Operational research for urban solar development

"PV failure detection based on operational time series"

13/11/2024

Alexandre Mathieu

UNIVERSITÉ SAVOIE MONT BLANC

Curriculum Plan

Day	Time	Duration	Content
Wednesday 13/11/2024	11h45-12h45 14h15-15h45	1h30 + 1h30	50% Lecture / 50 % Hands-on
Tuesday 26/11/2024	9h45-13h00	1h30 + 1h30	25% Lecture / 75 % Hands-on
Monday 02/12/2024	13h15-16h15	3h	15% Lecture / 85 % Hands-on
Monday 09/12/2024	8h-11h 13h15-16h15	6h	10% Lecture / 90 % Hands-on/Project
Tuesday 10/12/2024	8h-11h	3h	10% Lecture / 90 % Project
Monday 16/12/2024	8-11h	3h	10% Lecture / 90 % Project
Thursday 19/12/2024	9h45-12h45	3h	10% Lecture / 90 % Project
Monday 06/01/2025	13h15-14h45	1h30	100% Project
Monday 13/01/2025	9h45-11h45	1h30	100% Project
Total		**27h**	

Curriculum

Content

PV performance modeling from weather variables (Irradiance in the plane of array, ambient temperature etc..) and system configuration, which includes:

- Module temperature
- DC power
- AC/DC efficiency
- Performance metric calculations.

Failure detection based on real production time series.

Hands-on with **python** notebooks.

Curriculum

Motivations

PV capacity increases exponentially

+20%/year worldwide since 2010[1]

Complex in-situ O & M:

No one-fit-all O&M[2]

Expensive[3]

15%[4] of underperformances:

« Recoverable » Energy: 5%[4,5]

[1] Masson, G., Kaizuka, I., 2021. Trends in Photovoltaic Applications (IEA-PVPS T1-41:2021). IEA PVPS

[2] U. Jahn et al., 'Guidelines for Operation and Maintenance of Photovoltaic Power Plants in Different Climates', IEA, Technical Report IEA-PVPS T13-07:2022, Oct. 2022.

[3] « Coûts et rentabilités du grand photovoltaïque en métropole continentale », CRE, 2019

[4] Leloux, J., Narvarte, L., Trebosc, D., 2011. Performance analysis of 10,000 residential PV systems in France and Belgium. Presented at the 26th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, Germany.)

[5] Raycatch, 'Solar Asset Optimization, Industry Benchmark Study', Tel Aviv, Israel, Feb. 2021.

Curriculum

Objectives

At the end of this course, you should be able to:

- Perform data treatment and analysis with Python on operational PV time series.
- Model and calculate the performance of a PV installation.
- Detect and quantify underperformances.

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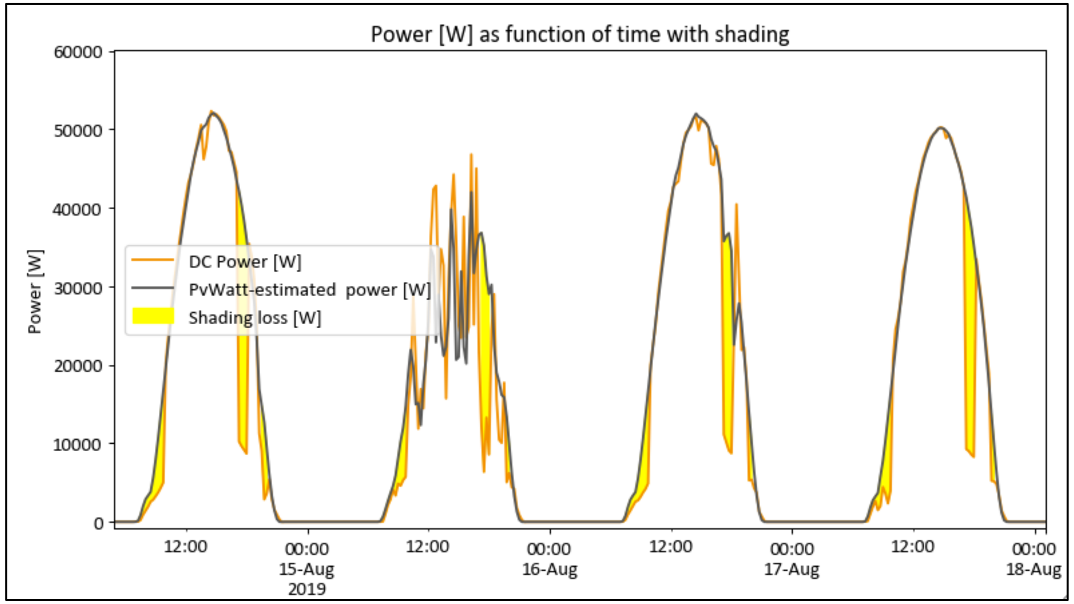
Final project

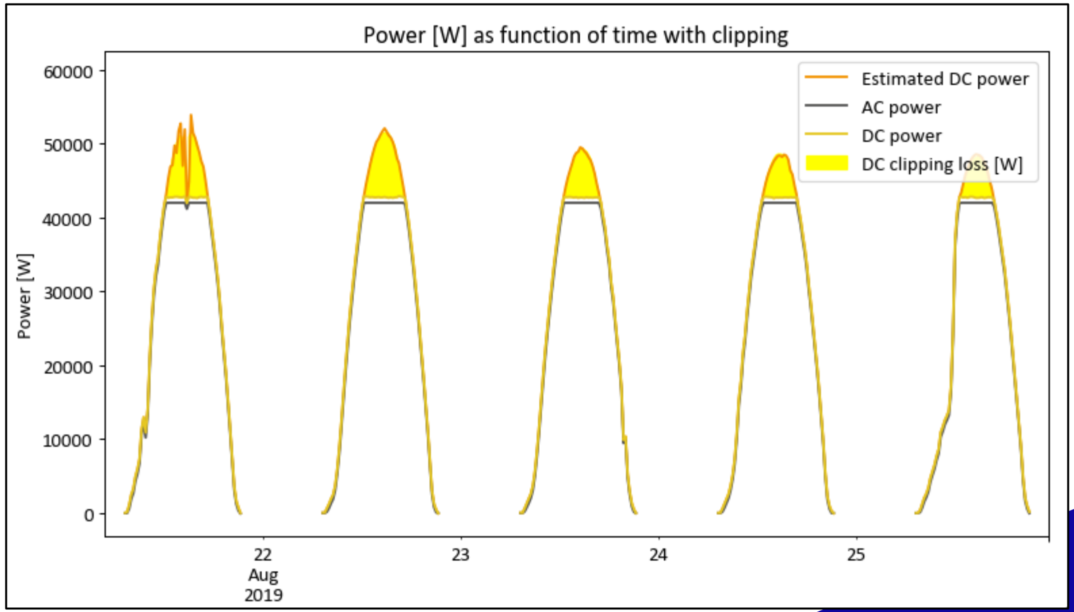


The project aims at detecting PV underperformances.

2 grades:

1. Estimation of the operating variables such as POA irradiance, module temperature, DC and AC power from in-situ data.

2. Loss quantification from some underperformances (shading, clipping, short-circuit…).



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CSTB le futur en construction

PROPOSITION DE STAGE INGENIEUR(E)

Détermination des gains réels d'actions d'efficacité énergétique dans le bâtiment : apprentissage statistique et estimation d'incertitudes

Internship offer

"Assessing Actual Gains of Energy Efficiency Actions in Buildings: Statistical Learning and Uncertainty Estimation"

Early 2025

6 mois

1200eur

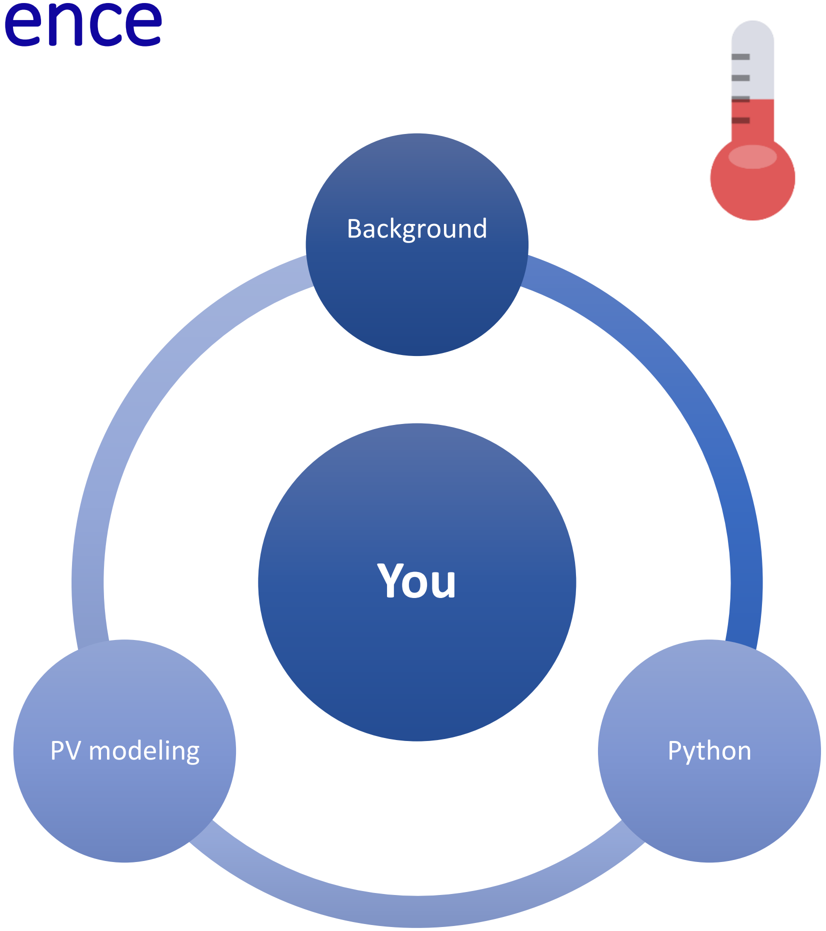
CSTB / Champs-sur Marne (around Paris)

Python / Data-analysis / Machine Learning

thimothee.thiery@cstb.fr

Audience

Audience



https://forms.gle/MVFYCf1i7MiT9oGs7

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Who am I ?

