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Renewable Energy generation
Solar PV

Solar PV Considerations

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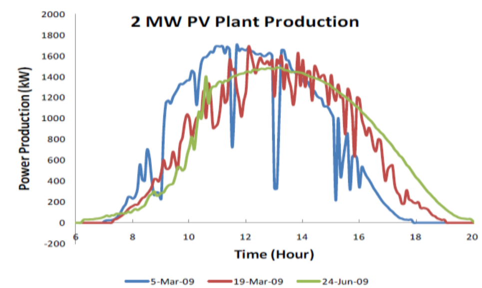
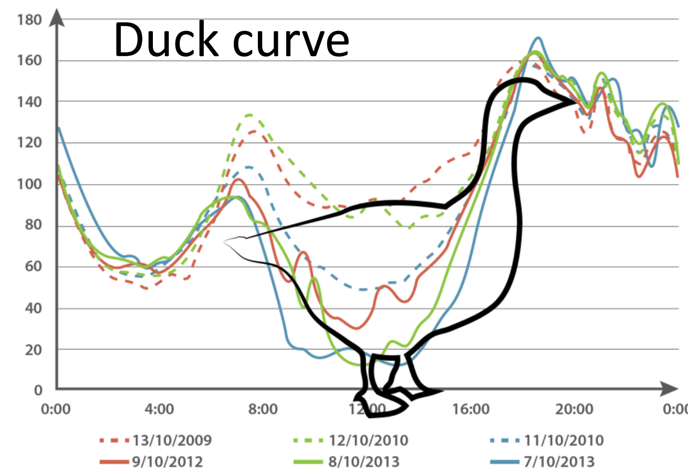
Solar PV is the cheapest renewable electricity generation approach however it does have some key drawbacks:

- **Solar PV** (like wind power) is intermittent and cannot be controlled by operators
- Peak supply and demand of the renewable energy technologies like solar energy do not match and hence create a gap
- Energy storage is therefore needed and batteries are expensive.





The **duck curve** shows electricity demand over the course of a day and shows the timing imbalance between **peak demand** and **renewable energy production.**

PV Installation options

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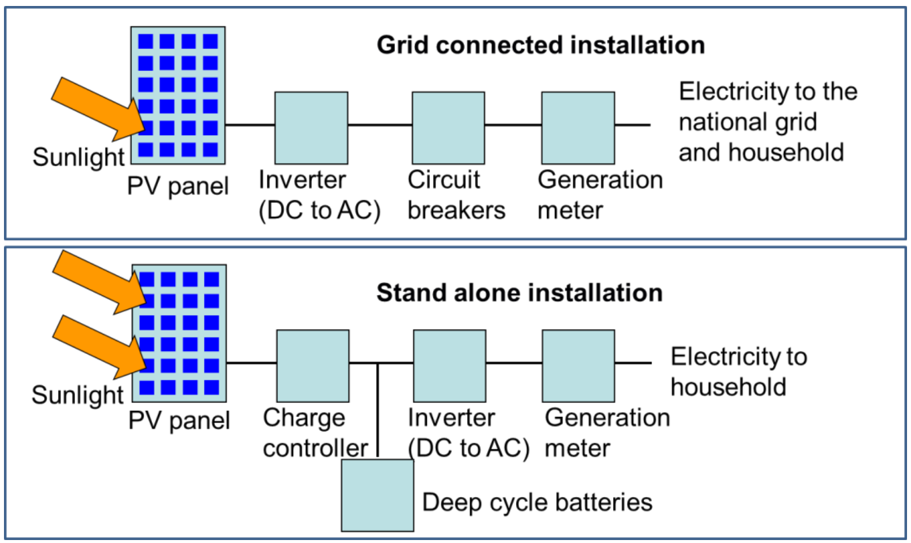
Solar PV produces DC current and therefore needs an invertor



- Solar PV can be configured in different ways:
- A GRID connected installation requires and inverter to convert to AC current
- A stand alone installation is used to charge batteries and uses DC current

The majority of simple Solar PV systems used in developing countries are 'stand alone' system.

Irradiance

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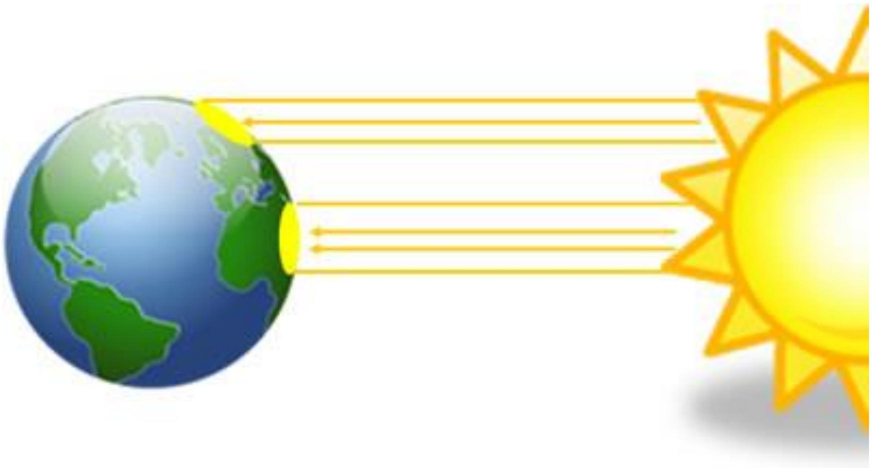
Irradiance is the optical energy incident on a surface. The SI units are W m^{-2}

