Short-Course

Solar PV System Installation and Maintenance

NTQF Level IV

Learning Guide -07

Unit of Competence	**Calculating System Components**
Module Title	**Calculating System Components**
LG Code	**EIS PIM4 M01 0120 LO3-LG07**
TTLM Code	**EIS PIM4 TTLM 0120v1**

LO 3: Calculate array size-07

Instruction Sheet	Learning Guide:- 07

This learning guide is developed to provide you the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Determining minimum solar insolation;
- Calculating array size;
- Adjusting array size based on the environmental factors.

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:-

- Determine minimum solar insolation;
- Calculate array size;
- Adjust array size based on the environmental factors.

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below:
3. Read the information written in the information Sheet 1 (page: 40), Sheet 2 (page: 52), Sheet 3 (page:57)
4. Accomplish the Self-Check 1 (page: 51), Self-Check 2 (page: 56), Self-Check 3 (page: 59)

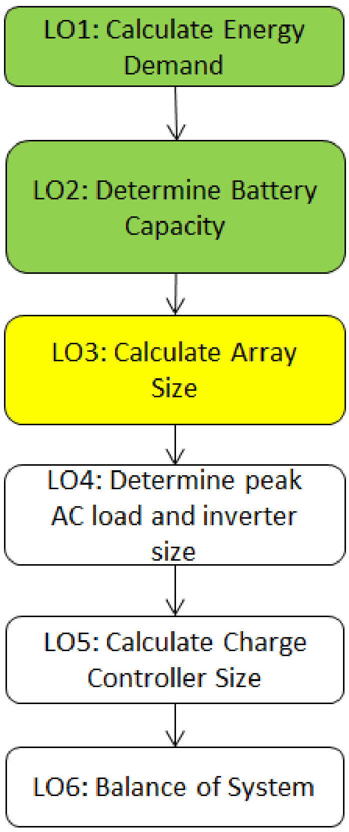
LO 3 Calculate array size

Information Sheet 1	Determining minimum solar insolation

1 Determining minimum solar insolation

1.1 Introduction

Step 3 in the design process is to calculate the array size:



1) Site survey
A Consumption
B Climate data

2) PV generator
C Design PV Generator
D Selection of System Voltage

3) Battery sizing (BAT)
E Battery Dimensioning based on consumption

4) Charge Controller (CC)
F Configuration of the Modules (G Charge Controller Dimensioning

5) Inverter (INV)
H Select an Inverter based on the Loads
I Cross-Check Battery/Inverter matching

6) Balance of System (BoS)
J Calculate Cabling diameters and length
K Calculate the Fuses
L Mounting System

2) PV generator

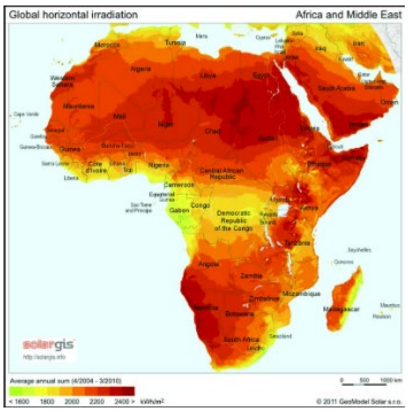
Calculate solar irradiation for the location of the planned solar system

Sizing the PV Generator

$$P_{PV} = \frac{E}{G \times h} = \frac{\text{Daily Energy Consumption } [\frac{Wh}{d}]}{\text{Sun Hours } [h] \times \text{ System Efficiency}}$$

Number of Modules

$$n = \frac{Power_{PV}}{Power_{Mod}} = \frac{P_{PV}}{P_{Mod}}$$



Sourcre: https://solargis.com/

Figure 32: Design Step3

In order to determine the size of the PV generator required, one needs to determine the available solar energy at the specific location, taking into consideration the location, mounting angle and azimuth.

1.2 Background

The following paragraphs are taken/adapted from (Hankins, 2010) chapter 2.

Sunshine reaches the earth as a type of energy called radiation. Radiation is composed of millions of high-energy particles called photons. Each unit of solar radiation, or photon, carries a fixed amount of energy. Depending on the amount of energy that it carries, solar radiation falls into different categories including infrared (i.e. heat), visible (radiation that we can see) and ultraviolet (very high energy radiation). The solar spectrum describes all of these groups of radiation energy that are constantly arriving from the sun, and categorizes them according to their wavelength. Different solar cells and solar energy collecting devices make use of different parts of the solar spectrum.

Solar energy arrives at the edge of the Earth's atmosphere at a constant rate of about 1350 watts per square metre (W/m2): this is called the 'solar constant'. However, not all this energy reaches the Earth's surface. The atmosphere absorbs and reflects much of it, and by the time it reaches the Earth's surface, it is reduced to a maximum of about 1000W/m2 (see Figure 33). This means that when the sun is directly overhead on a sunny day, solar radiation is arriving at the rate of about 1000W/m2. Northern countries (i.e. Europe) have lower annual solar radiation levels than countries nearer the Equator – mainly because they have shorter days in winter.

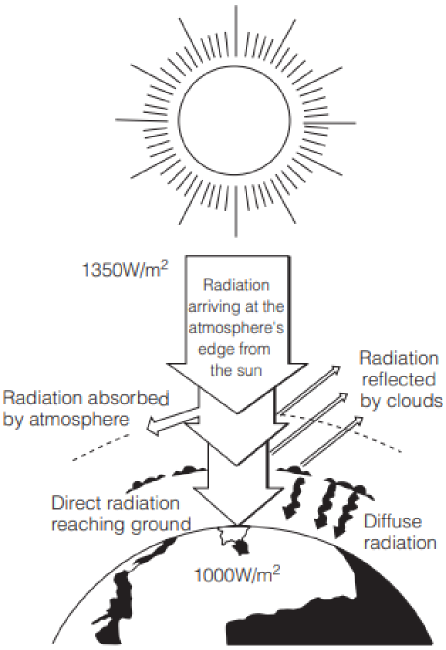


Figure 33 : Absorption and reflection of solar radiation by the Earth's atmosphere

1.2.1 Direct and Diffuse Radiation

Solar radiation can be divided into two types: direct and diffuse. Direct radiation comes in a straight beam and can be focused with a lens or mirror. Diffuse radiation is radiation reflected by the atmosphere or radiation scattered and reflected by clouds, smog or dust. Clouds and dust absorb and scatter radiation, reducing the amount that reaches the ground. On a sunny day, most radiation reaching the ground is direct, but on a cloudy day up to 100 per cent of the radiation is diffuse. Together, direct radiation and diffuse radiation are known as global radiation. Radiation received on a surface in cloudy weather can be as little as one tenth of that received in full sun (see Figure 34).

