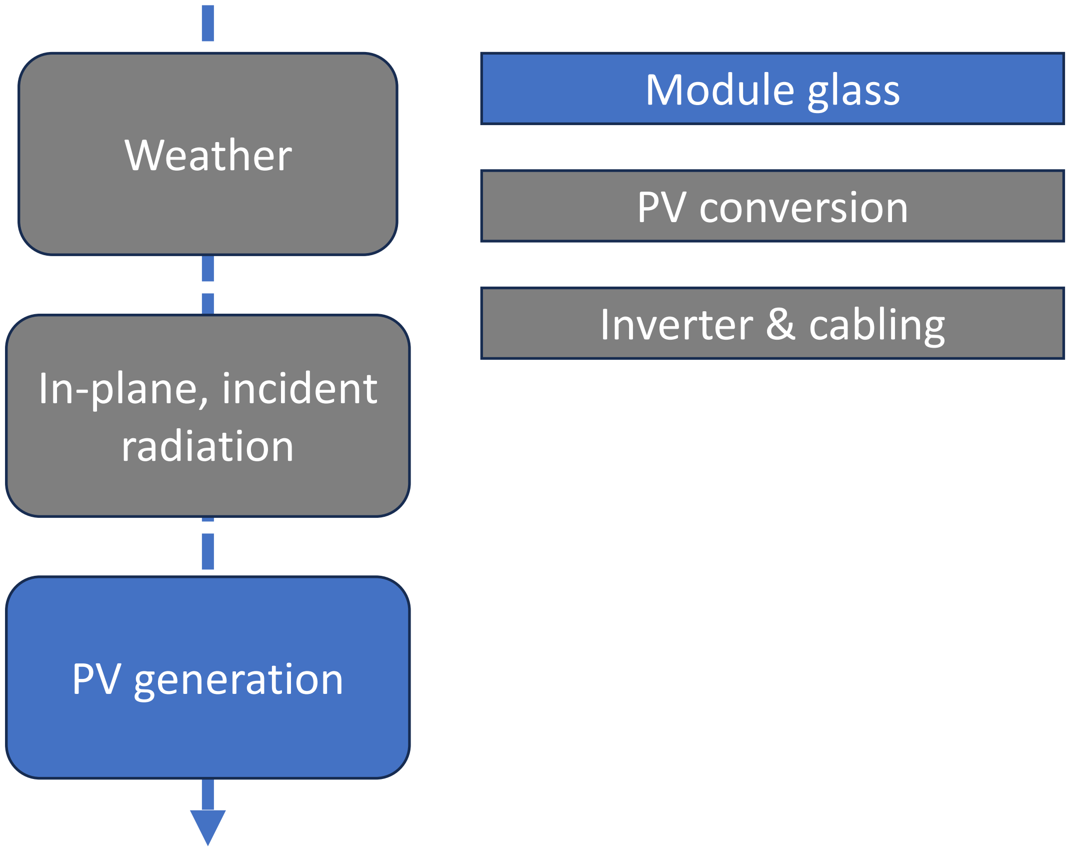


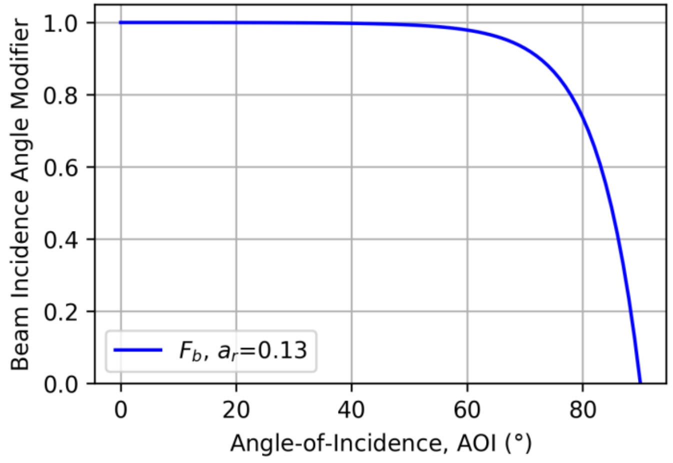
Martin-Ruiz model, doi: [10.1016/S0927-0248(00)00408-6](https://doi.org/10.1016/S0927-0248(00)00408-6)
Marion model, doi: [10.1016/j.solener.2017.03.027](https://doi.org/10.1016/j.solener.2017.03.027)

