TRABAJO FIN DE GRADO

Grado en Ingeniería Electrónica Industrial

UNIVERSIDAD DE ALMERIA

ESCUELA SUPERIOR DE INGENIERÍA

"DESIGN OF AN ON-GRID PHOTOVOLTAIC SYSTEM IN THE ROOF OF AN AUCTION CENTRE LOCATED IN SANTA MARIA DEL AGUILA, ALMERIA"

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ABSTRACT

This document contains a techno-economical assessment of the installation of a grid-connected system in the roof at an auction centre located in Santa Maria del Aguila (Almeria). As starting point for the design and evaluation of the installation, the following boundary conditions have been considered: the local weather and solar radiation availability, the need of a direct architectural integration of the solar modules in the pre-existing roof and the knowledge of the user hourly electricity load. On this basis, 7 different scenarios of photovoltaic grid connected plants have been created and analysed, both in terms of on-site installation and technical performance and in terms of economic profitability. The options considered consist of different combinations of sizes of storage and solar generation for a grid tied systems, even including a fully autonomous eventual operation.

In all the cases, calculations related to the losses (shadow, non-optimal orientation, etc.) have undertaken for a correct plants settlement. Afterwards, the sizing of corresponding modules arrays, inverters and batteries for each scenario have been carried out since it is requested as input for their detailed performance and economical profitability estimation. System Advisor Model (SAM) by NREL has been used as tool for the dynamic simulation of the 7 proposed plants configurations and for the integration of hourly systems estimations in global plant performance indicators (yearly production and payback period).

As result of the work, the more feasible option for the user is that consisting in a 216.4 kW plant with a cost of 362,081€, reaching a quite reasonable payback time. The rest of the options have been discarded because the period of payback was higher due to the expensive price of the batteries and the fact that the systems were oversized making the facility less profitable.

Keywords: photovoltaic, photovoltaic modules, inverter, orientation, shadows, losses, available roof, Almeria, irradiation, temperature, parallel, series, PVGIS, SAM, panels, energy consumption, photovoltaic production, surplus, profit, savings, profitability.

RESUMEN

Este documento contiene una valoración tecnoeconómica de la instalación de un sistema conectado a red en la cubierta de un centro de subastas ubicado en Santa María del Águila (Almería). Como punto de partida para el diseño y evaluación de la instalación, se han considerado las siguientes condiciones de contorno: la disponibilidad de radiación solar y meteorológica local, la necesidad de una integración arquitectónica directa de los módulos solares en la cubierta preexistente y el conocimiento de la carga de electricidad por hora del usuario. Sobre esta base, se han creado y analizado 7 escenarios diferentes de plantas fotovoltaicas conectadas a red, tanto en términos de instalación in situ y rendimiento técnico como en términos de rentabilidad económica. Las opciones consideradas han sido diferentes combinaciones de tamaños de baterías y generadores solares operando en un modo de conexión a red e incluyendo una eventual operación autónoma del sistema.

En todos los casos se han realizado cálculos relacionados con las pérdidas (sombra, orientación no óptima, etc.) para un correcto asentamiento de las plantas. Posteriormente se ha realizado el dimensionamiento de los correspondientes arreglos de módulos, inversores y baterías para cada escenario ya que se solicita como insumo para su detallado desempeño y estimación de rentabilidad económica. System Advisor Model (SAM) de NREL se ha utilizado como herramienta para la simulación dinámica de las 6 configuraciones de plantas propuestas y para la integración de estimaciones de sistemas horarios en indicadores globales de rendimiento de plantas (producción anual y período de recuperación).

Como resultado de la obra, la opción más factible para el usuario es la que consiste en una planta de 216,4 kW con un coste de 362.081 €, alcanzando su amortización en un periodo razonable de tiempo. El resto de opciones se han descartado porque el período de recuperación fue mayor debido al alto precio de las baterías y al hecho de que los sistemas eran sobredimensionados, lo que hacía que la instalación fuera menos rentable.

Palabras clave: fotovoltaica, módulos fotovoltaicos, inversor, orientación, sombras, pérdidas, cubierta disponible, Almería, irradiación, temperatura, paralelo, serie, PVGIS, SAM, paneles, consumo de energía, producción fotovoltaica, excedente, beneficio, ahorro, rentabilidad.

Index

1. Introduction

There are countless centers in which the idea of incorporating a photovoltaic system on the roof of the warehouses could potentially be contemplated in the province of Almería.

The case that we have decided to study is an auction center. Those are fundamental elements of the productive system of the province since they carry out the classification, packaging and conservation operations, essential for an adequate commercialization of the fruits and vegetables grown in the greenhouses located in these typical areas of operation.

These plants are semi-industrial and all of them have energy consuming systems such as conservation chambers and cold rooms, tapes for handling products, packaging and labeling lines, etc.

It has a particularity that makes the project interesting: the consumptions shifted towards the night, because they are mainly dedicated to recharging forklifts.

Numerous studies carried out over the years and even the own experience of centers with similar characteristics and nearby the location to the one that we are going to design, suggest in the first instance that the use of this type of roof will be favorable, with respect to the high potential for energy saving in these types of activities.

Another important aspect to take into account is the implementation of different measures, which is currently greatly favored by the recent political impulse, and the subsequent impact on the market, to photovoltaic self-consumption.

Likewise, the market study and the unstoppable trend in the rising prices of electricity in Spain only suggests that the profitability of this type of installation is more and more evident and is inexorably the future towards which we are heading to.

This project, which is presented in the technical work modality, aims to study different technical options and their subsequent functional and economic evaluation for a photovoltaic self-consumption installation in an auction center located in the area of Santa María del Águila, El Ejido (Almería).

The company will change its user role to a producer / consumer role and, thereby, contribute to the decarbonization of our planet through the generation of energy with an inexhaustible and clean energy source such as the sun and, it will even provide economic advantages in terms of a reduction in the current electricity consumption.

The before mentioned auction center is a real company located in the municipality of El Ejido (Almería) serving the high demand and production in the area and has a central warehouse 180 meters long and 66 meters wide. That makes a total of 12,744 square meters available for the purpose we propose.

As a starting reference, there is a record of the electricity consumption of the company that is 633 MWh/year.

Once the different technical options of the solar installation (peak power and inclination) have been studied and dimensioned in accordance with the restrictions imposed by the structure and size of the roof that will house it and the auxiliary equipment for connection to the pre-existing network (batteries, inverters and measurement equipment), a decisión will be made on one of the options that we believe to be the most convenient for the problem raised.

Images 1-4. Location of the auction centre

1.1 Objetives

The main purpose of this study is to calculate the technical and economic feasibility of a photovoltaic installation on the roof surface of a sales center located in El Ejido with the aim of reducing grid consumption in order to obtain greater economic profitability.

To achieve our main purpose, we will use the greatest amount of resources and data at our disposal so that the calculations are as reliable as possible once the installation becomes a reality.

- Application of knowledge related to photovoltaic solar energy.
- Carrying out a study of the energy balance in terms of consumption and potential solar electricity generation of the installation.

- Study of the hourly consumption profile according to the actual use of the auction center and the calculated solar electricity generation hourly profile.
- Adaptation to the existing real problem, in terms of available space and predefined orientations.
- Calculation of facilities, photovoltaic modules, inverters... to carry out a complete photovoltaic project.
- Application of current regulations.
- Cost and profitability analysis.
- Simulation of sistem performance
- Calculation of the amortization period of the initial investment made.

1.2. Phases of the project

This project will be divided into the following phases:

Phase 1. Initial planning of the project
1. Compilation of the basic information of the project.
2. Obtaining consumption data.
3. Consultation of current regulations and procedures.
4. Study of previous similar cases in the area.

Phase 2. Study of consumption and solar potential
1. Study of the existing solar resource for application in the selected site.
2. Analysis of the hourly consumption profile.
3. Energy balance: production / consumption.

Phase 3. Analysis of the possible installation
1. Proposal and approach to different facilities.
2. Economic estimate calculation of the proposals.
3. Selection of the most suitable installation for the case.

Phase 4. In-depth study of the solution
1. Sizing the installation.
2. Distribution of the modules on the roof.
3. Technical feasibility of the project.
4. Analysis of execution costs and amortization periods.

Phase 5. Results and conclusions
1. Final technical proposal.
2. Technical calculations.
3.. Results and conclusions.

1.3. Materials used

- Initial documentation of the project.
- Maps and location of the site.
- Consumption data.
- Sources of information on climate data.
- Technical documentation of selected materials for our installation.

1.4. Calculation tools and methods

- PVGIS
- SAM
- Excel
- Hourly estimate of consumption.
- Calculation of the design of the installation.
- Economic estimates and final balances.

1.5. Work Schedule

Month	Work Schedule
March	*Learning and gathering information related to solar panels*
April	*Structure of the proyect*
May	*Writing introductory chapters*
June	*Developing the chapters*
July	*Study and analysis of the location and features of the auction centre*
August	*Analysis of consumption of the auction centre*
September	*Preproject and Analysis of the possible solutions*
October	*Calculations of profitability and sizing the system*

Table 1. Monthly work schedule

2. Boundary conditions and users needs

The company we are going to study is an auction centre. We will define now the different specific characteristics of the centre we have chosen in order to be able to decide later which and how many solar panels that are more convenient for our system. The main goal of this chapter is settling the basic boundary conditions that will serve to study how to reach a reasonable level of self-consumption thanks to the installed system.

Self-consumption, as explained by the Spanish Foltovoltaic Union, represents 90% of the new installed power in 2017 (235.7 megawatts out of a total of 261.7) and in the coming years it will represent 15-20% of the new power installed annually. In addition, the Integrated National Plan (PNI) for Energy and Climate has set a 2030 target for Spain to reach 37,000 megawatts of installed photovoltaic power on that date. Now, with photovoltaic energy, whoever has a roof has a treasure, since it produces directly where it is consumed.

2.1 Location and climate

As we mentioned before, this project aims to study different technical options and their subsequent functional and economic evaluation for a photovoltaic self-consumption installation in an auction center located in the area of Santa María del Águila, El Ejido (Almería). The area surrounding the auction centre is mosty cropland and similar facilites to the one we are focused on.

The location has as geographical coordinates:

- Latitude: 36º 47’ 07” N
- Length: 2º 44’ 03” W

And an altitude of 98 meters.

The photovoltaic modules will be located on the metallic structure that constitutes the roof of said warehouse.

This place is located in Spain. To be more concrete in the south of east of the Iberian Peninsula. This area has a particular characteristic which is really propper for solar panels since it’s located next to Sierra Nevada, which highly prevents from rainning within all this territory and, hence, the total amount of solar hours per year is among the top ones in Europe.

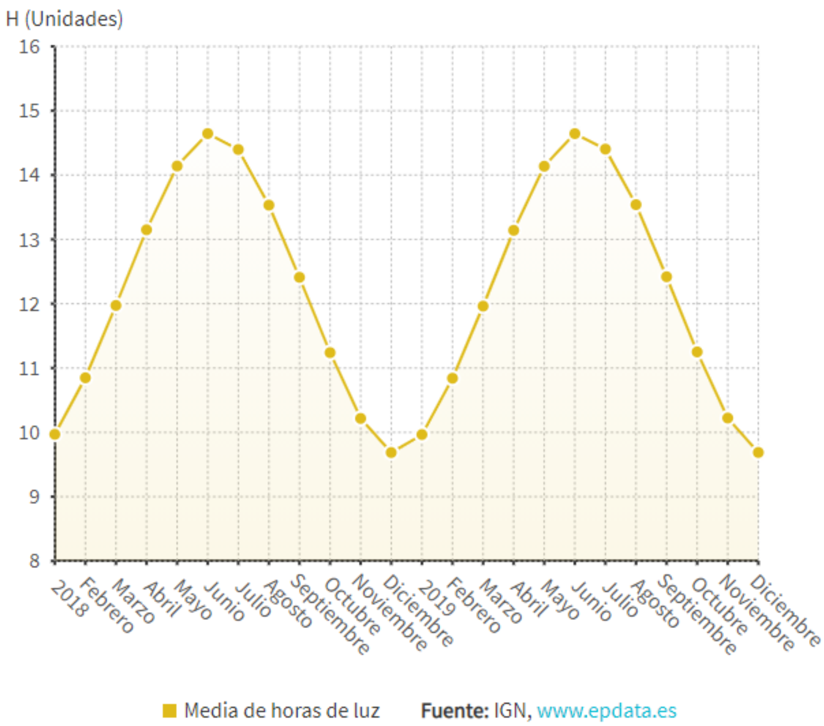


Figure 1. Solar hours per day each month in Almería

Source: https://www.epdata.es (17/09)

According to the annual insolation map in Spain published by the Spanish Geographical Institute, insolation increases regularly from north to south.

The highest values of insolation occur in Badajoz, Seville, Madrid, Almería and Alicante with more than 2,800 solar hours, reaching 3,000 in some points. Spain enjoys a Mediterranean climate that allows you to enjoy many more hours of light than in other countries in the world and this factor does not go unnoticed for the renewable energy sector.

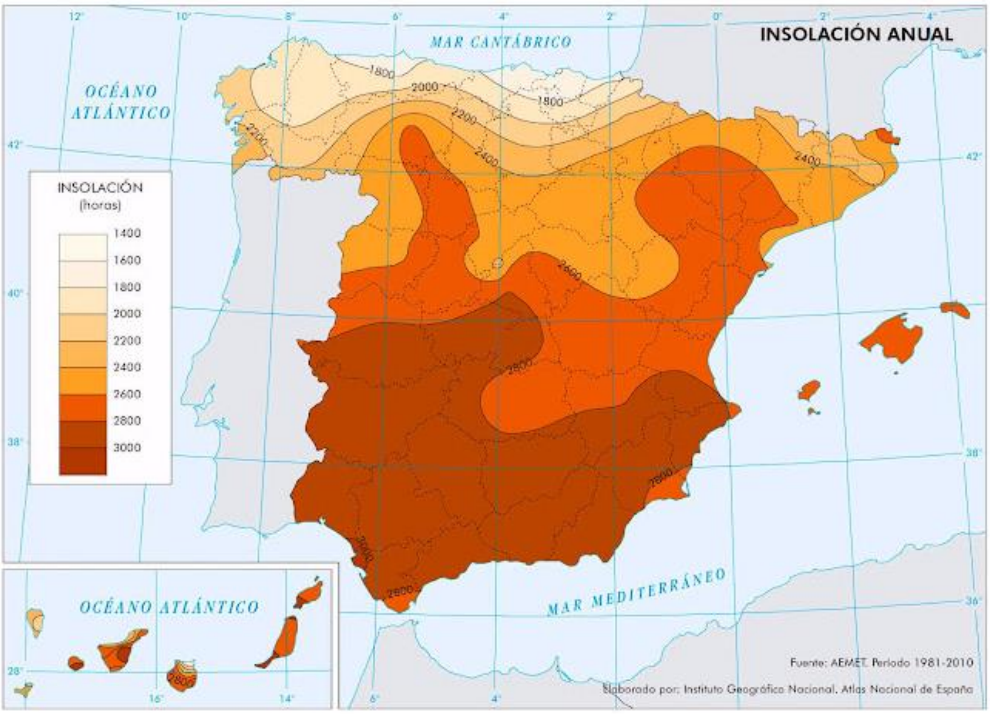


Figure 2. Annual Insolation in Spain

Source: http://enriqueviolanevado.blogspot.com/2020/03/ejercicio-practico-de-geografia-de_93.html (17/09)

2.2. Climate and average weather throughout the year in Almería, Spain

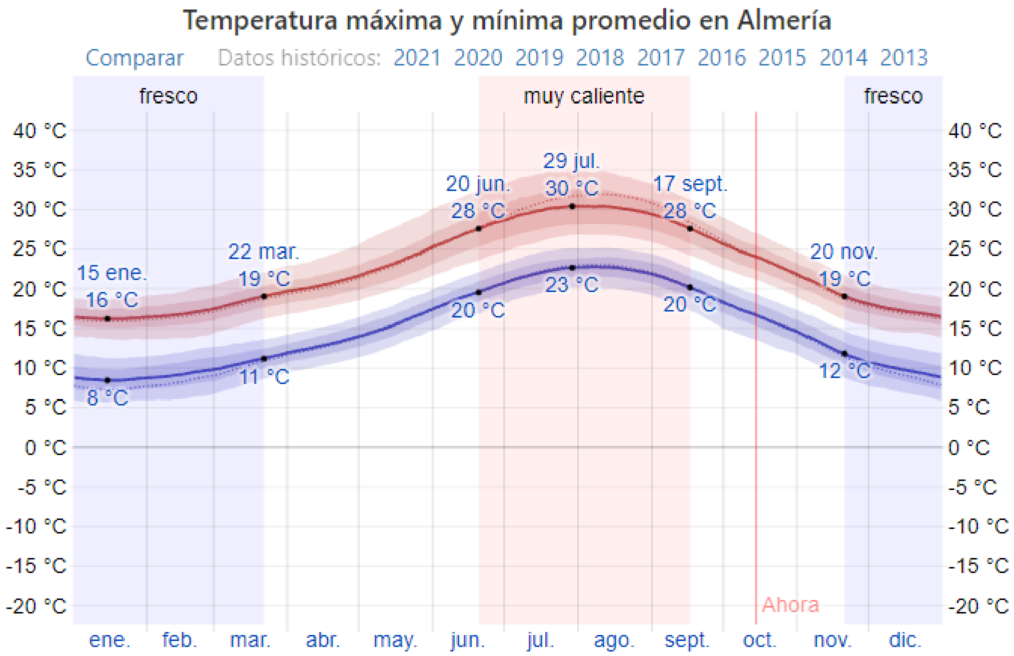
In general, summer is very hot, humid, arid and mostly clear. On the other hand, winter is cool, dry, windy and partially cloudy. Along the year, the temperature generally ranges from 8°C to 30°C and rarely goes lower than 6°C or rises above 35°C.

a) Average temperature in Almería

Temperature is an essential feature which we should have into account when calculating our facility since it affects directly to the production that our panels will have.

The hot season lasts 3 months, from June to September, and the daily average maximum temperature is over 28°C. The hottest month of the year in Almería is August.

The cool season lasts 4 months, from December to March, and the daily average maximum temperature is less than 19°C. The coldest month of the year in Almería is January.



Promedio	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Alto	16 °C	17 °C	19 °C	21 °C	23 °C	27 °C	30 °C	30 °C	28 °C	24 °C	20 °C	17 °C
Temp	12 °C	13 °C	15 °C	17 °C	19 °C	23 °C	26 °C	26 °C	24 °C	20 °C	16 °C	13 °C
Bajo	9 °C	9 °C	11 °C	13 °C	16 °C	19 °C	22 °C	22 °C	20 °C	16 °C	12 °C	10 °C

Figure 3. Maximum and minimum temperature in Almeria monthly

Source: https://es.weatherspark.com (20/09)

The daily average maximum temperature (red line) and minimum temperature (blue line) including the 25th to 75th percentile bands, and the 10th to 90th percentile. The dotted lines correspond to the average perceived temperatures.

The figure below shows the hourly average temperatures for the entire year. The vertical axis is the time while the horizontal axis is the day of the year, and the color is the average temperature for that day and at that hour.

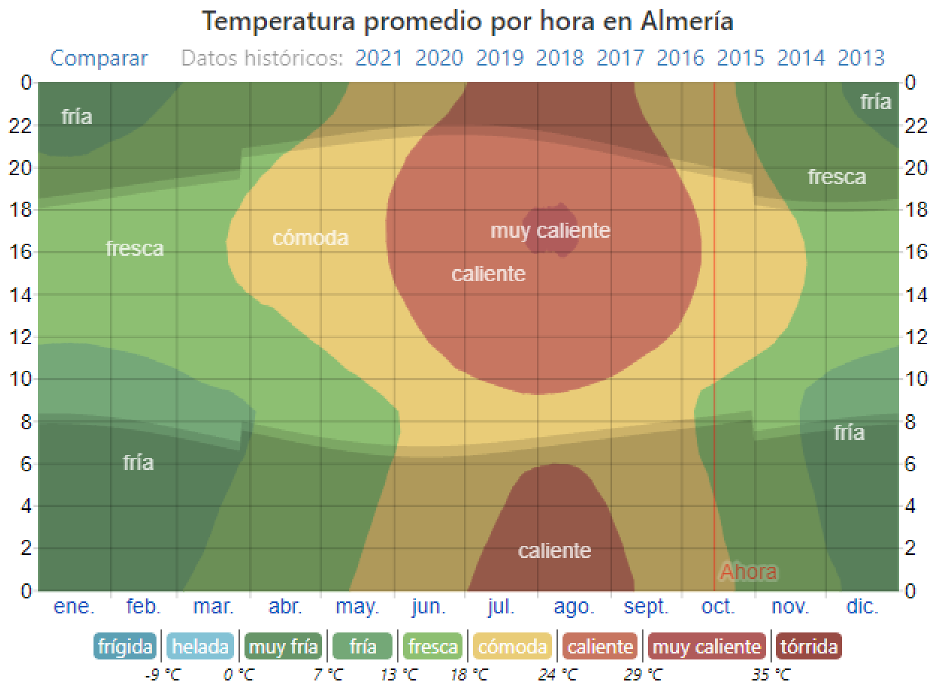


Figure 4. Monthly temperature per hour in Almería

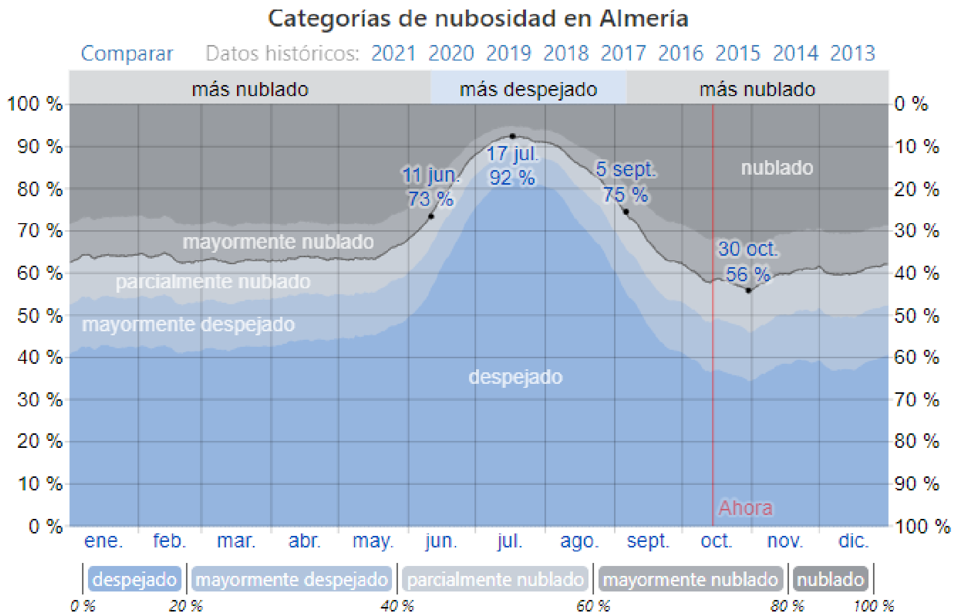
Source: https://es.weatherspark.com (20/09)

The hourly average temperature, with a code of colors into bands. Overlapping shaded areas indicate night and civil twilight.

b) Clouds

How often the sky is clear and the sort of clouds will aslo affect the production we will be able to generate. In Almería, the average percentage of the sky covered by clouds changes significantly throughout the year.

