Specificity of solar micro grids in island areas

SESSION 2

Access to electricity

Solar resource

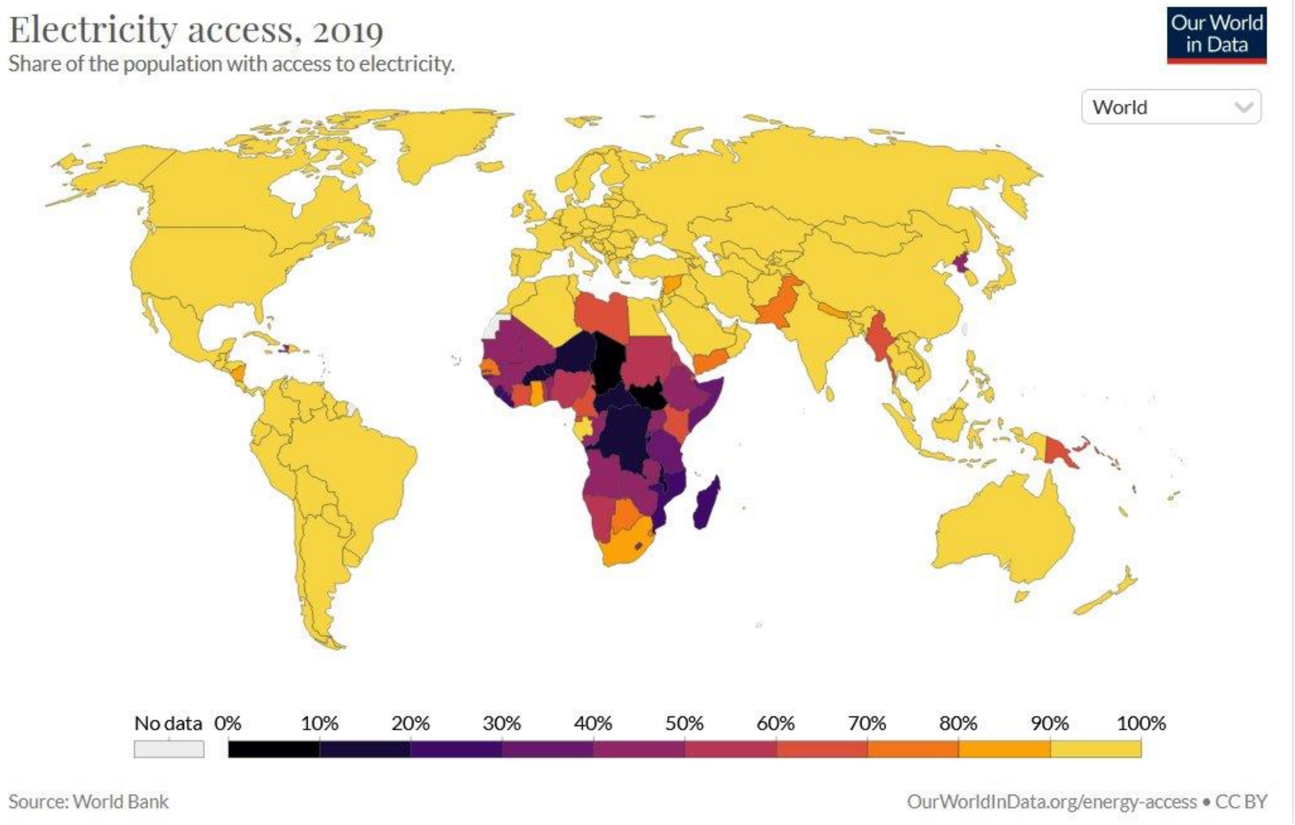
Micro grids as a solution

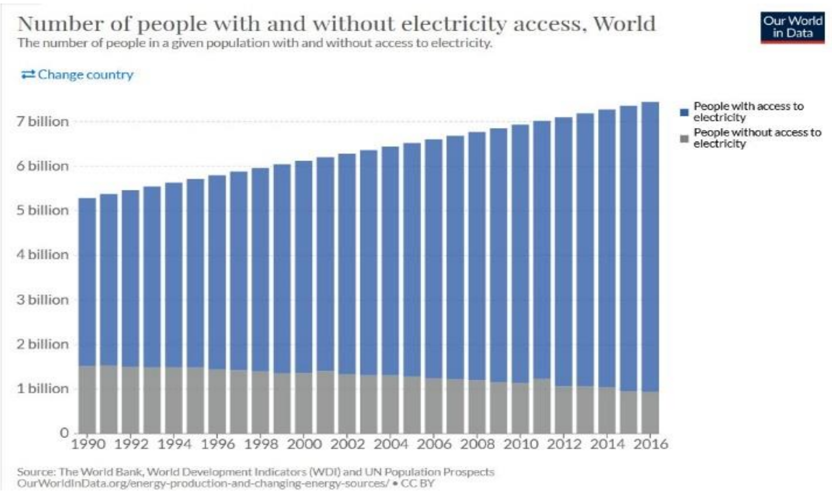
The MYRTE and PAGLIA ORBA platforms installed on the University of Corsica-CNRS site are among the rare installations in the world capable of studying the coupling of renewable energies and storage (H2) in real conditions.

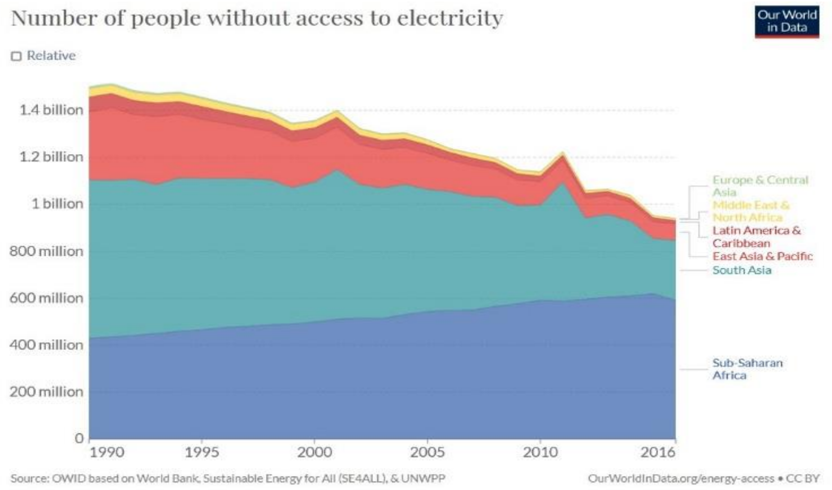
Francis DOMAIN & Olivier VERDEIL - Solar Photovoltaic Experts and Trainers at INES Online Training – November 2021

Specificity of solar micro grids in island areas

Electricity access in the world







In 2016, 940 million people (13%) do not have access to electricity , compared to 29% in 1990.

(Source : https://ourworldindata.org/energy-access)

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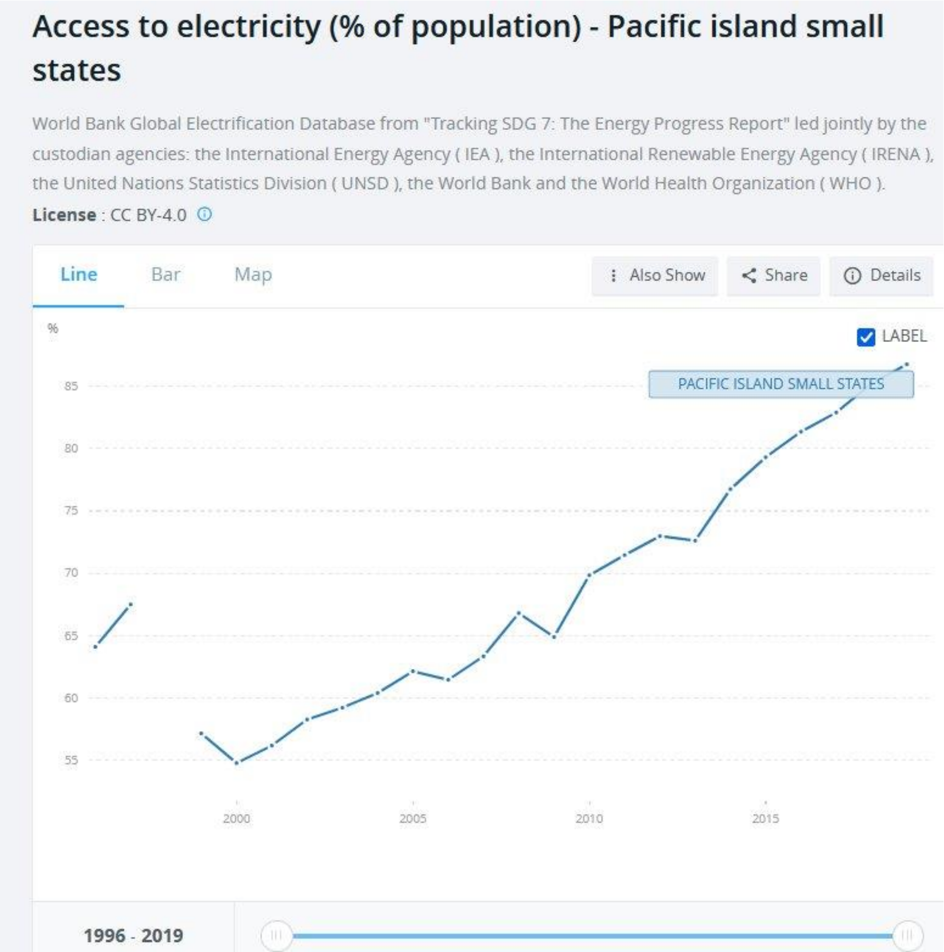
Following the website :

https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?end=2019&locations=S2&start=1996&view=chart

In the Pacific island small states , 95% of urban population have access to electricity and 81% of the rural population have access to electricity in 2019



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Following the website :

https://council.science/current/blog/the-drivers-of-a-clean-energy-transition-in-pacific-island-countries/

98% of the population of Tonga Islands have access to electricity,

but only 20% of renewable origin for this website

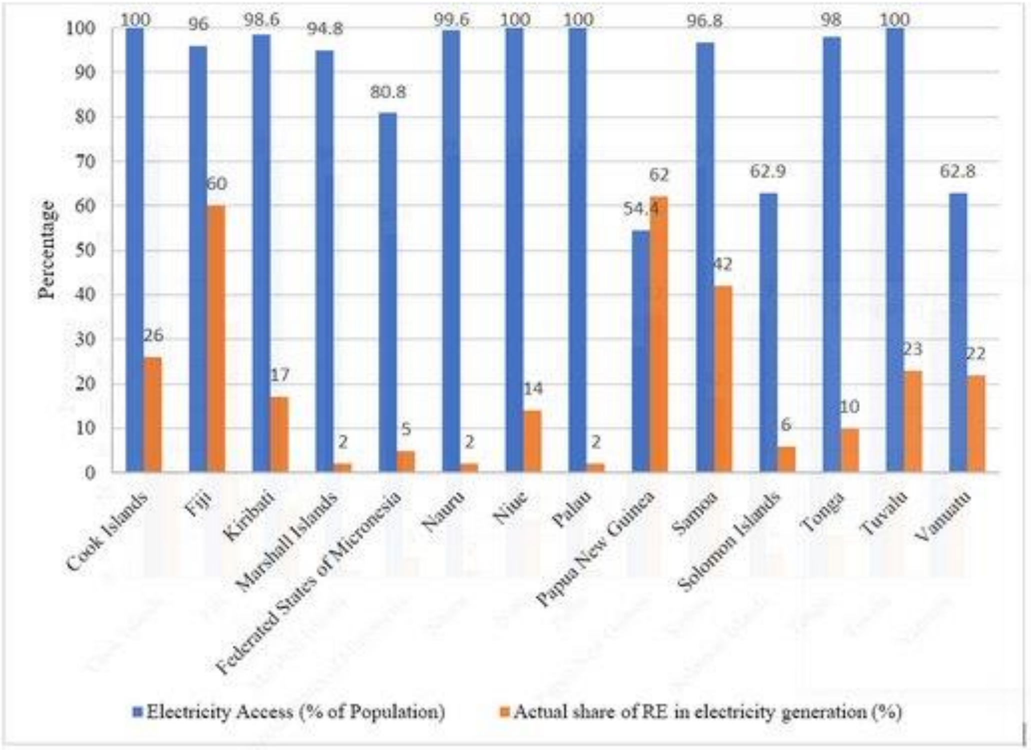

Figure 3: Renewable share in electricity generation and electricity access in PICs. (Data Source: SPREP)

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Always for the Tonga islands,
electricity is 74% of fossil origin (generator)
and 26% of renewable origin (solar, wind or biomass)

Energy source	total in Tonga	percentage in Tonga	percentage USA	per capita in Tonga	per capita USA
Fossil fuels	131.59 m kWh	74,0 %	70,0 %	1,245.00 kWh	20,230.06 kWh
Nuclear power	0.00 kWh	0,0 %	9,0 %	0.00 kWh	2,601.01 kWh
Water power	0.00 kWh	0,0 %	7,0 %	0.00 kWh	2,023.01 kWh
Renewable energy	46.24 m kWh	26,0 %	14,0 %	437.43 kWh	4,046.01 kWh
Total production capacity	177.83 m kWh	100,0 %	100,0 %	1,682.43 kWh	28,900.09 kWh
Actual total production	52.00 m kWh	29.2 %	43.0 %	491.97 kWh	12,428.52 kWh

https://www.worlddata.info/oceania/tonga/energy-consumption.php

Specificity of solar micro grids in island areas

The Tonga Islands are rather well electrified
but with regard to global warming and rising sea levels,
it is urgent to change from fossil energies to renewable energies , as commented below

https://council.science/current/blog/the-drivers-of-a-clean-energy-transition-in-pacific-island-countries/

The recent report of the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 finds that global temperatures are set to exceed 1.5°C of warming earlier than previously projected, and that if greenhouse gas emissions do not start to decline significantly before 2050, the world is extremely likely to reach 2°C warming during the 21st century.