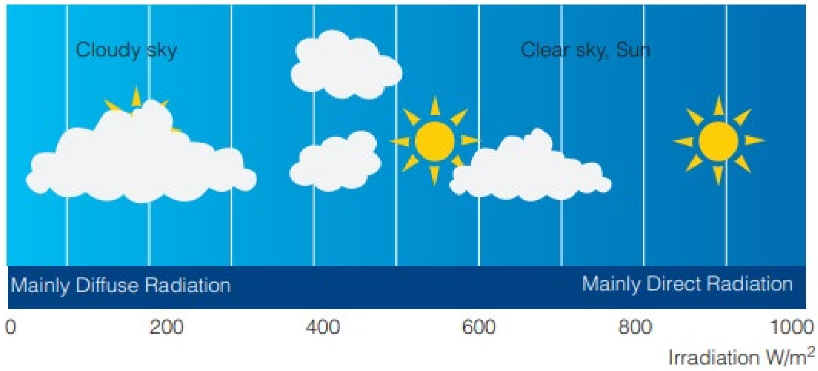


Figure 34 : Direct and diffuse radiation

Therefore, solar systems must be designed to guarantee enough power in cloudy periods and months with lower solar radiation levels. At the same time, system users must economize energy-use when it is cloudy. Annual and even monthly solar radiation is predictable.

Factors that affect the amount of solar radiation an area receives include the area's latitude, cloudy periods, humidity and atmospheric clarity. At high-intensity solar regions near the Equator, solar radiation is especially affected by cloudy periods. Long cloudy periods significantly reduce the amount of solar energy available. High humidity absorbs and hence reduces radiation. Atmospheric clarity, reduced by smoke, smog and dust, also affects incoming solar radiation. The total amount of solar energy that a location receives may vary from season to season, but is quite constant from year to year.

1.2.2 Solar Irradiance

Solar irradiance refers to the solar radiation actually striking a surface, or the power received per unit area from the sun. This is measured in watts per square metre (W/m2) or kilowatts per square metre (kW/m2). If a solar module is facing the sun directly (i.e. if the module is perpendicular to the sun's rays) irradiance will be much higher than if the module is at a large angle to the sun. Figure 35 shows the changes in the amount of power received on a flat surface over the course of a clear day.

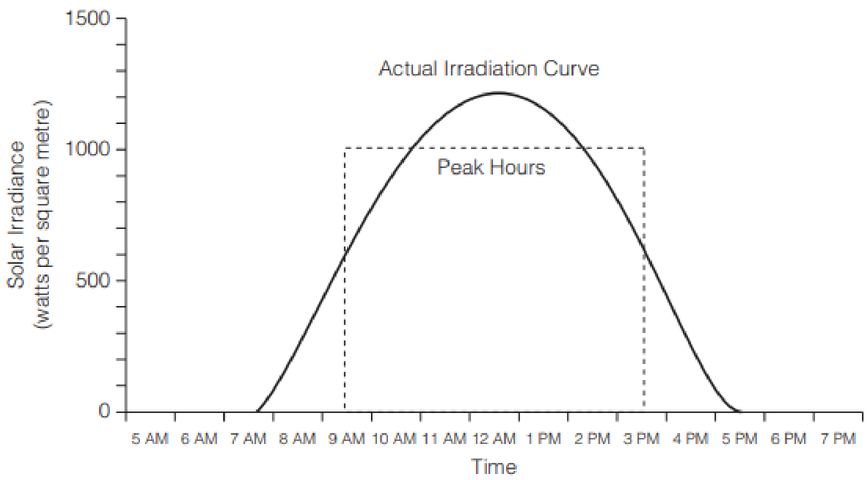


Figure 35 : Solar irradiance received over time

In the morning and late afternoon, less power is received because the flat surface is not at an optimum angle to the sun and because there is less energy in the solar beam. At noon, the amount of power received is highest. The actual amount of power received at a given time varies with passing clouds and the amount of dust in the atmosphere. The angle at which the solar beam strikes the surface is called the solar incident angle. The closer the solar incident angle is to 90°, the more energy is received on the surface (see Figure 36). If a solar module is turned to face the sun throughout the day, its energy output increases. This practice is called tracking.

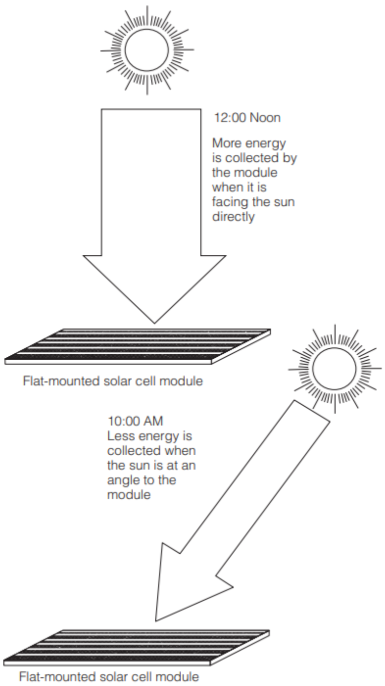


Figure 36 : Solar incident angle (synergyfiles.com)

1.2.3 Insolation

Insolation (a short way of saying incident solar radiation) is a measure of the solar energy received on a specified area over a specified period of time. Meteorological stations throughout the world keep records of monthly solar insolation that are useful in planning solar utilization systems. For the purposes of off-grid solar system design, insolation is normally measured in either of two methods, as described in Figure 37 below.

