Operational research for urban solar development

“PV failure detection based on operational time series”

27/11/2023 - Morning
Alexandre Mathieu

Agenda

Curriculum

Audience

PV performance model steps

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Curriculum

Initial plan

Day	Time	Duration	Content
Monday 27/11/2023	9h45-11h15 12h30-14h	1h30 + 1h30	50% Lecture / 50 % Hands-on
Tuesday 05/12/2023	8h-9h30 9h45-11h15	1h30 + 1h30	50% Lecture / 50 % Hands-on
Thursday 07/12/2023	8h-11h 12h45-15h45	6h	25% Lecture / 75 % Project
Monday 11/11/2023	8h-11h 12h30-15h30	6h	10% Lecture / 90 % Project
Friday 22/12/2023	8h-9h30	1h30	100 % Project

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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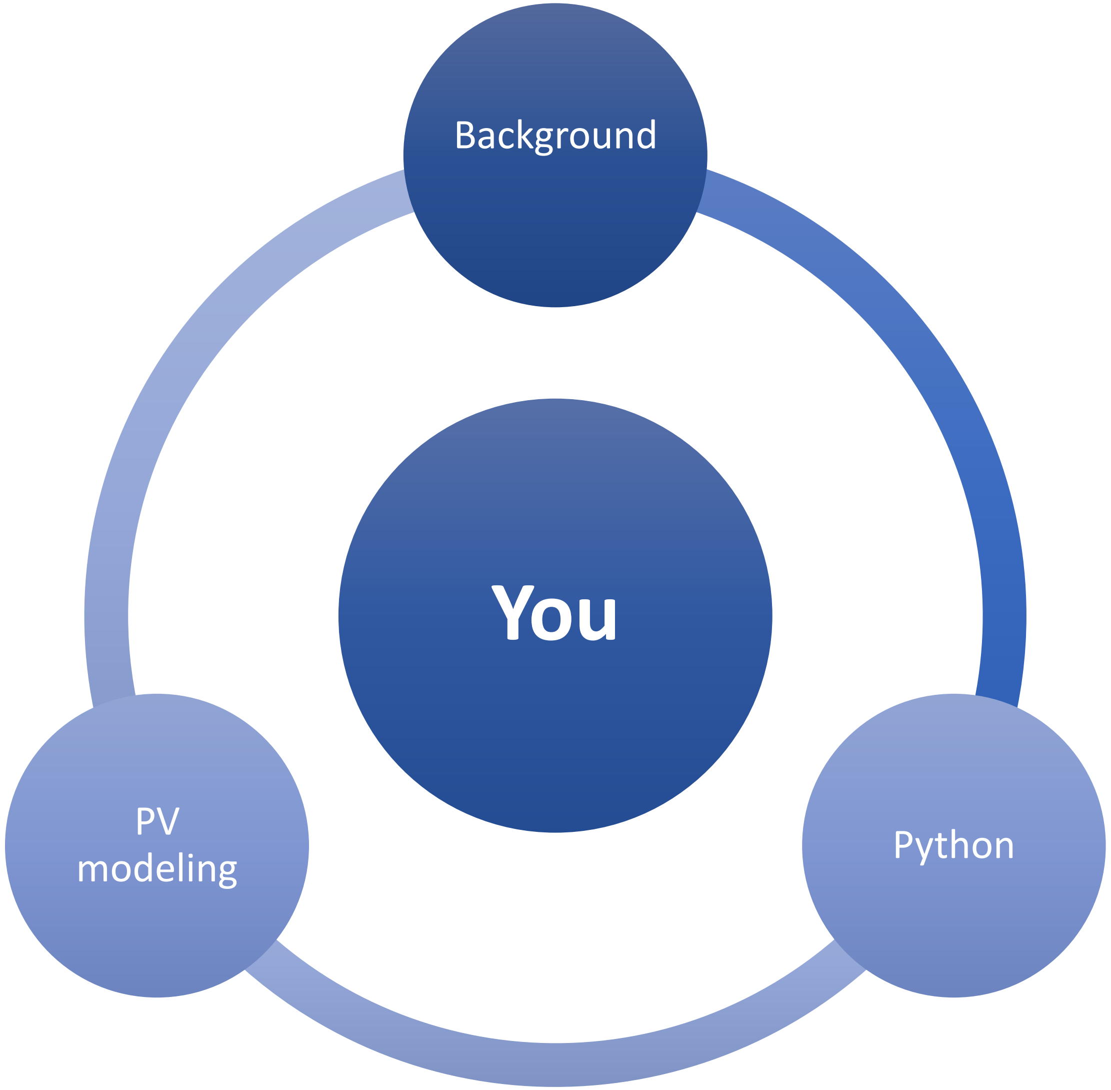
Audience

Audience



Agenda

Curriculum

Audience

PV performance model steps

Modeling steps

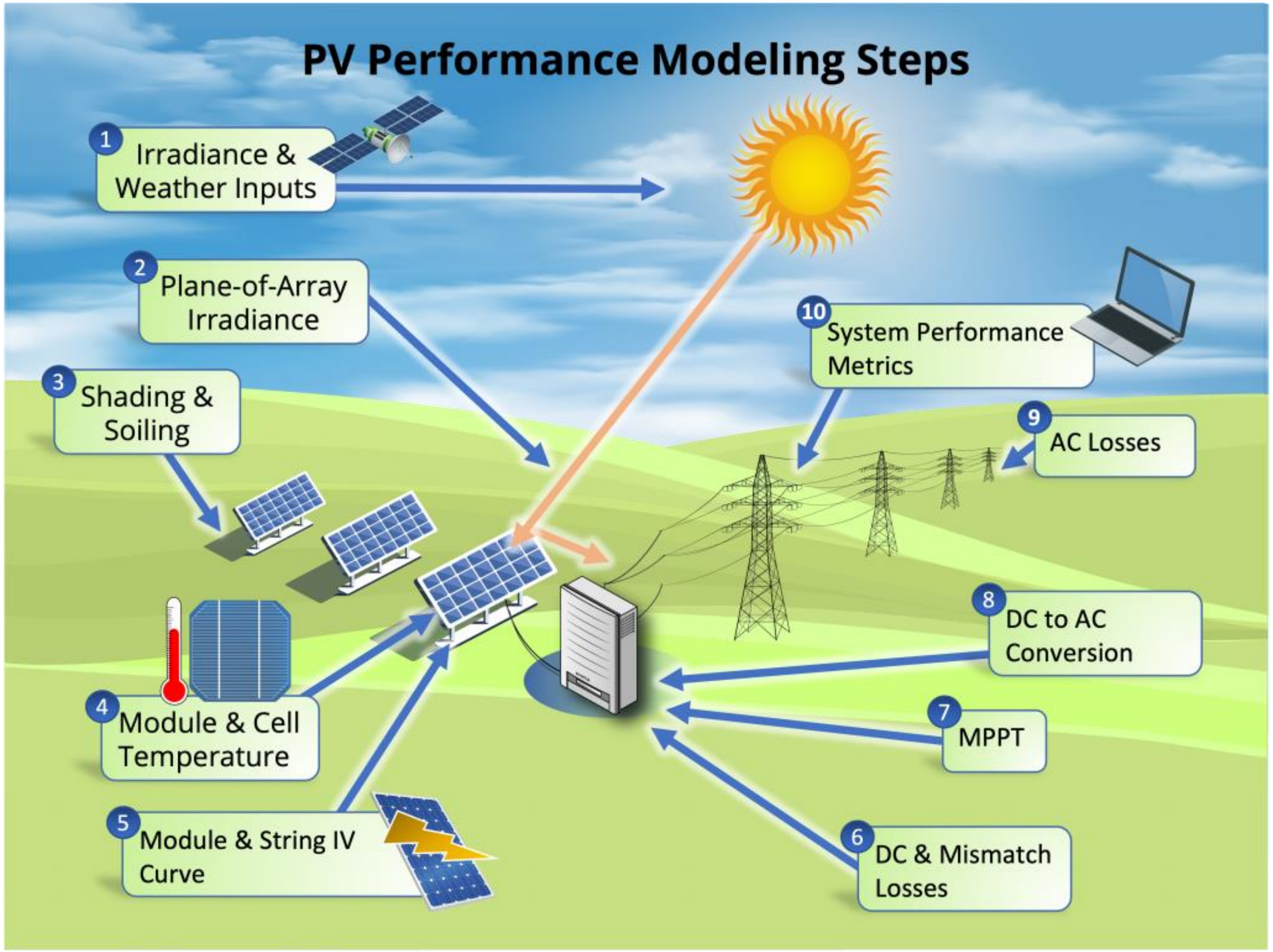
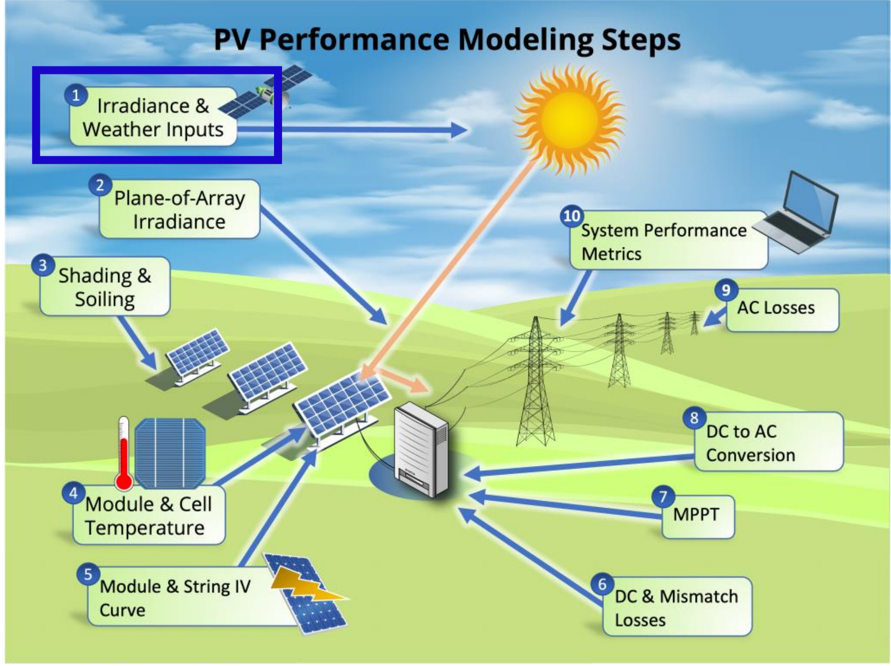