What does this mean for the Pacific Island Countries (PICs)? Raise the alarm! Pacific Island Countries are on the frontlines of severe climate change, with food, housing, businesses and industries all at risk of increasingly frequent extreme climatic events such as sea level rise, tropical cyclones, and flash flooding. However, despite having miniscule greenhouse gas (GHG) emissions, PICs have made bold, ambitious targets to reduce emissions and to promote sustainable and resilient development across all sectors of the economy. They set an example to the other world leaders that the PICs are committed to global emission reductions, and that all contributions matter.

First of all, the main driver for this clean energy transition is having experienced severe and intense natural disasters that cause inestimable damage to communities and economies. Clean energy holds promise for building back better in a more resilient and sustainable manner. In February 2016 Fiji experienced its worst tropical cyclone (TC), TC Winston, a category 5 cyclone which caused havoc when it made landfall amongst the small islands of Fiji, with around 40% of the population impacted by the storm. A total of 44 people lost their lives, and 40,000 homes were damaged or destroyed, leading to shock and negative psychological impacts in the communities affected. Power infrastructure and the forestry and agriculture sectors were also severely affected, with the total damage amounting to FJ$2.98 billion (US$ 1.4 billion). More recently, while battling the COVID-19 pandemic, the PICs have been burdened with the additional challenge of severe tropical cyclones. The category 5 TC Harold hit Vanuatu on 6 December 2020, causing massive destruction to buildings, water sources and agriculture, affecting 33% of the population and claiming the lives of 31 people in the region.

renewable energies are available depending on the site on earth

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Means of producing electricity in rural areas

Diesel generator set:

Micro hydro electricity (Nam Ou River, Laos) :

Small wind turbine :

Small photovoltaic system (Sahara, Algeria) :

Renewable energies are available depending on the site on earth

Specificity of solar micro grids in island areas

The solar resource

What about ?

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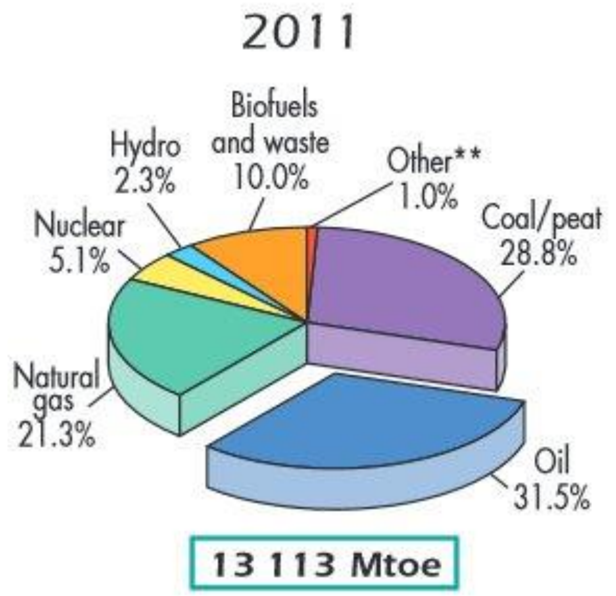
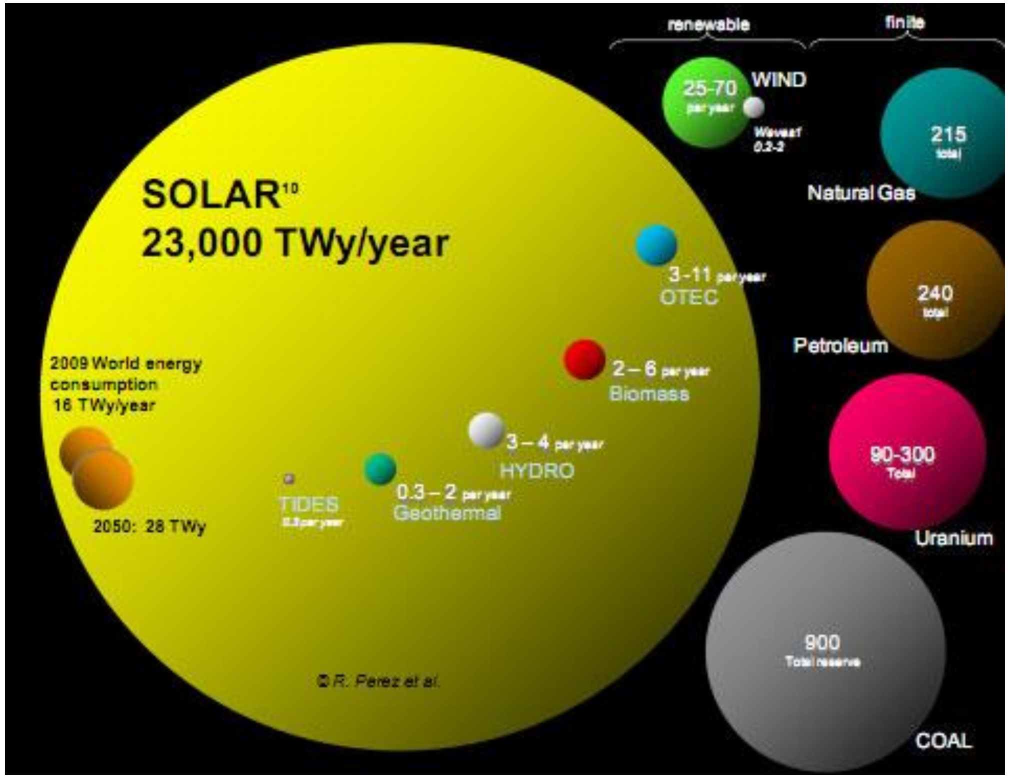
The Earth receives 10,000 times the annual human energy consumption from the Sun per year

Human energy consumption:



Source: AIE

Energy resource available:



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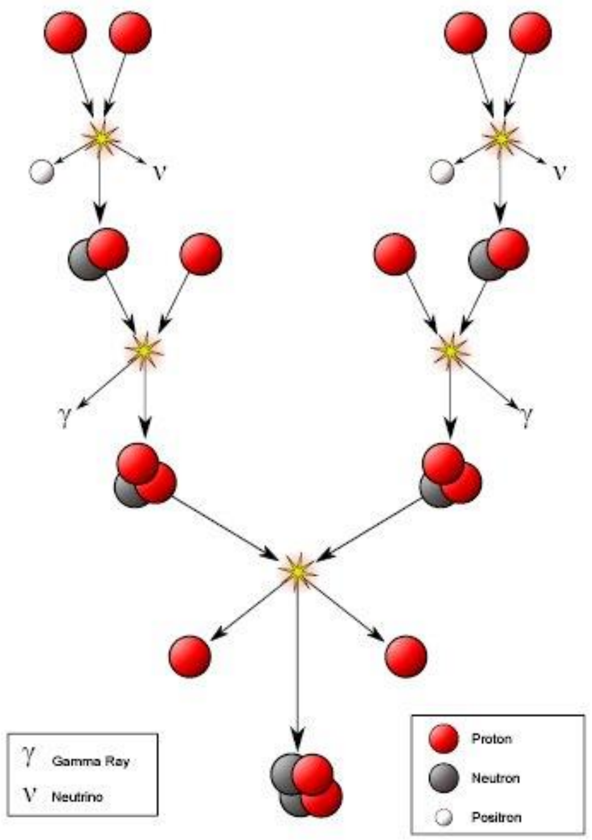
The Sun and the thermo nuclear reactions



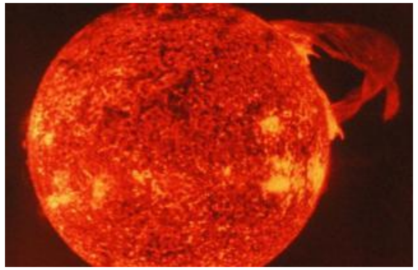
638 million tons of hydrogen are converted into 634 million tons of helium per second in the center of the Sun

The difference (4.26 million tons), is transformed into energy in accordance with Albert Einstein's famous equation :

$$E = mc^2$$

The energy released is emitted into space as light radiation with a power of $3{,}84.10^{26}$ Watts.

At the level of the planet earth, the power of solar radiation outside the atmosphere is I0 = 1 367 W / m²



The solar resource is a function of astronomical data Day / night alternation Seasonal effect with declination (23.45 °) Latitude of the site

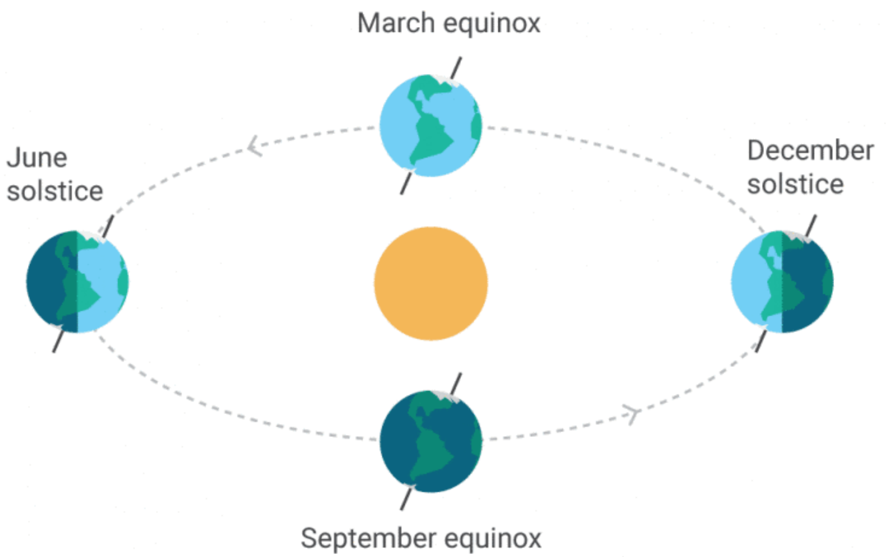
Specificity of solar micro grids in island areas

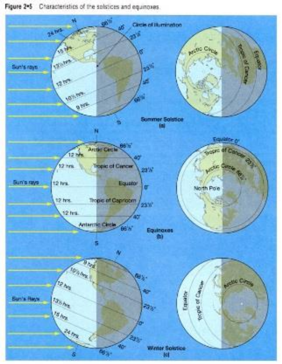
The solar resource is a function of astronomicals datas :

Day-night (due to the earth rotation)

Seasonal effect with declination (23.45 °)

