



CentraleSupélec

Estimation of the electricity production of a PV installation using PVGIS

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2023-04-18



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I. Objectives



Objectives

- 1) Understand the link between climate and intermittent renewable energy sources
- 2) Use climate models to assess the potential of solar PV rooftop residential
- 3) Learn some stuffs about PV (incidentally) and techno-economic analysis



CentraleSupélec

II. Resources



Find the location

Google maps: <https://www.google.fr/maps>



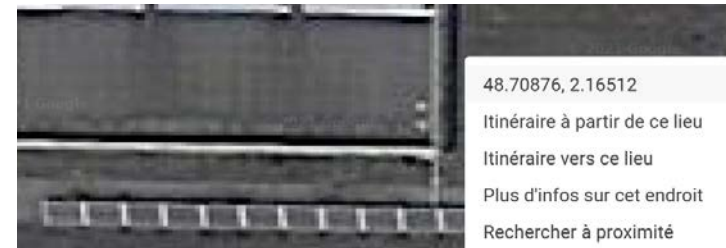
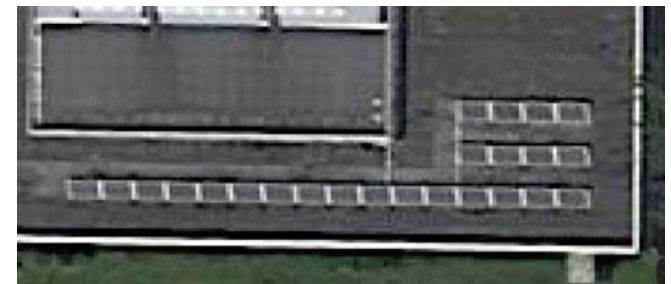
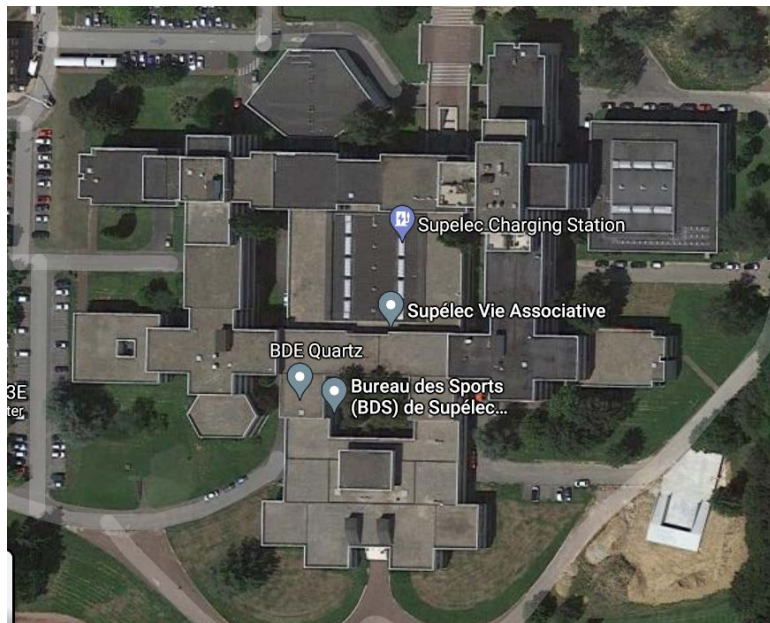
Mode satellite

Enter address: CentraleSupélec, 3 rue Joliot Curie, 91190 Gif-sur-Yvette

<https://www.google.fr/maps/place/CentraleSup%C3%A9lec/@48.7086882,2.1631571,231m/data=!3m1!1e3!4m5!3m4!1s0x47e67745e24d0f51:0x8cd75b7cb52a1f8c!8m2!3d48.709445!4d2.1661629>

Right click
on location

Copy by
clicking on the
GPS coord.





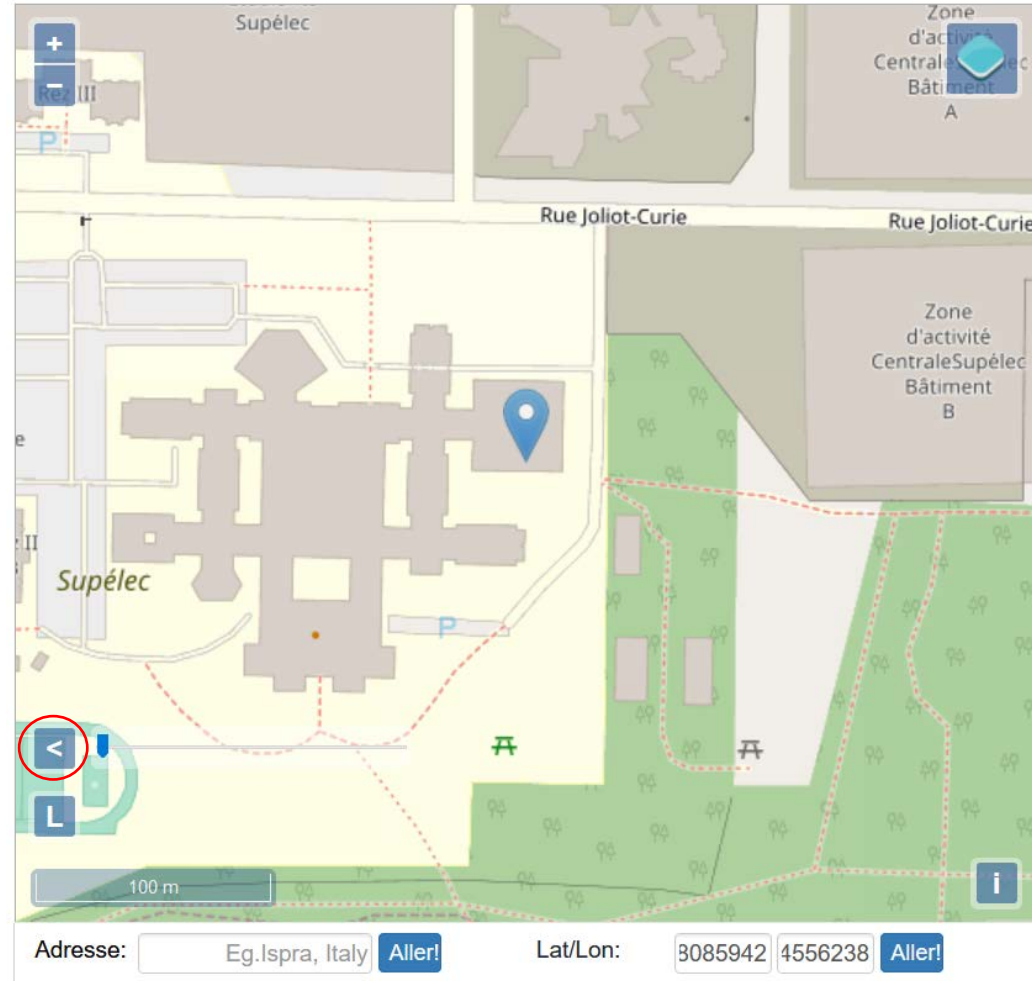
Find the location

PVGIS: https://re.jrc.ec.europa.eu/pvg_tools/fr/#PVP

Language = English
(French translation is approx...)

paste GPS to PVGIS
48.708758085942, 2.165121154556238

Remove opacity





Horizon

Cursor:


Selected: 48.709, 2.165


Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

 csv

 json

Parcourir...

Aucun fichier sélectionné.