*image from: PVSC48 python tutorial

Modeling steps



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

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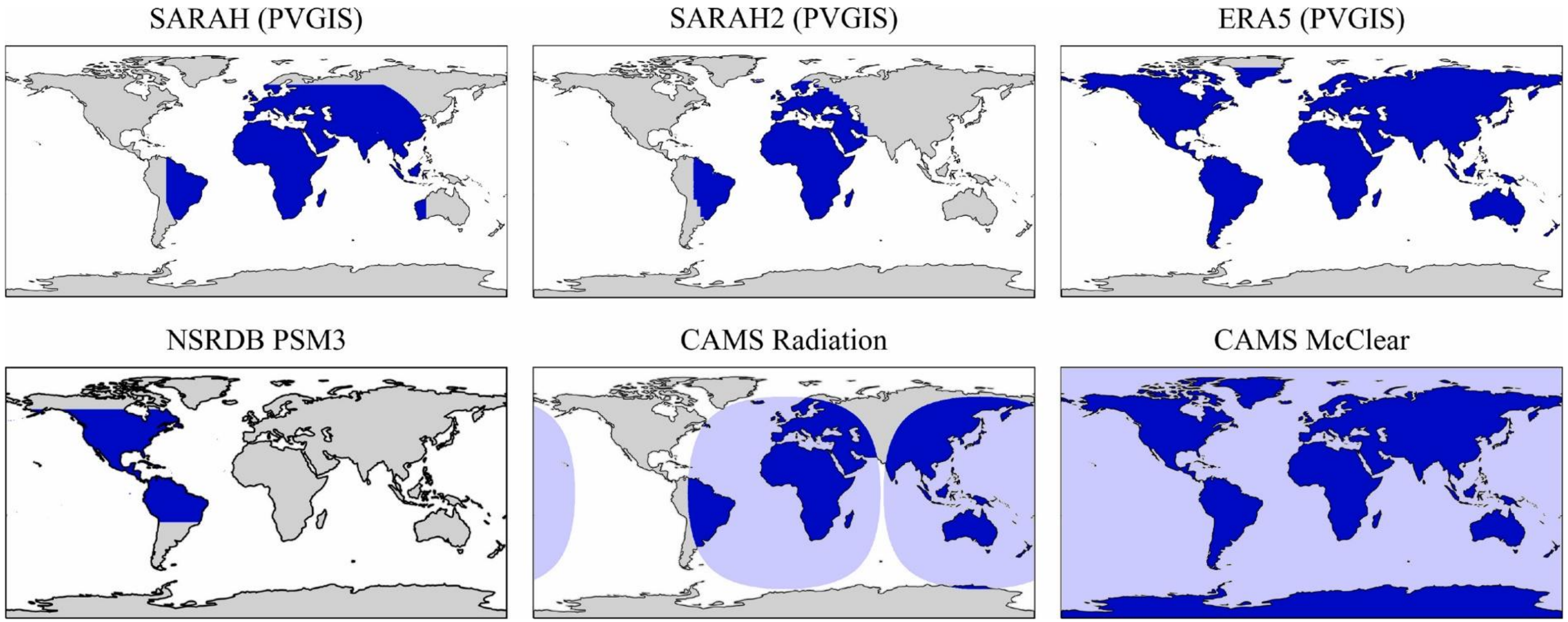
Modeling steps

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

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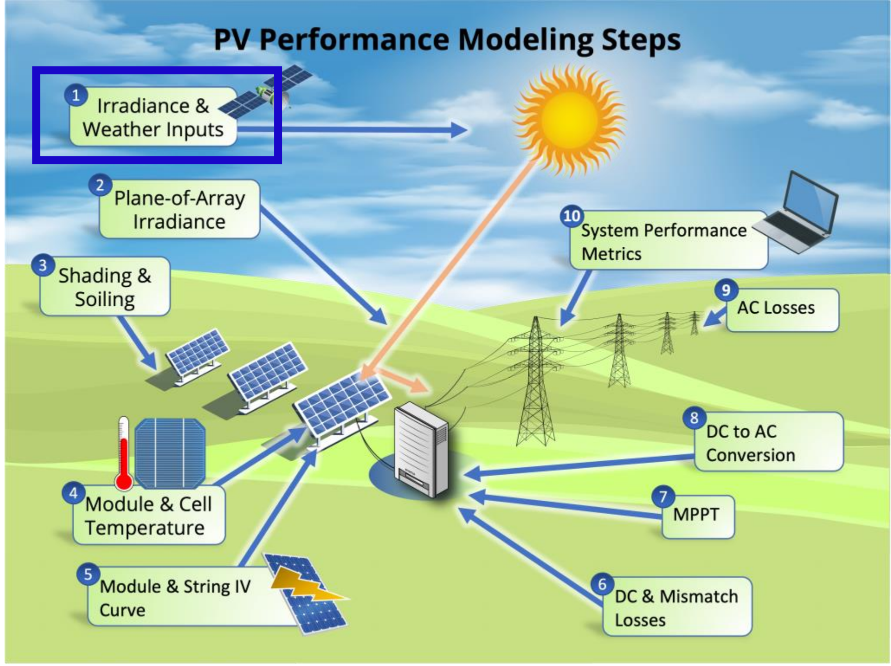
Modeling steps



1. Weather data:

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

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

b. In-situ instrumentations

Pyranometer:
Global/Inclined Irradiance

Pyrheliometer:
Direct irradiance

(Hukseflux product)

Pyranometer with shadow ring:
Diffuse Irradiance

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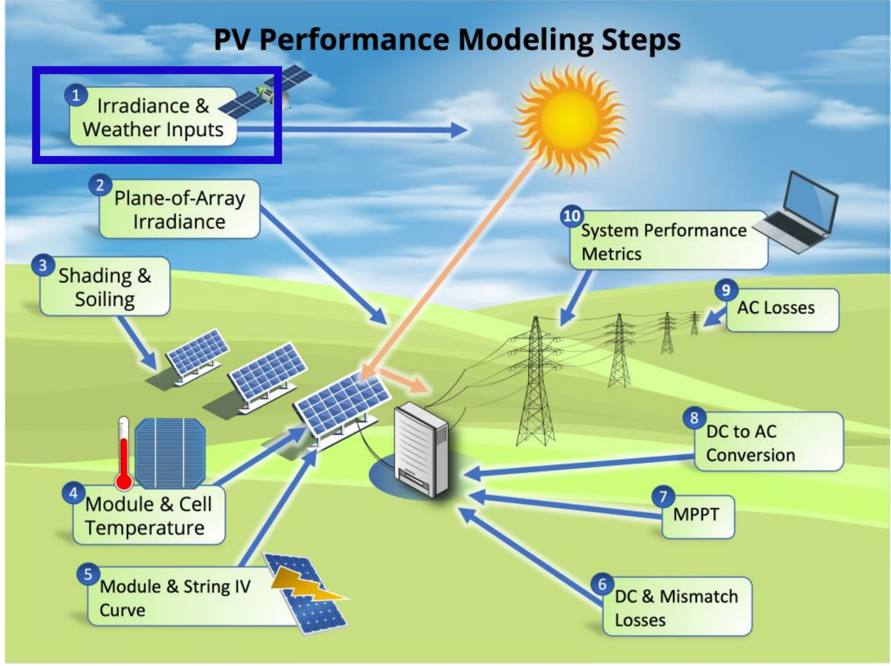
Modeling steps



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)