Latitude of the site





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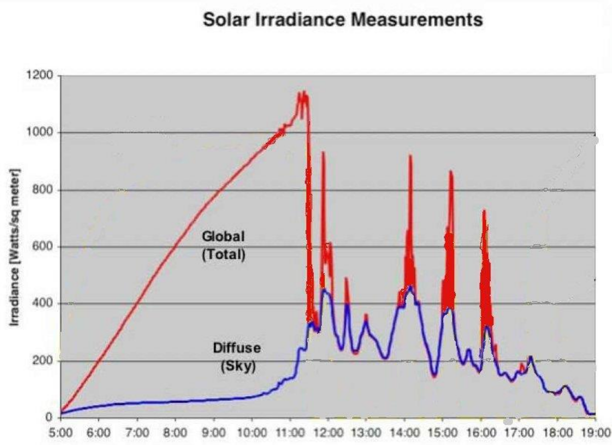
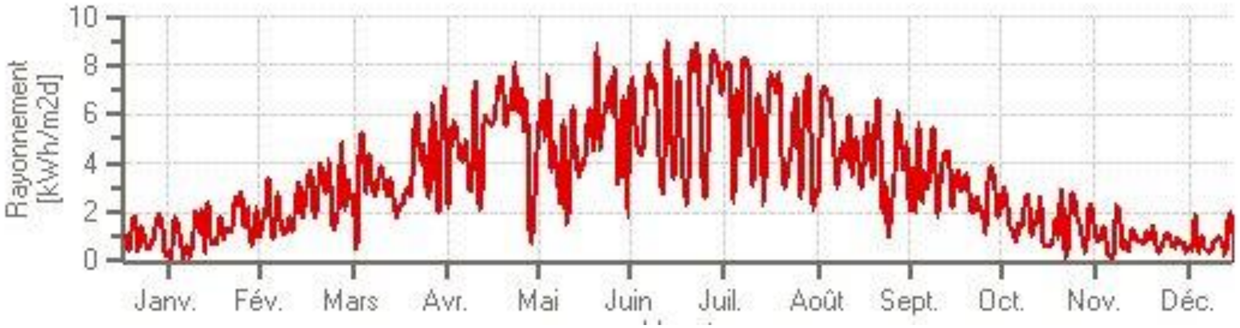
Solar data measurement (weather conditions)



	Clear sky:	Overcast sky:	Dark overcast sky:
Irradiance	1,000 W/m²	100 W/m²	10 W/m²





	Solar radiation integrated on a day	Solar radiation integrated on a year
Irradiation	0 to 8 kWh/m²	500 to 2,500 kWh/m²

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Definitions of Terms

- Solar Irradiance- It's the rate at which the sun's energy strikes an area at any given moment. It's expressed in W/m^2 or kW/m^2

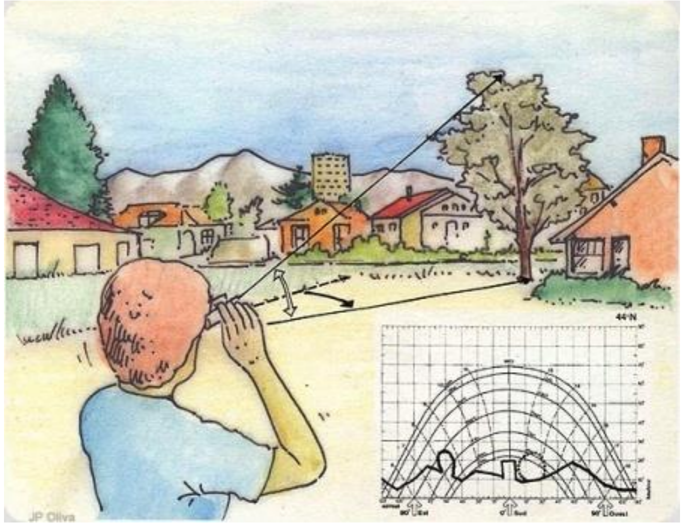
- Solar Irradiation- Is the accumulated amount of suns energy that strikes an area over a period of time. It's irradiance accumulated over time and expressed in Wh/m^2 or kWh/m^2

- Peak Sun Hours- Is the number of hours at a given irradiance of $1kW/m^2$. It is expressed in hours

Specificity of solar micro grids in island areas

Solar resource : the sun path mask , distant like montains or close like cocconut trees

Purpose of solar paths: trace solar mask distant to determine the available solar energy by software



Original Source: www.solmetic.com

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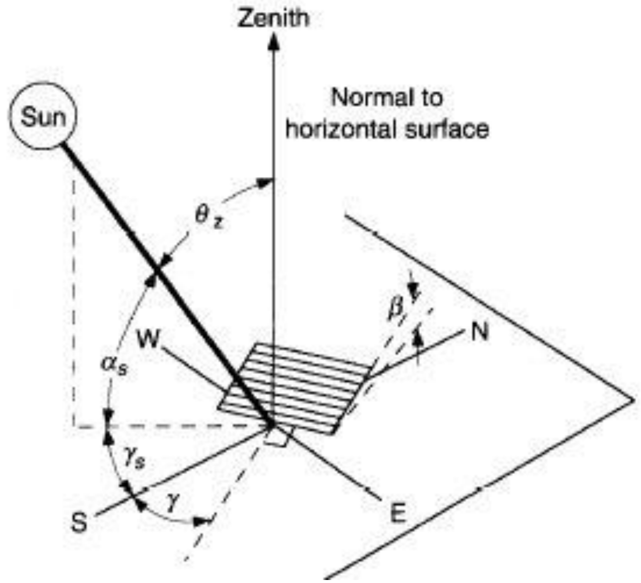
Solar resource is function the tilt and the orientation:

Optimum orientation: south if you are in the north hemisphere (or north if you are in the southern hemisphere)



Optimum tilt: 2 cases

- Maximize energy production during the year (on grid)
  tilt of 30° for France
- Maximize energy production for the worst month (off grid)
  tilt of 60° for France

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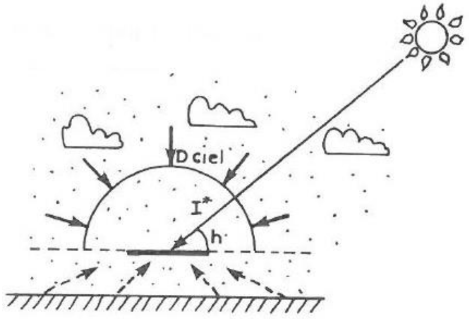
Solar resource : Global irradiation, direct irradiation or beam, diffuse irradiation

albedo and reflective irradiation

At ground level, on a horizontal plane,
the irradiance (W/m²) and the irradiation (Wh/m) is the sum:
- a direct part from the Sun
- a diffuse part from the sky dome (2 π steradians)

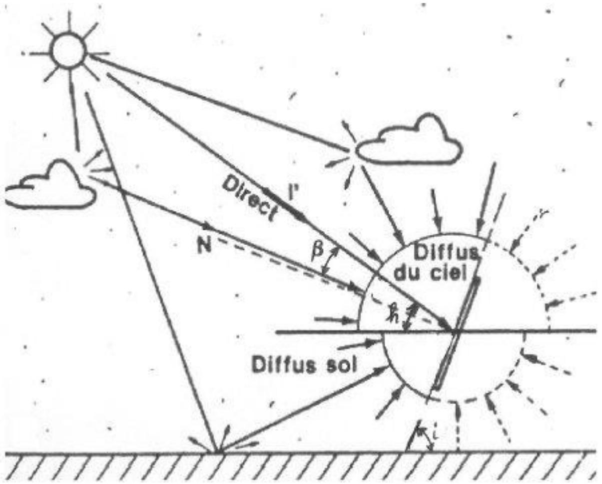
$$Igh = Ibh + Idh$$



Surface horizontale

At ground level, on a tilted plane,
the irradiance (W/m²) and the irradiation (Wh/m) is the sum:
- a direct part from the Sun
- a diffuse part from the sky dome (< 2 π steradians)
- a reflected part from the Earth dome (0 to 2 π steradians)

$$Igp = Ibp + Idp + Irp$$



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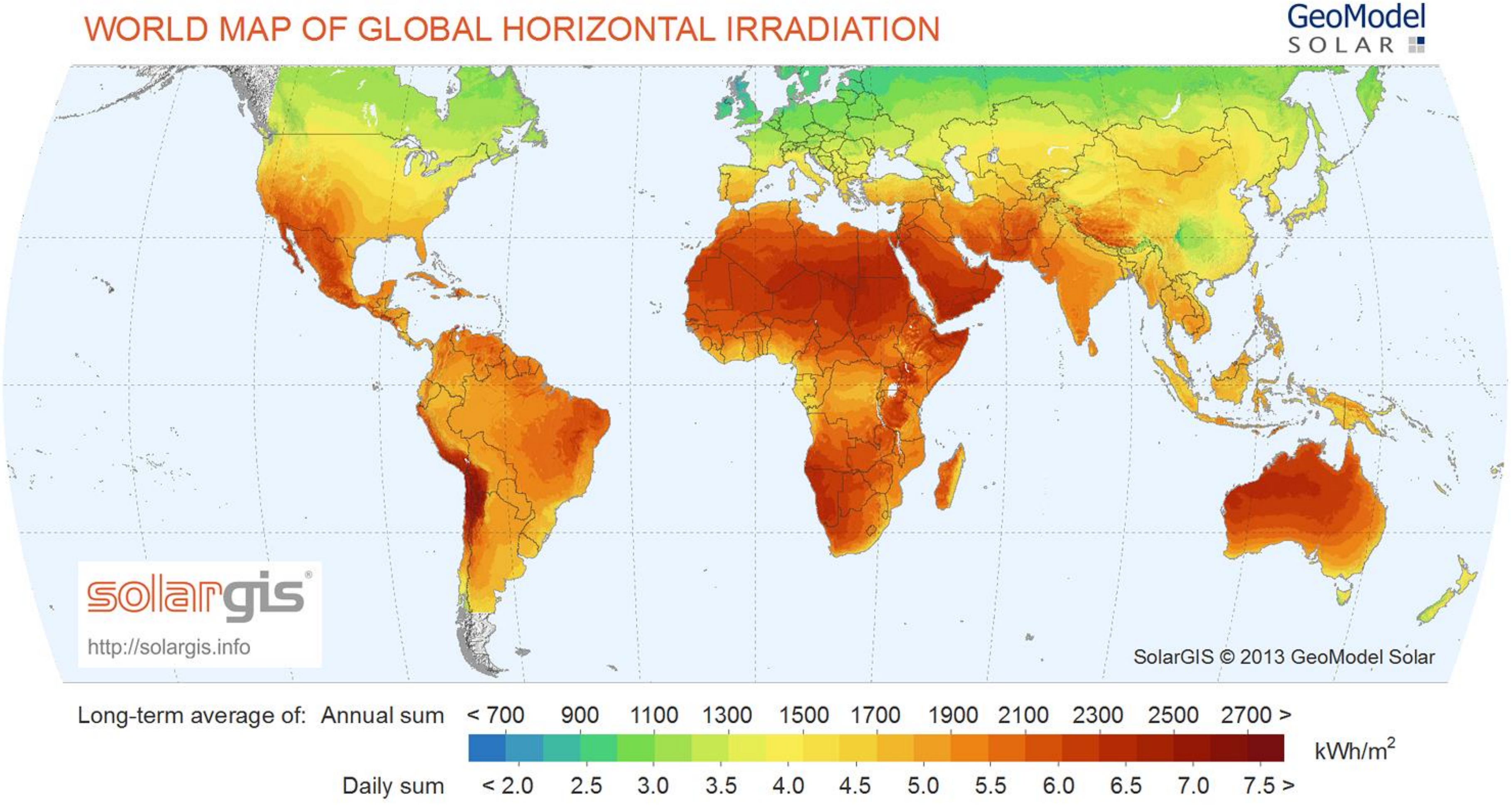

