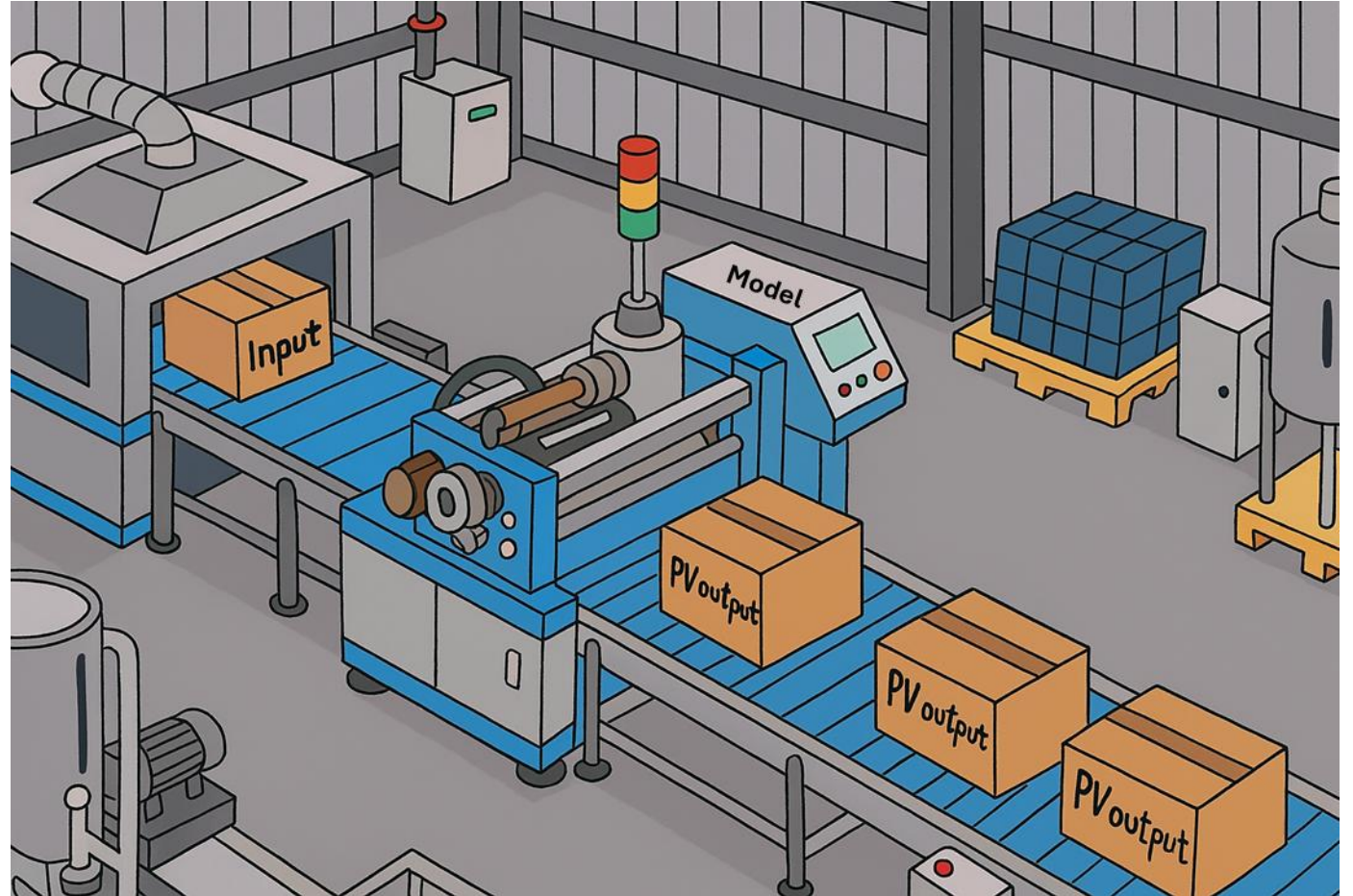


PV modelling an overview (#2)

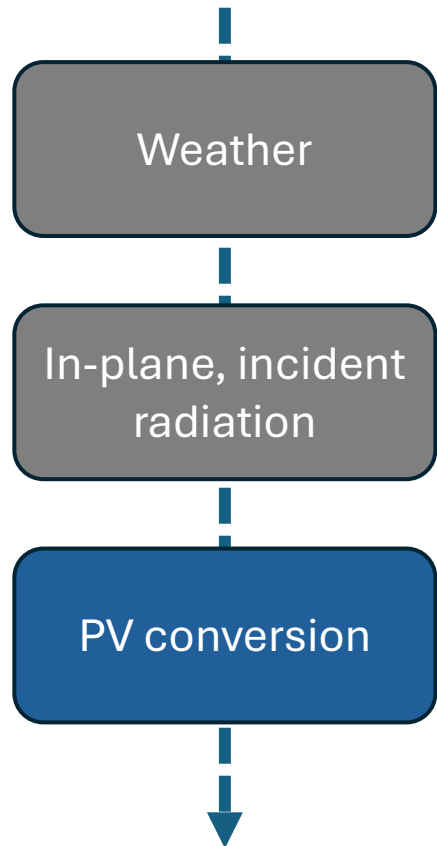
Rodrigo Amaro e Silva

rasilva@ciencias.ulisboa.pt

27/10/2026

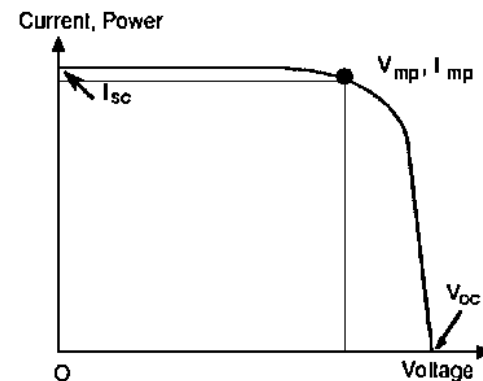
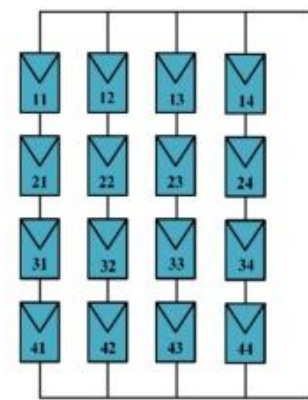