The clearest part of the year in Almería begins around June; It lasts for 3 months and ends approximately on September. July is the clearest month of the year in Almería, during which on average the sky is clear, mostly clear, or partly cloudy 91% of the time. On the other hand, October is the cloudiest. By that time, the average the sky is mostly cloudy 42% of the total time.



Fracción	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Más nublado	36 %	36 %	37 %	37 %	35 %	22 %	9 %	15 %	32 %	42 %	40 %	39 %
Más claro	64 %	64 %	63 %	63 %	65 %	78 %	91 %	85 %	68 %	58 %	60 %	61 %

Figure 5. Clouds along the year in Almería

Source: https://es.weatherspark.com (20/09)

The percentage of time spent in each cloud cover band, according to the percentage covered by clouds.

c) Precipitation

Rain in this region sometimes carries a lot of dust, so when the water falls and gets dry, it leaves a layer of mud wich we should clean if we dont want to have great losses due to that fact.

Another important issue is that once every few years it also hails which may damage our panels. A good side is that it harly ever snows, so we wont have to calculate the amount of snow that our panels should stand.

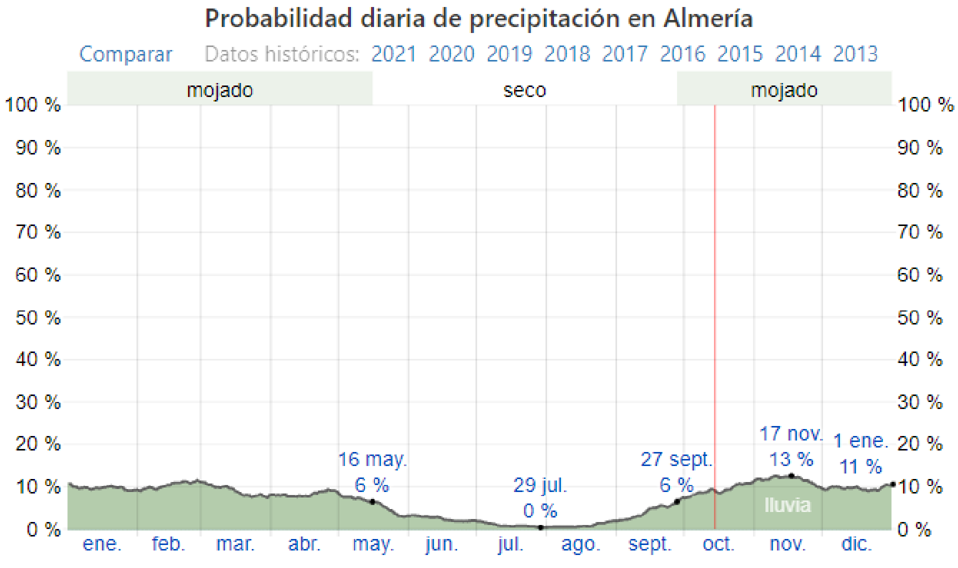
Apart from that, our panels will have to be ready to resist the effects of water as a chemical element and also as a physiscal one.

A wet day would be a day with at least 1 millimeter of water. The chance of wet days in Almería varies throughout the year.

The wetter season goes from September to May, with a greater than 6% chance that a given day will be a wet day. The month with the most wet days in Almería is November, with an average of 3.5 days with at least 1 millimeter of precipitation.

The drier season lasts 4.4 months, from May to September. The month with the fewest wet days in Almería is July, with an average of 0.3 days with at least 1 millimeter of precipitation.

Among wet days, we distinguish between those with only rain, only snow, or a combination of the two. The month with the most days of rain alone in Almería is November, with an average of 3.5 days. The most common type of precipitation is rain, with a maximum probability of 13% on November 17.



Días de	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Lluvia	3,0d	2,9d	2,8d	2,5d	1,8d	0,7d	0,3d	0,3d	1,4d	2,9d	3,5d	3,0d

Figure 6. Probability of rain each month in Almería

Source: https://es.weatherspark.com (20/09)

d) Rain

To show the variation over a month and not just monthly totals, we show the accumulated rainfall over a month on a sliding scale centered around each day of the year. Almería has a small variation of monthly rainfall by season.

The rainy period of the year lasts for 7.5 months, from September to May, with a sliding month rainfall of aa minimum of 0.5 inches. The month with the most rain in Almería is November, with an average rainfall of 23 millimeters.

The rainless period of the year lasts for 4.5 months, from May to September. The month with the least rain in Almería is July, with an average rainfall of 1 millimeter.

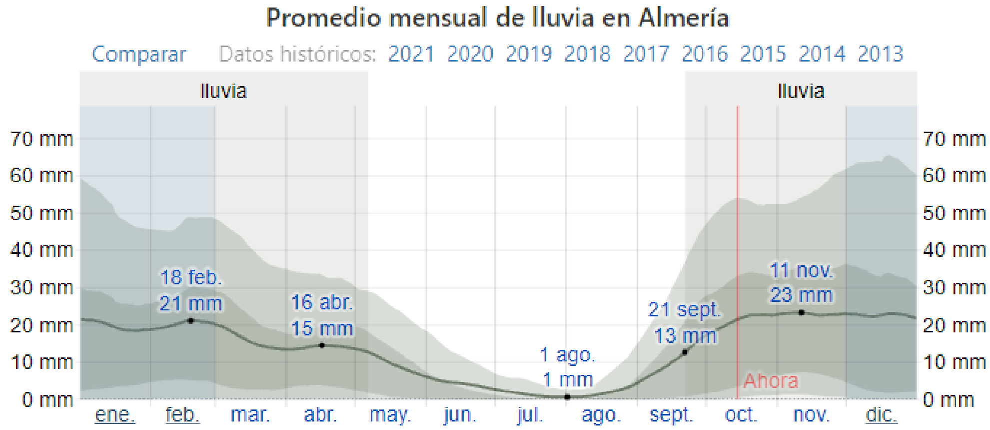


Figure 7. Rain each month in Almería

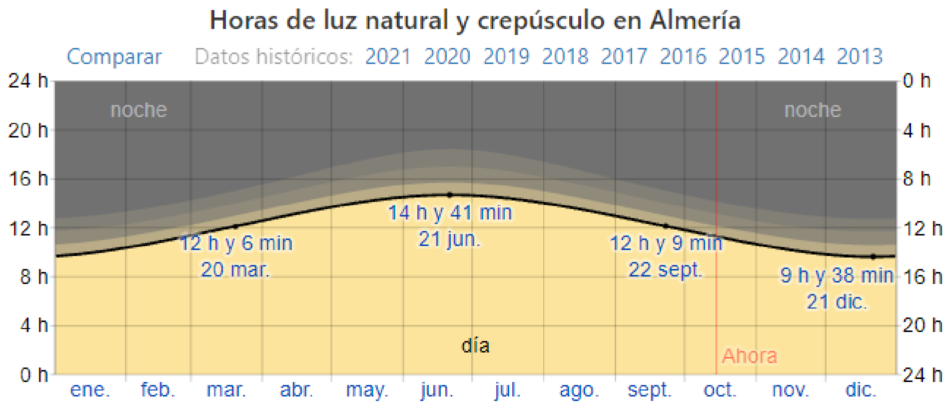
Source: https://es.weatherspark.com (20/09)

Average rainfall (solid line) accumulated over a month with the 25th to 75th and 10th to 90th percentile bands.

e) Sun

This is one of the main features that we need to know because it's the source from which solar panels generate the energy we need.

The length of the day in Almería varies significantly throughout the year. In 2021, the shortest day is December 21, with 9 hours and 38 minutes of natural light; while the longest day is June 21, with 14 hours and 41 minutes.



Horas de	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Luz natural	10,0h	10,9h	12,0h	13,2h	14,2h	14,6h	14,4h	13,5h	12,4h	11,2h	10,2h	9,7h

Figure 8. Hours of sunlight per month in Almería

Source: https://es.weatherspark.com (20/09)

The number of hours the sun is visible (black line). From the bottom (more yellow) to the top (more gray), the color bands indicate: total daylight, twilight (civil, nautical and astronomical) and total night.

The earliest sunrise is 6:50 AM on June 13, and the latest sunrise is 1 hour 42 minutes later at 8:31 AM on October 30. The earliest sunset is 5:53 PM on December 6, and the latest sunset is 3 hours 40 minutes later at 9:33 PM on June 28.

Daylight saving time (HDV) was observed in Almería during 2021; It happened on March 28 and on October 31.

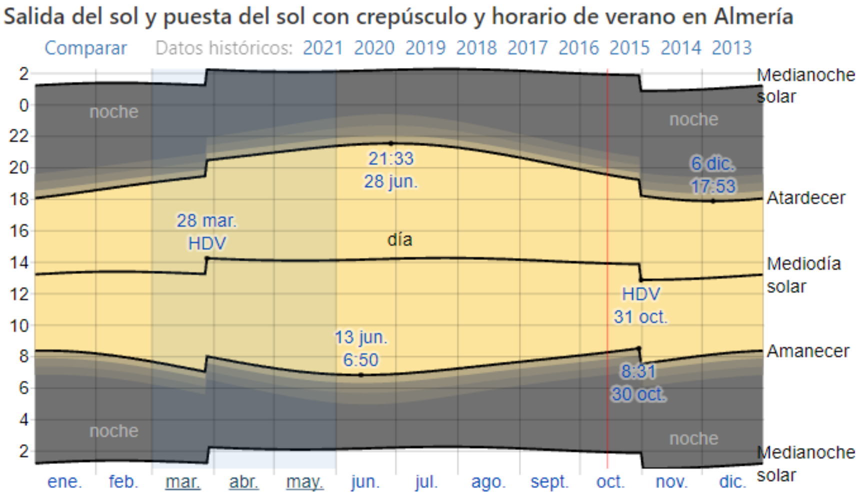


Figure 9. Solar hours per day each month in Almería

Source: https://es.weatherspark.com (20/09)

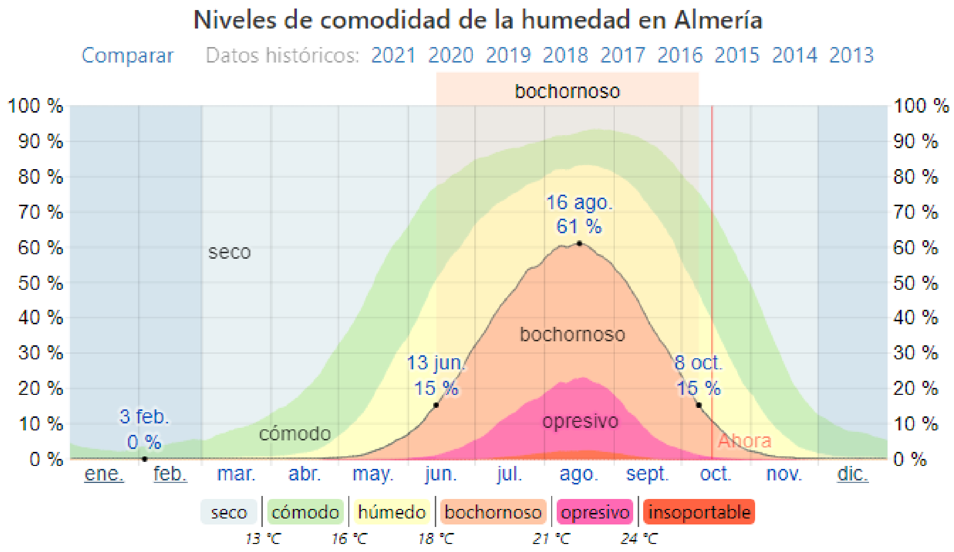
Solar day during the year 2021. Day, twilights and night are indicated by the color of the bands, from yellow to gray. Transitions to and from daylight saving time are indicated by the acronym HDV.

f) Humidity

Humedity affects the temperature and, hence, the production of our panels and the quantity of energy they are able to produce.

Unlike the temperature, which generally varies considerably between night and day, the dew point tends to change more slowly, so even if the temperature drops at night, on a humid day the night is generally humid.

In Almería the perceived humidity varies extremely. The wetter time of year lasts for 4 months, from June to October.



	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Muggy (días)	0,0d	0,0d	0,0d	0,0d	0,9d	5,7d	14,5d	18,3d	11,6d	3,0d	0,2d	0,0d

Figure 10. Monthly humedity and temperature in Almería

Source: https://es.weatherspark.com (20/09)

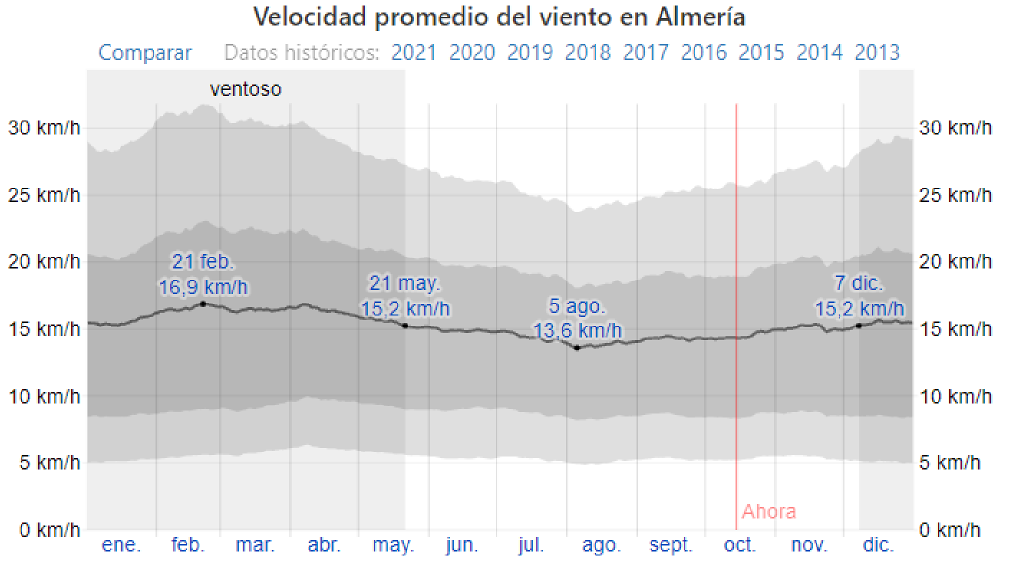
Representation of the percentage of time spent in various humidity comfort levels, categorized by dew point.

g) Wind

The wind direction and speed are also important matters that we should consider when mounting our panels over a roof. This section deals with the hourly average wind vector of the wide area (speed and direction) at 10 meters above the ground. The wind from a certain location depends in great measure on the local topography and other factors.

The average hourly wind speed in Almería has slight seasonal variations throughout the year. The windiest part of the year lasts from December to May, with average wind speeds of more than 15.2 km/h. The windiest month of the year in Almería is February, with an average hourly wind speed of 16.6 km/h.

The calmer time of year lasts from May to December. The calmest month of the year in Almería is August, with an average hourly wind speed of 13.9 km/h.



	ene.	feb.	mar.	abr.	may.	jun.	jul.	ago.	sept.	oct.	nov.	dic.
Wind Speed (kph)	15.6	16.6	16.5	16.4	15.4	14.9	14.4	13.9	14.3	14.5	15.1	15.4

Figure 11. Solar hours per day each month in Almería

Source: https://es.weatherspark.com (20/09)

Representation of the average hourly mean wind speed (dark gray line), with the 25th to 75th and 10th to 90th percentile bands.

The wind is most often from the east for 4 months, from May to October, with a peak percentage of 41% on September 6. The wind is most often from the west for 8 months, from Octobe to May, with a peak percentage of 41% on January 1.

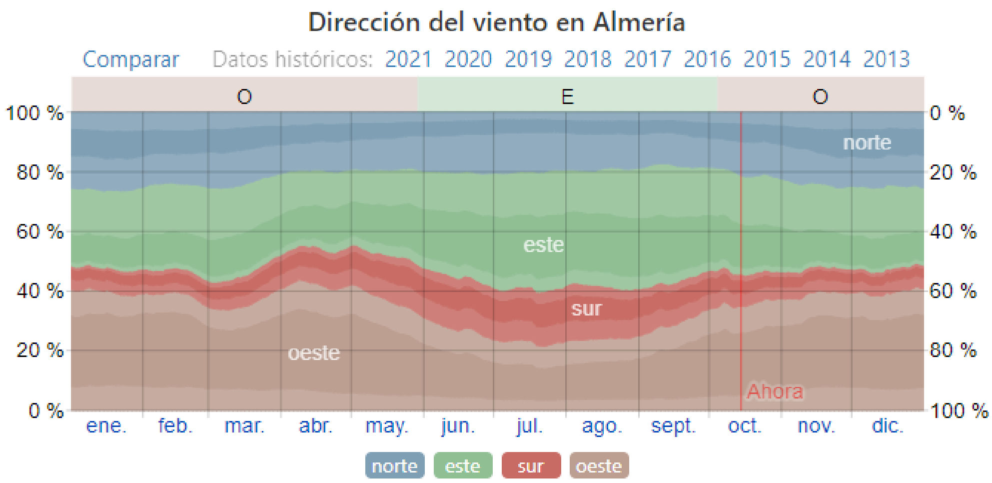


Figure 12. Solar hours per day each month in Almería

Source: https://es.weatherspark.com (20/09)

The percentage of hours in which the mean wind direction comes from each of the four cardinal points, excluding the hours in which the mean wind speed is less than 1.6 km / h. The light-colored areas in the boundaries are the percentage of hours spent in the implied intermediate directions (northeast, southeast, southwest, and northwest).

h) Solar energy

Now we will check the total daily incident solar energy reaching the earth's surface, taking into account seasonal variations in day length, the elevation of the sun above the horizon, and the absorption of solar radiation, clouds and other atmospheric elements. Shortwave radiation includes visible light and ultraviolet radiation.

Average daily incident solar energy has extreme seasonal variations throughout the year.

The brighter period of the year lasts for 3.5 months, from May to August, with an average daily incident energy per square meter above 7.1kWh. The brightest month of the year in Almería is June, with an average of 8.1kWh.

The darker period of the year lasts for 3.5 months, from November to February, with an average daily incident shortwave energy per square meter of less than 3.7 kWh. The darkest month of the year in Almería is December, with an average of 2.6 kWh.

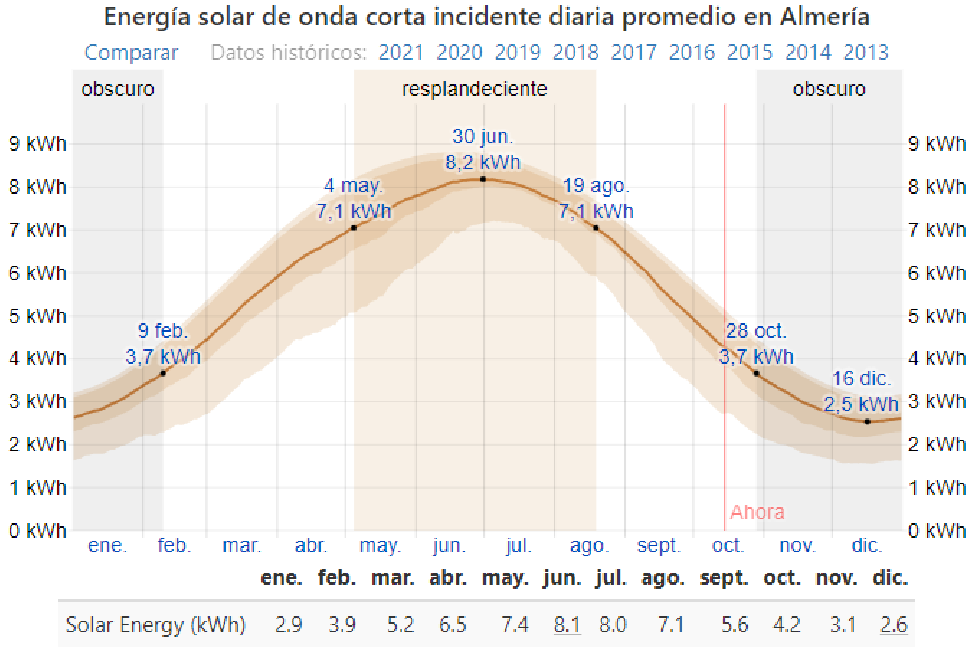


Figure 13. Energy of the sun each month in Almería
Source: https://es.weatherspark.com (20/09)

Representation of the average daily shortwave solar energy reaching the earth per square meter (orange line), with 25th to 75th and 10th to 90th percentile bands.

i) Topography

The geographical coordinates of Almería are latitude: 36.83°, longitude: -2.46°, and elevation: 21 m. This will be crucial when studying the orientation that the panels should have and the elevation of them as well.

The altitud of the region affects the climate. The topography within a radius of 3 kilometers from Almería has very large variations in altitude, with a maximum change in altitude of 267 meters and an average altitude above sea level of 46 meters. Within a radius of 16 kilometers it contains very large variations in altitude (1,188 meters). Within a radius of 80 km it also contains extreme variations in altitude (3,468 meters).