GRID CONNECTED

TRACKING PV

OFF-GRID

MONTHLY DATA

DAILY DATA

HOURLY DATA

TMY



Horizon

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

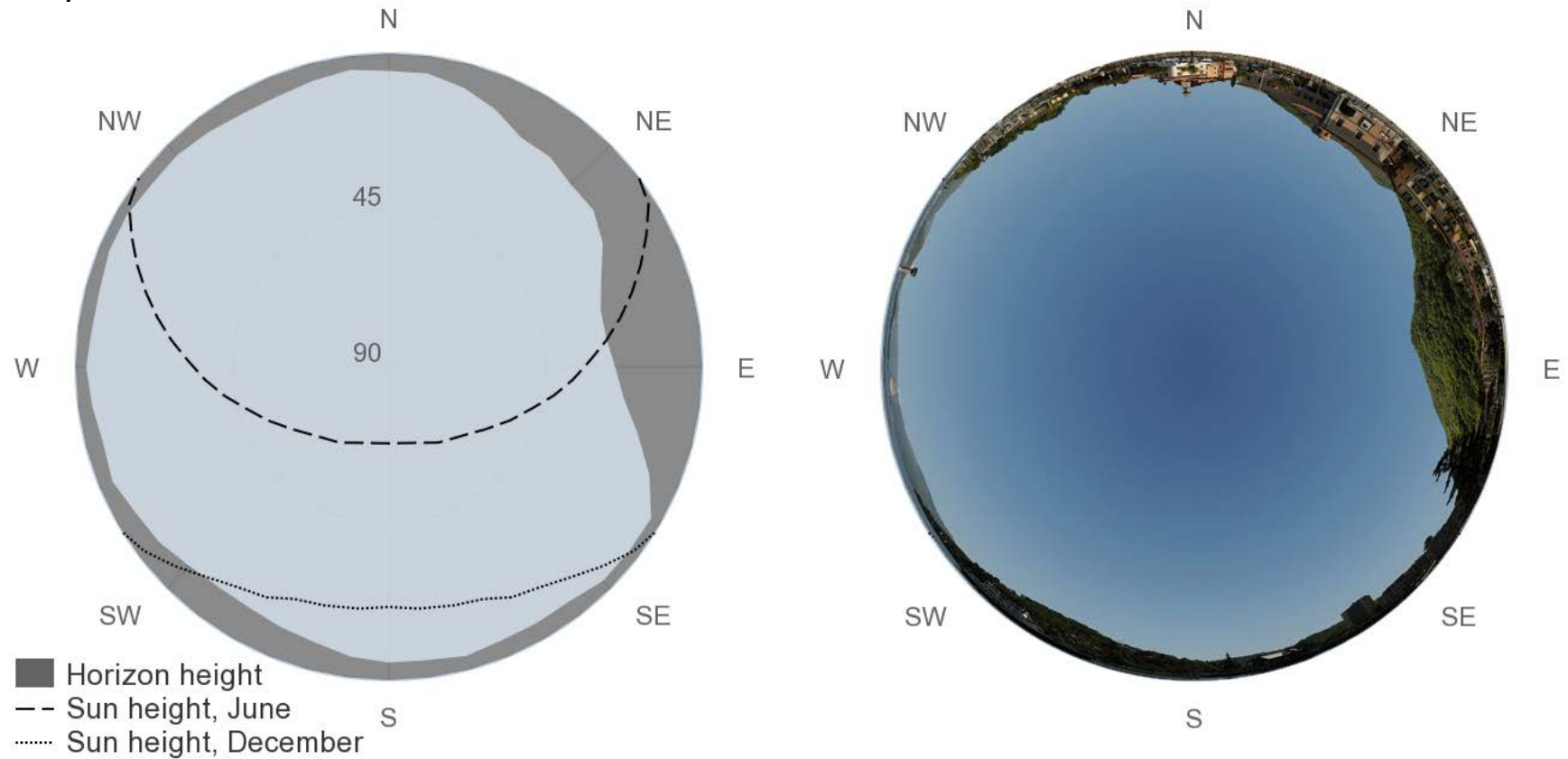
[↓ csv](#)

[↓ json](#)

Parcourir...

Aucun fichier sélectionné.

Example from PVGIS manual:





Horizon

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

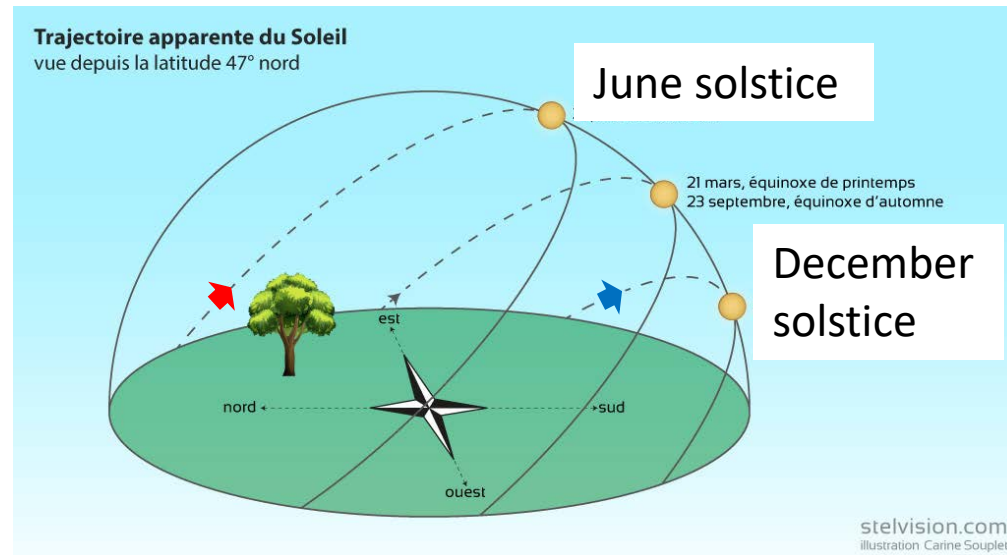
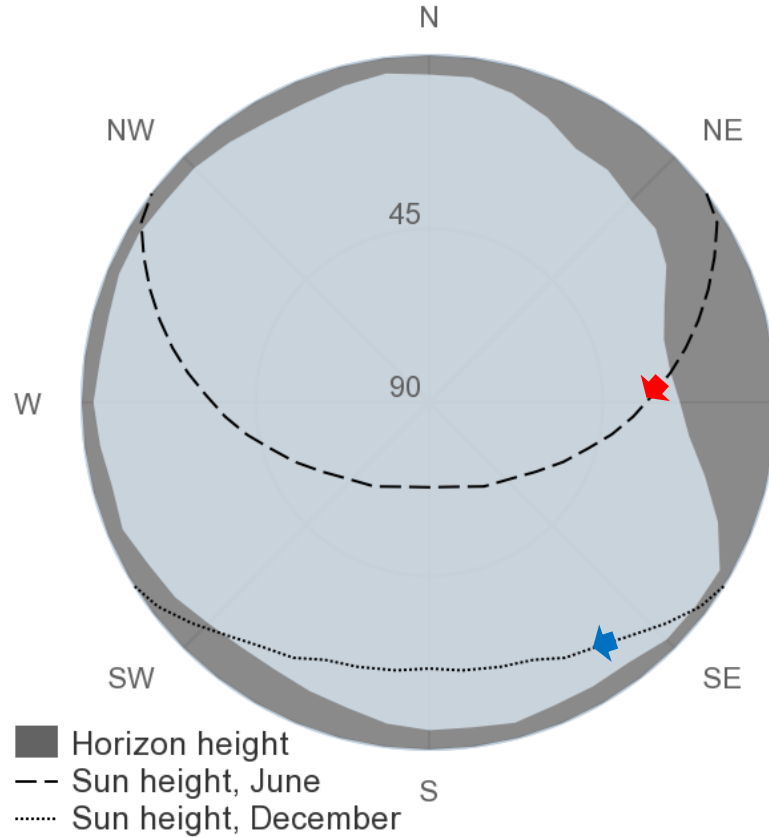
↓ csv

↓ json

Parcourir...

Aucun fichier sélectionné.

Example from PVGIS manual:





Daily data

Cursor:
Selected: 48.709, 2.165
Elevation (m): 166

Use terrain shadows:
 Calculated horizon
 Upload horizon file

Aucun fichier sélectionné.