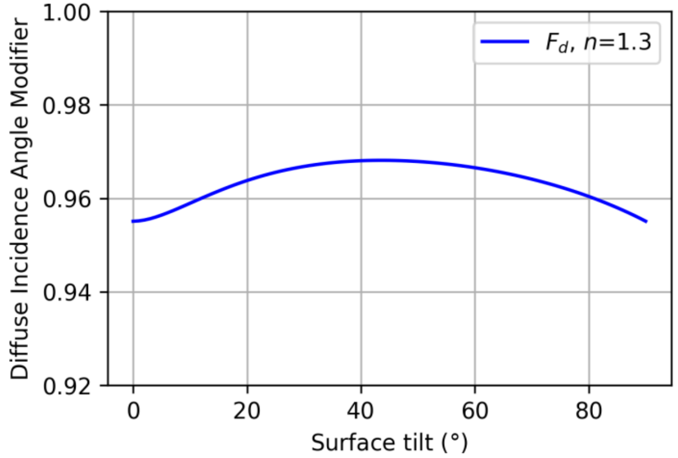
Configuration
Air/glass
Air/glass/Si
Air/glass/SiO_2/Si
Air/glass/triple coat./Si
Air/glass/ZnS/Si
Air/glass/a-Si:H/Ag
Air/glass/ITO(*d*1)/a-Si:H/Ag
Air/glass/ITO(*d*2)/a-Si:H/Ag

This is also impacted by the dust on the module surface.
pvlib is a good starting point. Look for IAM

