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Fakulta elektrotechnická

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Optimalizace náklad výroby elektrické energie

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Poděkování

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Téma

Optimalizace nákladů výroby elektrické energie fotovoltaicke elektrárny

Anotace

Předkládaná práce se zabývá analýzou a optimalizací obnovitelných zdrojů, zejména solární energií. V první části, která navazuje na mou SDZ práci, se zabývám spíše teoretickým základem problematiky. Hlavním přínosem práce je však analýza fotovoltaické elektrárny nacházející se ve Španělsku v provincii Murcia. Pro potřeby analýzy jsem sestrojila sérii excelovských tabulek, které po zadaní zakladních údajů dopočítávají data potřebné pro kvalitní návrh fotovoltaického pole a které dále slouží jako základ pro zakreslení fotovoltaické elektrárny v AutoCAD. Součásti excelu je i výpočet úspory CO_2 a SO_X stejně jako nástroj pro výpocet ekonomické analýzy pole.

Klíčová slova

Obnovitelné zdroje energie, Solární energie, Fotovoltaický panel

Theme

Optimization of Power Generation Costs of Photovoltaic Power Plant

Annotation

This thesis is focused on the analysis and optimization of renewable sources of energy, namely the photovoltaic energy. In the first part there is a theoretical base of the issue of photovoltaic energy. Nevertheless the most important part of this work is the analysis of photovoltaic field situated in Spain in the Murcia province. To evaluate and analyze this power plant I created several excel sheets and tables which provide the calculation of data needed for the analysis of this field. Inputing few basic data the excel calculates the rest of it. It is suitable for the comparison of various scenarios of power plant design as well as for the economical study calculation.

Key words

Renewable sources of energy, Solar energy, Photovoltaic panel

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1 Introduction

Solar electric or photovoltaic power is a clean and renewable energy, with easy installation and maintenance. Although solar PV represents only 0.001% of the electricity supply that meets consumer needs worldwide, provides a rapid and significant growth of its implementation, based on the current development of technology and environmental commitment more developed countries.

The photovoltaic sector is based on cutting-edge technology and leading industry in recent years is having an average annual growth of over 30%.

In the medium term, is estimated to be a further reduction in costs due to an improvement of the efficiency of existing technologies, to the optimization of manufacturing processes, the application of economies of scale and to develop new technologies.

Although traditionally the use of solar photovoltaic applications has been isolated from the mains, in recent years the incorporation of this technology to the urban environment is facilitating dissemination and development. It is necessary to consider that the photovoltaic power generation is the only one that can produce from a renewable source, where electricity is consumed.

The photovoltaic panel production in Spain has the one of the most advanced technologies and Spanish manufacturers have production facilities and processes that put the country in third place worldwide, after the United States and Japan.

In Spain there are more than 25 research facilities and universities that take part in the performance investigation. The development of photovoltaic panels with higher efficiency and lower cost of manufacture and improving the efficiency of power electronic devices which is one on the main goal.

Policies implemented by the Spanish government fostered the growth of the PV market through 2008, with output growing from 35 MW in 2005 to 110 MW in 2006, securing Spain the second position among European PV markets. Spain topped the European market for new installations in 2008.

After the record-breaking year in 2008, the Spanish government placed a cap on new PV installations, which caused the PV market in Spain to plummet to an estimated 70 MW of new installations in 2009. This unprecedented rise and fall in PV plant installations prompted the government to establish a new legal framework that limits the number of new PV installations to a 500 MW per annum.

At the end of January 2011, the government also decided to reduce the number of hours during which facilities can be operated over the next two years by 30%. This new regulation, which would apply retroactively to pending applications, has been challenged by the EU authorities and PV sector professionals. [17]

EU Heads of State and Government have committed to reduce greenhouse gas emissions by 80-95% below 1990 levels by 2050. As recognized in the Energy Roadmap 2050 published by the European Commission, this will imply a complete decarbonisation of the energy sector.

On 6 June 2012, the European Commission presented a Communication on the strategy for the deployment of renewable energy, outlining options for the period beyond 2020.

Preparing the grids and the markets of tomorrow requires a reliable forecast of the future energy mix. Given the lifetime of upcoming investments in grids and new generation capacities, technology-neutral decarbonisation strategies will have to face a “cost of uncertainty” that could even lead to lock-in, suboptimal solutions. An agreed vision of the future energy mix should therefore be developed.

On the road to 2020, a continued commitment to R&D and innovation will be needed. The full implementation of the priorities identified in the Solar Europe Industry Initiative (SEII) will ensure a further maturing of technology while supporting the transition towards a sustainable energy mix as part of a strong European industrial policy. [27]

1.1 Target of the thesis

There are many kinds of analysis how to evaluate the potential, productivity, output and many other parameters as well as economical analysis or reliability and viability analysis.

A reliability analysis of a system will always be based on a wide range of assumption and boundary conditions, such as which parts of the system will be used in the analysis and which are negligible. Precisely which are the objectives of analysis or which model will be used and so on.

I have been given a task to help evaluate why one production plant in Spain does not meet the expected production. I have data of daily production.

My targets are to analyze this photovoltaic installation. One on the first things I did was to see if there are some shadows, if the plant was designed correctly or if there is a problem in this. The installation is situated on 2 roofs which are slightly inclined.

For this I need to calculate the longitude of shadows at the roof. There are shadows of panels, chimneys and building design itself. I needed to create a program, perhaps excel, which will calculate the needed measures for purposes to draw them in AutoCAD or some similar program.

If I find out that the design is wrong, there will be suggested some remedial measures to meet the expected production. However if the problem will not be this, I will do comparison with PVgis data or some similar web page.

My target is to prepare data to work with them and to do final economical analysis and to fully evaluate the operation of this specific power plant.

Part of my work I would like to create an excel file, which would help with the analysis.

2 Renewable sources of energy - photovoltaic

There have been told and written so much about renewable sources of energy. It is one of the most popular themes in today's newspapers, TV news and even among the scientists and researchers.
To give thorough explication and research on renewable sources I think there is no need for that. Everybody knows or had heard of it, especially if it deals with the photovoltaic power. Nevertheless I will give some basic information about the solar energy and how to use it.

Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaic include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. Solar cells produce direct current electricity from sun light, which can be used to power equipment or to recharge a battery. The first practical application of photovoltaics was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. In this case an inverter is required to convert the DC to AC. There is a smaller market for off-grid power for remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing, and cathodic protection of pipelines. [1]

Nowadays solar panels are even used in architecture as a part of design buildings or even as a construction material.

Below is a distribution of sun irradiation in Europe.

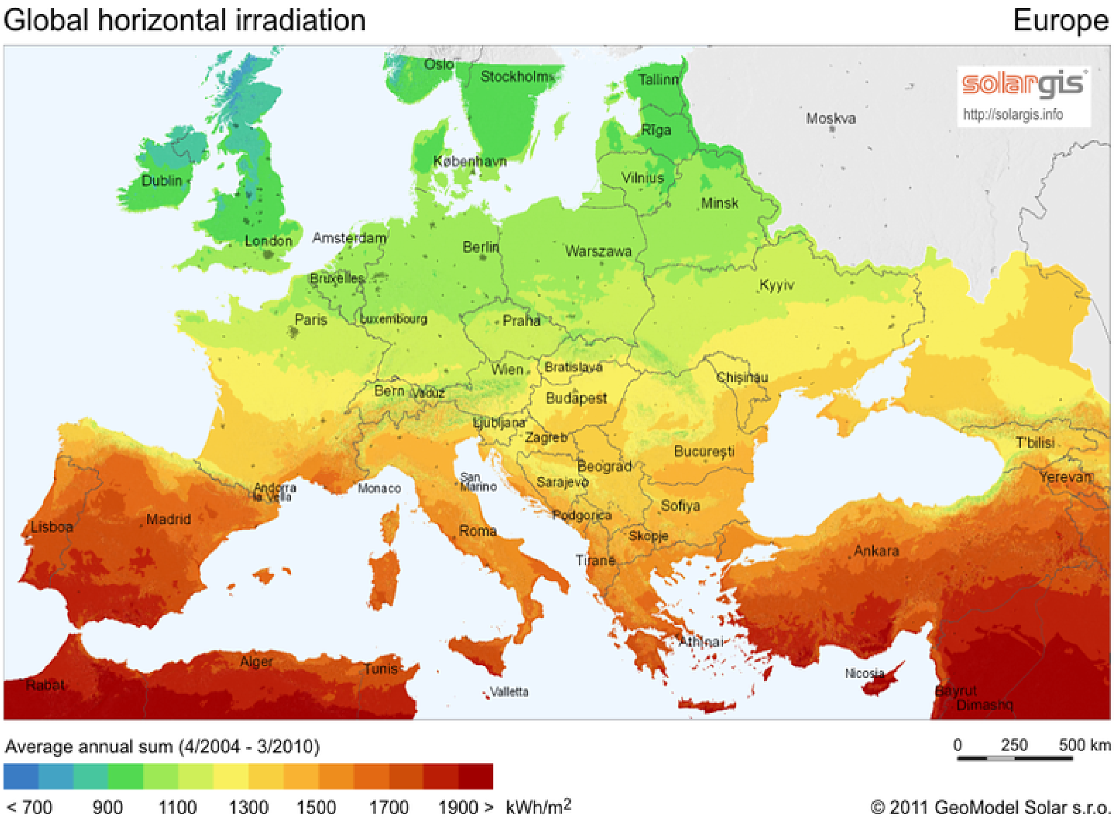

Figure 1: Global horizontal radiation [1]

Photovoltaic cells are developed for over 50 years now. Overall we can distinguish 4 generations. The first generation panel was made from the plates of mono-crystalline silicon, nowadays it is still the mostly used type.

The second generation is made from poly-crystalline, micro-crystalline or amorphous silicon. Compared to the first generation, these are cheaper, due to using a smaller amount of silicon and can be used on flexible bending (cloths, roofing, etc.).

The third generation, it does not use the silicon, but organic polymers. Until now they have not been used much and finally fourth generation is made from composite cells made of various layers. It is able to use wider solar spectrum because each layer uses a different wave length.

	General eff	Max eff in lab
Mono-crystalline	14-17 %	25%
Poly-crystalline	13-16%	20%
Amorphous	5-7%	12%

Table 1: General efficiency [22]

2.1 Nowadays situation of photovoltaics in Europe

The photovoltaic (PV) market has developed rapidly over the last few years, currently representing around 50% of the aggregate global capacity. Decreased costs, high investor interest, and continuing political support have all contributed to the market increase. [17]

The sector of PV is highly dependent on the political situation. In nowadays situation, as there is a strong demand and rapid growth the governments are taking steps all over the Europe. Here are some examples.

France

The French government established a three-month moratorium on approval of new PV installations as of December 2010. That moratorium ended on March 9, 2011. Subsequently, the government promulgated a revised PV feed-in tariff program as part of a new regulatory framework.

The new regulations set the annual target production of electricity at 500 MW, further provide for an automatic quarterly adjustment of the feed-in tariff according to the volume of project applications, and require mandatory calls for tenders concerning large roof-panel installations and solar farm projects. In addition, new projects will have to comply with certain requirements regarding environmental quality and provide a bank completion guarantee. [17]

Germany

The German government promoted the PV sector through feed-in tariffs and other incentives that were introduced by the Renewable Energy Act in 2000. Germany's cumulative solar PV installed capacity increased from 195 MW in 2001 to 5,337 GW in 2008. By the end of 2009, Germany's PV energy output had increased substantially to 9.8 GW.

The feed-in tariffs were charged to all consumers and covered the 1 billion Euros per month cost of subsidizing new PV installations. In response to complaints that the system was over-subsidizing the renewable energy industry and costing the consumer too much, the German government decided, at the end of January 2011, to advance the date of the next price reduction for purchasing electricity by six months. This price reduction will amount to between 3% and 15% effective July 1, 2011, depending on the sector's growth. [17]

Italy

The PV market substantially increased in Italy after a series of incentives known as “Conto Energia” went into effect in 2007.

Under this favorable legislation, if a PV producer installs a power plant that not only generates electricity for domestic use but is also linked up to the local grid, that producer will be able to save money on the power he no longer buys from Enel, the local power provider. He will also be entitled to sell any excess electricity to Enel at a fixed price (feed-in tariff), which will subsidize its initial investment.

The government’s strong support of the PV industry through feed-in-tariffs contributed to rapid growth in the PV sector in Italy, particularly in the residential field. In 2011 the Italian PV market continued to expand, growing a full 100% to 3.9 GW, up from 1.95 GW in 2010. [17]

Czech Republic

Since 2009 the Czech Republic has grown to be a leader in Europe for the use of PV energy. Our country has been fueled by foreign investments, creating a solar boom comparable to that in Spain in 2008. As a result, the output of this newly installed PV plants was the third highest in the European Union in 2010 and topped 1,000 MW.

However, the government undertook measures to drastically reduce the number of new PV plant installations. It cut more than 50% of the feed-in tariff for solar power plants with an output of over 100 kilowatts, imposed a 26% tax on PV energy from PV plants with an output of over 30 KW production for the next three years as well as 32% tax on carbon credits awarded to solar companies in the next two years, and implemented higher fees for the use of farmland for building PV plants.

As from January 2011, the new taxes were retroactively applied to all ground-mounted PV plants built in 2009–2010, which means a decrease of the purchase prices of solar energy under the feed-in tariffs that were supposed to be guaranteed to investors by the government for 20 years. The proceeds from the taxes was used to reduce the increase in household and industrial electricity prices next year. [17]

3 Principle parts of the installation

3.1 Photovoltaic system

To use the energy produced by the solar cell, we must add not just the consumer but also other technical parts, such as accumulator battery, recharging control device, tension chopper, indicating and measuring equipment and in some cases also Sun movement tracking device. For stand alone installations and inverter, protections, controlling measurements and others for the grid connected system. All these devices together are called the photovoltaic system. The number and lay-out of these devices depends on the usage of the system. We can differentiate 4 photovoltaic systems:

Small application:
This is the least but certainly not the last part on photovoltaic market. These small applications are, for example, cells in calculators of solar chargers for accumulators.

Isolated systems (off-grid):
They are used in areas, where it is not economical or it is impossible to build the power grid. For example the costs to build a new connection are equal or higher than the photovoltaic system (distance from the power grid is more than 1000 m, cottage, traffic signals and telecommunication device).

Network systems (on-grid):
These belong to an area with dense power grid. In the case of sufficient solar radiation, devices in the building are charged by the energy coming from solar cells and if there is more that can be used, this electrical energy is fed to the grid. But if there is not enough of radiation, these devices are supplied from the regular power grid. This system works on its own thanks to micro-processor controlling of a grid chopper.

BIPV - Building Integrated Photovoltaic:
As the name suggest, this is the photovoltaic integrated into buildings, for example in the façade of a building or on its roof. This way of usage contributes to its popularity and has significant impact on cost reduction.

These are the four main ways how to use the photovoltaic panels.

3.2 Solar panel

Solar panels can be taken for one of the best modern inventions, from the point of view of ecology. Solar panels are modules that use the energy from solar radiation, and there are various types, such as household producing hot water or photovoltaic solar panels that produce electricity.

In another definition could be that the solar panels are electricity generating element and can be put in series and / or parallel to obtain the required voltage. These panels are formed by a number of cells which are protected by glass, a plastic encapsulated on and the whole framed by a metal profile.

These cells take advantage of the photovoltaic effect, whereby the light energy produces positive and negative charges on two different types of semiconductors next to each other, so electric field is produced. Photovoltaic solar panels can also be used in solar vehicles. The standardized parameter to classify its power is called peak power, and corresponds to the maximum power that the module can deliver under standardized conditions, which are [24]:

- Radiation of 1000 W / m²
- Cell temperature of 25 ° C.

Photovoltaic panels are divided into:

- Mono crystalline: sections are composed of single crystal silicon (Si) (recognizable by their circular or octagonal shape).
- Poly crystalline: when formed by small crystallized particles.
- Amorphous: when silicon has not crystallized.

The efficiency of the cell is greater the larger the crystals, but it also depends on its weight, thickness and other environmental conditions. The mono crystalline performance can reach 20% while the amorphous one usually cannot reach 10%, but its cost and weight is much lower.

The cost of photovoltaic panels has declined steadily since the first solar cells was fabricated and its average cost of electricity generation is getting lower every year.

Throughput is defined as the ratio between the maximum electric power that can supply a photovoltaic cell and the light power impinging on its surface.

The yield obtained in the laboratory on mono crystalline silicon cells is 22% - 24%, but once that is passed to mass manufacture it goes down to an approximate value of 15%, which means that for every 100 watts we get only 15 are used for our use. [26]

The fact that such low performance is mainly due to the following factors:

- Insufficient energy of the incident photons.
- Recombination losses.
- Reflection losses.
- Losses from the electrical contacts.
- Series resistance losses.

The term comes from the Greek photovoltaic φώς: phos, meaning "light" and voltaic, which comes from the field of electricity, in honor of the Italian physicist Alessandro Volta, (which also provides the term volt to the unit of measurement of the difference in potential in the International System of measures). The term came into use in England in1849.

The photovoltaic effect was first recognized in 1839 by French physicist Becquerel, but the first solar cell was not built until 1883. Its author was Charles Fritts, who coated a sample of semiconductor selenium with gold leaf to form the joint. This primitive device had an efficiency of only 1%. In 1905 Albert Einstein gave a theoretical explanation of the photoelectric effect. Russell Ohl patented the modern solar cell in 1946, although Sven Ason Berglund had patented earlier, a method that was increasing the capacity of photosensitive cells. [24]

3.3 Inverter

The inverter is a key stone in the photovoltaic electrical system. It allows the conversion of the energy generated by the photovoltaic panels to AC current.

A photovoltaic panels produce DC current and thus loads can be fed only work with this type of current, generally with voltages of 12, 24 and 48V. Loads normally work with AC current and if the installation is connected to the power grid the current must necessarily be of this type. European standards provide for the single-phase 230V / 50Hz and 400V / 50Hz for three phase.

Hence the need to transform the output current into alternating current this task is performed by the inverter which in addition to dealing with the DC / AC conversion adjusts the output voltage to the voltage level of the power supply. The current must have a sinusoidal waveform synchronized with the network and if anything goes wrong even for brief moment, the inverter can be disconnected quickly. In addition, an essential feature for an inverter, is to optimize energy production of the system with respect to the incident solar radiation, through the regulation of Maximum Power Point (MPP). [25]

Optimal technical solutions due to local conditions have led to the classification of three types of inverters and different configurations:

- Centralized Inverter

A single inverter controls the entire system. All chains, consisting of modules connected in series, are gathered in a parallel connection. This solution offers limited economic investment, easy installation and reduced maintenance costs. Instead this type is particularly sensitive to partial shading limiting the optimal use of each chain. It is suitable for solar fields uniforms orientation, tilt and shading conditions.

- String inverter

Each string, consisting of different modules in series, has its inverter representing a mini-independent installation, thanks to this configuration higher yields are obtained with regard to central inverters each device through MPPT reducing losses due to shadows. It is suitable for solar fields with different radiation conditions. It can also be used for systems composed of more geographically distributed solar fields.

- Multi-chain inverter

This type stands between two previous types allowing connection of two or three strings for each unit with orientations, inclinations and different power outputs.

3.4 Supporting structure

The support structure ensures that the solar generator is in ideal angle for the best use of radiation and is being in charge of making photovoltaic modules and panels resistant to the wind, snow, etc.

Just to make the example I suppose that we have an area of 1 m^2 of panel, and in the area where it is installed can occur winds of 200 km / h. The formula expressing the maximum wind pressure is:

$$p=\frac{F}{S}=0{,}11\cdot V^2 \quad (3.1)$$

$$F=0{,}11\cdot V^2\cdot S \quad (3.2)$$

where

F is the force of the wind in kp

v is the air velocity in m / s

S is the receiving surface in m2

p is the pressure of the wind on kp/m2

If we apply the above data 200 km / h = 55.5 m / s we get:

$$F=0{,}11\cdot(55{,}5)^2\cdot 1=338.8\,kp \quad (3.3)$$

This shows the effect that can wind on a group of solar modules, and makes us think about the serious consequences of poor or wrong support structure design.

One must also be careful with the snow, rain, frost, type of environment where the facility is located, etc. Some of the actions described (snow, rain) affect the location and shape of the support bracket, while frosts or certain environments (eg, nearshore) have long term effect on the materials used for the construction of structures.

As for the orientation, it must always be south (if in the Northern Hemisphere), it is the only azimuth where the most of the radiation emitted by the Sun throughout the day can be caught. Only in very special circumstances can vary slightly westward direction or the east, such as in the event of a natural obstacles (mountains, etc..) or due to economic issues.

In general there are several alternatives for the installation of solar modules: architectural integration, architectural overlay ground installation or installation with tracking device.

Integration is considered when the modules have a dual function - energy and architecture. This option would be taken into account in the design phase of the project in order to design the cover with optimum pitch.

Architectural overlay is considered when the placement of the modules is parallel to the building roof which is also our case. Nowadays it is quite popular to do roof installation on buildings with bigger roof area. It is considered as a great way how to use unused space and how to make some more money.

The tracker system will not be described in this thesis because I am dealing just with the roof installation.

3.5 Control and measurement device

Nowadays more than before there is a demand on the system to be able to measure precisely the output and in general the behavior of the solar field. There are quite a lot of systems to provide this.

Many computers on the market include those functions, but in most cases are embedded to drive itself. Many of these systems have a built in alarm that warns us in the event of a major discharge, indicating in advance the possibility deterioration in the storage subsystem.

4 Installation conditions in Spain

4.1 Norms for solar panels in Spain

There are two basic norms for solar panels.

- Norma IEC 61215. Normalmente entidad certificadora TUV
- Norma IEC 61246 Para silicio amorfo y capa delgada.

The following sections give details about what to take into consideration for optimal sizing of the PV. In this case, the number of photovoltaic panels has been calculated to the available surface and aesthetic, architectural and sustainability.

4.2 Performance and life time

The modules manufactured in Spain, depending on the technology and power of photovoltaic cells yield values between 13.5% and 11.5%, ie 1 m^2 of module will have a rated power of 135 Wp and 115 Wp.