2.3. Solar energy potential

Among many different available tools we could find, we have decided to work with PVGIS since we believe is the most appropiate for our case. His name come from photovoltaic European Geographical Geographicalinformation Information System which is a really useful tool that the european European commision Commision created and it is helpful for studies related to solar panels. We will use it to show some features of the location of the auction center and also to analyse some data about the panels we are planning to install.

Images 5-6. Irradiation map of the auction centre's location

Once we have placed in the map where our auction centre is, the tool will be able to calculate interesting data after introducing some required values.

These are:

- Orientation angle or azimuth

The azimuth, or orientation, is the angle of the panels relative to the South which means -90° would be East, then 0° is South and last, 90° is West. For our modules, we already viewed that points slightly to the East, that means our angle is -10º.

- Inclination angle

This is the angle of the panels from the horizontal plane, for a fixed and non-tracking mounting.

For some applications the inclination and azimuth angles of the modules will already be known, for example if the modules are built into an existing roof, as we may do for the auction centre. Nevertheless, if we had the possibility to choose both of them, this application can also calculate for you the optimal values assuming fixed angles for the entire year.

- Mounting position

For fixed, non-tracking, systems, the way the panels are mounted will have an influence on their temperature, which obviously affects the efficiency. Some experiments have shown that if the movement of air under them is null, the modules can get up to 15°C hotter.

In the PVGIS there are two possibilities: free-standing modules, which means that the modules are mounted on a rack with air flowing freely behind them, and building-integrated panels, meaning no air movement behind.

- Estimated system losses

These are all the losses in the system, which means that the power delivered to the electricity grid islower than the one produced by the panels. Some of this losses are due to cables, power inverters, dirt on the panels and so on. We should also consider that over the years the panels also tend to lose a bit of their initial power, so their annual average output over the lifetime of the facility will be a bit lower than the output in the first years.

Hence, we have given a default value of 14% for the overall losses.

- Peak power

This value corresponds to the power the manufacturer say that the array of modules is able to produce under standard test conditions. This conditions are: 1000W of solar irradiation per square meter in the plane of the array at 25°C.

- Photovoltaic technology

The panel performance varies depending on the temperature, on the solar irradiance, on the spectrum of the sunlight, but most importantly, between different types of modules. Currently PVGIS can estimate the losses due to temperature and irradiance effects for crystalline silicon cells which are the ones we will use for our modules.

After this, using PVGIS we are able to work out a plot which shows the monthly irradiation of the sun. So, we can check the irradiation for a fixed angle. Since our roof has a slope of a 30º angle and an azimuth angle of -10º. We will introduce our data into the tool to check our results.

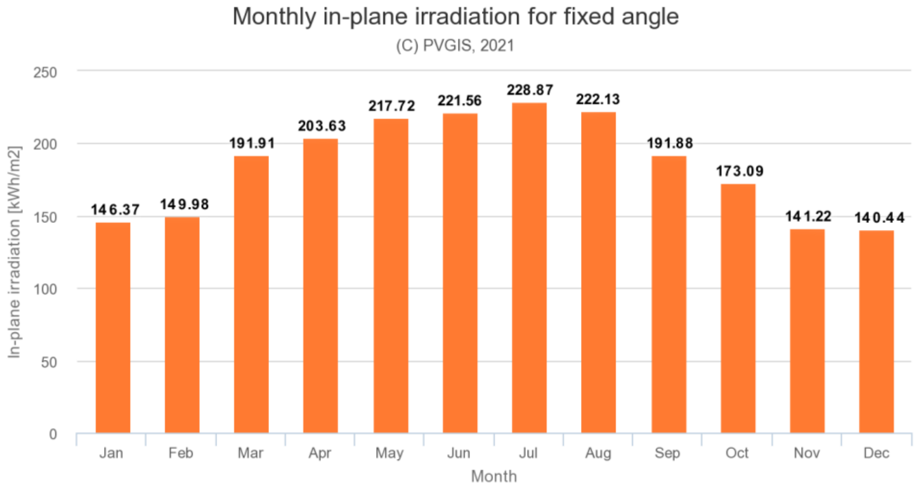


Figure 14. Monthly in-plane irradiation for fixed angle in Almería

This values would change depending on the elevation and azimuth of our panels. This tool also shows as a representation of the outline of horizon.

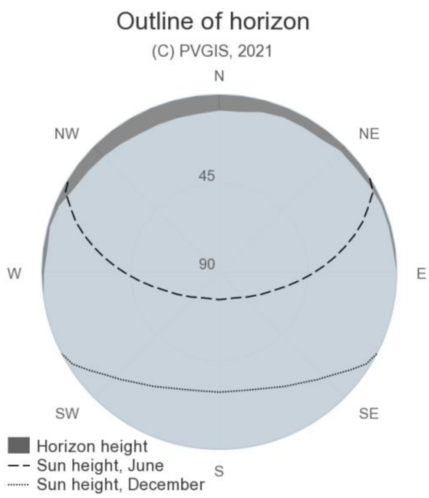


Figure 15. Outline of horizon in Almería

We also have a table with the values we have introduced for our solution and the amount of energy we would be able to produce and the stimated losses. This table corresponds to the values to calculate the solar irradiation and energy produced in a free structure.

Provided inputs:	
Location [Lat/Lon]:	36.786, -2.734
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [Â°]:	30
Azimuth angle [Â°]:	-10
Yearly PV energy production [kWh]:	1755.44
Yearly in-plane irradiation [kWh/m2]:	2228.81
Year-to-year variability [kWh]:	32.07
Changes in output due to:	
Angle of incidence [%]:	-2.54
Spectral effects [%]:	0.59
Temperature and low irradiance [%]:	-6.59
Total loss [%]:	-21.24
PV electricity cost [per kWh]:	

Table 2. Values to calculate the solar irradiation and energy produced in a free structure

System losses are calculated in every facility around a 15%. Due to a non-optimal angle of incidence we would loose around 2.5% of the total energy we could produce in this case. If our panels had a free structure, the losses related to this issue would be around 6.5%. All in all, the total losses would be around a 21% of the total energy we could obtain in an ideal system.

Using the automatic optimal orientation, the program determines that the optimal elevation for the panels for a fixed position would be a slope angle of 35º and an azimuth angle of 3º. This values do not differ much with the ones we will use indeed. That explains the the difference between a perfect orientation and ours is just a 0.06%.

Simulation outputs:	
Slope angle [°]:	35 (opt)
Azimuth angle [°]:	3 (opt)
Yearly PV energy production [kWh]:	1769.46
Yearly in-plane irradiation [kWh/m^2]:	2245.25
Year-to-year variability [kWh]:	32.19
Changes in output due to:	
Angle of incidence [%]:	-2.48
Spectral effects [%]:	0.61
Temperature and low irradiance [%]:	-6.6
Total loss [%]:	-21.19

Table 3. Values to calculate the solar irradiation and energy produced in a free structure with an optimal orientation

We have calculated the monthly energy we would generate for a system with just 1 KWh, so when we decide the amount of energy we will produce, we can multiply that number per our current values.

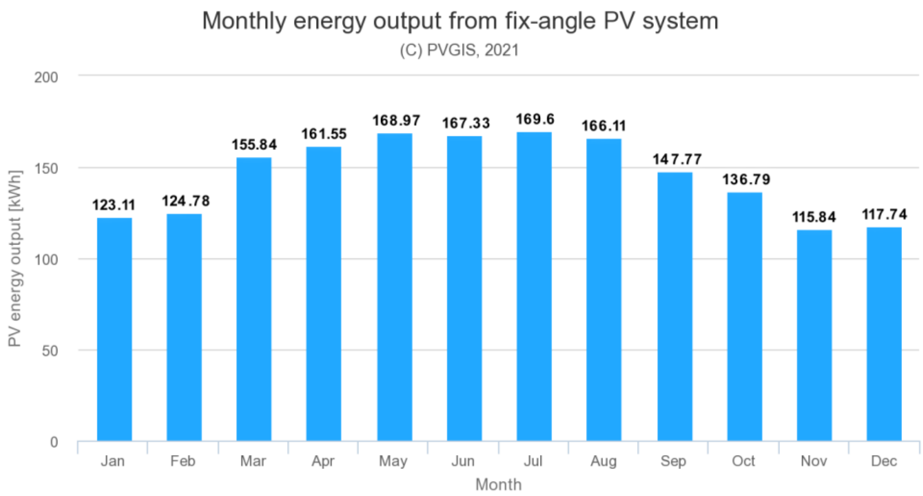


Figure 16. Monthly energy produced by solar panels from fixed angle and a free structure

Now, we will show the same table as before with the only difference that the structure will be mount over the roof we have available now.

Provided inputs:	
Location [Lat/Lon]:	36.786, -2.734
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [Â°]:	30
Azimuth angle [Â°]:	-10
Yearly PV energy production [kWh]:	1685.97
Yearly in-plane irradiation [kWh/m2]:	2228.81
Year-to-year variability [kWh]:	31.30
Changes in output due to:	
Angle of incidence [%]:	-2.54
Spectral effects [%]:	0.6
Temperature and low irradiance [%]:	-10.28
Total loss [%]:	-24.36
PV electricity cost [per kWh]:	

Table 4. Values to calculate the solar irradiation and energy produced in a fixed structure

We can check that the main difference are the losses related to the temperature. This may be, as we said in the introduction to the chapter, due to the absence of air flow below the panels which is cooling them. Also the refraction in the ground affects a bit since the panels are able to obtain a small percentage of energy from it.

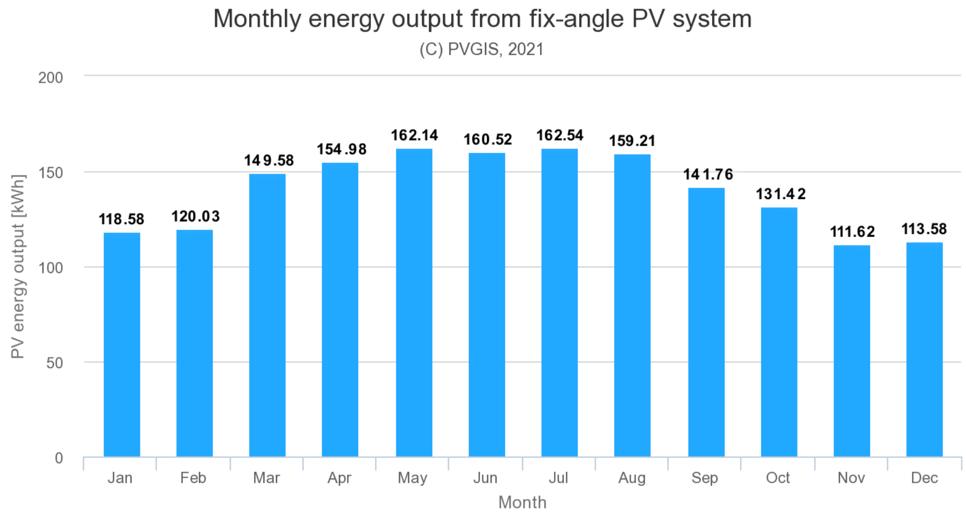


Figure 17. Monthly energy produced by solar panels from fixed angle and a free structure

➢ Irradiation data

To know how much energy we will be able to produce with our panels and also to help us decide which panels are more propper, we can use the data that this tool provides us when we introduce the coordinates of the auction centre.

- Monthly

  - Solar irradiation.

Thanks to the plot, we are able to check for each month the solar irradiation in our location. We can distinguish an anual pattern from 2005 until now.

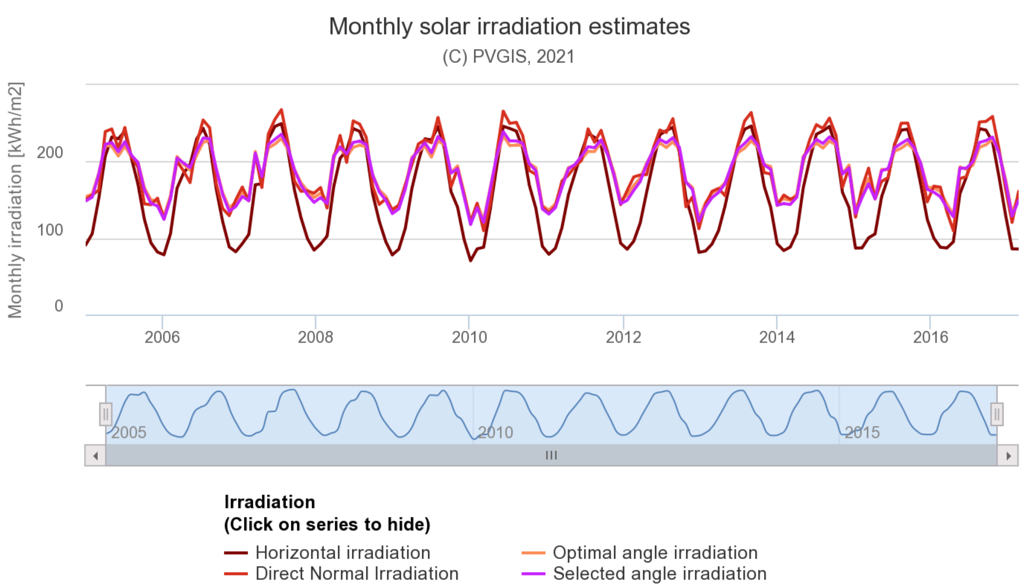


Figure 18. Monthly solar irradiation estimates 2005-2017

The horizontal irradiation is the monthly sum of the solar radiation energy in one square meter of a horizontal plane in kWh/m^2.

The direct normal irradiation is the monthly sum of the solar radiation energy in one square meter of a plane constantly facing in the direction of the sun in kWh/m^2, including only the radiation arriving directly from the sun.

Global irradiation, optimal angle. This value is the monthly sum of the solar radiation energy that hits one square meter of a plane facing in the direction of the equator, at the inclination angle that gives the highest annual irradiation, measured in kWh/m^2.

Global irradiation, selected angle. This value is the monthly sum of the solar radiation energy in one square meter of a plane at the inclination angle chosen in kWh/m^2.

We will zoom in to focus just in a period of two years to see everything with more accuracy. We realize that the optimal angle irradiation is just slightly above the selected angle irradiation due to non-optimal orientation as we calculate before.

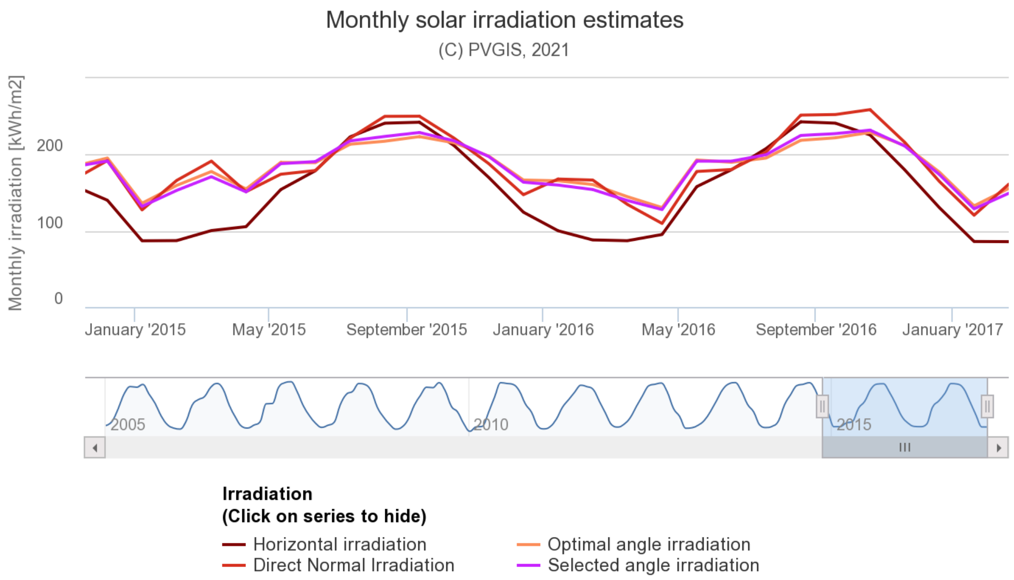


Figure 19. Monthly solar irradiation estimates 2015-2017

We can also conclude that thanks to the orientation on the roof, the most propper months fot the irradiation are from Agust to October. These are good news for our system since, as we will check later, our demand is higher in the second semester of the year.

- Ratio of diffuse to global radiation

The ratio of diffuse to global radiation is the monthly value of the ratio of the diffuse and the global horizontal irradiation, i.e. the fraction of the total solar irradiation that comes from the clouds and the sky so high values correspond to cloudy climates.

We can deduce that this rate in Almeria will be quite low compared to other places in the world.

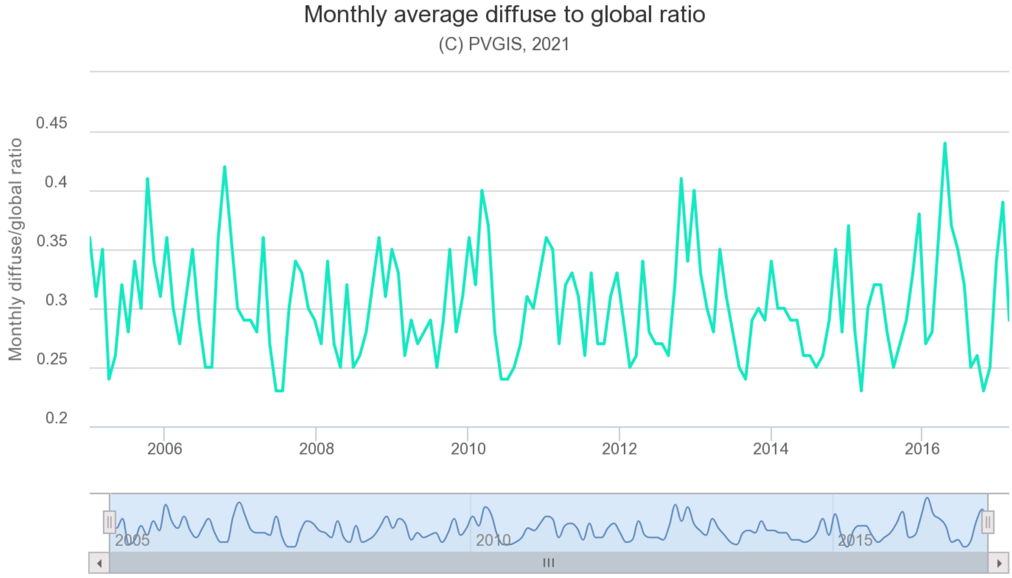


Figure 20. Monthly average diffuse to global ratio 2005-2017

As we did before, we will zoom in to focus just in a period of two years to see everything with more clearly.

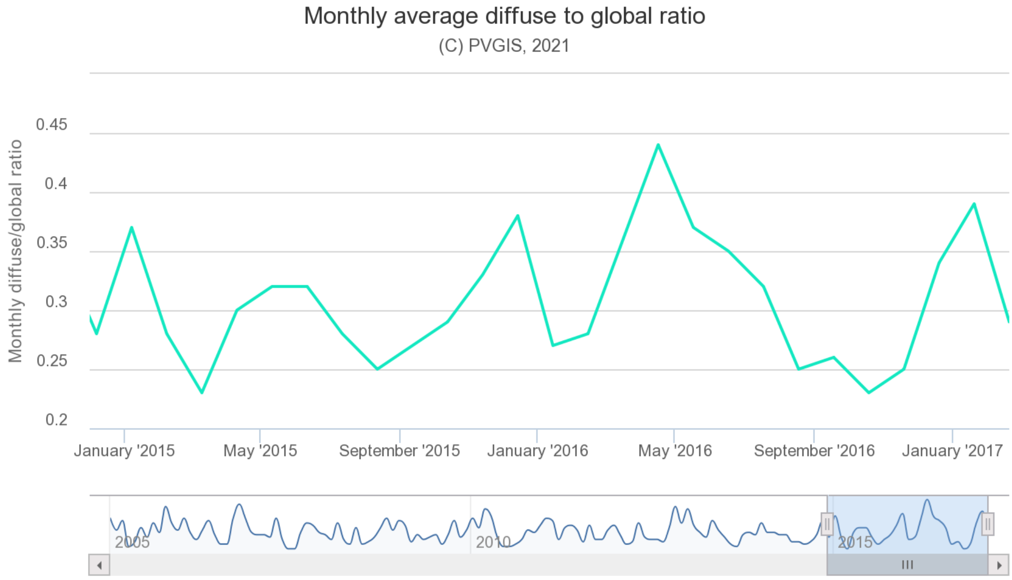


Figure 21. Monthly average diffuse to global ratio 2015-2017

Normally there is a peak around December and April. The lowest values often take place in August.

- Temperature

Once again we can distinguish an annual pattern, this time showing that the months with higher temperatures are in the summer seaon and the lowest values go from January to April. The coldest month is usually March and the hottest one are August or September.

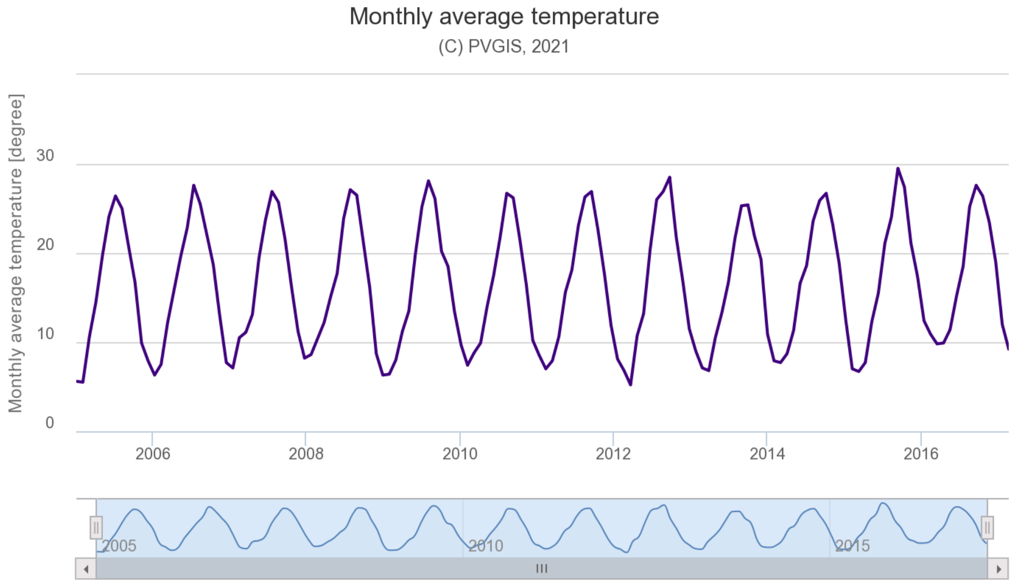


Figure 22. Monthly average temperature 2005-2017

As we did before, we will zoom in to focus just in a period of one years to see everything with more clearly.