GRID CONNECTED
TRACKING PV
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY

AVERAGE DAILY IRRADIANCE DATA

Solar radiation database* PVGIS-SARAH

Month* May

UTC time Local time

On fixed plane:

Irradiance
 Clear-sky irradiance

Slope [°] 35
Azimuth [°] 0

On sun-tracking plane:

Irradiance
 Clear-sky irradiance

Temperature:

Daily temperature profile

+ lecture notes "Position d'une surface inclinée"

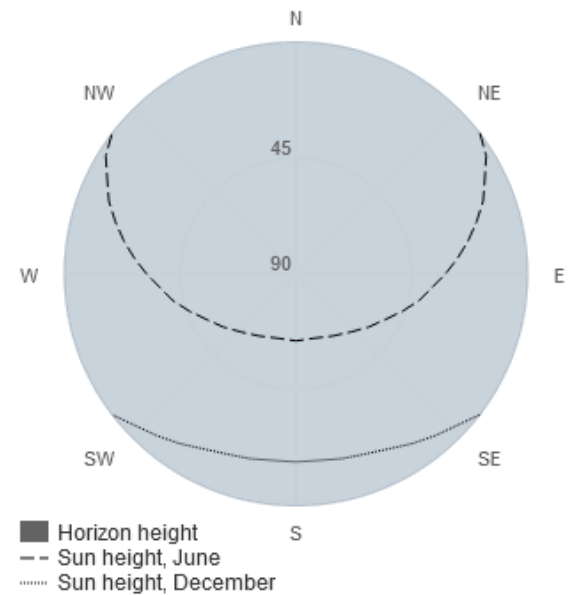
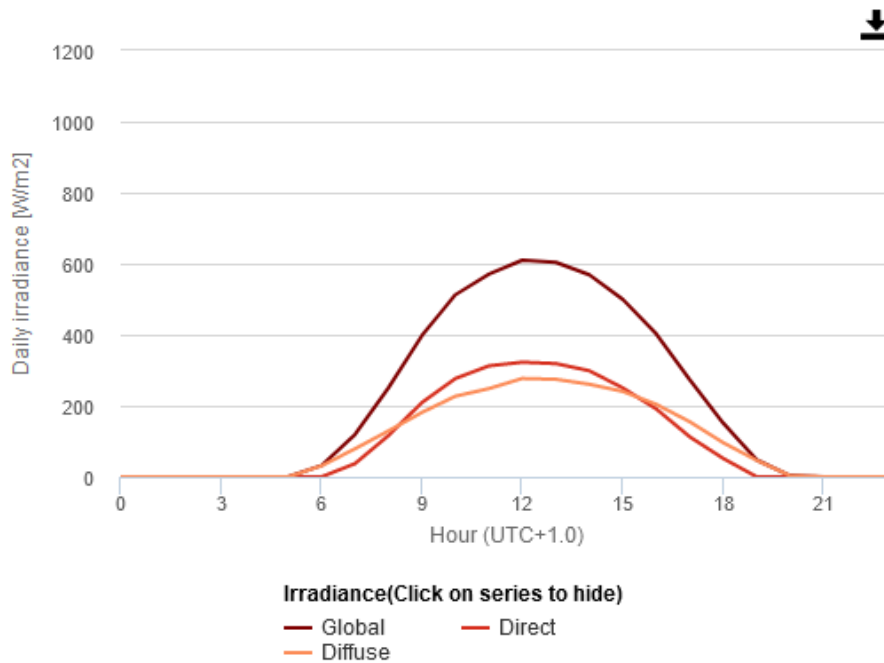


Daily data

AVERAGE DAILY IRRADIANCE DATA: RESULTS

- Fixed-plane
- Tracking
- Temperature
- Info
- PDF

Daily average irradiance



+ lecture notes "Irradiance" & "Air mass"

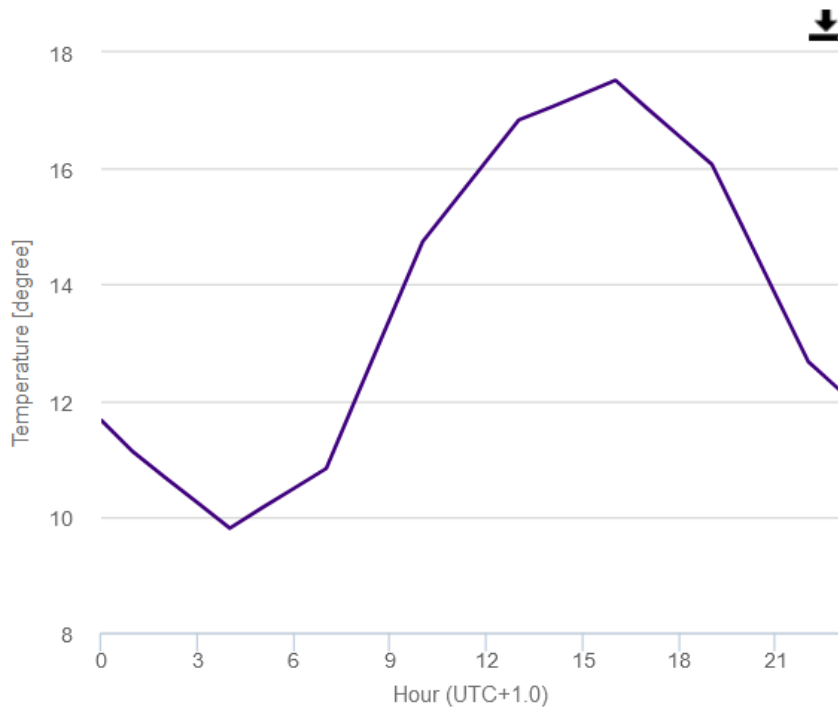


Daily data

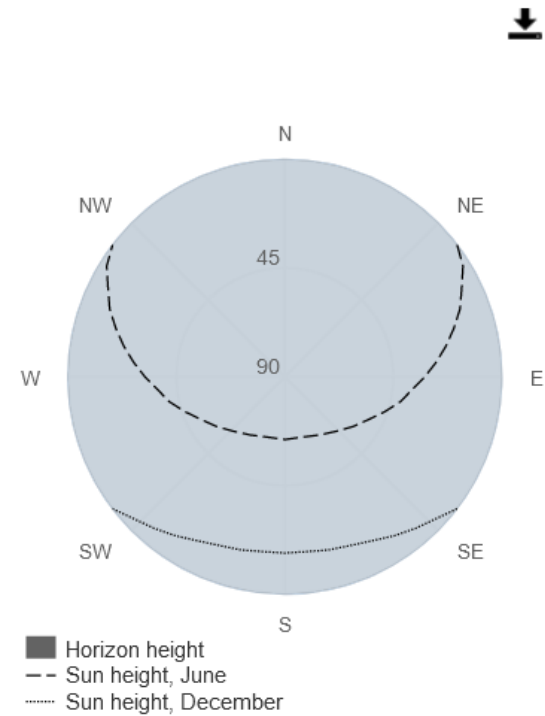
AVERAGE DAILY IRRADIANCE DATA: RESULTS

- Fixed-plane
- Tracking
- Temperature**
- Info
- PDF

Daily average temperature



Outline of horizon





Monthly data

Cursor:
Selected: 48.709, 2.165
Elevation (m): 166

Use terrain shadows:
 Calculated horizon
 Upload horizon file

[↓ csv](#) [↓ json](#)
Parcourir... Aucun fichier sélectionné.