A site that receives 6 peak sun hours a day receives the same amount of energy that would have been received if the sun had shone for 6 hours at 1000W/m2. In reality, irradiance changes throughout the day.

At a good solar energy site, irradiance is above 1000W/m2 for about 3 hours, between 800 and 1000W/m2 for 2 hours, between 600 and 800W/m2 for 2 hours and between 400 and 600W/m2 for 2 hours and between 200 and 400W/m2 for 2 hours. Still, the energy is equivalent to 6 hours of irradiance at 1000W/m2 (Figure 35). For example, during October a site in Arusha, Tanzania, would be expected to receive 6.3kWh/m2/day and 6.3 peak sun hours per day.

Method	Abbreviation	Definition
Kilowatt-hours per square metre per day	kWh/m²/day	Quantity of solar energy, in kilowatt-hours, falling on a square metre in a day.
Daily peak sun hours	PSH	Number of hours per day during which solar irradiance averages 1000W/m² at the site.

Figure 37 : Insolation Measurement

Peak sun hours are useful because they simplify calculations. Figure 38 shows the mean daily insolation in peak sun hours for each month at four sites around the world. Note that the total amount of energy available per day changes considerably from month to month, even in Equatorial countries. On a sunny October day, Arusha, Tanzania, receives more than 6 peak sun hours of insolation. However, on a cloudy day in July the same site might receive only 4.3 peak sun hours.

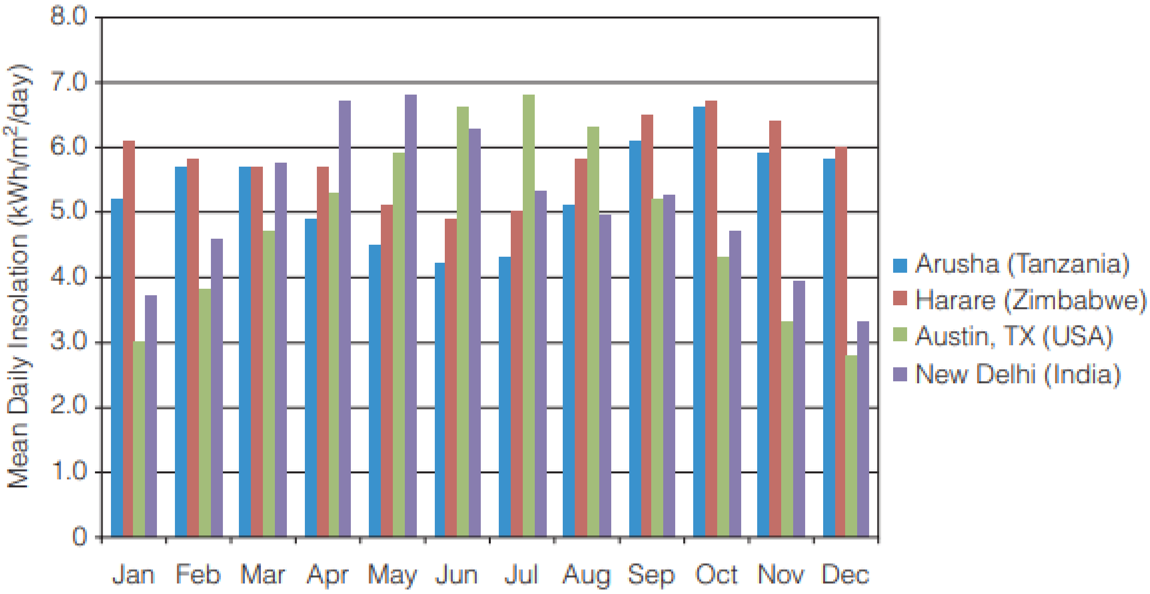


Figure 38 : Mean daily insolation in four cities

1.3 Source of data

When planning a solar electric system, you will need to estimate your site's monthly mean daily insolation in kWh/m2 or peak sun hours. As a general rule, tropical locations receive between 3 and 8 peak sun hours per day. In the winter, northern climates receive less than 2 peak sun hours per day. The exact amount of insolation depends on the location and time of year.

While it is difficult to accurately estimate how much solar energy a site will receive on any given day, it is possible to predict insolation fairly accurately on a monthly or annual basis.

Solar insolation is measured using a device called a pyranometer. For small systems, however, it is not necessary to buy or install an expensive pyranometer. Monthly daily insolation information is collected and kept by national and international agencies around the world. Insolation data for your site may be kept at a nearby meteorological station or at a government meteorological district office. It is also be available online.

Two online sources that can be used is: PVGIS and Power Data Access Viewer (previously RETSCREEN)