Irradiance at top of atmosphere	**1.4 kW m^{-2}**
Irradiance at surface (standard)	**1.0 kW m^{-2}**

The power per unit area of electromagnetic radiation over all wavelengths. $I = P / A$



Measuring Irradiance

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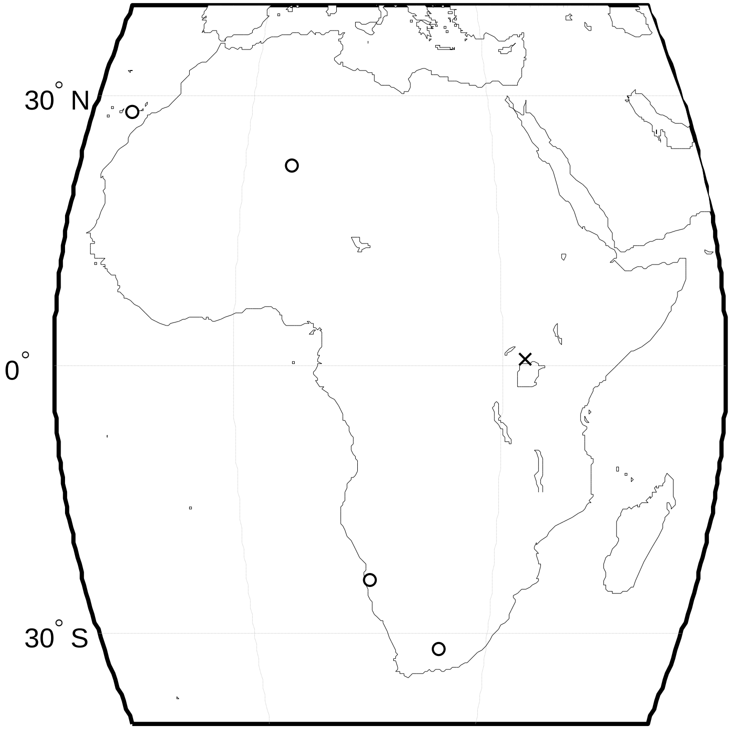
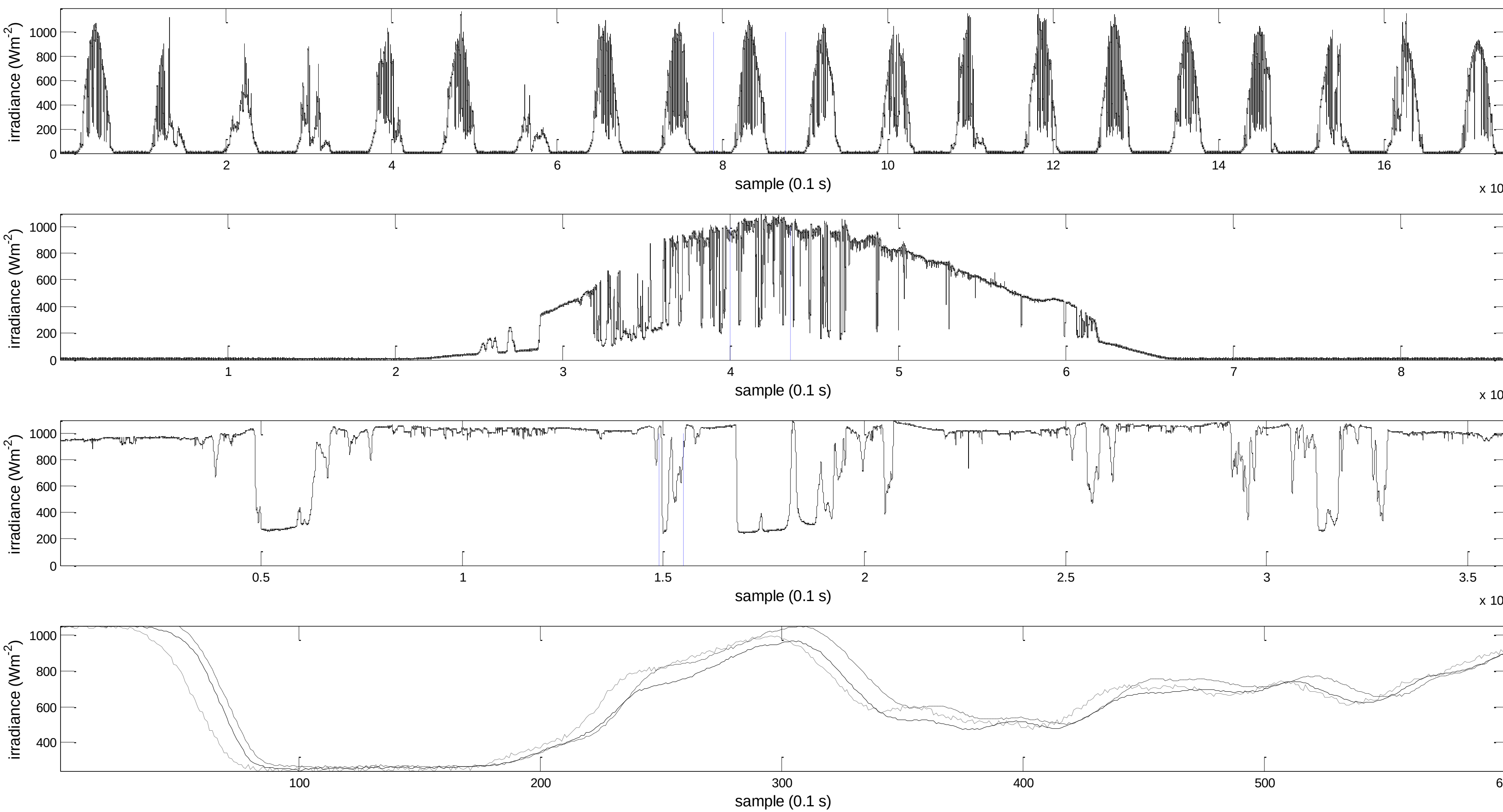