PhD: Methodology development to guarantee building photovoltaic systems' performance including failure modelling.

Started in March 2022. Aiming to finish in March 2025.

Studied Engineering / Sustainable Energy in France & Denmark.

My personal belief is that research owes to find solutions to mitigate the human environmental impact.

Hobbies:

- Mountains
- Sports
- Travelling

Born in Grenoble, Raised there, Living there…

Agenda

Curriculum

Audience

PV performance model steps

Modeling steps

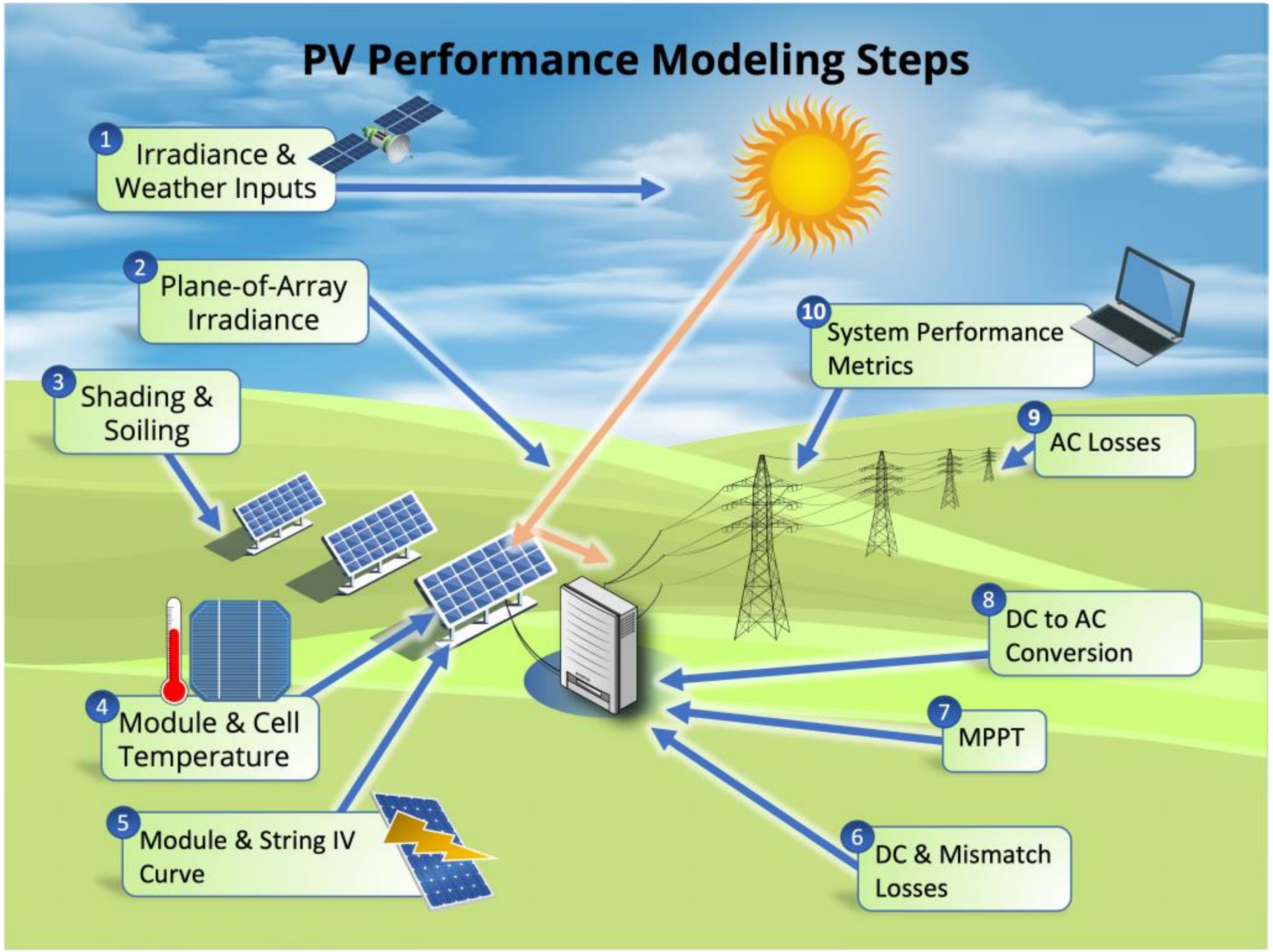

*image from: PVSC48 python tutorial

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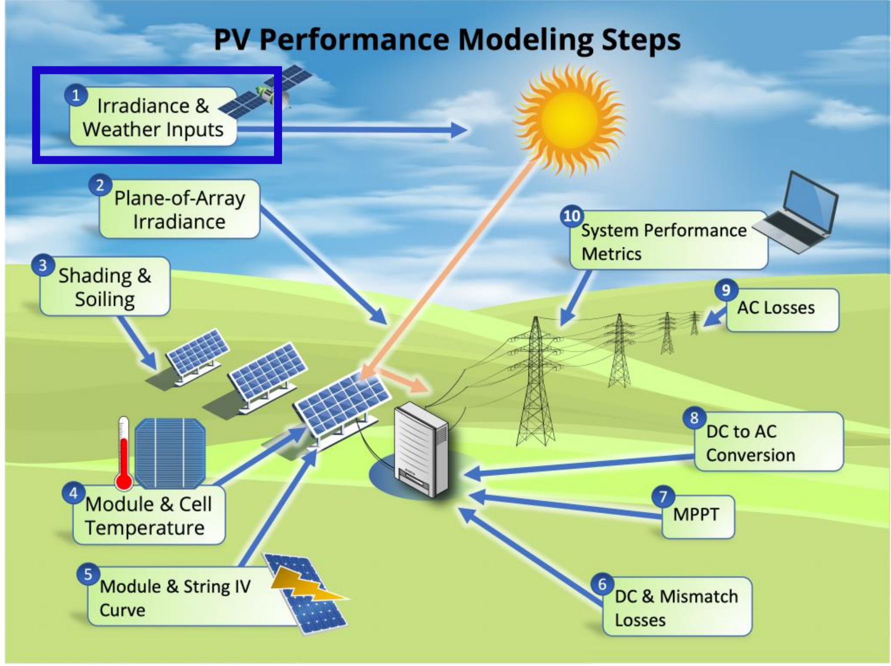
Modeling steps

1. **Weather data:** Irradiance, ambient temperature, humidity, rain, snow…



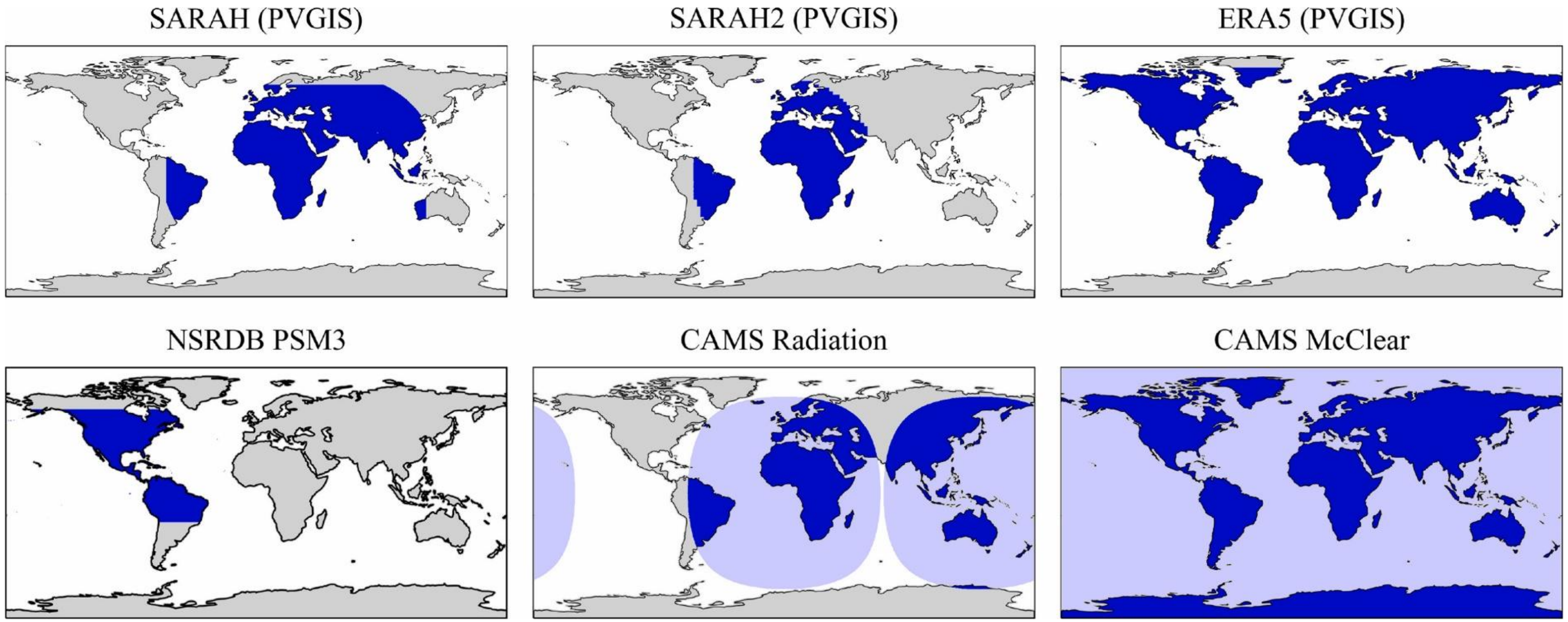
Modeling steps

1. **Weather data:**

Irradiance, measured in W/m2, with max instantaneous values around 1000 W/m2 is obtained from:

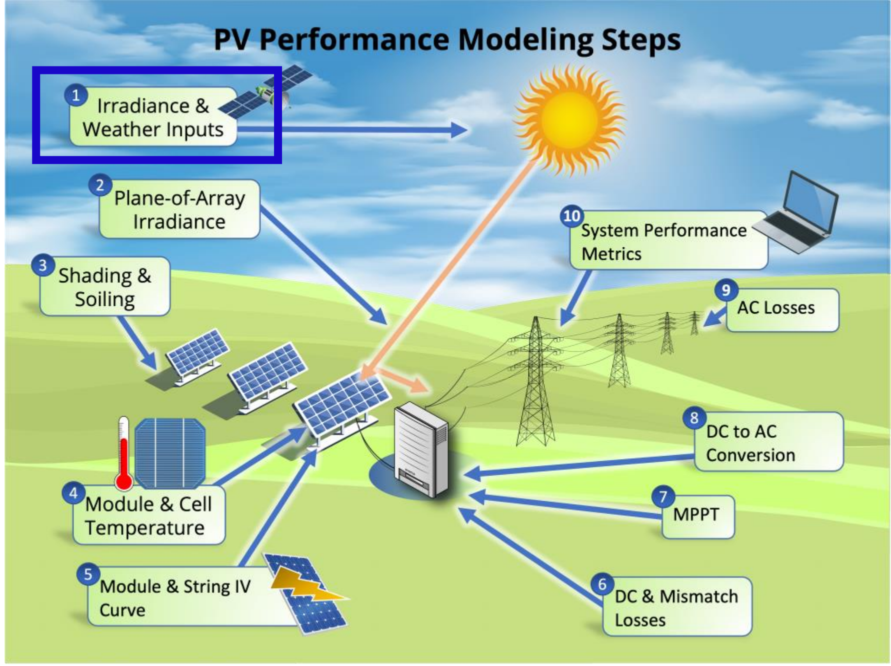
   a. Satellite data (CAMS, NSSRDB, SolarGis…)

Some Irradiance datasets, supported by pvlib [1]



[1] Adam R. Jensen, Kevin S. Anderson, William F. Holmgren, Mark A. Mikofski, Clifford W. Hansen, Leland J. Boeman, Roel Loonen, pvlib iotools—Open-source Python functions for seamless access to solar irradiance data, Solar Energy, 2023

Modeling steps



1. Weather data:

Irradiance, measured in W/m2, is obtained from:

a. Satellite data (CAMS, NSSRDB, SolarGis…)

b. In-situ instrumentations

Pyranometer:
Global/Inclined Irradiance

Pyrheliometer:
Direct irradiance

(Hukseflux product)

Pyranometer with shadow ring:
Diffuse Irradiance

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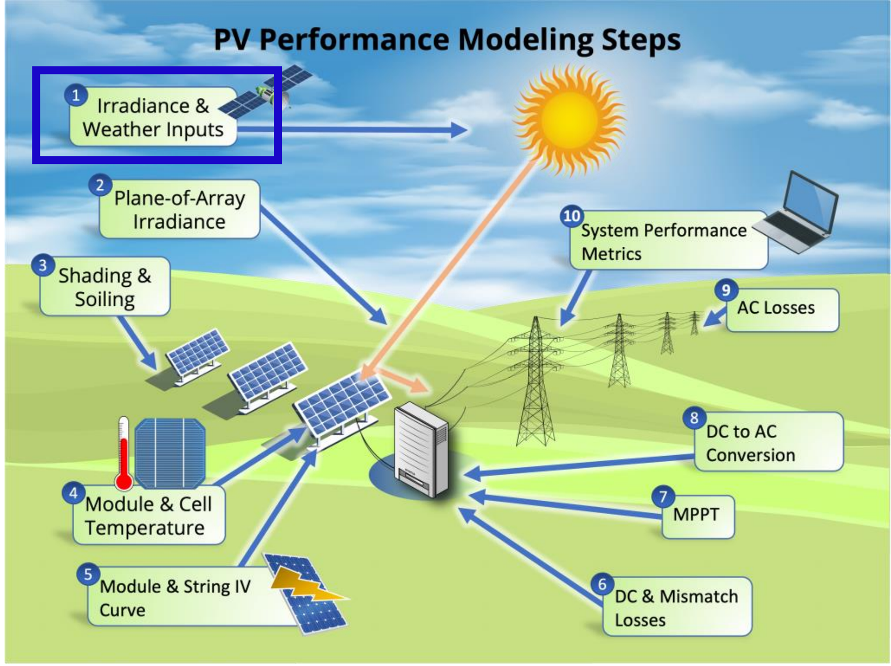
Modeling steps



1. Weather data:

Irradiance, measured in W/m2, is obtained from:

a. Satellite data (CAMS, NSSRDB, SolarGis…)
b. In-situ instrumentations

Reference cell: Inclined Irradiance (without reflection/spectral effects)

Modeling steps

1. Weather data

Reminder, the Global Horizontal Irradiance (GHI) can be broken down into 2 components (ignoring reflections from other surrounding elements):

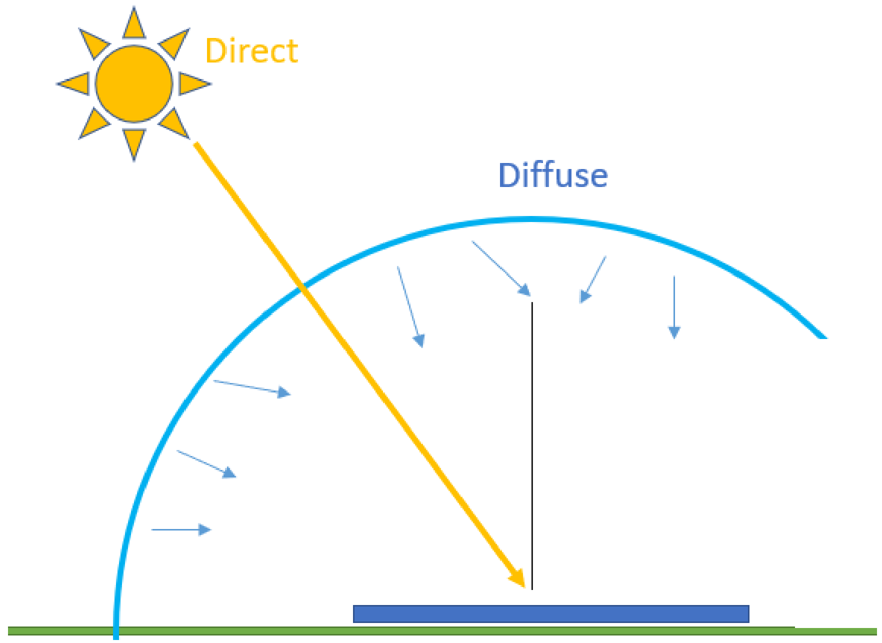


*image from PVSC48 tutorial

$$GHI = BHI + DHI$$

BHI (Beam Horizontal Irradiance): Power received from the Beam of the sun on the horizontal plan.

DHI (Diffuse Horizontal Irradiance): Power received from the sky diffusion of the light.

Modeling steps

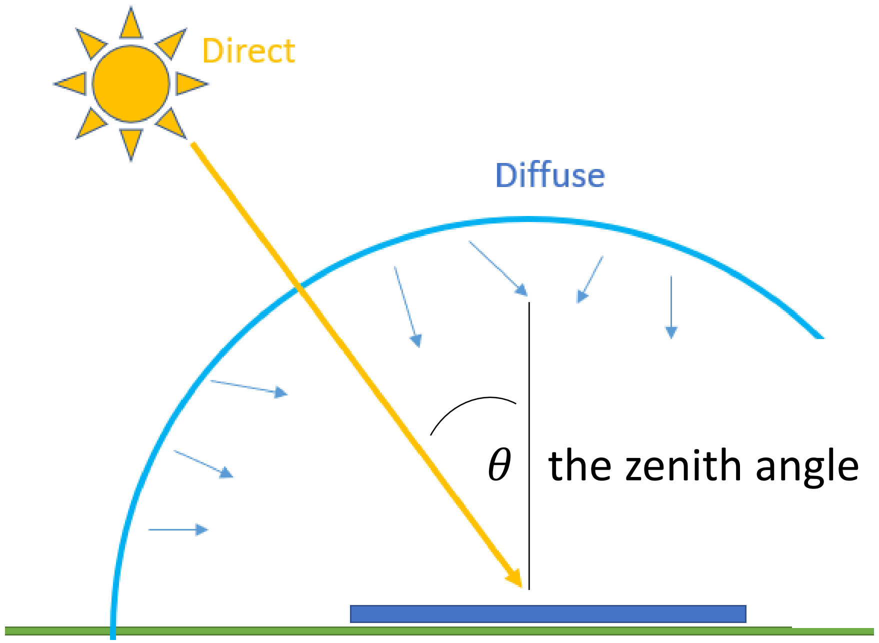


*image adapted from PVSC48 tutorial

1. Weather data

Reminder, the Global Horizontal Irradiance (GHI) can be broken down into 2 components (ignoring reflections from other surrounding elements):

$$GHI = BHI + DHI$$

BHI (Beam Horizontal Irradiance): Power received from the Beam of the sun on the horizontal plan.
BHI is usually deducted from DNI, the Direct Normal Irradiance, which is most commonly the output of weather models.

$$BHI = DNI \cdot \cos(\theta)$$

DHI (Diffuse Horizontal Irradiance): Power received from the sky diffusion of the light.