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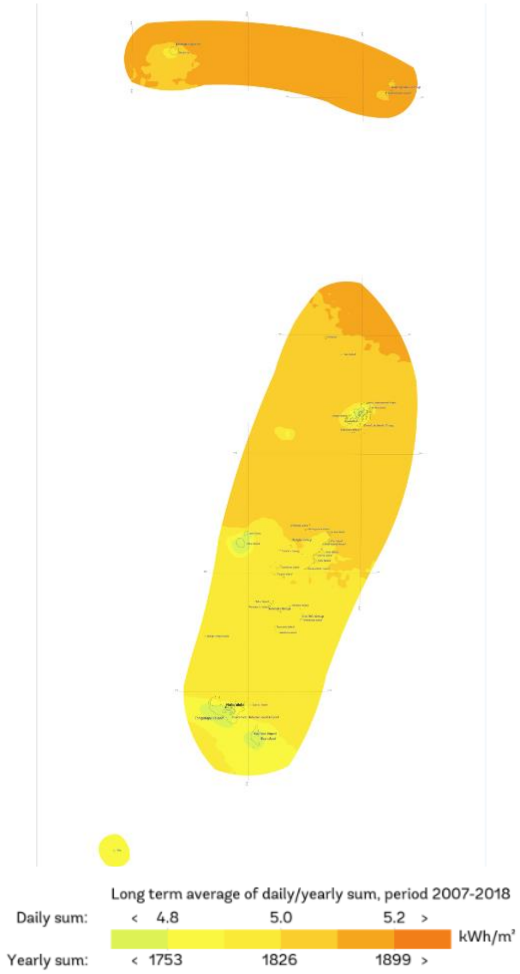
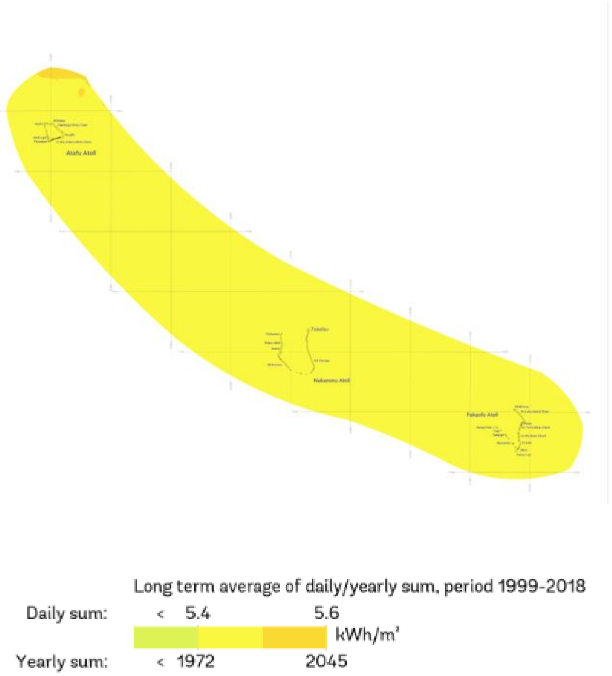
GLOBAL HORIZONTAL IRRADIATION

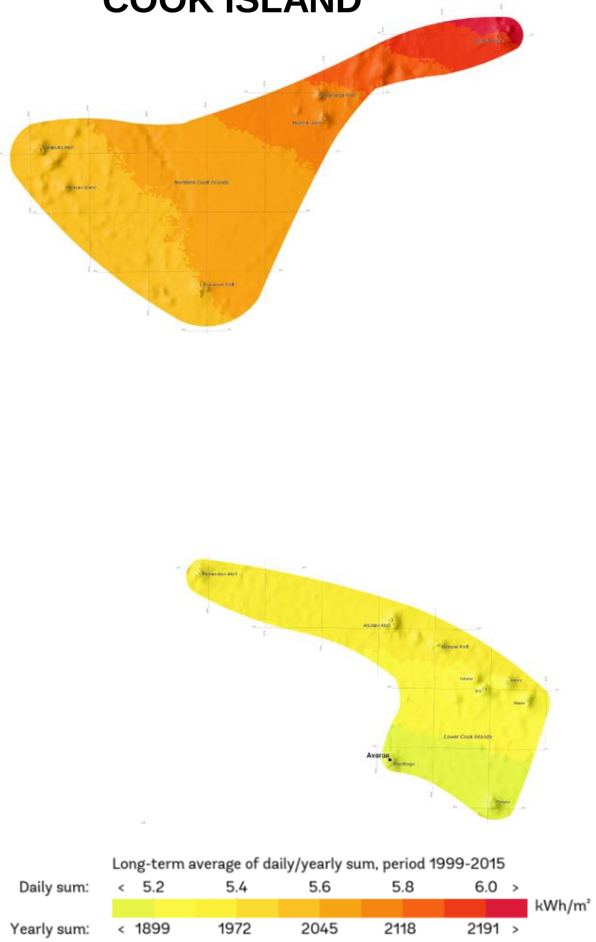
TONGA ISLANDS



TOKELAU ISLANDS



COOK ISLAND



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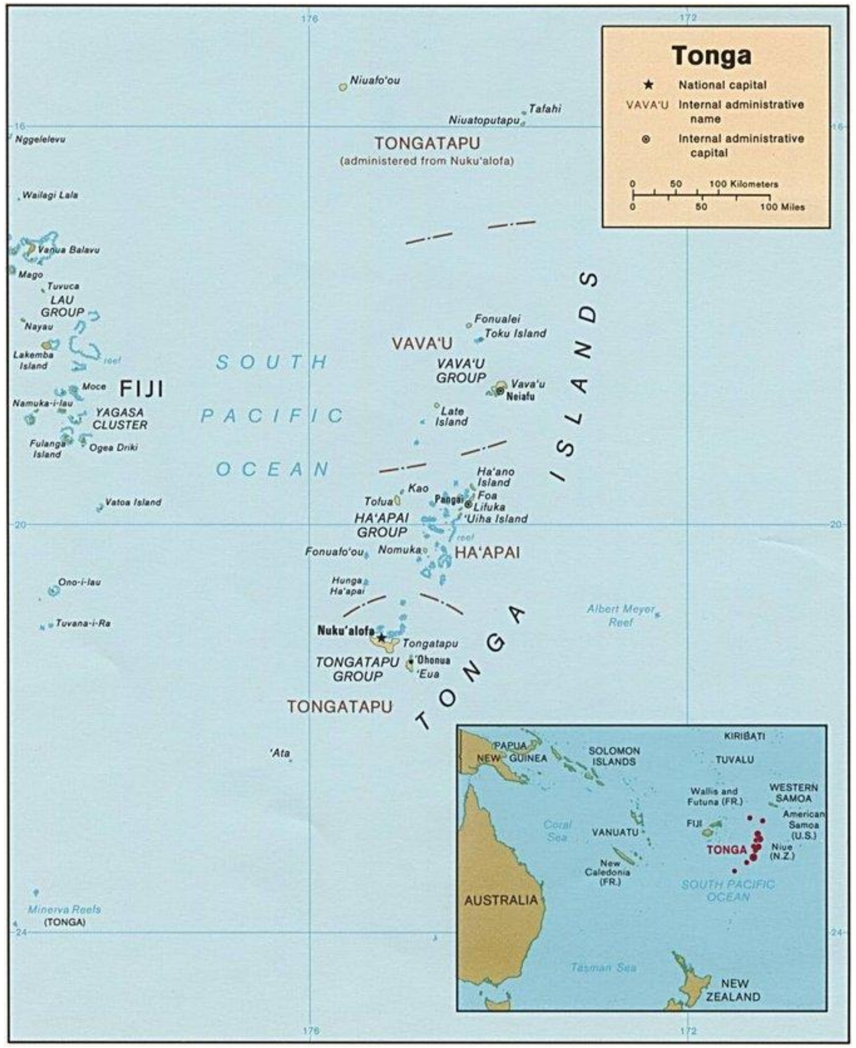
Example for Tonga Islands solar irradiation

Longitude : 172 – 176 ° W
Latitude : 15 – 22° S
Time zone : UTC+13

Capital : Nuku'Alofa
Longitude : 175° 12' 06" W (-175.2018°)
Latitude : 21° 08' 21" S (-21.13938°)
Elevation : 5 m

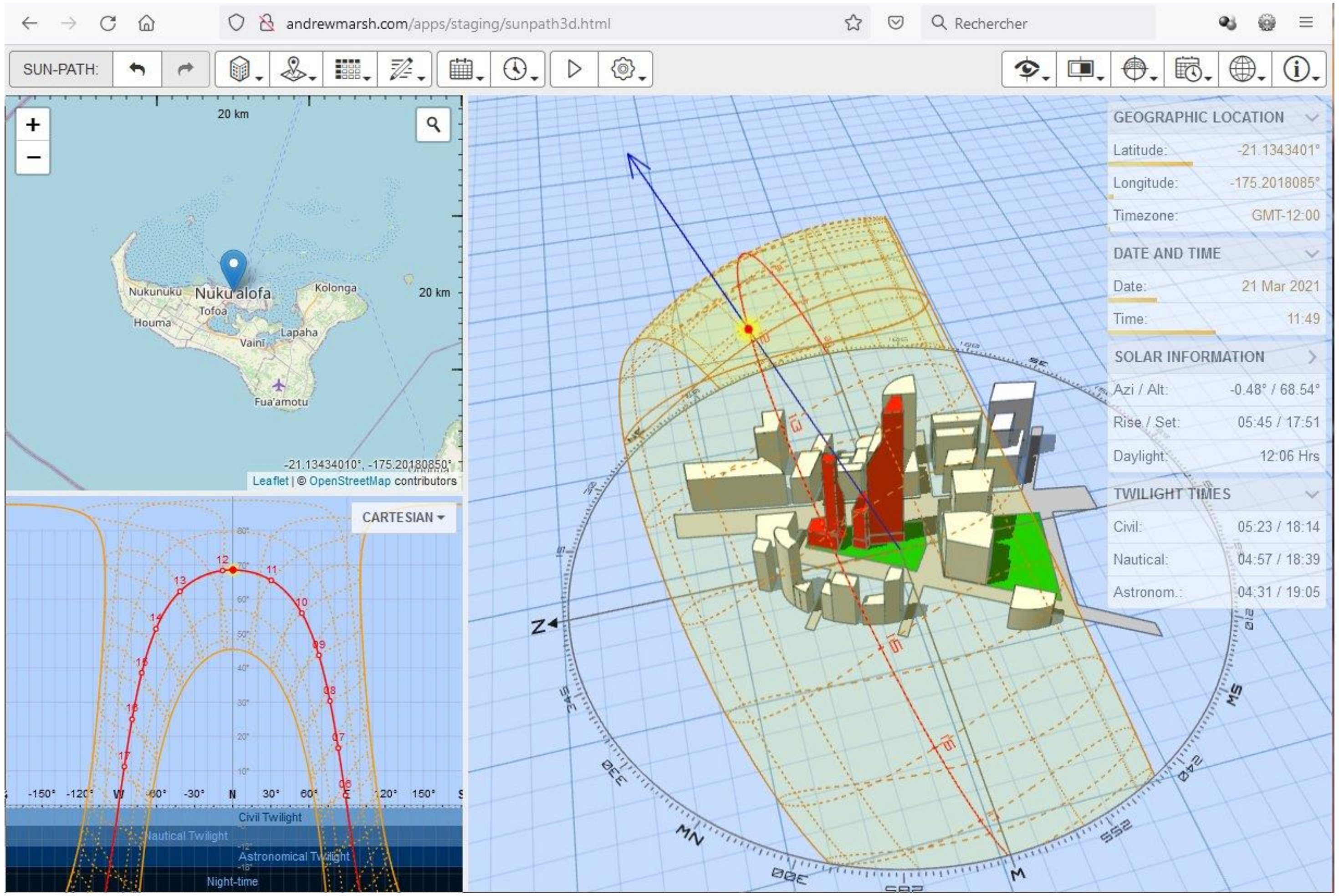


Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

Sun position

Rise time
Set time
Daylight
Sun path



(Source : http://andrewmarsh.com/apps/staging/sunpath3d.html)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