Modelling frameworks



Diode equivalent models⁺ (e.g., PVsyst):

- Describe a PV module in detail
- Get full I-V curve which is relevant for PV system design
- Requires many PV inputs* (often specifying equipment)

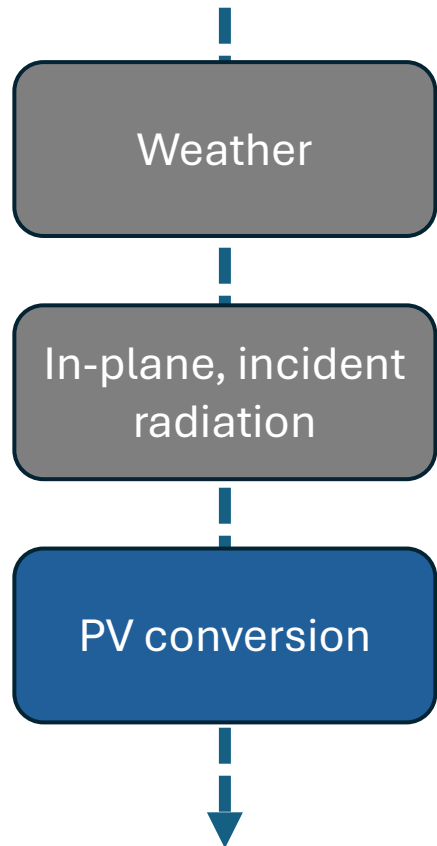


Relevant for designing arrays (with series and parallels) and their connection to the inverter

⁺ Find more [here](#).

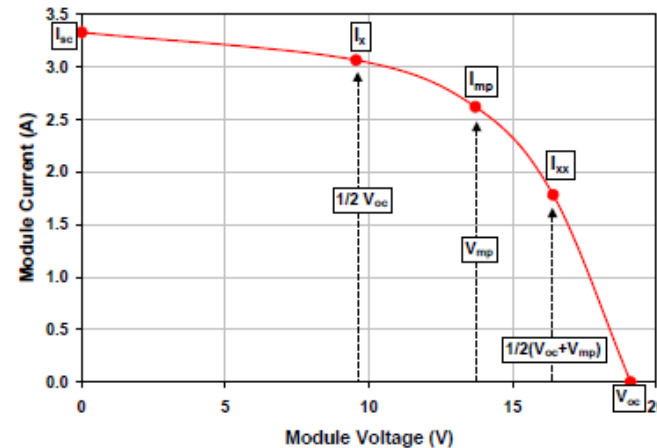
^{*} E.g., series and shunt resistances, band gap, short-circuit and open-circuit voltage in STC.

Modelling frameworks



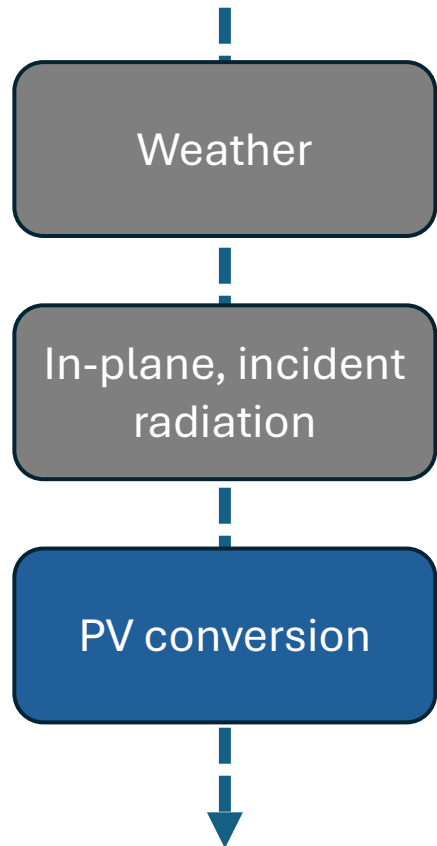
The [SAPM](#) point-value approach only considers 5 points from which the whole I-V curve can be derived.

- Still is input-demanding* (and, likely, specifying equipment)



* Requires equipment-specific empirical coefficients defined by Sandia National Laboratory. (but database only has a limited scope)

Modelling frameworks



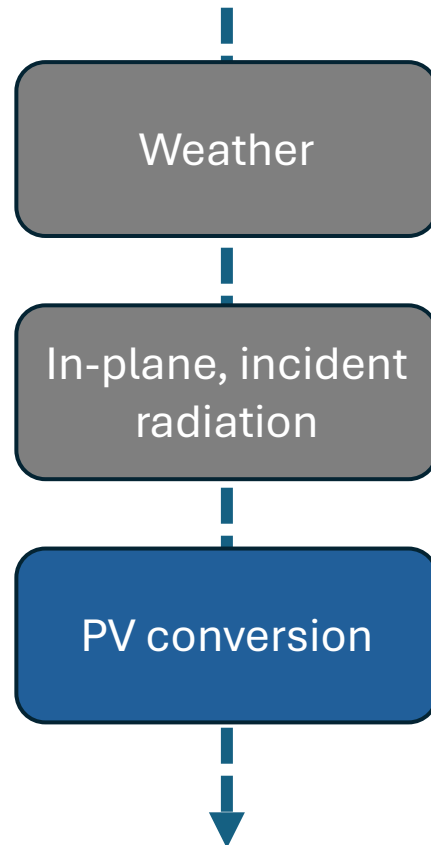
In turn, [PVWatts](#) assumes a simplified approach focusing on power output and “maximum power” conditions.

- Works rather well from a power perspective
- Ignores current and voltage, needed for proper system design
- Good solution for high-level or “first guess” studies

$$P_{out} = \frac{GTI_{eff}}{1000} P_{STC}$$



PV conversion: STC efficiency



PV efficiency in standard test conditions (STC)



Chef Ramsay, PV expert

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 Diode Passivating Contacts (TDPC) technology offer lower LID/Light Induced 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 static test load
2400 Pa rear side 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.