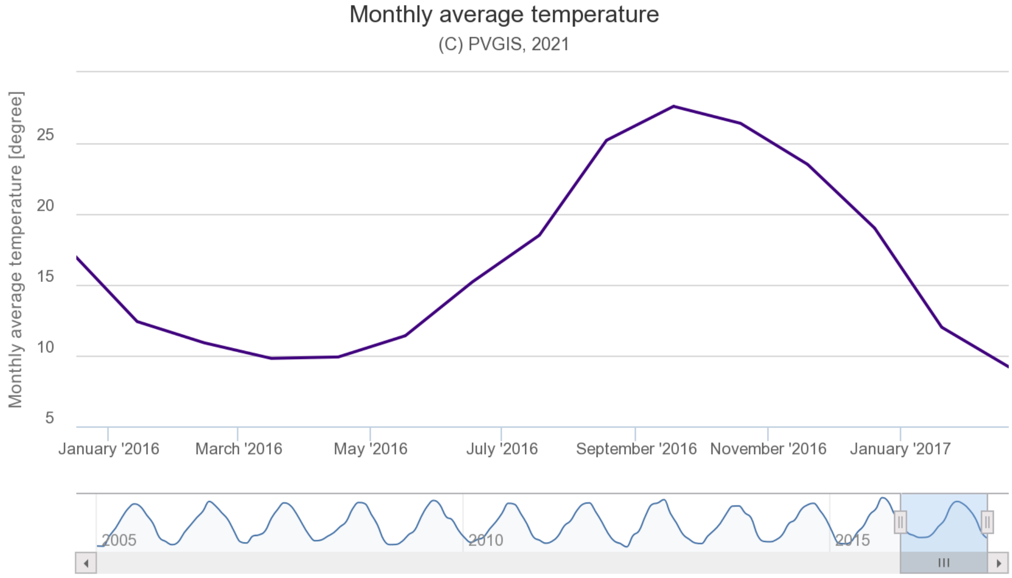


Figure 23. Monthly average temperature 2016-2017

- Daily

    - Temperature

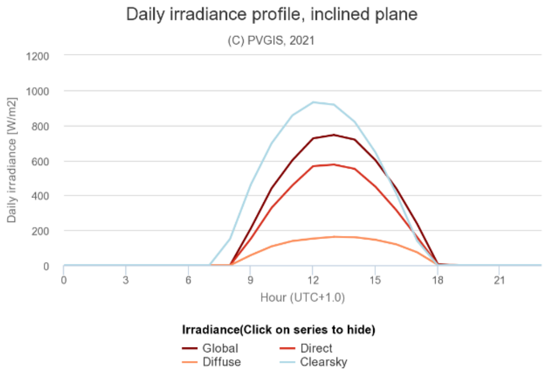
Now we are going to analyse how an average day temperature is each month.

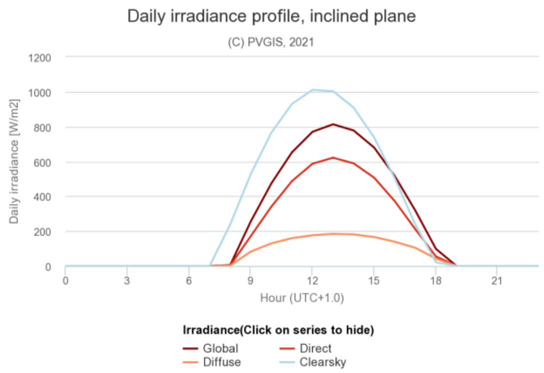
Figure 24. Daily average temperature from January to December

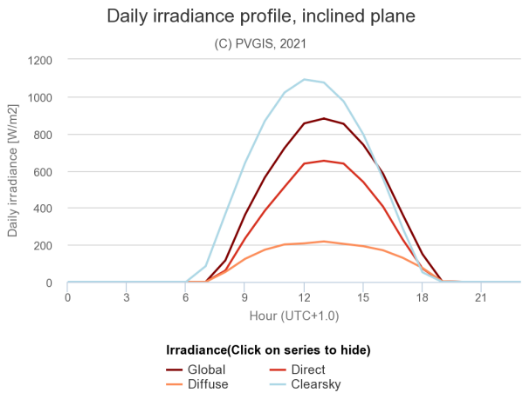
We checked that the lowest temperature in a normal day will be at 6:00 while the highest one will be at 15:00. On average, the temperature varies up to 15º from the coldest moment to the hottest. Normally the range of temperature along a day is 10º.

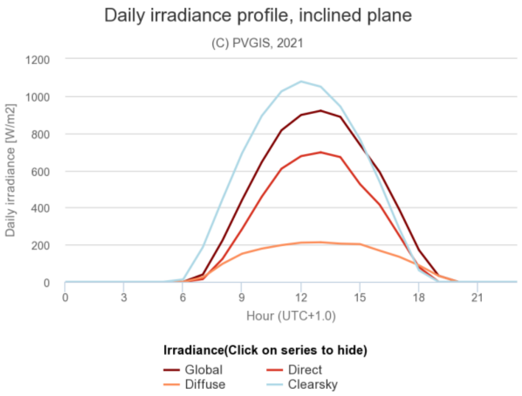
- Irradiance

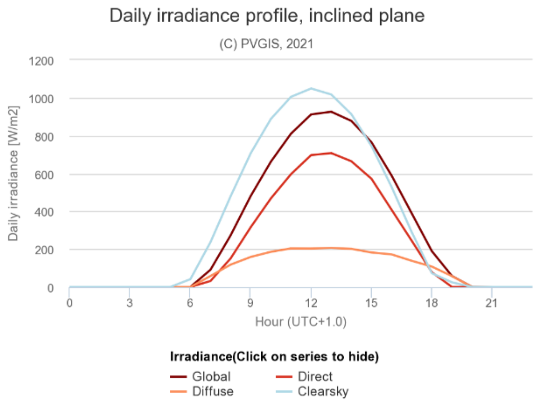
Now we are about to check the the horizontal, the direct normal, the global optimal irradiation and the global irradiation with our angle for an average day in the different months of the year.


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
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Diffuse
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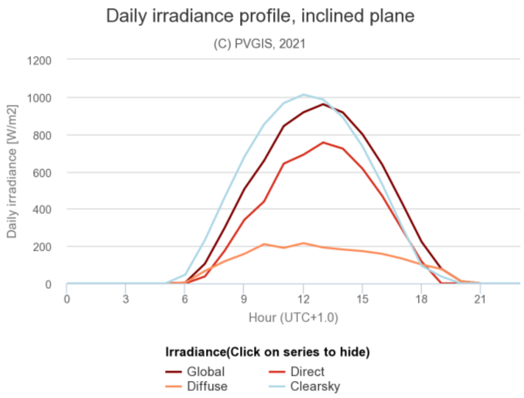
Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
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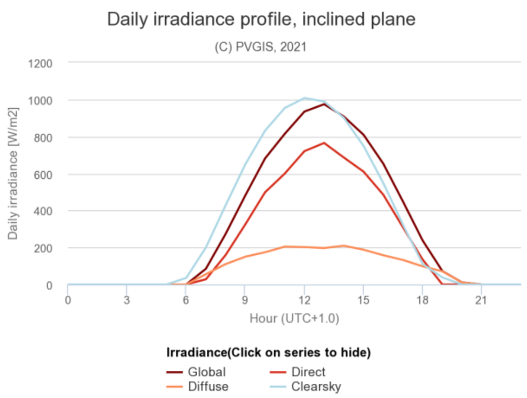
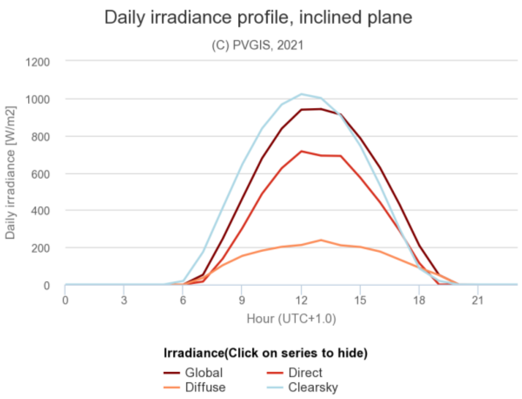

Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky


Daily irradiance profile, inclined plane
(C) PVGIS, 2021
Daily irradiance [W/m2]
Hour (UTC+1.0)
Irradiance(Click on series to hide)
Global
Direct
Diffuse
Clearsky

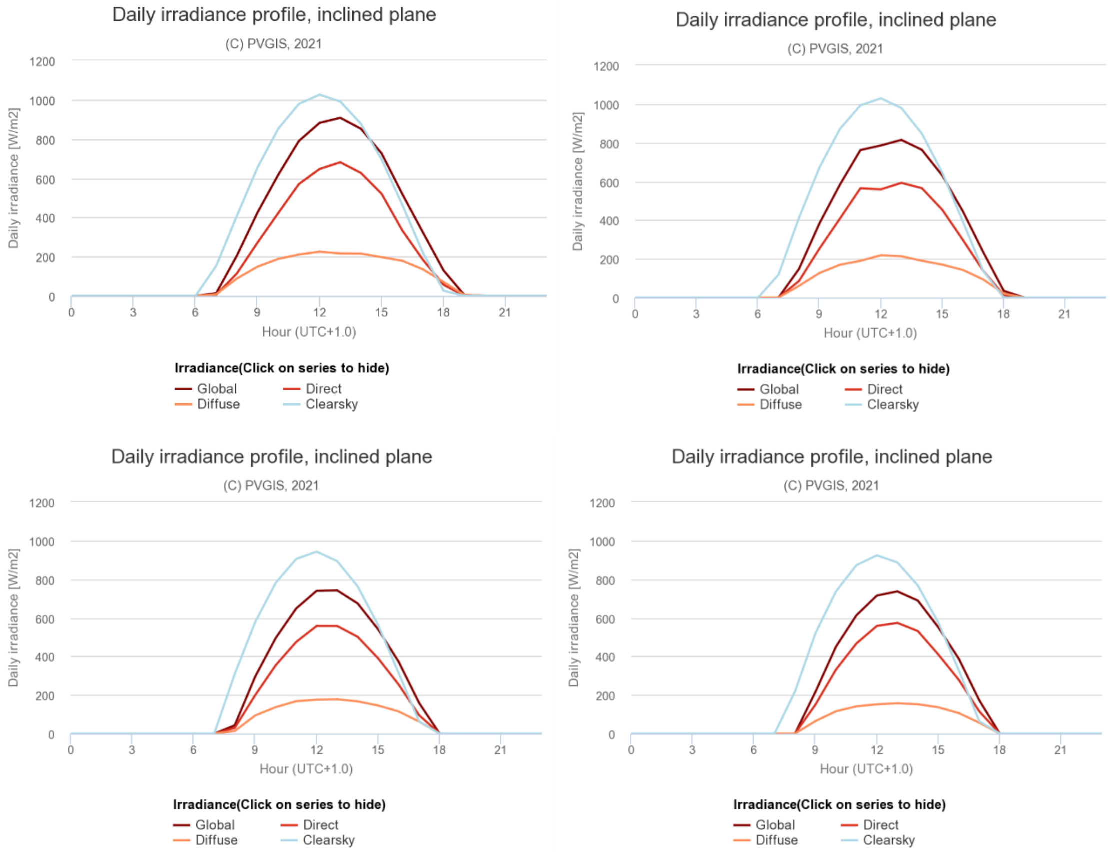


Figure 25. Daily average irradiance from January to December

Analysing this plots we can say that the irradiation is the highest in June and the curves are the wider, they start at 6:00 and end at 18:00. On the other hand, on December it wgoes from 7:00 to 17:00. We can also see that the peak is always at 12:00.

2.4. Study of available surface for solar installation

Now we need to know how much surface we have available to install our solar panels. The surface we have is limited so we will have to be really careful with this matter to know which is the best way we can mount the whole system and how many panels would fit on it.

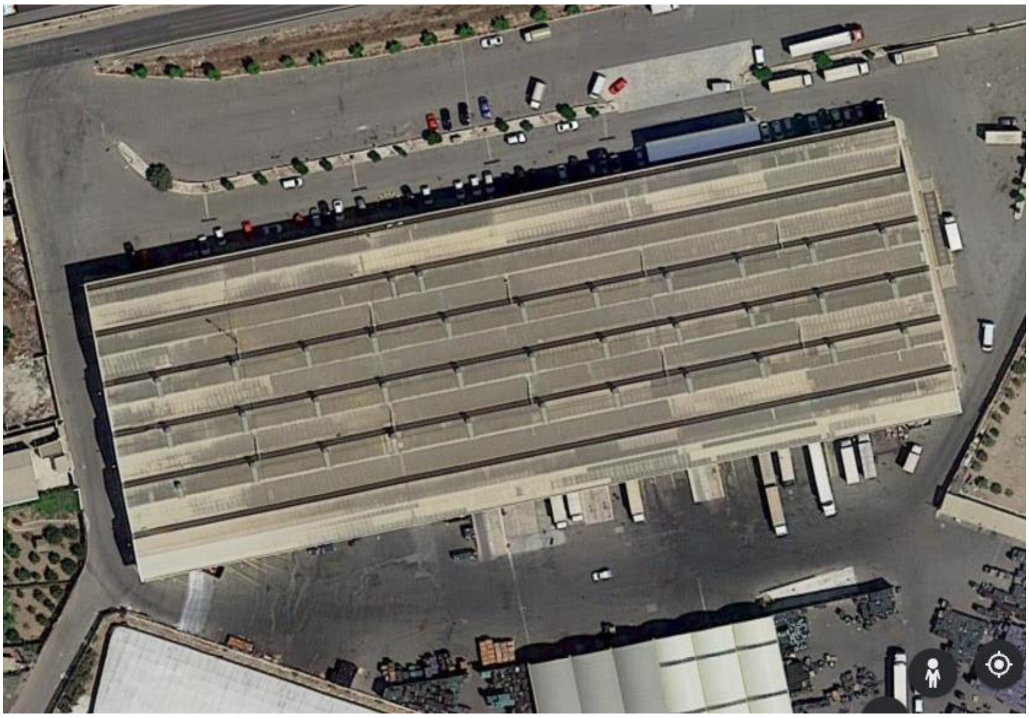


Image 7. Auction centre North-South view

We can see that the orientation of the warehouse is almost perfectly north-south but with a slight angle to the east.

The auction centre has a roof which wide is 66 metres long and the length is 180 metres. That roof is divided into 4 sections, each one measures 16.5 metres.

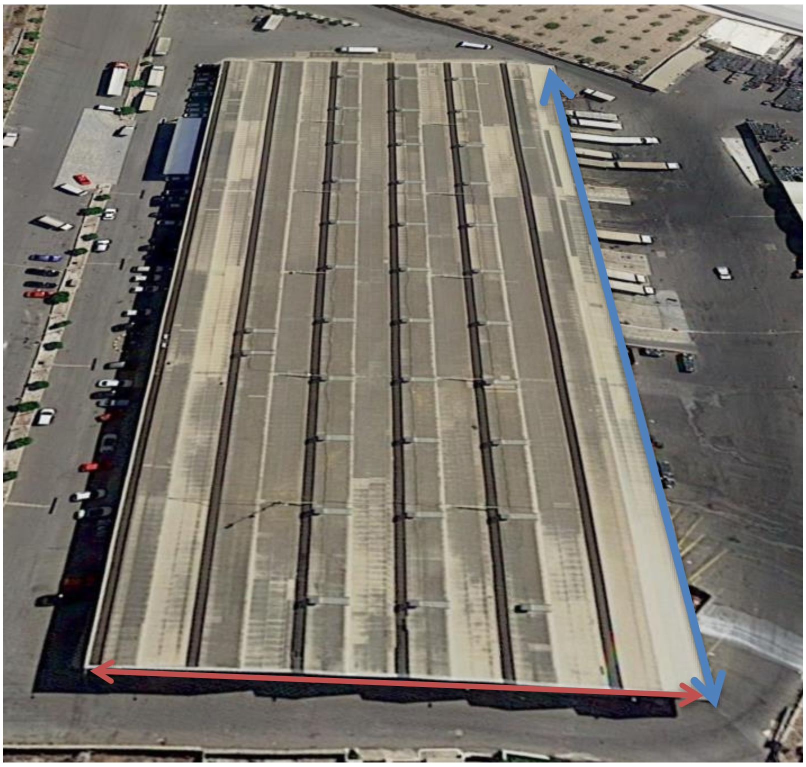


Image 8. Auction centre (Wide in red) (lenght in blue)

Those four sections are also divided into 3 parts which are a flat one, one declinated to the south and the last one inclinated to the north. Each one of them with a length of 5.5 metres.

Image 9. Auction centre (North face in red) (Flat face in blue) (South face in green)

Having in count that the declinated parts have an angle of 30º with respect to the floor, we can calculate the length of the hypotenuse.

$$\cos(30º) = \frac{5.5}{h} \rightarrow h = 6.35m$$

With those measures, we are able to calculate the real surface of the roof this way.

- South face of the roof:

$$(6.35m * 180m) * 4 = 4572\ m^2$$

- North face of the roof:

$$(6.35m * 180m) * 4 = 4572\ m^2$$

- Flat face of the roof:

$$(5.4m * 180m) * 4 = 3888\ m^2$$

Total surface: 12,744 m^2

We will follow this order of preference in order to mount our panels depending on the number of modules that we need. We know that we could fit three rows of panels fon the faces pointing north and south and just two for the flat ones.

In first place, we will place three rows in the face that is located in the southern part of the facility since it won't have any losses due to shadows.

Then we will mount the modules in the superior faces of the roof which points to the south. When we do not have more space in this upper row, we will go for the middle one.

With this should be more than enough for our system but in case we need to add more, we will have to decide among some options.

- Use a structure with a slope of 30º. I would just use this case if we just need between 1 and 4 more rows of panels. Since the orientation is better and we don't have shadow losses. On the other hand, a structure will be more expensive and will have to stand weather conditions such as strong wind and just one row of panels could be fitted.

- Use the flat faces. We would be able 2 add two more rows of panels without any losses due to shadows and a robust structure. The only downside is that we will loose a percentage due to the non optimal elevation. We would use this case if we need more than 4 more rows of panels since the power we can obtain is almost double than in the previous scenario.

- Use the lower rows in the south sections. We worked out, as in will be settled y next chapter, a 12% of losses due to shadows in the lower row which is higher than the percentage lost due to a non optimal elevation.

Hence, we conclude that if we need just some more power we could study if it is profitable to add the structure to create a 4 row of southern panels but if we need much more, we will have to use the flat roof. After that, we will use the lower part of the faces pointing to the south.

Faces pointing north are not even considered because they will be on the shadow most of the day time not producing almost any energy.

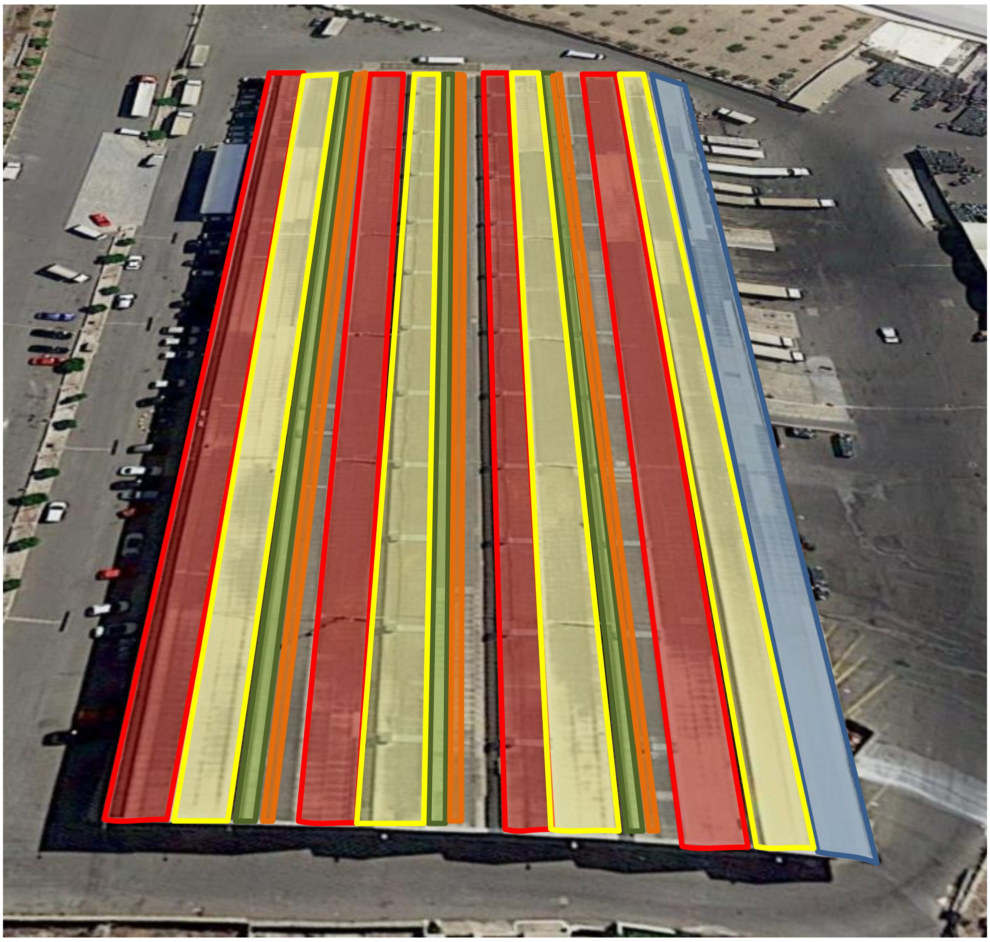


Image 10. Auction centre (North face in red) (Flat face in yellow) (South face in green, blue and orange)

Assuming a 2m leght x 1m width modules, which is a standard size for solar modules and it is quite close to the modules selected for this work, the availability por panels installation on the roof is the following:

1- Blue section (Southern face) ➔ 3*180=540 panels
2- Green sections (Upper rows south faces) ➔ 3*180=540 panels
3- Orange sections (Middle rows south faces) ➔ 3*180= 540 panels
4- Yellow section (Flat faces) ➔ 4*2*180 = 1440 panels
5- Grey sections (Lower rows south faces) ➔ 3*180=540 panels
6- Red sections (North faces) ➔ 3*180= 540 panels

Maximum amount of panels we can install (Without the red sections) ➔ 3600 panels

3. REQUIRED COMPONENTS OF THE INSTALLATION

We have decided to consider as basic configuration of our system that of the Image 11, in which we must identify the following interconnected elements 1) solar generator (orange), 2) inverter-charger (violet), 3) batteries (green), 4) user interface (gray) and 5) convetional networl feeding the facility. In our case, this basic configuration will be used for each one of the available solar areas on the roof, being each roof area converted in and individual plant. The sum of indicividuals plants in each scenario will be the corresponding building plant.