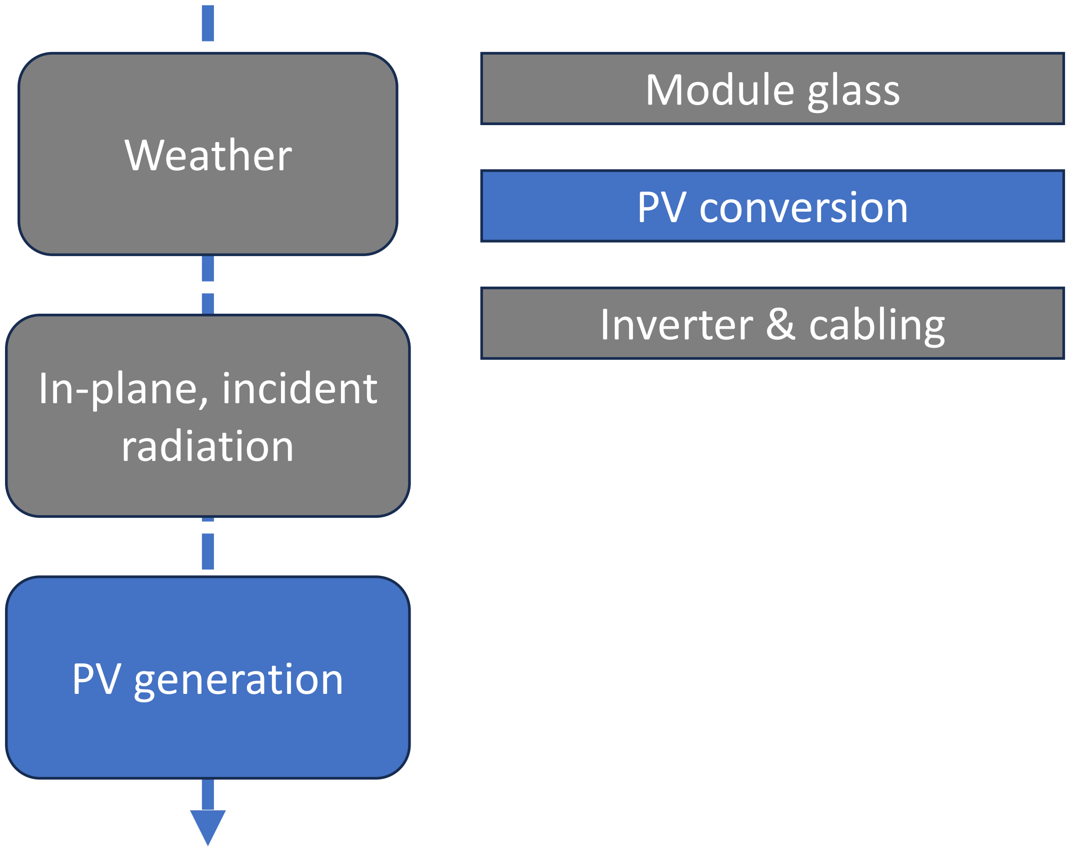
Optical losses







Conversion efficiency



PV efficiency in standard test conditions (STC)


www.jinkosolar.com

JinKO Solar

TiGER Neo

60HL4-(V)

475-500 Watt

MONO-FACIAL MODULE

N-type

N-type Technology

N-type modules with Tunnel Oxide Passivating Contacts (TOPcon) technology offer lower LID/LeTID degradation and better low light performance.

HOT 3.0 Technology

N-type modules with JinkoSolar's HOT 3.0 technology offer better reliability and efficiency.

Durability Against Extreme Environment

High salt mist and ammonia resistance.

Mechanical Load Enhanced

Certified to withstand:
5400 Pa front side max static test load
2400 Pa rear side max static test load

SMBB Technology

Better light trapping and current collection to improve module power output and reliability.

Anti-PID Guarantee

Minimizes the chance of degradation caused by PID phenomena through optimization of cell production technology and material control.

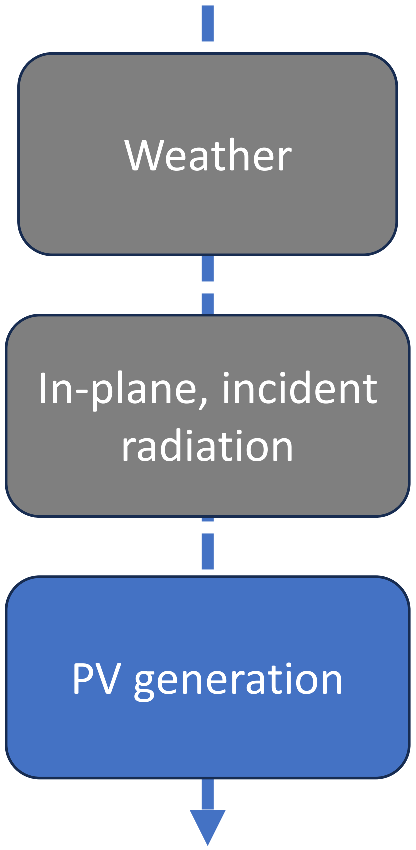
87.4%

12 Year | 30 Year | 1% | 0.40%

- IEC61215:2021 / IEC61730:2023
- IEC61701 / IEC62716 / IEC60068 / IEC62804
- ISO9001:2015: Quality Management System
- ISO14001:2015: Environment Management System
- ISO45001:2018: Occupational health and safety management systems