Irradiance datasets will be used as input to electrical models.
High-accuracy low-frequency data from pyranometer.
Low-accuracy high-frequency data from silicon sensors.

Insolation maps



Insolation maps

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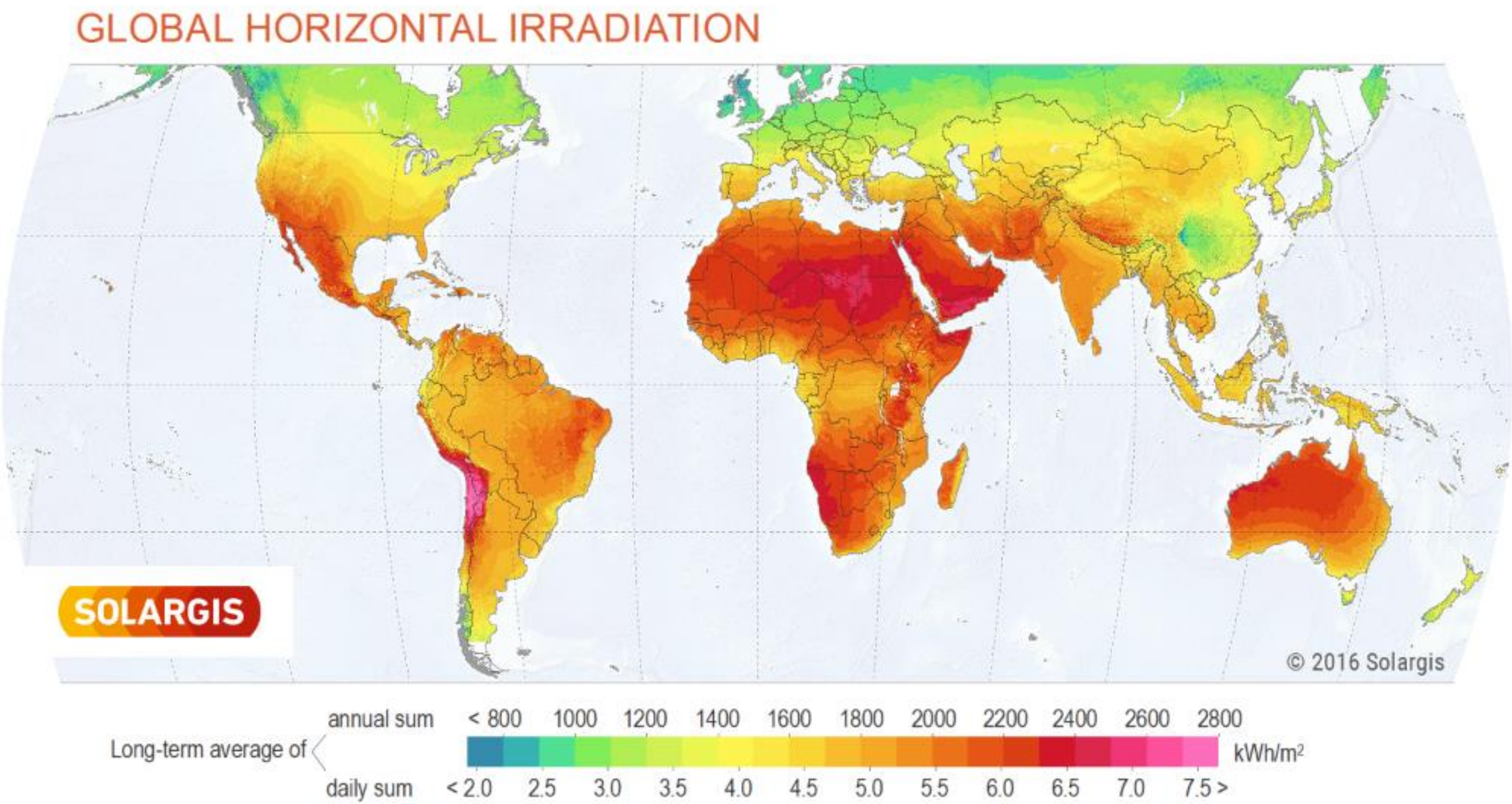