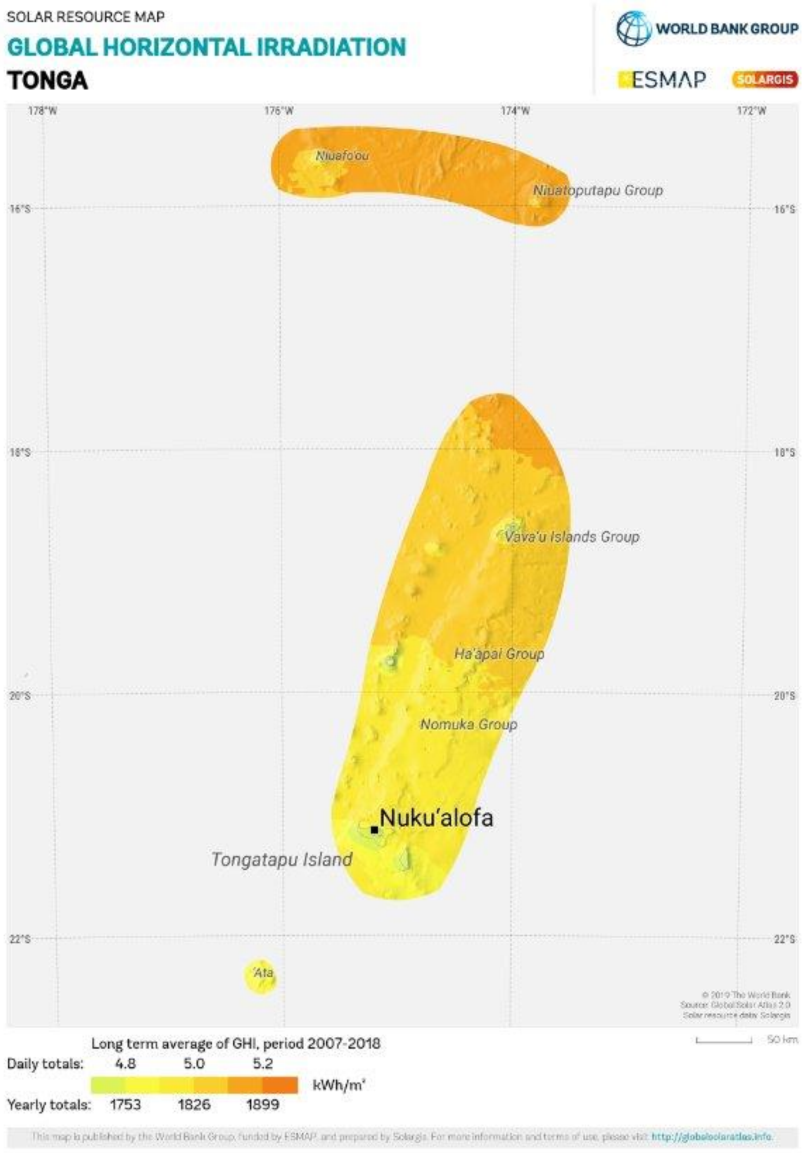
Solargis datas

GHI = 1 753 kWh/m² per year

This solar resource map provides a summary of the estimated solar energy available for power generation and other energy applications. It represents the average daily/yearly sum of global horizontal irradiation (GHI) covering a period of 12 recent years (2007-2018). The underlying solar resource database is calculated by the Solargis model from atmospheric and satellite data with 30-minute time step. The effects of terrain are considered at nominal spatial resolution of 250 m.

There is some uncertainty in the yearly GHI estimate as a result of limited potential for regional model validation due to a lack of high quality ground measurement data, which is estimated to vary regionally from approx. 6% to 9%.

GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies.



(Source : https://solargis.com/maps-and-gis-data/download/tonga)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

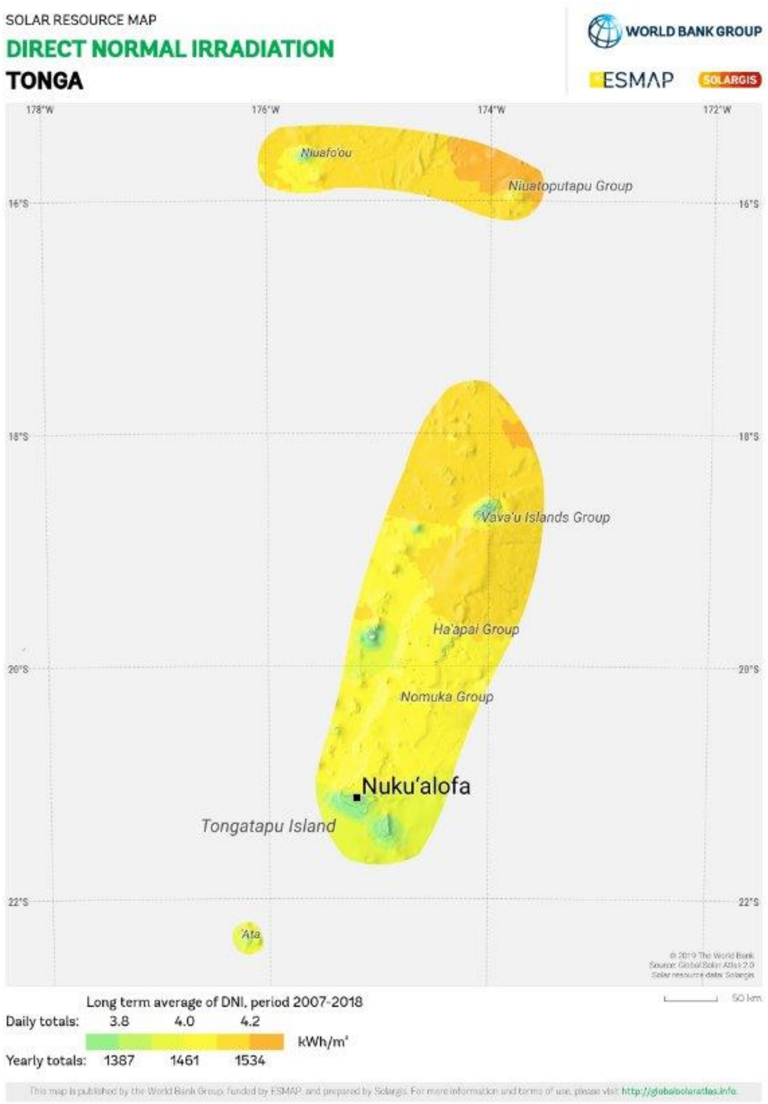
Solargis datas

DESCRIPTION

This solar resource map provides a summary of the estimated solar energy available for power generation and other energy applications. It represents the average daily/yearly sum of direct normal irradiation (DNI) covering a period of 12 recent years (2007-2018). The underlying solar resource database is calculated by the Solargis model from atmospheric and satellite data with 30-minute time step. The effects of terrain are considered at nominal spatial resolution of 250 m.

There is some uncertainty in the yearly DNI estimate as a result of limited potential for regional model validation due to a lack of high quality ground measurement data, which is estimated to vary regionally from approx. 8% to 15%.

DNI is the most important parameter for energy yield calculation and performance assessment of concentrating solar power (CSP) and concentrator solar photovoltaic (CPV) technologies. DNI is also important for the calculation of global irradiation received by tilted or sun-tracking photovoltaic modules.



(Source : https://solargis.com/maps-and-gis-data/download/tonga)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

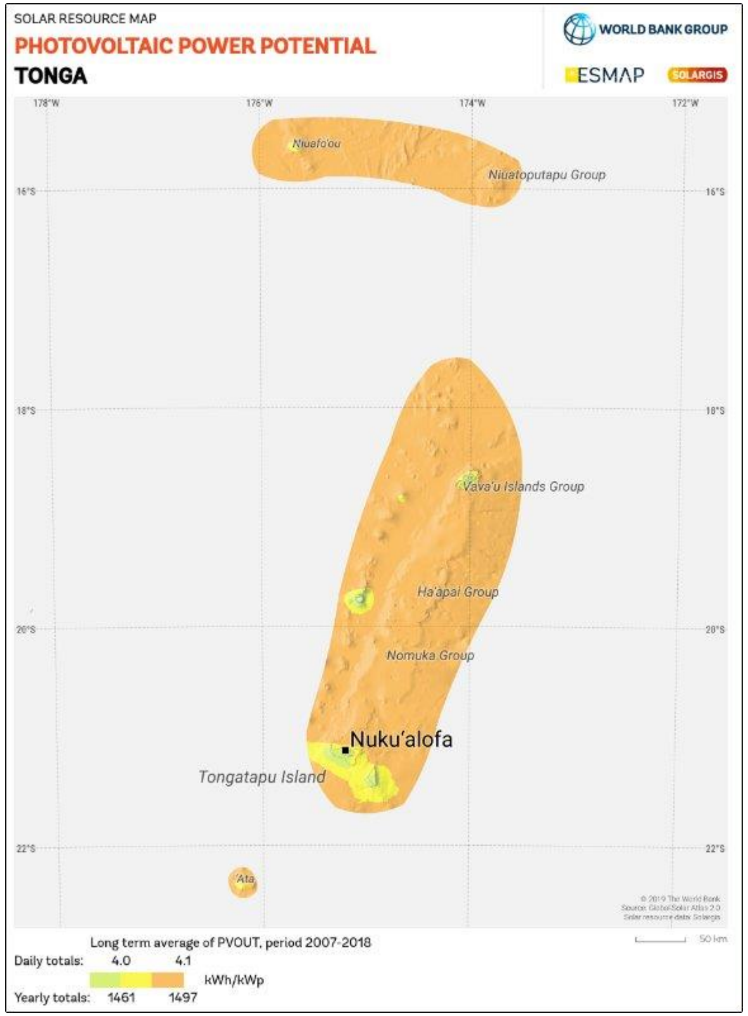
Solargis datas

PV production = 1 461 kWh per year

This solar resource map provides a summary of estimated solar photovoltaic (PV) power generation potential. It represents the average daily/yearly totals of electricity production from a 1 kW-peak grid-connected solar PV power plant, calculated for a period of 12 recent years (2007-2018).

The PV system configuration consists of ground-based, free-standing structures with crystalline-silicon PV modules mounted at a fixed position, with optimum tilt to maximize yearly energy yield. The optimum tilt ranges from 15° to 19° towards the equator. Use of high efficiency inverters is assumed. The solar electricity calculation is based on high-resolution solar resource data and PV modeling software provided by Solargis. The calculation takes into account solar radiation, air temperature, and terrain, to simulate the energy conversion and losses in the PV modules and other components of a PV power plant. In the simulation, losses due to dirt and soiling was estimated to be 3.5%. The cumulative effect of other conversion losses (inter-row shading, mismatch, inverters, cables, transformer, etc.) is assumed to be 7.5%. The power plant availability is considered to be 100%.

The underlying solar resource database is calculated from atmospheric and satellite data with a 30-minute time step, and a spatial resolution of 1000 m.



(Source : https://solargis.com/maps-and-gis-data/download/tonga)

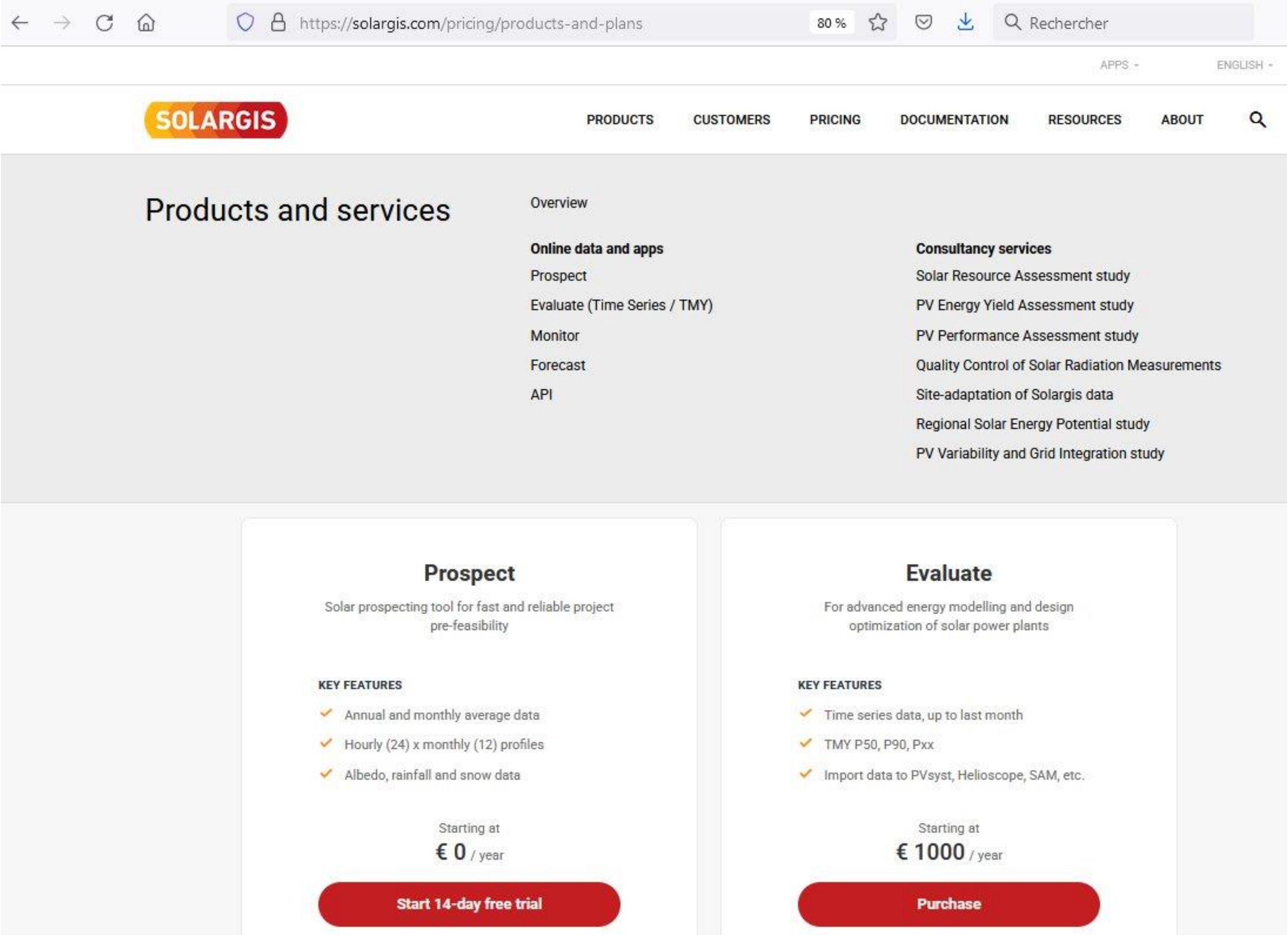
Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