Modeling steps

1. Weather data:

Sun path

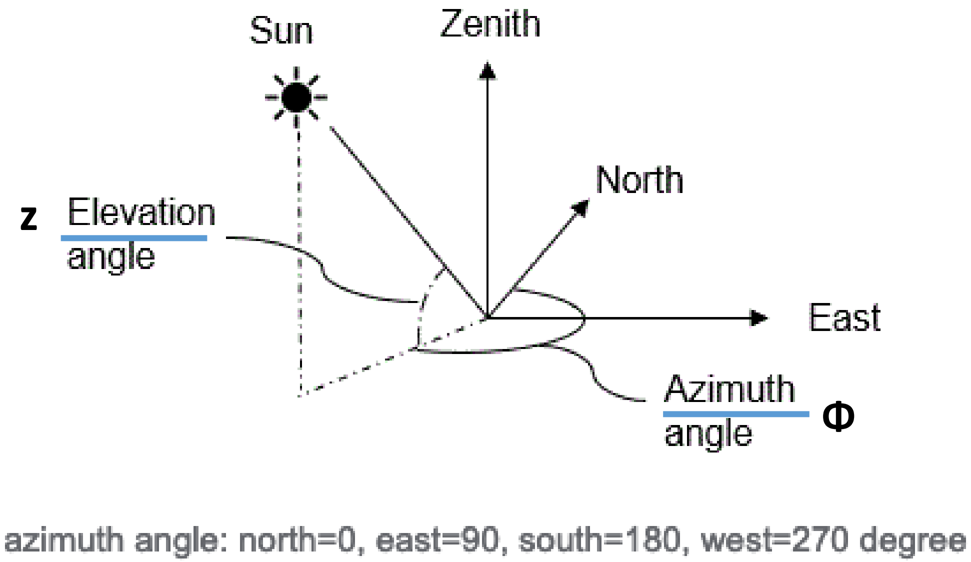
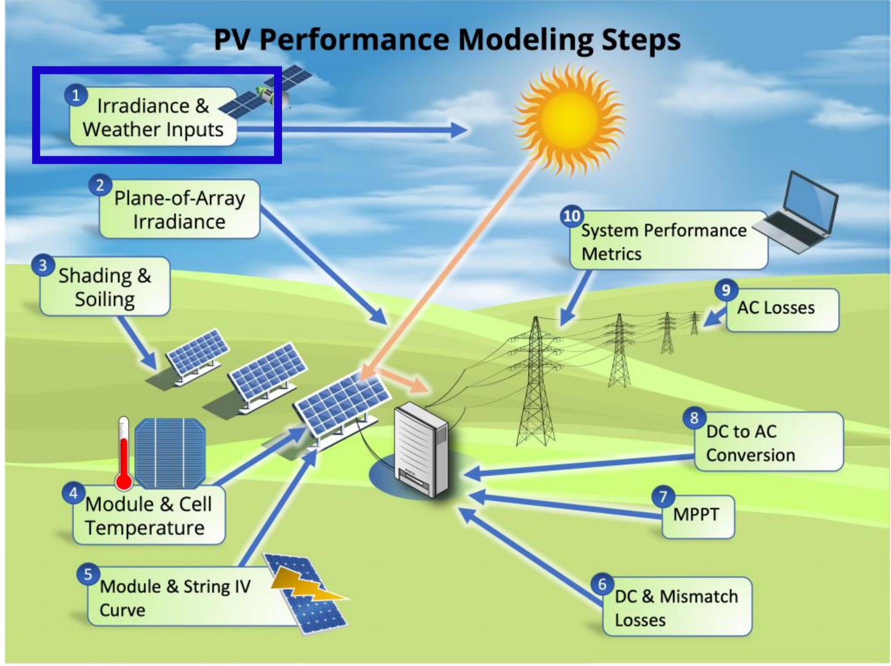


Image: https://www.prairielittlebighouse.com/prairie-blog/archives/03-2021



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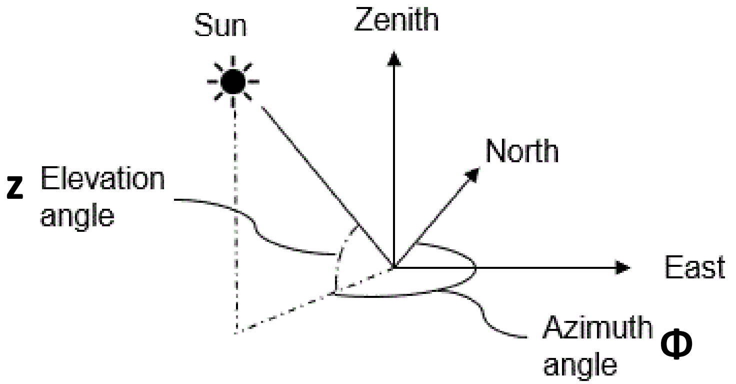
Modeling steps

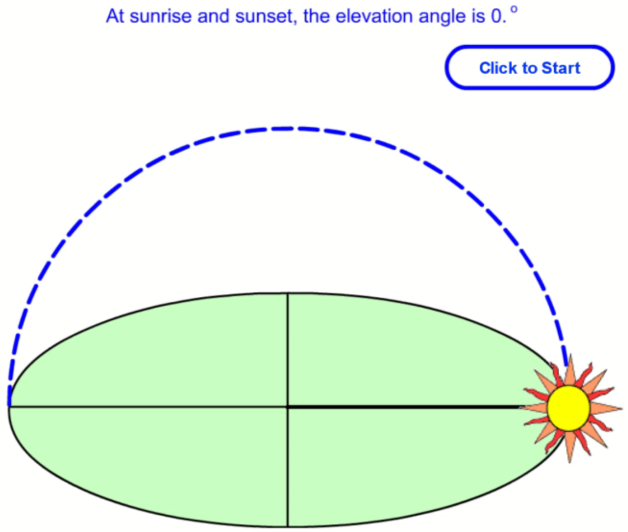


azimuth angle: north=0, east=90, south=180, west=270 degree

1. Weather data:

The sun path is characterized by:

- **h** [°], elevation angle, height of the sun in the sky



*animation from pveducation

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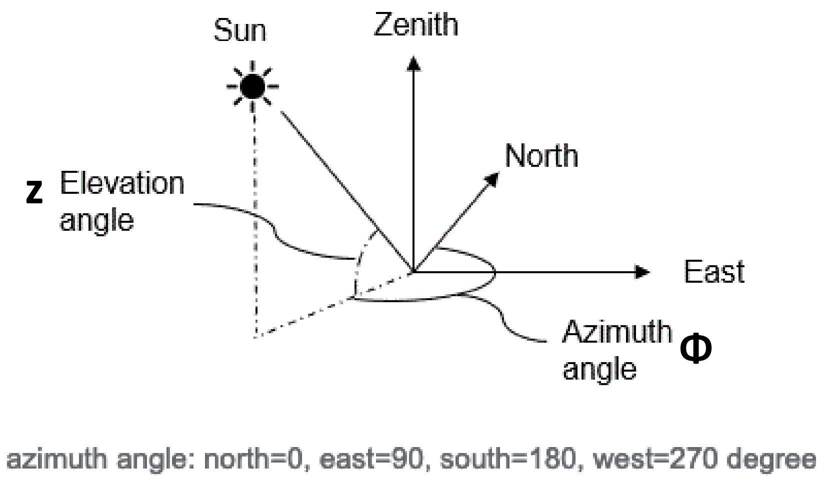
Modeling steps



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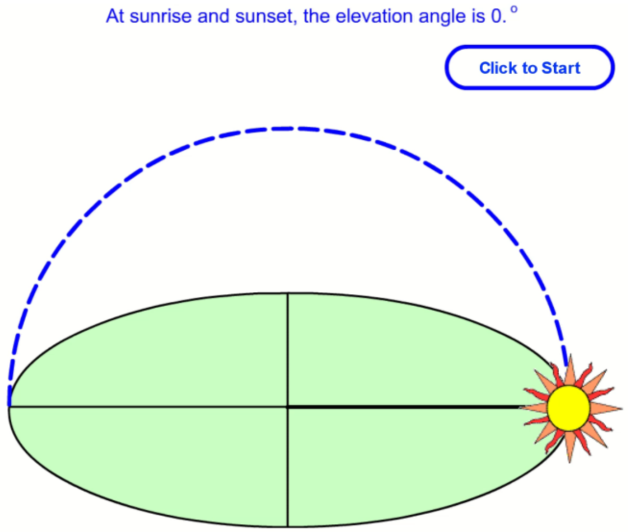
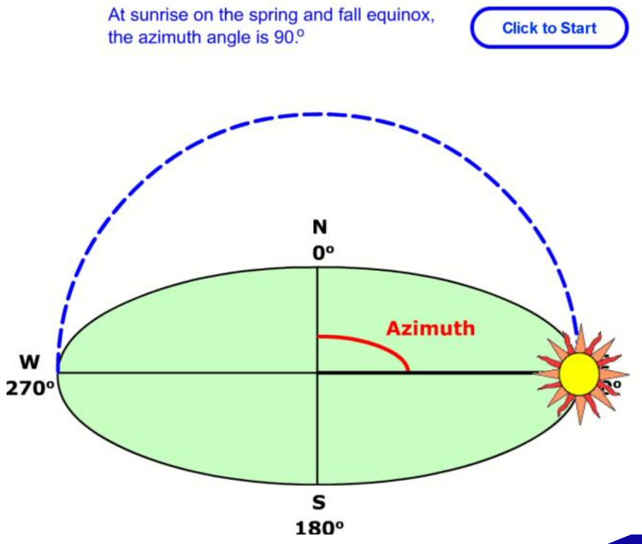