Irradiance calculations

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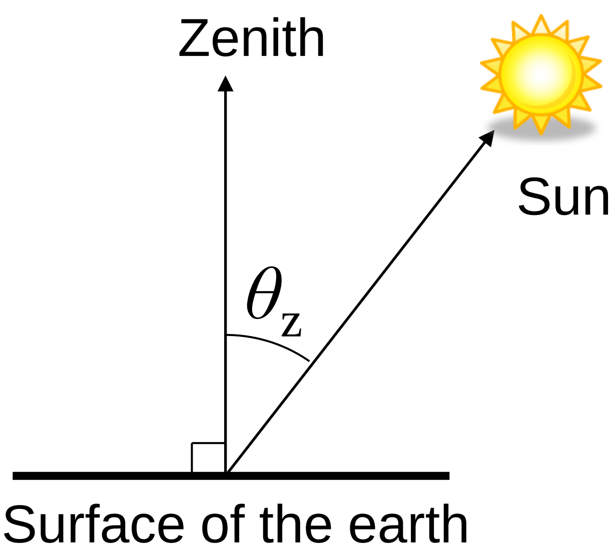
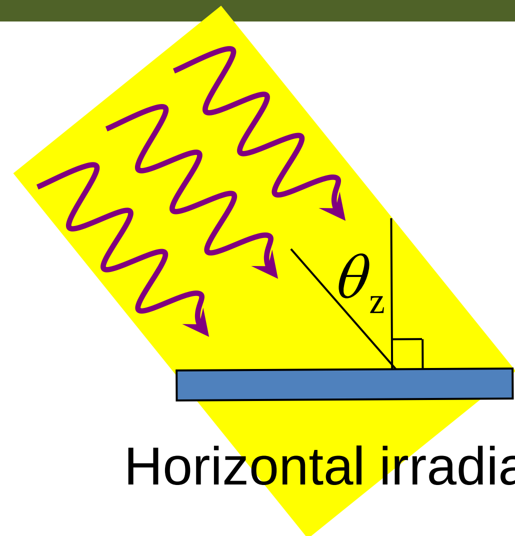
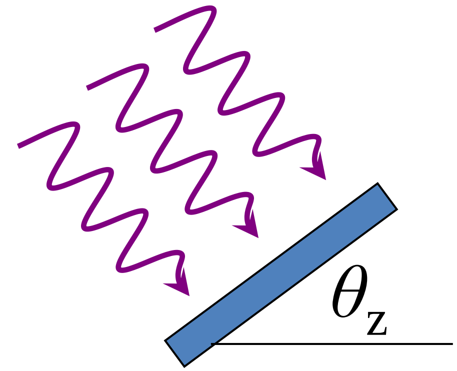
Zenith angle, θ_z
The angle between the vertical and the Sun.

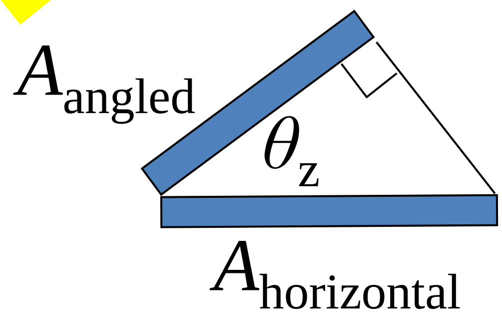




Horizontal irradiance



Angled irradiance



$$P = IA = I_{horizontal} A_{horizontal} = I_{angled} A_{angled}$$

$$\frac{I_{\text{horizontal}}}{I_{\text{angled}}} = \frac{A_{\text{angled}}}{A_{\text{horizontal}}} = \cos\theta_z$$

Irradiance calculations

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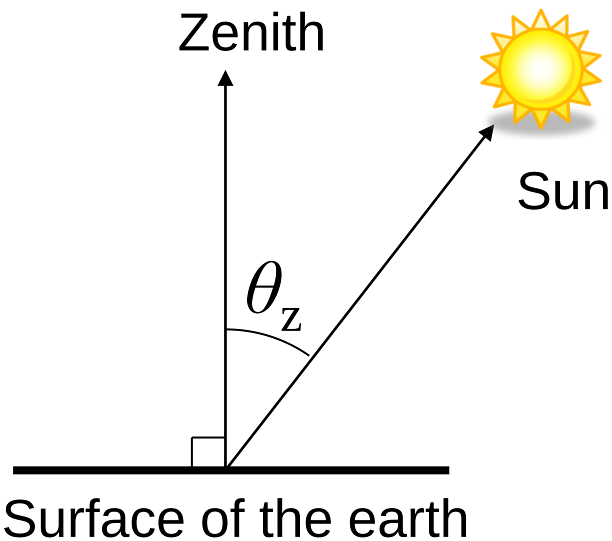
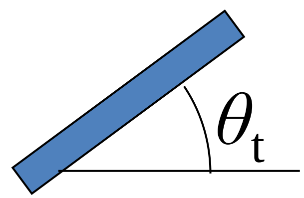
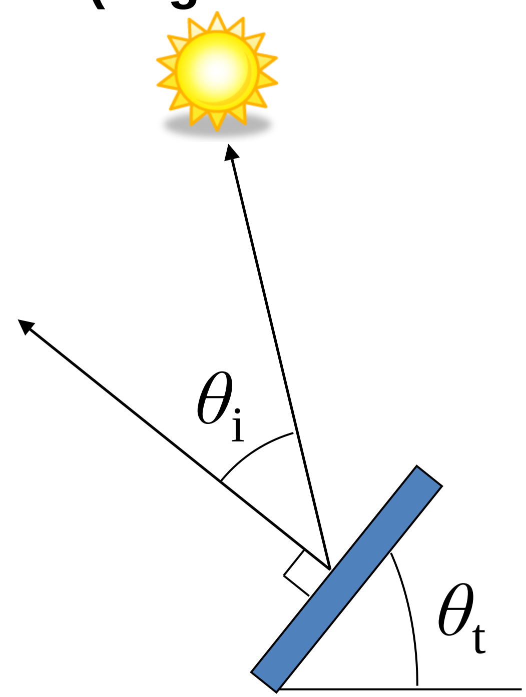
Zenith angle