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Modeling steps

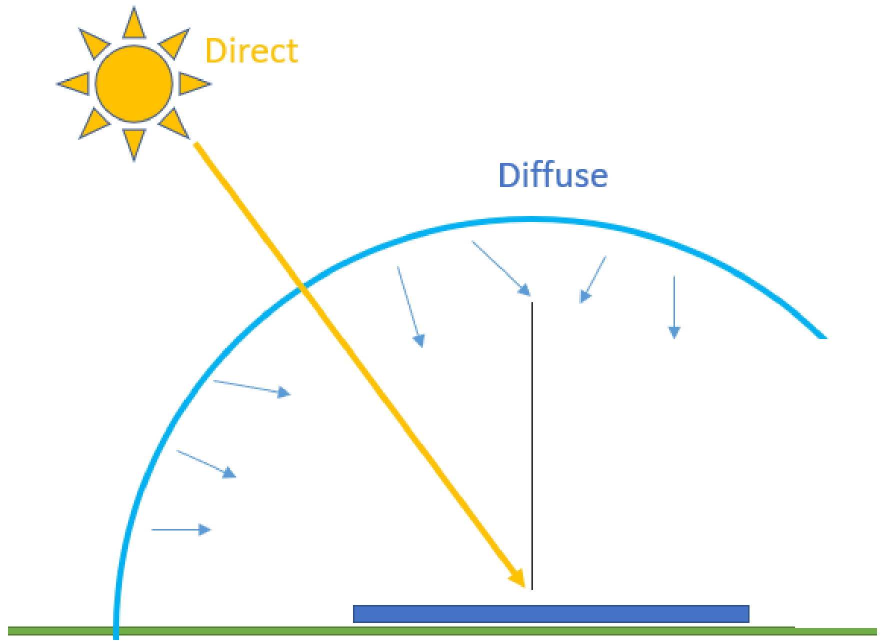

*image from PVSC48 tutorial

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.

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

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Modeling steps

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

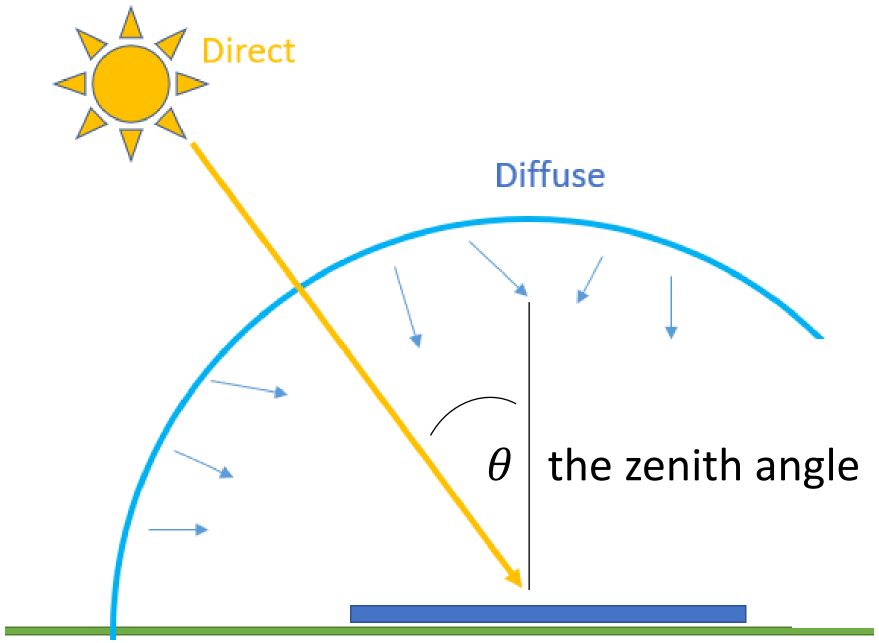


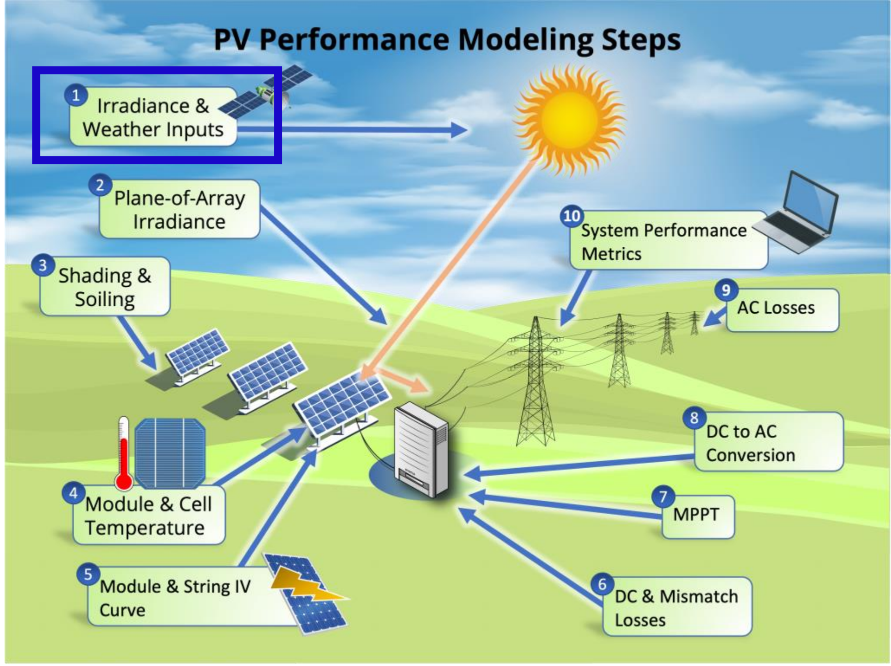
*image adapted from PVSC48 tutorial

$$GHI = BHI + DHI$$

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.

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

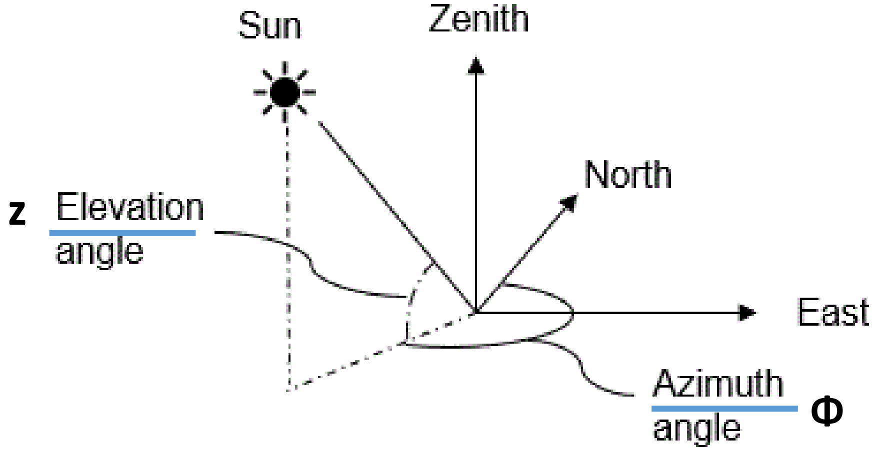
DHI (Diffuse Horizontal Irradiance): Power received from the sky diffusion of the light.