12mm | 30mm | 1mm | 0.40mm

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

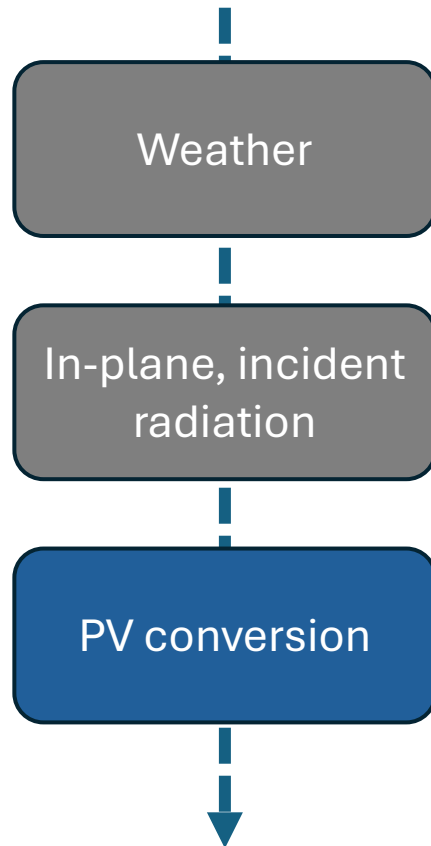
Specifications (STC)

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

Parameters change
from module to module

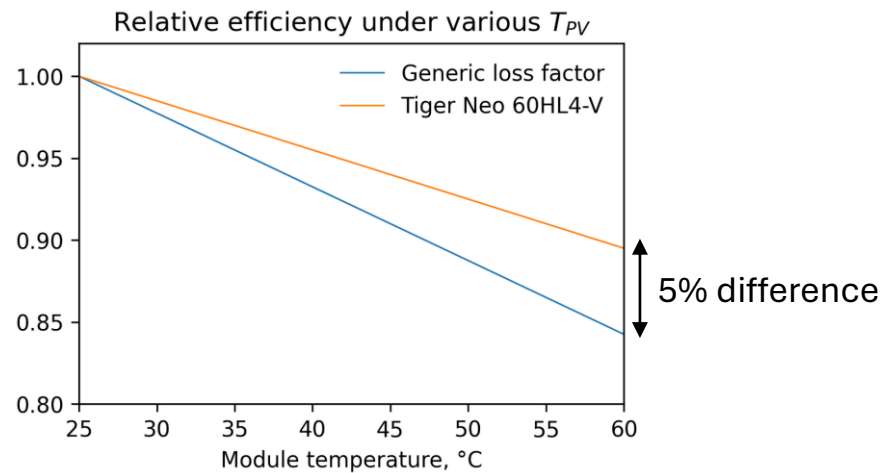
PV conversion: thermal losses



Typically modelled as a linear loss factor γ

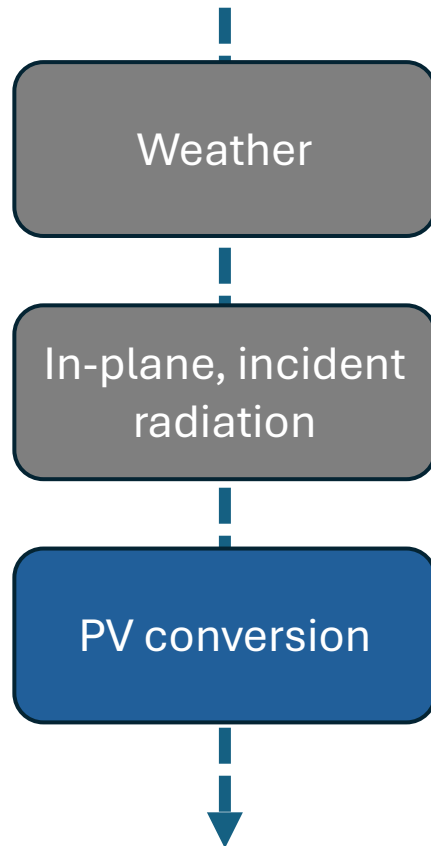
$$\eta = 1 - \gamma \times (T_{PV} - 25)$$

Depends on module, but -0.45 %/°C as a generic (outdated) γ value
-0.30 %/°C for Tiger Neo 60HL4-V



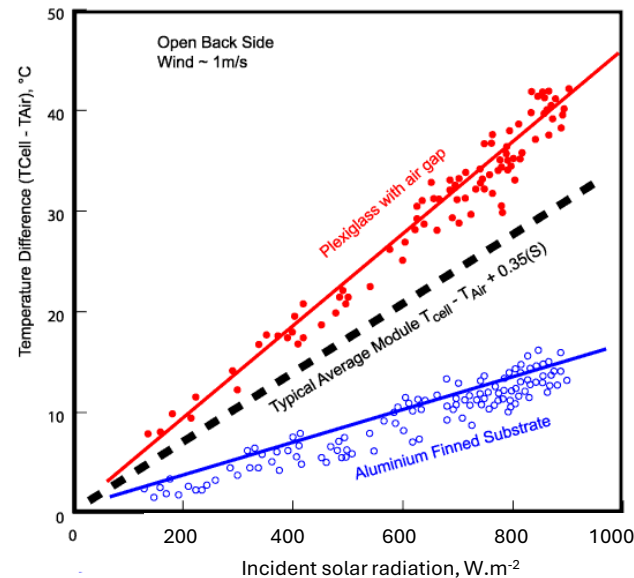
More on this topic in appendix.