Tilt angle



Incident angle (angle of incidence)



Relationships depend on geometry

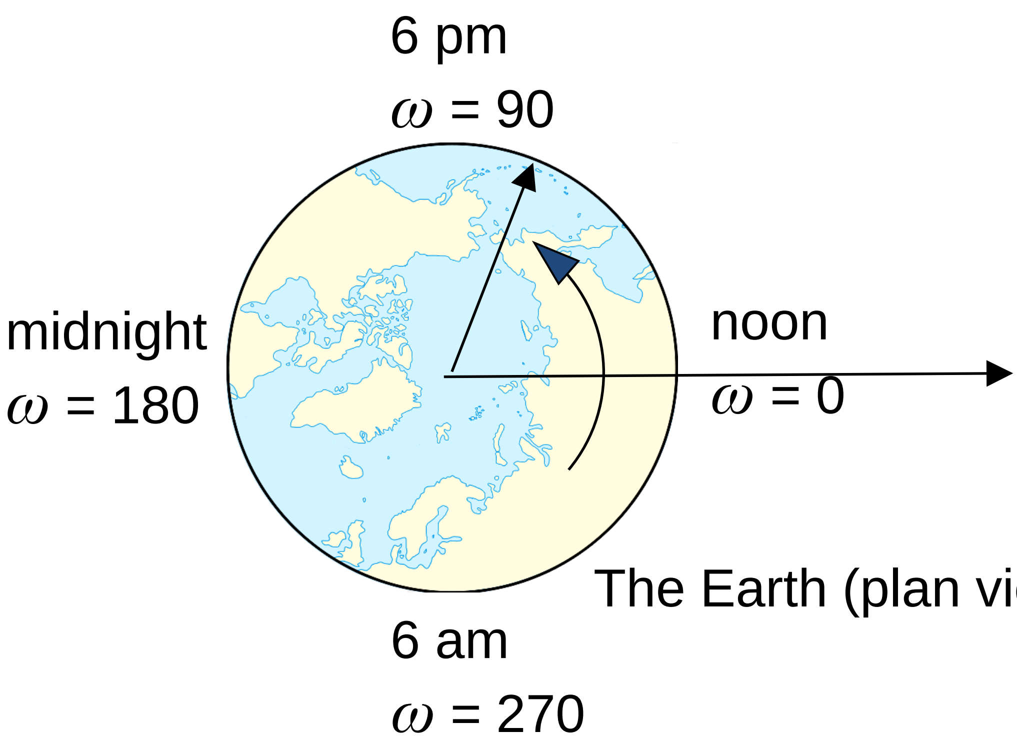
Usually $\theta_i = |\theta_z - \theta_t|$

$$I_{panel} = I_{normal} \cos \theta_i$$

DNI = Direct Normal Irradiance

Irradiance calculations

Hour angle, ω
The angular position of the sun (east or west).
360° corresponds to 24 hours.



$$\omega = \left(\frac{t_{24} - 12}{24}\right) 360°$$

Irradiance calculations

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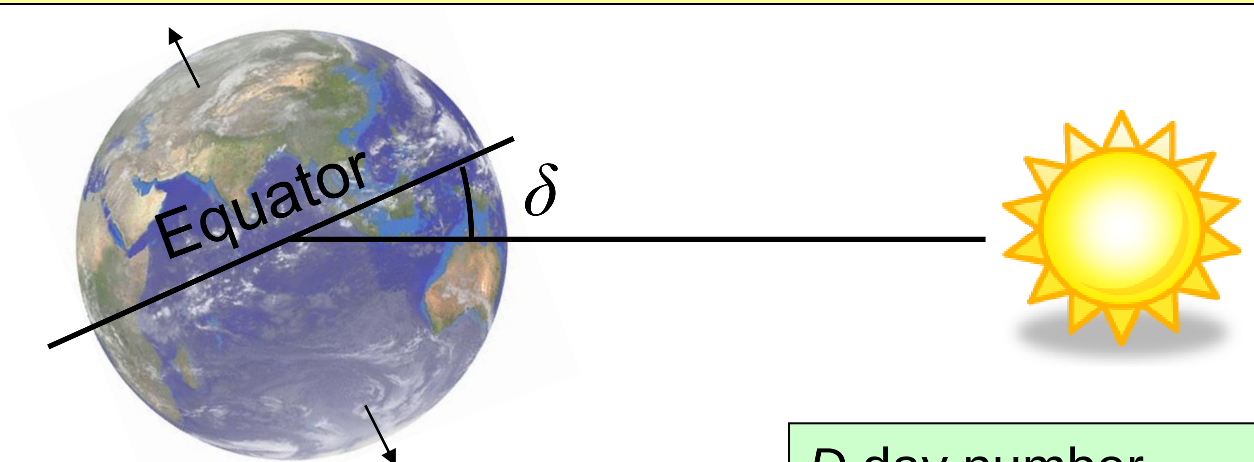
Declination, δ
The angular position of the sun at noon relative to the plane of the equator.