JKM475-500N-60HL4-(V)-F8-EU

Conversion efficiency



- Module glass
- PV conversion
- Inverter & cabling

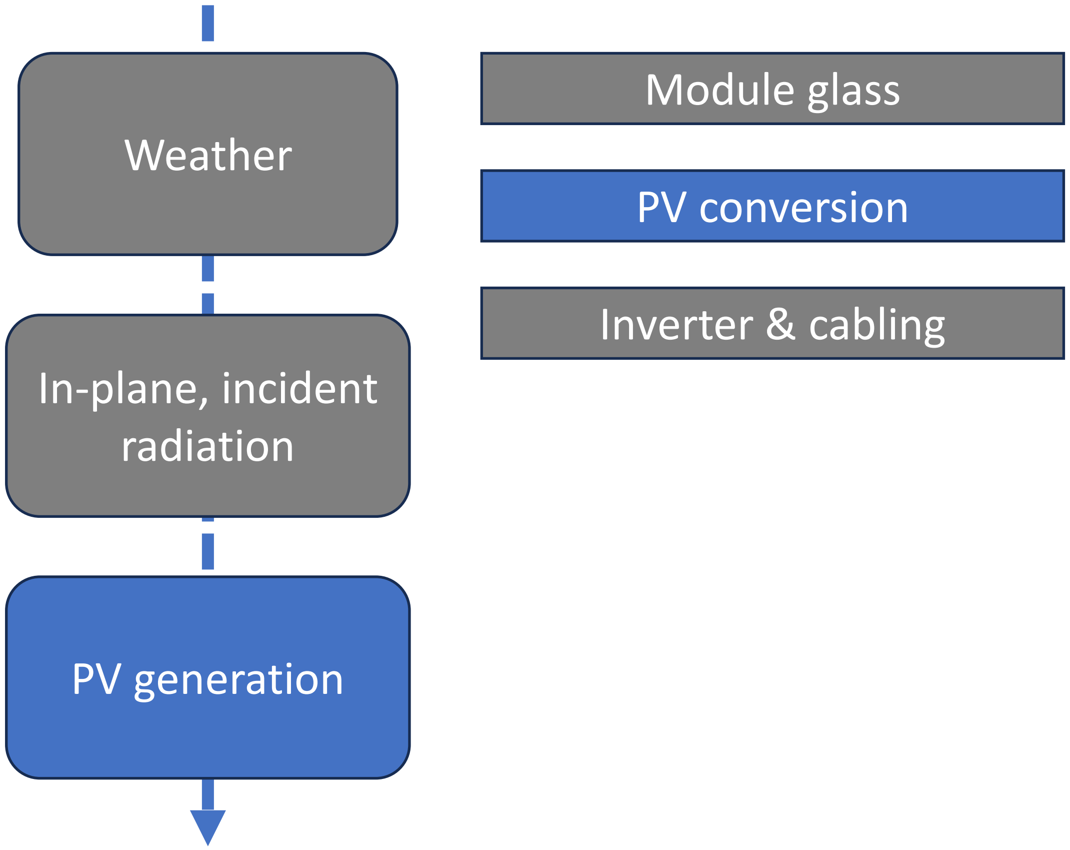
First, PV efficiency in standard test conditions

Specifications (STC)
Maximum Power – Pmax [Wp]
Maximum Power Voltage – Vmp [V]
Maximum Power Current – Imp [A]
Open-circuit Voltage – Voc [V]
Short-circuit Current – Isc [A]
Module Efficiency STC [%]
Power Tolerance
Temperature Coefficients of Pmax
Temperature Coefficients of Voc
Temperature Coefficients of Isc

STC: Irradiance 1000W/m², Cell Temperature 25°C, AM=1.5

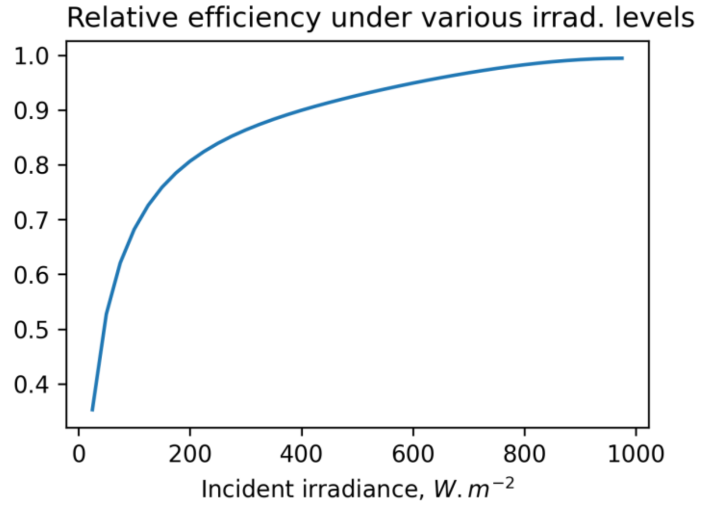
Varies from module to module

Conversion efficiency



Then, account for low-irradiance losses

- Example from Beyer model:



Thermal losses

Weather

In-plane, incident radiation

PV generation

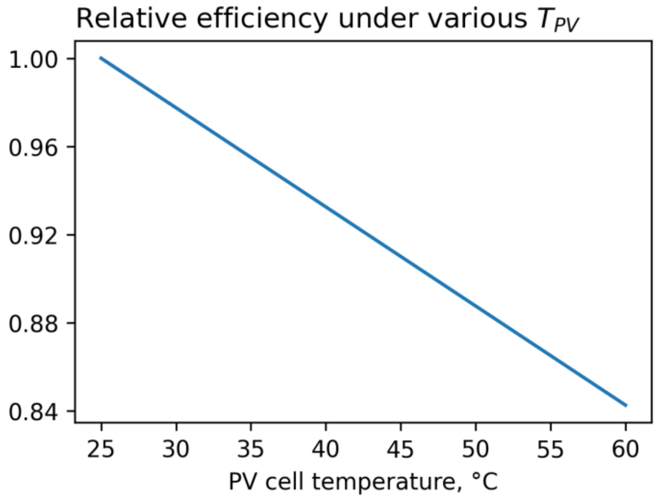
Module glass

PV conversion

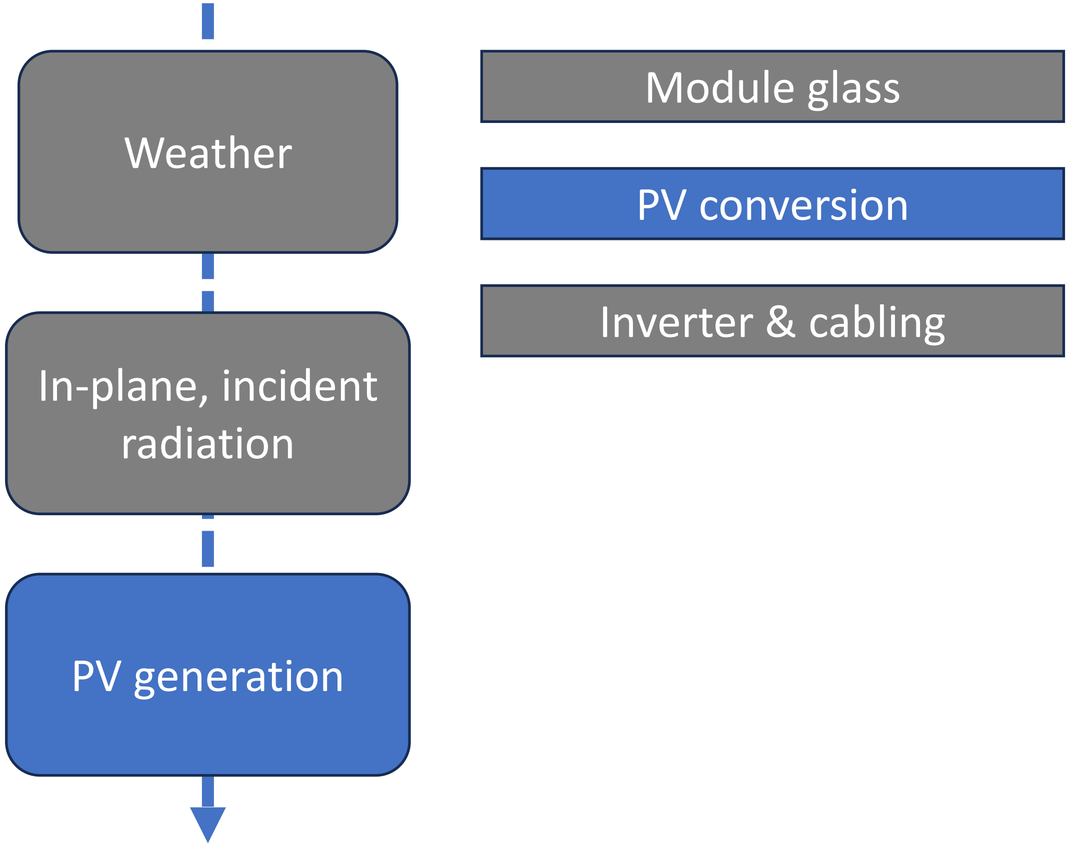
Inverter & cabling

Then, account for thermal losses

- Depends on module, but generic -0.45%/°C



Thermal losses



Need to calculate PV cell temperature

- Many models @pvlib with different input needs
- Can depend on air temperature, GTI, wind speed, type of installation (e.g. rooftop vs ground-based)