Solargis website

Data provider

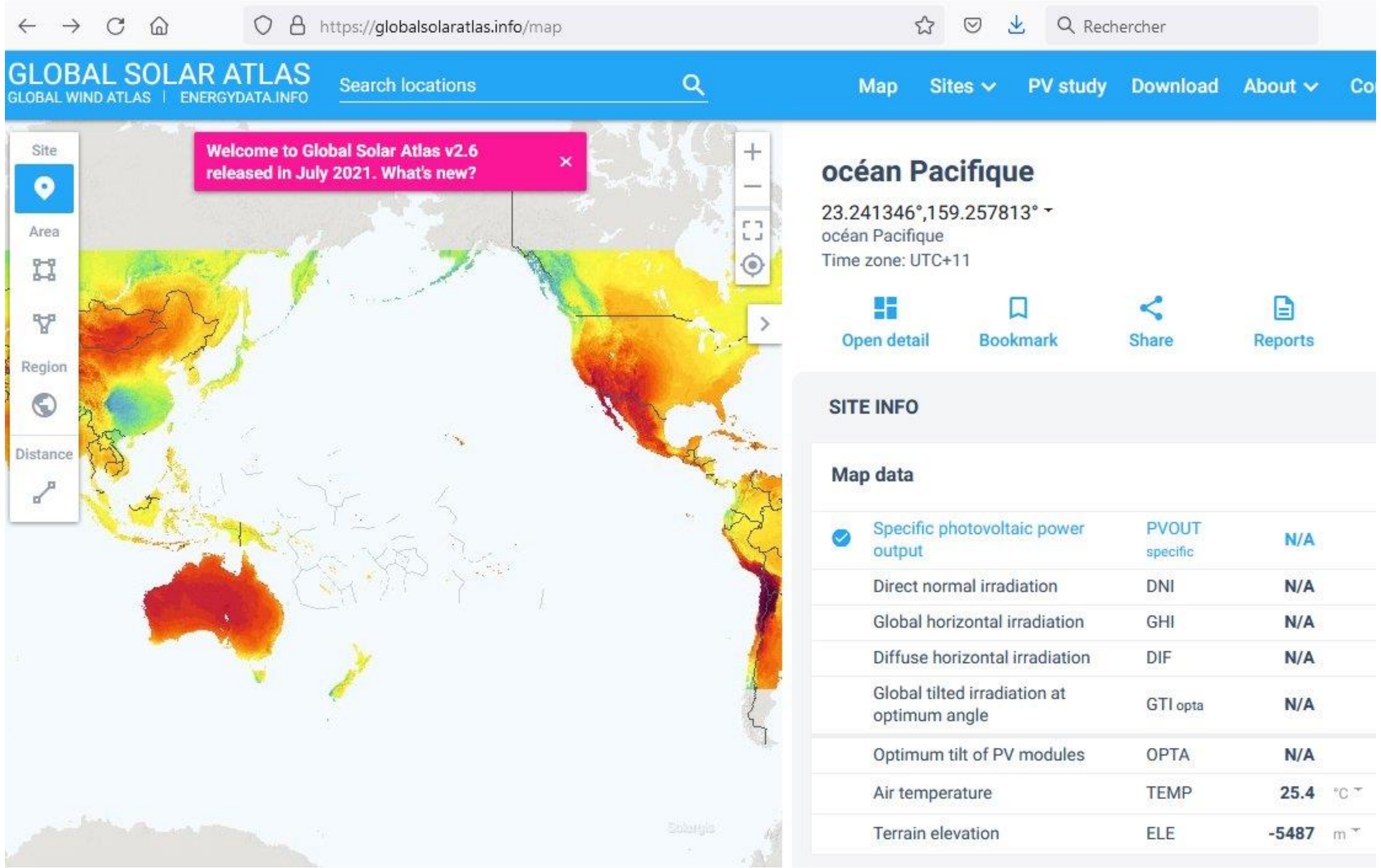
for studies
For monitoring



https://solargis.com/pricing/products-and-plans

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation



(Source : https://globalsolaratlas.info/map)

Specificity of solar micro grids in island areas

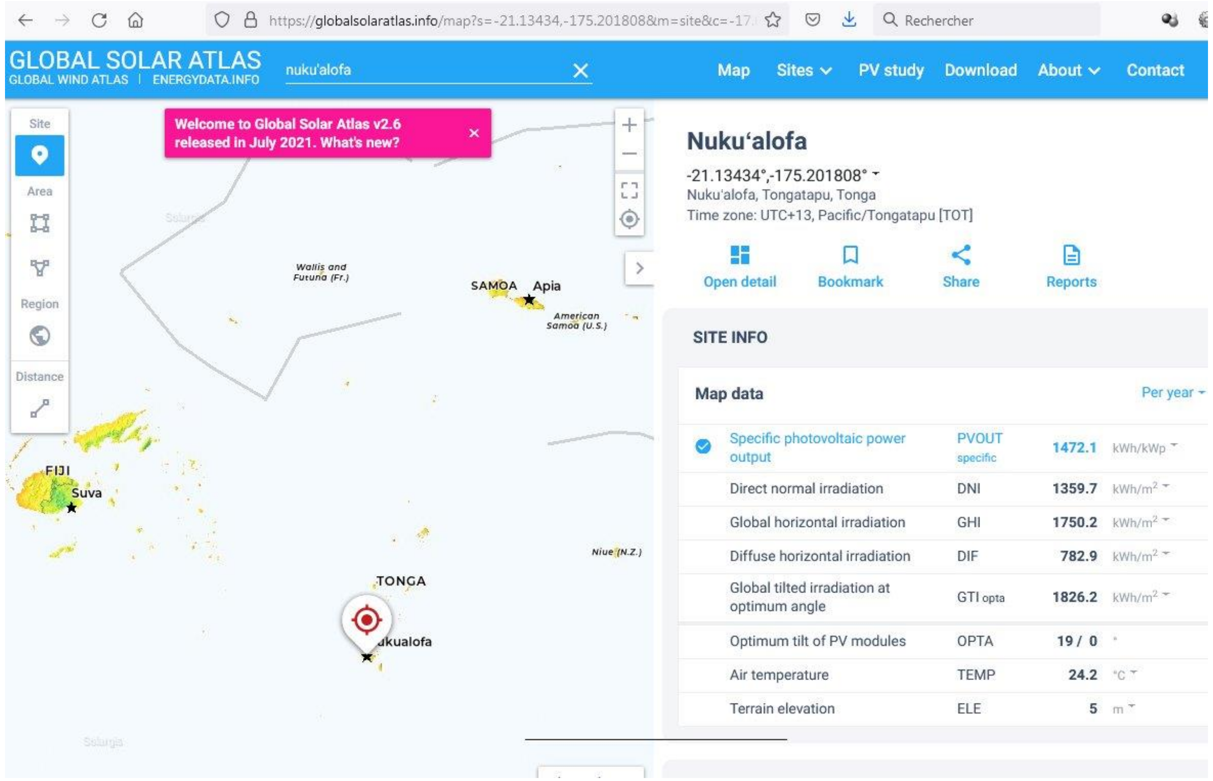
Tonga Islands solar irradiation

For Nuku'alofa

GHI = 1 750 kWh/m² per Year

Optimum tilt = 19° (north)

GTI = 1 826 kWh/m² per year
for optimum tilt on year
(not for the worst month)



(Source https://globalsolaratlas.info/map?s=-21.13434,-175.201808&m=site&c=-17.654491,-176.066895,6)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

Data from the software MeteoNorm 6.1

Nuku'Alofa site, interpolation with three fairly distant weather stations

<u>On horizontal plan</u>

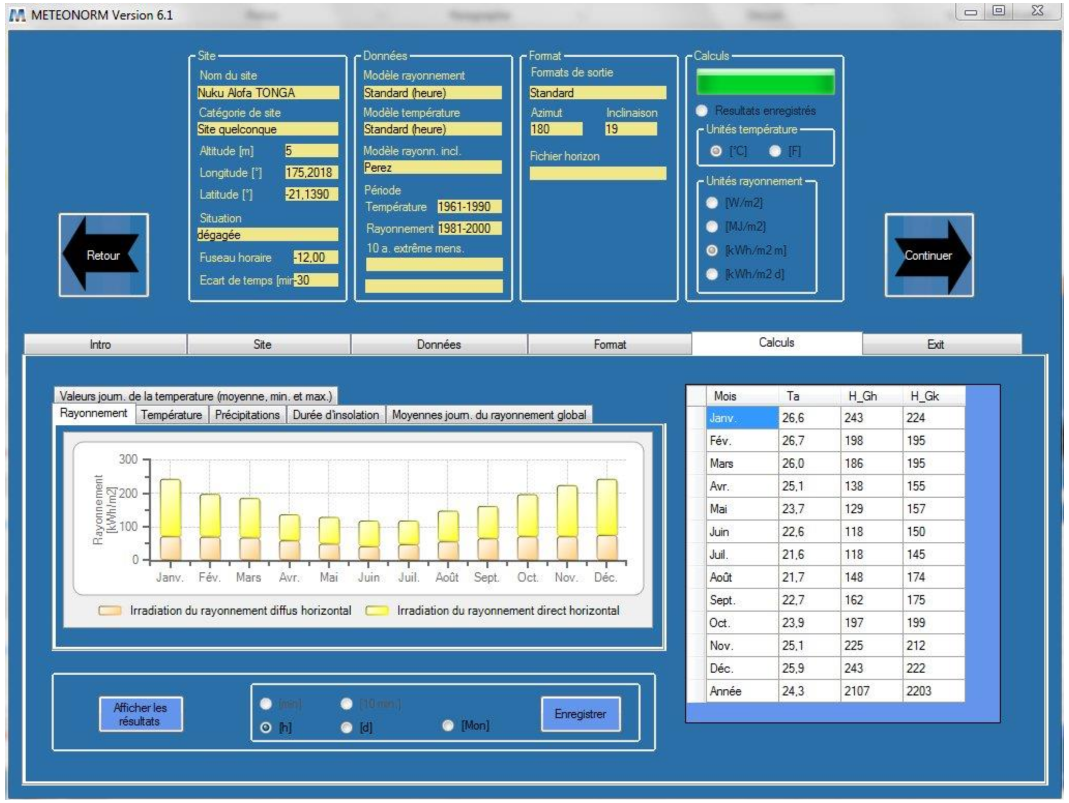
GHI = 2 107 kWh/m² per year

<u>On tilt plane 19° north</u>

GTI = 2 203 kWh/m² per year

Meteonorm6.1 seems to overestimate the annual irradiation

The worth month seems to be July with 145/31 = 4,67 kWh/m² per day



("Fairly" distant weather stations : Aukland Airport, Nandi Fidji, Lihue Hawai)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation

Data from the software MeteoNorm 6.1

Nuku'Alofa site, interpolation with three fairly distant weather stations

The best tilt to have
a maximum irradiation per year
is 20 ° north with 2 203 kWh/m²

The best tilt to have
maximum irradiation for the worst month
is 40 ° north with 159/31 = 5,13 kWh per day