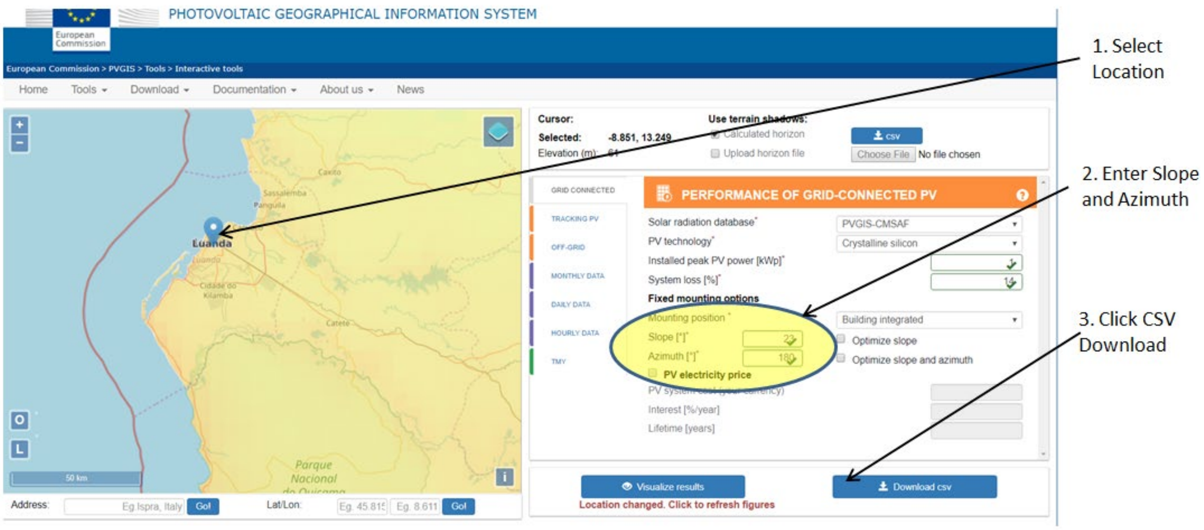
Table 5: Insolation Sources

Source	Link	Notes
Power Data Access Viewer	https://power.larc.nasa.gov/data-access-viewer/	Maintained by NASA
PVGIS	https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html	Maintained by the European Commission

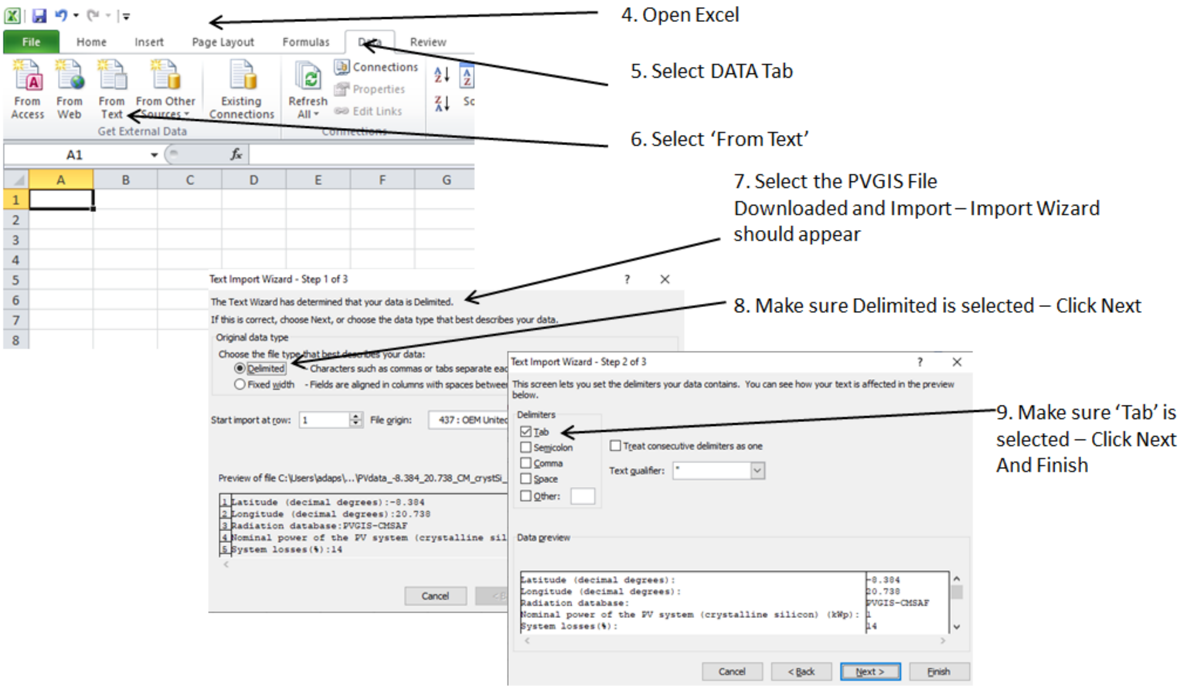
1.3.1 Getting Insolation data from PVGIS

The following procedure can be followed to get the insolation data from PVGIS:

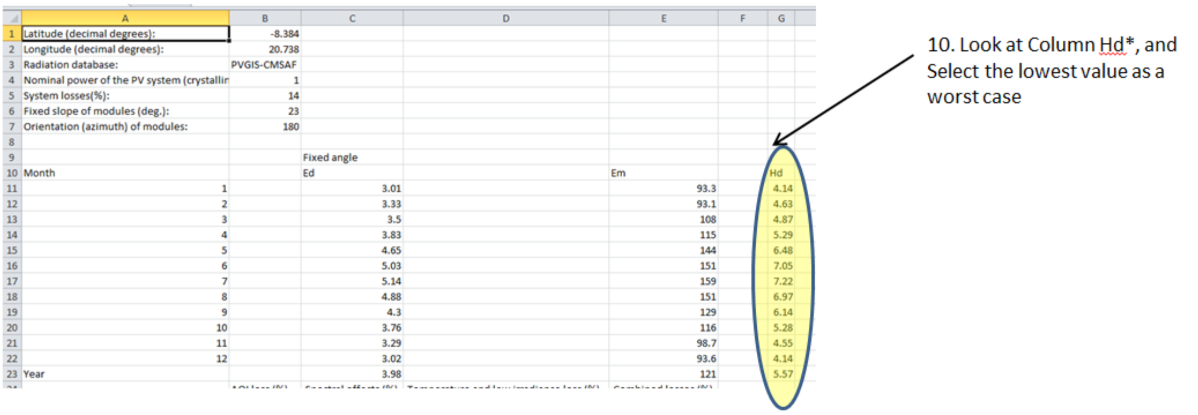
- Step 1 – Select location
- Step 2 – Select Slope and Azimuth
- Step 3 – Click Download data



- Step 4 – Open Excel
- Step 5 – Select DATA tab
- Step 6 – Select ‘From Text’
- Step 7 – Select PVGIS file downloaded
- Step 8 – Make sure ‘Delimited’ is selected
- Step 9 – Make sure ‘TAB’ is selected



- Step 10 – Look at the Hd* column to get average daily insolation per month. Hd is the average daily sum of global irradiation per square meter received by the modules (kWh/m^2)