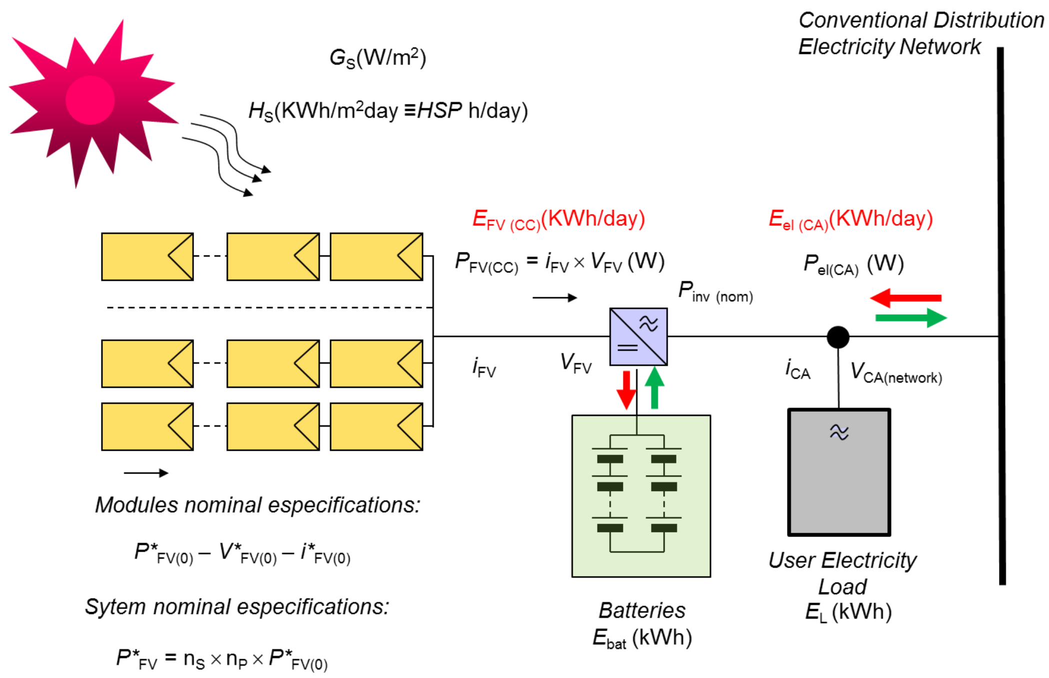


Figure 26. Basic technical configuration of a single plant for roof strip

3.1 Solar generator

It is constituted by a group of individual modules in which we identify n_p strings connected in parallel, each one containing n_s modules in serial connection. Installations in most solar plants have a wide range of voltages and current according the corresponding values of n_p and n_s from few 48 V to 1500V and for few to hundreds amperes.

Nominal especifications of commercial modules should always be measured and expressed under an international standard operating environment known as Standard Test Conditions (STC (represented by 1000 W/m2 of irradiance (peak solar hour definition), an AM 1.5 spectral distribution, and a temperature of 25°C. These nominal specifications are:

- Short-circuit current (I^*_{sc}), which is the value of the current that circulates through the solar panel when the voltage at its terminals is zero, V =0, and it is the maximum current that could be obtained (in an ideal case) of the solar panel when it works as a generator.

- Open circuit voltage (V_{oc}^*), which is the highest voltage that can bias the device when working as a generator.
- $V_{MP}^* - I_{MP}^*$ maximum power point (MPP) operation conditions, which is a working point in which the power delivered by the solar panel to the external load is maximum.
- Peak Power or maximum power P_{FV}^*, which s the module nominal power, that is, the product of VFV and IFV
- η_{FV}^* Efficiency, the ratio of the maximum electrical power delivered by the panel and the power of the incident radiation. A standard efficiency would be around 15-17%, and a high-efficiency panel would be from 19-20%

$$\eta_{FV}^* = \frac{P_{FV}^*}{A_m G_\beta^*} = \frac{V_{MP}^* I_{MP}^*}{A_m G_\beta^*}$$

In the formula G_β^* is the solar irradiance over the module in W/m^2 at nominal conditions and $A_m$the module surface in m^2

Additionally, existing standards require manufacturers to provide the specifications of their modules allowing assessing the efficiency and the rest of electrical performance characteristics for any condition of operation, that is, any ambient temperature and irradiance, both also determining module surface temperature, T_c.

$$I_{sc} = I_{sc}^* \frac{G_\beta}{G_\beta^*} [1 + \alpha(T_c - T_c^*)]$$

$$V_{oc} = V_{oc}^* [1 + \beta(T_c - T_c^*)]$$

$$\eta_{PV} = \frac{P_{PV}}{A_m\, G_\beta} = \eta_{PV}^* [1 + \delta(T_c - T_c^*)]$$

$$P_{PVT(el)} = P_{PV}^* \cdot \frac{G_\beta}{1000} \cdot [1 - \delta(T_c - 25)]$$

The efficiency of the panels, as usually happens in most systems, decreases as the temperature increases. This efficiency also decreases slightly from year to year over time.

There are many types of modules that we can classify according to various factors. Deciding which is the most appropriate for our project will depend on the needs and on the characteristics and specificities inherent to the chosen place.

On the other hand, photovoltaic panels directly generate electricity because they create an electric current thanks to the energy from the sun. Each panel contains photovoltaic cells that are connected to each other and are responsible for transforming light energy into photovoltaic.

In our case, we will focus on photovoltaic panels, because for the type of company that we are going to analyze the heating and hot water system do not represent a considerably enough amount to be included in the project as if it could be a heated pool for example.

Figure 27. Types of solar panels

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

It is true that in recent decades the power output delivered by the new panels has not stopped increasing almost exponentially. So does its efficiency. Although it should be clarified that the efficiency of cells is not advancing as much as we might think. With which, we are going to see the technologies that are being implemented to achieve that increase in power that has been seen in recent years.

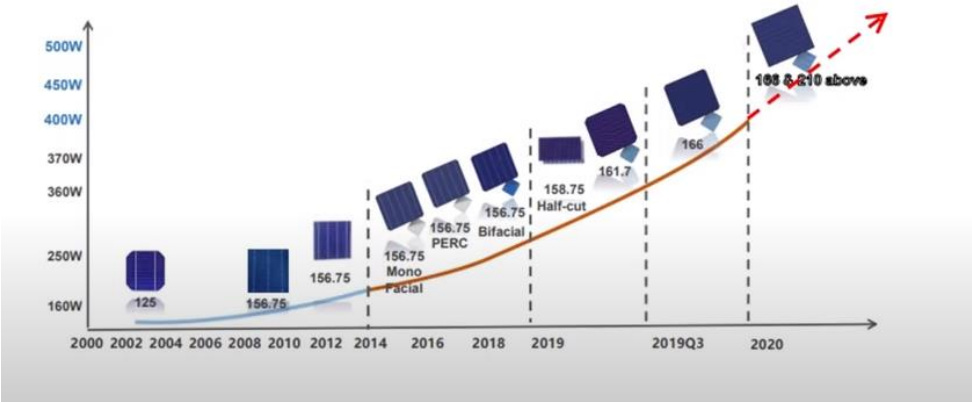


Figure 28. Evolution of solar panels through time

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

To begin with, we can say that there are two standard sizes of panels. The first one has 60 to 120 cells and delivers an output power of between 285W and 400W. We are talking about panels of a size of 1 meter wide by 1.7 meters high.

For the second model that we are analyzing, we are talking about having 72 to 144 cells and being capable of delivering an output power between 350W and 490W. These are 1 meter wide panels like the previous ones with the difference of having a length of 2 meters high.

For the third model, we see that it has in this case from 132 to 156 cells and is capable of delivering an output power between 350W and 560W. These are panels where we see an increase in width to 1.1 meters and a length of 2.3 meters high.

For the larger model the cell number is the same as in the previous case but it is capable of delivering a higher power output between 560W and 680W. These are panels that are 1.3 meters wide and 2.4 meters high, thus considerably increasing their surface area.

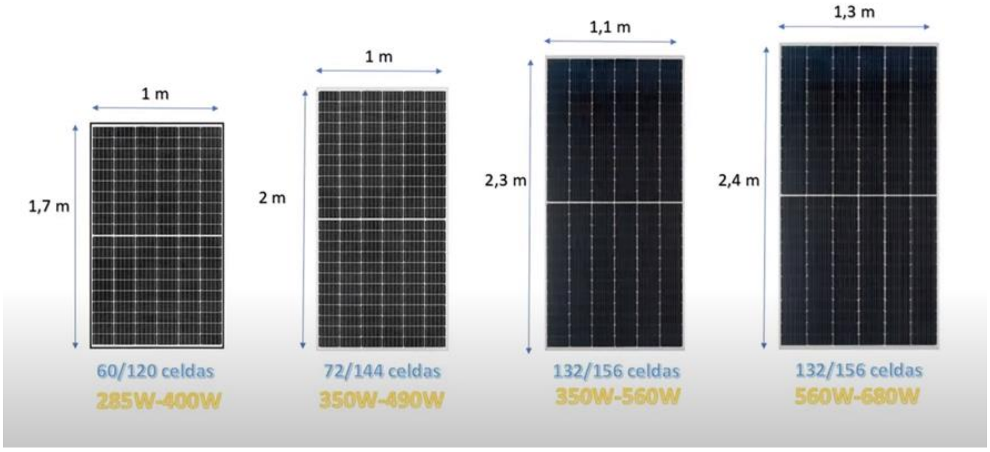


Figure 29. Solar panels depending on the amount of cells

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

For residential use, the 60-cell module is more than sufficient. In addition, they have the great advantage that they resist both snow and wind loads much better, an aspect that must be taken into account in the chosen area. The general trend in the market is that of 72 cells to lower costs in the investment / power ratio (€ / W) and the structures for the panels.

Larger modules with more power are usually used on exceptional occasions where installation conditions favor these types of characteristics.
In the following image we see the models that we are going to compare and analyze to see which would be the most appropriate for our problem.

Figure 30. Solar panels in 2021

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

a) Polycristalline

The first option that we are going to analyze are the plates that contain polycrystalline crystal. This technology has been on the market for a long time and they are characterized by their high durability and by having a fairly simple manufacturing process that makes their cost cheaper than many of their competitors.

This type of panels is characterized at first glance by their bluish color as can be seen in the following image.

Figure 31. Polycristalline solar panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Like many other types of panels in this range, it uses a P-type silicon, which does not have much difference from the n-type, which is the one used in high-end manufacturers, although their final performance does improve somewhat.

This configuration makes manufacturing more economical in exchange for a somewhat lower power delivery.

In the image we see the two types of silicon used in the photovoltaic industry.

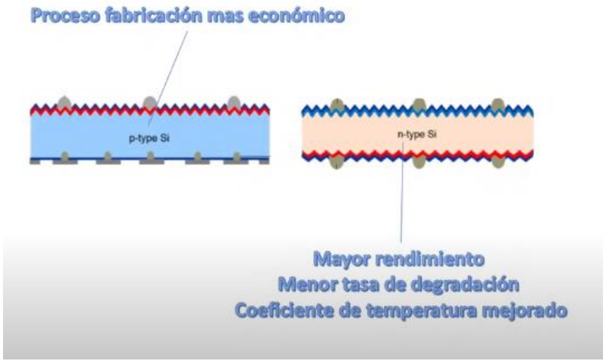


Figure 32. P-type silicon

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The output power that these photovoltaic panels reach is up to 285kW in 60-cell format modules, although there are also some split-cell modules that can reach a little more power.

Power is measured under STC conditions, which are standard conditions with an irradiance of 1000W / m2 and cells at 25 ° C.

Tecnología	POLICRISTALINO
Silicio	P
Potencia	285W
Eficiencia	16-17%
C.Temp	-0,40
Degradación 25 años	20%

Table 5. Main caharacteristics of a polycrystalline panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The efficiency serves to compare different models since in this parameter we do take into account the surface of the photovoltaic solar panel. It is also measured under STC conditions. It is usually around 16% or 17% which, as we are going to see below, is the lowest of all the ones we are going to compare. The formula to calculate it would be the following:

$$\eta_{FV}^{*} = \frac{P_{FV}^{*}}{A_m G_{\beta}^{*}} = \frac{V_{MP}^{*} I_{MP}^{*}}{A_m G_{\beta}^{*}}$$

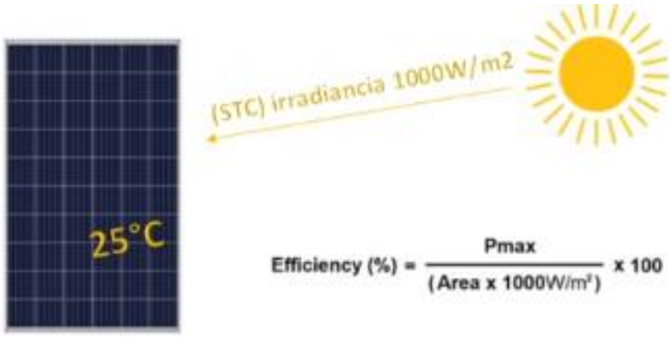


Figure 33. Efficiency due to temperature

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Regarding the temperature coefficient, this indicates the losses that we are going to have in the module for each degree that we increase in temperature from 25º of reference. In photovoltaic modules, the higher the temperature, the less efficient they are and, therefore, the greater losses will occur. This is characterised by thermal coefficient δ which normally has a value of 0.4% for this type of modules.

$$\eta_{PV} = \frac{P_{PV}}{A_m\, G_{\beta}} = \eta_{PV}^{*}[1 + \delta(T_c - T_c^{*})]$$

For example, if we have a polycrystalline panel at 50ºC, we can calculate the difference up to 25 degrees, multiply it by the coefficient, in this case 0.40%. We would get 10% losses that correspond to 28.5W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.40\%) = 10\%$$
$$10\%\ de\ 285W = 28.5W$$
$$285W - 28.5 = 256.5W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 256.5W, always taking into account that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that power from final departure.

It should be noted that it is very common for a panel that we have at an ambient temperature of 25ºC, after a few hours of direct sun exposure it is very likely that it is around 50ºC or even higher.

Last but not least, we have another very interesting parameter, which is the degradation that we are going to have with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout the useful life of the panel.

In the case of polycrystallines, manufacturers usually give a production guarantee of up to 80% when we reach 25 years. Therefore, 25 years from now, the degradation of this type of panels is usually 20%.
To calculate the power that this photovoltaic module can give us after those 25 years of life, it would be as simple as applying that 20% to the initial maximum output power. We would have a panel capable of delivering 228W after the warranty period.

$$20\%\ de\ 285W = 57W$$

$$285W - 57W = 228W$$

Figure 34. Panel power after 25 years

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

b) Monocrystalline PERC Divided Cel

This type of panel has a more intense and characteristic black color to the naked eye, as can be seen in the following image.

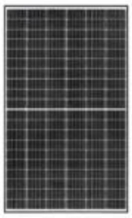


Figure 35. Monocrystalline panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

These are the most common modules today. They have, as can be seen in the representation below, a PERC-type cell that adds a small sheet to the cell, with which we are going to absorb more photons of light, thus increasing efficiency. In a normal cell, without this sheet, we would lose those photons and therefore that energy.

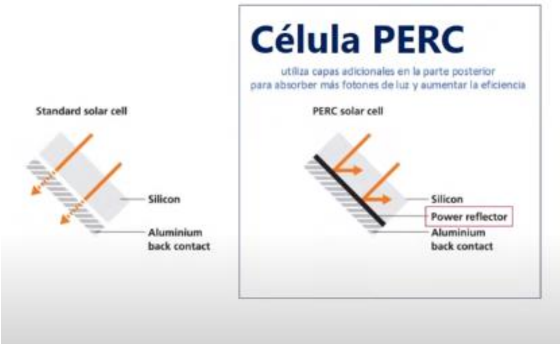


Figure 36. PERC technology

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

They have implemented half-cell technology, which means that the manufacturer takes one cell and divides it into two, thereby reducing the current that passes through these cells and thus reducing losses due to thermal resistance.

These panels are divided in two. It is as if they were two panels in one panel. They are two series of panels that are joined in parallel. And that helps to greatly reduce losses due to shadows, dirt or any element that obstructs the passage of light to the cell. It is one of the great advantages that these photovoltaic modules have.

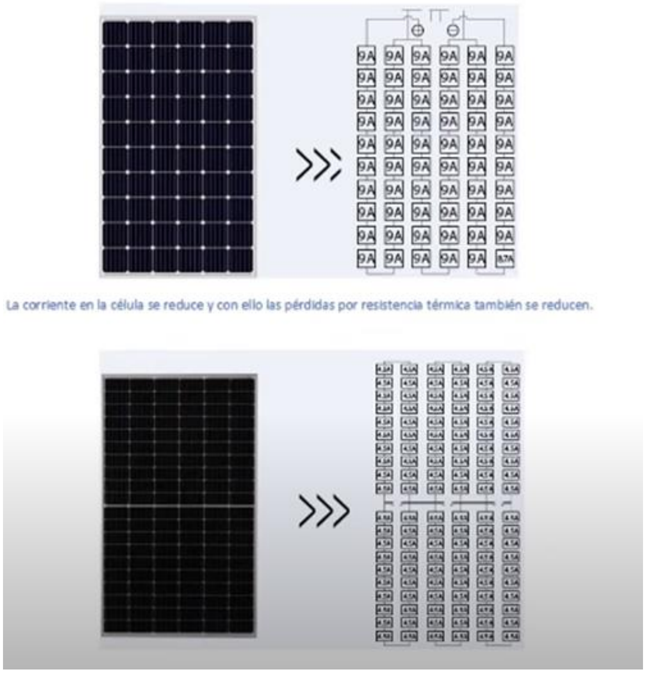


Figure 37. Normal panel vs divided panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

They also use P-type silicon. The power output is higher than that of polycrystalline ones. We are already talking about 345W or 375W of power. Efficiency is also clearly better with the Perc cell and with this split cell technology. The temperature coefficient is also lower.

Therefore, it should be noted that the assumption that polycrystallines are more efficient with higher temperatures is not fulfilled. Well, as can be seen in the tables provided by the manufacturers, the temperature coefficient is lower in Perc-type monocrystalline than in polycrystalline ones.

Tecnología	POLICRISTALINO	MONO PERC HALF CELL
Silicio	P	P
Potencia	285W	345W
Eficiencia	16-17%	18-20%
C.Temp	-0,40	-0,35
Degradación 25 años	20%	15-18%

Table 6. Main caharacteristics of a monocrystalline panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

For example, if we have a Perc monocrystalline panel with a split cell at 50 degrees. We can calculate the difference up to 25 degrees, multiply it by the coefficient, in this case 0.35%. We would get 8.75% losses that correspond to 28.5W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.35\%) = 8.75\%$$
$$8.75\% \ de \ 345W = 30.19W$$
$$345W - 30.19W = 314.81W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 314.81W, always taking into account that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that power from final departure.

We must remember again that it is very common for a panel that we have at an ambient temperature of 25ºC, after a few hours of direct solar exposure it is very likely that it is around 50 degrees or even higher.
Finally, we have another very interesting parameter, which is the degradation that we are going to suffer with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout its useful life.

In the case of monocrystallines, manufacturers usually give a production guarantee of up to 85% when we reach 25 years. Therefore, 25 years from now, the degradation of this type of panels is usually between 15% and 18%. We therefore verify that this type of panel is better preserved over time than those previously mentioned in this chapter.

To calculate the power that this photovoltaic module can give us after those 25 years of life, it would be as simple as applying that 15% to the initial maximum output power.

$$15\%\ de\ 345W = 51.75W$$
$$345W - 51.75W = 293.95W$$

As we have just verified the power would drop to almost 300W, which is still a fairly acceptable amount.

c) SHINGLED

It is a technology used, for example, by the manufacturer SUNPOWER for its Performance range or the manufacturer Hyundai in some of its product ranges.

In the image you can see what a panel with this type of technology would look like.

Figure 38. SHINGLED panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

These panels also use PERC-type monocrystalline cells. The most striking thing is that the wafer is cut into 5 pieces, unlike those with a split cell that do it in two, and all these cells are superimposed on each other in a tile format, joined by means of an adhesive. With this, the welds and, thus, the hot spots that they may have are reduced.

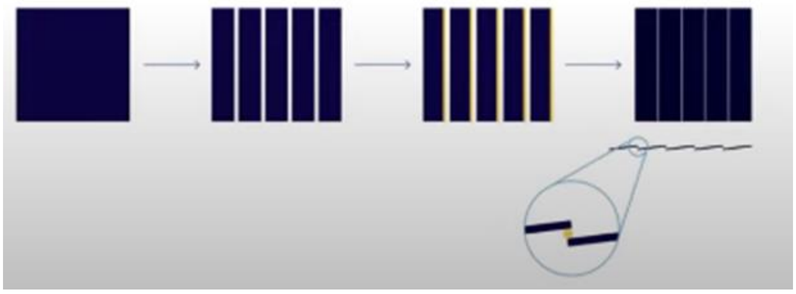


Figure 39. Main feature of SHINGLED panels

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In the following representation, we are able to see the behavior of a Sunpower in the shadows. We see that if we cover a part in a panel with 60 cells in series, we would lose all that part in the red box if it is a conventional panel while, in a Sunpower, we lose only that proportional part of production.