The installation performance is also determined by a number of factors among which are:

- tolerance values in the nominal power of the photovoltaic module (between +0% and -10%)
- power loss of module working under operating conditions others than those it had when it was measured its rated power. The module, for example, acquires operating temperatures of 25°C with that measured in the factory (loss between 5 and 10%)
- inverter losses are between 5 and 11%
- other losses, usually voltage drops (usually take 3% approximately).

Therefore, on the rated power module must implement the following values as a first approximation

Installation	Perfor
Small (1-5 kW)	0,75
Medium (5-100 kW)	0,77
Big (100 kW -1MW)	0,80
Power Plant (1-50 MW)	0,82

Table 2: Performance of installation

The life of a photovoltaic plant is the lifetime of its components. If the plant is properly designed and recommended maintenance is performed, you can expect the following values in Spain:

- modules expected life of over 40 years;
- life of electronics is more than 30 years;
- batteries, more than 10 years for lead-acid and more than 20 years for alkaline batteries, nickel-cadmium;
- auxiliary elements such as the installation wiring, conduits, junction boxes etc., can last more than 40 years.

4.3 Climate elements in Spain

4.3.1 Solar radiation

Spain receives a significant amount of solar radiation, with values lower than those recorded in the tropical latitudes, but similar to those observed in the equatorial zone. The available series of data of solar radiation, which is measured in very few places (in 1998 in Spain there were 29 observatories that made national radiometric network), it can be concluded:

1. the average daily global irradiation is less than 15 MJ/m^2 in the Cantabrian fringe and much of Galicia, the Pyrenees and the Ebro valley, do not reach 12 MJ/m^2;
2. the middle peninsular south, Ibiza and Canary Island exceed 16 MJ/m^2;
3. in sectors of the Andalusian coast and part of the Canary Islands, the radiation can exceed 18 MJ/m^2. The maximum daily global irradiation are reached in June and July, with more than 20 MJ/m^2, except the Cantabrian fringe, and even more than 25 MJ/m^2 in the southern half of the peninsula, Canary and Ibiza.
4. The minimum Irradiation is in December, followed by January, with values below 10 MJ/m^2, except in sections of the Andalusian coast and the Canary Islands, also remaining below the 5 MJ/m^2 in Galicia, Cantabrian region, the Pyrenees and part of the valley of the Duero and Ebro.

Another part of the terrain or roof issue is in which zone it is. In Spain there are also 5 climate zones.

In order that the producer can calculate PV output that the panels can give him, and due to the boom that the photovoltaic industry had in 2008 with the Royal Decree Law 14/2010 the government cut the hours that the Iberdrola will pay for depending on the solar zone in which the photovoltaic power plant is situated.

Many photovoltaic producers were confused due to the difference between solar maps published in the IDEA, or in the MITyC, or at CIEMAT. They did not know exactly where their power plant corresponds.

HE Section 5 of the Technical Building Code, entitled "Contribution Minimum PV Electric Building Code," we know the limits of homogeneous zones for the purposes of the requirement.

The zones are defined in the Technical Building Code considering Global Solar Radiation annual daily average surface (H), taking the intervals that relate to each of the areas. [26]

	Zone				
	I	II	III	IV	V
Fixed inst	1232	1362	1492	1632	1753
Inst 1 axis tracking	1602	1770	1940	2122	2279
Inst 2 axis tracking	1664	1838	2015	2204	2367

Table 3: Hours per zone

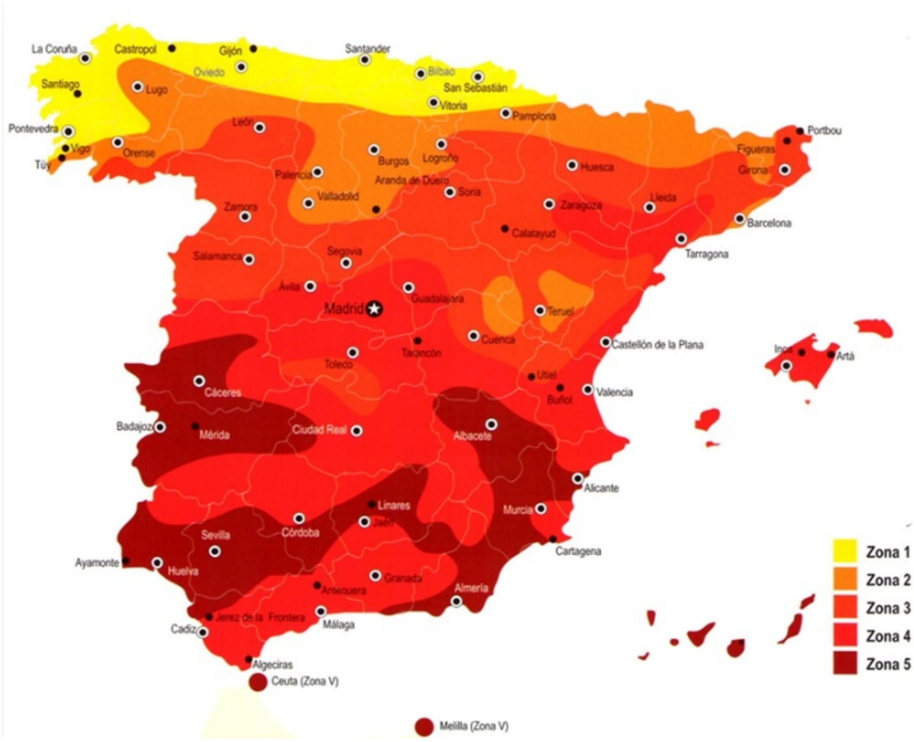

Figure 2: Zones of solar radiation in Spain [6]

4.3.2 Cloudiness

With sunshine data and number of days of clear sky and overcast sky of 88 Spanish observatories the 1961-1990 period, the average annual number of clear days is between only 25.8 in Vitoria airfield and 176.2 in Izaña. The contrast at the mainland of Spain is also quite big where there is a maximum of 155.8 days in Cadiz and the areas with fewer clear days by numbers less than 40 are Asturias, Cantabria, the Basque Country and Galicia inside.

The average annual number of days with the sky completely covered by clouds is from just 13.4 in the airport of Iron and 170.1 and 169.9, in San Sebastian and Vitoria airfield. In Cadiz there are only 53.3 days recorded. In Baleares Islands, the airports of Palma de Mallorca and Ibiza do not reach 50 days. The number of days covered is less than 60 days on the Mediterranean coast from Valencia to Malaga, southern Mallorca, Ibiza, somewhere in the northeast of Catalonia, the Atlantic coast of Cadiz, Lanzarote, Fuerteventura and the remaining southern Canary Islands. Instead beyond the 120 days of covered sky goes Galicia, Asturias, Cantabria, Basque Country, the high Ebro to Logrono, northern Castilla-Leon, part of the Iberian mountain ranges, Central and Pyrenees and humid places the Canaries. [5]

4.3.3 Atmospheric pressure

Atmospheric pressure of Spain is at its monthly maximum in winter, usually in January, and the lowest values in spring, especially in April. The overall seasonal behavior is dependent on the predominance of low relative pressures in the inland areas of the Peninsula in summer, the result of strong warm-air with a consequent drop in atmospheric pressure (1015 - 1017 hPa), while in the front Cantabrian extends a belt of high pressure (1020 hPa) relative to the Azores anticyclone, prolonged dorsal north of Spain, and the prevalence of high pressure in winter heat inside peninsular (1020-1022 hPa) and an area cyclonic Galicia, frequently visited by storms and cold fronts front. [5]

4.3.4 Wind

Due to the diverse topography of Spain there are a lot of areas with the significant wind activity. In each region there are winds depending on the local parameters if it is costal area or a mountain terrain. Apart from them, the sea breeze regime characterizes the coastal atmosphere during the warm half of the year and on other days stable. The trade wind is typical of the Canaries.

Values lower wind activity are in some observatories in the southern Plateau, and in certain regions out of the wind (Bierzo, valleys Orense, Alavese plain interior of Catalonia), while the highest numbers for the period 1961 – 1990 are held Tarifa, followed by two mountain observatories, Izaña and Turo de l'Home (Montseny Barcelona). The mountain tops are windier than depressions; certain ends and coastal areas have elevated paths as well.

In terms of maximum gusts, in that period, the fastest recorded in Izaña, with 200 km / h and 100 km / h having surpassed the vast majority in all Spanish observatories. While the wind does not show a general pattern in their occurrence throughout the year, but the maximum generally occurs in the months of October to March. By combining high tours and gusts of wind, the country's windiest areas are near the Strait of Gibraltar, some coruñeses ends, the coast of Guipuzcoa, northern Navarra, some wheels Ebro Valley, the northern and southern coasts Catalonia, the Canary Islands barloventos the trade winds and the peaks and ridges of the main gates.

4.4 Calculation of solar hour

4.4.1 Sun hours

From the records of insolation of 88 international observatories for the period 1961 to 1990, can be established that the extreme values are in Iza?a, with 3448 hours of sunshine a year, in the clear sky and Bilbao airport, with 1525 hours. In mainland Spain presents the annual average insolation is also a wide variation, since values almost doubled between Bilbao and Cadiz observatory where th e number of sun hours exceeded 3000 hours of sunshine a year. Overall less sunny area of Spain is the Cantabrian coast which does not reach 1750 hours, while there is a greater number of hours of sunshine is the Costa de la Luz, between Cadiz and Huelva, bordering or exceeds the number of 3000 hours. [5]

The number of 2000 hours is the point beyond which the uses of solar energy can reasonably cover many domestic needs. In Asturias, Cantabria, the Basque Country, a Galicia's Atlantic cost and Pyrenees have just about 2000 hours of sunlight. The rest of the country has a lot more of sunshine. The entire southern half of mainland of Spain, the Balearic Islands and much of even large areas of the northern half of the peninsula, such as the western part of the Duero Basin, Aragon and the south of Catalonia, have more than 2500 hours of sunshine a year.

If you know the number of peak sun hours N, to calculate the times of sunrise and sunset daylight referred to solar hour. It is considered that as the central value is noon (at noon, when the sun is in its highest position) the output daylight (sunrise) and sunset (sunset), is the result of subtracting and adding half the number of hours of sunshine midday maximum value:

$$12 \pm \left(\frac{N}{2}\right) \tag{4.1}$$

Previous hours refer to solar hour. It is better to refer this time to a reference meridian. The reference meridian is generally the Greenwich International Meridian, where we obtain the hour UTC (Coordinated Universal Time), also called GMT (Greenwich Mean Time). UTC time is used as a reference to all data collected in the world at that time, thus avoiding confusion and facilitating data synchronization time.

The UTC time is obtained by considering the length referring to the Greenwich meridian. For the correction should be considered the direction of rotation of the Earth's rotation, the earth turns around 360 degrees in 24 hours (i.e. one hour rotates 15 degrees), and if we are on the left or right of the meridian .

So for example if Vigo "INM Peinador Station" is at 8°37'55" W (8.632° W) and the Costa Brava Airport (Gerona) is at length of 2°45'37" E (2.76° E), to adjust the solar hour to the Greenwich meridian we have to ask ourselves:

- If we are at solar noon in Vigo what time is at the meridian of Greenwich International. For the hour that would be 12 hours plus the time taken for the Earth to travel the 8.632 degrees separating the meridians passing through Greenwich and Vigo.
  360 ° → 24 hours
  Degrees 8.632 → 0.57 hours. After 12 + 0.57 h = 12.57 h = 12 h 34 minutes

- If we are at solar noon in Gerona, what time is at the meridian of Greenwich International. For the hour that would be 12 hours less than the time it takes the Earth to travel the 2.76 degrees separating the Greenwich meridian passing through Girona (airport).
  360 ° → 24 hours
  Degrees 2.76 → 0.184 hours. After 12 to 0.184 h = 11.81 h = 11 h 48 minutes

In general, when referring to Greenwich Mean Time (UTC) is:

$$UTC\ Time = Hs + CM \tag{4.2}$$

where

Hs is daylight

CM is length offset in hours considering every hour corresponds to 15 degrees.

If the point is west of the Prime Meridian the correction is positive and negative if the East. The official time of each country is set to UTC by adding the value according to their location (time zones). In Spain (Peninsular) local time is obtained by adding an hour (in winter) and two hours (in summer) to UTC.

4.5 Time calculations

This is an astronomic term that refers to changes which occur over the years on the duration of rotation of the Earth. The value depends on the day of the year and can be obtained graphically or by a formulation, the value obtained in minutes subtract with its symbol the value obtained sunrise and sunset.

Día	Ec.T	Día	Ec.T	Día	Ec.T	Día	Ec.T	Día	Ec.T	Día	Ec.T
1	-2,9	70	-10,7	140	3,8	210	-6,6	280	12,4	350	4,5
5	-4,7	75	-9,4	145	3,4	215	-6,4	285	13,7	355	2,2
10	-6,7	80	-7,9	150	2,8	220	-5,9	290	14,8	360	-0,2
15	-8,6	85	-6,3	155	2,1	225	-5,2	295	15,7	365	-2,5
20	-10,3	90	-4,7	160	1,2	230	-4,3	300	16,2		
25	-11,7	95	-3,1	165	0,2	235	-3,1	305	16,4		
30	-12,8	100	-1,6	170	-0,9	240	-1,6	310	16,2		
35	-13,6	105	-0,2	175	-2,0	245	0,0	315	15,8		
40	-14,1	110	1,0	180	-3,1	250	1,7	320	15,0		
45	-14,3	115	2,0	185	-4,0	255	3,5	325	13,8		
50	-14,1	120	2,9	190	-4,9	260	5,4	330	12,4		
55	-13,6	125	3,5	195	-5,7	265	7,3	335	10,7		
60	-12,9	130	3,8	200	-6,2	270	9,1	340	8,8		
65	-11,9	135	3,9	205	-6,5	275	10,8	345	6,7		

Table 4: Estimated value of the equation of time in minutes (ECT) for different days of the year. The day of the year is calculated from January 1.

4.5.1 Sunrise and sunset

Day length is defined between sunrise and sunset, and can be calculated, as we saw, from hour angle w:

$$w = \frac{N}{7,5} \tag{4.3}$$

The hour angle w has been defined from the latitude δ and declination Φ

$$w = \cos^{-1}\left[\frac{(-\sin\delta \cdot \sin\Phi)}{(\cos\Phi \cdot \cos\delta)}\right] \tag{4.4}$$

This equation can be modified to include different definitions of day length. The different definitions are based on the consideration of the position of the sun relative to the horizon (Ψ, elevation of the Sun above the horizon at sunrise). The introduction of this value modifies the above equation:

$$w = \cos^{-1}\left[\frac{(\sin\Psi - \sin\delta \cdot \sin\Phi)}{(\cos\Phi \cdot \cos\delta)}\right] \tag{4.5}$$

The value of the elevation of the sun Ψ, with respect to the horizon will be zero when the rising and setting sun occurs when the center of the sun is on the horizon. When Sunrise and Sunset occurs when the upper part of the Sun is apparently on the horizon, it is defined as apparent sunset. The effect causes the hour angle interval increases, so that the apparent sunrise occurs before the real one (the same applies for the evening). The hour angle considering the rising and setting sun will be apparent:

$$w = \cos^{-1}\left[\frac{\sin(-0{,}833) - \sin\delta \cdot \sin\Phi}{\cos\Phi \cdot \cos\delta}\right] \tag{4.6}$$

In general, to calculate the times of sunrise and sunset it must be taken into account the equation of time of apparent sunrise and sunset. One can also consider the effect of altitude relative to the environment. So if you are in a high isolation (such as a hill top) the sun appears above, the effect will be zero if we are surrounded by mountains of equal height. To consider the effect of elevation and refraction of the atmosphere (Christopher Gronbeck. Web: SunAngle) can introduce the concept of elevation angle (A)

$$A = -0.8333 - 0.347 \cdot (\mathit{relative\,elevation\;m}) \cdot 0.5 \tag{4.7}$$

Considering the effect of altitude and considering that the rising and setting of the sun occurs when the top of the Sun is apparently on the horizon. The hour angle w will be [9]

$$w = \arccos\left[-1 \cdot \frac{(\sin(\varphi) \cdot \sin(\delta) - \mathit{seno}(-0.8333 - 0.0347 \cdot (\mathit{elevation\ angle}) \cdot 0{,}5))}{(\cos(\varphi) \cdot \cos(\delta))}\right]. \tag{4.8}$$

5 Solar panel

5.1 Equivalent electrical circuit

The physic of a solar panel cell can be represented by the following electrical circuit. PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell.

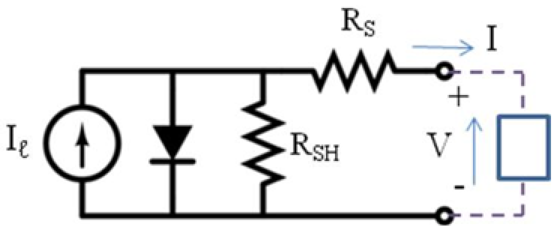

Figure 3: Equivalent circuit model for photovoltaic cell [15]

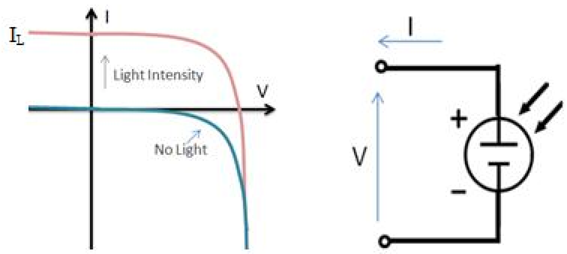

Figure 4: I-V curve of PV cell [15]

In an ideal cell, the total current I is equal to the current I_L generated by the photoelectric effect minus the diode current I_D, according to the equation below.

$$I = I_L - I_D = I_L - I_0 \cdot (e^{(\frac{qV}{kT})} - 1) \qquad (5.1)$$

where

I_0 is the saturation current of the diode,

q is the elementary charge $1.6x10^{-19}$ Coulombs,

k is a constant of value $1.38x10^{-23}$J/K,

T is the cell temperature in Kelvin,

V is the measured cell voltage that is either produced or applied.

A more accurate model will include two diode terms, however, for the purposes of sole explanation of the theory of photovoltaic cell I will concentrate on a single diode model in this thesis.

Expanding the equation gives the simplified circuit model shown above and the following associated equation,

$$I = I_L - I_0 \cdot (e^{\frac{q \cdot (V + I \cdot R_s)}{n \cdot k \cdot T}} - 1) - \frac{V + I \cdot R_s}{R_{SH}} \qquad (5.2)$$

where

n is the diode ideality factor (typically between 1 and 2),

R_S and R_{SH} represents the series and shunt resistances

5.1.1 Electric characteristics of solar panels

There are several characteristics given by the producer.

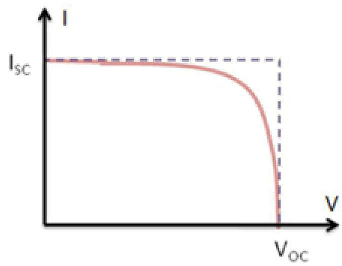

Figure 5: Illuminated I-V sweep curve [15]

- Short circuit current I_{SC}

This is the highest value of current that a panel may sustain. It is measured between panel clamps when the voltage is zero. [15]

$$I_{(at\ V=0)} = I_{SC} \qquad (5.3)$$

- Open circuit voltage V_{OC}

The maximum voltage which can be measured between panel clamps when the current is zero.

$$V_{(at\ I=0)} = V_{OC} \tag{5.4}$$

- Maximum power P_{MAX}

The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation

$$P = I \cdot V \tag{5.5}$$

At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively. [15]

- Maximum current I_{mp}

This is the current at which the panel is working with maximum output.

- Maximum voltage V_{mp}

maximum voltage is the voltage at which the panel is working with maximum output.

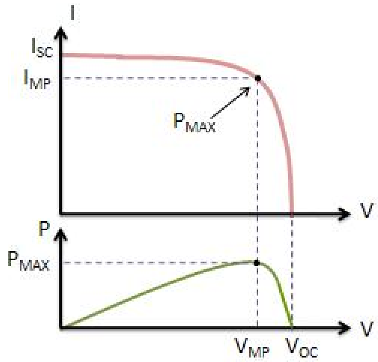

Figure 6: Maximum power for an I-P sweep [15]

- Fill factor (FF)

The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power (P_T) that would be output at both the open circuit voltage and short circuit current together. FF can also be interpreted graphically as the ratio of the rectangular areas depicted in figure below.[15]

$$FF = \frac{P_{MAX}}{P_T} = \frac{I_{mp} \cdot V_{mp}}{I_{SC} \cdot V_{OC}} \tag{5.6}$$

A larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like. Typical fill factors range from 0.5 to 0.82. Fill factor is also often represented as a percentage.

- Efficiency η

Efficiency is the ratio of the electrical power output P_{out} compared to the solar power input, P_{in} into the PV cell. P_{out} can be taken to be P_{MAX} since the solar cell can be operated up to its maximum power output to get the maximum efficiency. [15]

$$\eta = \frac{P_{out}}{P_{in.}} \tag{5.7}$$

$$\eta_{MAX} = \frac{P_{MAX}}{P_{in.}} \tag{5.8}$$

P_{in} is taken as the product of the irradiance of the incident light, measured in W/m^2 or 1000 W/m^2, with the surface area of the solar cell [m^2]. The maximum efficiency (η_{MAX}) found from a light test is not only an indication of the performance of the device under test, but, like all of the I-V parameters, can also be affected by ambient conditions such as temperature and the intensity and spectrum of the incident light. For this reason, it is recommended to test and compare PV cells using similar lighting and temperature conditions.

There are standardized condition at which the panel is working. Such as irradiance 1000 W/m^2, spectrum distribution 1,5 and temperature at which the panel is working 25°C.

At this conditions it is common to measure the panel output, temperature dependence and quality of the panel just to be sure about the specification given by the producer. This is usually done when one buys panels from companies not that well known. [15]

- Shunt resistance R_{SH} and series resistance R_S

During operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances. These parasitic resistances can be modeled as a parallel shunt resistance (R_{SH}) and series resistance (R_S), as depicted in equivalent circuit figure.