Modeling steps

1. Weather data:

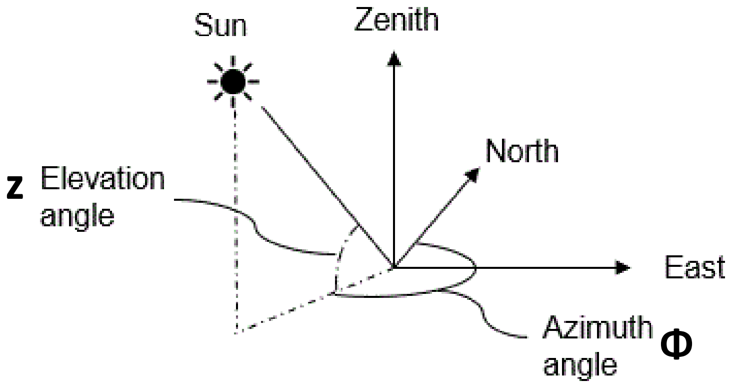
Sun path



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

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

Modeling steps

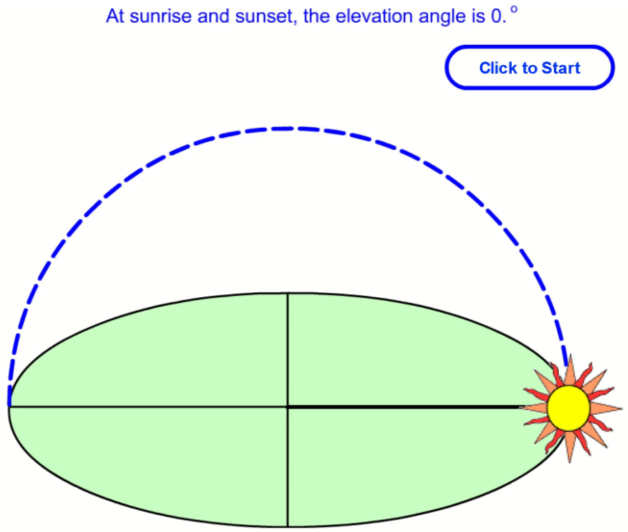


azimuth angle: north=0, east=90, south=180, west=270 degree

1. Weather data:

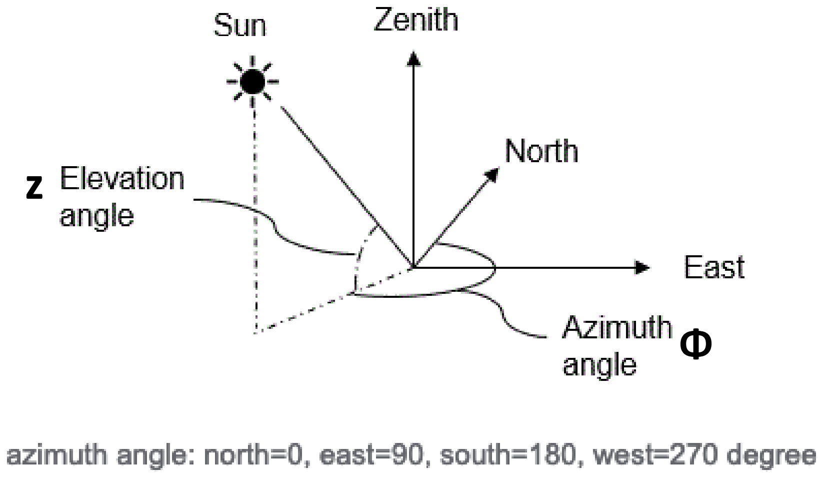
The sun path is characterized by:

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



*animation from pveducation

Modeling steps



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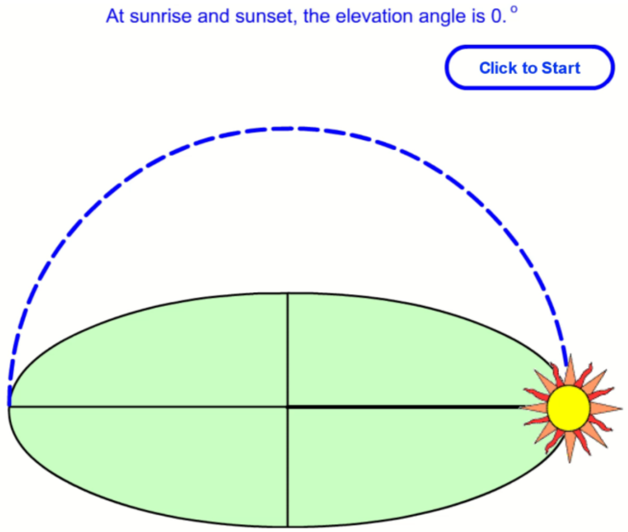
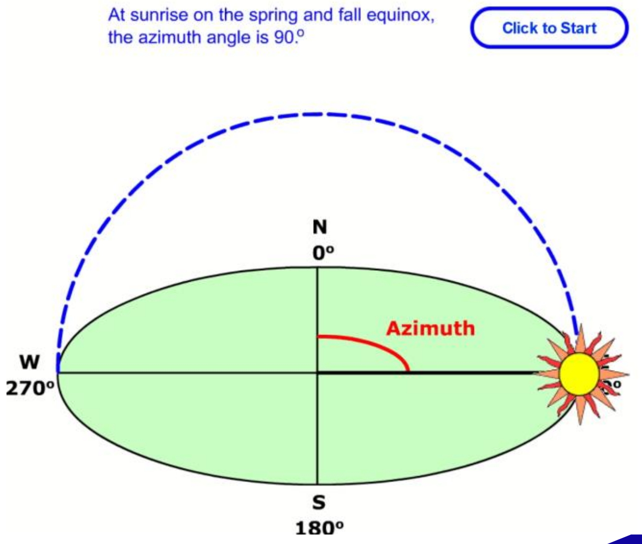


*animation from pveducation

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



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Modeling steps

1. Weather data:

The sun path is characterized by:

- **z** [°], elevation angle, height of the sun in the sky
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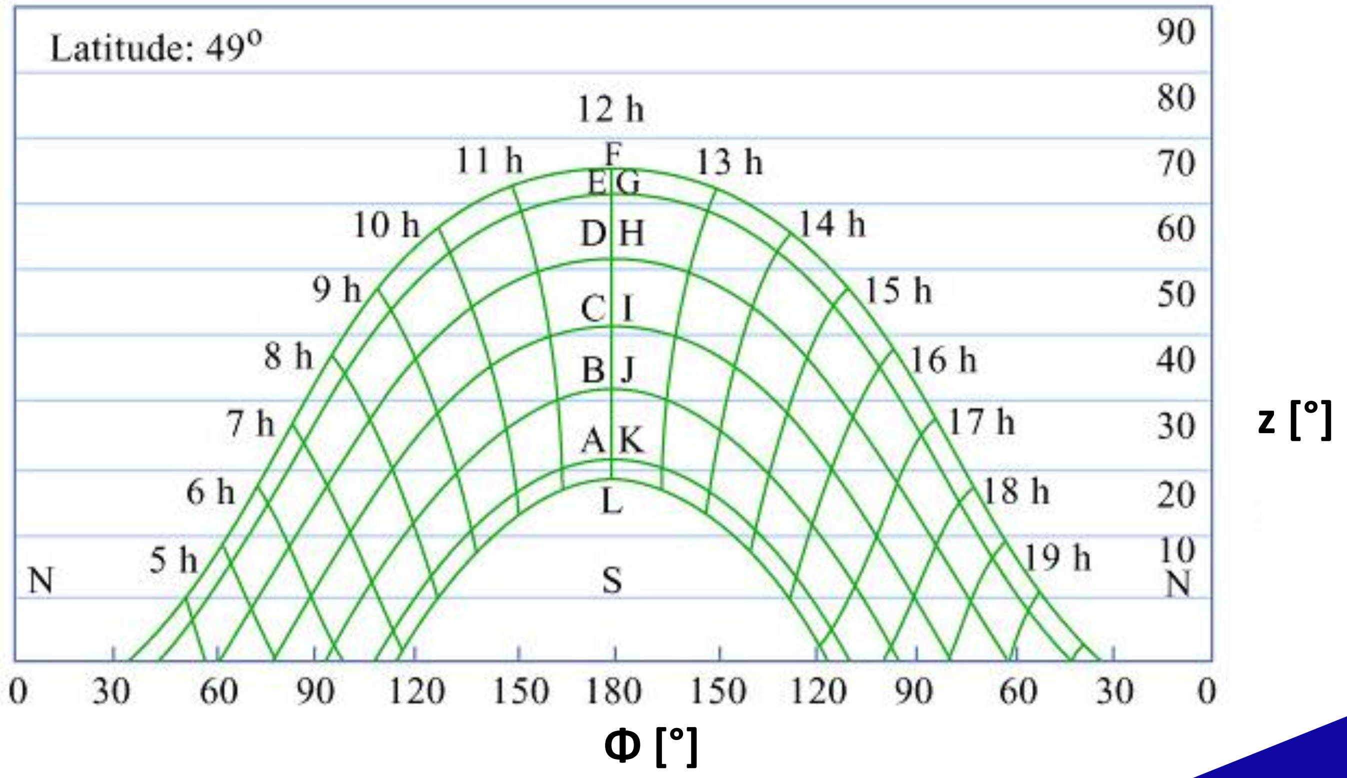
Typical sun path diagram



Modeling steps

1. Weather data:

The sun path is characterized by:

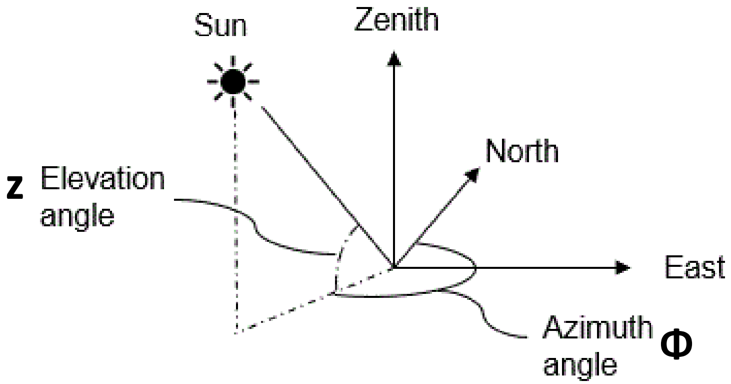
- **z** [°], elevation angle, height of the sun in the sky
- **Φ** [°], the azimuth angle: angle between north and the sun direction

Remember ? To calculate BHI:

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

With θ, the zenith angle

$$\theta = 90° - z$$



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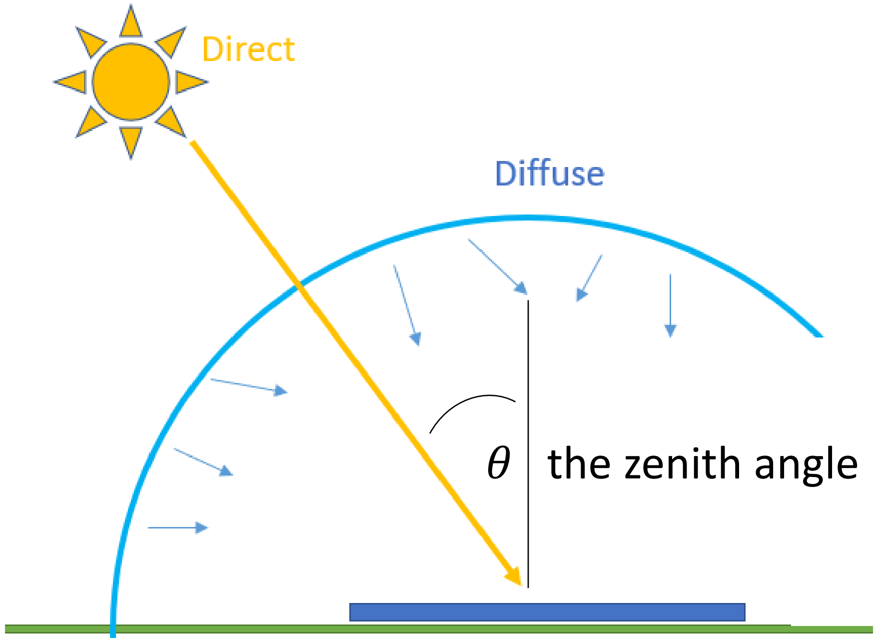

*image adapted from PVSC48 tutorial

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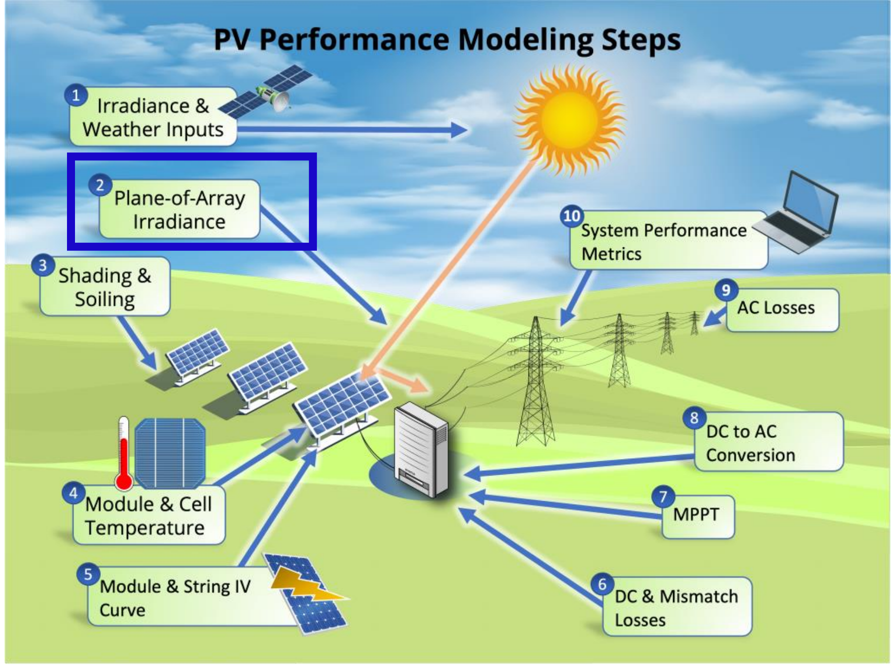
Modeling steps

2. Plan-of-Array Irradiance

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



Modeling steps

2. Plan-of-Array Irradiance

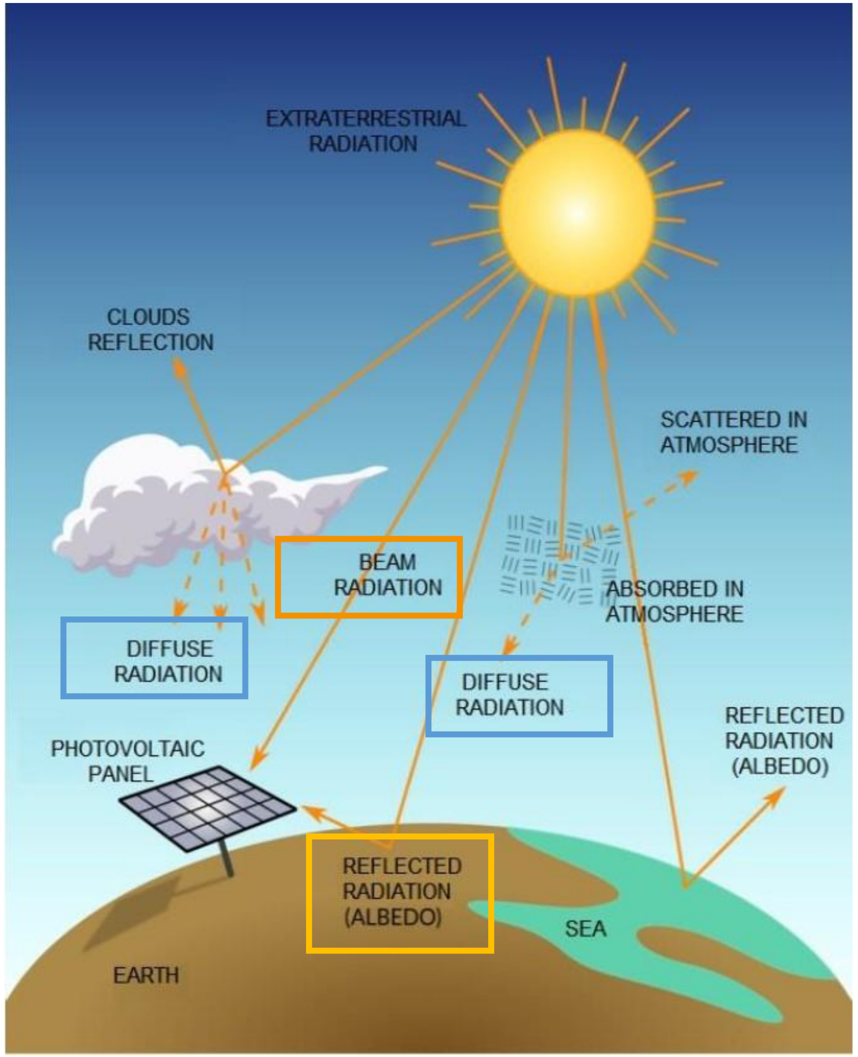
Reminder, the Global Plane-Of-Array (GPOA) irradiance can be calculated from DHI, **GHI** and DNI and are broken down into 3 components:

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

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.

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Modeling steps

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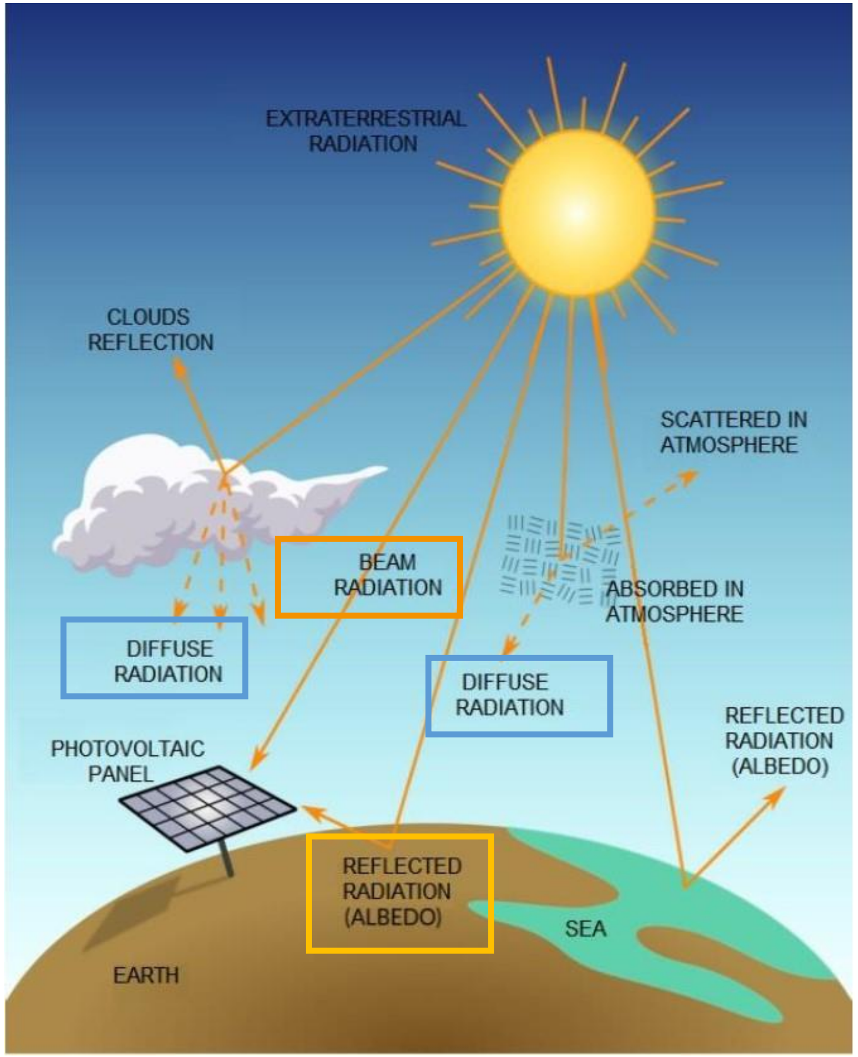
$$GPOA = POA_b + POA_d + POA_{grd}$$