Datas calculed with Meteonorm6.1 for Nuku'Alofa/TONGA

Tilt =	worth month	IGP for worth month	IGP per year
0°	July	118 kWh/m²	2107 kWh/m²
5° N	July	126 kWh/m²	2149 kWh/m²
10° N	July	134 kWh/m²	2181 kWh/m²
15° N	July	140 kWh/m²	2199 kWh/m²
20° N	July	146 kWh/m²	2203 kWh/m²
25° N	July	151 kWh/m²	2194 kWh/m²
30° N	July	155 kWh/m²	2172 kWh/m²
35° N	July	158 kWh/m²	2135 kWh/m²
40° N	July	160 kWh/m²	2088 kWh/m²
	April	159 kWh/m²	
45° N	July	161 kWh/m²	2028 kWh/m²
	April	157 kWh/m²	
50° N	July	160 kWh/m²	1955 kWh/m²
	April	155 kWh/m²	

Note : an inclination of 40 ° north allows to have 35% more solar irradiation compared to a horizontal plane (160/118 = 1,35)

Specificity of solar micro grids in island areas

Tonga Islands solar irradiation
Data from https://www.gaisma.com/en/location/nukualofa.html

Nuku'alofa, Tonga - Solar energy and surface meteorology

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	6.60	6.19	5.68	4.80	4.16	3.77	3.91	4.54	5.28	6.24	6.59	6.55
Clearness, 0 - 1	0.57	0.56	0.57	0.56	0.57	0.57	0.57	0.57	0.57	0.59	0.58	0.56
Temperature, °C	26.09	26.66	26.61	25.97	24.68	23.81	22.93	22.69	22.82	23.25	24.26	25.54
Wind speed, m/s	6.23	6.01	6.12	7.44	7.03	6.94	7.01	6.99	6.19	6.88	6.78	7.02
Precipitation, mm	---	---	---	---	---	---	---	---	---	---	---	---
Wet days, d	---	---	---	---	---	---	---	---	---	---	---	---

These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002
Notes: Help. Change preferences.

Insolation : The monthly average amount of **the total solar radiation incident on a horizontal surface** at the surface of the earth for a given month, averaged for that month over the 22-year period (Jul 1983 - Jun 2005).
Source: NASA Langley Research Center Atmospheric Science Data Center.

Note : an tilt of 40 ° north increases the daily solar irradiation from 3.77 kWh/m² in a horizontal plane to 5.08 kWh/m² (plus 35% following the previous slide).

In conclusion : for the sizing of photovoltaic installations in isolated sites, it is preferable to use an inclination of 40 ° north to produce as much as possible for the worth month in solar irradiation (all the other months have more solar irradiation).

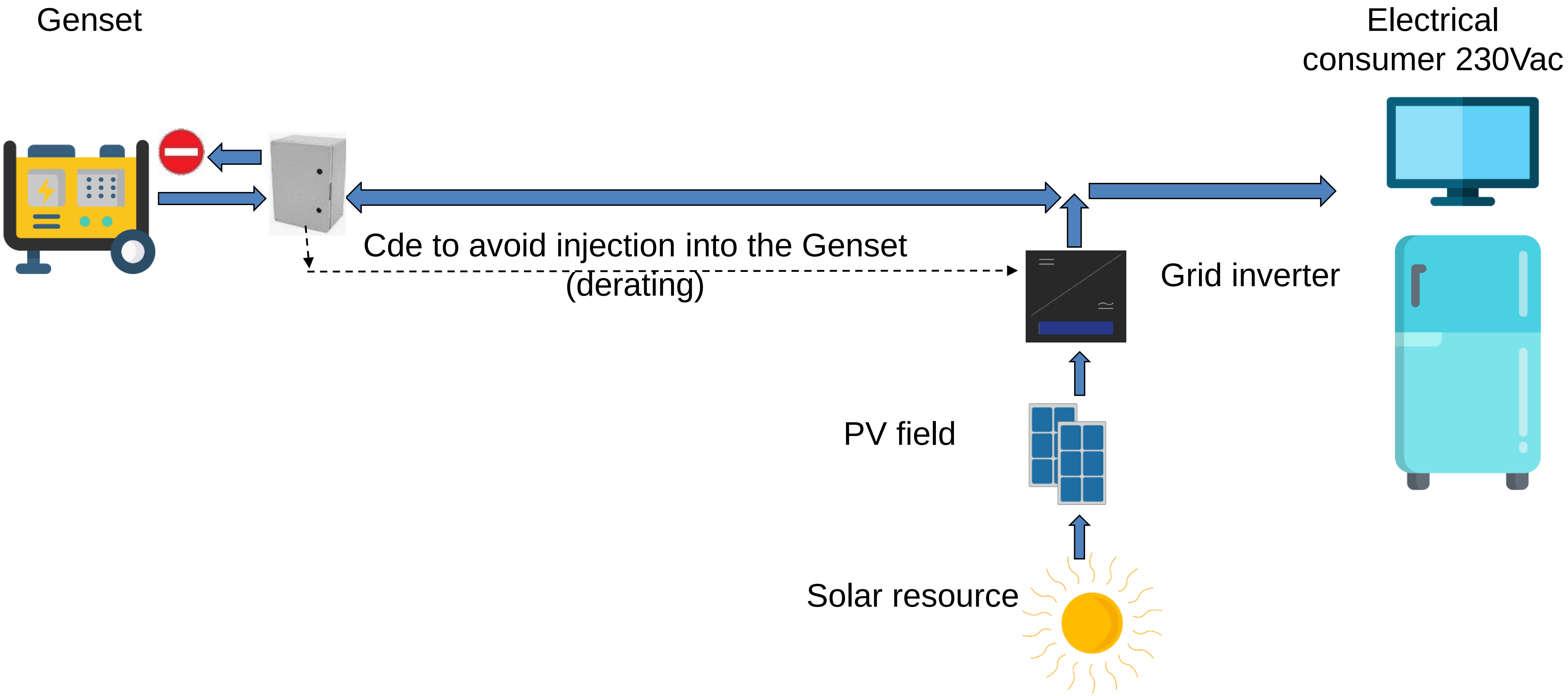
Specificity of solar micro grids in island areas

Micro grids

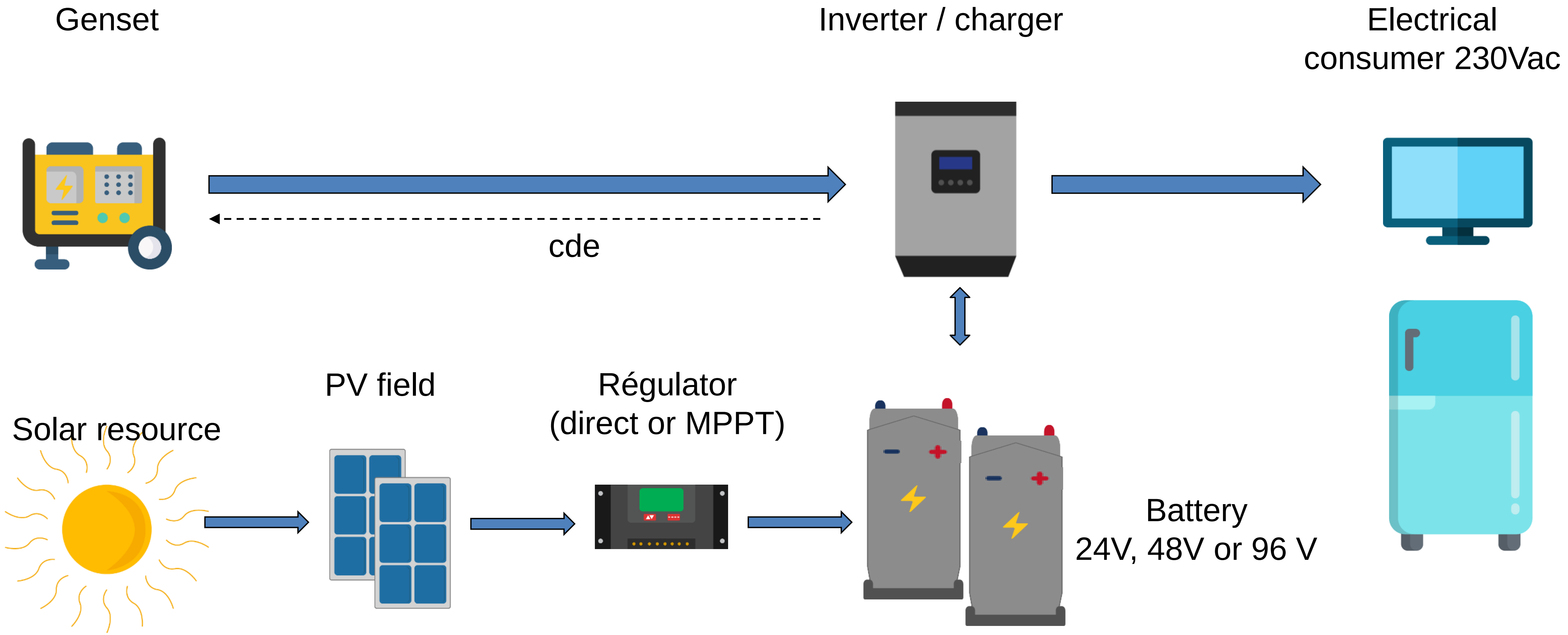
Since 2012, the famous island of Alcatraz has become one of the largest hybrid micro-grids in the United States (305 kWp PV + 1920 kWh battery + 2 Diesel generators + Solar ferry)

Specificity of solar micro grids in island areas

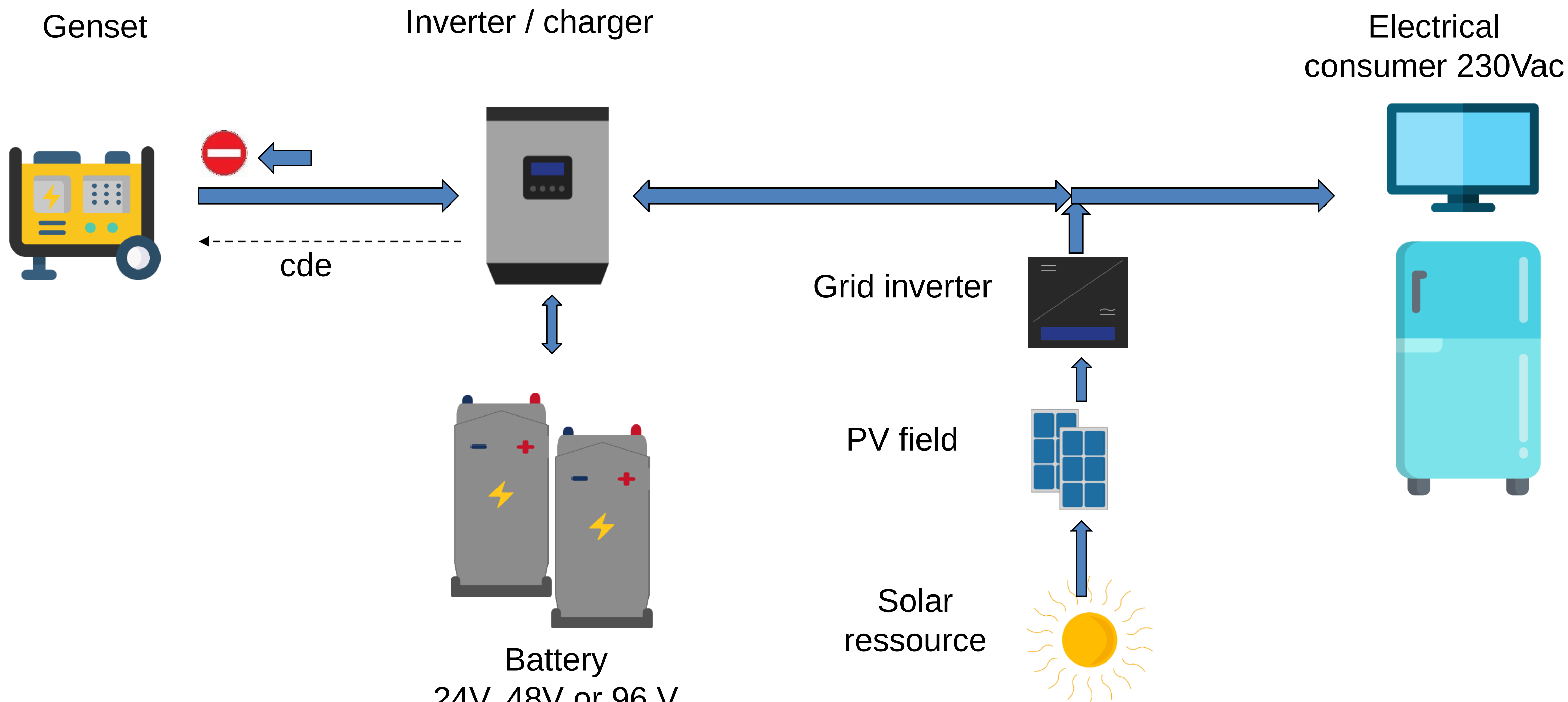
Specificity of solar micro grids in island areas