For an ideal cell, R_{SH} would be infinite and would not provide an alternate path for current to flow, while R_S would be zero, resulting in no further voltage drop before the load.

Decreasing R_{SH} and increasing R_s will decrease the fill factor (FF) and P_{MAX} as shown in figure below. If R_{SH} is decreased too much, V_{OC} will drop, while increasing R_S excessively can cause I_{SC} to drop instead. [15]

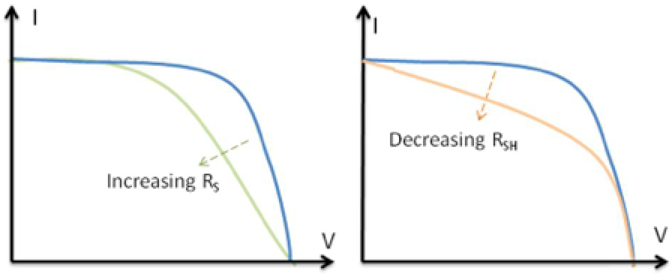

Figure 7: Effect of diverging R_{SH} and R_S [15]

It is possible to approximate the series and shunt resistances, R_S and R_{SH}, from the slopes of the I-V curve at V_{OC} and I_{SC}, respectively. The resistance at V_{oc}, however, is at best proportional to the series resistance but it is larger than the series resistance. R_{SH} is represented by the slope at I_{SC}. [15]

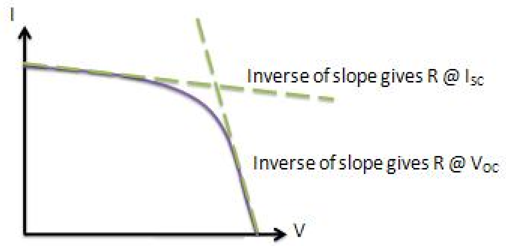

Figure 8: Obtaining resistance from I-V curve [15]

There are 2 more parameters that help to design the photovoltaic plant. It is

- Solar hour peak (hora solar pico)

it is the number of solar hours where the irradiance of 1000 W/m^2 impact the surface of the solar panel. In Spain it is agreed that during the winter time the SHP is 2 and in the summer time it is 4.

- Watt peak (Watio pico)

it is the maximum output that a panel can give when the irradiance is constant at 1000 W/m^2 and the temperature is 25°C.

5.2 Aspects of PV field design

The following sections give details about aspects that were taken into consideration for optimal sizing of the PV. In any case, the area has not been sized according to the energy needs of the building, but has been conditioned to the available surface, architectural and sustainability possibilities.

It is not intended to achieve energy self-sufficiency of the building but pursued the optimum use of the cover in order to install the maximum possible number of photovoltaic generators.

As a general rule we have to decide the layout of the photovoltaic modules, because we have to install them in a place where you get as much sunlight as possible. This leads us to consider in sizing the system three basic factors: the orientation, inclination and possible shadows.

Solar energy as a renewable energy is more abundant and better distributed, but despite its abundance, this energy has two major drawbacks:

- it is highly diffused (low concentration);
- is subjected to a daily cycle and year cycle, caused by movements translation and rotation of the earth.

The major factors which influence the electrical behavior of the photovoltaic cell are

1. Sun intensity
2. Sun angle
3. Ecuatorial coordinates
4. Sun coordinates.

5.2.1 Sun intensity

The output of the solar plant is directly dependent on the sunlight. As we can see in the I-V characteristics the short-circuit current decreases, the reduction in the V_{OC} however is small.

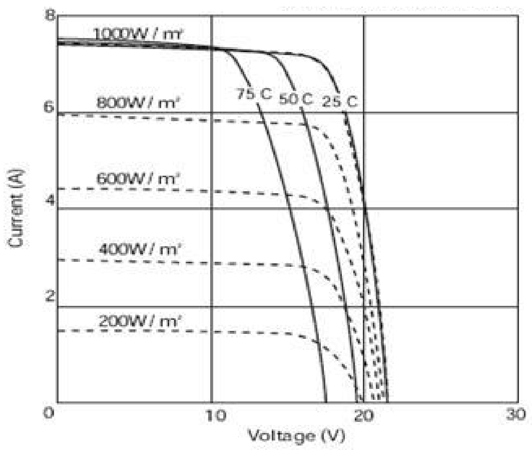

Figure 9: I-V characteristic of PV module [15]

This shows that the conversion efficiency is the same on a bright sunny day as on a cloudy day. We get lower power output at a cloudy day because of the lower solar energy impinging on the cell.

5.2.2 Operating temperature.

Solar-panel is a device that is highly influenced by the temperature. As it was proven the higher the temperature the smaller the output.

- Temperature measurement considerations

The crystals used to make PV cells, like all semiconductors, are sensitive to temperature. Figugure below depicts the effect of temperature on an I-V curve. When a PV cell is exposed to higher temperatures, I_{SC} increases slightly, while V_{OC} decreases more significantly. [15]

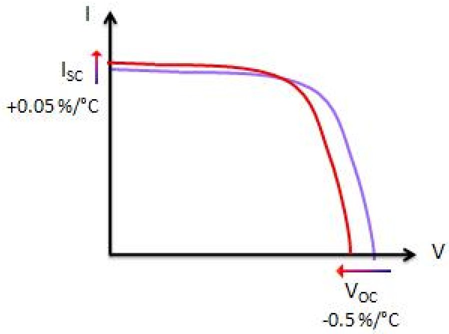

Figure 10: Temperature effect on I-V curve [15]

For a specified set of ambient conditions, higher temperatures result in a decrease in the maximum power output P_{MAX}. Since the I-V curve will vary according to temperature, it is beneficial to record the conditions under which the I-V sweep was conducted. Temperature can be measured using sensors such as RTDs, thermistors or thermocouples.

- TONC

One of the most important parameter is TONC - Nominal operation temperature of the solar cell. The temperature is measured or calculated at following conditions.

Irradiance	800 W/m2
Spectrum distribution	AM 1,5
Impact	Normal
Temperature	20 C
Windspeed	1 m/s

Table 5: TONC conditions

If we know the four basic parameters P_{MAX}, I_{SC}, V_{OC} and TONC we have enough to estimate the behavior of the panel at any condition where we know the Irradiance G and Temperature of environment T_a.

There are 3 cases that should be discussed.
The short-circuit current depends only on the irradiance.

$$I_{SC(G)}=C_1 G \tag{5.9}$$

where
C_1 is a constant

$$C_1 = \frac{I_{SC}(1000\,W/m^2)}{1000\,W/m^2} \tag{5.10}$$

This theory works with the idea that just the radiance will be consider. There is an estimation that the error would be less than 5% in the real conditions.

The open circuit voltage of one solar cell depends only on the temperature T_C.

$$\frac{dV_{OC}}{dT_C} = -230[mV/°C] \tag{5.11}$$

At this case we do not consider the effect of of the irradiance at the V_{OC}. In the real condition there should be and error minor a 1%.

The operating temperature (temperatura del trabajo T_C) of the solar cell depends only on irradiance and environmental temperature (temperatura ambiente T_a)

$$T_C - T_a = C_2 G \tag{5.12}$$

where

C_2 is

$$C_2 = \frac{TONC(°C) - 20}{800\text{W}/m^2} \tag{5.13}$$

The TONC is nowadays between 42 and 46°C and so the C_2 vary between 0,27 and 0,32 °C/mWm^2. If we do not know the TONC, it is common to use the value of 0,3°C/mWm^2.

What is important to remember that not all the panels are equal even those form the same manufacturer are not. Each panel has the small variety of given output which fluctuate around given number.

5.2.3 Earth coordinates

There are 3 basic Earth movements, the rotation, translations and . Earth every 24 hours, every 23 h 56 minutes exactly, Earth makes a complete circle around an axis passing through poles, west-east direction in the forward direction (anti-clockwise), producing the impression that the sky is swirling around our planet. This movement called rotation is the reason why we have nights and days.

The translational motion is an important movement of the earth, by which our globe moves around the Sun driven by gravitation, and in 365 days, 5 hours and 57 minutes, equivalent to 365.2422 that is the length of the year. Our planet describes an elliptical path of 930 million miles, at an average distance of 150 million miles far from the Sun, where the Sun-Earth distance is 1 AU (an astronomical unit is equal to the average distance between the Sun and Earth, ie 149,675,000 km).

The Earth moves through the space at the speed of 29.5 kilometers per second, covering 106,000 kilometers in one hour, or 2,544,000 miles each day.

The eccentricity of Earth's orbit varies the distance between Earth and the Sun in the course of a year. In early January, the Earth reaches its closest approach to the Sun and is said to pass through perihelion, and the 1st of July it reaches its maximum distance and is at aphelion. The Earth-Sun distance at perihelion is 142 700 000 km and the distance Earth-Sun at aphelion is 151,800,000 kilometers.

The rotation and translation movements alone would be done by Earth if it were completely spherical, but being an irregular ellipsoid with poles crushed by the gravitational pull of the Sun and Moon and equatorial widening caused by very slow rolling of Earth during its movement. This movement is called precession, or precession of the equinoxes, and that is done in reverse rotation, ie retrograde (meaning clockwise).

There is a second phenomenon that overlaps with the precession, the nutation which is a tiny wobble of Earth's axis. As the Earth is not spherical the attraction of the Moon on Earth's equatorial bulge causes the phenomenon of nutation. To get an idea of this movement imagine that while the rotation axis describes the motion of precession cone, runs a small ellipse turn or loop over a period of 18.6 years, and a full turn of precession (25,767 years) the Earth will have performed over 1,300 loops.

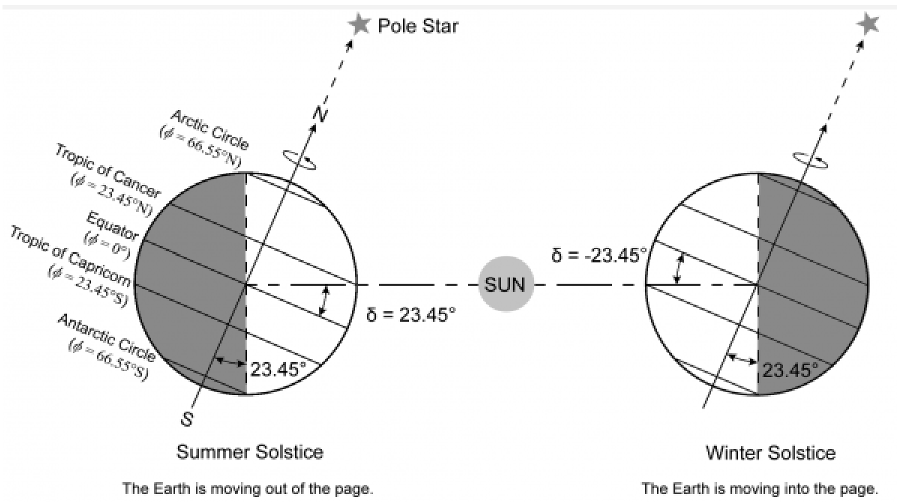

Figure 11: Earth movements [8]

The solar declination (δ) is the angle between the equatorial plane and the place where we have the power plant. It is dependent on the inclination of the rotational axis 23°27' which the rotation axis form with the ecliptic. The declination varies by date and at loa equinoxes of spring and autumn (March 22 and September 22) is equal a zero. The declining value for each day of the year, you can roughly estimate Cooper's formula, depending on the ordinal day "N", from the first day, January the 1st, to 365th day, on 31st of December.

$$\delta = 23{,}45 \cdot sen\left(\frac{360 \cdot (284 + N)}{365}\right) \quad (5.14)$$

The hour angle (ω) represents the instantaneous orbital arc of the sun due to the local noon sun. As throughout the day the sun covers 360° of the celestial sphere, for each hour there is a 15°. The most widespread international criteria says that in the morning there is a positive sign and negative for the afternoon that refers to the local solar time (LST). So that by noon hour angle (12 HSL) is zero, for 6LST is worth + 90°, at 18LST,-90° at midnight (0LST) reaches 180°.

$$\omega = 180 - 15\text{LST} \quad (5.15)$$

5.2.4 Geographic coordinates

The geographical coordinates are "latitude" and "longitude".

Latitude is the meridian arc counted from Ecuador to the point where the observer is. Is represented by the letter f or l. Latitude is always less than 90 º North latitude and is called when the observer or the place is in the Northern Hemisphere and south when in the Southern Hemisphere. In the calculations the Northern latitudes are given positive sign and Southern latitudes negative. The points that lie on the same latitude are on the same parallel.

Colatitude is the complement of the latitude (c = 90 - f), therefore it is the meridian arc between the observer and the pole.

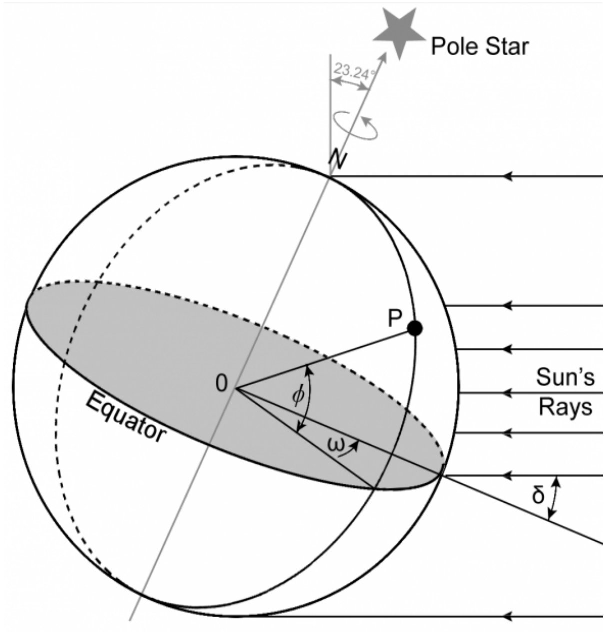

Figure 12: Determination of longitude and latitude of a specific place [8]

Longitude is the arc at Ecuador from the Greenwich meridian to the meridian of the place up. It has less than 180 º called West longitude (W) when viewed from outside the Earth and the North Pole up the place is to the left of the upper meridian of Greenwich and East longitude (E) if the location is at the upper right from the Greenwich meridian. It is represented by the symbol L.

Knowing the geographic coordinates (f, L) we can locate the point where we are at the earth's surface.

5.2.5 Solar movement

Horizon points where the Sun appears (ortho) and sets (ocaso) constantly varies as the Earth moves around the sun in the course of one year.

On March 21, the date of the spring equinox, the sun rises in the east and sets in the west. As the days passed, these points are cumming north, first rapidly, then slowly, until June 21, the date of the summer solstice, when the Sun reaches its maximum height.

As of June 21st, the North points away and get closer to the East and the West, whose positions reoccupied on 22nd or 23rd of September, autumn equinox. Then approach the South point, until 22nd of December, the winter solstice.

If you build a device called gnomon (as an important instrument of astronomical calculation) that consists of a rod placed vertically in the ground, it is possible to measure the distance between the shadow cast by the rod and rod length. Through a simple trigonometric calculation using the formula:

$$tang(a) = \frac{rod\ length}{shadow\ length} \tag{5.15}$$

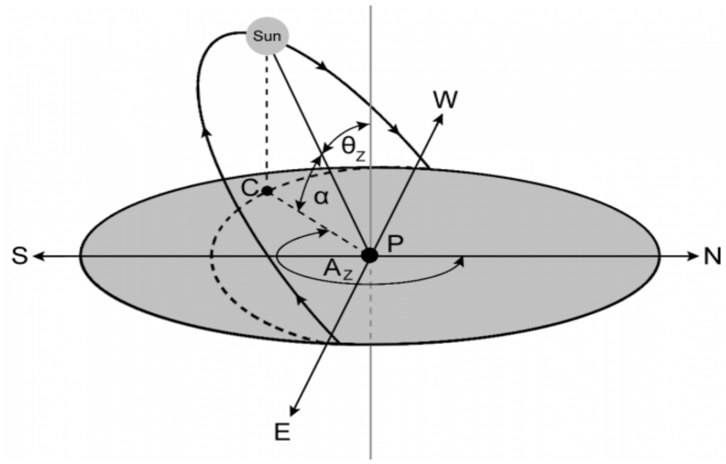

Figure 13: Shadow measuring [8]

Determine the angle that gives the height of the sun above the horizon at any moment.

A consequence of diurnal motion, the shadow of the rod is moved in the horizontal plane and crosses the north-south axis when the sun passes the meridian, that happens at noon (the time when the sun reaches its upper culmination and when in the lower is said to midnight).

On December 21, the winter solstice, the shadow of the rod is high, since the sun is low on the horizon, while the June 21, summer solstice, the shadow of the rod is minimal, due to the high height reached by the Sun on the horizon.

One day before the sun passes through Ecuador on March 21 its declination is negative, the next day (March 21) its declination is zero. Day length would equal the night. In days after the d is positive and keep increasing until it reaches the d +23° 27', the Sun is at that moment in the summer solstice. In the northern hemisphere that day is the longest of the year. From that moment the sun's declination begins to decrease again until d = 0 on September 21, time again the day length is equal to that of the night. Keep decreasing now with negative values until the Winter Solstice(December 21) where reaching its decline the value d = -23° 27', a time that correspond to the longest nights.

Horizontal coordinates

The horizontal coordinates are those that are referred to the horizon of the observer. The origin of the coordinates is in a topocentric system where the basic axis it the vertical of the chosen area. The point of intersection with the celestial sphere is above the observer's zenith, while the opposite is the nadir point.

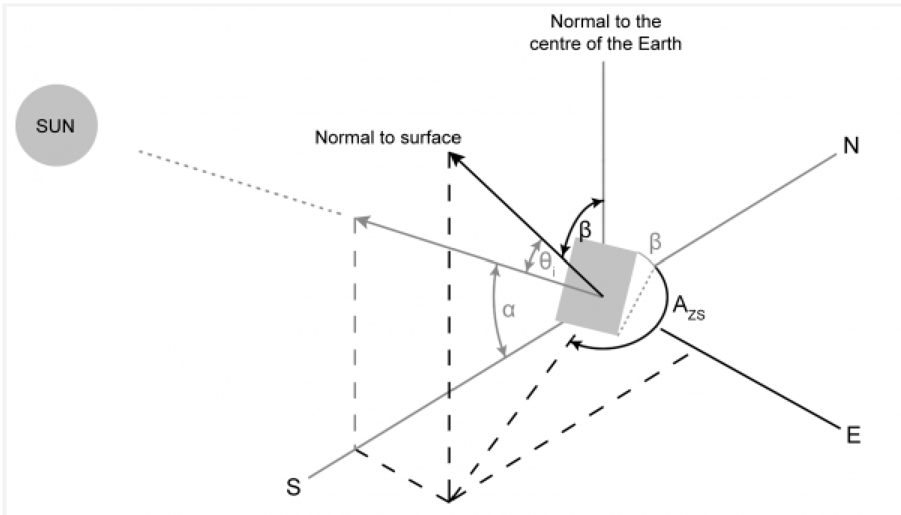

Figure 14: Inclined panel [8]

The horizontal coordinates are the height (altitude) and azimuth. Altitude is the height of the sun above the horizon (arc semidiameter vertically between the horizon of the place and the center of the star) is measured from 0 ° to 90 ° from the horizon, and has a positive sign for the stars located above the horizon and the negative sign located below the same, is represented by the letter h. It is also used instead of the height, the zenith distance, is the semi-diameter arc vertically between the zenith and the center of the star. And Z is represented by the height is related by the equation:

$$h = 90 - Z \tag{5.16}$$

The azimuth is the horizontal arc measured retrograde from the South to the vertical extent of the star. Its value ranges from 0 ° to 360 ° and is represented by the letter A or a.

In the horizontal coordinate system, elevation and azimuth of the stars vary by the Earth's rotation and according to the observer's horizon.

To accurately define the position of the sun at every moment with respect to a hypothetical observer who does not move in a horizontal plane, we use two coordinates, called solar azimuth A and solar height h.

- The height h is the angle between the rays on the horizontal surface. Sometimes it is also used zenith angle, which is the angle between the solar ray and the vertical, so it is the complementary angle to the height.
- The azimuth (z), azimuth angle is the angle of rotation of the Sun measured on the horizontal plane through the projection of the ray on the plane and taking as origin the South, if in the Northern Hemisphere.

Obviously, both the azimuth and the height of the sun at a given time will be different for two observers in different parts of the world, so that when using tables that express these coordinates, you have to watch carefully what latitude is calculated.

In the following graph, called cylindrical charter, we can see how they are related to the solar height and azimuth based on different months. This cylindrical charter corresponds to the south of the Iberian Peninsula with an approximate latitude of 40° which is where the power plant installation is located approximately:

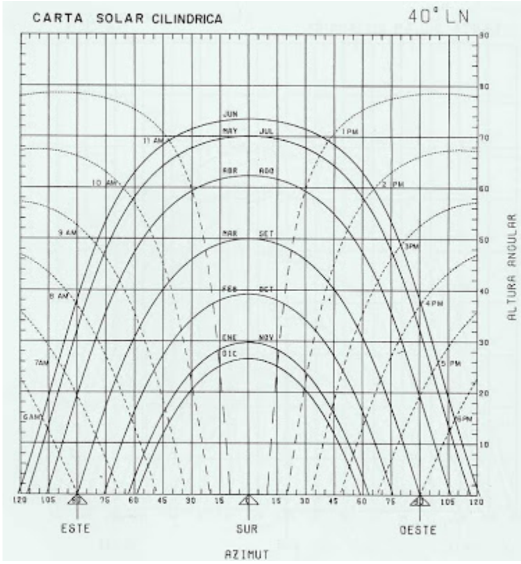

Figure 15: Cylindrical charter [2]

It is a solar chart that help us know determine the sun's path in any month and time of year. It is very useful to see the correct orientation of our project, so we can adapt our design. For example if we want to look at the front of the house areas "cold" receives the highest possible sun exposure, thereby further warming by radiation in the facade. Or for example, allows us to determine the design of the windows or parasols.