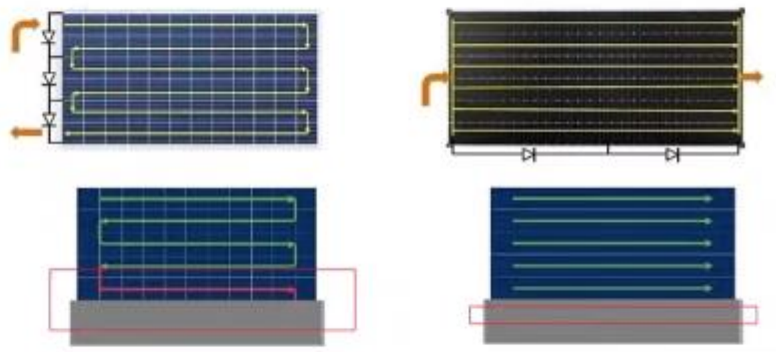


Figure 40. How current flows through a normal and SHINGLED panel with and without a shadow.

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In the case of the Hyundai, in vertical arrangement they behave very well as well. The cells are also superimposed, thus avoiding those contacts with respect to conventional cells that generate so many problems now of improving performance.

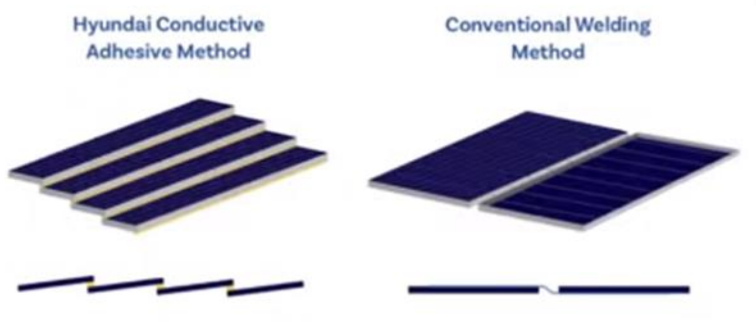


Figure 41. Hyunday conductive adhesive method vs conventional conductive method

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

As we see in the following example, a tree that blocks the passage of light to the lower part of a standard panel would produce the loss of practically all the energy production at that moment, while in the case of the Hyundai, only that strip where the shadow falls.

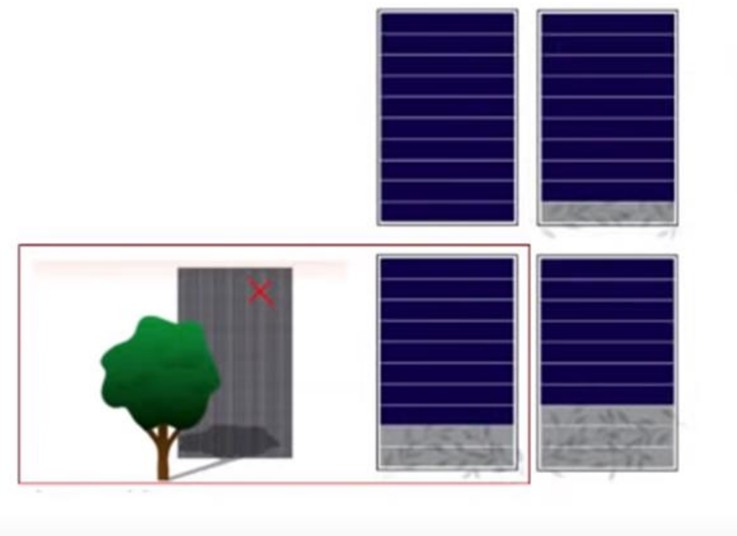


Figure 42. How a shadow affects these divided panels

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In general, we could say that the great improvements with respect to other technologies are the best behavior in the shadows, also avoiding risks during micro-breaks and aesthetics.

Tecnología	POLICRISTALINO	MONO PERC HALF CELL	SHINGLED MONO PERC
Silicio	P	P	P
Potencia	285W	345W	390W
Eficiencia	16-17%	18-20%	19-20,5%
C.Temp	-0,40	-0,35	-0,28
Degradación 25 años	20%	15-18%	12,5%

Table 7. Main caharacteristics of a SHINGLED panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The power output is higher than that of the two models named above. We already refer to 390W of power. Efficiency is also clearly better with the PERC cell and with this split cell technology. The temperature coefficient is also lower.
For example, if we have a panel with these characteristics at 50ºC, we can calculate the difference up to 25ºC, multiply it by the coefficient, in this case 0.28%. We would get 8.75% losses that correspond to 28.5W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.28\%) = 7\%$$
$$7\% \; de \; 390W = 27.3W$$
$$345W - 27.3W = 362.7W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 362.7W, always bearing in mind that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that power final output.

Finally, we have another very interesting parameter, which is the degradation that we are going to have with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout the useful life of the panel.

In this case, manufacturers usually give a production guarantee of up to 87.5% when we reach 25 years. Therefore, after 25 years, the degradation of this type of panels is usually between 12.5%. We therefore see that this type of panel is better preserved over time than those previously mentioned in this chapter.

To calculate the power that this photovoltaic module can give us after those 25 years of life, it would be as simple as applying that 12.5% to the initial maximum output power.

$$12{,}5\%\ de\ 390W = 46.8W$$
$$390W - 46.8W = 343.2W$$

As we have just verified, the power would be reduced to almost 350W, which is a higher amount than the previous two newly manufactured.

d) Mono PERC divided cel MBB

This type of panel is an evolution of the split cell in which manufacturers add multibus bars that characterize them and larger cells such as M10 or M12.

Figure 43. Mono PERC divided cel MBB panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In the following diagram, we can see how the development of the bus bars was. In this case, the manufacturers realized that by adding more bus bars in the cells, greater efficiency is achieved.

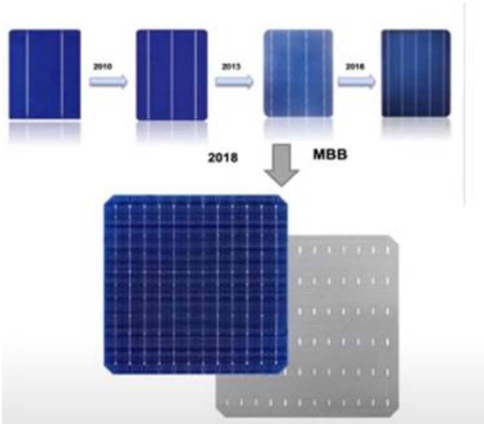


Figure 44. Multibus bars

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The bus bars are metal bars that conduct electricity. Depending on the manufacturer, they are usually between 9 and 12 units.

Apart from this improvement, they also include larger cells that are evolving. Each manufacturer decides to divide these cells into different parts to achieve the highest efficiency. In the image we appreciate the evolution of this type of cells in recent years.

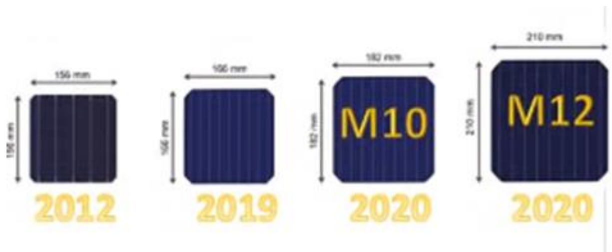


Figure 45. Sizes of cells

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In addition, in some cases, manufacturers include some technologies such as Jimko, which with this configuration reduces the space between cells. In this way, a greater useful surface of cells is achieved within the solar panel, thus achieving greater efficiency.

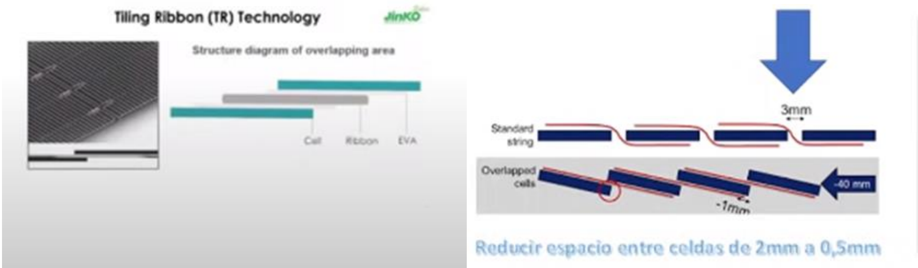


Figure 46. Tiling ribbon technology vs conventional

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The power output is higher than that of the two models named above again but this time it is not much difference. In this case it is 405W of power. The efficiency and the temperature coefficient have been the same as in the case of PERC-type lenses with split cells. At the end of the day, it has been an evolution of the monocrystalline ones to which we have added a new feature that increases its power but keeps the rest of the parameters the same.

Tecnología	POLICRISTALINO	MONO PERC HALF CELL	SHINGLED MONO PERC	MONO PERC HALF CELL MBB M10 M12
Silicio	P	P	P	P
Potencia	285W	345W	390W	405W
Eficiencia	16-17%	18-20%	19-20,5%	19-21,1%
C.Temp	-0,40	-0,35	-0,28	-0,35
Degradación 25 años	20%	15-18%	12,5%	15-18%

Figure 8. Main caharacteristics of a Mono PERC divided cel MBB panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Now we will go on to analyze this type of panel according to the characteristics given by the manufacturer.

For example, if we have a panel of this nature at 50ºC, we can calculate the difference up to 25ºC, multiply it by the coefficient, in this case 0.35%. We would get 8.75% losses that correspond to 28.5W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.35\%) = 8.75\%$$
$$8.75\%\ de\ 345W = 30.19W$$
$$405W - 30.19W = 374.81W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 374.81W, always taking into account that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that power from final departure.

Finally, we have another very interesting parameter, which is the degradation that we are going to have with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout the useful life of the panel.
As we have already mentioned in the monocrystalline group, manufacturers usually give a production guarantee of up to 85% when we reach 25 years. Therefore, 25 years from now, the degradation of this type of panels is usually between 15% and 18%. We therefore see that this type of panel is better preserved over time than those previously mentioned in this chapter.

To calculate the power that this photovoltaic module can give us after those 25 years of life, it would only be to apply that 15% to the initial maximum output power.

$$15\%\ de\ 405W = 60.75W$$
$$405W - 60.75W = 344.25W$$

As we just checked the power would drop to almost 350W, which is still a pretty good amount.

- Highest quality

The commercial brands Panasonic and REC are the manufacturers that bet the most on this technology based on N-type silicon that we already mentioned in passing at the beginning of the chapter. These are high-end photovoltaic modules.

Figure 47. Panasonic panel and LG panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Silicon of type N, is purer so a higher performance is achieved as well as a lower degradation rate and improved temperature coefficients.

e) HJT

Due to the physical characteristics of this type of panel, an optimal case to take it into account in our installation are installations that are located in places where it is very hot.

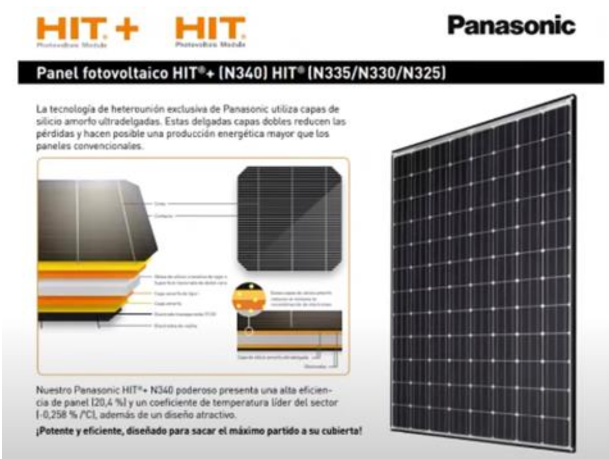


Figure 48. Panasonic panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The power output for this type of plate is not the best, but it is still one of the best. In this case it is 380W of power. Where there is a very appreciable difference is in the efficiency and the temperature coefficient.

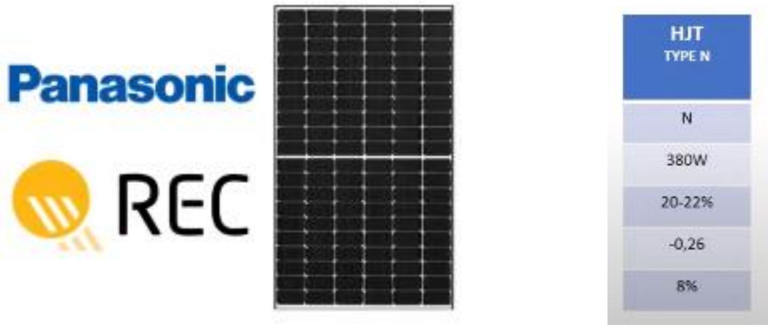


Figure 49, Table 9. Panasonic panel and main characteristic

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Now we will go on to analyze this type of panels according to the characteristics given by the manufacturer.

For example, if we have a panel of this kind at 50ºC. We can calculate the difference up to 25ºC, multiply it by the coefficient, in this case 0.26%. We would get 6.5% losses that correspond to 28.5W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.26\%) = 6.5\%$$
$$6.5\%\ de\ 380W = 24.7W$$
$$380W - 24.7W = 355.3W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 355.3W, always taking into account that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that power from final departure.
Finally, we have another very interesting parameter, which is the degradation that we are going to have with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout the useful life of the panel.

For this type of high-end panels, the biggest difference is their durability, manufacturers usually give a production guarantee of up to 92% when we reach 25 years. Therefore, 25 years from now, the degradation of this type of panels is usually between 8%. We therefore see that these types of panels are the ones that are better preserved over time than those previously mentioned in this chapter.

To calculate the power that this photovoltaic module can give us after those 25 years of life, it would be as simple as applying that 15% to the initial maximum output power.

$$8\%\ de\ 380W = 30.4W$$
$$380W - 30{,}4W = 349.6W$$

As we just checked the power would drop to almost 350W, which is still a pretty good amount.

f) IBC

LG and SUNPOWER, are the companies that bet the most on this type of technology in which the contacts would go to the back so that we avoid the shadows with the bus bars.

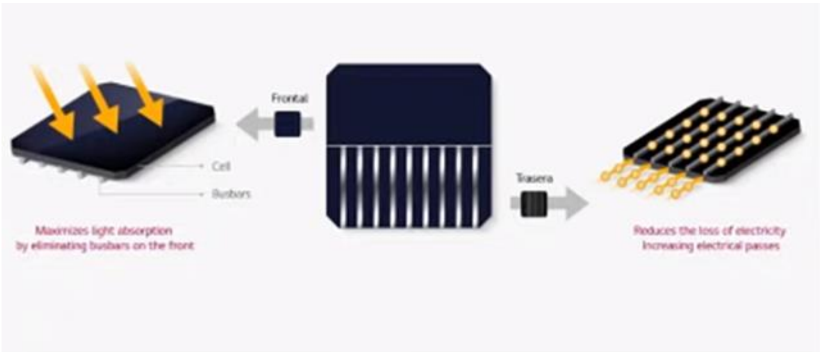


Figure 50. Bus bars behind the panel

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

In the previous image we see how the configuration of this type of solar panels would be.

LG Solar

SUNPOWER® | MAXEON® 3

IBC TYPE N
N
400W
20-23%
-0,27
8%

Figure 51, Table 10. LG panel and main characteristic

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

The power output for this type of panle is not the highest but it is still one of the best as in the previous case. Now it's about 400W of power. Where there is a very appreciable difference is in the efficiency and the temperature coefficient.

Now we will go on to analyze this type of panels according to the characteristics given by the manufacturer, although they are quite similar to the HJT.

For example, if we have like this at 50 degrees, we can calculate the difference up to 25 degrees, multiply it by the coefficient, in this case 0.27%. We would get a 6.5% loss corresponding to 26W of the output power in the assumed case.

$$50ºC - 25ºC = 25ºC$$
$$25ºC * (-0.27\%) = 6.75\%$$
$$6{,}75\%\ de\ 400W = 30W$$
$$400W - 30W = 370W$$

Therefore, the maximum power that this particular panel can deliver for these conditions would be 370W, always bearing in mind that it is a completely new panel and ignoring the rest of the causes that may affect when obtaining that final output power.

Finally, we have another very interesting parameter, which is the degradation that we are going to have with the photovoltaic module, which consists of the decrease in the efficiency of the panel throughout the useful life of the panel.

For this type of high-end panels, which are very similar to the previous ones, the biggest difference is their durability, manufacturers usually give a production guarantee of up to 92% when we reach 25 years. Therefore, 25 years from now, the degradation of this type of panels is usually between 8%. We therefore see that these types of panels are the ones that are better preserved over time than those previously mentioned in this chapter.

To calculate the power that this photovoltaic module can give us after those 25 years of life, it would be as simple as applying that 15% to the initial maximum output power.

$$8\%\ de\ 400W = 32W$$
$$400W - 32W = 368W$$

As we just checked the power would drop to almost 350W, which is still a pretty good amount.

3.3.1. Comparing different types of the most efficient panels in 2021

We go to see a table where we find some of the most characteristic and popular panels this 2021.

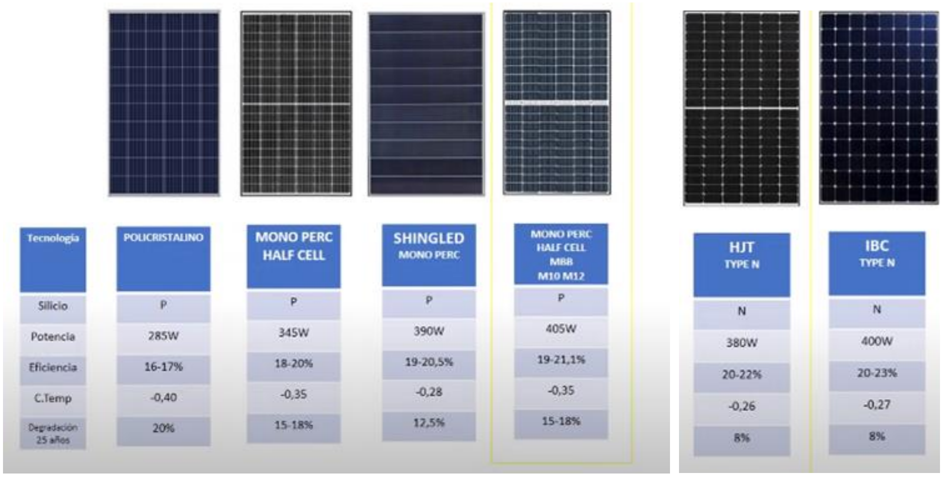
Most Efficient Solar Panels 2021 *

Manufacturer	Model	Max power (W)	Cell Type	Efficiency %
SUNPOWER	Maxeon 3	400W	N-type IBC	22.6
LG	Neon R	380W	N-type IBC	22.0
REC	Alpha	380W	N-type HJT Half-cut	21.7
FuturaSun	FU 360 M Zebra	360W	N-type IBC Half-cut	21.3
Panasonic	EverVolt	370W	N-type HJT Half-cut	21.2
Trinasolar	Vertex S	405W	P-Type Mono Half-cut	21.1
JinKO Solar	Tiger Pro 6RL3	390W	N-Type Mono Half-cut	20.7
Q CELLS	Q.PEAK DUO ML-G9	390W	P-Type Mono Half-cut	20.6
WINAICO	WST-375MG	375W	P-Type Mono Half-cut	20.6
LONGi Solar	Hi-MO 4	375W	P-Type Mono Half-cut	20.6
SOLARIA	Power XT	370W	P-Type Mono Half-cut	20.5
CanadianSolar	HiDM CS1H-MS	345W	P-Type Mono Shingled	20.4
Phono Solar	TwinPlus M4-9B-R	375W	P-Type Mono Half-cut	20.4
ASTRONERGY	AstroSemi 60M	375W	P-Type Mono Half-cut	20.3
HYUNDAI	HiE-S355SG	350W	P-Type Mono Shingled	20.2
JA SOLAR	JAM60S10	345W	P-Type Mono Half-cut	20.2

Table 11. Main characteristics of panels comparison

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

We also include a comparative table of the panels that we have been anilizing up to now along with their prices to be able to get a more complete idea of the panel that interests us the most, taking into account not only the quality of the product, but also the profitability, the cost benefit that you can provide us with the available budget and other financial parameters.



Tecnología	POLICRISTALINO	MONO PERC HALF CELL	SHINGLED MONO PERC	MONO PERC HALF CELL MBB M10 M12	HJT TYPE N	IBC TYPE N
Silicio	P	P	P	P	N	N
Potencia	285W	345W	390W	405W	380W	400W
Eficiencia	16-17%	18-20%	19-20,5%	19-21,1%	20-22%	20-23%
C.Temp	-0,40	-0,35	-0,28	-0,35	-0,26	-0,27
Degradación 25 años	20%	15-18%	12,5%	15-18%	8%	8%

Table 12. Sum up of the main characteristics of the mentioned panels

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

Figure 52. Coefficient between cost and production of the mentioned panels

Source: https://www.youtube.com/watch?v=LvLoBe_99QQ&ab_channel=AutoconsumoSolarF%C3%A1cil (23/04)

As a conclusion to this section, we consider that for the objective pursued, the high-quality panels do not make so much difference as to opt for them due to their high price and not so remarkable benefits for that difference in the investment of the installation.

Among the mid-range ones, we would discard the basic polycrystalline ones since the power they provide may not be enough if the surface area we have is limited. Comparing monocrystalline ones, the price difference is minimal, so it would be advisable to purchase those ones which incorporate bus bar technology. The Shingled would also be a good option to consider.

3.2. Inverter-charger

The inverter is the device that transforms direct current into alternating current. On the one hand, electronic devices work on alternating current, so we need an inverter to be able to use the energy in the form of direct current that the panels produce.

On the other hand, the grid also works in alternating mode, so if we want to add electricity to the grid, this inverter will also be necessary.

When batteries are includen in grid tied sytems, the inverter function must also include the charging capacity so the the inverter became inverter-charger. This device, in addition to changing from direct current to alternating current, detects when the charge level of the batteries is too low and they can connect to the mains, charge the batteries from the mains.

The network voltage is specific to each country and the frequency in some countries is 50 Hz, as is the case in Spain, and in others it is 60Hz. As the system that we have installed must necessarily operate at the voltages and frequencies that were designed, the inverter has to produce that frequency and that voltage or, otherwise, we will damage what is connected to our circuit.