The Earth (side view)

$$\delta = -23.45\cos\left(\frac{D+10}{365}360^\circ\right)$$

D day number	
1 January	$D = 1$
Spring equinox	$D = 81$
Summer solstice	$D = 172$
Autumn equinox	$D = 263$
Winter solstice	$D = 355$

Solar energy variability

This equation calculates the zenith angle. As a function of hour angle, it provides solar energy variability.

$$\cos\theta_z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$$

θ is the zenith angle

φ is the latitude

ω is the hour angle

δ is the declination

PV electrical characterisation

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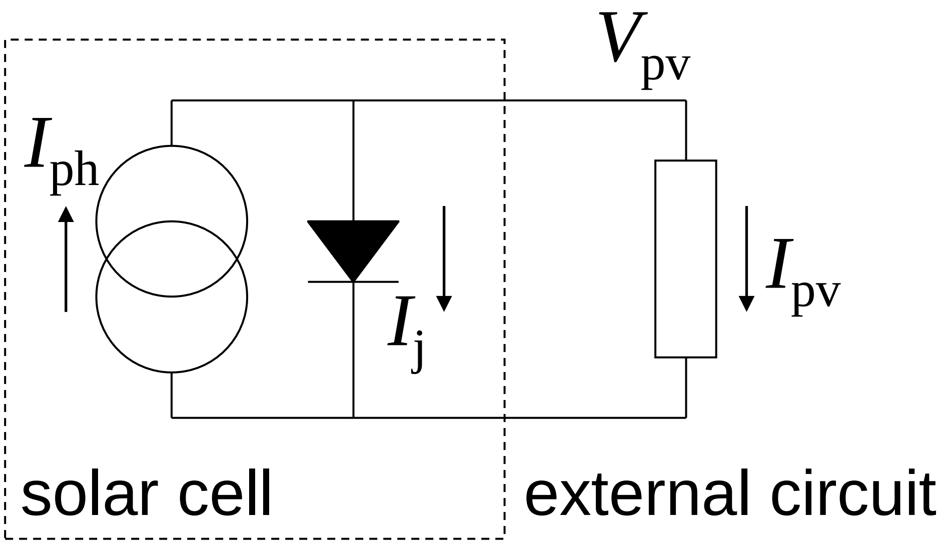
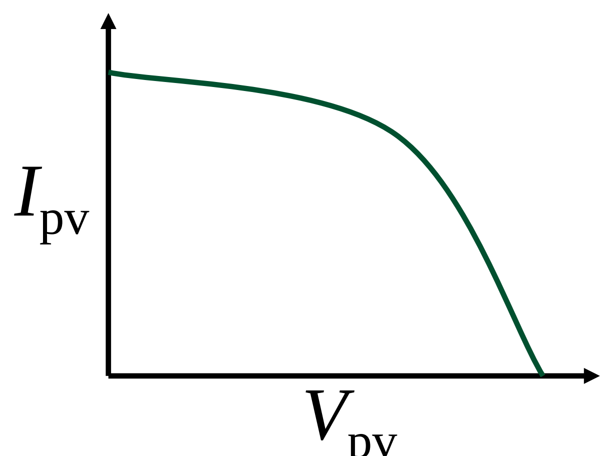


$$I_{ph} = I_j + I_{pv}$$

$$I_{pv} = I_{ph} - I_j$$

$$I_{pv} = I_{ph} - I_0\left(e^{V_{pv}/kT} - 1\right)$$

$$P_{pv} = I_{pv} V_{pv}$$



I_0 reverse saturation current
I_{ph} photocurrent
I_j junction current
I_{pv} solar cell current

PV electrical characterisation

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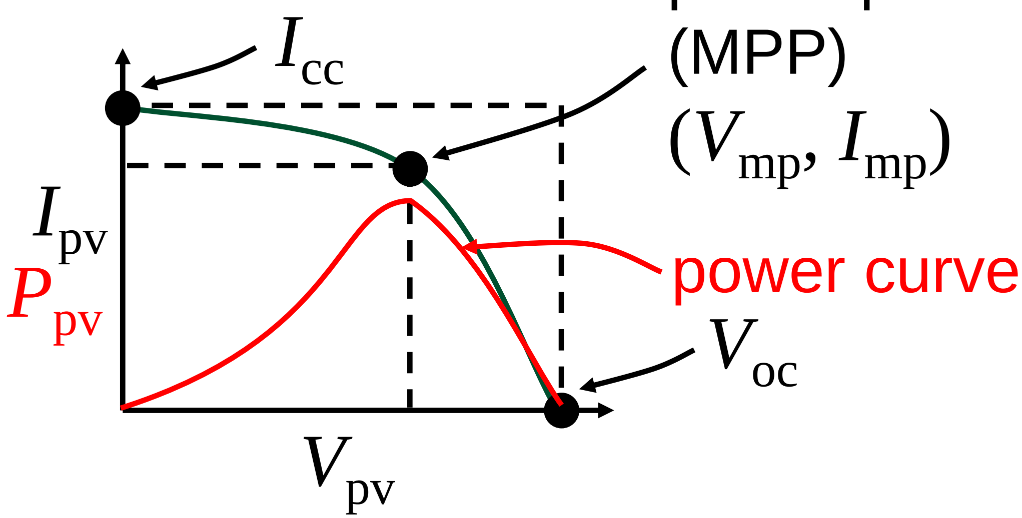