*animation from pveducation

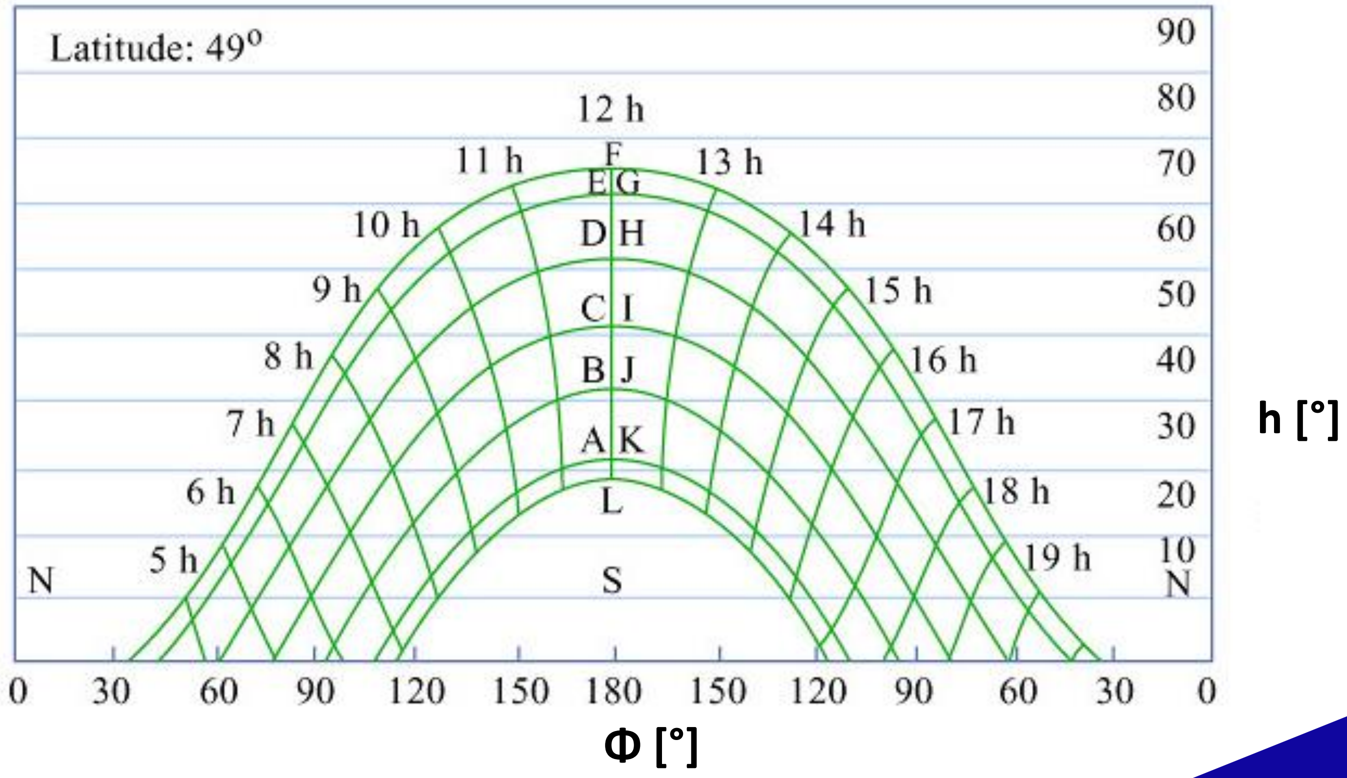
- **Φ** [°], the azimuth angle: angle of sun between north and sun direction



*animation from pveducation

Modeling steps

Typical sun path diagram



1. **Weather data:**

The sun path is characterized by:

- **h** [°], elevation angle, height of the sun in the sky
- **Φ** [°], the azimuth angle: angle between north and the sun direction

Modeling steps

1. Weather data:

The sun path is characterized by:

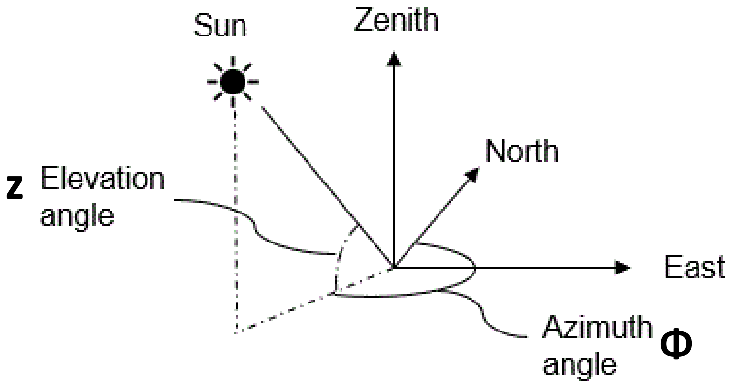
- **h** [°], elevation angle, height of the sun in the sky
- **Φ** [°], the azimuth angle: angle between north and the sun direction

Remember ? To calculate BHI:

$$BHI = DNI \cdot \cos(\theta)$$

With θ, the zenith angle

$$\theta = 90° - h$$



azimuth angle: north=0, east=90, south=180, west=270 degree

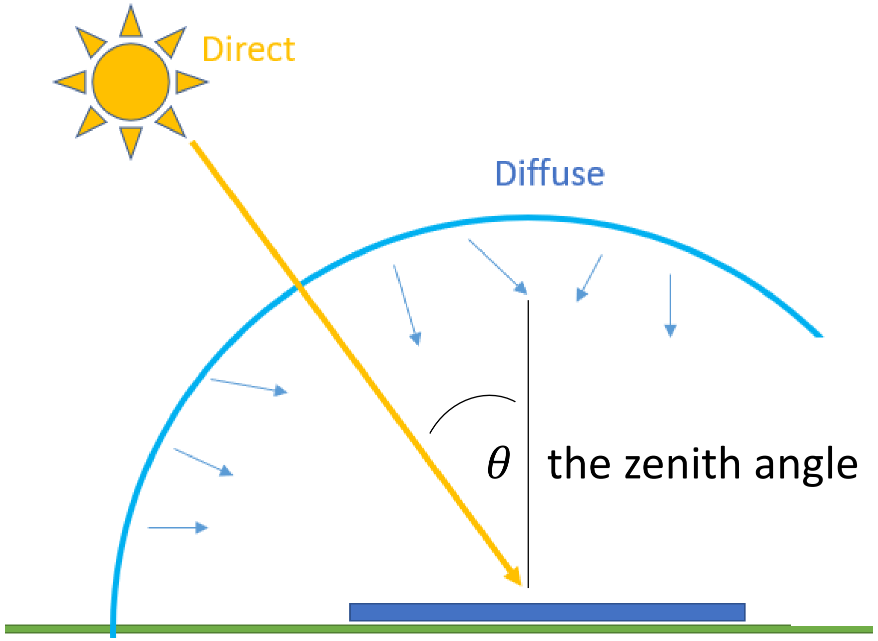


*image adapted from PVSC48 tutorial

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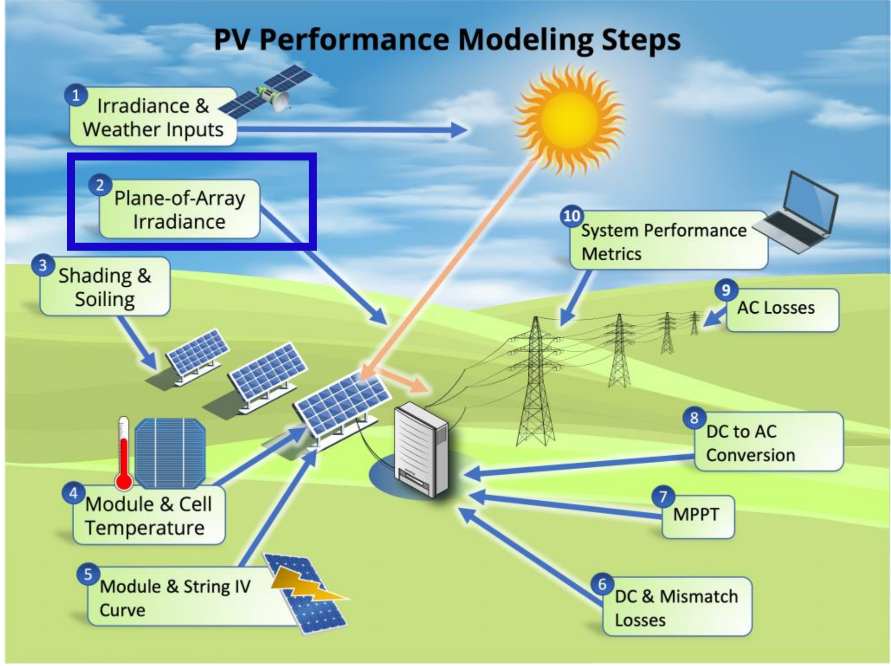
Modeling steps

2. Plane-of-Array Irradiance

Reminder, the Global Plane-Of-Array (POA) irradiance can be calculated from DHI, **GHI** and DNI.



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Modeling steps

2. Plane-of-Array Irradiance

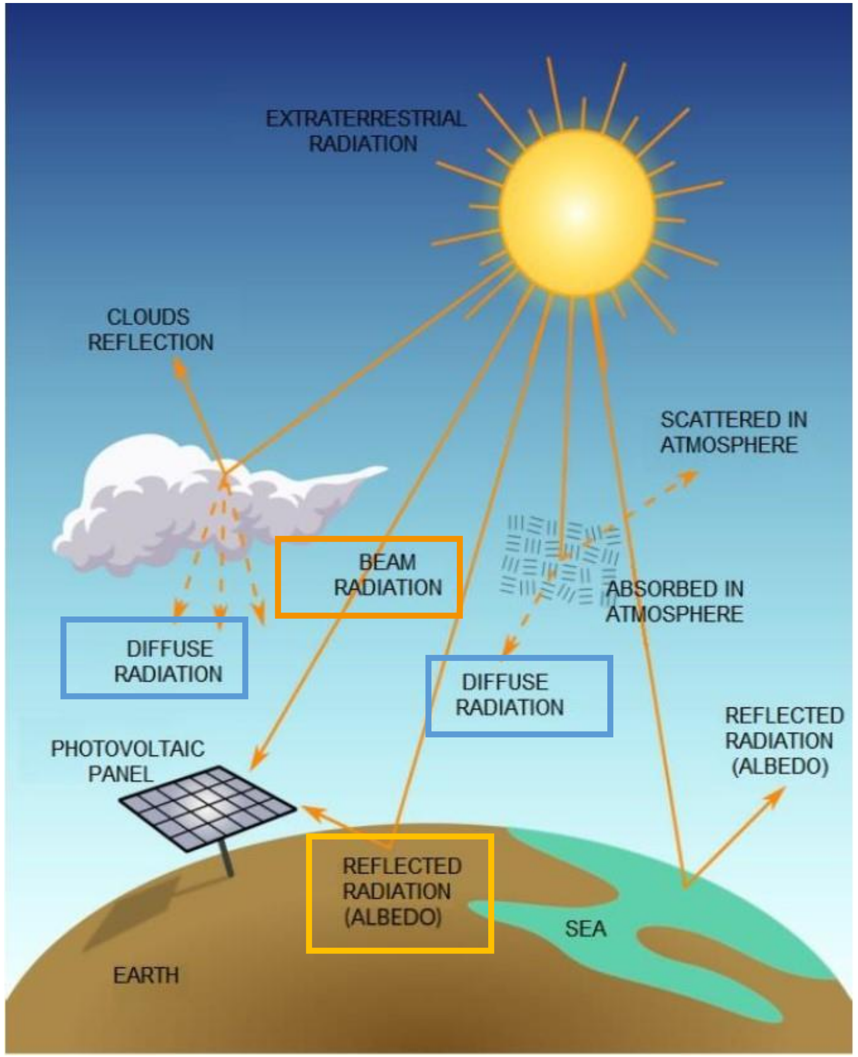
Reminder, the Global Plane-Of-Array (POA) irradiance can be calculated from DHI, **GHI** and DNI and are broken down into 3 components:

$$POA = POA_b + POA_d + POA_{grd}$$

POA_b: **The direct component -** Power received from the Beam of the sun on the horizontal plan

POA_d: **The diffuse component** - Power received from the sky diffusion of the light,

POA_{grd}**: The ground-reflected component** - Power received from reflections from the ground



Souza, Muriele et al. (2019). Determination of Diffused Irradiation from Horizontal Global Irradiation - Study for the City of Curitiba.