For example for a latitude of 41 º N, when the Sun is directly over the celestial Ecuador, then its height above the horizon is precisely 49. At the point of maximum separation of the ecliptic above the celestial Ecuador, the Sun will be located at 49 ° + 23.5 ° = 72.5 ° above the horizon as it passes through the meridian, while passing through the lowest point of the ecliptic, its height will be only 49 ° - 23.5 ° = 25.5 °.

Latitude is the angle measured on a meridian which is forming two lines: the one connecting the center of the planet to the point on the surface where we are with respect to the line connecting the center of the Earth to a point on Ecuador.

The number of hours of sunshine is the theoretical time between sunrise and sunset which are moments where in both the solar height is zero. This depends on the length of day and geographical point considered the season.

Once we know all the parameters and latitude (L) of the place, we can use the following equation:

$$senh = senL \cdot sen\delta + cosL \cdot cos\omega \cdot cos\delta \quad (5.17)$$

$$senZ = sen\omega \cdot cos\delta \cdot sec \quad (5.18)$$

Apart from this basics parameters mentioned above there are several more. Such as Completion Height (h_C): height reached by the sun at noon so it is the maximum height of the day.

$$h_C = 90 - (L - \delta) \quad (5.19)$$

Length of Day (T_d): Number of hours of sunshine. It is determined from the times of sunrise and sunset (equal and opposite) ± ωS, both corresponding to a solar height h = 0.

$$T_d = \frac{2}{15} \arccos(-tg\delta \cdot tgL) \quad (5.20)$$

5.2.6 Sun angle

Superficial irradiance is the irradiance impinging on a given surface at specified time. Therefore the irradiance intensity is

$$I = \frac{E}{S \cdot t} \quad (5.21)$$

The quantity of energy which can be absorbed by a given surface depends on the angle between the solar ray and the surface. If the angle is 90° there is a maximum output.

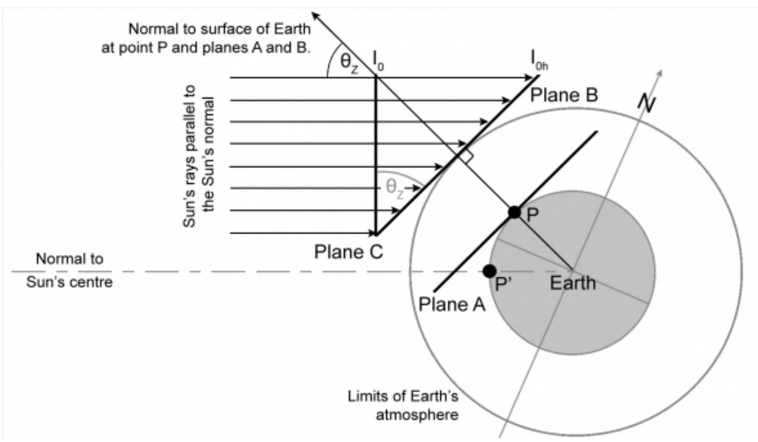

Figure 16: Solar rays reaching the Earth [8]

The cell output current dependent on the sun angle, so if the I is the current at the surface of the panel

$$I = I_0 \cos \Theta \tag{5.22}$$

where

I_0 is the current at the surface

If the panel were perpendicular at the sun rays and Θ is the angle of the sun line measured from the normal. This cosine law holds well for sun angles ranging from 0 to 50°. Beyond 50° the output deviates a lot and beyond 85° there is literally non as it is shown at the Kely cosine curve below.

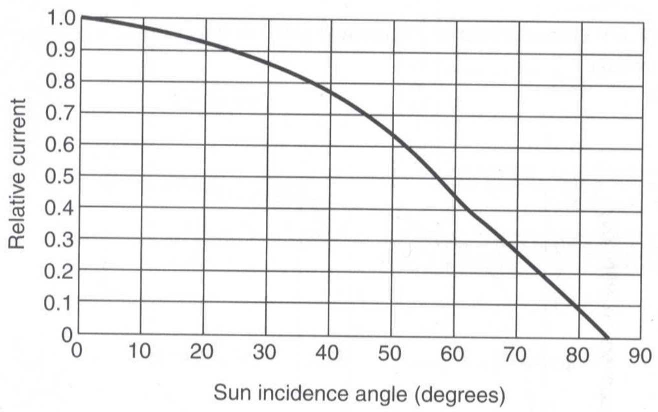

Figure 17: Kelly cosine curve for PV cell at sun angles from 0 to 90° [1]

Because we are in the northern hemisphere and not at the ecuador, we must calculate the angle in which to put the panes so they have the optimal position due to the solar arrays and so we can have the maximal output.

Apart from the angle of the sun rays we need to calculate the angle of inclination and should be calculated as well to see that we have the maximum output. This angle depends on the latitude of the power plant. It is also important that we know the azimuth of the building or terrain in degrees respecting the axis N-S. Obviously the best orientation is heading south, so it would be 0°.

The inclination issue it the reason why the solar light heats the surface of the panel much more around noon than in the morning of afternoon. This can be seen at Kelly cosine curve.

At the Tropic of Cancer (northern hemisphere), the solar radiation incident perpendicularly on the surface of the earth at noon on June 21 (summer solstice), while the December 21 (winter solstice) the same angle of incidence, would be δmax φ = 2. ° The rest of the year at solar noon the value is between 0 ° and 2 δmax o = 46 ° 54.

Our planet has an elliptical orbit while rotating around the sun, and spends about 365 days to complete a cycle (year). This path is called ecliptic. And the world which we can idealized as a sphere rotates around an axis cross from north to south through the center. Regardless of their accuracy gyroscopic movements (of the equinoxes advance at a rate of 50.25 "per year due to the change of orientation) and nutation (wobble poles 9.2" per year by the lunar attraction) we can say that this rotational axis is continuously tilted with respect to the ecliptic plane 23°27'. Therefore, the equatorial plane being perpendicular to the axis through its center, have the same amplitude. Mechanical laws governing the spatial displacement are expressed in sexagesimal degree, whose variables measured from the center of the globe are three: the latitude, declination and hour angle at each moment of the day. These variables were mentioned before.

6 Laws and norms

The current legislation in the field of photovoltaic production is crucial for the viability of these facilities. The spanish PV market was experiencing strong moment back in 2008 thanks to growing interest from investors and developers, caused by the good solar conditions and favorable legislative environment that ensured a stable compensation framework. It follows the development of relevant legislation affecting such facilities in different frames of influence:

1. European legislative framework.
2. National legislative framework.
3. Autonomic Legislative Framework.

I will mention just the relevant law for the issue of photovoltaic plant design.

6.1 European legislative framework

"Effective Buildings". Summary of EU legislation on energy savings in buildings. DG TREN of the European Commission.

A major step forward was taken in 2009 with the adoption of the Renewable Energy Directive (2009/28/EC). This ground-breaking regulatory framework aims to cover 20% of the European growth in final energy consumption by renewable sources by 2020. [27]

6.2 Spanish national legislative framework

- Plan de Energías Renovables en España (PER) 2005-2010.

- Ley 54/1997 de 27/11/97, de Regulación del Sector Eléctrico. Regulation of activities for the supply of electricity. BOE 285/1997 del 28/11/1997

Its main objective is the liberalization of the electricity market. Sets: special arrangements for Renewable Energies (<50 MW) and guaranteed access to the grid. It introduces: target for Renewable Energies: 12% in 2010, and the Renewable Energy Plan 2005-2010.

- Real Decreto 661/2007, de 25 de mayo, establishes the procedure for inclusion in the special regime, enabling the autonomous regions to establish simplified procedures for facilities P <100KW.

Defines the tariffs, premiums and incentives for renewable energy, as well as its review and update. Extends the installed capacity target by PER 2005-2010, to 371 MW for photovoltaic.

It incorporates the need to provide a guarantee of 500 € per kW to gain access to the transmission and distribution network for photovoltaic. Requires all producers to sell energy in the electricity market which was which was later on annulated by CNE.

It also sets a transitional period until 2009, during which continue to be billed to the distributor. It forces the distributor to give the producer a fee of 0,5 c€/kWh as of July 1, 2008. Enter the Renewable Energy Plan 2011-2020.

- Real Decreto 1578/2008 de

In late 2006 the installed capacity was about 120 MW[2], but the rate set by the RD 661/2007 in rates made the installation of large production of solar PV was very profitable. It began funding projects on large scale, so in August 2007 it was reported that the CNE had already exceeded the goal of 85% power, and it was expected that in May 2008 and the installed capacity would be around 1000 MW.

The problem with this large increase, which was positive in terms of reducing CO_2 emissions, is that according to the government it helped to destabilize the electricity tariff system causing an increase in the deficit tarifario3.

Moreover, according to RD 661/2007 (art. 22), to reach 85% of the installed capacity target, it should set a deadline after which the new facility would charge the energy generated as the final price. But this would have bankrupt the industry, then the government had to set new targets.

That is the reason why there has been installed so much power in such a short time. It was highly profitable, firstly due to increased rates established in the RD 661/2007, and on the other hand the prices for the installation decreased. Therefore it would be possible to reduce the charges, which will enhance effective solutions.

To do this the new regulation office sets new annual installed capacity targets. It assumes that the installation would be done more objectively and that means that the business is profitable and therefore can the rate (up to 10% annually) could be reduced.

There are 2 types of installations: on facade or roof and ground. The first consists of small installations (up to 20 kW) and large systems (over 20 kW). The maximum power is 2 MW in roof and 10 MW on the ground. The capacity quota for 2009 is 400 MW. Two thirds (267 MW) for roof and third (133 MW) to ground. Power quotas for type I are distributed as follows: 10% for installations of less than 20 kW and 90% for larger installations. The quotas of the following years will be calculated on the reference base power of each type / subtype.

Additional quotas are established extraordinary power of ground installation 100 MW for 2009 and 60 MW by 2010. [7]

- Real Decreto 1011/2009 de 19 de Junio. It modifies the classification introduced in Ral Decreto 1578/2008 about the auto-consumption of electricity.

- Real Decreto 1565/2010 de 19 de Noviembre. It regulates and modifies the aspects of production of electrical energy at the special regime.

- Real Decreto 1663/2000 de 29 de Septiembre. It deals with photovoltaic connection to the low voltage network.

Sets the technical and administrative conditions necessary for connecting photovoltaic installations to the low voltage network. Aplication: PV rated power not exceeding 100 kVA and its connection to the distribution network is made in low voltage (<1 kV). Possibility of intervention by the competent authority (usually regional) in case of not honoring an agreement.

- Real Decreto 436/2004 de 12/03/04. Establishing the methodology for updating and systematization of the legal and economic framework of electricity production in the special regime. BOE No. 75 of March 27, 2004. Repealed by RD 661/2007.

- Corrección de errores del Real Decreto 436/2004 de 12/03/04. BOE Núm. 85, de 8 de abril de 2004.

- Real Decreto 841/2002. For regulating the production facilities for electricity in particular at the market share of production, certain disclosure requirements of their production forecasts, and the acquisition by its marketers electricity produced.

- Orden ITC 4112 2005 de 30 de diciembre

6.3 Legislative in the Czech Republic

The Czech Republic promised to generate 8% of its brutto generated power from renewable sources until the year 2010 and together with this to create market conditions so the investors can put their trust into technologies of renewable sources (OZE). This is said in direction 2001/77/ES, which was implemented into our law system with the law Nr. 180/2005 Sb. Nevertheless this direction does not says how to manage it and leaves the decision on the governments of each and every country.

The development of photovoltaic power plants was supported by the law 180/2005 Sb. dealing with the support of power generation from renewable sources.

Other laws dealing with this issue are for example

- Direction 2001/77/EC of European parliament from 27. 9. 2001 about the support of power generation from renewable sources

- Ordinance Nr.475/2005 and its novelization Nr. 364/2007 Sb. This one gives a change of indicative numbers of technical and economical parameters, for example that the life period of solar cells was increased from 15 years to 20 years.

- Ordinance 150/2007 Sb. and its novelization Nr.140/2009 Sb. about the regulation of prices in power engineering. From the point of view of photovoltaic, the significant part is § 2 paragraph (9) : „The office sets prices and green bonuses of electricity from renewable sources according to special prescript. These prices are fixed during the lifetime of a facility." The newest one for the year 2010 in Nr 5/2009.

- Novelty in electricity buy-out is a novelization of ordinance 51/2006 Sb. which sets the conditions of facility connection to power grid in 2010. There are also more terms for concessions. For example in the case of power source between 30 kV and 5 MW there must be a proof that the project corresponds with the territorial plan. After contraction the connection should be finished in 180 days in case of 30 kW and in a year by bigger sources. By the word of authors it should be clear then who is a serious investor and who is a speculator.

- Amendment of Act No. 1820/2005 Sb., On the promotion of renewable energy sources. This amendment restricts only support the photovoltaic power plant with an installed capacity of 30 kWp, which are located on the roof structure or on the outside walls of buildings.
- ERO Price Decision No. 7/2013 - provides support for 2013
- Act No. 458/2000 Coll., On business conditions and public administration in the energy sector and amending certain acts (the Energy Act)
- Decree No. 426/2005 Coll., The details of the licensing business in the energy sector
- Decree No. 363/2007 Coll. Amending Decree No. 426/2005 Coll., The details of the licensing business in the energy sector

It is quite hard to predict how the legislative in the issue of photovoltaic power plant will evolve. There are several possible scenarios that we have seen in Europe and in the United States. Nowadays photovoltaics is demonized by the mass media because of what happened in 2010. We must wait and see if it will come back again. For example in Spain last few months there has been one of the best opportunities to build new photovoltaic power plant.

7 How to design a PV field

The following sections gives detailed aspects that were taken into consideration for optimal sizing of the PV at hand. In any case, the cover has not been dimensioned according to the building energy needs, but has been conditioned to the roof surface and aesthetic, architectural and sustainability point of view. I did not aimed building energy self-sufficiency but pursued the optimum use of the cover in order to install the maximum possible number of photovoltaic generators. It has been designed as pouring a small electrical energy produced to the grid.

First of all we must know where we will have our installation. We need to know the terrain or the roof well. We must estimate where the shadows will be, if there are any buildings at the terrain or perhaps a chimney or other tall building nearby if we have the case of a roof installation. If it is the case of a larger installation we must consider the distance between panel lines, because the structure may interfere with the Sun line. If a cell in long series of string gets completely shadowed it loses its photo-voltage but still must carry the string current, because it is in the long series string with other cells which operate at the full sunlight for example.

Because of the shadow the cell does not produce the power but instead it behaves like a load, producing local I^2R loss and heat. [1] The remaining cells in must produce higher outputs to cover the loss of the shadowed cell. If just one cell is shadowed, it does not have a greater influence, however if a larger area of a panel is shadowed and it overcome the critical limit, the I-V curves goes below the operating voltage of the string, making the current goes to zero and loosing all the power int he string.

There are several tricks and techniques how to overcome this problem, such as to subdivide the circuit length in several segments with bypass diodes. The diode across the shadowed segment bypasses only that segment of the string. This causes a proportionate loss of the string current and voltage without loosing the whole string. [1]

For photovoltaic solar roof installation one must take into account two of the many possible alternatives, prevailing in any case for the architectural integration of photovoltaic modules in the structure of the building, thus preventing visual impact.

- Possibility 1: It is a two-fold roof with integrated solar modules on the south side.

Figure 18: A house with two-fold roof with integrated solar modules on the south side [10]

- Cover structured in "sawtooth" on the plane roof with photovoltaic solar modules heading south to obtain the maximum output.

Figure 19: Photovoltaic modules on the plane roof [11]

There can be also a case that the roof is slightly inclined. This means that it is not optimal to put the panels directly on the roof, but the structure for the panels must be adjusted so the panels are heading south but also that they have the proper angle. Perhaps the situation can be explained better with the picture below.

Figure 20: Solar panels on a slightly inclined roof [12]

In my work I decided to do once again the layout of the PV modules relative to the sun, because I needed to check if the position was optimal and correctly calculated. This leads us to consider the dimensioning the three basic factors: the orientation, inclination and possible shadows.

The issue of orientation was discussed before. Here I would like to mention just some facts important for the installation it self. The photovoltaic modules are installed facing south, because we want the highest output possible. If the building layout is not ideal, we need to calculate the richt position of the panel line. This can get more complicated when we have inclined roof as in our case.

The angle of incidence of the solar ray on the surface determines the density of sunlight rays within a determined area. A surface positioned perpendicular to the path of sunlight rays collect more energy than another surface of the same area but with a different inclination.

As the sun has two types of apparent movement on the horizon, the path azimuth and height, the angle of incidence of sunlight on a fixed surface is constantly changing throughout the day and overnight.

In the case of photovoltaic systems connected to the network in which the solar modules are arranged at a fixed tilt throughout the year, as is this case, the criteria to follow to obtain a global optimization of the system is to give such a pitch that can receive as much energy during the whole year as possible.

We will use the table of solar radiation on inclined surfaces facing south to the province of Alicante, region of Murcia.

Factor de corrección para superficie inclinada en Murcia												
Inclinación superficie	E	F	M	A	M	J	Jl	A	S	O	N	D
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10°	1.16	1.13	1.08	1.03	1.00	0.99	0.99	1.02	1.05	1.08	1.12	1.15
20°	1.30	1.24	1.14	1.05	0.98	0.95	0.97	1.01	1.08	1.15	1.21	1.27
30°	1.41	1.32	1.17	1.03	0.94	0.91	0.92	0.99	1.08	1.19	1.29	1.37
40°	1.48	1.37	1.17	1.00	0.89	0.84	0.87	0.95	1.07	1.20	1.33	1.44
50°	1.53	1.38	1.15	0.95	0.82	0.76	0.79	0.89	1.03	1.20	1.35	1.48
60°	1.54	1.37	1.11	0.87	0.73	0.67	0.70	0.81	0.97	1.16	1.34	1.49
70°	1.51	1.32	1.03	0.78	0.63	0.57	0.61	0.72	0.90	1.11	1.30	1.46
80°	1.45	1.25	0.94	0.68	0.53	0.47	0.50	0.62	0.80	1.03	1.23	1.40
90°	1.35	1.14	0.83	0.56	0.42	0.37	0.40	0.51	0.70	0.93	1.14	1.31

Table 6: Correction factor for region of Murcia [13]

From the table above we can see that for latitude that we have the inclination to receive more energy is 30° above the horizon. Therefore, alternative designs for both, the degree of tilt of the solar panels to the horizontal is 30 °.

The presence of objects that could cover a part of the solar rays will cause the projection of shadow on it. The bigger the shadow, the less energy can be capture. On the worst day of the year, the solar modules should have no more than 5% of the receiving surface covered by shadows. It would stop working if 20% of the collection surface were shaded. In the present case, there are no buildings taller around our building roof where the panels will be installed or any other obstacle.

Logically, the minimum distance from row to row is given by the latitude of the installation, since the solar incidence angle is dependent on the latitude.

The spacing between rows of photovoltaic modules is set so that at solar noon of the worst day (minimum solar height) of the year, the shadow of the upper edge of a line projecting at maximum on the lower edge of the next row.

In power plants used throughout the year, as is this case, the worst day corresponds to December 21. On this day the solar altitude at solar noon is minimum and has the following value

$$h=(90°-latitude)-23{,}5° \qquad (7.1)$$

where

h is the solar altitude at noon worst month. The worst day belongs to winter, and its solar height.

Using the data from the installation, which is near Murcia, the previous figure, it follows that

$$d_{min} = l \cdot (\cos\beta + \frac{\sin\beta}{tg(h)}) \qquad (7.2)$$

where:

d_{min} is the minimum distance between modules to avoid shadows, expressed in meters.
l is the length of the module, including the frame and the corresponding support. In the following table the total length is reflected by the number of modules available
β is the angle of inclination of the horizontal modules. As we have determined above in this case it is 30°

This is just an example how the distance can be calculated for a case of the roof that is not inclined. More complex calculation will be presented later on.

8 Roof installation

The roof installation could be more complicated then the terrain one. All depends on the azimuth and inclination of the roof.

In 2009 was connected to the grid a solar power plant in the region of Murcia in Spain. The output from this power plant does not meet the expectations. Therefore my task is to evaluate and calculate parameters of this installation.

Nominal output is 120 kWn. There are two inverters, one is Solarmax 100C and the other one is Solarmax 20S. They are situated in exterior case at the building wall.

There are 179 photovoltaic panels Himin, type HG 185S. The capture area is 968,97 m^2. They are situated at 2 roofs with inclination of 8,6˚ and the second one 7,8˚.

Panel	Himin
Model	HG 185S
Hight	1,58 m
Width	0,808 m
Area	1,27664 m2
Output	185 W
Nr of Panels	759
Area of Panels	968,97 m2

Table 7: Installation data

I have data of daily production in kWh for years 2009, 2010 and 2011.

In our case the building roof is slightly inclined. It makes the calculation whole worse. The case above could be user for the plane roof. Now I will try to explain the issue of calculation the panel distribution on inclined roof.

First of all the building dimensions.

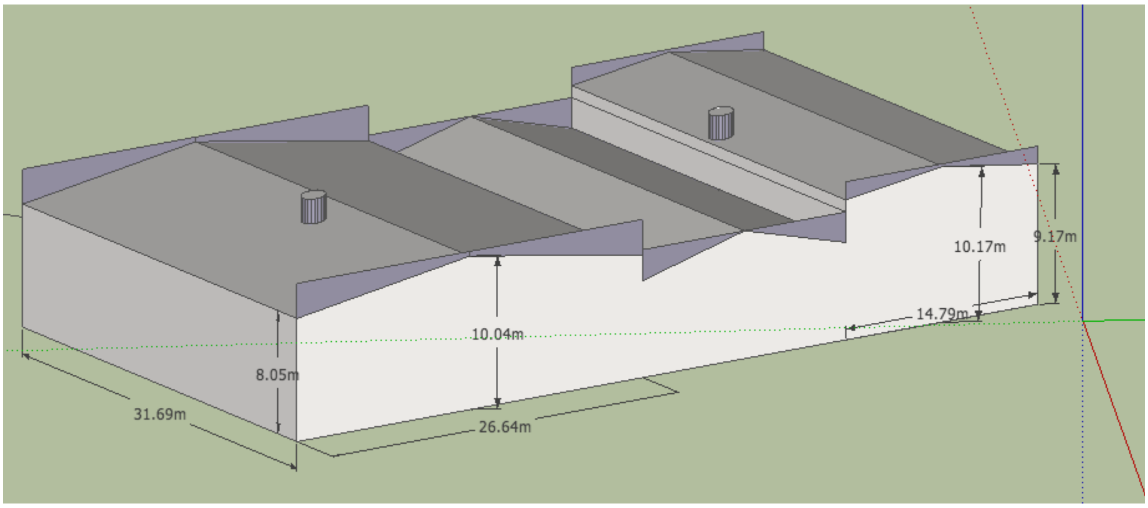

Figure 21: Building dimensions

As it can be seen from the picture above, the building it self constrain from 3 separated halls. There are 2 chimneys and a design overlap at the rooftop. It is just a design, it has no constructional justification. In Spain in it quite common that the photovoltaic panels are seen as functional and there are to be hidden. It is unfortunate though, because it complicates the work of designers of photovoltaic power plants. There must be a lot more calculation concerning the shadows and because of the shadows it is not possible to fit more panels, therefore there are losses. But the owner of the building has the final vote.