GRID CONNECTED
TRACKING PV
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY

MONTHLY IRRADIATION DATA

Solar radiation database* PVGIS-SARAH
Start year:* 2005 End year:* 2016

Irradiation:
 Global horizontal irradiation
 Direct Normal Irradiation
 Global irradiation optimum angle
 Global irradiation at angle: (0-90)

Ratio:
 Diffuse/global ratio

Temperature:
 Average temperature



Monthly data

MONTHLY IRRADIATION DATA: RESULTS

Radiation

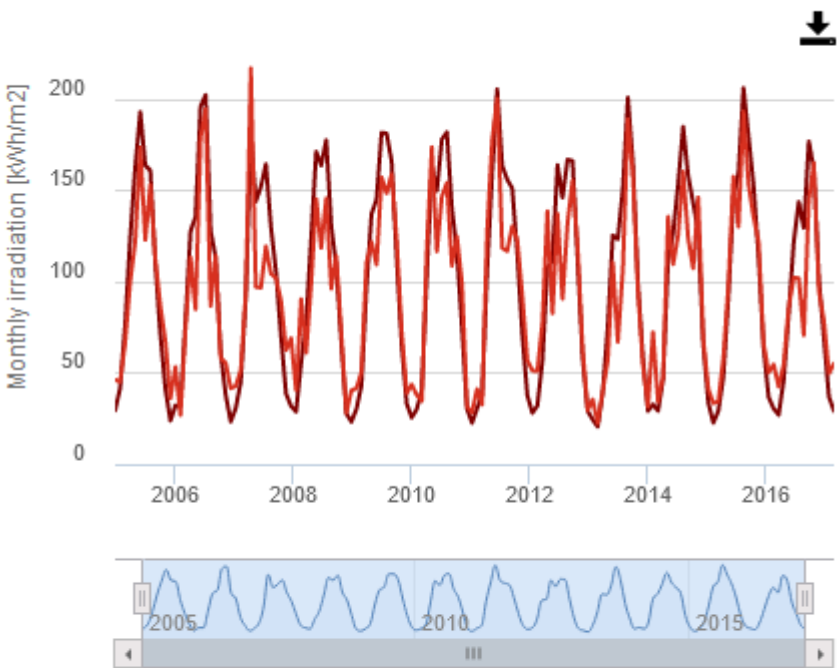
Diffuse/Globa

Temperature

Info

PDF

Monthly solar irradiation estimates

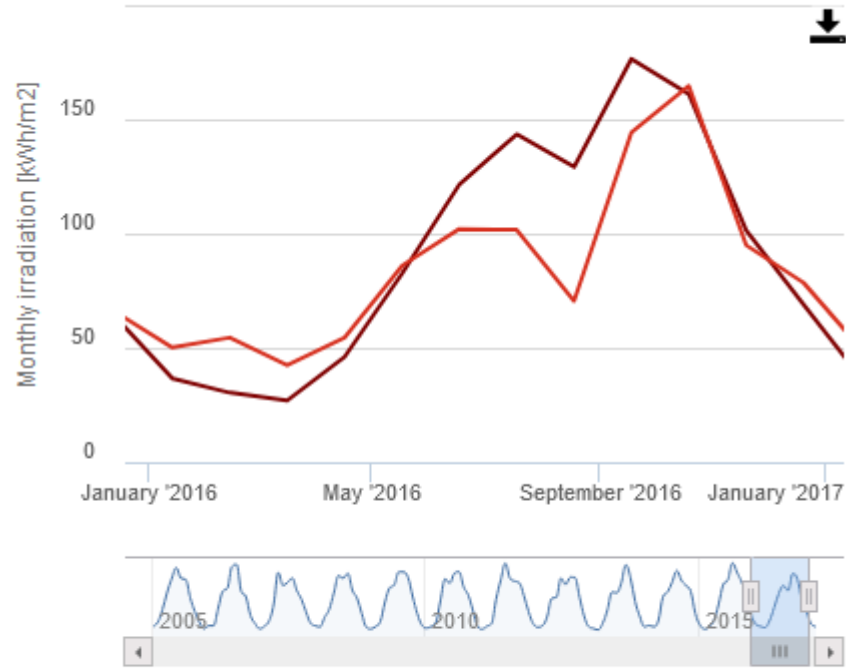


Irradiation
(Click on series to hide)

- Horizontal irradiation
- Direct Normal Irradiation

— Optimal angle irradiation

Monthly solar irradiation estimates



Irradiation
(Click on series to hide)

- Horizontal irradiation
- Direct Normal Irradiation

— Optimal angle irradiation



Monthly data

MONTHLY IRRADIATION DATA: RESULTS

Radiation

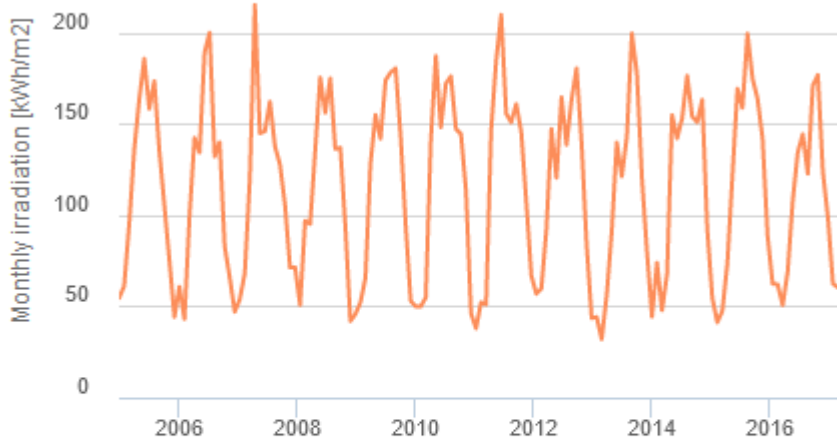
Diffuse/Globa

Temperature

Info

PDF

Monthly solar irradiation estimates

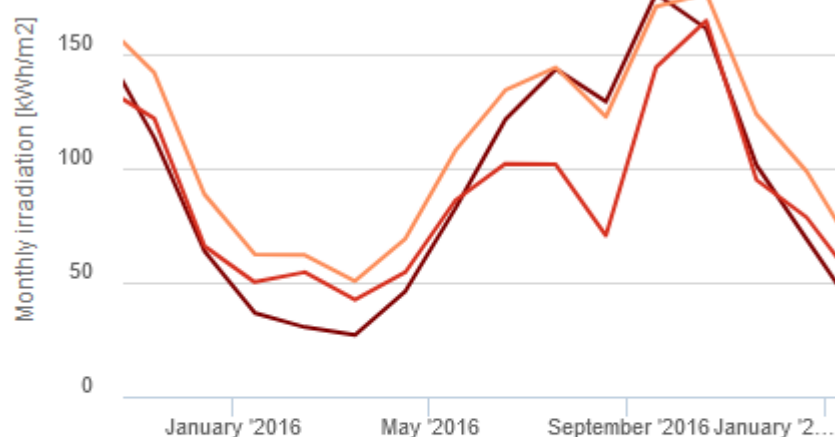


Irradiation
(Click on series to hide)

- Horizontal irradiation
- Direct Normal Irradiation

Optimal angle irradiation

Monthly solar irradiation estimates



Irradiation
(Click on series to hide)