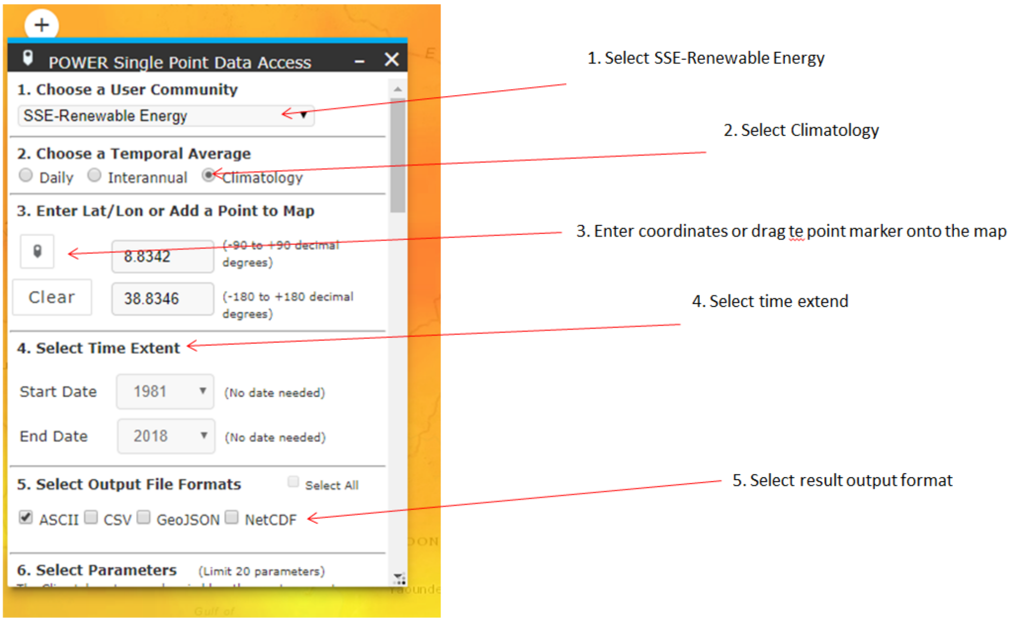


	A	B	C	D	E	F	G
1	Latitude (decimal degrees):	-8.384					
2	Longitude (decimal degrees):	20.738					
3	Radiation database:	PVGIS-CMSAF					
4	Nominal power of the PV system (crystallin	1					
5	System losses(%):	14					
6	Fixed slope of modules (deg.):	23					
7	Orientation (azimuth) of modules:	180					
8							
9			Fixed angle				
10	Month		Ed		Em		Hd
11		1	3.01		93.3		4.14
12		2	3.33		93.1		4.63
13		3	3.5		108		4.87
14		4	3.83		115		5.29
15		5	4.65		144		6.48
16		6	5.03		151		7.05
17		7	5.14		159		7.22
18		8	4.88		151		6.97
19		9	4.3		129		6.14
20		10	3.76		116		5.28
21		11	3.29		98.7		4.55
22		12	3.02		93.6		4.14
23	Year		3.98		121		5.57

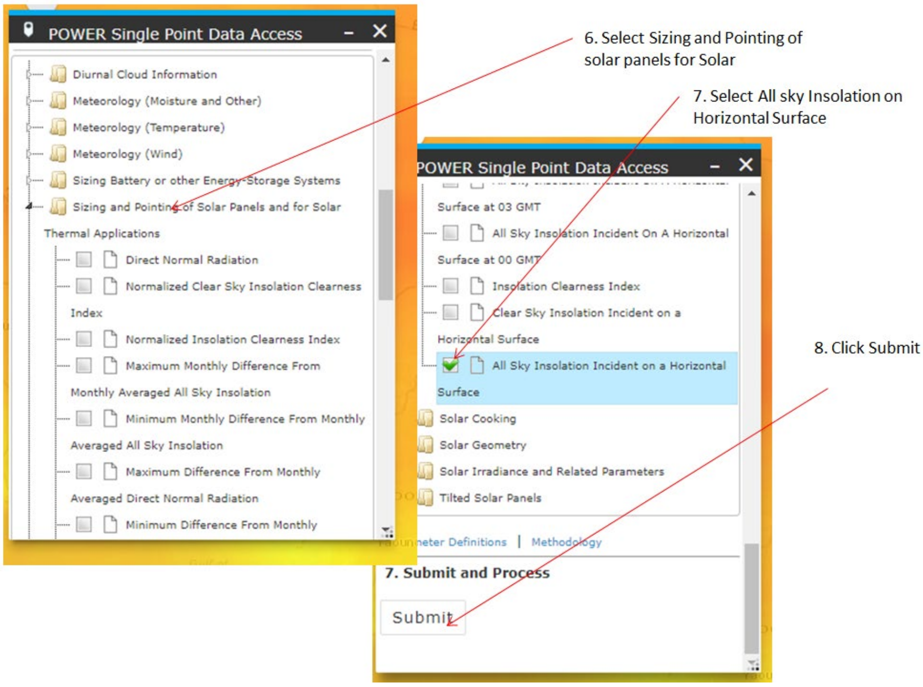
1.3.2 Getting Insolation Data from Power Data Access Viewer

The following procedure can be followed to get the insolation data from RETSCREEN:

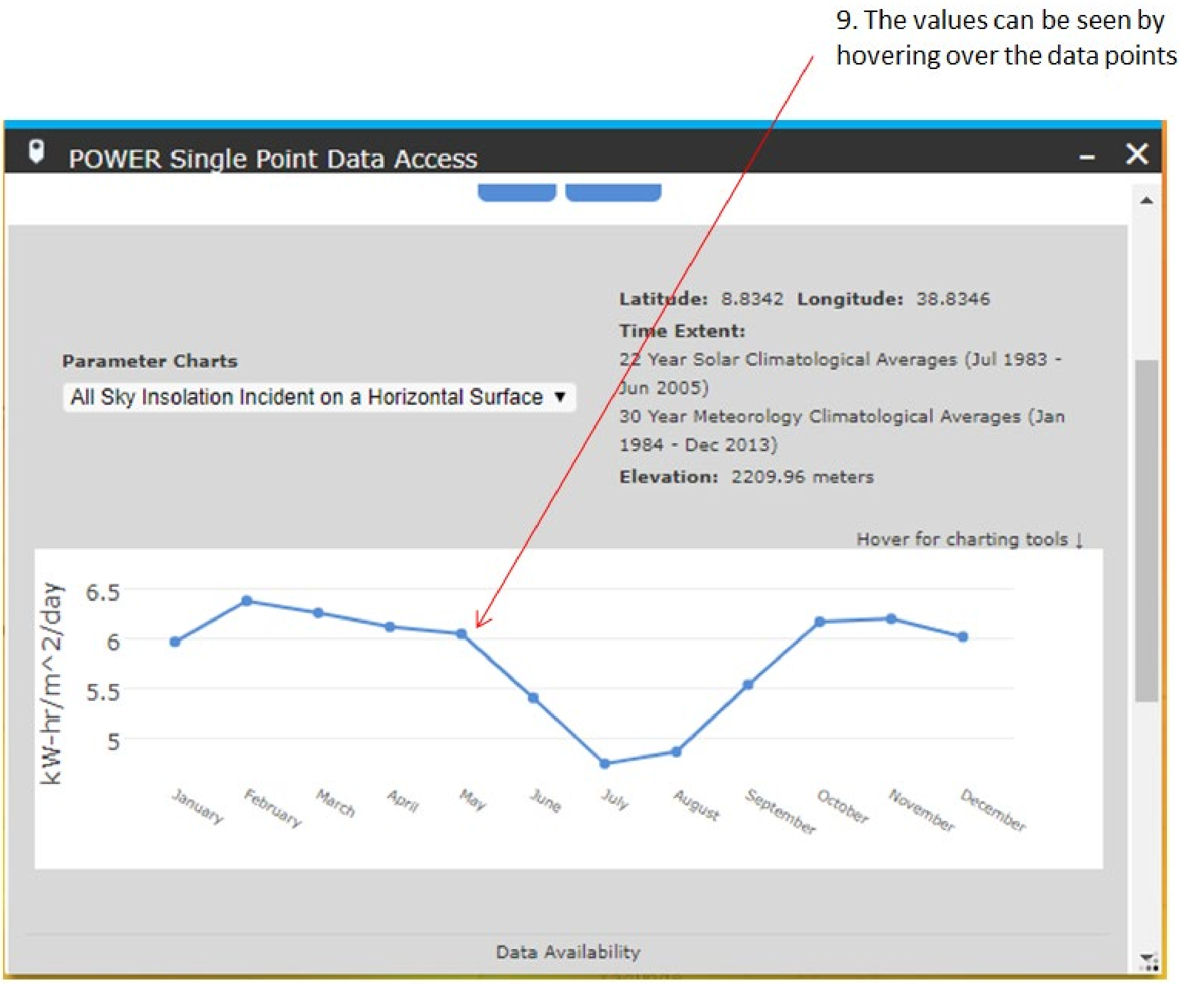
- Step 1 – Select SSE-Renewable Energy from Power single point Data Access Menu
- Select Climatology
- Enter coordinates or drag point marker onto the map
- Select time extend
- Select result format



- Select Sizing and Pointing of solar panels for solar
- Select All sky insolation on horizontal surface
- Click Submit



- The values can be seen by hovering with the mouse over the monthly data points



1.3.3 Interpreting Insolation Data

It is quite important to understand the insolation data received from the various sources. One important distinction between PVGIS and Power Data Access Viewer is that PVGIS calculate the insolation on the module plane (in other words, based on the slope and azimuth entered), while Power Data Access Viewer give insolation on a horizontal plane (in other words 0 degree slope). To explain the difference, Figure 39 shows a graph of PVGIS data for a specific point at North 30 degree angle, PVGIS data at 0 degree angle and Power Data Access Viewer data (no option to specify slope). As expected, there is a very good correlation between PVGIS at 0 degrees and Power Access Data Viewer as both are on the horizontal plane, but there is a significant difference for PVGIS at 30 degree angle.

This means that if any source that provide data that is not measured on the module slope and azimuth, needs to be compensated for when sizing the array.

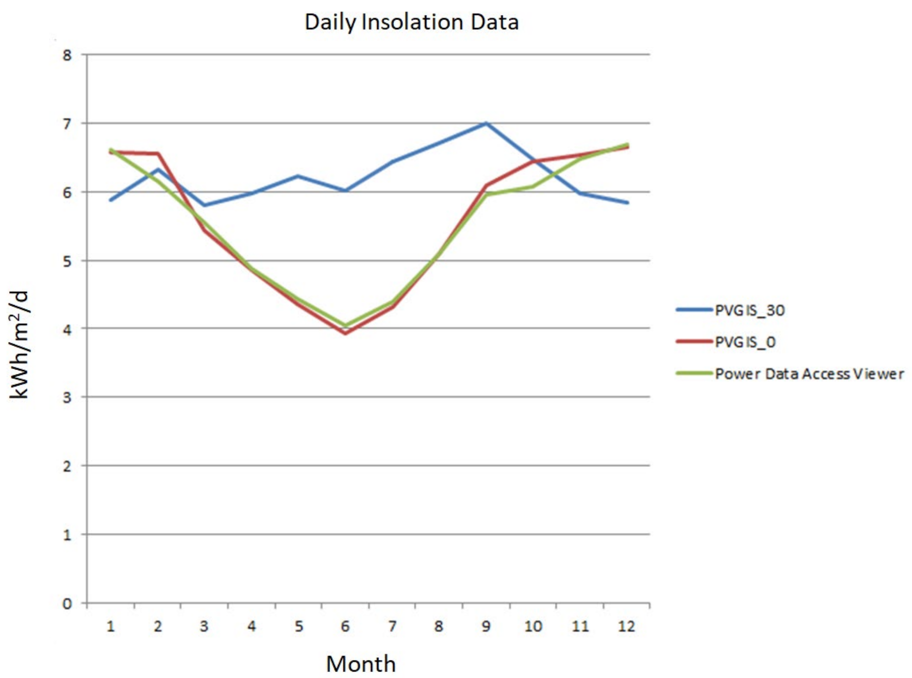


Figure 39 : Insolation Data

1.4 Calculating minimum solar insolation

For an off-grid PV system, one usually designs according to the worst case scenario, i.e. the month with the lowest insolation. If the system will work for the worst month, it will work for all the other months as well.