As it was said before, first of all we must take the building dimensions and insert it in the excel file. From the brief look at the situation, we can see, that there is no use to put panels at the middle roof, there are just to much shadows. So we have the building separated into 2 rooftops and I will calculate it as such.

DATA BUILDING 1		
	m/degrees	rad
y2	10,04	
y1	8,05	
x	26,64	
Inclination	8.497	0.148
Azimuth (θ)	21	0.367

DATA BUILDING 2		
	m/degrees	rad
y2	10,17	
y1	9,15	
x	14,79	
Inclination	7.853	0.137
Azimuth (θ)	21	0.367

Table 8: Building parameters

The roof inclinations are calculated from the given dimensions of the building. The inclination is with the plus sign because the south facade of the building is heading south-east. It is understood that the north is heading towards the paper so we see the south facade of the buildings. See the picture below.

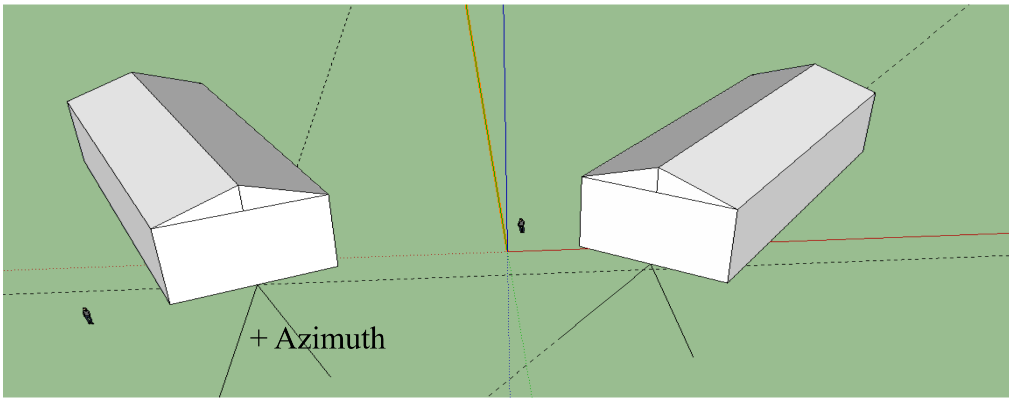

Figure 22: Azimuth signs according to the building position

8.1 Shadow

The calculation and estimation of shadows is essential for good photovoltaic plant design. If the shadow issue is underestimated the final output will be smaller or in some severe errors in design the panel might not work at all.

It is clear that the maximum height of the Sun above the horizon varies over the year, and that this is directly related to seasonal climate changes.

Since the Sun is at a different height above the horizon, its radiation heats the surface more or less effectively and projects shadows of different length. For a beam of solar energy (light and other radiation) with a section of $1m^2$, when it reaches the ground during the summer solstice (see Figure above) at a latitude of 40 ° N, it is spread over an area of 1.04 m^2, while during the winter solstice does over an area of 2.24 m^2. That is, during the winter ground surface $1m^2$ receives less than half of the energy received during the summer, which is why it is colder environment.

There is a rule that the solar panel should be exposed to a direct sunlight for at least 4 hours between the 10AM an 2 PM on the 21st of December. On this day the elevation of the Sun at 10AM is 22° and the azimuth is 30°. At 12AM the elevation of the Sun is 28° and azimuth is 0° and finally at 2PM the elevation is again 22° and azimuth -30°.

Because of this the calculation of the shadow length should have at least these three positions. Where the 3 lines have 30° between each other. I will explain this later on.

We must see to it that we know the building surrounding well enough, that there are no tall trees or other buildings that might produce shadows. It is possible that the shadows are there just in the early morning or late afternoon, but still we must count with them.

When the building has inclined roof as in this case, the shadow calculation must be done for both sides of the roof.

The shadow length is dependent on the day of the year and the hour of the day. In the conditions of Europe the longest shadows are the 21st of December, when the Sun in the the lowest position. Just to have the idea, see the figure below, were I put 2 chimneys at the south facing side of the roof and the north facing side of the roof and simulated shadows on the 21st of December and on the 21st of June at 2PM. You can see the difference in the shadow length.

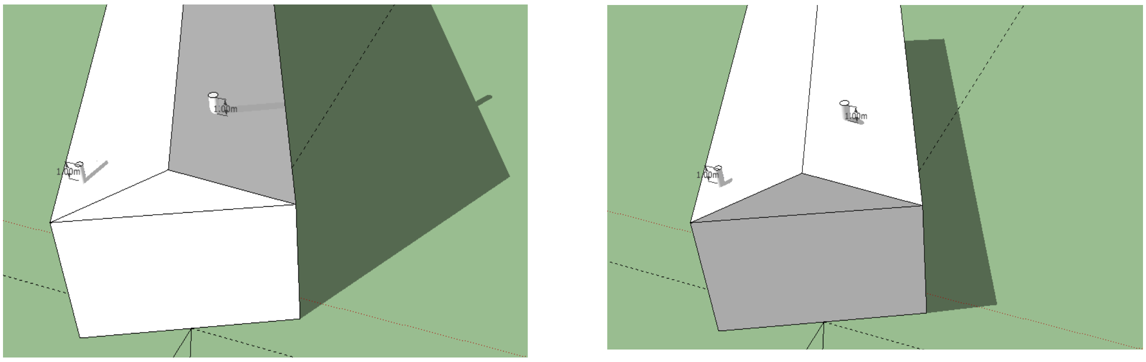

Figure 23: Shadows at different 2 days of the year

Perhaps an interesting point of view of the diference between the 2 days of the year might be from a free program SolarBeam [14] which I found and I think it might be quite useful.

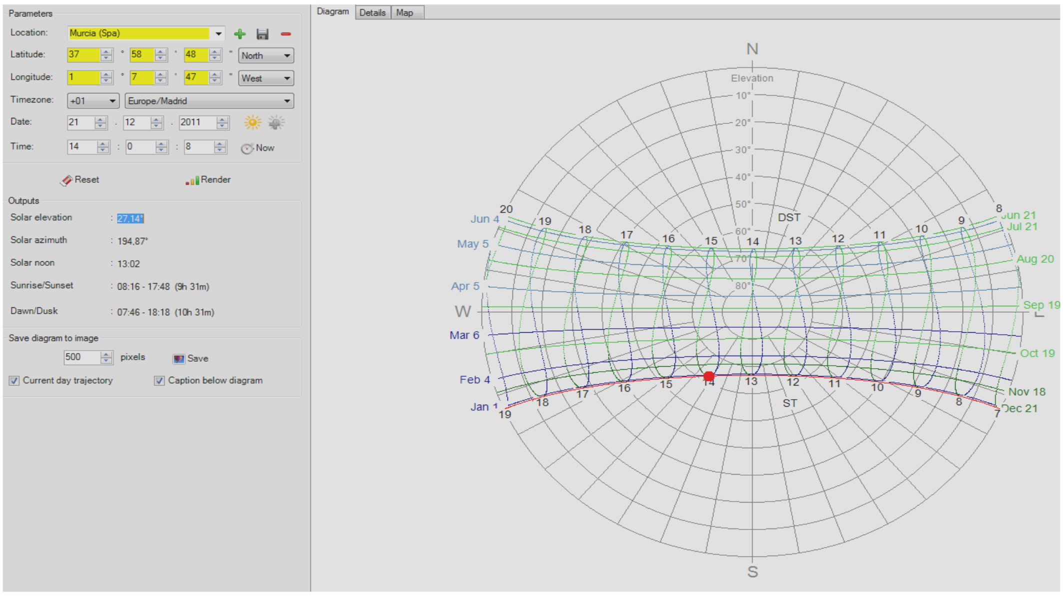

Figure 24: SolarBeam for Murcia region [14]

A solar diagram shows the position (and in general, the trajectory) of the sun at a given time of day, for a given day of the year. It answers the questions:

- Where is the sun in the sky?
- How high in the sky is the sun at noon?
- When does the sun rise and set?
- How many hours of sunlight are there in January?
- How different (in terms of sunlight) is a day in summer from a day in winter?

As it is expected, the answers differ depending on where you are on Earth.

Suppose there is an observer somewhere on Earth. A solar diagram is then a chart of where the observer sees the sun in the sky, how high and in what direction he has to look.

This diagram shows the sun's trajectory during some particular day of the year. Along the trajectory (the red line) there are particular points of interest:

- The sun rises in the East. This is shown in the diagram by the fact that the angle of elevation exceeds 0°.
- The sun sets in the West. This means the angle of elevation drops below 0°.
- The highest elevation of the sun in a day is called solar noon.

It is clear that for the south facing part of the roof the shadow will be shorter then at the north facing side. To calculate the length of the shadow at the south facing part of the roof a simple equation can be used

$$C = \frac{h}{[\tan\beta + \tan(solar\,inclination)]} \qquad (8.1)$$

Similar equation serves for the north facing part of the roof

$$C = \frac{h}{[\tan(solar\,inclination) - \tan\beta]} \qquad (8.2)$$

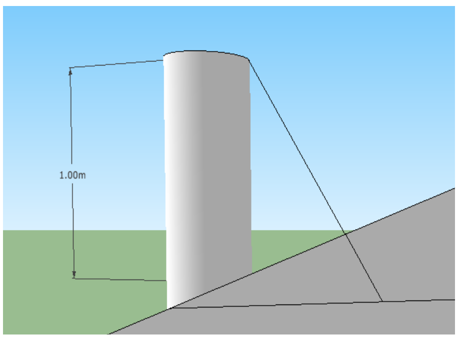

Figure 25: Projection of chimney shadow

There is one method how to see clearly the shadows affecting the design of the photovoltaic field. It is a method for calculating solar radiation losses experienced due to surface surrounding shadows. Such losses are expressed as a percentage of global solar radiation would impact on said surface. It can be represented by the obstacle profile representation in the diagram on figure below, which shows the band trajectories of the Sun throughout the year, valid for locations in the Iberian Peninsula and Balearic Islands (Canary Islands for the plot should move 12° vertically upwards). This band is divided into lots, bounded by solar hours (negative before solar noon and positive after wards) and identified by a letter and a number (A1, A2, ... D14) Notice that module facing east has negative azimuth.

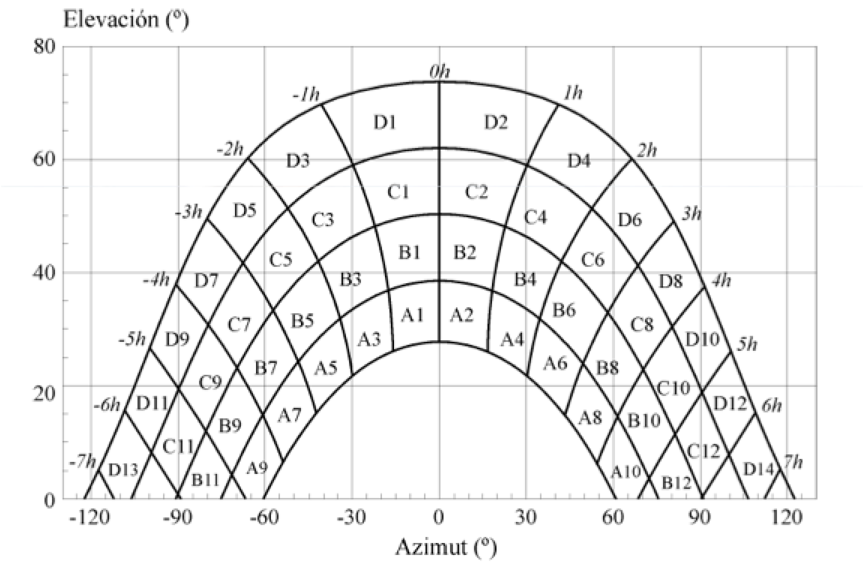

Figure 26: Diagram of Sun trajectories

Each of the portions of this figure depicts the path of the sun at a certain period of time (one hour over several days), and has therefore a certain contribution to the annual solar radiation incident on the surface study. Thus, the fact that a barrier covering a portion involves a certain loss of irradiation. This should be chosen as the reference for calculating the most appropriate table, among which some are included below.

Comparing obstacles profile diagram to calculated trajectories of the sun help determine shading losses of global solar radiation incident on the surface throughout the whole year. For this one must add the contributions of those portions that are totally or partially shadowed by obstacles. In the case of partial concealment there is a fill factor used (hidden in the total fraction of the portion) closer to the values: 0.25, 0.50, 0.75 or 1.

Each of the portions of the diagram represents the path of the sun in a certain period of time (one hour over several days), and has therefore a certain contribution to the annual solar radiation incident on the surface study. Thus, the fact that a barrier covering a portion involves a certain loss of irradiation. Should be chosen as a reference for calculating the most appropriate table. There are tables for each inclination and azimuth. You can see just one table as an example below.

b=35º; a=0º	A	B	C	D
13	0	0	0	0
11	0	0.01	0.12	0.44
9	0.13	0.41	0.62	1.49
7	1	0.95	1.27	2.76
5	1.84	1.5	1.83	3.87
3	2.7	1.88	2.21	4.67
1	3.17	2.12	2.43	5.04
2	3.17	2.12	2.33	4.99
4	2.7	1.89	2.01	4.46
6	1.79	1.51	1.65	3.63
8	0.98	0.99	1.08	2.55
10	0.11	0.42	0.52	1.33
12	0	0.02	0.1	0.4
14	0	0	0	0.02

Table 9: Data for the Diagram of Sun trajectories

There are several tables like the one you can see above, but they are just for some inclinations and azimuths and their combinations. Therefore even at this method one must consider some error. But still it is a fine way how to estimate the shadow losses at the Iberian peninsula. That is why I implemented it in my calculations.

Now I am getting to the shadow length calculation. As it was said earlier on, as the Sun moves in the sky during the whole day, it is projecting different shadows with different azimuth and different length. The 3 most important lengths are the ones at 10AM, 12AM and 2PM because at these hours the output is major. Nevertheless in other hours the output is significant as well even more in Spain.

Therefore I decided to do the rose of shadows, which is calculated for each hour and has 9 thorns each separated from the previous one for 30°. See the picture below.

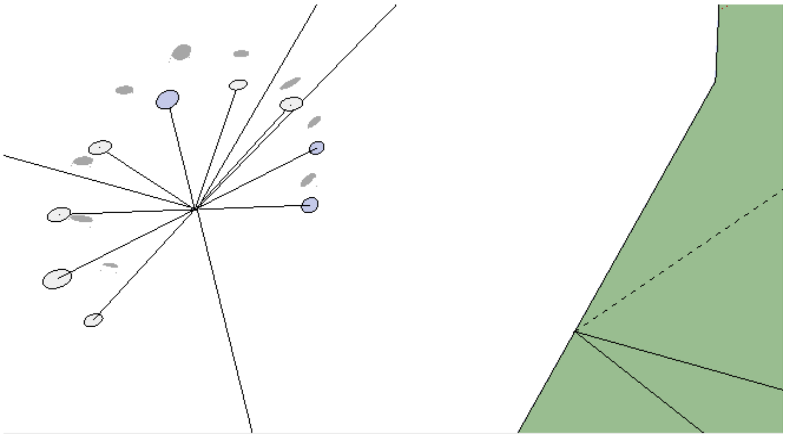

Figure 27: Rose of shadows

As you can se in the figure above, the rose is composed from 9 thorns and each has length of 1m. In Excel I did a table which calculates the shadow length of a shadow 1m high, which at this picture is at the edge of the roof south corner. The shadow length is calculated for the worst day of the zear in our conditions which is the 21st of December.

Solar Position Data		
	m/degrees	rad
Inclination (1)	28,42	0.496
Inclination (2 y 3)	22,42	0.391
Acimuth (2 y 3)	30	0.524
Inclination (4 y 5)	18	0.314
Acimuth (4 y 5)Acimuth	40	0.698
Inclination(6 y 7)Inclina	18	0.314
Acimuth (6 y 7)Acimuth	90	1.571
Inclination (8 y 9)Inclin	26	0.454
Acimuth (8 y 9)Acimuth	100	1.745
Length l (1)Length l (1)	37.169	
Length l (2)Length l (2)	-85.147	
Length l (3)Length l (3)	17.140	
Length l (4)Length l (4)	-40.913	
Length l (5)Length l (5)	15.229	
Length l (6)Length l (6)	-14.268	
Length l (7)Lengthl (7)	14.268	
Length l (8)Length l (8)	-13.569	
Length l (9)Length l (9)	15.540	

Table 10: Solar position data

From the table above Where the first calculation of azimuth and inclination are done I took data and put it in another table where the shadow projections are calculated for a object of 1 m height.

Shadows		
	m/degrees	rad
Height of object	1	
Beta (1)	3.065	0.053
Beta (2)	-1.339	-0.023
Beta (3)	6.623	0.116
Beta (4)	-2.785	-0.049
Beta (5)	7.445	0.130
Beta (6)	-7.940	-0.139
Beta (7)	7.940	0.139
Beta (8)	-8.343	-0.146
Beta (9)	7.298	0.127

Table 11: Shadows

Finally a length of a shadows is calculated in the table below.

Length/ Hour	1	2 (M)	3 (T)	4 (M)	5 (T)	6 (M)	7 (T)	8 (M)	9 (T)
Length at south facing side (c)	1.682	2.294	1.891	2.677	2.195	2.153	2.153	1.576	1.624
Length at norht facing side (d)	2.051	2.569	3.373	3.620	5.148	5.392	5.392	2.932	2.780

Table 12: Shadow length

Just to show how the diagram of Sun trajectories works, you can se it below for this case.

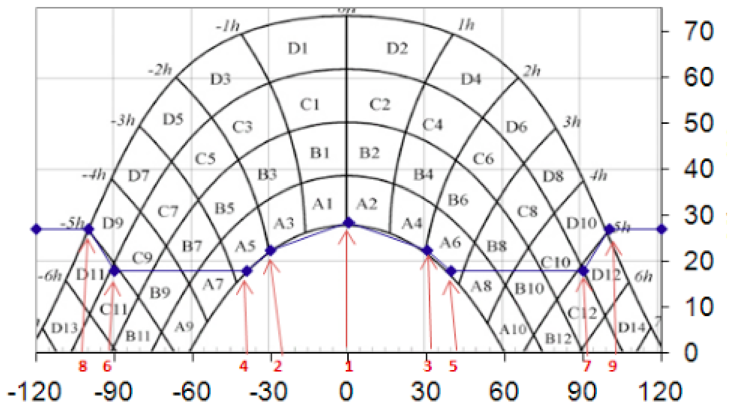

Figure 28: Diagram of Sun trajectories for this case

You can see that even for the worst day of the year which is the 21st of December there are no major shadows at the panel. Therefore we fulfilled the condition that even on the worst day of the year the panel must have access to the sunlight from 10AM to 2PM.

Now I have data about the shadow length and the next step would be to draw the layout of the panels in AutoCAD or some similar program.

To make it easier for me and for better orientation I adjusted a little bit the table so I can clearly see the sequence in which I must draw the lines of shadow length.

AUTOCAD									
8 (M)	6 (M)	4 (M)	2 (M)	1	3 (T)	5 (T)	7 (T)	9 (T)	
2.932	5.392	3.620	2.569	1.682	1.891	2.195	2.153	1.624	South
1.576	2.153	2.677	2.294	2.051	3.373	5.148	5.392	2.780	North

Table 13: Shadow length for AutoCAD

Now there is time to measure all the objects that can project a shadow on the rooftop and around. The calculation is done for objects of 1m high so first of all I did the rose of shadows for object 1 m high and then I magnified the rose accordingly to the real hight of the object. In this case there is a design facade in the south side, because is spain it is not desirable to se the photovoltaic panels. This is for example one of the objects that will project the shadow. Another one is obviously the chimney, both on the south facing part of the roof as well as on the north part.

These calculations are used for AutoCAD. It is a good way how to project and design the photovoltaic field on the roof top.

When I had the shadow restrictions of the objects on the roof top I was able to try to fit as many panels as possible. Panel it self has some dimensions, but as the roof is inclined and the panel lines will have the inclination of 30° and I want to draw it in 2D in AutoCAD, I must recalculate dimensions of the panel itself so it will correspond with 2D projection. The adjusted panel dimensions are in the table below.

Panel Data	m
Length	1,58
Width	1
Position	vertical

Table 14: Panel data from the brochure

In this table I can chose if the panel will be installed horizontally of vertically. Acording to these inputs there are another tables that calculate the 2D panel dimensions for the south facing part of the roof and north facing part of the roof.

Length at plane SOUTH	1.388
Width at plane	0.989

Length at plane NORTH	1.382
Width at plane	0.992

Table 15: 2D panel dimensions for both sides of the roof

When I got the panel dimensions and was able to draw it in AutoCAD I can calculate the shadow that the panel will project. This is crucial for the distance between the panel lines. It is done the same way as shadows, at the 2 upper corners of the panel a rose of shadows is drawn and the hight of the shadows is 1,388 at the south side of 1,382 at the north side. This calculation is done in the same way for the second roof as well.