Fill factor

$$FF = \frac{I_{mp}V_{mp}}{I_{cc}V_{oc}}$$

Fill factor is a figure of merit for PV. The higher the better. A typical value is 0.7

Renewable energy generation

Solar

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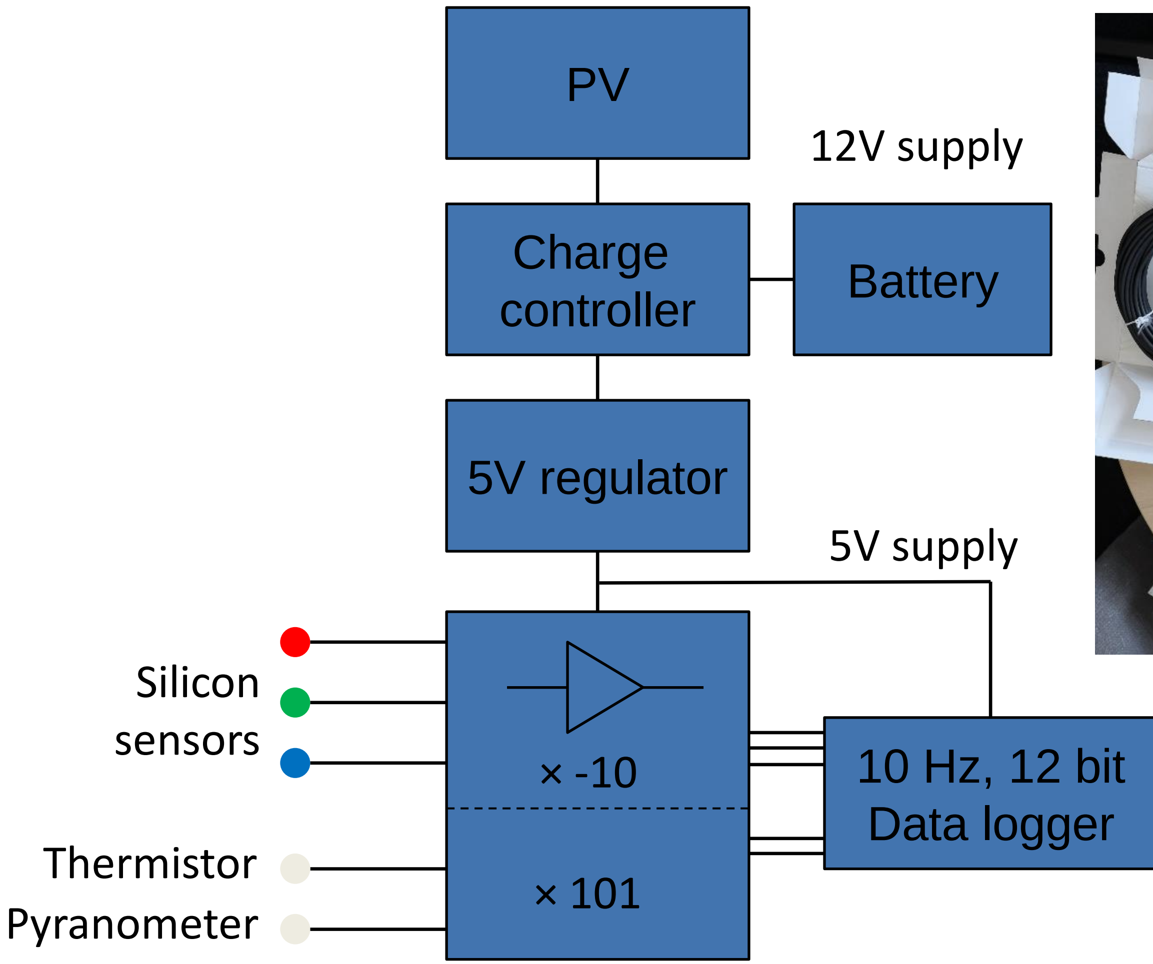