In rare cases where the system is used only for portions of the year (e.g. only summer months), then the insolation for that period can be used.

The insolation based on the Adama design can be tabled as shown in Table 6. The Adama design roof is sloped at 20 degrees East-South-East

Table 6: Average Daily Insolation data per month for Adama

J	F	M	A	M	J	J	A	S	O	N	D	Ø
7.31 kW/ m²*d	7.61 kWh/ m²*d	7.3 kWh/ m²*d	6.28 kWh/ m²*d	5.83 kWh/ m²*d	5.68 kWh/ m²*d	5.35 kW/ m²*d	5.57 kWh/ m²*d	6.15 kWh/ m²*d	7.14 kWh/ m²*d	7.2 kWh/ m²*d	7.3 kWh/ m²*d	6.56 kWh/ m²*d

As can be seen, in this case the worst month is June with an average daily insolation of 5.35kWh/m^2/d or 5.35 peak sun hours per day.

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**Solar energy arrives at the edge of the Earth's atmosphere at a constant rate of about 1350 watts per square metre (W/m2)**
	True or false:
2	**Insolation is measured in kWh/m^2/day and is also referred to as 'sun hours'**
	True or false:
3	**We normally use the average insolation of the best month in the year to design the PV Array?**
	True or false:

Note: the satisfactory rating is as followed

Satisfactory	3 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

Information Sheet 2	Calculating array size

2 Calculating array size

2.1 Introduction

In order to calculate the size of the PV array required for a specific location, two pieces of information is required:

- Daily energy consumption, i.e. how much energy do we need to supply by the array; (Covered in LO1, Information Sheet 2)
- Insolation, in other words how much energy can we get from the sun. Covered in LO3, information sheet 1)

Once we get these two values, we can calculate the size of the array. It is also important to compensate for system losses.

2.2 System losses and efficiency

Energy is always lost due to inefficiencies in cables, modules, batteries, charge controllers and inverters. The extra amount of energy lost must be estimated and added to the daily energy demand. As a general rule, the loss for DC loads is about 20% and for AC loads about 35%.

One can attempt to calculate all losses as shown in Table 7.

Table 7: Table to calculate losses

Efficiencies [ɲ]	Efficiency	Efficiency Range	Project Efficiency
Deviation MPP / Type of the CC	$ɲ_{CC}$	0,9-0,95	0.95
Line Losses between Battery and Generator	$ɲ_{cable-bat}$	0.97	0.95
Line Losses between Battery and Inverter	$ɲ_{cable-inverter}$	0.97	0.95
Battery Charge and Discharge	$ɲ_{bat}$	0.8-0.9	0.95
Efficiency of the Charge Controller	$ɲ_{CC}$	0.9-0.98	0.95
Efficiency of the Inverter	$ɲ_{inv}$	0.85-0.95	0.90
Influence of the Ambient Temperature	$ɲ_{Tenp}$	0.9-0.95	0.95
Insolation	$ɲ_{incl}$	0.9-1.1	1.00

The total efficiency will be the product of all individual efficiencies e.g.

ɲTotal = ɲ1 x ɲ2x … ɲx.

In practice though, an assumed efficiency of 65% (35% losses) is often used.

2.3 Calculating array size

To calculate the array size, the following formula can be used:

$$P_{PV} = \frac{E}{G \times \eta} = \frac{\text{Energy Consumption in } [\frac{Wh}{d}]}{\text{Peak Sun Hours in}[h] \times \text{System Efficieny}}$$

Where:

E = Energy consumption (Wh/d or kWh/d)

G = Insolation (kwh/m^2/day), also peak sun hours

ɲ = System efficiency

As an example, let's use the Adama design to calculate the PV array size with a daily energy consumption of 12964Wh (See Table 2), worst case peak sun hours of 5.35 (see Table 6) and 65% system efficiency:

$$P_{PV} = \frac{E}{G \times \eta} = \frac{12964\,[\frac{Wh}{d}]}{5.35[h] \times 0.65} = 3728Wp$$

2.3.1 Determining number of Modules

Once the array size has been determined, the number of modules required can be calculated as follows:

$$n = \frac{P_{PV}}{P_{mod}}$$

Where:

n= the number of modules required

P_{PV} = the calculated PV array power

P_{mod} = the module power at STC

The number of modules (n) is usually rounded up.

For the Adama example, the calculated number of Phaesun PN6M72-350 E modules is:

$$n = \frac{P_{PV}}{P_{mod}} = \frac{3728\text{Wp}}{350\text{Wp}} = 10.65 \text{ modules} = 11 \text{ modules}$$

In practice, the number of modules is often increased to compensate for module degradation. Modules degrade in the region of 20% over 25 Years. For the Adama example, we selected 14 modules.

Total PV Size = 14 modules a 350Wp = 4900Wp

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**As a general rule, the loss for DC loads is about 20% and for AC loads about 35%**
	True or false:
2	**The number of modules required is calculated by dividing the Calculated PV array (kWp) size into the module size (Wp)**
	True or false:

Answer all the questions listed below. Use the Answer sheet provided in the next page:

N°	Questions and answers
1	Calculate the PV array size with a daily energy consumption of 1750Wh, worst case peak sun hours of 5.25 and 65% system efficiency:

Note: the satisfactory rating is as followed

Satisfactory	3 points
Unsatisfactory	Below 3 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

Information Sheet 3	Adjusting array size based on the environmental factors

3 Adjusting array size based on the environmental factors

3.1 Introduction

It is important to consider the local environmental conditions when designing a solar system as it can have a profound influence on the size of a system required.