Just to check I did the calculation in excel.

Panel shadow	0,75	South
Panel shadow	0,89	North

Table 16: Panel shadows

Now when we have the distance between the panels one must proceed with the calculation of the optimal azimuth of the line of panels at the south-facing part of roof and the north-facing part. This might me a little bit tricky, because the roof itself is inclined and the panels are inclined as well. Tha calculation is done in the table below.

South	Acimuth module line	14,91
North	Acimuth module line	-12,47
South	Lateral module inclin	28,5491
North	Lateral module inclin	28,9767

Table 17:Module line azimuth for the south and north part of the roof

With this calculations one should be able to draw the layout of panel lines in AutoCAD and be able to fir as many modules as possible.

9 Field data analysis

As it was said above I have production date from 2 whole years and a part of 2009, too. I needed a source of information that I can compare my data to. One of the way is to get data from the website PVgis [21].

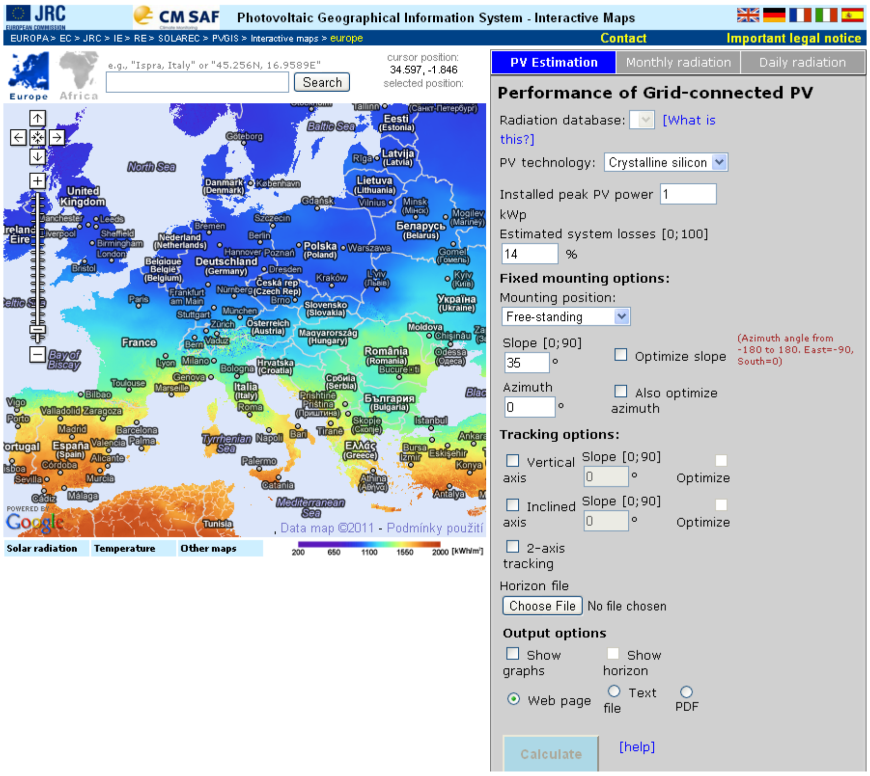

Figure 29: PVgis

	A	B	C	D	E	F
1						
2			AÑO DE INICIO:	2009		
3			AÑO ACTUAL:	2011		
4			CORRECCIÓN:	0,998		
5						
6						
7		**Fixed system: inclination=30°, orientation=21°**				
8	2008	**Month**	E_d	E_m	H_d	H_m
9	412,6	Jan	410,95	12739,49	3,87	120
10	474,4	Feb	472,50	13230,12	4,47	125
11	577,6	Mar	575,29	17834,05	5,51	171
12	596,4	Apr	594,02	17820,50	5,75	172
13	646	May	643,42	19945,98	6,31	196
14	657	Jun	654,37	19631,24	6,55	197
15	668	Jul	665,33	20625,25	6,73	209
16	636,9	Aug	634,35	19665,00	6,35	197
17	596,5	Sep	594,12	17823,49	5,82	174
18	512,3	Oct	510,25	15817,84	4,96	154
19	389,1	Nov	387,55	11626,35	3,68	110
20	367,6	Dec	366,13	11350,06	3,55	110
21						
22		**Yearly average**	**542,36**	**16509,11**	**5,30**	**161,25**
23		**Total for year**		**198109,38**		**1935,00**
24						
25		**Fixed system: inclination=30°, orientation=21°**				
26		**Month**	E_d	E_m	H_d	H_m
27	348	Jan	346,61	10744,89	3,79	117,49
28	400	Feb	398,40	11155,24	4,44	124,32
29	487	Mar	485,05	15036,67	5,57	172,67
30	503	Apr	500,99	15029,70	5,82	174,60
31	545	May	542,82	16827,49	6,43	199,33
32	554	Jun	551,79	16553,59	6,68	200,40
33	563	Jul	560,75	17383,26	6,88	213,28
34	537	Aug	534,85	16580,48	6,54	202,74
35	503	Sep	500,99	15029,70	5,96	178,80
36	432	Oct	430,27	13338,49	5	155,00
37	328	Nov	326,69	9800,68	3,67	110,10
38	310	Dec	308,76	9571,60	3,4	105,40
39						
40		**Yearly average**	**457,33**	**13920,98**	**5,35**	**162,84**
41		**Total for year**		**167051,78**		**1954,13**
42						

Table 18: Data from Pvgis

Then I put these numbers to another excel table and compared them with the real daily production. This is the first column in excel table below

	PRODUCCIÓN REAL VS. PVGIS					
	FECHA	PVGIS	(kWh.)	CHECKING	(kWh.)	PRODUCCIÓN
21	2.1.2011	Prod. Día:	410,95	Prod. Día:	352,8	85,85%
22		Prod. Mes:	821,90	Prod. Mes:	583,6	71,01%
23		Prod. Acum.:	282259,09	Prod. Acum.:	285562,41	101,17%
24				Prod. Cont.:		
26	3.1.2011	Prod. Día:	410,95	Prod. Día:	548,6	133,50%
27		Prod. Mes:	1232,85	Prod. Mes:	1132,2	91,84%
28		Prod. Acum.:	282670,04	Prod. Acum.:	286111,01	101,22%
29				Prod. Cont.:		
31	4.1.2011	Prod. Día:	410,95	Prod. Día:	469,2	114,17%
32		Prod. Mes:	1643,81	Prod. Mes:	1601,4	97,42%
33		Prod. Acum.:	283081,00	Prod. Acum.:	286580,21	101,24%
34				Prod. Cont.:		
36	5.1.2011	Prod. Día:	410,95	Prod. Día:	339,1	82,52%
37		Prod. Mes:	2054,76	Prod. Mes:	1940,5	94,44%
38		Prod. Acum.:	283491,95	Prod. Acum.:	286919,31	101,21%
39				Prod. Cont.:		
41	6.1.2011	Prod. Día:	410,95	Prod. Día:	463,1	112,69%
42		Prod. Mes:	2465,71	Prod. Mes:	2403,6	97,48%

AÑO 2011

	PRODUCCIÓN REAL VS. E. RADIADA			FACTURACIÓN REAL VS. FAC. IBERDROLA					
	RAD. (kWh/m2)	E. RADIADA	PRODUCCIÓN	FACTURACIÓN	Rep. Merc.	Fac. Iberdrola	Abonado	SM100C	SM20S
21	2,8	286,67	123,07%	116,42 €	115,41 €			296	56,8
22	4,8	491,43	118,75%	192,59 €	190,91 €			489	94,6
23	2512,9	257276,00	110,99%	92 302,51 €	90 100,84 €			239632,99	45929,42
24	2512,9	257276,00							
26	4,5	460,72	119,07%	181,01 €	179,45 €			461	87,6
27	9,3	952,15	118,91%	373,61 €	370,36 €			950	182,2
28	2517,4	257736,72	111,01%	92 483,53 €	90 280,29 €			240093,99	46017,02
29	2517,4	257736,72							
31	3,8	389,05	120,60%	154,80 €	153,47 €			395	74,2
32	13,1	1341,21	119,40%	528,41 €	523,83 €			1345	256,4
33	2521,2	258125,77	111,02%	92 638,33 €	90 433,76 €			240488,99	46091,22
34	2521,2	258125,77							
36	2,9	296,91	114,21%	111,87 €	110,91 €			286	53,1
37	16	1638,11	118,46%	640,28 €	634,73 €			1631	309,5
38	2524,1	258422,68	111,03%	92 750,20 €	90 544,66 €			240774,99	46144,32
39	2524,1	258422,68							
41	3,9	399,29	115,98%	152,79 €	151,47 €			390	73,1
42	19,9	2037,40	117,97%	793,06 €	786,20 €			2021	382,6

Table 19: Compare of real and theoretical production in daily production

To have a clear vision how the production is going, there is another list with the monthly production. From given data, data obtained from PVgis and data calculated in excel there are output figures are shown below. I put there just 2 of them just to show the difference between months of December and July.

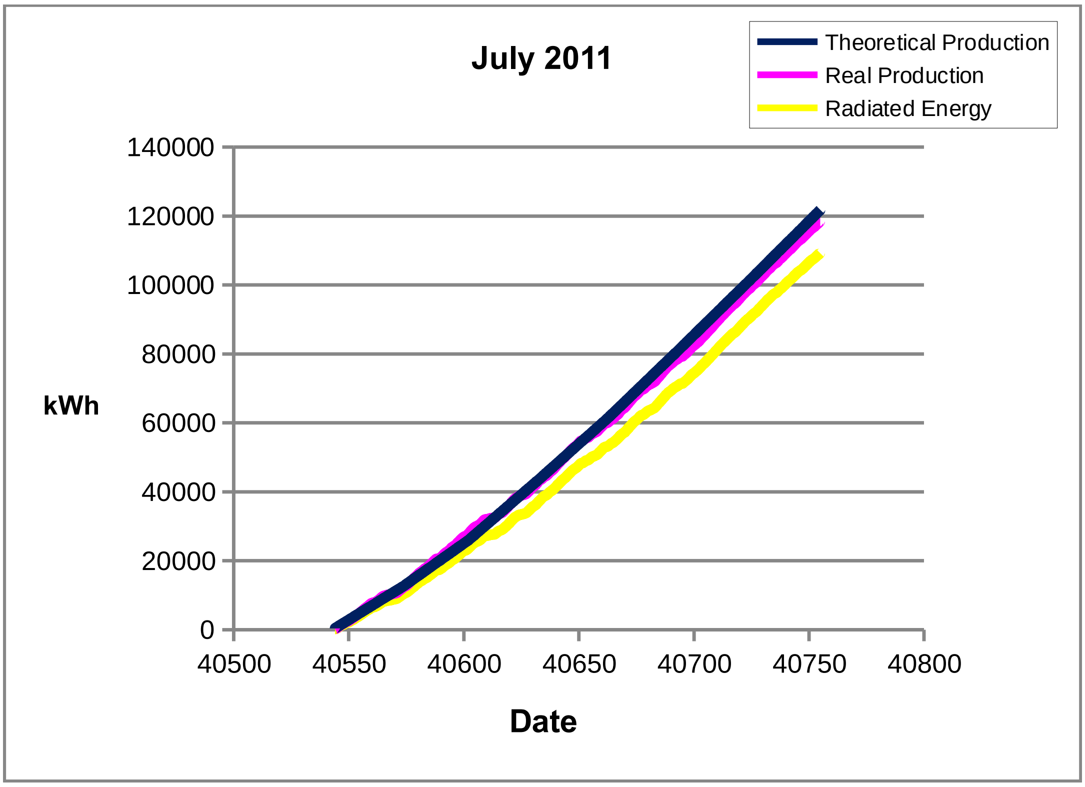

Figure 30: July production

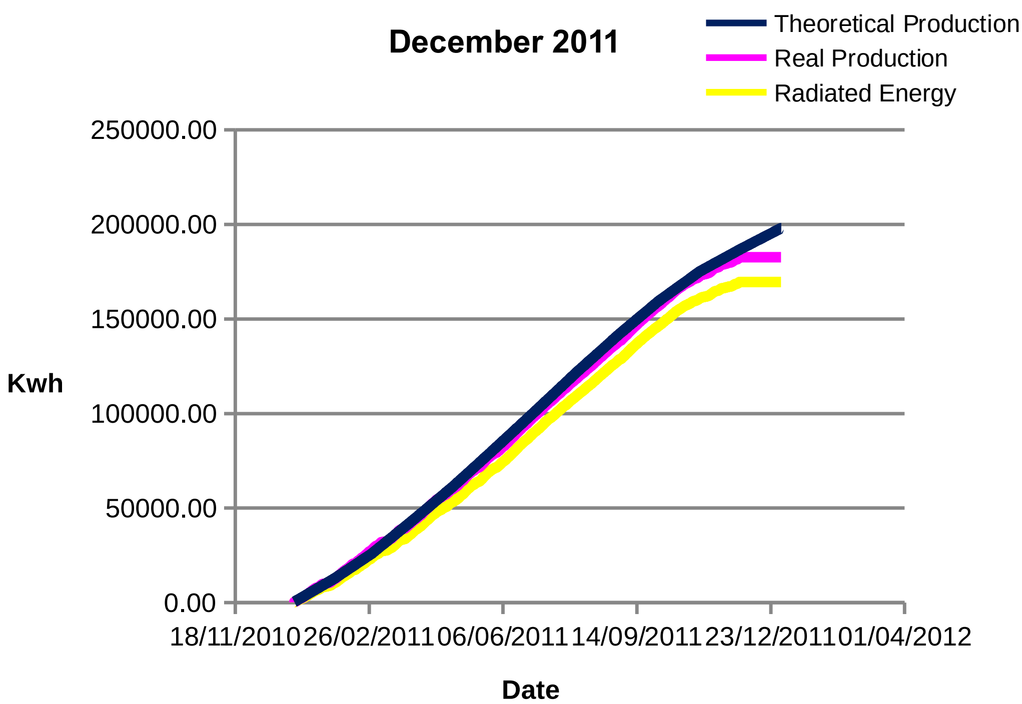

Figure 31: December production

AÑO 2011

		PRODUCCIÓN REAL VS. PVGIS					PRODUCCIÓN REAL VS. E. RADIADA			FACTURACIÓN REAL VS. FAC. IBERDROLA				SM100C	SM20S
9							PRODUCCIÓN ENERO								
11	FECHA	PVGIS	(kWh.)	CHECKING	(kWh.)	PRODUCCIÓN	RAD. (kWh/m2)	E. RADIADA	PRODUCCIÓN	FACTURACIÓN	Rep. Merc.	Iber	Fco	SM100C	SM20S
12		Prod. Mes:	12739,49	Prod. Mes:	12473,3	97,91%	102,3	10473,69	119,09%	4 115,57 €	4 079,97 €	3 425,78 €	689,79 €	10486	1987,3
13		Prod. Año:	12739,49	Prod. Año:	12473,3	97,91%	102,3	10473,69	119,09%	4 115,57 €	4 079,97 €	3 425,78 €	689,79 €	10486	1987,3
14		Prod. Acum.:	294176,68	Prod. Acum.:	297 452,11	101,11%	2 610,40	267258,25	111,30%	96 225,49 €	93 989,90 €	26 616,81 €	5 389,77 €	82 957,99	15 810,77
16							PRODUCCIÓN FEBRERO								
18	FECHA	PVGIS	(kWh.)	CHECKING	(kWh.)	PRODUCCIÓN	RAD. (kWh/m2)	E. RADIADA	PRODUCCIÓN	FACTURACIÓN	Rep. Merc.	Iber	Fco	SM100C	SM20S
19		Prod. Mes:	13230,12	Prod. Mes:	15349,50	116,02%	128,60	13166,34	116,58%	5 064,67 €	5 020,82 €	4 214,10 €	850,57 €	12899	2450,5
20		Prod. Año:	25969,61	Prod. Año:	27822,80	107,14%	230,90	23640,03	117,69%	9 180,24 €	9 100,78 €	7 639,88 €	1 540,36 €	23385	4437,8
21		Prod. Acum.:	307406,80	Prod. Acum.:	312801,61	101,75%	2739,00	280424,59	111,55%	101 290,16 €	99 010,71 €	30 830,92 €	6 240,34 €	95856,99	18261,27
23							PRODUCCIÓN MARZO								
25	FECHA	PVGIS	(kWh.)	CHECKING	(kWh.)	PRODUCCIÓN	RAD. (kWh/m2)	E. RADIADA	PRODUCCIÓN	FACTURACIÓN	Rep. Merc.	Iber	Fco	SM100C	SM20S
26		Prod. Mes:	17834,05	Prod. Mes:	15598,30	87,46%	135,30	13852,30	112,60%	5 146,54 €	5 102,07 €	4 285,98 €	860,57 €	13119	2479,3
27		Prod. Año:	43803,66	Prod. Año:	43421,10	99,13%	366,20	37492,33	115,81%	14 326,78 €	14 202,86 €	11 925,86 €	2 400,93 €	36504	6917,1
28		Prod. Acum.:	325240,85	Prod. Acum.:	328399,91	100,97%	2874,30	294276,89	111,60%	106 436,70 €	104 112,79 €	35 116,89 €	7 100,91 €	108975,99	20740,57
30							PRODUCCIÓN ABRIL								
32	FECHA	PVGIS	(kWh.)	CHECKING	(kWh.)	PRODUCCIÓN	RAD. (kWh/m2)	E. RADIADA	PRODUCCIÓN	FACTURACIÓN	Rep. Merc.	Iber	Fco	SM100C	SM20S
33		Prod. Mes:	17820,50	Prod. Mes:	16905,30	94,86%	155,50	15920,42	106,19%	5 579,09 €	5 530,34 €	4 624,11 €	954,98 €	14154	2751,3
34		Prod. Año:	61624,16	Prod. Año:	60326,40	97,89%	521,70	53412,75	112,94%	19 905,87 €	19 733,20 €	16 549,97 €	3 355,90 €	50658	9668,4
35		Prod. Acum.:	343061,35	Prod. Acum.:	345305,21	100,65%	3029,80	310197,31	111,32%	112 015,79 €	109 643,13 €	39 741,01 €	8 055,88 €	123129,99	23491,87

Table 20: Monthly data

This table shows the data of monthly production.

And finally an overview of the production in 2011.

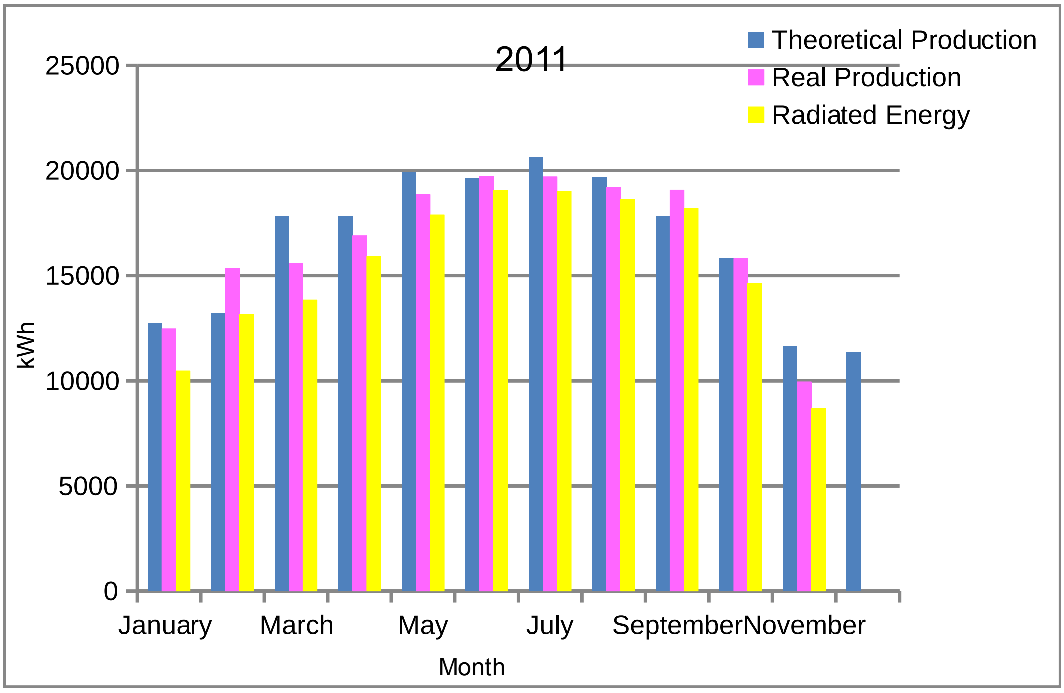

Figure 32: Overview of production for the whole year

10 Power output estimation

Following calculations are for estimation of the electric power injected to the electricity distribution network. This analysis is implemented in the system losses, obtaining an estimated yield of the PV system. There are 2 possibilities, the first one is more theoretical and the second one is empirical, used in Spain

10.1 Estimation of losses and production rate

Production ratio is the ratio of the energy actually produced by the installation and the maximum theoretical energy can be generated and can quantify losses and compare PV systems located in different places.

It is an experimental parameter, so it means that it is only an estimation that can be made of various losses that installation can suffer, bearing in mind that the production ratio of a typical installation ranges between 0,6 and 0,8.

For our case study losses are evaluated for their relevance and a detailed calculation of these is presented below:

- Losses in the generator.

Losses related to the photovoltaic generator are listed and quantified below.

orientation and tilt losses.

They consider losses due to a disposition that differs from the optimal generator both inclination and orientation. Because the two different approaches will be discussed here installation for each:

1. Flat roof: as the tilt orientation is optimal for the location, and there is no deviation from the south. So that

$$P_{azimuth}=0\, P_{inclination}=0 \quad (10.1)$$

2. Twofold roof: In this case the inclination of the panels forming the subfields is optimal, but not the orientation towards the south, due to the layout of the warehouse, which is not corrected in installation. Therefore, at this point, it requires the calculation of orientation losses

P = [1.2 · 10-4 (β-φ +10) 2 + 3.5 · 10-5 · α2] · 100 _ bent orientation

Φ being the latitude of the location, so that:

P = [1.2 · 10-4 (30-40,1 +10) 2 +3.5 · 10-5 · 242] · 100 = 2.01%

And to emphasize the importance of the correctness of the inclination of the panels on this surface, it is then the calculation of losses for the case of inclination, possessed on the cover (an angle of 8):

P = [1, 2 · 1 0 - 4 (8 - 4 0, 1 + 1 0) 2] · 1 0 0 = 5. 8 6% _ bent orientation

Losses which are considered significant are from 2% to 6%.