PV conversion: thermal losses



Need to calculate PV cell temperature

- [Various models](#), with different degrees of complexity* / input needs
- Grows rather linearly with incident radiation

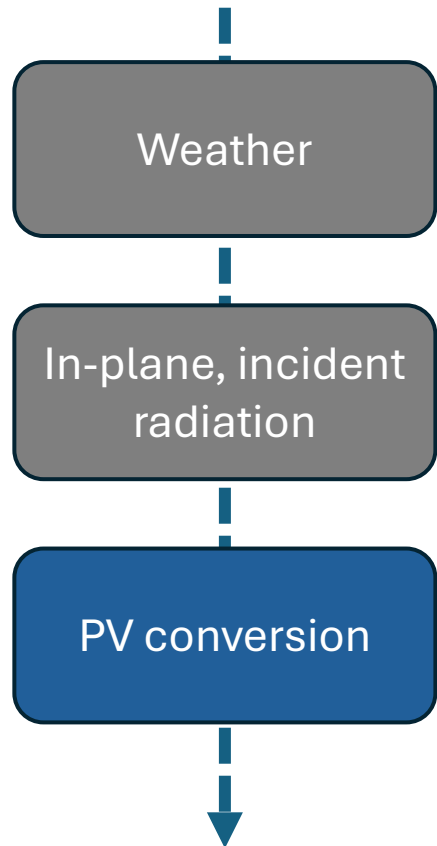


Slope depends on:

- backside material
- wind conditions

*More complex solutions also account for wind speed or relative humidity

PV conversion: thermal losses



Need to calculate PV cell temperature

- [Various models](#), with different degrees of complexity* / input needs
- A classic example*:

$$T_{PV} = T_{air} + \frac{GTI}{800} \times (NOCT - 20)$$

T_{PV} @ $GTI = 800 \text{ W/m}^2$
 $T_{air} = 20^\circ\text{C}$
 $w_s = 1 \text{ m/s}$
open back side

$$= T_{air} + GTI \times \frac{NOCT - 20}{800 - 0}$$

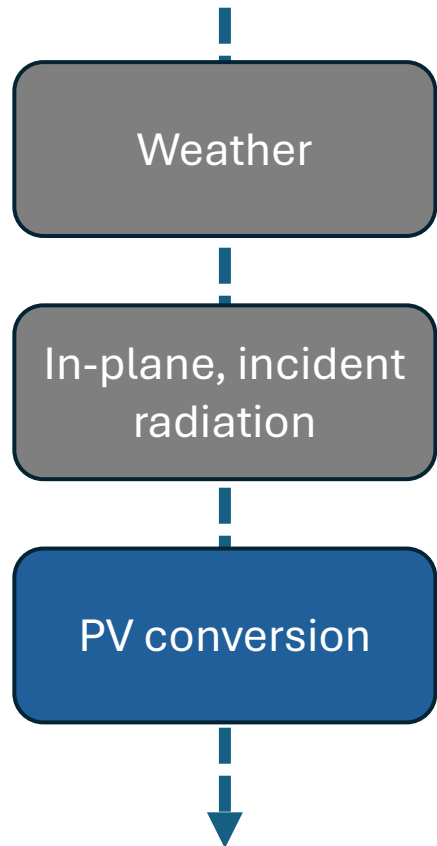
Ross coefficient, k
($^\circ\text{C}$ increase per W/m^2)



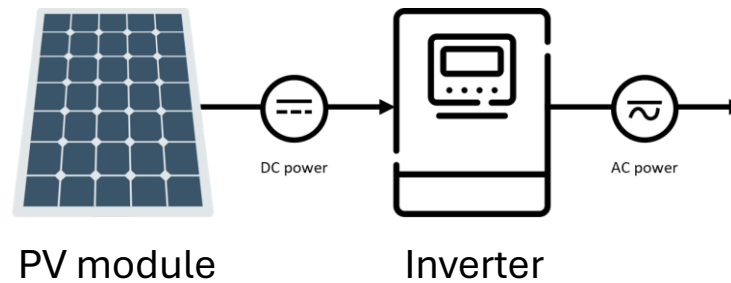
[Skoplaki et al. \(2009\)](#) list k values for PV setups with different degrees of back ventilation

*More complex solutions also account for wind speed or relative humidity

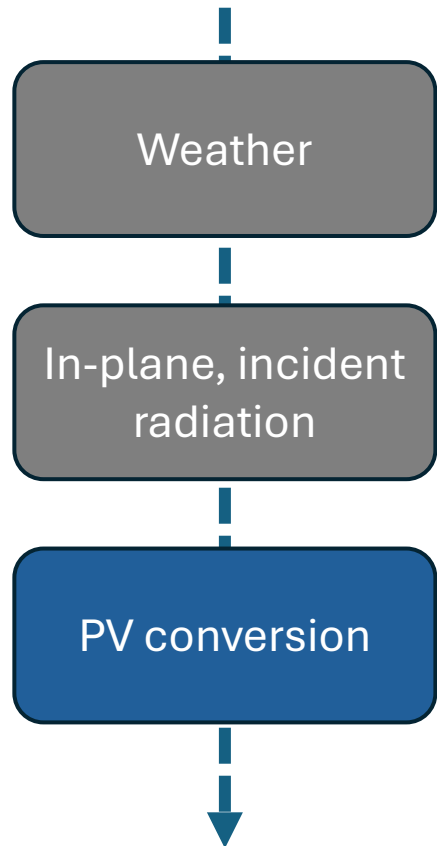
Inverter and other electric losses



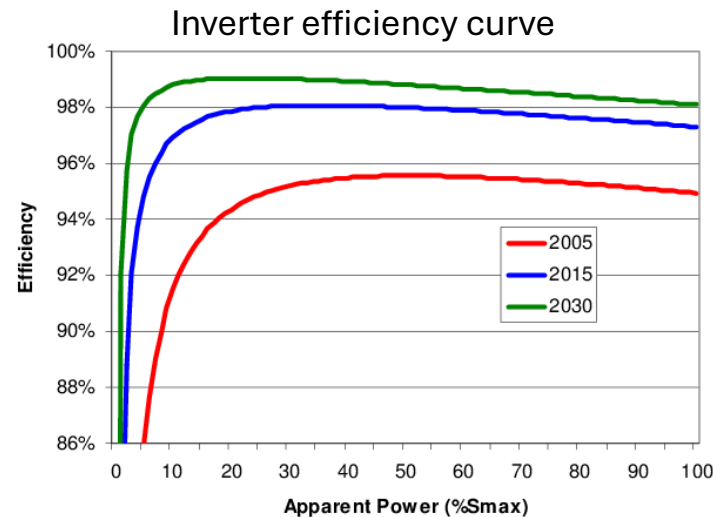
Electric conversion losses: inverter, cabling, and others.