The supply voltage of the inverter, which is in direct current, is the voltage of the batteries or solar generator, so it has to be able to feed itself at that voltage.

The next value that we have to check is the power of the inverter, since if it is too small, we will not be able to use all our system simultaneously.

A typical inverter has red and black DC terminals on the back and some AC outlets on the front. That is because there are two types of electricity, AC and DC, an inverter is used to convert direct current (DC) into alternating current (AC).

Figure 53. Inversor and its terminals

We could also convert AC to DC with the use of a rectifier as shown in the schematic.

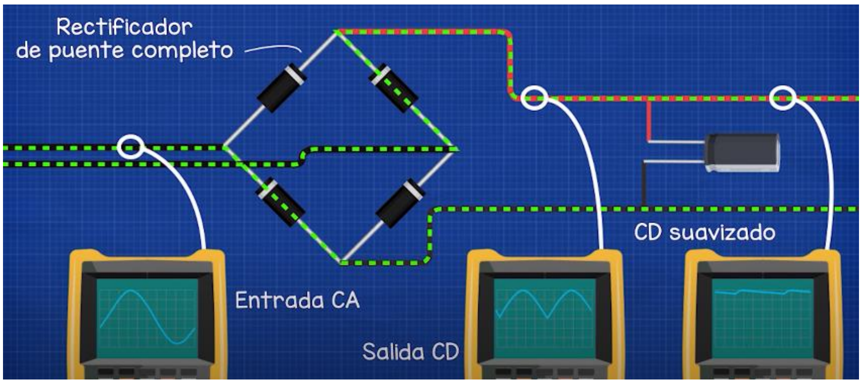


Figure 54. Rectifier

The inverter consists of a number of electronic switches known as IGBTs. The opening and closing of these switches is controlled by a controller.

These can be opened and closed quickly to control the flow of electricity. By controlling the path the electricity takes and how long it flows on the different paths, we can produce AC electricity from the DC source.

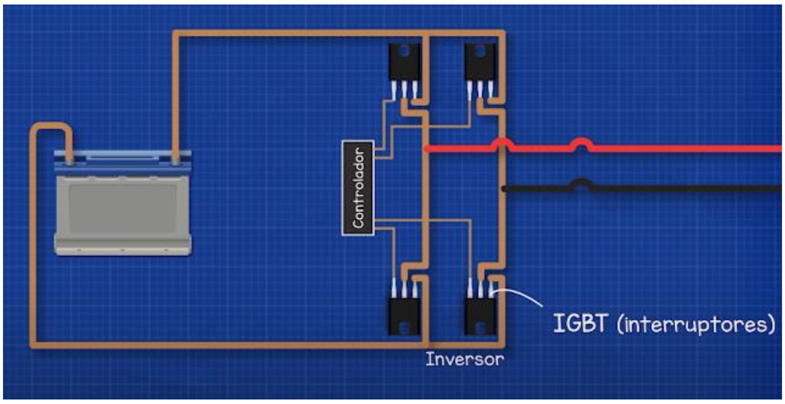


Figure 55. IGBT

To improve this behavior, we use the controller to open and close the switch several times per cycle in a pattern of pulses at different speeds and durations to change the waveform. This is known as pulse width modulation.

The cycle is divided into multiple smaller segments. Each segment has a total amount of current that could flow but by quickly pressing the switches we control the amount of flow that occurs through each segment. This will result in an average current per segment that we must increase and decrease, thus giving us a wave. The more segments we have, the closer to imitating a uniform wave it will be.

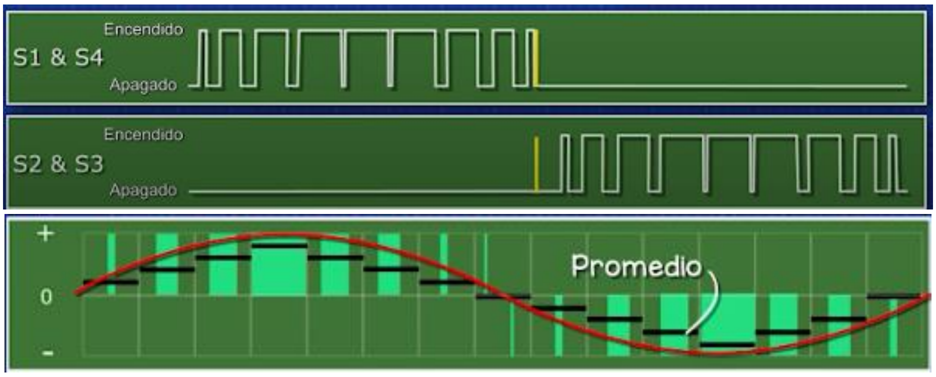


Figure 56. Impulses to switch the switches and generate the signal
Figure 57. Generation of the sein signal

3.3. Batteries

Batteries are formed by individual electrochemical cells where reversible REDOX reactions occurs in charge and discharge processes. The most important thing we have to keep in mind when choosing batteries is the number of hours that they have to be able to power our installation. Knowing how much our installation consumes and how many hours the batteries have to endure to cover our needs, we calculate the energy that they should accumulate in the worst case and, with that, we choose the number of batteries necessary.

It is not enough to just look at the storage capacity, we must also know the depth of discharge, since many types of batteries cannot be fully discharged without damage. This means that, if we do not want our batteries to be damaged or considerably reduce their useful life, it is advisable that they never discharge below a certain percentage that will depend on the battery we have chosen.

Figure 58. Batteries

But this is not all, we also have to take into account how quickly these are loaded and unloaded. The charge or discharge capacity of a battery will be somewhat higher the slower we charge or discharge it. If we force the battery to charge too fast, we could even burn it.

This battery charging capacity is usually measured in Ah. Knowing the number of discharge hours, the manufacturer tells us the current with which it will work. With this value we calculate the number of batteries connected in parallel, since all the current intensity that comes from the photovoltaic field must be distributed through the battery lines in parallel without exceeding the maximum current intensity with which we want our batteries to work.

To calculate the number of batteries in series, we will add the voltage of each battery in the series knowing that we cannot exceed the voltage value provided by our photovoltaic field because, otherwise, the batteries will not be charged.

4. Specifications and regulations to be applied to the system

4.1. Introduction

The purpose of this section is to establish the minimum technical conditions that the photovoltaic installation connected to the grid that would be projected must meet, to ensure its quality and correct execution.

The scope of application of this technical specification (PCT) extends to all the mechanical, electrical and electronic elements that make up the installation, whose specifications and compliance with regulations have been set out in section 2. Report.

This PCT has been developed based on the specifications included in the IDAE document: Photovoltaic Solar Energy Installations, Technical Specifications for Grid Connected Installations, July 2011.

4.2. Generalities

All equipment (modules and inverters) and materials (conductors, boxes and connection cabinets) must, as a general rule, ensure a minimum degree of class I electrical insulation, with the exception of DC wiring which must have class II insulation. and a minimum degree of protection of IP65 (dust tightness and protection against jets of water).

The installation will incorporate the necessary elements to guarantee the quality of the electricity supply; it will not cause breakdowns, decreases in security conditions or alterations in the network greater than those allowed by regulations; and its operation may not create conditions that endanger the safety of the network maintenance and operation personnel.

Materials located outdoors will be protected against environmental agents: solar radiation and humidity.

All the necessary security and protection elements for people and devices of the photovoltaic installation itself will be included, to ensure compliance with current legislation.

The memory will include the technical descriptions of all installed components.

For safety and operation reasons, all the indicators and labels of the equipment will be in Spanish.

4.3. Photovoltaic generator systems

The photovoltaic modules must incorporate the CE marking, in addition to complying with the UNE-EN 61730 and UNE-EN 50380 standards. Additionally, as they are crystalline silicon photovoltaic modules, they must meet the UNE-EN 61215 standard.

The photovoltaic module will have the model and name or logo of the manufacturer clearly visible. Likewise, it will carry an individual identification or serial number that allows the date of manufacture to be identified.

The modules used must comply with the following technical characteristics:

- They must have bypass diodes to avoid possible breakdowns of the cells and their circuits due to partial shading and will have a degree of protection IP65

- The side frames will be made of aluminum or stainless Steel

- The maximum power and actual short-circuit current referred to standard conditions must be within the margin of ± 3% of the nominal catalog values, to be considered acceptable.

- Any module with manufacturing defects such as breaks or stains, misalignment of the cells or bubbles in the encapsulant will be rejected.

High cell efficiency will be desirable.

The generator frame will be grounded.

For safety reasons and to facilitate the maintenance and repair of the generator, the necessary elements will be installed for the disconnection, independently and in both terminals, of all the branches of the generator.

The photovoltaic modules will be guaranteed by the manufacturer for a minimum period of 10 years and will have a performance guarantee for 25 years.

4.4. Support structure

In addition to complying with the technical specifications that are set out below, the structure will comply with the requirements of the CTE.

The module support structure must withstand, with the modules installed, wind and snow overloads, in accordance with the provisions of the CTE and other applicable regulations.

The attachment points for the module will be sufficient in number, so that no bending will occur in the modules greater than those allowed by the manufacturer and the approved methods.

The design of the structure will be made for the orientation and the angle of inclination specified in the memory for the photovoltaic generator, taking into account the ease of assembly and disassembly, and the possible need to replace elements.

The structure will be superficially protected against the action of environmental agents. The holes in the structure will be made before galvanizing and protecting it.

The screws will be made of stainless steel. If the structure is galvanized, galvanized screws will be accepted, except for the fastening of the modules to it, which will be made of stainless steel.

The module clamping stops and the structure itself will not cast a shadow on the modules.

In the case of roof-integrated installations, the design of the structure and the tightness between modules will be adjusted to current building requirements.

The necessary support structures will be provided to mount the modules, complying with what is specified in point 4.1.2 of the IDAE PCT on shadows, that is, not to exceed 10% of losses due to shadows.

The support structure will be calculated according to current regulations (the CTE) to withstand extreme loads due to adverse weather factors, such as wind, snow, etc.

4.5. Inverter

It will be the right type for connection to the electricity grid, with a variable input power so that it is capable of extracting at all times the maximum potential that the photovoltaic generator can provide throughout each day.

The basic characteristics of the investor will be the following:

- Working principle: current source

- Auto switched

- Automatic monitoring of the generator's maximum power point

- Will not work in island or isolated mode

The characterization of the investor must be done according to the following standards:

- UNE-EN 60293: Components for accumulation, conversion and energy management of photovoltaic systems. Design qualification and environmental testing

- UNE-EN 61683: Photovoltaic systems. Power conditioners. Procedure for performance measurement.

- IEC 62116. Testing procedure of islanding prevention measures for utility interactive photovoltaic inverters.

The inverter will comply with the community directives on Electrical Safety and Electromagnetic Compatibility, incorporating protections against:

- AC short circuits

- Mains voltage out of range

- Network frequency out of range

- Overvoltages, by varistors or similar

- Disturbances present in the network such as micro-cuts, pulses, cycle defects, absence and return of the network, etc.

The inverter will have the necessary signals for its correct operation, and will incorporate the essential automatic controls that ensure its adequate supervision and handling.

The inverter shall incorporate at least the following manual controls:

- General on and off of the inverter

- Connection and disconnection of the inverter to the AC interface

The electrical characteristics of the inverter will be the following:

- The inverter will continue to deliver power to the grid continuously under solar irradiance conditions 10% higher than EMC (standard measurement conditions 1000 W / m2 and 25 ºC). It will also withstand peaks of 30% higher than EMF for periods of up to 10 seconds.

- The power efficiency of the inverter (Psalida / Pentrada) for an output power in AC equal to 50% and 100% of the nominal power, will be at least 92% and 94% respectively.

- The self-consumption of the equipment in "stand-by" (no-load losses) or night mode must be less than 2% of its nominal output power.

- The power factor of the generated power must be greater than 0.95, between 25% and 100% of the nominal power.

- From powers greater than 10% of its nominal power, the inverter must inject into the grid.

The inverter will have a minimum degree of protection IP30 for inverters inside buildings and accessible places.

The inverter will be guaranteed for operation in the following environmental conditions: between 0ºC and 40ºC of temperature and between 0% and 85% of relative humidity.

The inverter must guarantee galvanic isolation between the photovoltaic installation and the distribution network to which it is connected.

The inverter will be guaranteed by the manufacturer for a minimum period of 3 years.

4.6. Cabling

The positives and negatives of each group of modules will be conducted separately and protected according to current regulations.

The conductors will be made of copper and will have the appropriate section to avoid voltage drops and overheating. Specifically, for any working condition, the conductors must have a sufficient section so that the voltage drop is less than 1.5%.

The cable must have the necessary length so as not to generate efforts in the various elements or the possibility of being hooked by the normal traffic of people.

All DC wiring will be double insulated and suitable for use outdoors, in the air or buried, in accordance with the UNE 21123 standard.

4.7. Network connection

The photovoltaic installation, will comply with the provisions of Royal Decree 1663/2000 (articles 8 and 9) on the connection of photovoltaic installations connected to the low voltage network.

4.8. Measures

The photovoltaic installation will comply with RD 1110/2007, of August 24, which approves the Unified Regulation of measurement points in the electrical system.

It will also comply with the provisions of RD 900/2015 regarding the specifications of the measurement equipment.

4.9. Protections

The installation will comply with the provisions of RD 1663/2000 (article 11) on protections in photovoltaic installations connected to the low voltage network.

In connections to the three-phase network, the protections for the interconnection of maximum and minimum frequency (51 Hz and 49 Hz respectively) and of maximum and minimum voltage (1.1Un and 0.85Um respectively) will be for each phase.

4.10. Grounding

The photovoltaic installation will comply with the provisions of RD 1663/200 (article 12) on grounding conditions in photovoltaic installations connected to the low voltage network.

All the masses of the photovoltaic installation, both DC and AC, will be connected to a single ground, which will be independent of the neutral of the distribution company, according to the REBT.

4.11. Harmonics and electromagnetic compatibility

The photovoltaic installation should comply with the provisions of RD 1663/2000 (article 13) on harmonics and electromagnetic compatibility in photovoltaic installations connected to the low voltage network.

4.12. Security measures

The photovoltaic plant should be equipped with a protection system that guarantees its disconnection in the event of a network failure or internal failures in the installation of the plant itself, so that they do not disturb the correct operation of the networks to which they are connected, both in normal operation as well as during the incident.

The photovoltaic plant must avoid unintended operation on an island with part of the distribution network, in the event of disconnection from the general network. The anti-island protection must detect the disconnection of the network in a time according to the protection criteria of the distribution network to which it is connected, or in the maximum time set by the regulations or corresponding technical specifications. The system used must work correctly in parallel with other power plants with the same or different technology, and feeding the usual loads in the network, such as motors.

The photovoltaic plant must be equipped with the necessary means to admit a reclosing of the distribution network without causing damage. Likewise, they will not produce overvoltages that can cause damage to other equipment, even in the transitory passage to the island, with low or no load loads. Likewise, the installed equipment must comply with the emission limits of disturbances indicated in the national and international standards of electromagnetic compatibility.

4.13. Applicable regulations

This project should include the characteristics of the materials, the calculations that justify their use and the way in which the works to be carried out are carried out, thereby complying with the following provisions:

National legislation

National Standardization. UNE standards

Technical distribution manual. IBERDROLA ELECTRICITY DISTRIBUTION

Technical building code (CTE). Royal Decree 314/2006, of March 17, approving the Technical Building Code.

Royal Decree 1699/2011, of November 18, which regulates the connection to the grid of small power production facilities

Royal Decree 842/2002, of August 2, which approves the electrotechnical regulation for low voltage

Law 24/2013, of December 26, on the Electricity Sector

Royal Decree 413/2014, of June 6, which regulates the activity of electricity production from renewable energy sources, cogeneration and waste

RD 900/2015, of October 9, which regulates the administrative, technical and economic conditions of the modes of electricity supply with self-consumption and production with self-consumption

5. Photovoltaic modules integration analysis

5.1. Inclination and orientation of the panels

a) Acimuth orientation

The best azimuth for Northern Hemosphere is South, that is 0º, the plate faces directly noon. This is true most of the time, but it might not be the best option for a specific installation. It will depend on the use that is going to be given to the solar panel.

We have the example of panels whose main function will be to heat the interior of a house. In this case, the best orientation is not going to be the south as we need more energy in the morning after the house has been cooling all night. Knowing this, perhaps it would be more interesting to place it a little eastward.

On the other hand, if the only thing that interests us is to obtain the greatest contribution of energy, this south orientation would be the most appropriate.

b) Panel inclination

The elevation of the plate again depends on the use that will be given to the installation.

If the installation is isolated, surely the best option is to optimize the installation for the worst month of the year because, if the panels are sufficient for the month of the year with less light, the rest of the months we will not have any problem.

If it is connected to the grid, we do not care having to buy energy some month. So we will place our solar panels so that they produce more throughout the year. This fact is justified even more if the installation includes batteries.

We also have to be very clear if we are willing to change the inclination of the plates from time to time. If it seems good to us to make this change, an advisable model would be to place a structure with two positions, one for summer and one for winter.

Figure 59. Fixed structure for solar panels with two positions

Source: https://atad.vn (05/05)

The IDAE, Institute for Energy Diversification and Saving, suggests that the best elevation in winter is the latitude of the place plus ten degrees, while in summer it would be the latitude of the place minus twenty degrees. The elevation for a plate that is going to be fixed all year round is latitude minus ten degrees.

c) Panels over the roof

If what we are considering is the installation on a roof, we have to assess how much the structure costs and how much money the panels cost. Lately the prices of the panels have dropped so much that it is possible that it is more convenient to save the structure and compensate the loss of power due to a bad inclination with better panels or simply more of them.

Figure 60. Panels over a roof

Source: https://www.solarcas.es (05/05)

If the available space is reduced compared to the power we want to install, we may be more obliged to orient them well.

5.2. Losses due to non optimal orientation and inclination

For this we need a method that tells us the losses of solar radiation due to a non-optimal orientation. We use the FI, Irradiation Factor, as propodes at mentioned IDAE PCT installation guide.

This is calculated by doing 1-losses.

$$FI = 1 - P_{OI}$$

Where P_{OI} are the losses due to inclination and non-optimal orientation.

- For 15º< β<90º

$$P_{OI} = 1,2 * 10^{-4}(\beta - \beta_{opt})^2 + 3,5 * 10^{-5} * \alpha^2$$

- For β <15º

$$P_{OI} = 1,2 * 10^{-4}(\beta - \beta_{opt})^2$$

α = Azimuth of the panel in sexagesimal degrees
β = Angle of inclination of the panel in sexagesimal degrees
βopt = Optimum angle of inclination of the panel in sexagesimal degrees

$$P_{OI} = 1,2 * 10^{-4}(\beta - \beta_{opt})^2 + 3,5 * 10^{-5} * \alpha^2$$

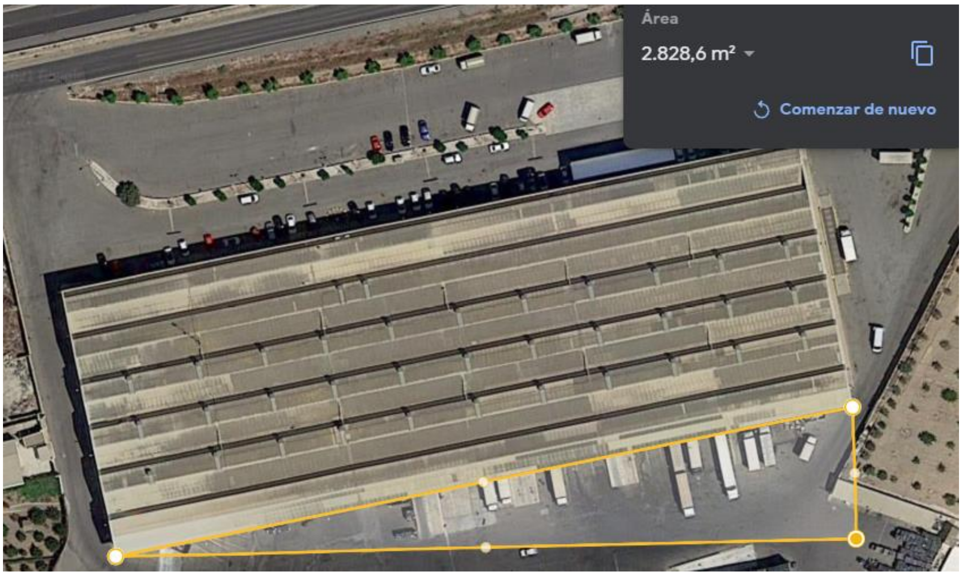


Image 11. Azimuth angle fo the auction centre

Knowing the hypotenuse (180 meters) and the area of the right triangle, we can find by trigonometry the azimuth angle with which we will collapse our plates. In this case it would be an azimuth of 10.2º.

α = 10.2º
β = 30º

Calculating the optimal elevation.

- Two positions:
  - Winter:

$$\beta opt \ = \ latitude + 10º = 36'47'' + 10º = 46.47º$$

  - Summer:

$$\beta opt \ = \ latitude - 20º = 36'47'' - 20º = 16.47º$$

- Fixed elevation:

$$\beta opt \ = \ latitude - 10º = 36'47'' - 10º = 26.47º$$

Now we will use the formula to calculate the losses due to a non perfect elevation and azimuth

$$P_{OI} = 1.2 * 10^{-4}(\beta - \beta_{opt})^2 + 3.5 * 10^{-5} * \alpha^2$$

- Two positions:
  - Winter:

$$P_{OI} = 1.2 * 10^{-4}(30 - 46.5)^2 + 3.5 * 10^{-5} * 10^2$$

$$P_{OI} = 0.0015$$

  - Summer:

$$P_{OI} = 1.2 * 10^{-4}(30 - 16.5)^2 + 3.5 * 10^{-5} * 10^2$$

$$P_{OI} = 0.0051$$

- Fixed elevation:

$$P_{OI} = 1.2 * 10^{-4}(30 - 26.5)^2 + 3.5 * 10^{-5} * 10^2$$

$$P_{OI} = 0.0039$$

Once we have calculated the losses we can get to know the Irradiation Factor like this:

$$FI = 1 - P_{OI}$$

- Winter:

$$P_{OI} = 0.0015$$

$$FI = 1 - 0.0015 = 0.9985$$

- Summer:

$$P_{OI} = 0.0051$$

$$FI = 1 - 0.0051 = 0.9949$$

- Fixed elevation:

$$FI = 1 - 0.0039 = 0.9961$$

5.3. Losses due to shadows and optimal distance between panels

We are then going to calculate the percentage that the panel would produce without shadows.