Modeling steps

2. Plane-of-Array Irradiance

Reminder, the Global Plane-Of-Array (POA) irradiance can be calculated from DHI, **GHI** and DNI and are broken down into 3 components:

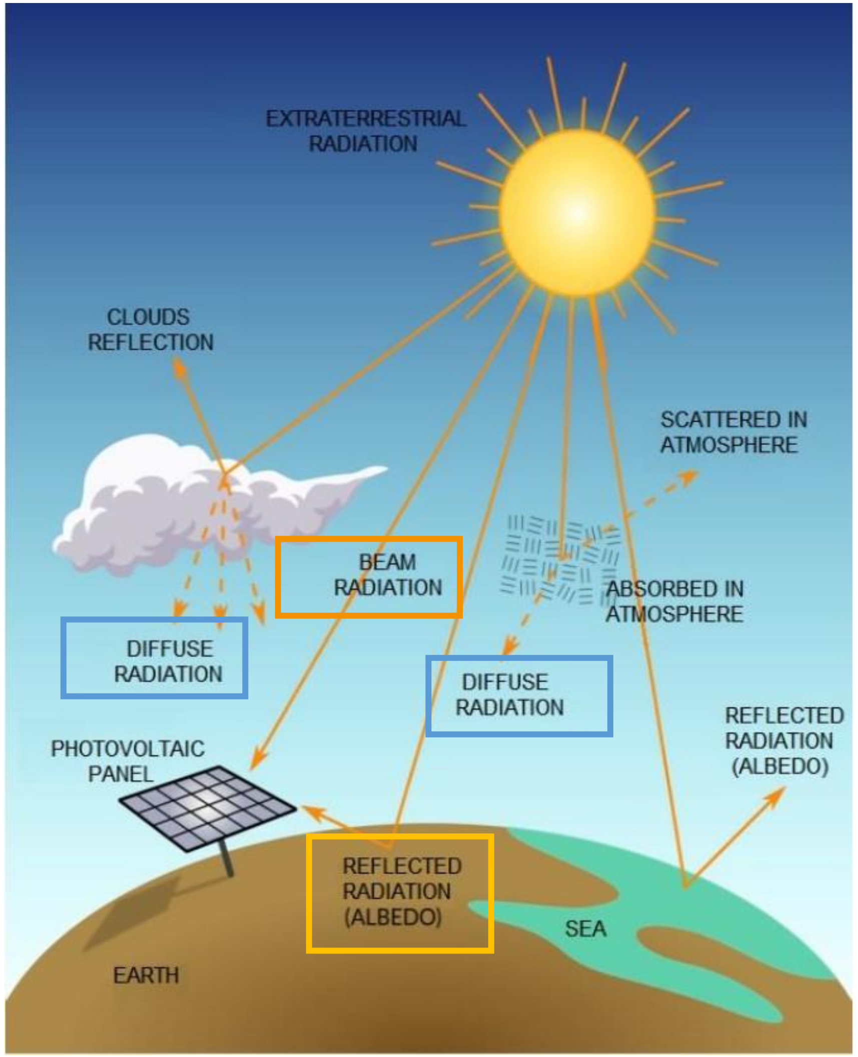
$$POA = POA_b + POA_d + POA_{grd}$$

- $POA_b = DNI \cdot \cos(AOI)$

Under the isotropic/no-shading assumption

- $POA_d = DHI \cdot \frac{1+\cos(\beta)}{2}$

- $POA_{grd} = \boldsymbol{GHI} \cdot \rho \cdot \frac{1-\cos(\beta)}{2}$



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With:

- β, PV installation tilt

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Modeling steps

2. Plane-of-Array Irradiance

Reminder, the Global Plane-Of-Array (POA) irradiance can be calculated from DHI, **GHI** and DNI and are broken down into 3 components:

$$POA = POA_b + POA_d + POA_{grd}$$

- $POA_b = DNI \cdot \cos(AOI) \longleftarrow \cos(AOI) = [\cos(\beta) \cdot \sin(h) + \sin(\beta) \cdot \cos(h) \cdot \cos(\boldsymbol{\Phi} - \boldsymbol{\Phi}_{install})]$

Under the isotropic/no-shading assumption

- $POA_d = DHI \cdot \frac{1+\cos(\beta)}{2}$
- $POA_{grd} = \boldsymbol{GHI} \cdot \rho \cdot \frac{1-\cos(\beta)}{2}$

With:

- AOI, angle of incidence
- β, PV installation tilt
- $\boldsymbol{\Phi}_{install}$, PV installation azimuth
- h, Sun elevation
- $\boldsymbol{\Phi}$, sun azimuth

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Modeling steps

2. Plane-of-Array Irradiance

Time for some
hands-on exercises

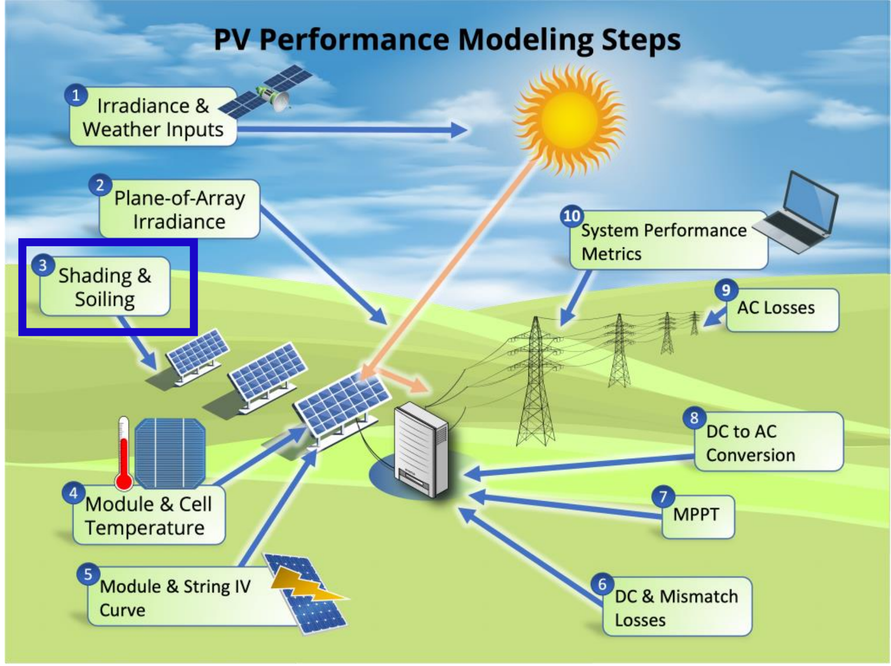
Use the notebook:

https://colab.research.google.com/drive/1y9-l7Vf9I7qTfaDfnh4ubo5kybaRqehb?usp=sharing

Follow the python tutorial and calculate the 3 POA components for:

- One timestep
- Over one year

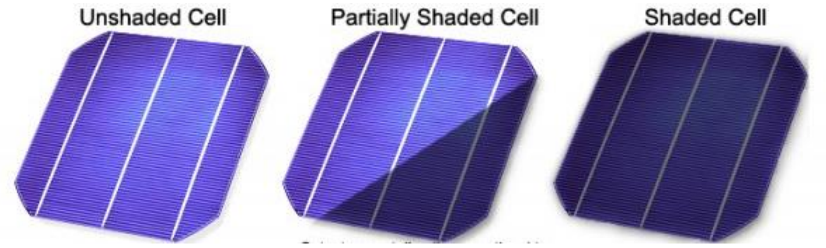
Modeling steps



3. Shading

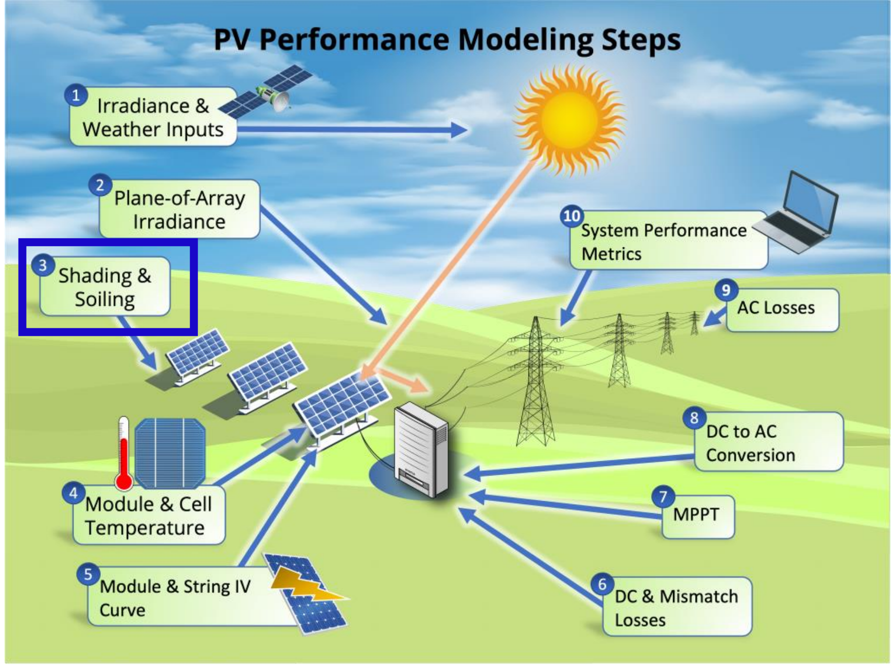
Shadow can come from near and far elements and their impact can be distinguished into two categories

1. **Partial shading** refers to a condition where some but not all of the solar cells or panels in a PV array are exposed to sunlight while others are shaded.
2. **Full shading** occurs when the entire PV array is covered and deprived of direct sunlight.