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

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

Modeling steps

2. Plan-of-Array Irradiance

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

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

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

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
- z, Sun elevation
- $\boldsymbol{\Phi}$, sun azimuth

Modeling steps

2. Plan-of-Array Irradiance

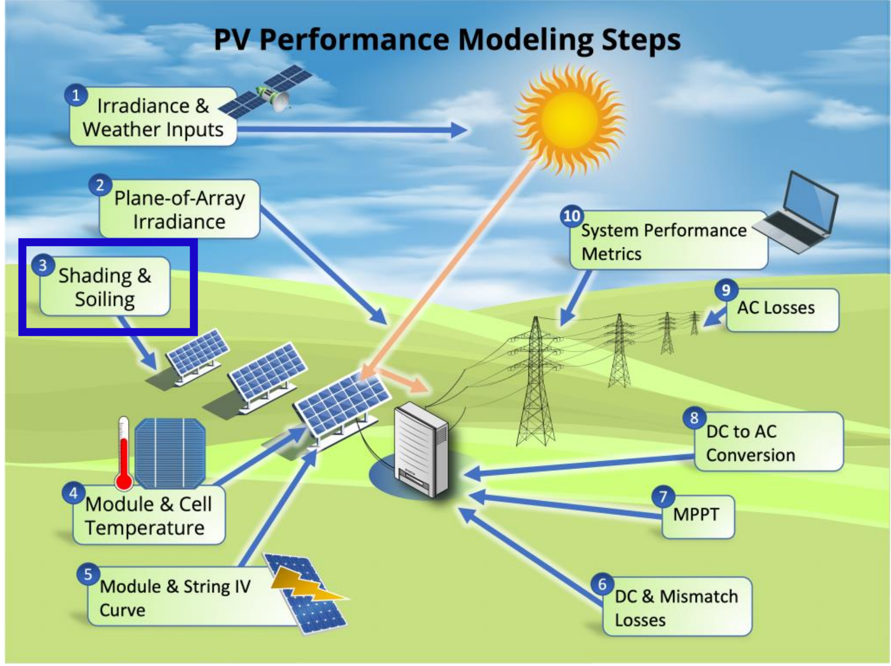
Time for some
hands-on exercises

Use the notebook:
https://github.com/AlexandreHugoMathieu/pvfault_detection_solar_academy/blob/master/notebooks/python_intro_poa.ipynb

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

- One timestep
- Over one year

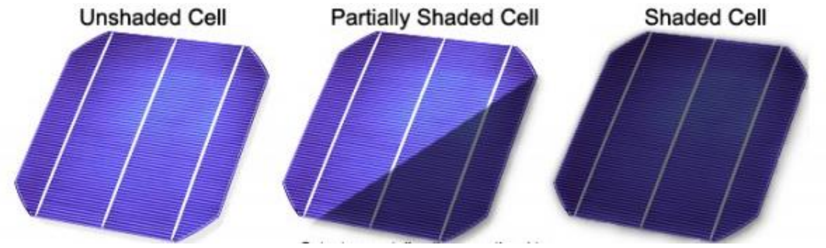
Modeling steps



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/

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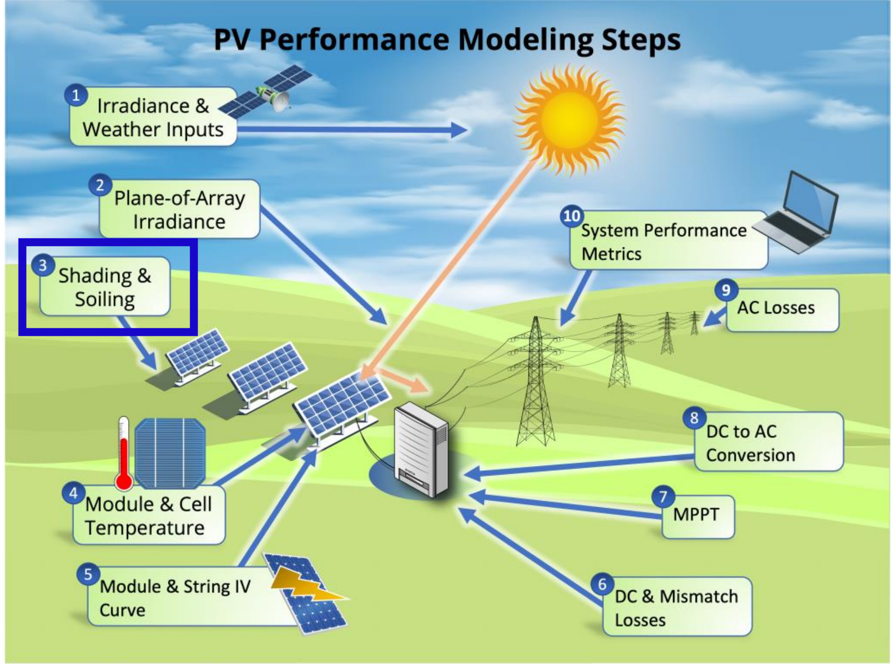
Modeling steps



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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, the whole PV panel is bypassed and then, do not produce.