Different levels of back ventilation

Thermal losses

Weather

In-plane, incident radiation

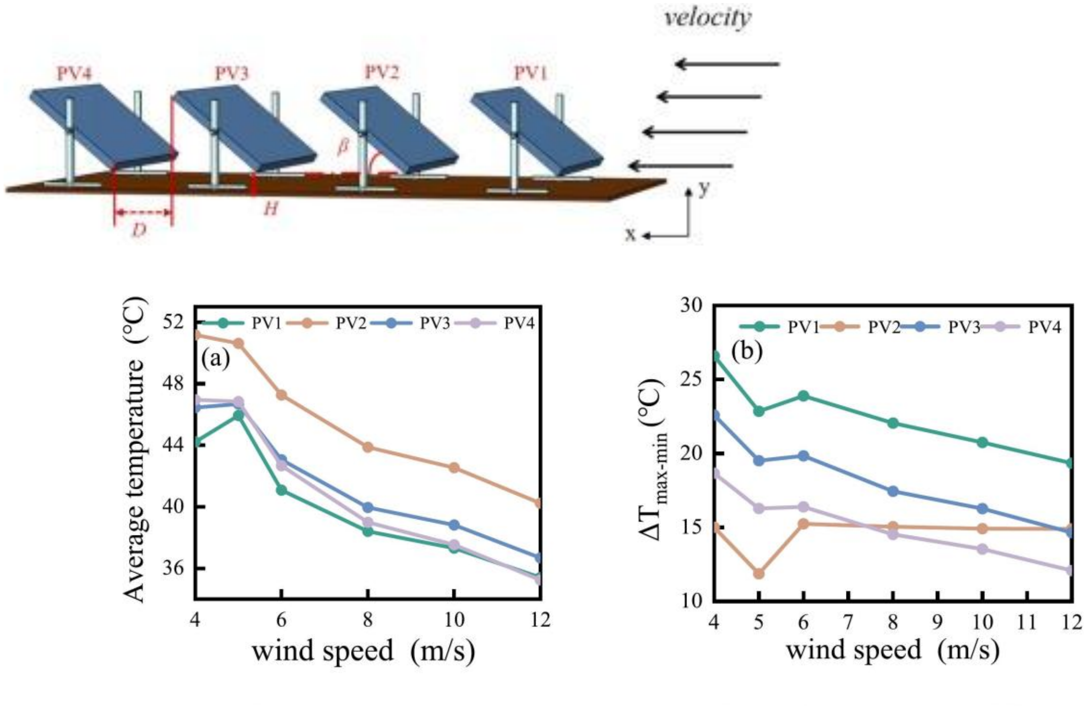
PV generation

Module glass

PV conversion

Inverter

Also impacted by spatial arrangement



(a) Average temperature

(b) Maximum temperature difference

Inverter and electric losses

Weather

In-plane, incident radiation

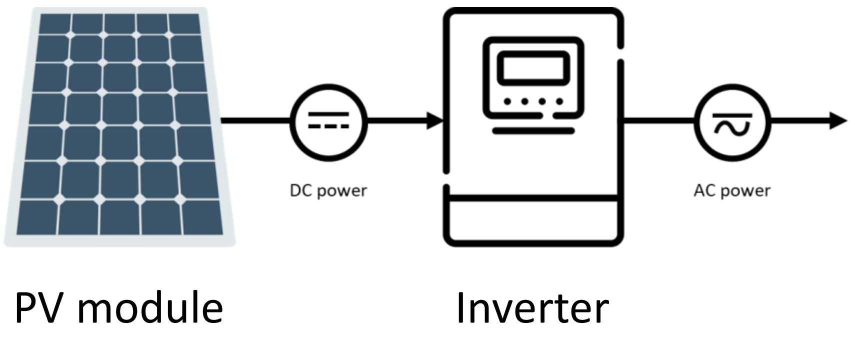
PV generation