*https://mcisolutions.ca/effect-of-shade-on-solar-panels/

Modeling steps



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*https://mcisolutions.ca/effect-of-shade-on-solar-panels/

Not treated in this course but, in average, if a PV panel is around 8% covered, bypass diodes start to activate and **might** reduce the whole module production.

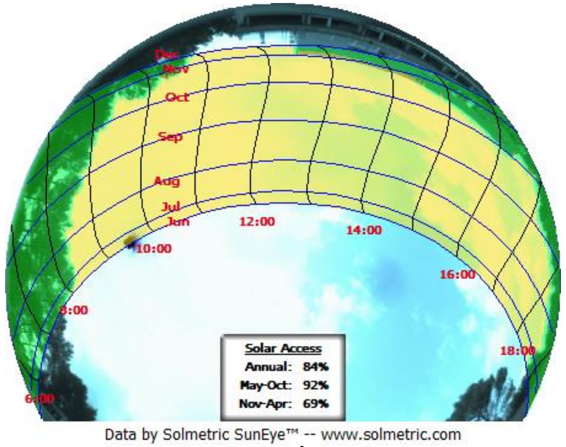
Demonstrated in one of pvlib example:
https://pvlib-python.readthedocs.io/en/stable/gallery/shading/plot_partial_module_shading_simple.html

Modeling steps

3. Shading

The Fisheye camera enables to account for the in-situ (full) shading in PV modeling.

South



East

West

North

Example in South of France

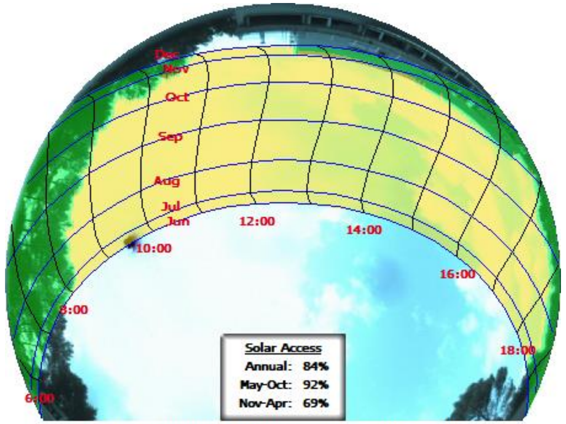
Modeling steps

3. Shading

The Fisheye camera enables to account for the in-situ (full) shading in PV modeling.

South

East

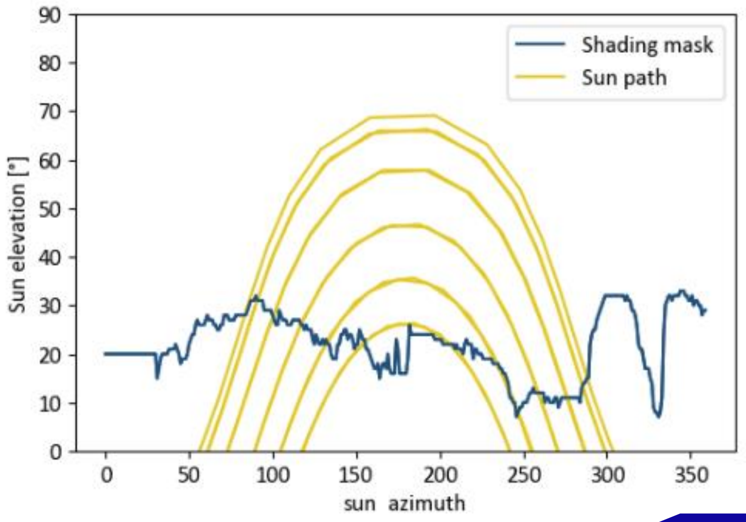


West

Data by Solmetric SunEye™ -- www.solmetric.com

North

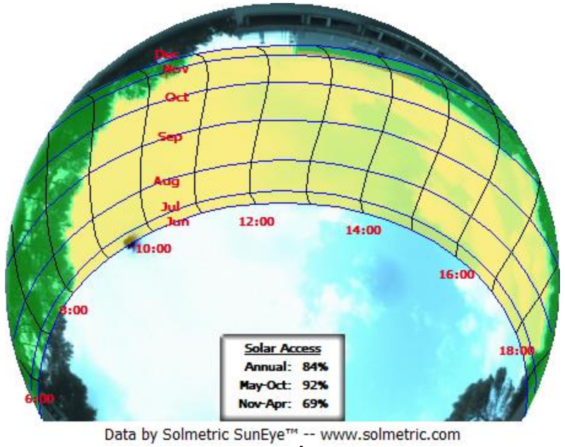
Example in South of France



Modeling steps

South

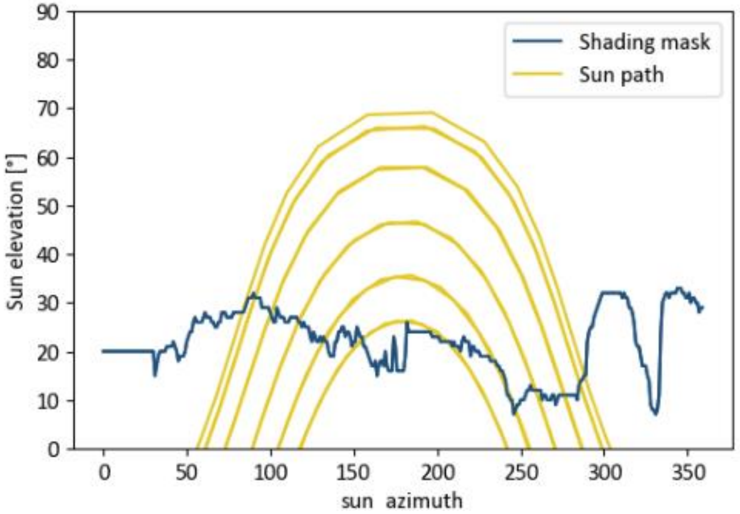
East



West

North

Example in South of France



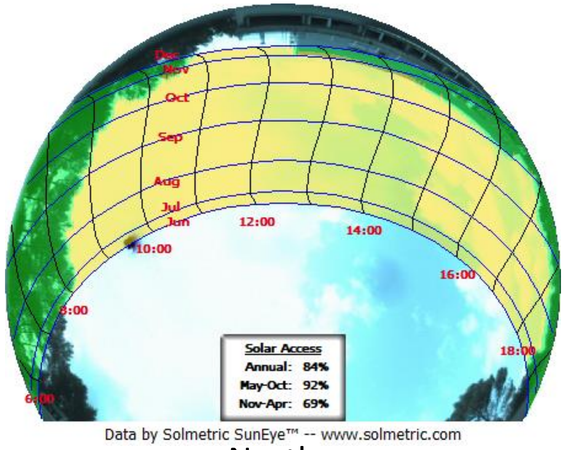
Modeling steps

3. Shading

The Fisheye camera enables to account for the in-situ (full) shading in PV modeling.

South

East



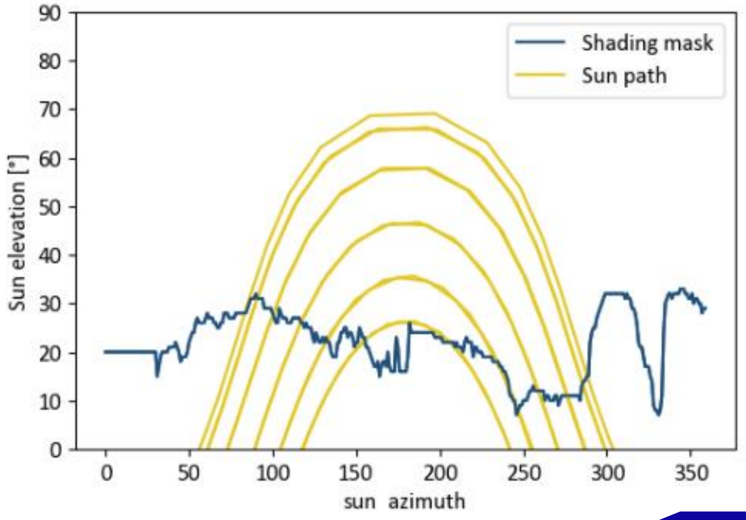
West

North

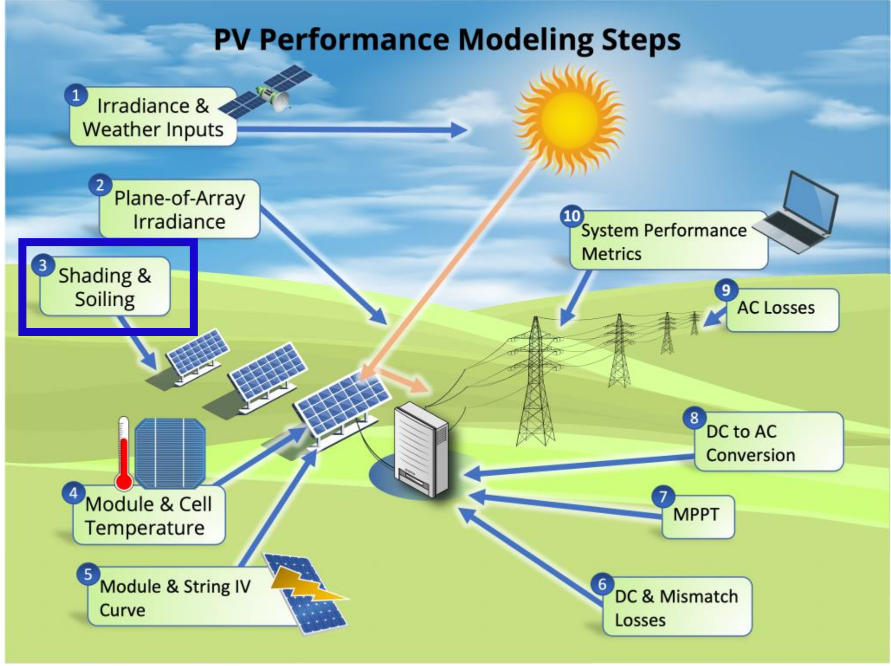
Example in South of France

Under the black curve, simple assumptions lead to:

- $POA_b = 0 \frac{W}{m2}$
- POA_d, POA_{grd} are not significantly modified



Modeling steps



3. Soiling losses

Big subject in the PV industry:

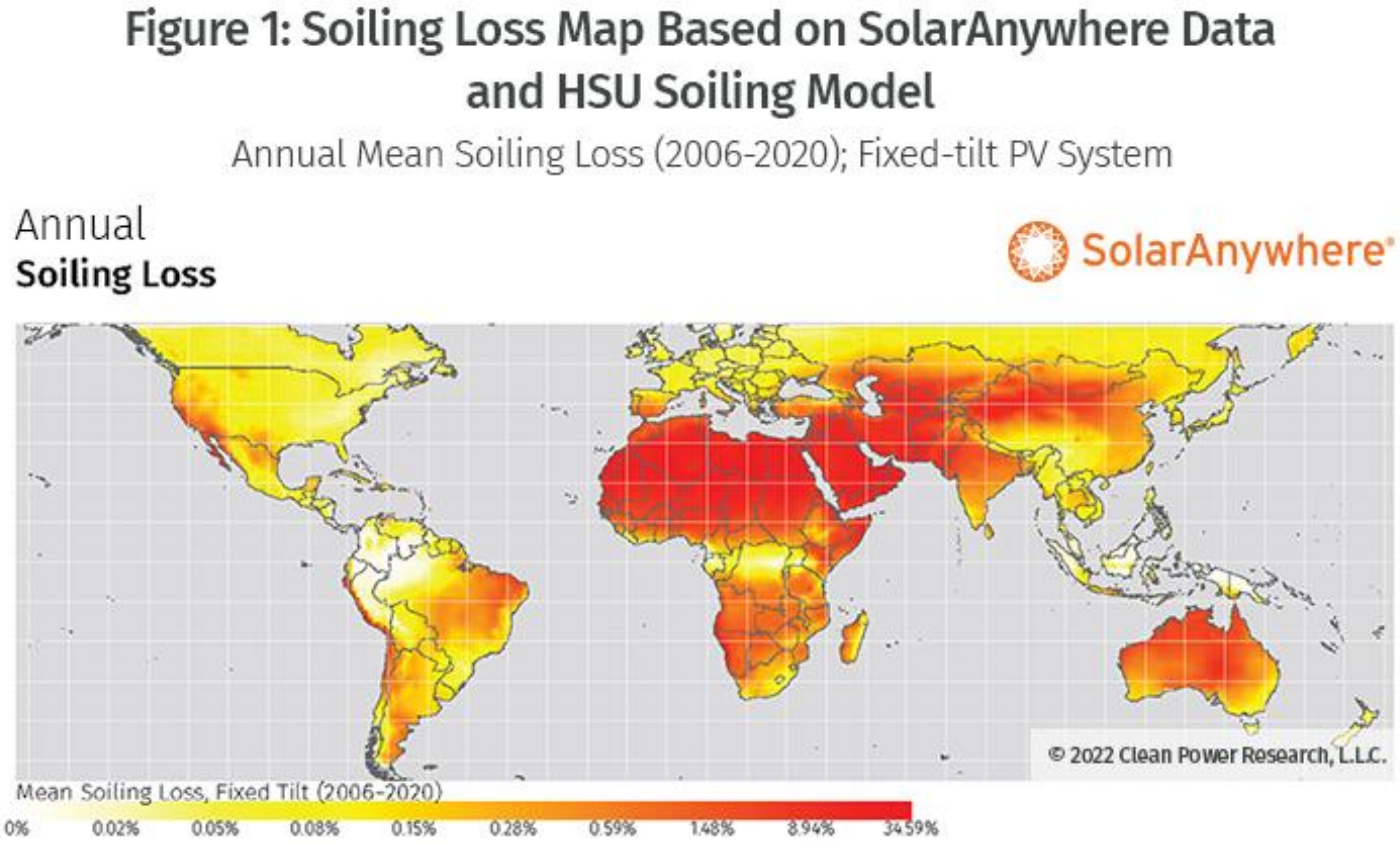
“**Soiling losses** refer to loss in power resulting from snow, dirt, dust and other particles that cover the surface of the PV module.” (Maghami et al., 2016)

Report of 130 pages on PV soiling: IEA PVPS, Soiling Losses – Impact on the Performance of Photovoltaic Power Plants 2022

Modeling steps

3. Soiling losses

Can roughly be ignored in France according to the HSU model.



Model HSU: M. Coello and L. Boyle, "Simple Model for Predicting Time Series Soiling of Photovoltaic Panels, Sept. 2019.

Modeling steps

3. Shading / Terrain horizon mask

Time for some
hands-on exercises,
Again!

Modeling steps

3. Shading / Terrain horizon mask

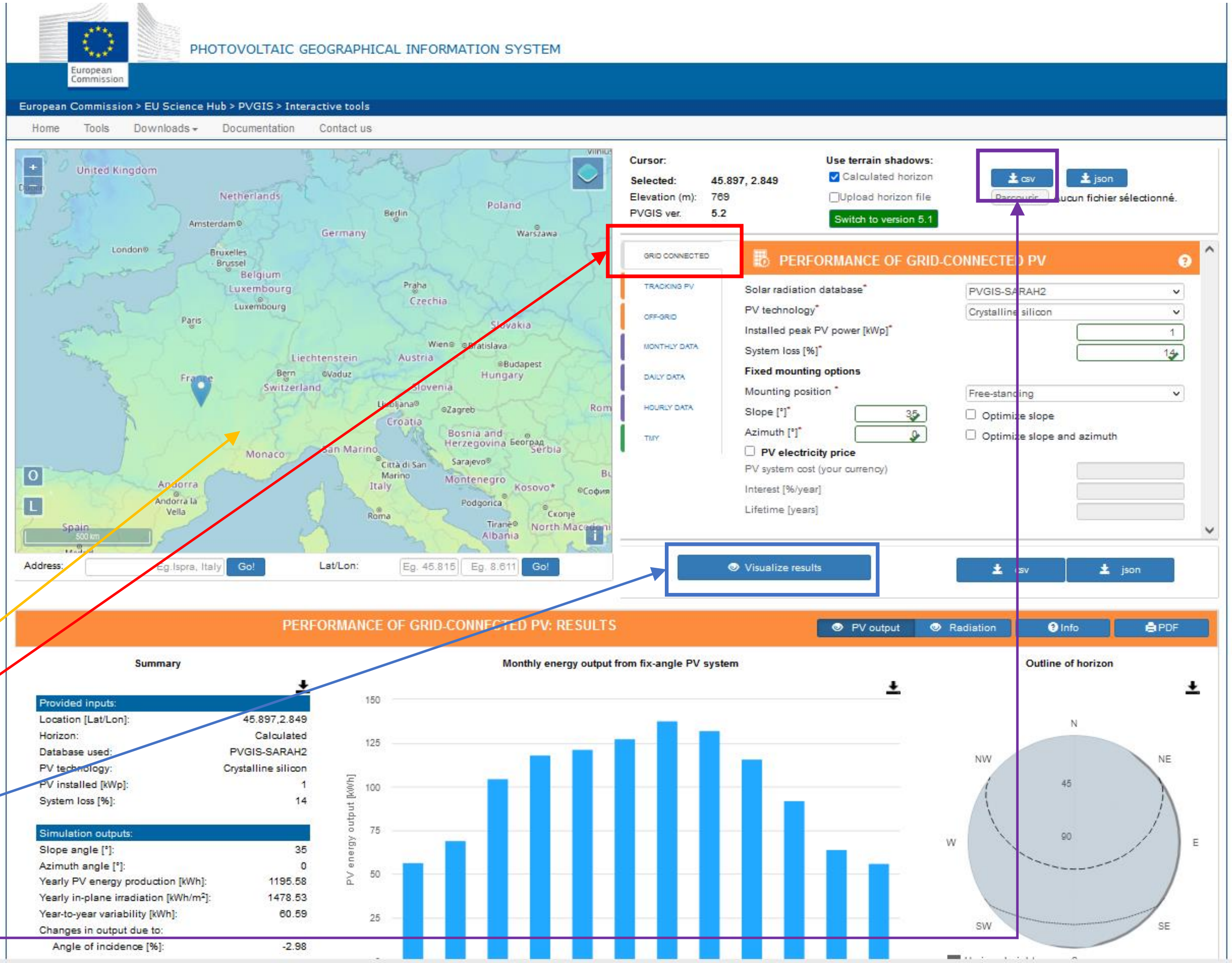
PVGIS: Website/Online Tool to estimate power production: https://re.jrc.ec.europa.eu/pvg_tools/en/

- Enables to extract the horizon mask with a Digital Surface Model (DSM).

Instructions:

1. Generate a simulation on PVGIS
   a. Click on the map on Grenoble and select the « Grid connected tab »
   b. Vizualize
   c. Extract the horizon file in csv format

2. Follow the instructions on the jupyter notebook and calculate the modified POA on one year.
https://colab.research.google.com/drive/1hB1pmBw-n7RiS99vCHQi2OKicfcQxpcO?usp=sharing



Resources

- Modeling guide PVPMC: https://pvpmc.sandia.gov/modeling-guide/
- Python / Pvlib tutorial: https://pvsc-python-tutorials.github.io/PVSC48-Python-Tutorial/
- To go further:
    - The Use of Advanced Algorithms in PV Failure Monitoring: https://iea-pvps.org/wp-content/uploads/2021/10/Final-Report-IEA-PVPS-T13-19_2021_PV-Failure-Monitoring.pdf

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That’s it