Inverter and other electric losses



Electric conversion losses: cabling, inverter, and others.



- Very low at $P_{in} < 5-10\%$
- Peaks at a certain P_{out}
- Then slowly decreases

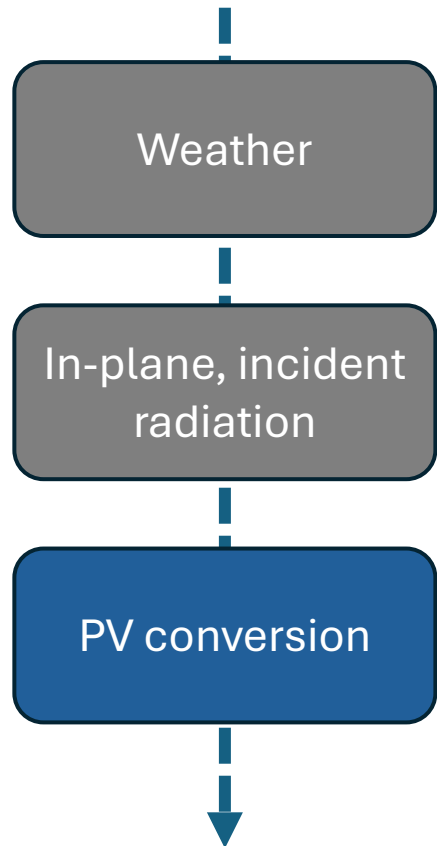
Source: [Braun \(2007\)](#)

This means that inverter losses are dynamic, vary in time.

Engineering practice of [oversizing module capacity wrt inverter](#).

One of the advantages: overall increase in inverter efficiency.

Inverter and other electric losses



From a [2005 NREL study](#) (should be seen as outdated/pessimistic)

Table 1. Derate Factors for A.C. Power Rating

Item	Typical
d.c. cabling	0.98
Diodes and connections	0.995
Mismatch	0.98
Transformers	0.97
a.c. wiring	0.99

An aggregate value of 0.917
(more than 8% losses)

Optimistic values at the time
would be around 0.946 (5.4% loss)

According to [Aurora Solar](#), DC cabling losses can be lower (1%)
when short/thicker cables are used

More specific nuances

Today's focus was on a more generic framework.

However, more niche applications may require some “add-ons”.



Bifacial PV



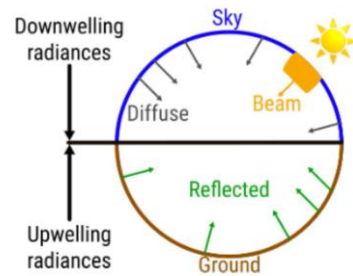
Floating PV

For bifacial PV, take a look at [Sandia](#), [Ernst \(2024\)](#), [Nygard \(2025\)](#), and [Brecl \(2025\)](#).

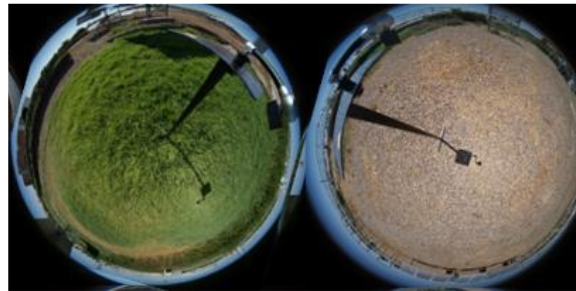
For floating PV, take a look at [Kjeldstad \(2021\)](#) and [IEA PVPS Task13 report](#).

More specific nuances

Main topics for bifacial (shared by vertical PV):



Angle of incidence

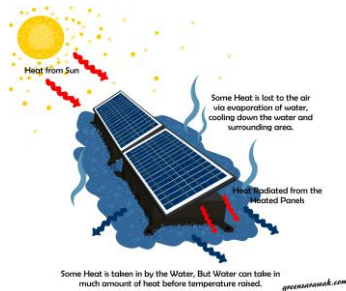


Ground albedo



Sky radiance

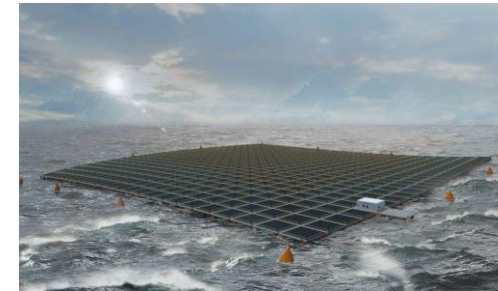
Main topics for floating PV:



Thermal dynamics

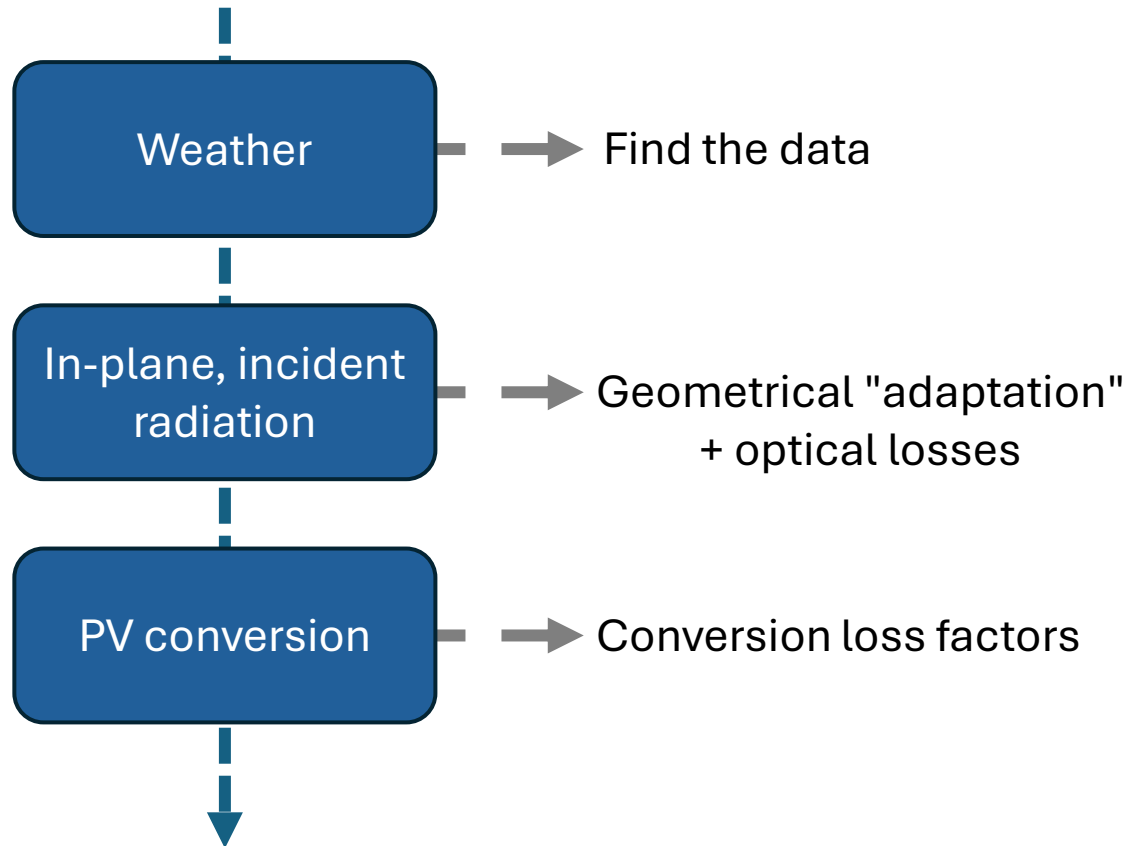


Soiling



Waves & angle of incidence

In a nutshell



PV conversion

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

Overall efficiency

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

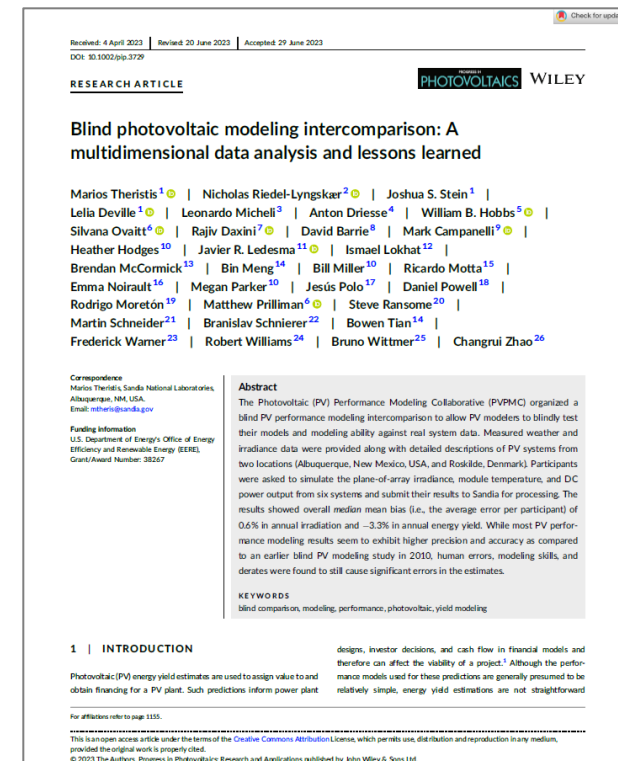
Many modelling choices to be done, these end up being done based on:

- available data,
- geography of interest
- personal experience

Final remark: blind test example

In 2021 a blind intercomparison between PV models raised a very interesting point:

“While most PV performance modeling results seem to exhibit higher precision and accuracy as compared to an earlier blind PV modeling study in 2010, **human errors, modeling skills, and derates were found to still cause significant errors in the estimates.**”



Theristis et al. (2021)

pvlib: a snapshot

Rodrigo Amaro e Silva

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18/11/2025

Intro

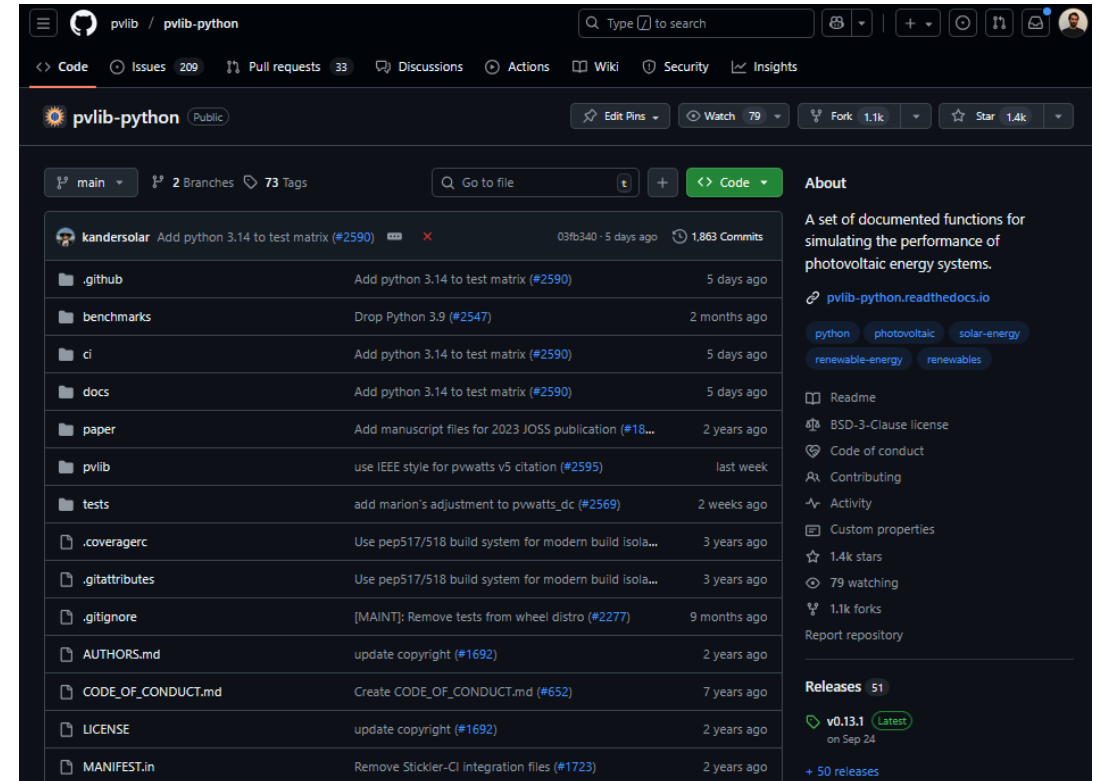
- **pvlb** is a Python library, which is free and is regularly updated
- It is not a PV model *per se*, but more of a repository of algorithms that aims to make the job of a PV modeller easier



Intro

It is a fully open-source, designed and developed by volunteers.