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

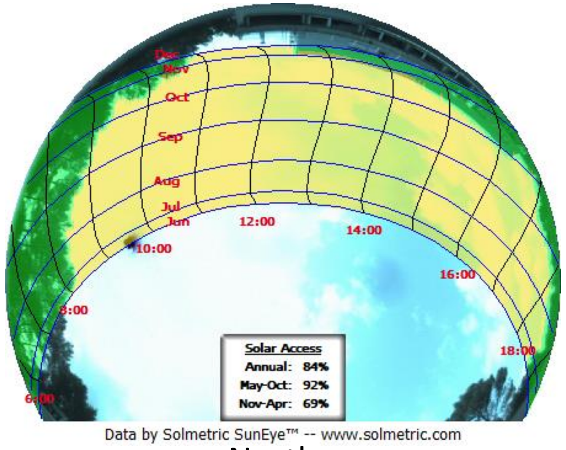
Modeling steps

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

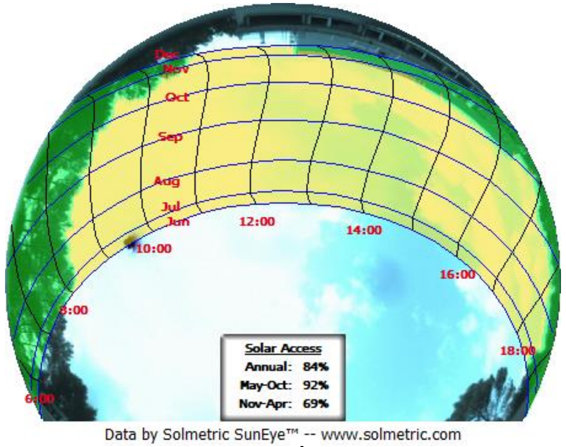
Modeling steps

3. Shading

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

South

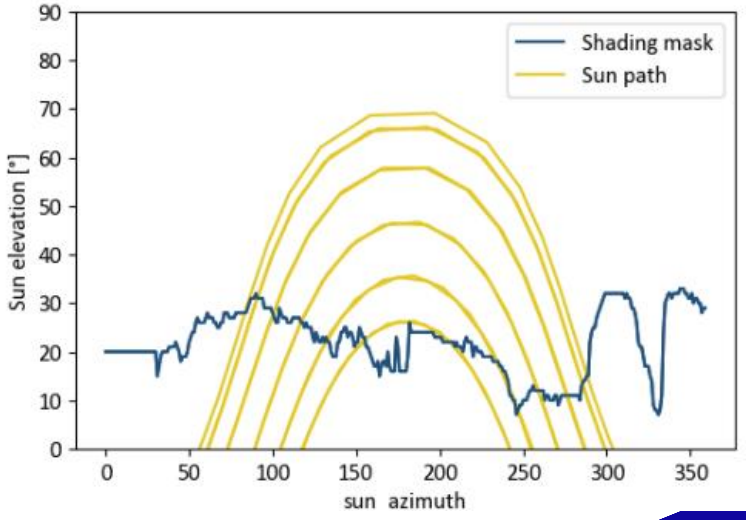
East



West

North

Example in South of France



Modeling steps

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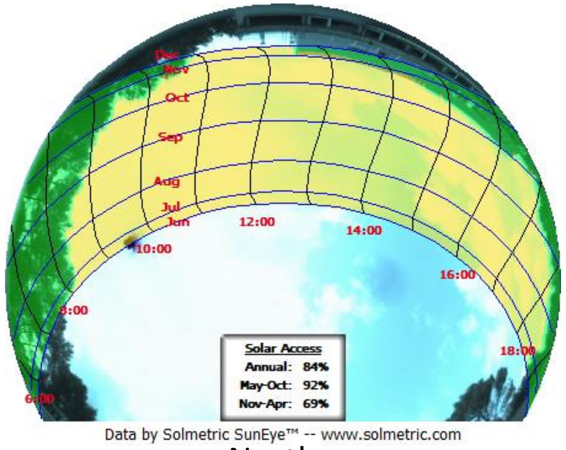
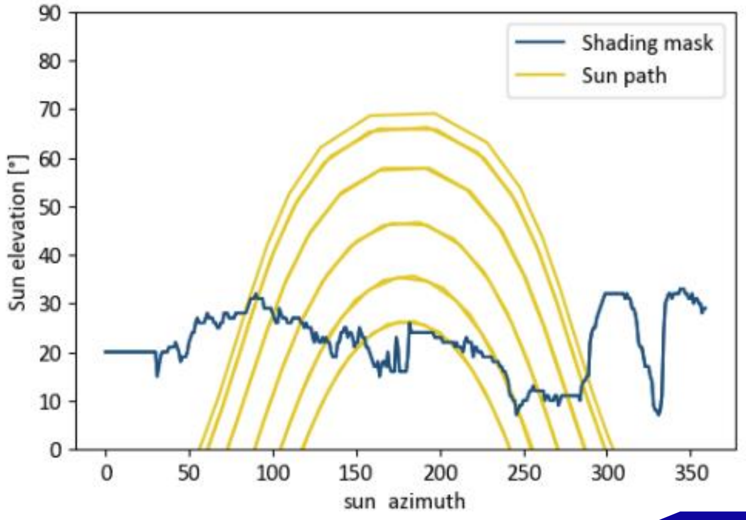


Example in South of France

Under the black curve, simple assumptions lead to:

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



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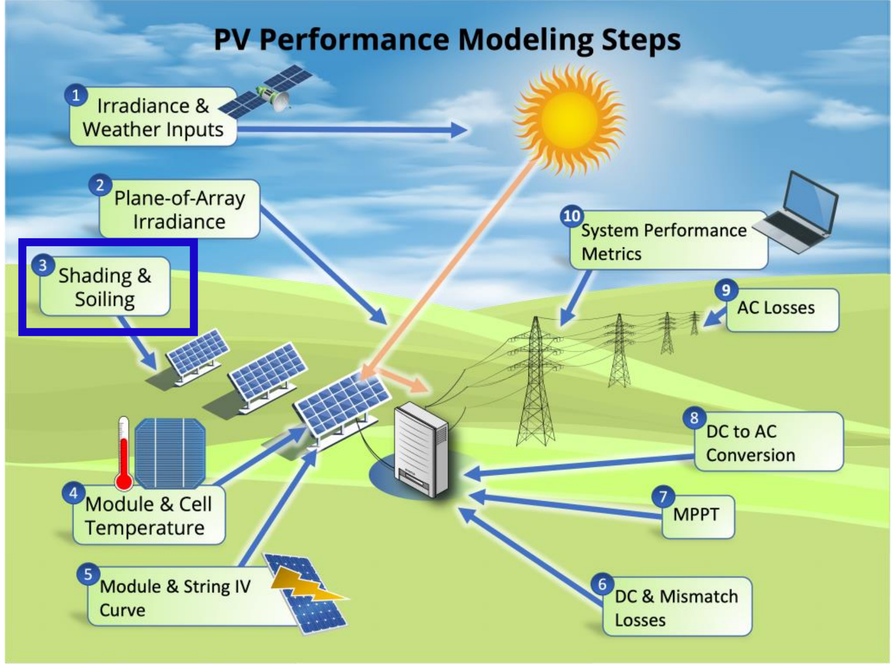
Modeling steps



3. Soiling losses

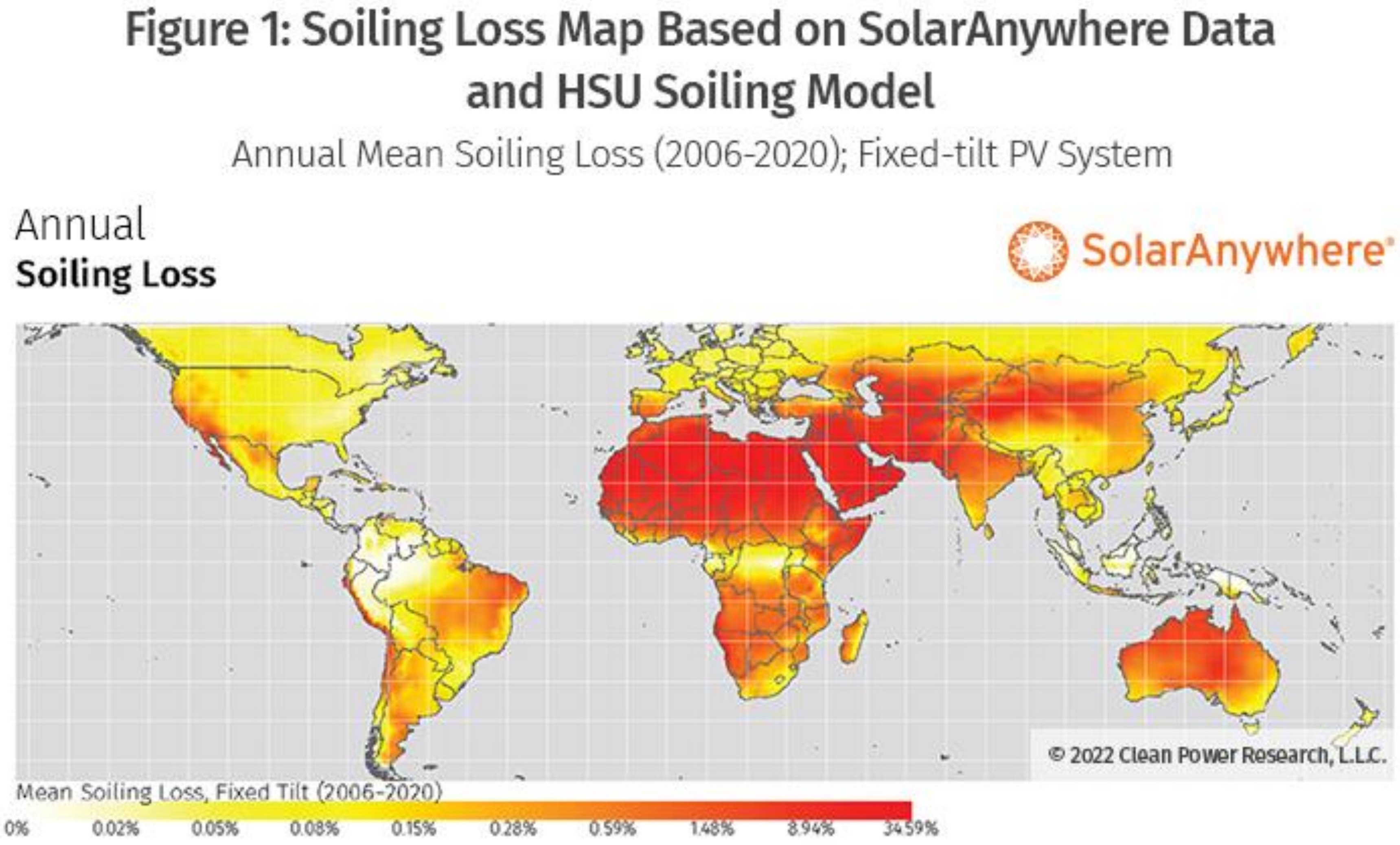
Big subject in the PV industry:

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:

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

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

Time for some hands-on exercises, Again !