- Horizontal irradiation
- Direct Normal Irradiation

Optimal angle irradiation



Monthly data

MONTHLY IRRADIATION DATA: RESULTS

Radiation

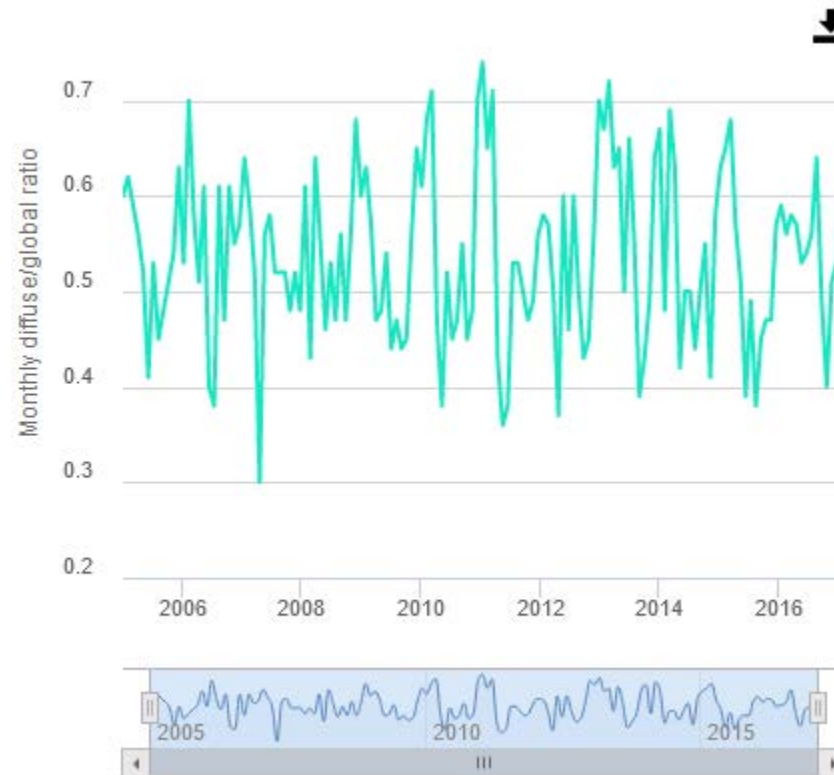
Diffuse/Globa

Temperature

Info

PDF

Monthly average diffuse to global ratio





Données mensuelles d'irradiation

MONTHLY IRRADIATION DATA: RESULTS

Radiation

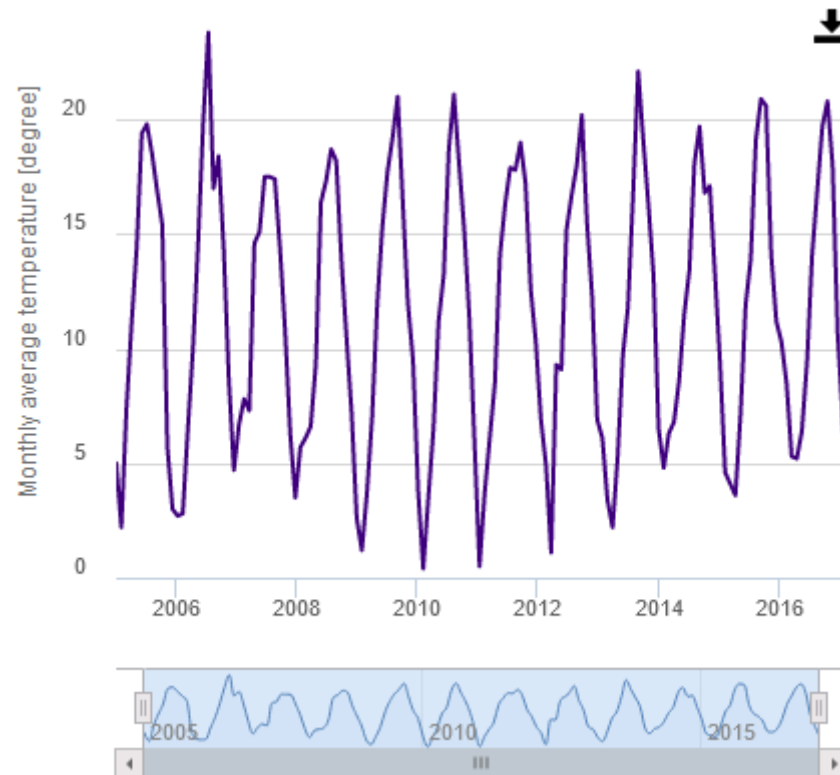
Diffuse/Glob

Temperature

Info

PDF

Monthly average temperature





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III. PV Technology



PV technology

Cursor:
Selected: 48.709, 2.165
Elevation (m): 166

Use terrain shadows:
 Calculated horizon
 Upload horizon file

[↓ csv](#) [↓ json](#)
Parcourir... Aucun fichier sélectionné.

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
Crystalline silicon
CIS
CdTe
Unknown
Free standing

Installed peak PV power [kWp]*
System loss [%]*

Fixed mounting options

Mounting position*
Slope [°]* 35
Azimuth [°]* 0

PV electricity price

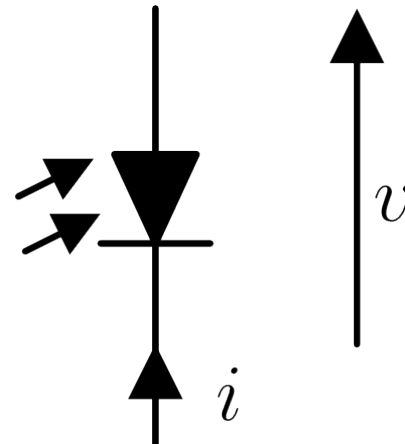
PV system cost (your currency)
Interest [%/year]
Lifetime [years]

Optimize slope
 Optimize slope and azimuth

<https://www.youtube.com/watch?v=am54b15RZMI>



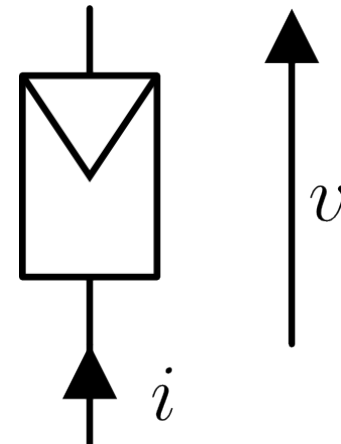
Photovoltaic cell



+ lecture notes "Cellules PV"



Photovoltaic module



+ lecture notes “Module PV” & “Champ PV”



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IV. Installation



Installation

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

↓ csv

↓ json

Parcourir...

Aucun fichier sélectionné.

GRID CONNECTED



PERFORMANCE OF GRID-CONNECTED PV



TRACKING PV

OFF-GRID

MONTHLY DATA

DAILY DATA

HOURLY DATA

TMY

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]

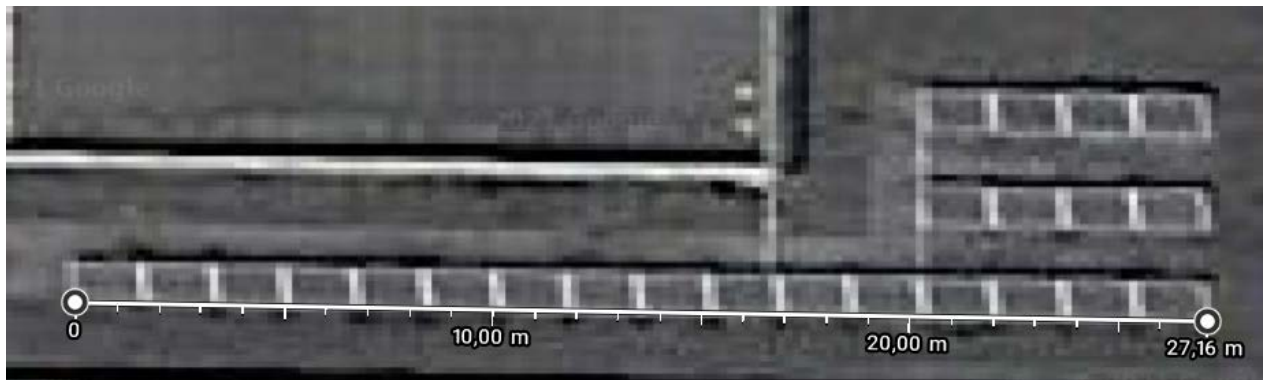
Lifetime [years]

Installed peak PV power

Installed peak PV power [kWp] - Peak power

This is the power that the manufacturer declares that the PV array can produce under standard test conditions, which are a constant 1000W of solar irradiance per square meter in the plane of the array, at an array temperature of 25°C. The peak power should be entered in kilowatt-peak (kWp). If you do not know the declared peak power of your modules but instead know the area of the modules (in m²) and the declared conversion efficiency (in percent), you can calculate the peak power as $power (kWp) = 1 kW/m^2 * area * efficiency / 100$. See more explanation in the [FAQ](#)

$$\begin{aligned} power [kW] &= 1 [kW/m^2] * area [m^2] * efficiency [\%] / 100 \\ &= 1 * (27*0.9) * 18/100 = 4.374 kWp \end{aligned}$$





System loss

Estimated system losses ✕

The estimated system losses are all the losses in the system, which cause the power actually delivered to the electricity grid to be lower than the power produced by the PV modules. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the modules and so on. Over the years the modules also tend to lose a bit of their power, so the average yearly output over the lifetime of the system will be a few percent lower than the output in the first years.

We have given a default value of 14% for the overall losses. If you have a good idea that your value will be different (maybe due to a really high-efficiency inverter) you may reduce this value a little.