Module glass

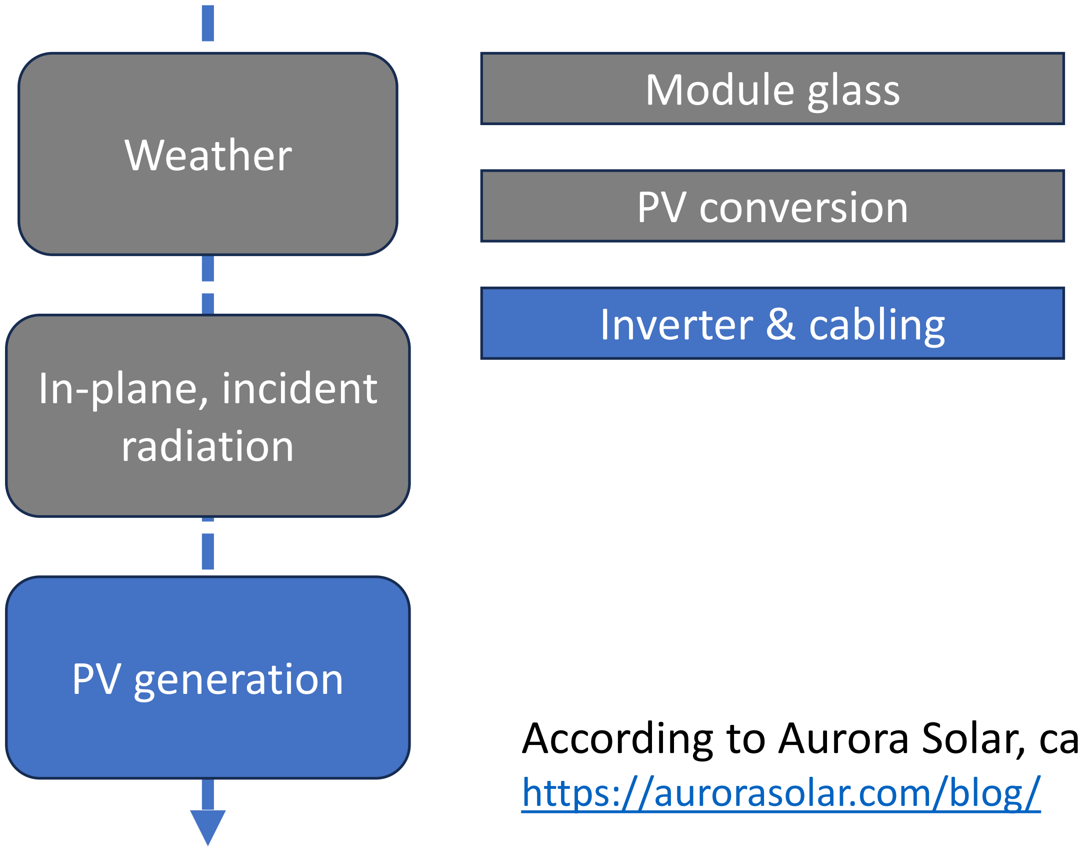
PV conversion

Inverter & cabling

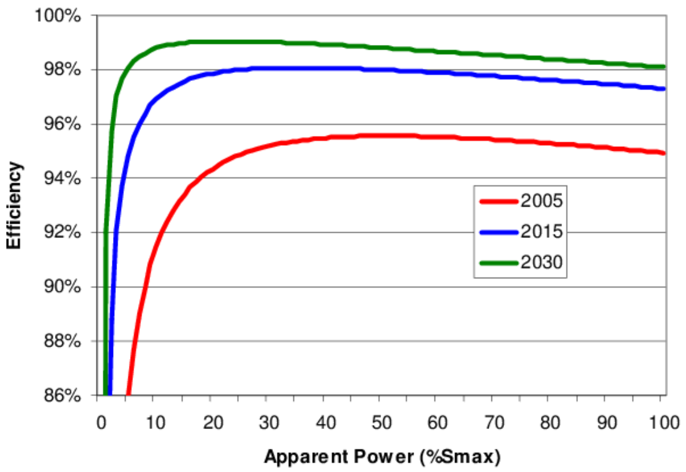
Electric conversion losses



Inverter and electric losses



An inverter efficiency curve



- Very low at P_{in} < 10%
- Peaks at a certain %
- Then slowly decreases

Source: Braun (2007)

According to Aurora Solar, cabling losses vary between 1-2%
https://aurorasolar.com/blog/