Modeling steps

3. Shading / Terrain horizon mask

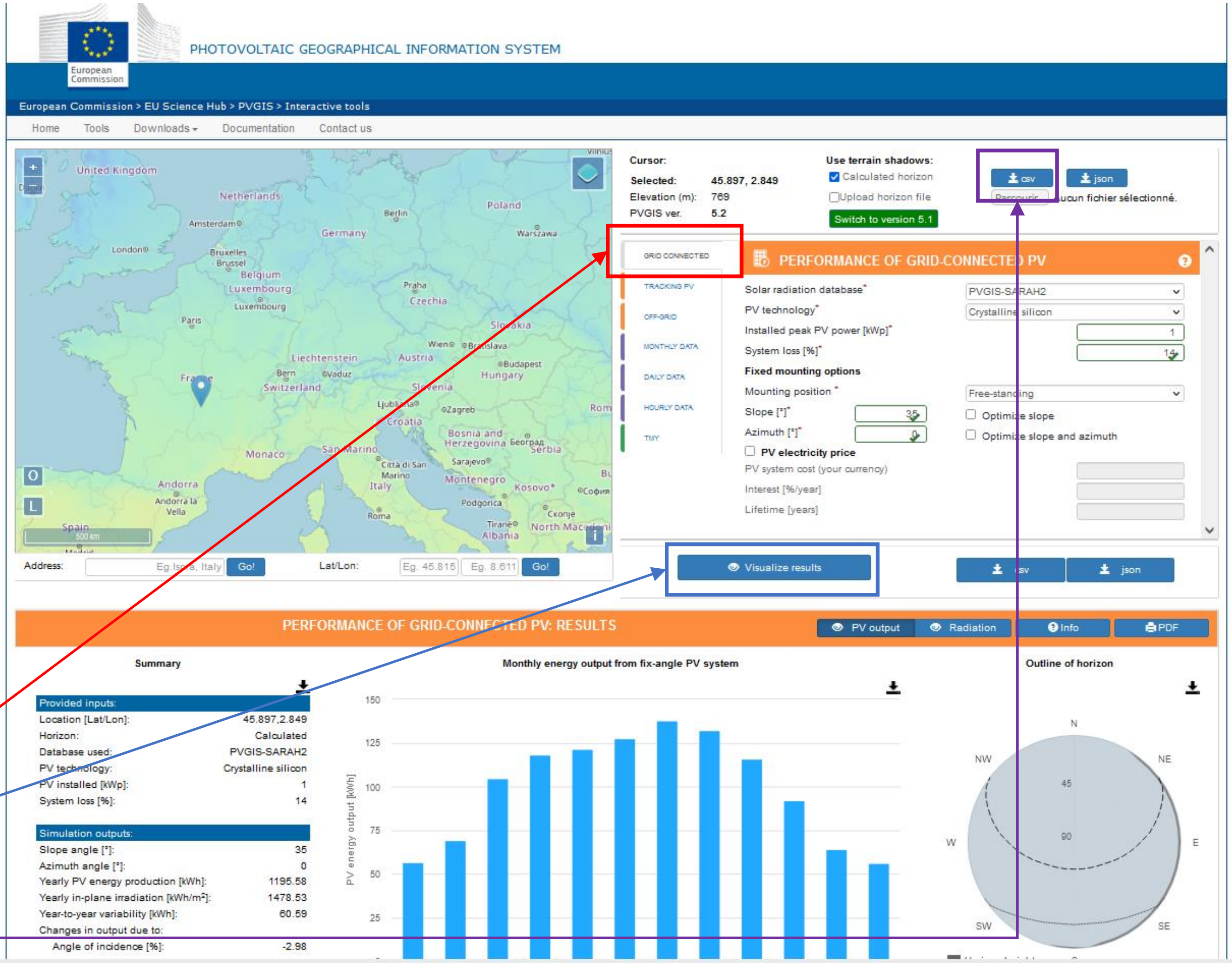
PVGIS: Website/Online Tool to estimate power production: https://re.jrc.ec.europa.eu/pvg_tools/en/

- 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://github.com/AlexandreHugoMathieu/pvfault_detection_solar_academy/blob/master/notebooks/python_intro2_horizon_mask.ipynb



Resources

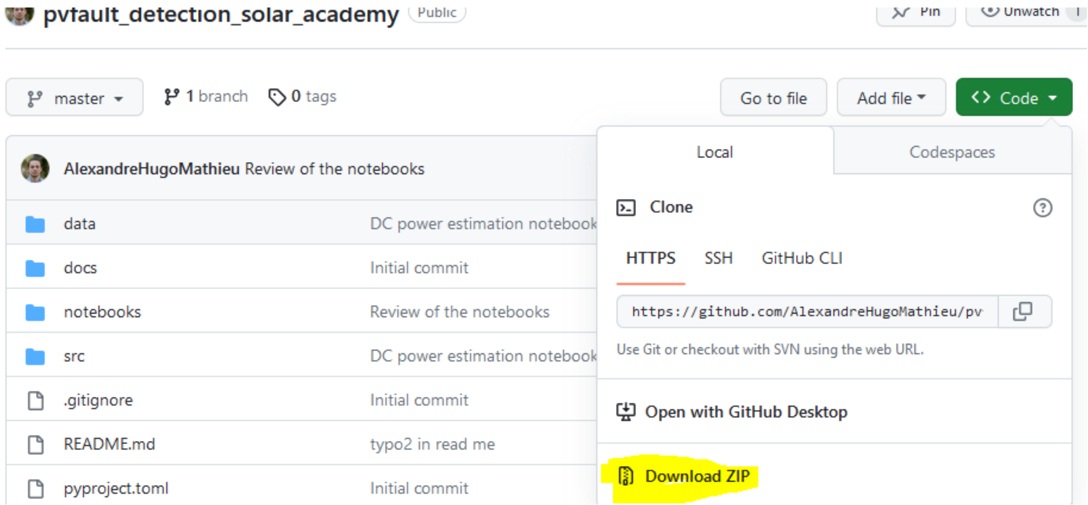
- Modeling guide PVPMC: https://pvpmc.sandia.gov/modeling-guide/
- Python / Pvlib tutorial: https://pvsc-python-tutorials.github.io/PVSC48-Python-Tutorial/
- To go further:
    - The Use of Advanced Algorithms in PV Failure Monitoring: https://iea-pvps.org/wp-content/uploads/2021/10/Final-Report-IEA-PVPS-T13-19_2021_PV-Failure-Monitoring.pdf

Appendix

How to install Python and import the course repository to use the notebooks on your local PC.

1. Install python: www.python.org/downloads/, download and install the 3.9.13 “release” (Add python to your Path)

2. Go to https://github.com/AlexandreHugoMathieu/pvfault_detection_solar_academy, click on the green “Code” button and then download the folder as the zip



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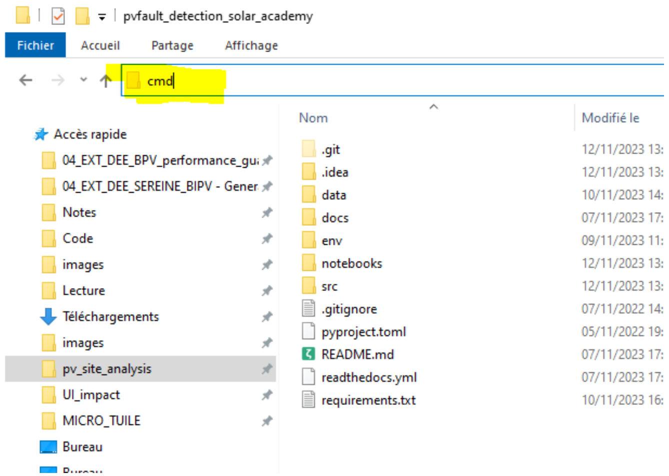

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2. Go to https://github.com/AlexandreHugoMathieu/pvfault_detection_solar_academy, click on the green “Code” button and then download the folder as the zip
3. Unzip it and put it in adequate location in your PC.
4. Let’s create a virtual environment where you will find all the functions for this course:
    1. Go in the folder and open the command line from that same folder by writing “cmd” in the path bar (with Windows)

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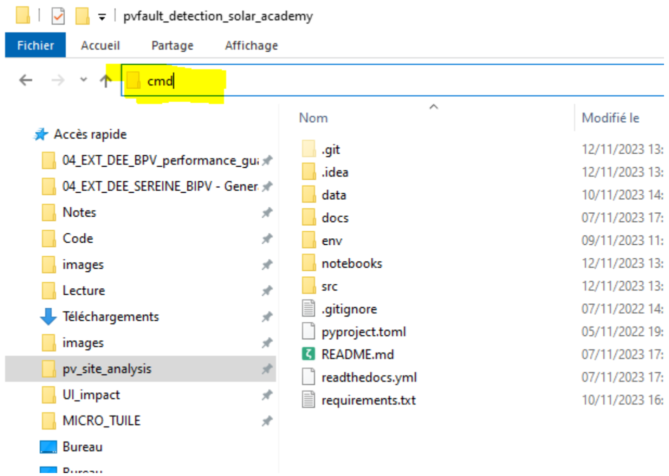
4. Let’s create a virtual environment where you will find all the functions for this course:
    1. Go in the folder and open the command line from that same folder by writing “cmd” in the path bar (with Windows)
    2. In the command bar: execute the following line to create the “solar_env” environnement that you will use in your notebooks
        1. “pip install virtualenv”
        2. “python –m virtualenv solar_env”
        3. “call solar_env\Scripts\activate” (you should have a ‘solar_env’ on the left of the command at this point)
        4. “pip install –r requirements.txt” (load all the libraries, take a little time, be patient)
        5. “python -m ipykernel install --name=solarkernel” (create a kernel for the notebooks)

It’s ready !

Appendix

How to start a notebook

1. Go in the folder and open the command line from that same folder by writing “cmd” in the path bar (with Windows)
2. In the command bar, exexute:
    1. “call solar_env\Scripts\activate” (go in the virtual env)
    2. “jupyter notebook” (open the notebooks browser)



3. Browse to the notebooks folder, choose one and pick the solarkernel when asked.