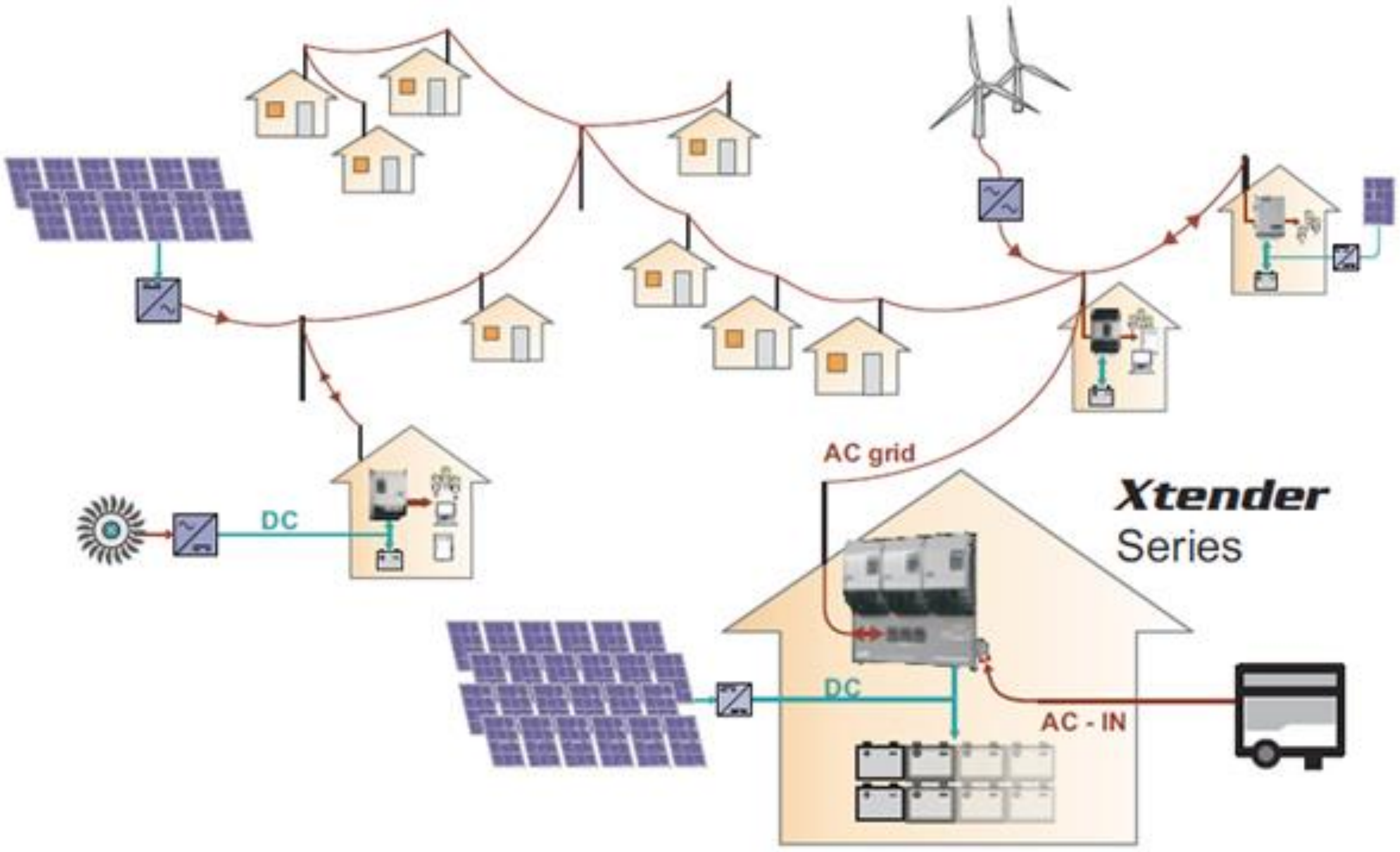
Specificity of solar micro grids in island areas



Specificity of solar micro grids in island areas

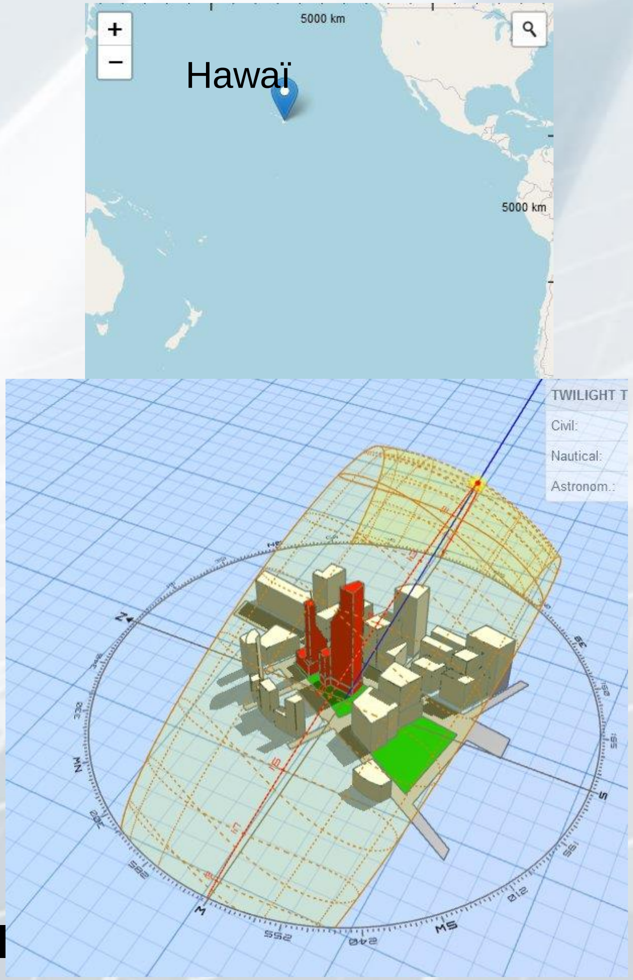


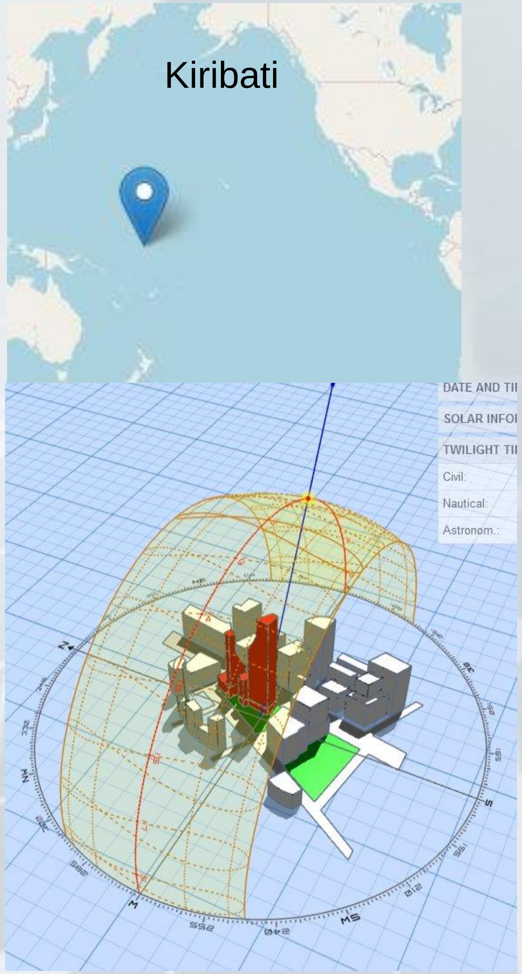
Specificity of solar micro grids in island areas

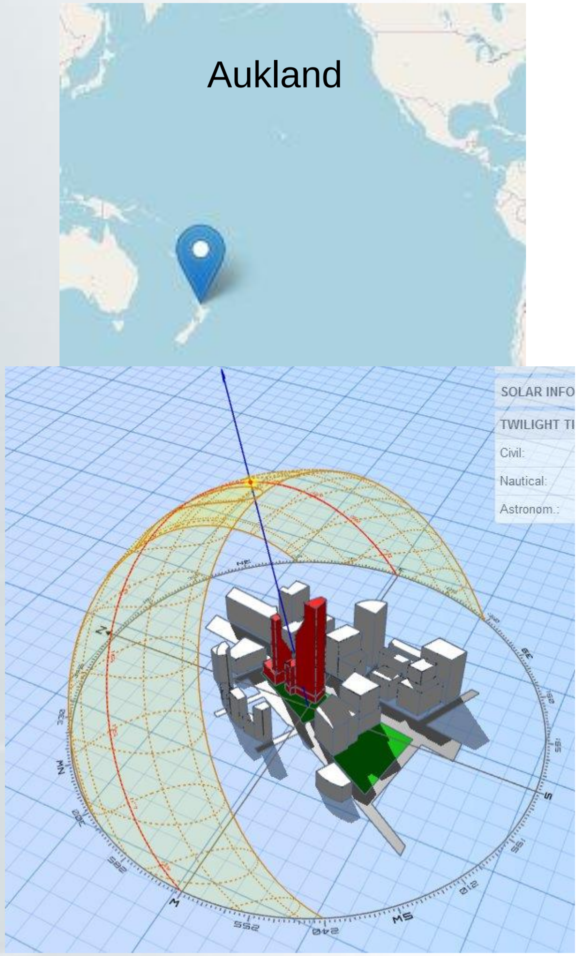


Path of the sun

Solar elevation angle – Between 0° and 90°
Solar azimuth angle – Between -180° and 180°







TOPIC

Day 1 : Micro-grids adapted to the Pacific context		
Time & medium	Topic	Detailed outline
1 hr Online	Session-1 : Solar potential in the Pacific islands (Olivier)	• Existing territorial energy mix • Solar resource in the Pacific • Energy production W/m2 in the Pacific • Why is PV best alternative for conventional power generation • Interest in solarising micro-grids
30 mins Online	Q & A Session	
1 hr Outline	Session-2 : Grid and micro-grid fundamentals (Bruno)	• Grid typologies • Power quality : voltage and frequency • Grid forming generators • Connection of PV to micro-grids • Micro-grid system architectures • Case-studies : Tangatapu and Pitcairn
1 hr Outline	Session-3 : How to select components adapted to the Pacific context? (Olivier)	• Criteria to select components in the Pacific salty & windy context • Resilience and robustness of components • Key decision-making rule-of-thumb ➔ Choice of modules ➔ Choice of mounting structure ➔ Choice of converter & inverter ➔ Choice of storage system • Case-study : Pitcairn case-study in the light of solar under storm recommendations
15 Mins.	Wrapping-up	

TOPIC

	Day 2 : Design & Operation in Practice	
Time	Topic	Session Outline
1 hr Outline	Session-4 : PV system and storage pre-design (Bruno)	• Assesment of load profile • Sizing of the PV generator • Land use, location, grid change • Sizing of the storage • Case-study 1 : Pitcairn PV generator • Case-study 2 : Tongatapu PV generators
30 Mins. Online	Q & A Session	
1 hr Online	Session-5 : Commissioning on the ground (Olivier)	• Static and dynamic commissioning (components & performance) • Inspects, testing protocol, standard criterias • Commissioning check-list role play • Relevance of remote monitoring systems • Operation • Case-studies : Tuvalu, Tokelau, Cook Island
1 hr Outline	Session- 6 : Optimizing maintenance (Olivier)	• Maintenance in the light of natural disasters • Preventive maintenance • Review of participants' case studies • Identification of main challenging points & group solving • Case-study : Tuvalu storage system
15 Mins	**Wrapping-up**	

Specificity of solar micro grids in island areas

THANK FOR YOUR ATTENTION