- Losses because of shadows

There are several methods for calculating shading losses. One of them I described before, a profile of obstacles affecting the PV array surface that could be represented on a solar path diagram and thus able to get the shading loss charts.

In the case of the proposed installation is considered that no obstacles affecting the surface of the panels. We have calculated the minimum separation between panels to prevent shadows generated between them. Therefore can be considered zero losses for this concept.

- Losses due to the temperature.

Effect losses due ti temperature are considered constant. Empirical Schmidt equation is used for calculation of a loss of correlation between temperature and latitude. The following expression is used:

$$FT = 1 - 0{,}065 \cdot \sqrt{1 - \left(\frac{(\Phi - 25)}{30}\right)^2} \qquad (10.2)$$

where

Φ is being the latitude of the location of the building.

Calculated below for the location of the installation:

$$FT = 1 - 0{,}065 \cdot \sqrt{1 - \left(\frac{(40-25)}{30} \right)^2} = 0{,}9437 \qquad (10.3)$$

Another possibility is following the specifications and technical conditions of the IDEA Network Connection to determine the cell temperature the formula is:

$$T_C = T_{amb} + I_{inc} \frac{TONC - 20}{800} \qquad (10.4)$$

where

Tc is cell temperature

T_{amb} is ambient temperature

I_{inc} [W/m2] Irradiance

TONC temperature reaching solar cells when subjected to the module at an irradiance of 800 W/m2, ambient temperature of 20 ° C, wind speed of 1m / s.

The temperature mainly affects the values of voltage I-V characteristic, and has the most influence on the open circuit voltage, but also changes the values of the maximum power point and the value of Icc (very slightly).

Taking temperature data in Elche 2010, by month according to the National Institute of Meteorology of Spain, and considering that the module has a loss of 0.5% / ° C, we obtain the correction power of each month:

	Ta aver	Tc cell	Loss [%]
January	11,3	37,30	5,54
February	12,3	38,30	5,99
March	13,4	39,40	6,48
April	16,3	42,30	7,79
May	19,7	45,70	9,32
June	23,4	49,40	10,98
July	27,1	53,10	12,65
August	27,2	53,20	12,69
September	24,3	50,30	11,39
October	19,5	45,50	9,23
November	14,9	40,90	7,16
December	11,1	37,10	5,45

Table 21: Temperature losses

- Scattering losses

Cells and modules are never identical due to scattering parameters, typical of any manufacturing process, especially in the electronics technology.

In PV technology, the maximum power that can deliver the generator is less than the sum of the maximum power of the modules that constitute to. According to the manufacturer, the maximum deviation from the nominal in used power modules is -5%.

- Transmittance losses

When the solar rays do not impinge perpendicularly on the module, there are certain reflection and absorption losses in the above layers to the solar cells. According to previous studies, the range of losses for this type is in the range 3-5%, depending on conditions. For this study we take the average value of 4%.

- Losses because of dirt

In most cases, the rain water is usually sufficient to maintain the levels assumable during year, only in the case of generators subjected to high levels of contamination or spoilage local losses can reach representative values. I did not estimate these losses for the installation to study.

So the total losses in the generator are the sum of the losses exposed at this point, and a total of:

$$P = P_{orientation} + P_{shadows} + P_{temp} + P_{disp} + P_{trans} \quad (10.5)$$

Plane roof

$$P_{gen} = 0 + 0 + 0.0563 + 0.05 + 0.04 = 0.146 \quad (10.6)$$

Inclined roof

$$P_{gen} = 0.02 + 0 + 0.0563 + 0.05 + 0.04 = 0.166 \quad (10.7)$$

Another possibility how to estimate production is a method that is commonly used in Spain to calculate the losses and the average kWh per month or year.

Production data											
MES	A1	A2	A3	A4	Ptemp	B	C	D	E	F	PR
January	2	2	3	1,5	5,54	0,985	0,98	0,98	0,96	0,98	0.7651
February	2	2	3	1,5	5,99	0,985	0,98	0,98	0,96	0,98	0.7611
March	2	2	3	1,5	6,48	0,985	0,98	0,98	0,96	0,98	0.7567
April	2	2	3	1,5	7,79	0,985	0,98	0,98	0,96	0,98	0.7451
May	2	2	3	1,5	9,32	0,985	0,98	0,98	0,96	0,98	0.7314
June	2	2	3	1,5	10,98	0,985	0,98	0,98	0,96	0,98	0.7166
July	2	2	3	1,5	12,65	0,985	0,98	0,98	0,96	0,98	0.7018
August	2	2	3	1,5	12,69	0,985	0,98	0,98	0,96	0,98	0.7014
September	2	2	3	1,5	11,39	0,985	0,98	0,98	0,96	0,98	0.7130
October	2	2	3	1,5	9,23	0,985	0,98	0,98	0,96	0,98	0.7322
November	2	2	3	1,5	7,16	0,985	0,98	0,98	0,96	0,98	0.7507
December	2	2	3	1,5	5,45	0,985	0,98	0,98	0,96	0,98	0.7659

Table 22: Losses calculation part A

Daily G	Days per Month	Production [kW]	Prodution [kWh]
3.1500	31	74.710	9712,31944
3.8900	28	82.896	10776,5308
5.0400	31	118.222	15368,8855
5.6500	30	126.287	16417,3111
6.4800	31	146.932	19101,0967
6.9000	30	148.341	19284,2678
6.9700	31	151.638	19713,0013
6.4000	31	139.158	18090,5611
5.5600	30	118.931	15461,0479
4.4700	31	101.467	13190,6486
3.1200	30	70.262	9134,06787
2.9100	31	69.090	8981,72667

Table 23: Losses calculation part B

A1 Losses in the modules

A2 Dust losses

A3 Losses for reflection

A4 Shadow losses

Ptemp Temperature losses

B Looses in cables (DC)

C Looses in cables (AC)

D Blackout losses, maintenance losses

E Inverter efficiency

F Other losses

PR Performance factor

Other values used in this method are Tonc and peak output. This methods is mainly based on empiric numbers, though it results are quite accurate.

The temperature losses are taken from the table above,which were calculated from the parameters given by the manufacturer of the solar panels used in this installation.

Daily radiance is taken from the average radiance in Murcia, Spain.

11 Calculation of CO_2 and SO_x

In this section I estimate the savings in CO_2 and SO_x emissions referring to electricity generated by the PV system.

An isolated PV system replaces a typical diesel fall about of 1 kg of CO2 per kWh produced. For grid connected systems depend on electricity production profile of each country. The global average figure is set to 0,6 kg of CO_2 per kWh and about 2,95 grams of SO_x.

	Production [kWh]	Emisiones CO2 notproduced [kg]	Sox notproduced [g]
January	9712,32	5827,39	28651,34
February	10776,53	6465,92	31790,77
March	15368,89	9221,33	45338,21
April	16417,31	9850,39	48431,07
May	19101,10	11460,66	56348,24
June	19284,27	11570,56	56888,59
July	19713,00	11827,80	58153,35
August	18090,56	10854,34	53367,16
September	15461,05	9276,63	45610,09
October	13190,65	7914,39	38912,41
November	9134,07	5480,44	26945,50
December	8981,73	5389,04	26496,09
Total	**175231,46**	**105138,88**	**516932,82**

Table 24: CO_2 ans SO_X saved for the PV plant

12 Budget

In order to perform a feasibility analysis of the different solutions proposed in the previous sections I performed a PV budget of 120 kW. The installation is on inclined roof, the investor chose to do the more expensive possibility, where the structural support had been adjusted to enable the optimal angle of the sunlight. The budget consists of components and installation, including direct taxes of all goods.

While calculating the budget I needed to find prices from the year 2008 where the calculation was done. The field it self started functioning in 2009. Perhaps in some cases I needed to do some estimation of the prices that could have been in 2008, so tis budget should not be taken as a real one. I tried to do it as accurate as possible but nevertheless there could be some deviation from the actual price.

This budget estimation suits just for the purposes of the cost estimation that will follow later on it the thesis. The budget consists of prices for the solar panels, where there are 759 of them type Himin, HG 185S. Then from inverters Solarmax types 100C and 20S, support structure for all the panels, cables, protections and equipment boxes. Especially these last goods were estimated, because I do not have data about cables and how much of them there are. I measured the length of the building and the rows and estimated the number. The same thing is about the protection, I did not have the exact information what kind of protections there are.

The price for the goods I calculated something below 360 000 €. Apart from the goods there is a part of cost for the wok on site. Because this construction was more complicated than the usual one at ground or at flat roof, I put the price of 50 000 € for the construction and 10 000 € for the site management, which is a usual price in Spain.

Altogether it and divided for the kWp it comes at 2,96 € per kWp. This I will need for the economical calculation which follows.

13 Economic study

13.1 Introduction

Correct analysis of economic viability of a project is crucial, not only to determine the suitability of an investment making, but also to predict the likely behavior of the installation to avoid or limit economic damage important for investors.

Moreover, financial institutions require such studies before approving the data required for the execution of any type of financial help and loans.

In the following study, I calculate estimation of the income of the facility during the 25 years of estimated useful life with simulated annual cash flow and the parameters NPV, IRR and PR, which are commonly used indicators for analysis investment feasibility.

13.2 Preliminary considerations. Assumptions adopted

Notwithstanding that the facility can continue to function properly and provide sufficient economic returns over a longer period, it is considered a useful life of 25 years for installation nowadays.

Because the installation is a renewable energy investment, according regulates corporate tax at 2008, business or legal entity making the investment may be deducted by 10% of the amount invested during the first 10 years, provided they do not exceed 35% annual tax to pay. The corporate income tax is chargeable only if the accumulated balance of the company is positive, otherwise they do not receive anything.

Investment is the amount budgeted for the project overall PV system, except the part that was funded by the bank. This provides funding for 80% of the total budget of the facility I will use interest at 3,5%. This loan is repayable in 11 years.

13.3 Electricity rates for 2008. Special Regimen group B.1.1.

PV installation is in special regimen established in Royal Decree 661/2007, it says that this is one production facility Energy electric contemplated in Article 27.1 it to the Law 54/1997 of 27 November. Inside the 1st Group, B.1. it says that the facilities that use the primary energy the renewable energy. This group is divided into the subgroups corresponding Sub b.1.1 al. Facilities that use only sunlight as the primary means of the

Energy PV Technology.

On December 29, 2007 the spanish government published in the BOE the new electricity tariffs for 2008, including renewable energy, coming into force on January 1, 2008.

ORDER ITC/3860/2007, 28 December, revising electricity tariffs from January 1, 2008.

On page 21 of this document (or 53801 BOE) are the rates for photovoltaic installations of Special regime up to 100 kW is at 45.5134 c € / kWh. So, compared to 44.0381 c € / kWh, which had since January 2006, resulting in an increase of 3.35%.

According Art.44, 1 RD661/2007 the increase is CPI-0, 25% through 2012. For the calculation of electricity prices, has taken the CPI YOY October, which is 3.60%. Since the rates for photovoltaics are updated with the CPI - 0.25%, for 2008 are as follows

Output≤ 100kW	
First 25 years	45,5134 c€/kWh
Rest	36,4107 c€/kWh

Output≥ 100kW	
First 25 years	43,1486 c€/kWh
Rest	34,5189 c€/kWh

Table 25: Prices in year 2008

As the boom of photovoltaic power plants occurred in Spain in 2007 and 2008, the government lowered the prices and for the purpose of this thesis it was considered the price from 2010 20,8 c€/kWh.

13.4 Definition of terms

13.4.1 Income Statement.

The income statement reflects the differences between the flows of costs and profits attributable to the same period. Resume operations on a limited period, usually taken as year study period.

$$\mathit{Profit\ After\ Tax} = \mathit{Income} - \mathit{Expenses} - \mathit{Depreciation} - \mathit{Interest} - \mathit{Taxes} \quad (13.1)$$

The income statement also includes disaggregated components comprising the totality of the business output, as well as knowing if the progress of each point is desired.

For a correct analysis of the management is essential to know the profit or loss obtained and where it is generated. These data are key to current developments and the forecast for the future of the company.

- Income: At this point I consider only sales of power to the grid annually. Will take into account the following factors:
  - Predictable - annual increase in electricity tariff reference. As this increase estimate at 3.25% per annum.
  - Possible reduction - annual performance installation component wear. The reduction is generally estimated at 0.09% for the first 12 years of service, and by 0.08% in the following 13.
- Costs: they reflect the cost of annual operation and maintenance, including the maintenance contract for an annual amount of sales revenue earned in the previous year. As well as, the annual disbursement insurance premium installation, considering an annual CPI increase of 3.5%.
- Amortization: reflects the return on investment that is the distribution of spending installation acquisition over several accounting periods. It takes constant amortization method with equal annual amount devoted to this concept. Highlight here, which relates to amortization accounting element to represent that currency depreciation over time suffer the assets of the company.
- Interest: financial loan disbursements per a year in interest, according to the loan amortization schedule.
- Taxation: paying corporate income tax, accounting for 30% of annual profits. Here and conditions apply tax benefits set out in the section on initial considerations.

After studying the various points mentioned so far, it has been to provide the accumulated after-tax profit over the useful life established for the planned installation.

13.4.2 Net Present Value (NPV).

One of the criteria used to analyze the performance of the PV system will be the NPV.

The Net Present Value (NPV) of an investment project is defined as the algebraic sum of the equivalent values of all partial cash flows from the start date of the project. Flows are the annual amounts of income and expenses, may be of any sign. So, if in a year you have a negative cash flow mean that in that period, expenditures have exceeded income, and conversely, indicate that revenues were higher.

Therefore, the NPV provides an absolute measure of performance of the installation. A positive NPV indicates that the installation creates value. Otherwise, negative NPV, the installation will loose and it is not interesting for investment.

Below are the criteria for assessing investment in terms of NPV:

If NPV> 0 The installation is profitable.

If NPV <0 The facility is not profitable.

The NPV is also quantitative parameter, so the higher the investment will bring higher returns.

The big disadvantage of a cost benefit analysis using this criterion is that one has to set the interest rate, which depends on many factors, including: the price of money, the opportunity costs and risks of such investment.

The NPV can be calculated by the following expression:

$$NPV = -Invertion + \sum \frac{FC_n}{(1+r)^n} \tag{13.2}$$

where

r is a discount rate.

It can be understood as the discount rate or minimum interest value that the investor expects to obtain for financing and implementation.

13.4.3 IRR: Internal Rate of Return.

We define the internal rate of return as the discount rate or interest rate that equates the NPV to zero.

$$NPV = -Invertion + \sum \frac{FC_n}{(1+r)^n} = 0 \tag{13.3}$$

To perform this calculation one need an iterative processes of mathematical computing software. It is understood that if the IRR is greater than the discount rate applied, the project will be profitable.

Also called "Cash-Flow" is an annual estimate of net cash balance of the company, detailing the difference between the projected sales revenues and expected monthly payments.

Unlike the income statement, this analysis does not include the accounting issues represents the net inflows or outflows of money annually. This economic evaluation is based on expectations of the moments of need provide capital, and which will result revenue due to productive activity. The IRR is also used for calculating:

PR, NPV and IRR

13.4.4 Return Period (RP).

It is defined as the period of time that returns the initial investment through cash flows generated by the project. This occurs in the year in which the cumulative cash flows exceeds the initial investment.

13.5 Taxes and deductions of the installation.

The electricity generation thanks to a photovoltaic power plant connected to the grid involves the development of productive means in order to obtain a profitable return on investment.

This makes it an economic activity and therefore will be subject to tax and tax on the items that are listed below:

1. Business tax

It should be enlisted under the document paragraph 151.4 from IAE corresponding to solar energy production. From the Law 51/2002 of December 27 on Local Taxes, photovoltaic production facilities will be exempt from paying, as a company that bills for its generation.

2. Income tax of individuals

Taxes must be paid by the result of subtracting net income from sale of electricity generated, deductible expenses resulting from the installation, such as maintenance and amortization of order.

3. Value added tax

It must make a quarterly statement for the purchase of equipment and the invoice to the electricity distribution company.

At the end of the first year of operation of the facility can claim back all the VAT amount, concerning the implementation of the installation. For what should be registered in the IAE.

If the installation has been funded in part by a grant, there is a limit to deduct VAT, which is the percentage by which the facility is funded by the grant.

As for deductions that could benefit the facility can be defined as follows:

- As the economic activity generating electricity by photovoltaic generators, you can deduct the first year 10% of the investment in the PV.
- Another way to deduct 10% of the value of the investment, is imputing it to environmental investments.

13.6 Evaluation for the installation

There are several numbers that I need for the calculation of the economical study for this installation. Average kWh per year, kWp, price for which the Iberdrola buys the electricity, the budget which is the price for the installation. As with all the loans I also considered that for the beginning the company will have the 20% of the needed capital in cash at its disposal and that it will take a loan for the rest 80%. For the loan I estimated the interest for 3,5 % and the inflation for 2,5%.

I also put there a price for insurance as it is usually about 500 € per year. In the price of installation it should be considered also the cost of maintenance of the photovoltaic power plant. I put there an empiric number of 2%.

As in most of the cases of photovoltaic field the economic calculation is done for the 25 years which is considered that the plant should function without problems and with given efficiency.

Due to the budget calculation and the price for kWh the loan calculation came out to be optimal to take a loan for 11 years. In general, the bigger the installation in less years it is paid so mayor the outcome.

As I mentioned earlier one of the economic parameters is NPV. In this study it is 8,34%. Which according to the theory mentioned earlier, where if the NPV is greater than 0, then the installation os profitable.

In the table on the next page, one can see the estimated production, the money that

Iberdrola will pay for the electricity, considering that the price for kWh is 20,8 c€. How much is the loan it self, the cost of maintenance which is considered 2% from the whole price and insurance. As it was said earlier there is an inflation of 2,5%.

The total income after paying the loan with all the interests is 717 350,82 €.

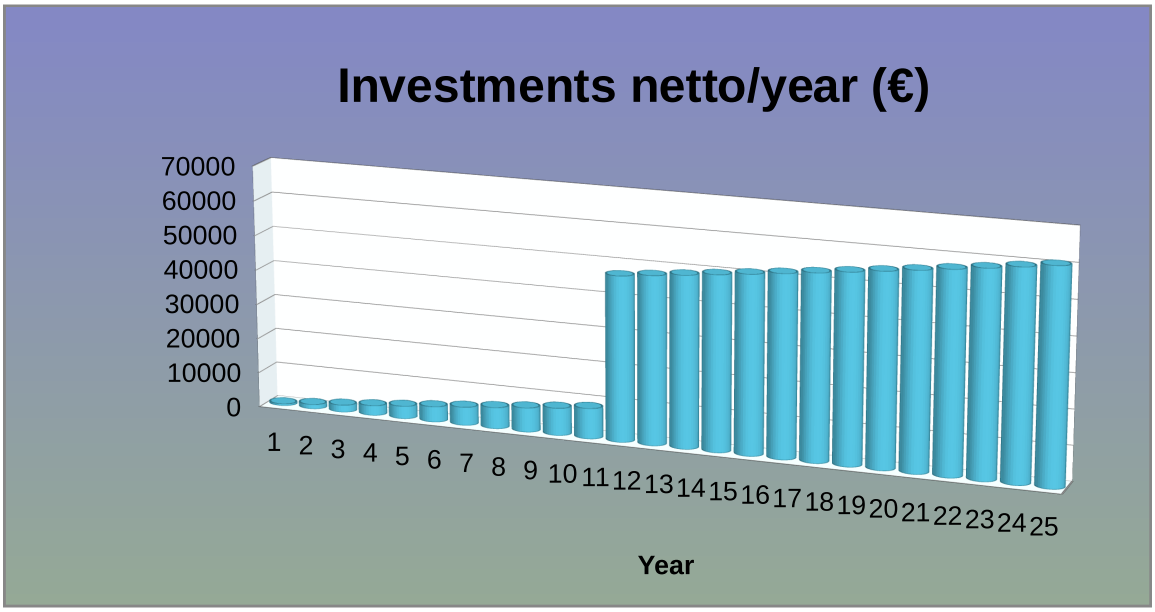

Figure 33: Investments per year during the 25 years

Year	Produc (Kwh/year)	Elect. Sales	Expences			Investments netos month	Outcome neto per year	Acumulated cash
			Loan	Mainten	Insurence			
1	189,271.00	39,368.37 €	37,581.75 €	787.37 €	500.00 €	41.60 €	499.25 €	-84,311.41 €
2	188,324.64	40,150.81 €	37,581.75 €	803.02 €	515.00 €	104.25 €	1,251.05 €	-83,060.35 €
3	187,383.02	40,948.81 €	37,581.75 €	818.98 €	530.45 €	168.14 €	2,017.64 €	-81,042.71 €
4	186,446.10	41,762.67 €	37,581.75 €	835.25 €	546.36 €	233.28 €	2,799.31 €	-78,243.41 €
5	185,513.87	42,592.70 €	37,581.75 €	851.85 €	562.75 €	299.70 €	3,596.35 €	-74,647.06 €
6	184,586.30	43,439.23 €	37,581.75 €	868.78 €	579.64 €	367.42 €	4,409.06 €	-70,238.00 €
7	183,663.37	44,302.59 €	37,581.75 €	886.05 €	597.03 €	436.48 €	5,237.76 €	-65,000.23 €
8	182,745.05	45,183.10 €	37,581.75 €	903.66 €	614.94 €	506.90 €	6,082.76 €	-58,917.48 €
9	181,831.33	46,081.11 €	37,581.75 €	921.62 €	633.39 €	578.70 €	6,944.36 €	-51,973.12 €
10	180,922.17	46,996.98 €	37,581.75 €	939.94 €	652.39 €	651.91 €	7,822.90 €	-44,150.21 €
11	180,017.56	47,931.04 €	37,581.75 €	958.62 €	671.96 €	726.56 €	8,718.72 €	-35,431.49 €
12	179,117.47	48,883.67 €	0.00 €	977.67 €	692.12 €	3,934.49 €	47,213.88 €	11,782.39 €
13	178,221.89	49,855.23 €	0.00 €	997.10 €	712.88 €	4,012.10 €	48,145.25 €	59,927.63 €
14	177,330.78	50,846.11 €	0.00 €	1,016.92 €	734.27 €	4,091.24 €	49,094.92 €	109,022.55 €
15	176,444.12	51,856.67 €	0.00 €	1,037.13 €	756.29 €	4,171.94 €	50,063.24 €	159,085.80 €
16	175,561.90	52,887.32 €	0.00 €	1,057.75 €	778.98 €	4,254.22 €	51,050.59 €	210,136.39 €
17	174,684.09	53,938.46 €	0.00 €	1,078.77 €	802.35 €	4,338.11 €	52,057.34 €	262,193.73 €
18	173,810.67	55,010.49 €	0.00 €	1,100.21 €	826.42 €	4,423.65 €	53,083.85 €	315,277.58 €
19	172,941.62	56,103.82 €	0.00 €	1,122.08 €	851.22 €	4,510.88 €	54,130.53 €	369,408.11 €
20	172,076.91	57,218.88 €	0.00 €	1,144.38 €	876.75 €	4,599.81 €	55,197.75 €	424,605.86 €
21	171,216.53	58,356.11 €	0.00 €	1,167.12 €	903.06 €	4,690.49 €	56,285.93 €	480,891.79 €
22	170,360.44	59,515.94 €	0.00 €	1,190.32 €	930.15 €	4,782.96 €	57,395.47 €	538,287.26 €
23	169,508.64	60,698.82 €	0.00 €	1,213.98 €	958.05 €	4,877.23 €	58,526.79 €	596,814.05 €
24	168,661.10	61,905.20 €	0.00 €	1,238.10 €	986.79 €	4,973.36 €	59,680.31 €	656,494.35 €
25	167,817.79	63,135.57 €	0.00 €	1,262.71 €	1,016.40 €	5,071.37 €	60,856.46 €	717,350.82 €

Table 26 : Economic calculation

14 Conclusion

If you try and submit Solar energy in Google, it gives you more than 68 million links. Solar energy is successfully being used for cooking, cooling, heating, communications, driving space craft, lighting and many more purposes.