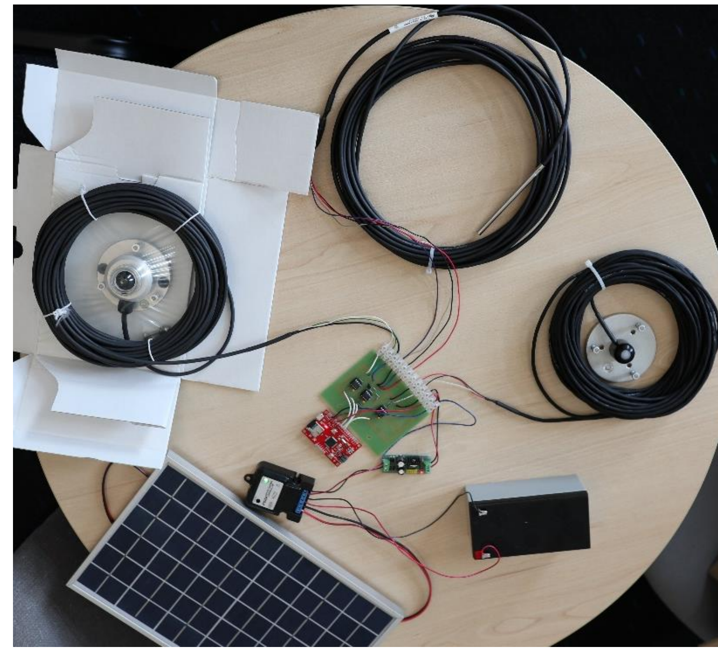

Predicting solar availability

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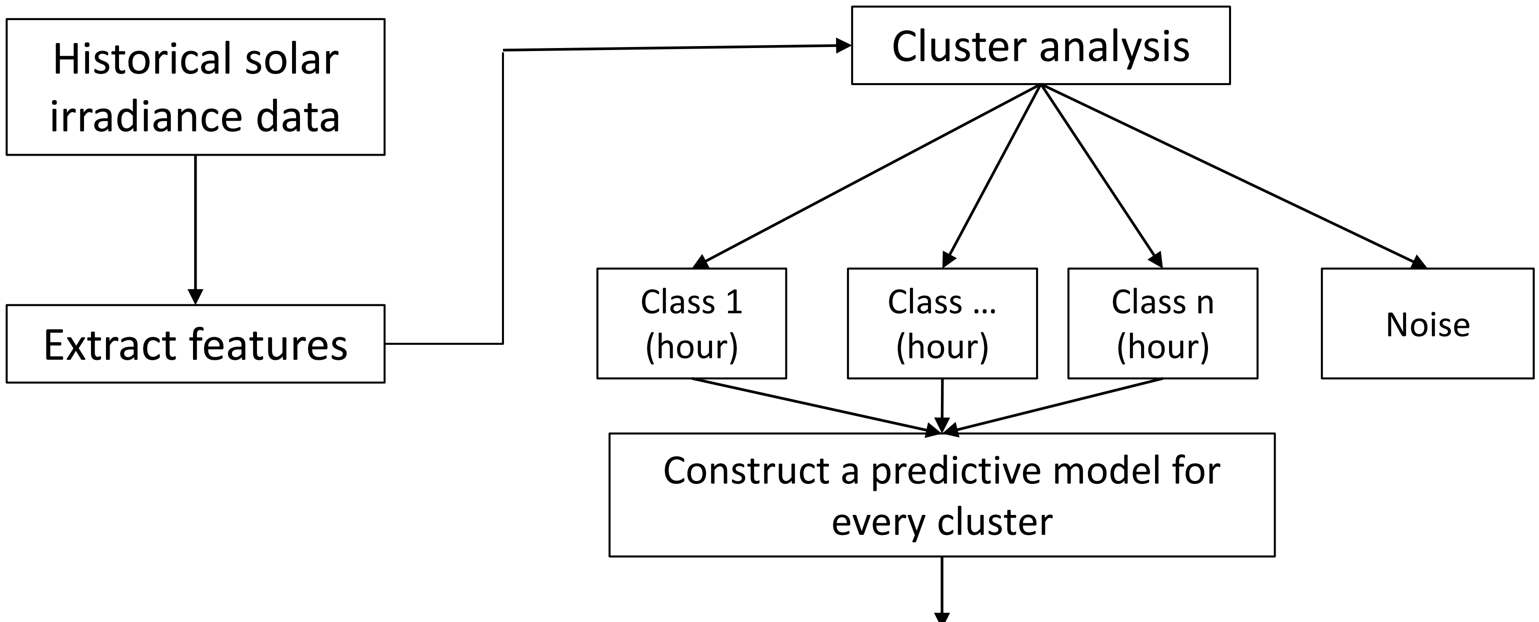
Several approaches using historical data

Satellite data	**Ground observations from meteorological stations**	**Measure at proposed site ourselves**
Decades of data for the entire world	Decades of data from locations throughout the world	Possibly a few years of data at exact point of construction
Typical resolution is 10-100km	Nearest location could be long distance from proposed site	Designed to collect the exact data required
Low frequency data	High frequency data	High frequency data
Tends to overestimate solar irradiance	Observation sites scarce in remote areas	Highly accurate
		Data collected may be from a year when weather was different from the typical

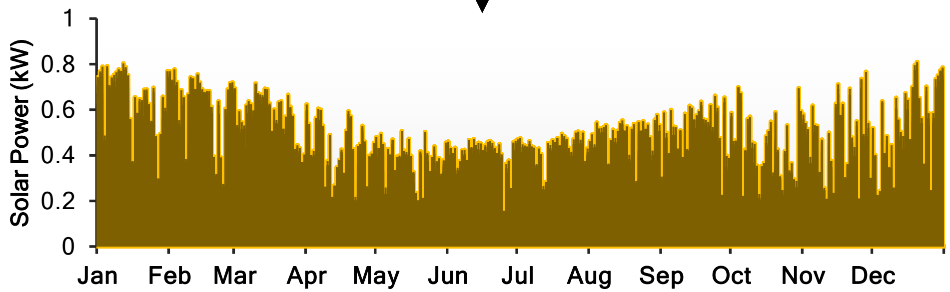
- Historical meterological station data available through Global Energy Balance https://geba.ethz.ch/
- https://www.meteoblue.com/ has satellite weather data

Predicting solar availability

- Need to condense years of data into a few typical days to apply to microgrid model
    - Days might reflect different seasons



Prediction of solar power from 1KWp panel



Case studies – Solar/Diesel Hybrid

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Kalangala island, Uganda

- Hybrid power station: Three diesel generators (1 MW total), sun tracking solar PV (600 kW) and battery storage
- In the progress of connecting to the main land
- Low demand, high tariffs
- Operates on solar during the day, generators in the evening and batteries overnight