Open to feedback & contributions:
<https://github.com/pvlib/pvlib-python>



pvlib main functionalities



- **PV modelchains**, to quickly implement full modelling pipelines
- **Individual algorithms**, for a customized modelling of each step of the pipeline
- **APIs**, to easily access weather and PVGIS data

First step: designing a case study

`pvlib.location.Location`

(define where your project is located)

```
class pvlib.location.Location(latitude, longitude, tz='UTC', altitude=None, name=None)
```

`pvlib.pvsystem.PVSystem`

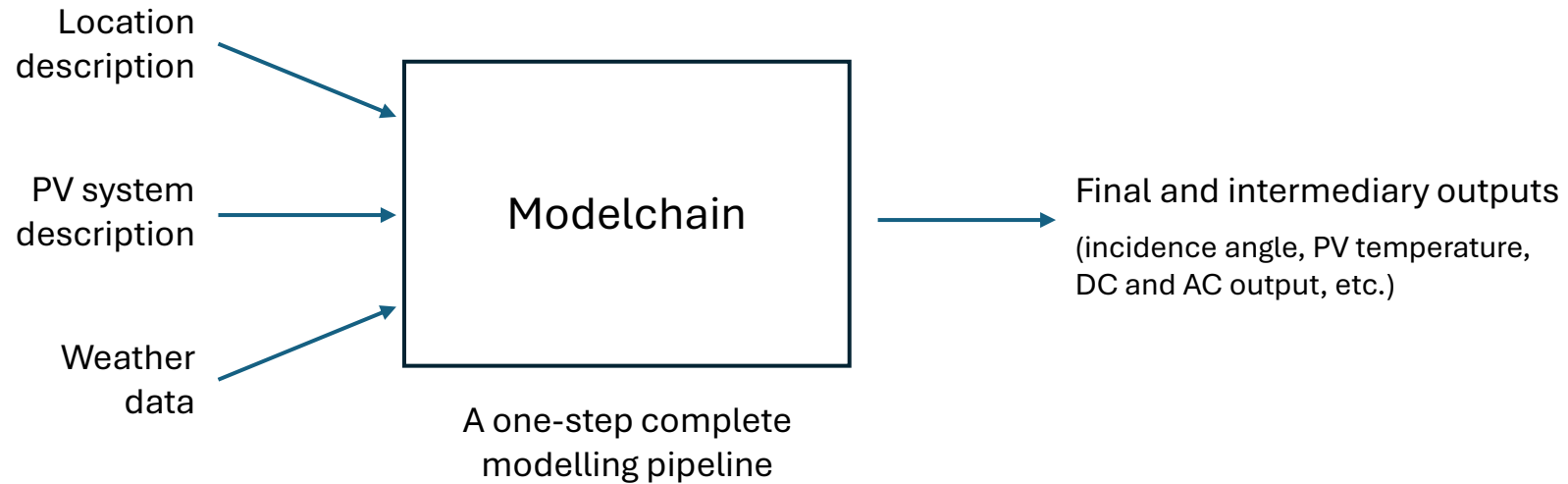
(define your PV project)

```
class pvlib.pvsystem.PVSystem(arrays=None, surface_tilt=0, surface_azimuth=180, albedo=None,
surface_type=None, module=None, module_type=None, module_parameters=None,
temperature_model_parameters=None, modules_per_string=1, strings_per_inverter=1, inverter=None,
inverter_parameters=None, racking_model=None, losses_parameters=None, name=None)
```

Can do it in more detail for diode models,
or with less parameters for PVWATTS

Whenever in a document you see “parameter=something” the something is the default value assumed by the function when no value is provided by the user (e.g. if you don’t define a `surface_tilt`, it will be `0` by default)

Modelchain: in a nutshell



Modelchain: setting up

pvlib.modelchain.ModelChain

```
class pvlib.modelchain.ModelChain(system, location, clearsky_model='ineichen',  
transposition_model='haydavies', solar_position_method='nrel_numpy', airmass_model='kastenyoung1989',  
dc_model=None, ac_model=None, aoi_model=None, spectral_model=None, temperature_model=None,  
dc_ohmic_model='no_loss', losses_model='no_loss', name=None)
```

[\[source\]](#)

The modelchain defines the algorithm used in each modelling step.
As you can see, there is a default configuration already set up (but unlikely to be the best)

Modelchain: running

`pvlib.modelchain.ModelChain.run_model`

`ModelChain.run_model(weather)`

(only requires weather data,
assumes you have horizontal
irradiance data)

`pvlib.modelchain.ModelChain.run_model_from_poa`

`ModelChain.run_model_from_poa(data)`

(same as above, for you when have
plane-of-array irradiance data)

Individual algorithms: examples

Doing step by step, with more control/customization. Examples below:

`pvlib.iam.martin_ruiz`

(example of optical loss algorithm,
pvlib.iam contains other options)

`pvlib.irradiance.perez`

(example of radiation transposition algorithm,
pvlib.irradiance contains other options)

`pvlib.temperature.sapm_cell`

(example of PV temperature algorithm,
pvlib.temperature contains other options)

APIs: pvlib as a data facilitator

Access to several databases, examples below:

`pvlib.iotools.get_cams`

(solar radiation estimated
by satellite, from CAMS)