Mounting position

Fixed mounting options

Mounting position *

Free-standing

Slope [°]*

35

Free-standing

Azimuth [°]*

0

Building integrated

Mounting position

For fixed (non-tracking) systems, the way the modules are mounted will have an influence on the temperature of the module, which in turn affects the efficiency. Experiments have shown that if the movement of air behind the modules is restricted, the modules can get considerably hotter (up to 15°C at 1000W/m² of sunlight).

In the application there are two possibilities: *free-standing*, meaning that the modules are mounted on a rack with air flowing freely behind the modules; and *roof added / building-integrated*, which means that the modules are completely built into the structure of the wall or roof of a building, with little or no air movement behind the modules.

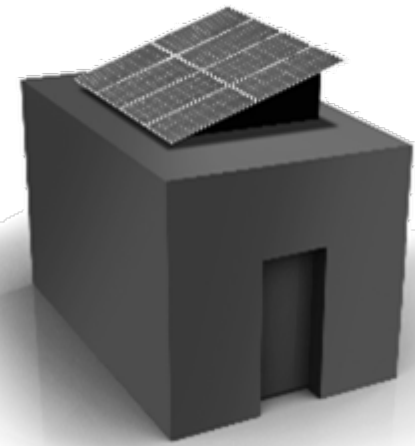
Some types of mounting are in between these two extremes, for instance if the modules are mounted on a roof with curved roof tiles, allowing air to move behind the modules. In such cases, the performance will be somewhere between the results of the two calculations that are possible here. For such cases, to be conservative, the roof added / building integrated option can be used.



Solar in-roof



Solar on-roof



Free-standing



Inclination angle or slope

Orientation angle or azimuth

Inclination angle or slope

Slope [°]*

Azimuth [°]*

Optimize slope

Optimize slope and azimuth

This is the angle of the PV modules from the horizontal plane, for a fixed (non-tracking) mounting.

For some applications the slope and orientation angles will already be known, for instance if the PV modules are to be built into an existing roof. However, if you have the possibility to choose the slope and/or azimuth (orientation), this application can also calculate for you the optimal values for slope and orientation (assuming fixed angles for the entire year).

Orientation angle or azimuth

✕

The azimuth, or orientation, is the angle of the PV modules relative to the direction due South. -90° is East, 0° is South and 90° is West.

For some applications the slope and azimuth angles will already be known, for instance if the PV modules are to be built into an existing roof. However, if you have the possibility to choose the inclination and/or orientation, this application can also calculate for you the optimal values for inclination and orientation (assuming fixed angles for the entire year).

+ lecture notes “Position d’une surface inclinée”



Installation

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

↓ csv

↓ json

Parcourir...

Aucun fichier sélectionné.

GRID CONNECTED



PERFORMANCE OF GRID-CONNECTED PV



TRACKING PV

OFF-GRID

MONTHLY DATA

DAILY DATA

HOURLY DATA

TMY

Solar radiation database*

PVGIS-SARAH

PV technology*

Crystalline silicon

Installed peak PV power [kWp]*

4.374

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]



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V. Production



Monthly in-plane radiation

PERFORMANCE OF GRID-CONNECTED PV: RESULTS

PV output **Radiation** Info PDF

Summary

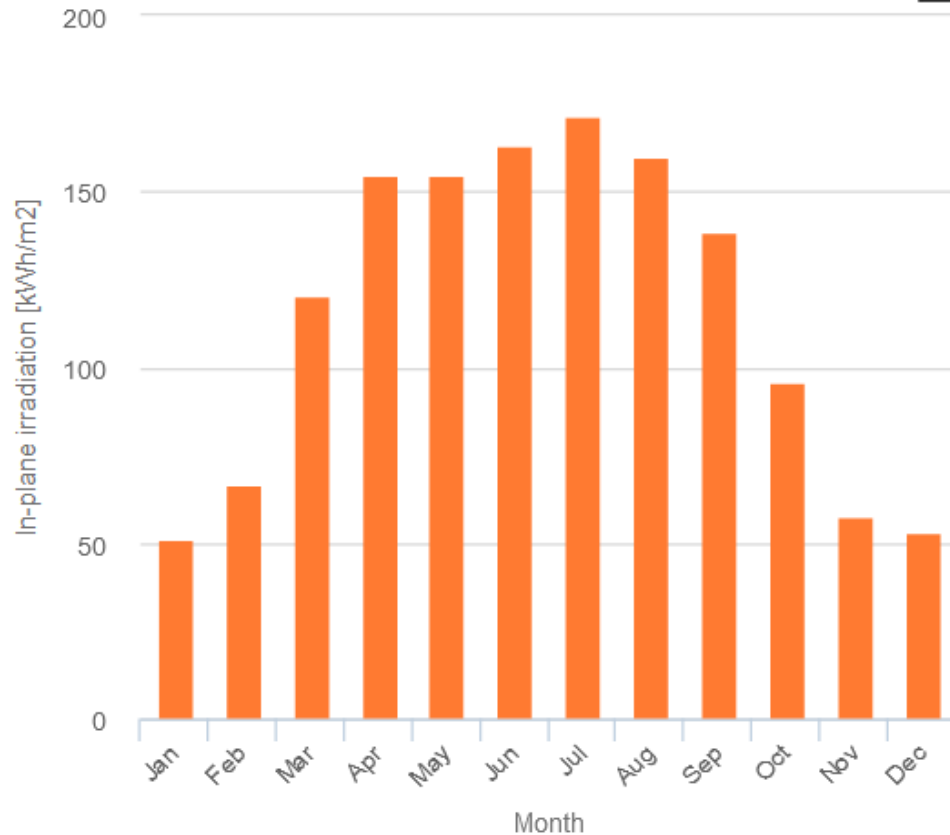
Provided inputs:

Location [Lat/Lon]:	48.709, 2.165
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	4.374
System loss [%]:	14

Simulation outputs:

Slope angle [°]:	38 (opt)
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	4883.69
Yearly in-plane irradiation [kWh/m²]:	1386.48
Year-to-year variability [kWh]:	208.27
Changes in output due to:	
Angle of incidence [%]:	-2.98
Spectral effects [%]:	1.66
Temperature and low irradiance [%]:	-5.06
Total loss [%]:	-19.47

Monthly in-plane irradiation for fixed angle



Monthly energy output

PERFORMANCE OF GRID-CONNECTED PV: RESULTS

PV output

Radiation

Info

PDF

Summary

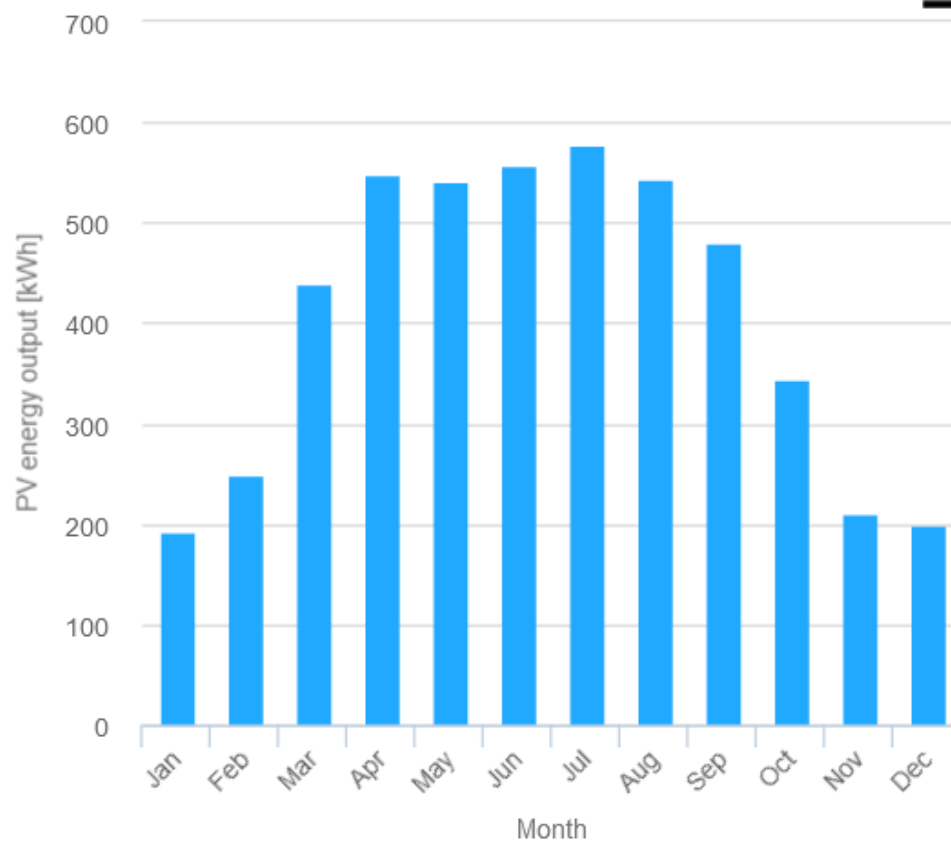
Provided inputs:

Location [Lat/Lon]:	48.709, 2.165
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	4.374
System loss [%]:	14

Simulation outputs:

Slope angle [°]:	38 (opt)
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	4883.69
Yearly in-plane irradiation [kWh/m ²]:	1386.48
Year-to-year variability [kWh]:	208.27
Changes in output due to:	
Angle of incidence [%]:	-2.98
Spectral effects [%]:	1.66
Temperature and low irradiance [%]:	-5.06
Total loss [%]:	-19.47

Monthly energy output from fix-angle PV system





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VI. PV electricity price



Installation

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

↓ csv

↓ json

Parcourir...

Aucun fichier sélectionné.

GRID CONNECTED



PERFORMANCE OF GRID-CONNECTED PV



TRACKING PV

OFF-GRID

MONTHLY DATA

DAILY DATA

HOURLY DATA

TMY

Solar radiation database*

PVGIS-SARAH

PV technology*

Crystalline silicon

Installed peak PV power [kWp]*

4.374

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]



PV system cost

PV system cost



Here you should input the total cost of installing the PV system, including PV system components (PV modules, mounting, inverters, cables etc.) and installation costs (planning, installation....). The choice of currency is up to you, the electricity price calculated by PVGIS will then be the price per kWh of electricity in the same currency you used.

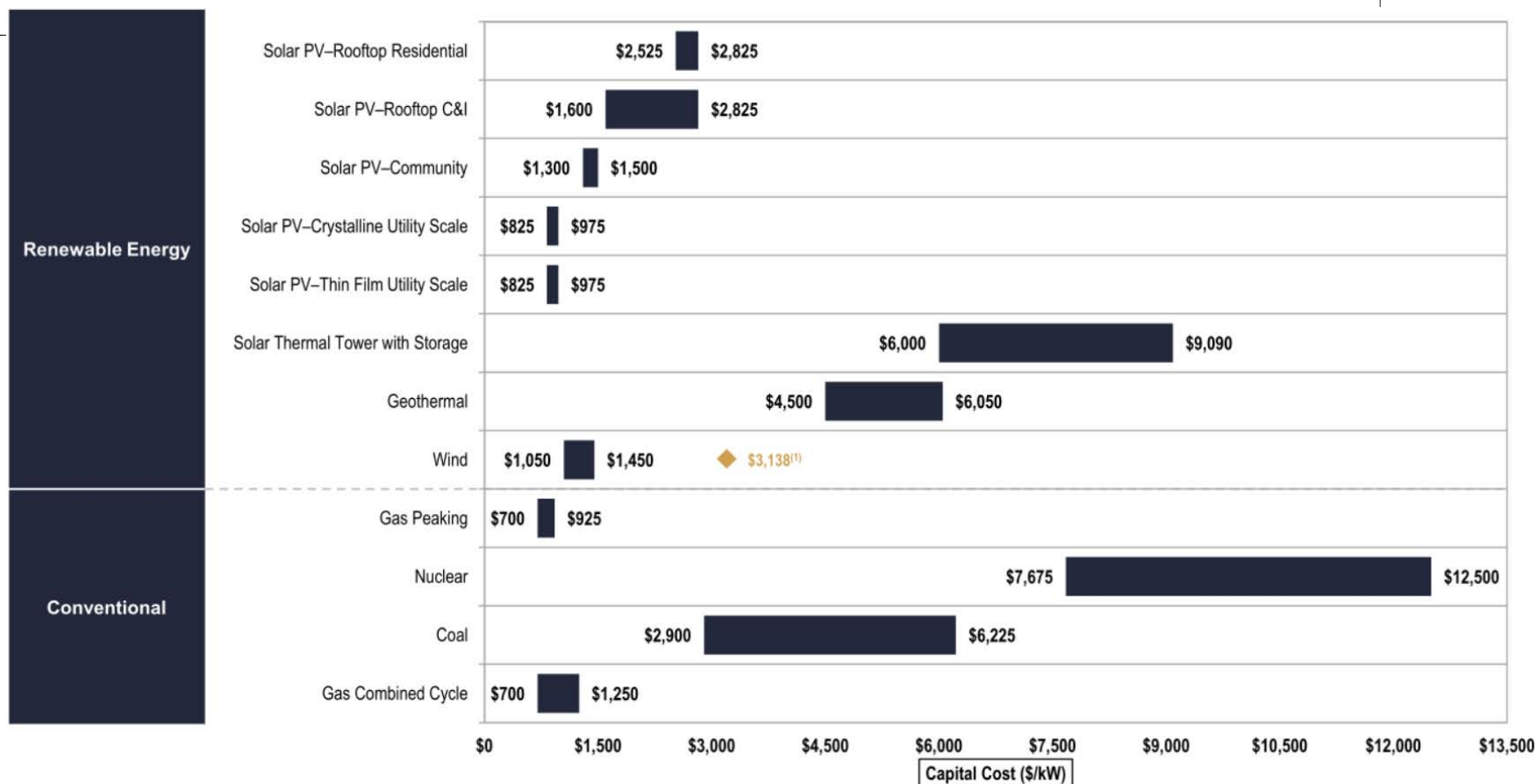


PV system cost

PV system cost



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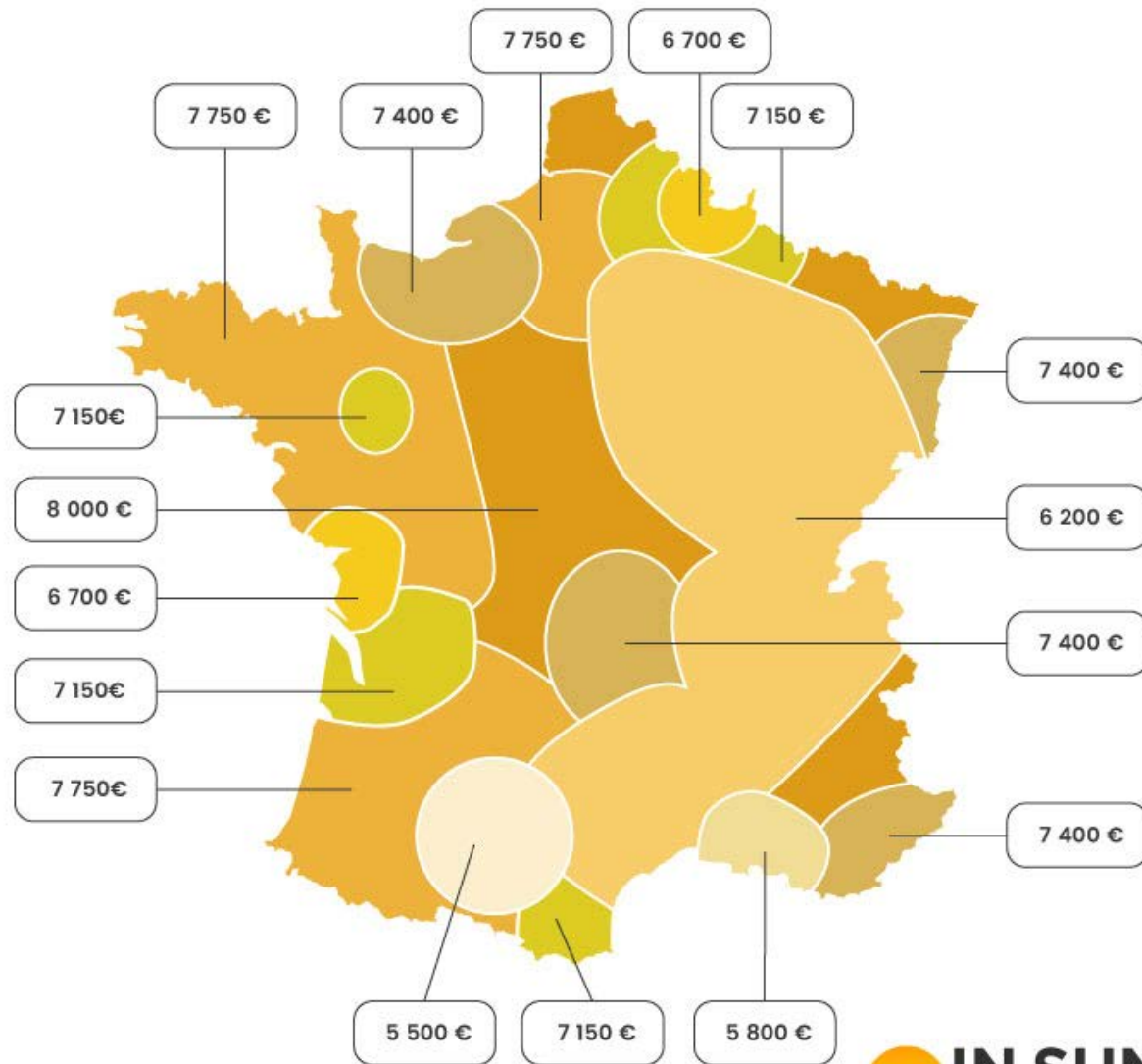
PV system cost