Renewable sources are with no doubts part of our future. They have a lot of popularity even more, after what happened in Fukushima in Japan. It is true that solar energy is still more expensive than classical sources, but many countries targeted these sources as a priority in their power researches. [12] Every year the cost of photovoltaic installation is decreasing. In many countries there is a policy that every home should have photovoltaic panels at its roof if it is possible. In Spain a new law dealing with small installations just came up few months ago. In England the government pays you a good money and even helps you to put photovoltaic panels on your roof.

At the end of 2005 total global peak power of installed solar panels was about 5,300 MW. Now there are many projects in Morocco in Sahara desert. They are building several photovoltaic power plants there. The only problem is to get it from there.

The solar power is a standard in many countries. It does not have to be only photovoltaic panels but there are also solar panels to heat water. Solar panels will be a standard feature for newly constructed homes and commercial buildings. In Spain it is already on. And the solar panels used to warm up the water can be also used for cooling or air-conditioning. You just have to pick the application that suits you.

Nevertheless I saw in my case study, the power output from these sources is unstable. It is not available during the night so there is a need to back up. If there is a bad weather there is almost no electric power produced. In Spain as they installed a lot of photovoltaic panels and during the day they have stable output due to good weather condition and an increased radiation activity. Therefore they are trying to find a way to solve energy peaks during the day. One such project is electric car.

I made my calculations so that I do not have to consider shadow impact, there is almost none. As it can be seen from graphics, some days the production is just around 50% of estimated production. This mainly happened in winter time, so we can assume that it is because of the weather.

Perhaps the future is here now. Shell has predicted that 50% of the world's energy will come from renewable sources by 2040. Shell will also join in a massive renewable energy development project supported by the UAE. Several industrial heavyweights will join them: British Petroleum, Total, and Occidental Petroleum Corp, General Electric, Rolls Royce, Fiat and Mitsubishi. [23]

14.1 Contribution

My contribution is that I created an extended excel file, which can be used for calculation of any installation in conditions of Spain and with slight transformation also for the conditions of the Czech republic. This model is able to calculate all kind of measurements according to the azimuth and inclination of the panels. It is done for the worst case of installation, where the panels are located on inclined roof and the panels their-selves are inclined, as you can see in the Appendix A, where I made the model of the installation in the SketchUp for better understanding.

The excel is able co calculate the dimensions for he design purposes, it gives the dimensions for the manufacturer of the support structure and also has incorporated alarms, when the designed installation does not meet the requirements given by the norms and real decree in Spain.

Apart from the dimension calculation, it also has a script and tables to calculate the CO_2 and SO_X that are saved due to the installation of PV field.

There is also a part for calculation of losses that occur for all kind of reasons such as temperature, efficiency of equipment etc. All these tables were used in this thesis.

The last part is dedicated to the calculation of the economical study, which is a very important part in the project design.

The whole excel is working automatically, so the need to input the numbers for the installation is minimal and therefore the errors while changing the parameters is also minimal, if the costumer wants some changes.

It is also useful for the sole purpose to compare various scenarios of installation, f.e. the best inclination, the losses which are produces, which type of panel would be better, or which inverter to use. If it would be favorable to use 2 smaller or just one bigger and so on.

14.2 Future investigation

As there are interesting data available there could be done an analysis for a Smart Grid purposes. As we have the production, perhaps there could be done a simulation of customers needs. For this it would be better to have more detail data, perhaps to have the output measured not just for one day but for one hour, so the analysis could be done.

Another interesting future investigation based on my research could be a combination of this PV field and wind turbine, because in the area that this installation is situated, there are several project of wind power plant. It would be interesting to do the simulation of Island regime.

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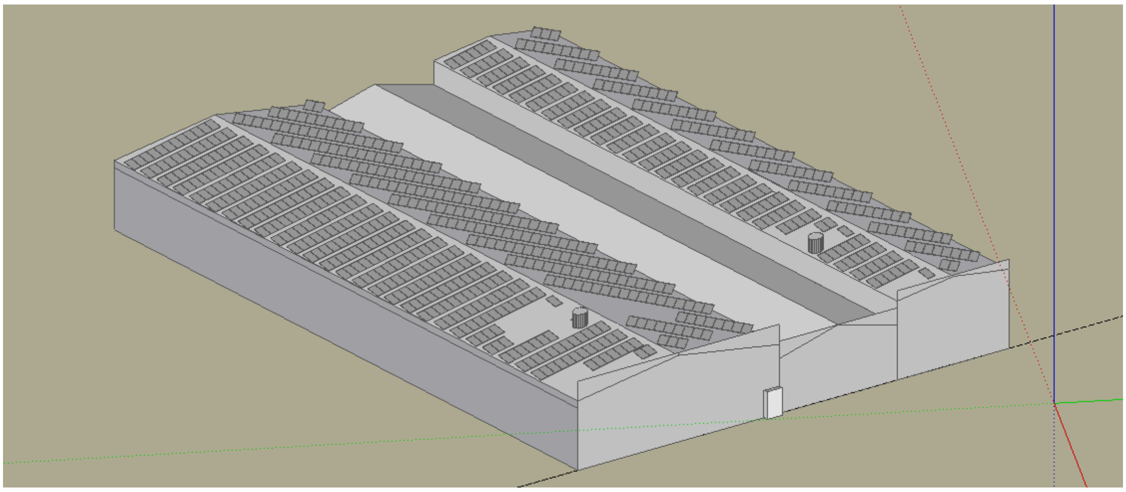
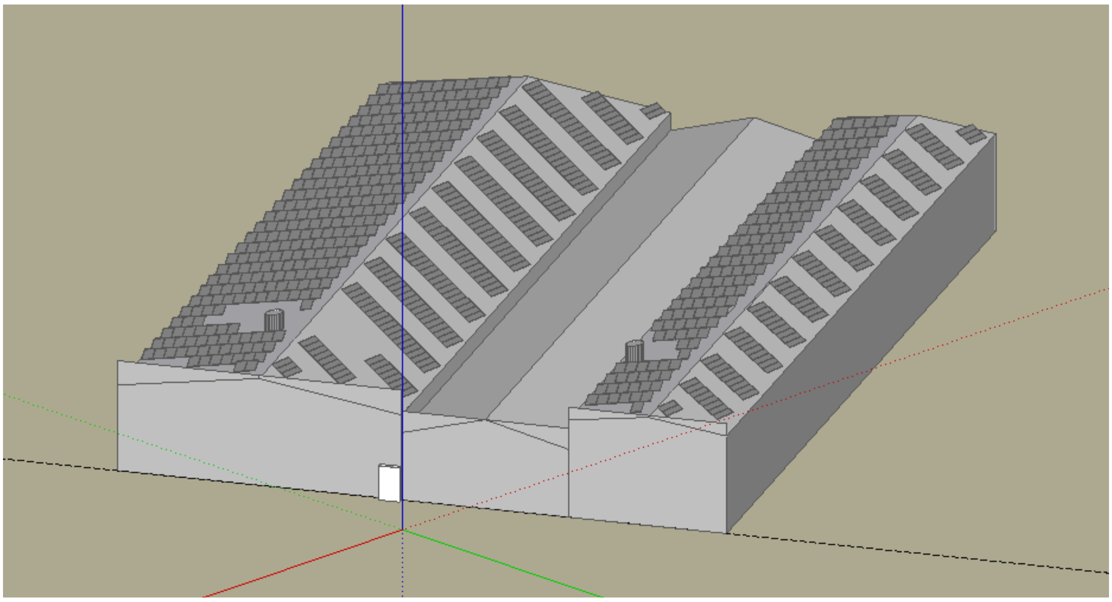
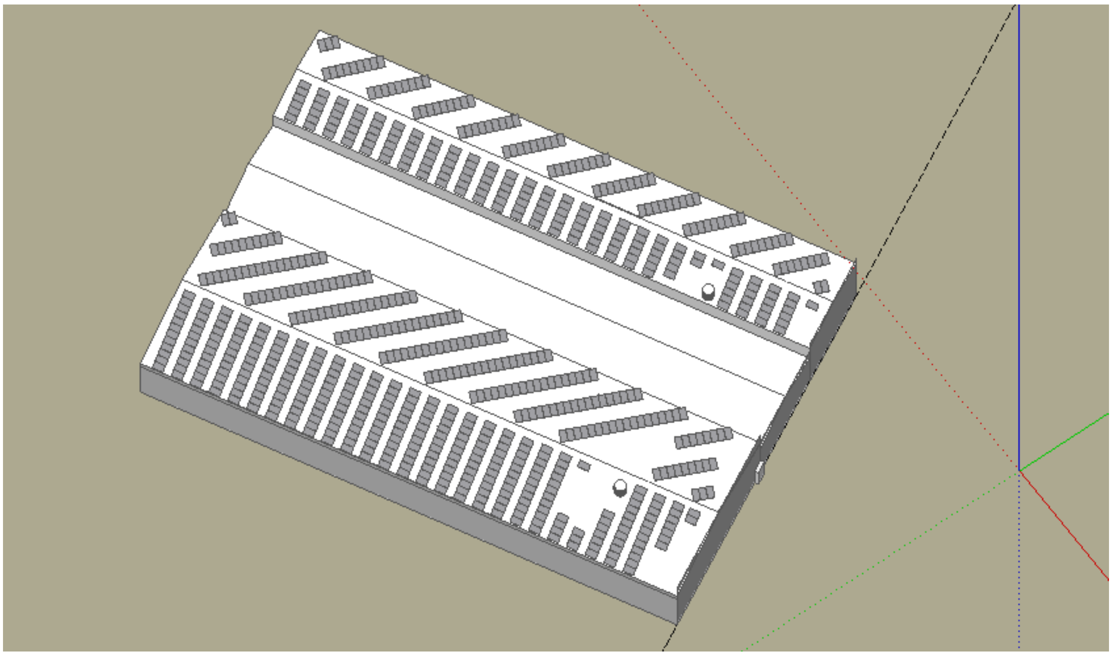
17 Appendix A







18 Appendix B

18.1 Inverters

Cualidades:

- Inversor sinusoidal PWM compacto
- Máxima Eficiencia
- Eficiencia MPP sobre el 99%
- Relación precio/calidad altamente competitiva
- Peso ligero y diseño compacto
- Apropiado para instalaciones en lugares desprovistos de calefacción
- Garantía de hasta veinte años
- Opción MaxControl para la identificación automática de desperfectos, monitoreo del sistema y análisis de los datos de funcionamiento
- Certificación TÜV Rheinland "DE TIPO APROBADO"
- Servicio de entrega puntual
- Servicio telefónico al cliente rápido y eficiente

Especificaciones Técnicas

	SolarMax 50C	SolarMax 80C	SolarMax 100C
Entrada de corriente CC			
Máxima potencia FV instalada en STC* (condiciones de prueba estándar)	66kW	105kW	130kW
Máxima Potencia del sistema de regulación	430...800 Vcc		
Máximo Voltaje de Circuito Abierto	900 Vcc		
Para la configuración del módulo del sistema UMPP (STC) (Para la configuración del módulo del sistema UMPP (STC) con células solares mono o policristalinas)	550...635Vcc		
Corriente operativa	0…120Acc	0…180Acc	0…225Acc
Ondulación de corriente	<4% pico - pico		
Salida de corriente CA			
Rango de salida	50kW	80kW	100kW
Voltaje de la red operativa	3 * 400 + 10% / - 15% Vca		
Corriente operativa	0...76Aca	0…125Aca	0…175Aca
Rango de Potencia	> 0.95		
Frecuencia	50 +/- 0.5 Hz		
Distorsión de corriente armónica	< 3%		
Sistemas			
Pérdidas de Carga	2..7 W		
Máxima eficiencia	96%		
Eficiencia europea	94.8%		
Temperatura del ambiente de funcionamiento	- 20°C ... 40°C		
Tipo de protección	IP 20		
Topologia	PWM, IGBT, con Transformador		
Humedad	0...98% sin condensación		
EMI	EN 50081-1, EN 50082-1		
Armonía	EN 60555-2		
Estándares	Etiqueta CE Certificación TÜV Rheinland: "TIPO APROBADO"		
Panel de Control	2 Líneas de 16 Caracteres LCD (iluminación de fondo)		
Comunicaciones de datos	Interfase RS485 Integrada		
Dimensiones (ancho/profundidad/peso)	120 x 80 x 130 cm		
Peso	450 kg	550 kg	600 kg

*) sobrecarga recomendada del 15% (remitirse al estudio de ISE Fraunhofer)

	SolarMax 20S	SolarMax 35S
Entrée (DC)		
Puissance DC maximale*	24 kW	45 kW
Plage de tension MPP	400...800 Vdc	
Tension d'entrée maximale	900 Vdc	
Plage de tension STC du générateur photovoltaïque (aide pour la détermination du branchement des modules en cas d'utilisation de cellules photovoltaïques monocristalines et polycristalines)	540...635 Vdc	
Courant d'entrée	0...48 Adc	0...78 Adc
Ondulation de courant	< 4 % peak-peak	
Sortie (AC)		
Puissance nominale	20 kW	35 kW
Puissance maximale	22 kW	38 kW
Tension nominale réseau / plage	3 * 400 Vac / 340…460 Vac	
Courant de sortie	0...31 Aac	0...54 Aac
Facteur de puissance (FP)	> 0.98	
Fréquence nominale réseau / plage	50 Hz / 45…55 Hz	
Taux d'harmoniques	< 3 %	
Caractéristiques du système		
Consommation de nuit	2..7 W	
Rendement maximum	> 96.5 %	
Rendement européen	> 95.5 %	
Température ambiante	–20 °C...+ 60 °C	
Puissance nominale jusqu'à une température ambiante de	+ 45 °C	
Type de protection	IP 54	
Concept de circuit	Sans transformateur, deux étages, PWM (IGBT) (sans séparation galvanique)	
Humidité relative de l'air	0...98 %, sans condensation	
Conformité CE selon	EN 61000-6-2, EN 61000-6-4, EN 50178	
Surveillance réseau	selon VDE 0126-1-1	
Marque de contrôle	«Type de construction testé TÜV»	
Affichage	Ecran graphique LCD	
Communication de données	RS485 / Ethernet	
Dimensions (LxHxP)	655 x 455 x 1090 mm	
Poids	98 kg	125 kg
Raccordement AC	Bornes à vis 5 x 35 mm, traversée 1 x M40 pour section de câble 20-33 mm	
Raccordement DC	Bornes à vis 3 x 35 mm, traversée 3 x M20 pour section de câble 6-15 mm module intégré de fusibles de branches	
	Connecteur MC4 pour 7 branches	Connecteur MC4 pour 14 branches

*) Surdimensionnement recommandé de 15 % (étude ISE Fraunhofer)

18.2 Solar PV Module

Description of Solar PV Module:

Himin solar PV module or so called photovoltaic module or photovoltaic panel is an interconnected array of monocrystalline silicon solar cells. The service time can be over 25 years, during which, the power decay is less than 20%.

Features of Solar PV Module:

1. The raw material (Photovoltaic cells) are tested by the high precise testing meter;
2. The raw material passed the anti-ultraviolet radiation aging test;
3. Extruders through strict cross-link test ensures cross-link intensity in 75% to 85%, which will protect the layers to separate from each other and guarantee its long lifespan;
4. Design under precise calculation, minimize the tolerance of power to meet system needs;
5. Develop standard testing sample to create super accurate testing data for comparing with national authentic testing institutes on time.

Technical parameters of Solar PV Module:

Himin

Microstrain Ireland (01-8038388)

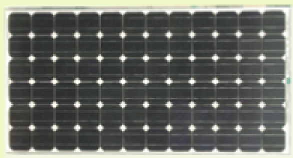
HG-185S

185W www.microstrain.ie

Monocrystalline photovoltaic module

MONOCRYSTALLINE SILICON PHOTOVOLTAIC MODULE WITH 185W MAXIMUM POWER

Himin Clean Energy Holdings Co.,ltd has concentrated on solar energy research for 12 years. Himin's HG-185S photovoltaic module is designed for large electrical power requirements, this module has superb durability to withstand rigorous operating conditions and is suitable for grid connected systems.



Features

- ◆ High-power module(185W)using 125mm square monocrystalline silicon solar cells with 14.5% module conversion efficienry.
- ◆Photovoltaic module with bypass diode minimises the power drop caused by shade.Textured cell surface to reduce the reflection of sunlight and BSF(Back Surface Field)structure to improve cell conversion efficiency : 17.3%
- ◆Using white tempered glass,EVA resin and an aluminium frame for extended outdoor use
- ◆DC 24V system and high-voltage output for grid connected system
- ◆Output terminal:Lead wire with waterproof connector

Specifications HG-185S

Cell	Monocrystalline silicon solar cells, 125mm square
No.of cells and connections	72 in series
Application	DC 24V system
Maximum system voltage	DC 1,000V
Series fuse rating	10A
Nominal power	185W
Dimensions	1580×808×50mm
Weight	16.2Kg
Type of output terminal	Lead wire with connector

Absolute maximum ratings

Parameters	Rating	Unit
Operating temperature	-40 to +85	℃
Storage temperature	-40 to +85	℃

Temperature coefficients

α Pm	-0.490%/℃
α Isc	+0.050%/℃
α Voc	-152mv/℃

Electro-optical characteristics

Parameters	Symbol	Min.	Typ .	Unit
Open circuit voltage	Voc	—	45.4	V
Maximum power voltage	Vpm	—	36.5	V
Short circuit current	Isc	—	5.49	A
Maximum power current	Ipm	—	5.05	A
Power tolerance	---	---	3	%
Encapsulated solar cell efficiency	η c	—	17.3	%
Module efficiency	η m	—	14.5	%

Conditions

Standard test conditions (STC)

Irradiance 1,000W/m²

AM1.5

Module temperature 25℃

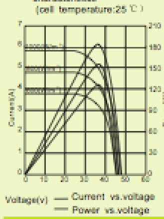
Applications

- ◎Grid connected residential system
- ◎Office buildings
- ◎Solar power stations
- ◎Solar villages
- ◎Villas,mountain cottages
- ◎Pumps
- ◎Lighting equipment
- ◎Traffic signs
- ◎Radio relay stations
- ◎Beacons
- ◎Telemeter systems
- ◎Telecommunication systems

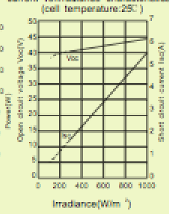
In the absence of confirmation by specification sheets ,Himin takes no responsibility for any defects that any occur in equipment using any Himin products shown in catalogs,data books,etc.Contact Himin in order to obtain the latest specification sheets before using any Himin products. Specifications are subject to change without notice.

Characteristics

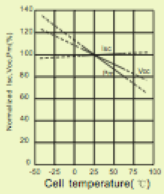
Current, power vs. voltage characteristics (cell temperature:25 ℃)



Open circuit voltage,short circuit current vs.irradiance characteristics (cell temperature:25℃)

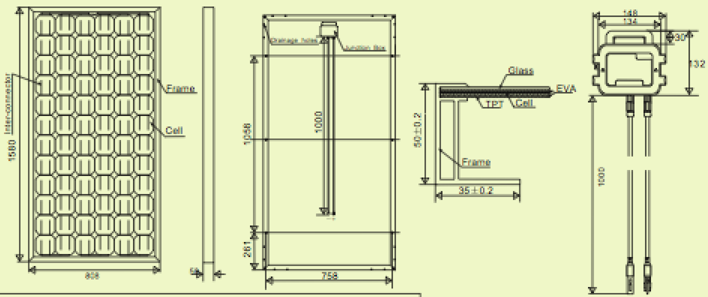


Normalized Isc,Voc,Pm vs.cell temperature characteristics



Outline dimensions

(Unit:mm)



Please contact Microstrain on 01 8038388 for futher information and pricing. www.microstrain.ie.