3.2 Environmental factors

3.2.1 Insolation

Insolation (kwh/m^2/day) values differ from place to place and also from month to month. It is therefore important to get the insolation values for the specific location. Information sheet 2 deals with getting insolation values.

Most of the environmental conditions like cloud cover, particles in the air, location etc. are already accommodated for in the insolation value for a site.

If the insolation data source provide insolation data for the horizontal plane and not the actual module plane (see Figure 40), it is important to compensate for the difference as it will affect the size of the PV Generator.

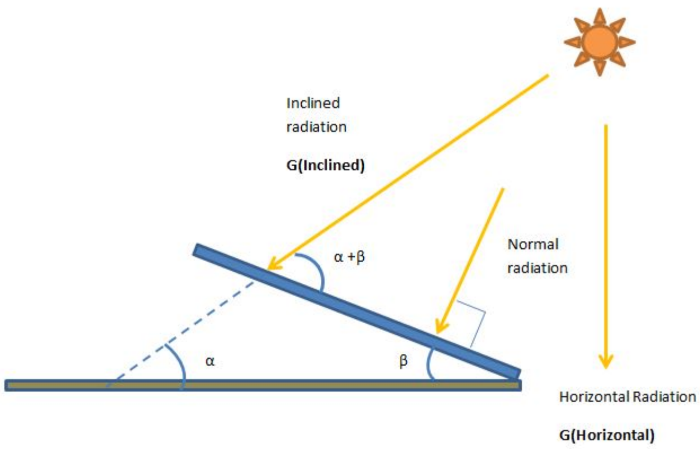


Figure 40 : Insolation planes

As we look at the average insolation for the 'worst' month (see 2.3 above) when we size the PV Generator, there can be a significant difference between worst month for the module plane and worst month for the horizontal plane as can be seen in Figure 41. If the horizontal plane insolation is used, the net effect will be a generator that is significantly oversized.

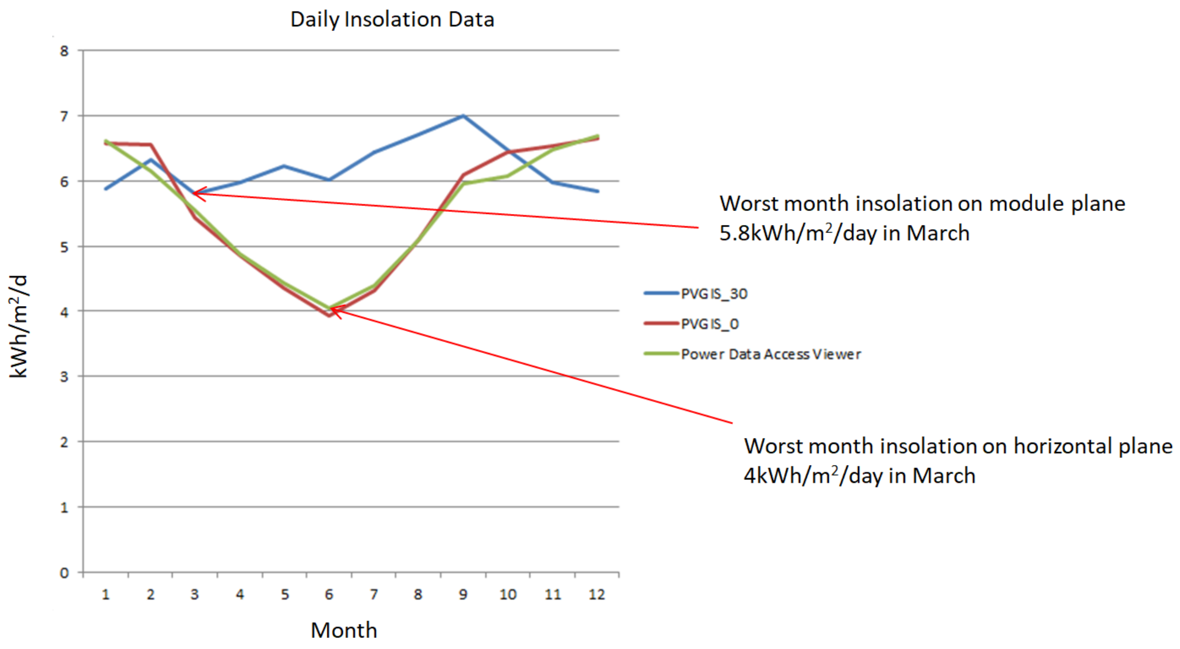


Figure 41 : Insolation difference between horizontal- and module planes

3.2.2 Temperature

Temperature does have an effect on the output of PV systems. Crystalline PV modules have a negative temperature coefficient for power which means that as the temperature rises, the power decreases. This is one of the parameters considered when calculating the PV array size and is encapsulated in the efficiency factor used in Table 7of information sheet 2.

3.2.3 Shading

Shading in PV systems should be avoided as far as possible. If it is unavoidable, the effects of shading should be considered when sizing a system. The effect of shading can also be reduced by planning strings to ensure that shaded strings are kept on separate charge controllers/MPPT trackers where possible.

3.2.4 Dust

In areas with a lot of dust, PV array sizes may needs to be increased to compensate for the loss of power due to dust. The effect of dust can also be mitigated by regular cleaning of the modules.

Self-Check - 3	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**Insolation (kwh/m^2/day) values differ from place to place and also from month to month**
	True or false:
2	**Temperature has no effect on the output of a PV system**
	True or false:

For each of the following question choose the best answer and circle the letter of your choice.

N°	Questions and answers	
1	**The best angle for a PV module is:**	
	A –0 Degrees	B – 30 Degrees
	C – 90 Degrees	D – It depends on location
1	**PV Modules should preferably:**	
	A – Only Face North	B – Face the equator
	C – Only Face South	D – Always face East

Note: the satisfactory rating is as followed

Satisfactory	3 points
Unsatisfactory	Below 3 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date