PV system cost

Here you should input the total cost of in mounting, inverters, cables etc.) and install the electricity price calculated by PVGIS will

Ask for an invoice !

Prix d'une installation photovoltaïque de 3 kWc par In Sun We Trust en 2021 :





Interest

Interest rate



This is the interest rate you pay on any loans needed to finance the PV system. This assumes a fixed interest rate on the loan which will be paid back in yearly installments for the lifetime of the system.



Lifetime

PV system lifetime



This is the expected lifetime of the PV system in years. This is used to calculate the effective electricity cost for the system. If the PV system happens to last longer the electricity cost will be correspondingly lower

PV electricity price

Cursor:

Selected: 48.709, 2.165

Elevation (m): 166

Use terrain shadows:

Calculated horizon

Upload horizon file

↓ csv

↓ json

Parcourir...

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Solar radiation database*

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PV technology*

Crystalline silicon

Installed peak PV power [kWp]*

4.374

System loss [%]*

14

Fixed mounting options

Mounting position *

Free-standing

Slope [°]*

35

Azimuth [°]*



PV electricity price

PV system cost (your currency)*

9050

Interest [%/year]*

2

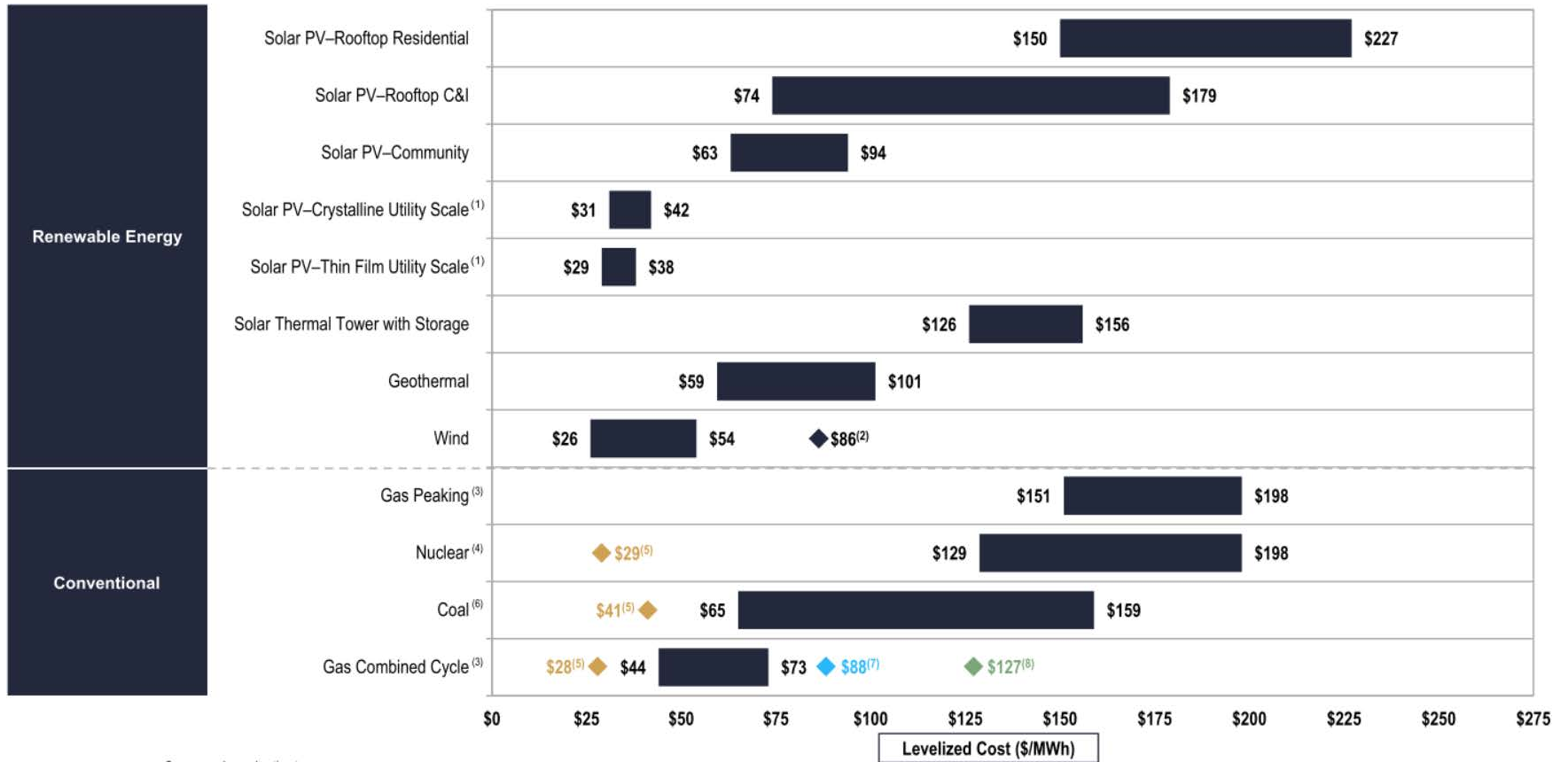
Lifetime [years]*

20



Results

PV electricity cost : 0.150 €/kWh = 150 €/MWh



Source: Levelized estimates



But ... is it worth it ?

Puissance de l'installation photovoltaïque	Montant de l'aide versé pour chaque kWc installé
≤ 3 kWc	380 €
≤ 9 kWc	280 €
≤ 36 kWc	160 €
≤ 100 kWc	80 €

Prime à l'autoconsommation

Puissance de votre installation solaire	Tarif en vente totale (€/kWh)
≤ 3 kWc	0,1779
≤ 9 kWc	0,1512
≤ 36 kWc	0,1095
≤ 100 kWc	0,0952

Tarif rachat en vente totale

Source:

Prime à l'autoconsommation >> <https://www.insunwetrust.solar/blog/le-solaire-et-vous/autofinancement-panneau-solaire/>

Tarif de rachat en vente totale >> <https://www.insunwetrust.solar/blog/le-solaire-et-vous/tarif-rachat-photovoltaique/>



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Conclusion



Conclusion

- 1) Understand the link between climate and intermittent renewable energy sources
- 2) Use climate models to assess the potential of solar PV rooftop residential
- 3) Learn some stuffs about PV (incidentally) and techno-economic analysis