`pvlib.iotools.get_pvgis_tmy`

weather data for a Typical
meteorological year, from PVGIS)

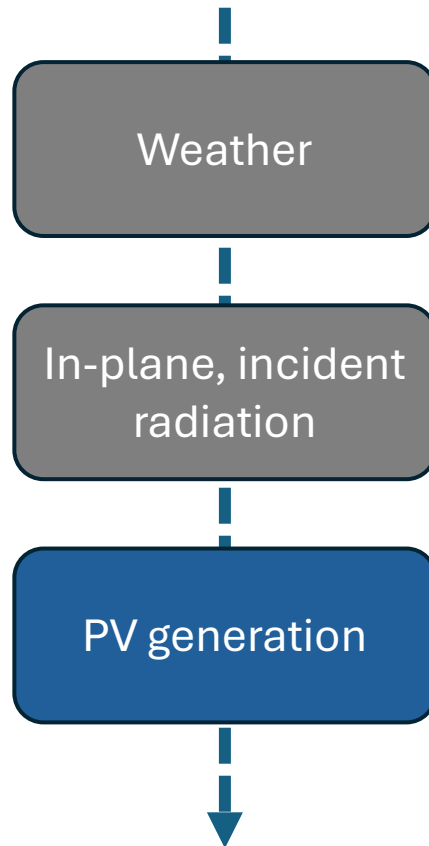
`pvlib.iotools.get_pvgis_hourly`

(PV and weather data, from PVGIS)

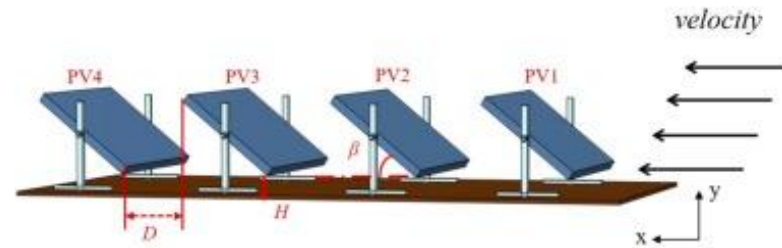
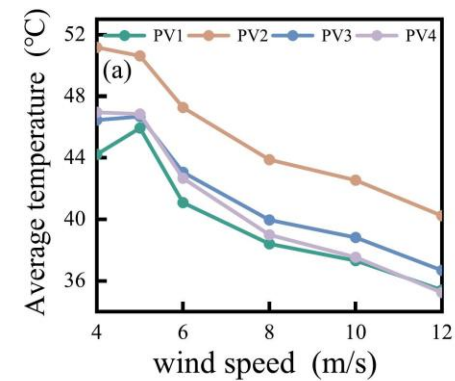
And many others: <https://pvlib-python.readthedocs.io/en/latest/reference/iotools.html>
[Jensen et al. \(2023\)](#)

Appendix

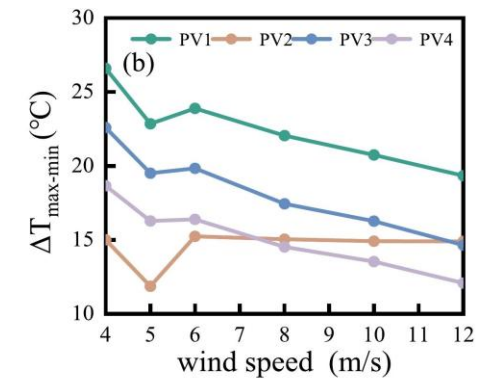
PV conversion: thermal losses



Also impacted by spatial arrangement

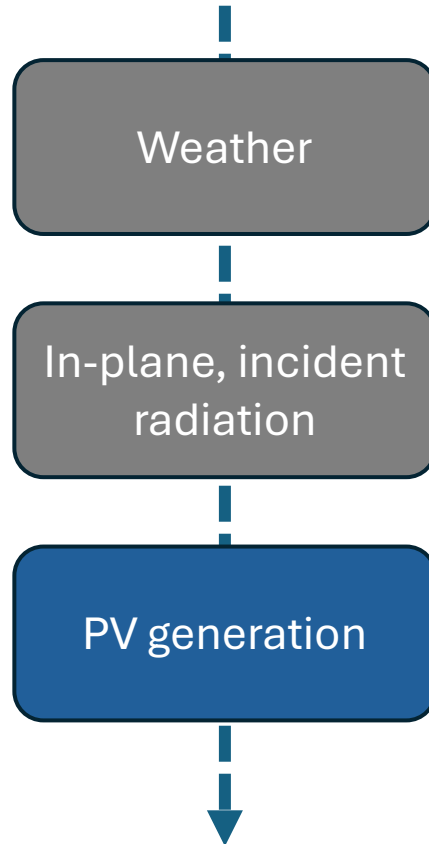


(a) Average temperature



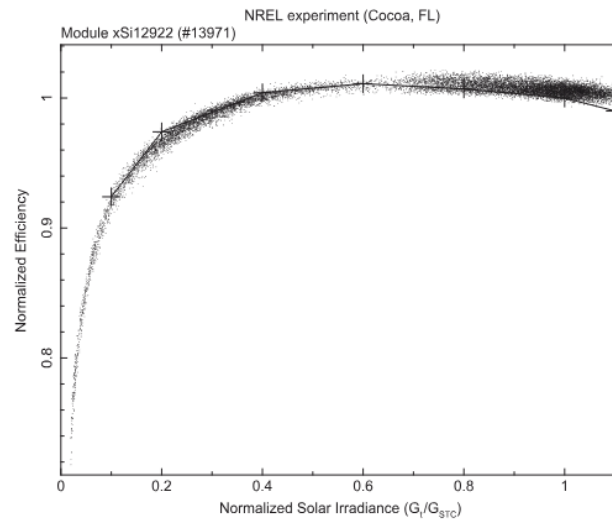
(b) Maximum temperature difference

PV conversion: low-irradiance losses



Then, account for low-level irradiance loss

- Typical in crystalline silicon, due to parasitic shunt resistance
- Example: [Marion model](#) (eq. 11)



[Mavromatakis et al. \(2017\)](#)