The panels not only work with the light that reaches them directly, they also receive light both scattered and reflected from other nearby objects. So what we are calculating is the percentage of energy lost throughout the year.

Getting the obstacle profile is simply going to the place where you want to place the solar panels and looking for objects that can cast shadows. In winter, the shadows are longer than in summer, so we have to take this factor into account.

Once the objects that obstruct the solar incidence have been identified, we have to measure two angles, both the azimuth angle and the elevation angle of the object that is going to shade, measured from the place where the plate is located, taking only the values for the corners of the object in question.

Once these data have been obtained, we use the following diagram that is used for the Iberian Peninsula and has been obtained from the IDAE website.

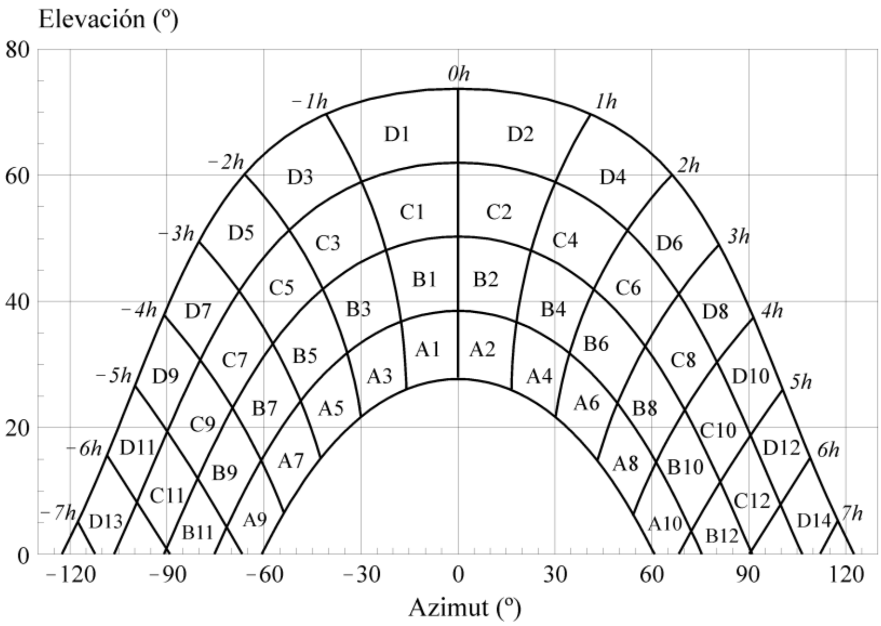


Figure 61. Sun's incidence diagrame

Source: https://www.idae.es/ (18/09)

The diagram is accompanied by a series of tables with numerical values. To know which one we should go to, we have to know the elevation and azimuth of the solar panels.

The angle α corresponds to the azimuth of our installation and the angle β is the elevation. Hence, we took the table with a better aproximation to our case.

Tabla V-1

$\beta = 35°$ $\alpha = 0°$	A	B	C	D
13	0,00	0,00	0,00	0,03
11	0,00	0,01	0,12	0,44
9	0,13	0,41	0,62	1,49
7	1,00	0,95	1,27	2,76
5	1,84	1,50	1,83	3,87
3	2,70	1,88	2,21	4,67
1	3,15	2,12	2,43	5,04
2	3,17	2,12	2,33	4,99
4	2,70	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	0,00	0,02	0,10	0,40
14	0,00	0,00	0,00	0,02

Table 13. Table of acimuth and elevation

Source: https://www.idae.es/ (18/09)

To use this table, we go back to the previous diagram and look at the grid. Within each box we have a letter accompanied by a number that letter refers to a specific value in the table. We are going to mark the values in the table on which our object casts its shadow.

Once we have marked the values of the table that we needed, we proceed to carry out the last step, which basically consists of adding all the values marked in the reference table by making a small modification. As some values are not completely covered by the shadow, we must make a weighted sum according to the amount of square covered by the shadow. Once this is done, the addition is done. And we obtain the percentage of energy loss throughout the year due to the influence of the shade. It would look like this:

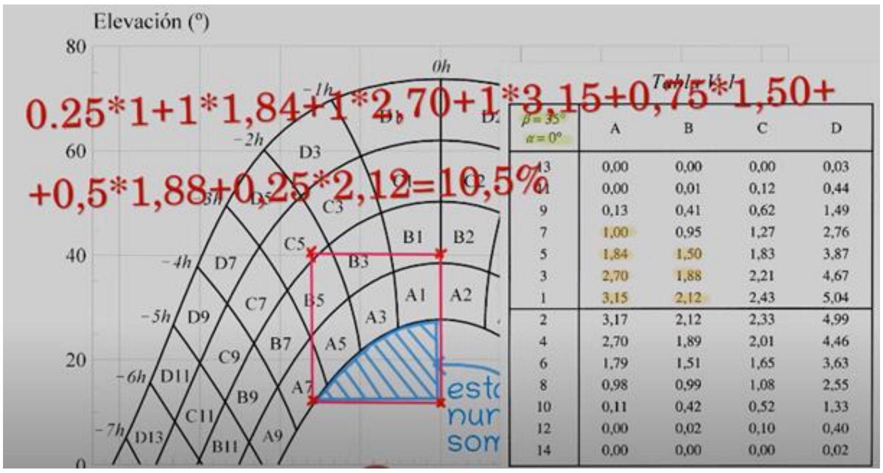


Figure 62. Losses due to shadows

Source: https://www.youtube.com/watch?v=JtetvZdDaRs&t=325s&ab_channel=Ponuningenieroentuvida (18/09)

In addition to the above, IDEA PCT guide stablish a minum distance between modules rows to avoid shadow at least 2 hours around noon along al the year the following procedure:

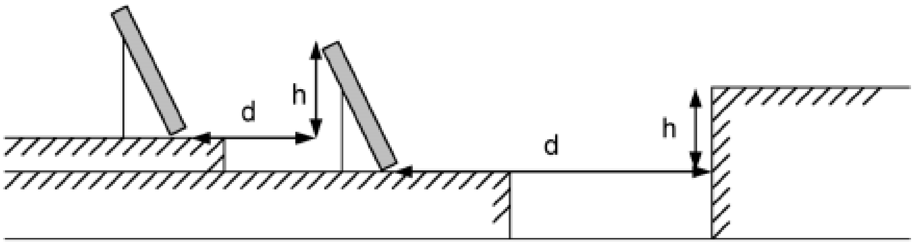


Figure 63. Scheme of distance between panels

Source: https://www.idae.es/ (18/09)

First we calculate the factor k by dividing the tangent of the angle resulting from subtracting the latitude of the place from 61º from the place where we are. We use this k value later to find the row spacing.

$$k = \frac{1}{\tan(61 - latitude)}$$

The separation of the panels comes from multiplying this factor K that we have just calculated by the height (h) of the object that casts the shadow. In this case, the object that casts the shadow is the panel in front of us. The value of k is dimensionless.

$$d = k * h$$

The unit of measurement that we put for the height is the same that we get in the calculation for the separation. If we put the height of the object in meters in the formula, the separation will come out in meters.

What this formula intends is to guarantee at least four hours without shade around noon on the winter solstice, that is, on the worst day of the year we would have at least the best four hours of the day without shade at least. We check its veracity by means of simple calculations, assuming that our latitude is 36.47º and the elevation of the plate is 3.17 meters.

In our particular case, the value of k would be calculated as:

$$k = \frac{1}{\tan(61 - 36.47)} = 2.19$$

Knowing k value, we can determine the distance we should have between our panles as:

$$d = k * h = 2.19 * 3.17 = 6.95m$$

We calculate the beta value by trigonometry that corresponds to the elevation of the shading plate with respect to the one that is covered, and an angle of 19º results.

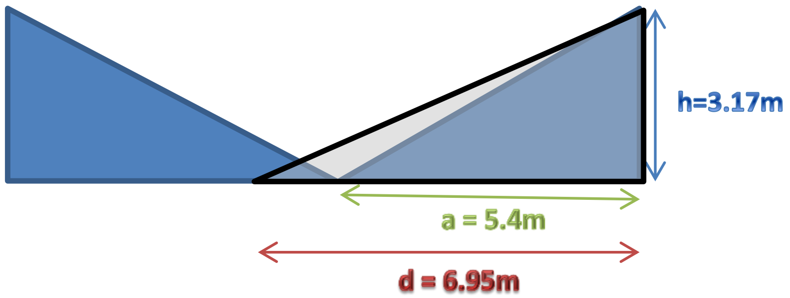


Figure 64. Scheme of distance between panels with on object 3,17 meters tall

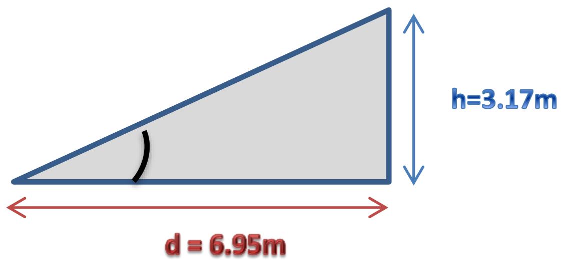


Figure 65. Scheme of distance between panels with on object 3,17 meters tall

$$\tan(\beta) = \frac{3.17}{6.95} = 24.51º$$

This angle means the panels should have that elevation or less to be able to have at least 4 four hours of solar irradiation in the day with less hours of winter, in other words the 21st of December. With this elevation we go to the solar chart of the place where the installation is located. In this case it would be a solar chart for a latitude of 36.47º. We then mark a horizontal line for the elevation of the panel of 24.51º, which is what has come out of us.

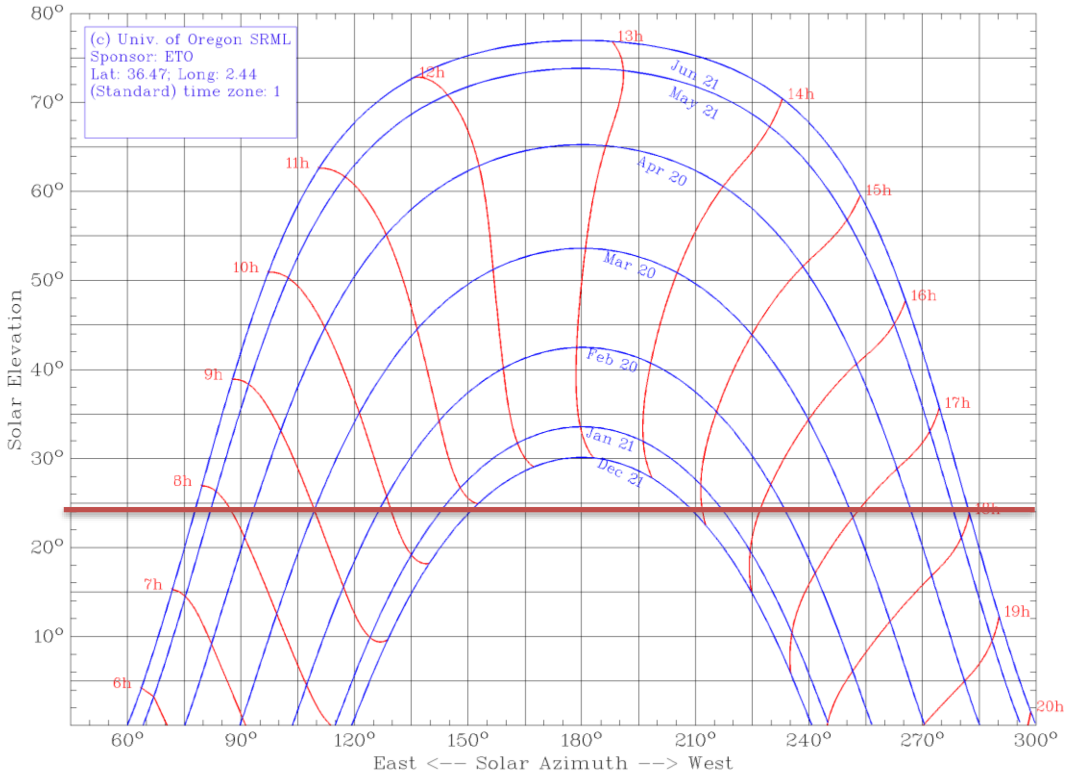


Figure 66. Losses due to shadows (winter session)

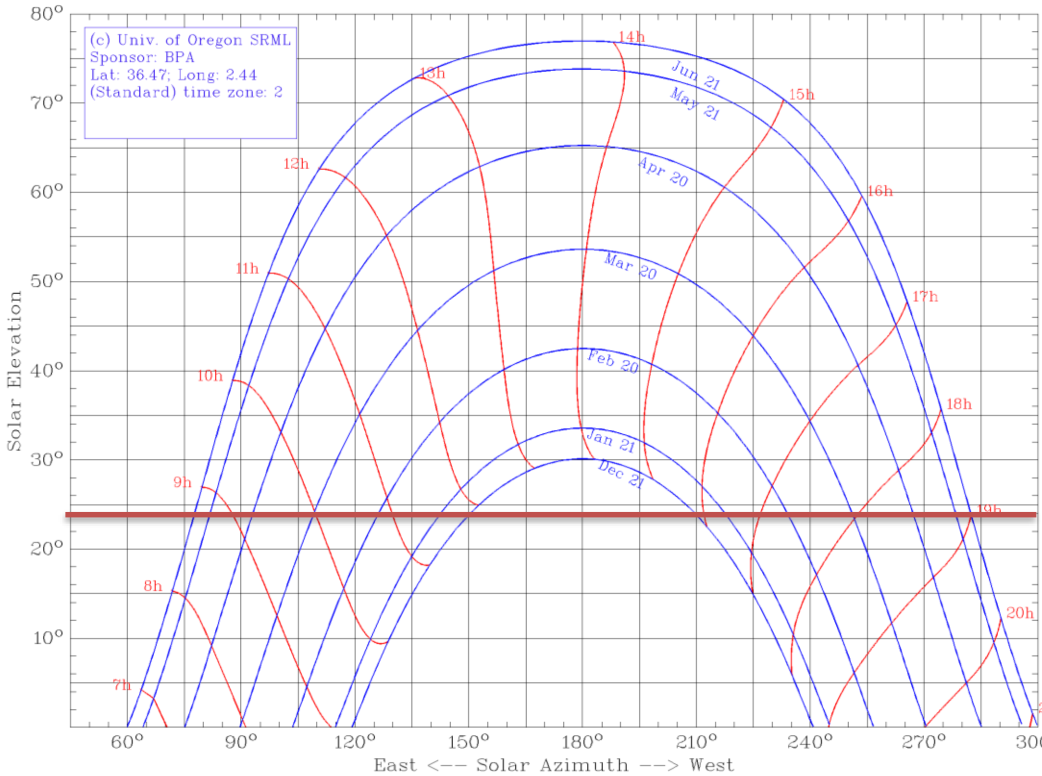


Figure 67. Losses due to shadows (Summer session)

The lines mark the position of the sun in the sky from sunrise to sunset, we have different lines to represent the different days of the year. The lower line corresponds to the winter solstice, the day with the least light of the year, while the upper line corresponds to the summer solstice, the day with the lightest of the year. On the other hand, the red lines mark the time of day when the sun is in each point of the sky.

As long as the sun is below that line that we have marked, the panels will not generate energy due to the panels in front while, when the sun is above that line, the panels will be exposed to the sun.

This case will be valid to calculate a fixed structure in which we will mount our modules. For our scenario, we will use the available roof and inclination the we already have to mount our system on it in order to reduce costs and make the structure more robust since the losses due to a non optimal orientation are minimal. So with that being said, we will calculate in the next section the losses we have in our warehouse due to the shape of the roof.

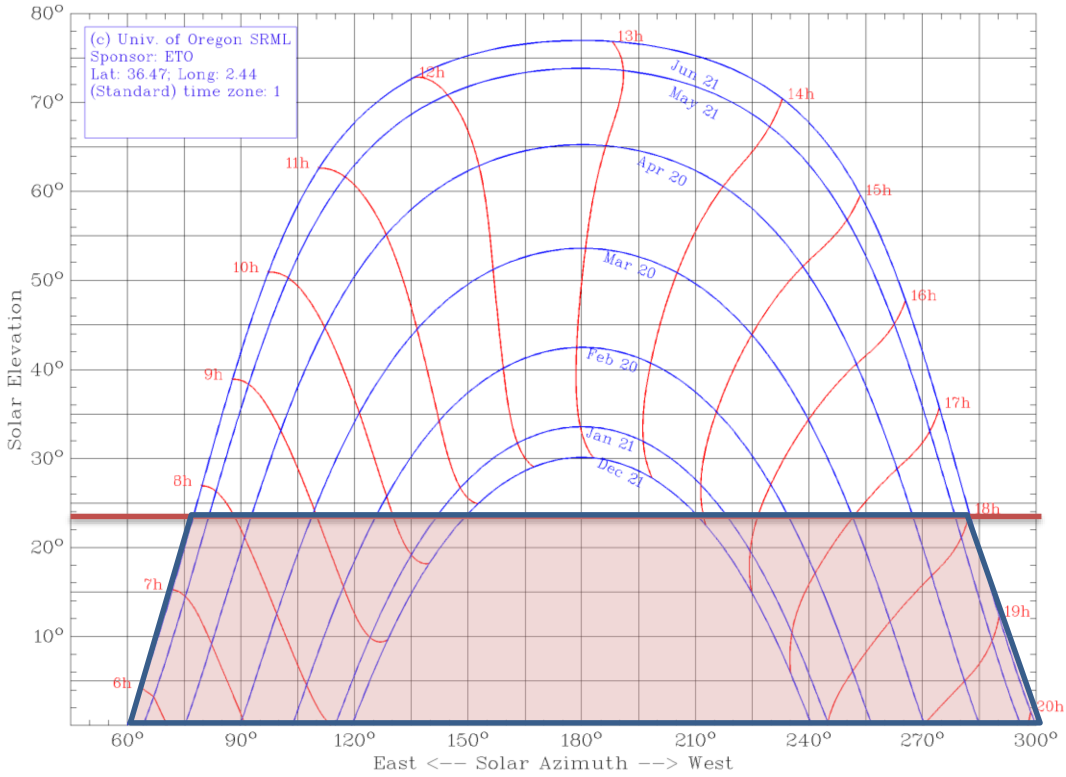


Figure 68. Permanent losses due shadow (Winter season)

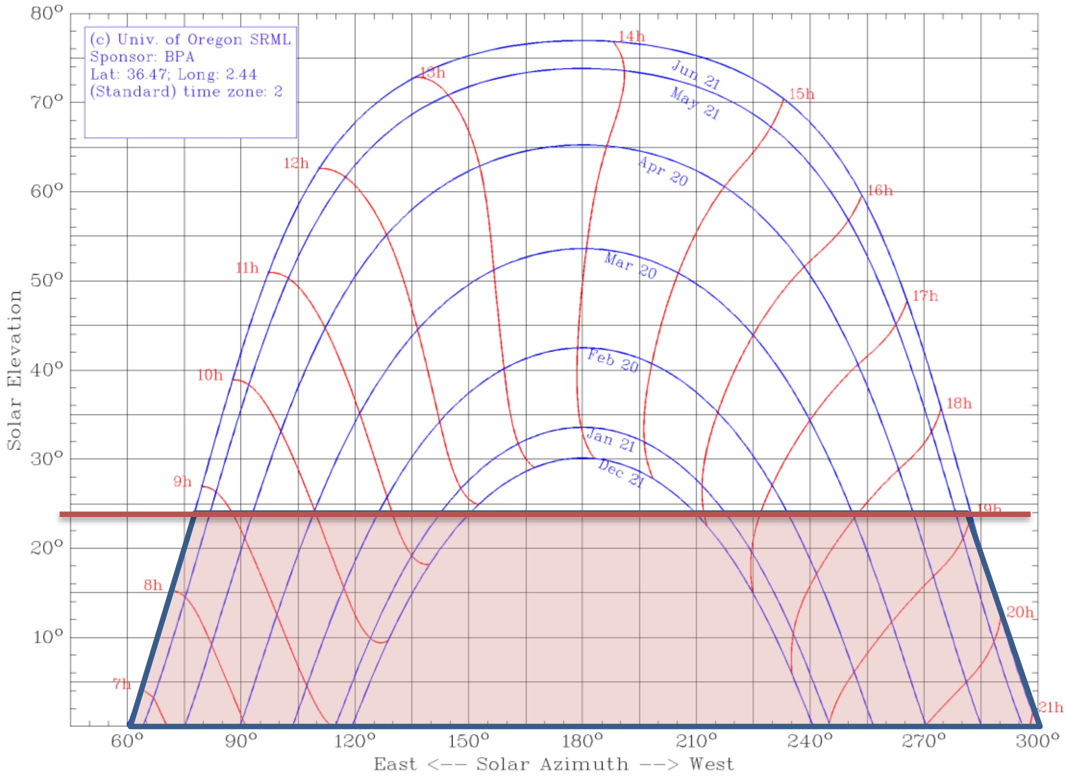


Figure 69. Permanent losses due shadow (Summer season)

To check that the calculations are correct, we look at the lower blue line that refers to the winter solstice and mark the points where this line and the one we have previously drawn corresponding to our latitude intersect. These two points are exactly two hours before and after noon as we had forseen in the introduction of the chapter for this formula.

The energy that we lose per year due to these shadows is not as much as it might seem because, the hours in which the panels are shaded, are precisely those in which the sunlight falls more steeply, crosses more kilometers of atmosphere and, therefore, arrives more weakened.

We will then use the shadows method already seen above to calculate the separation losses between panels.

On the diagram, we mark the shadows. In this case, everything that is below the horizontal line of 19 degrees.

Shade losses change depending on the inclination at which we place the panel. We will consider that the panels are placed with an elevation angle of 30º, which is usually optimal for panels on a fixed structure placed at a latitude of 36º5'' and is the example we are using. So, we use the table for azimuth of 0º and elevation of 35º which is the table that most closely resembles our data.

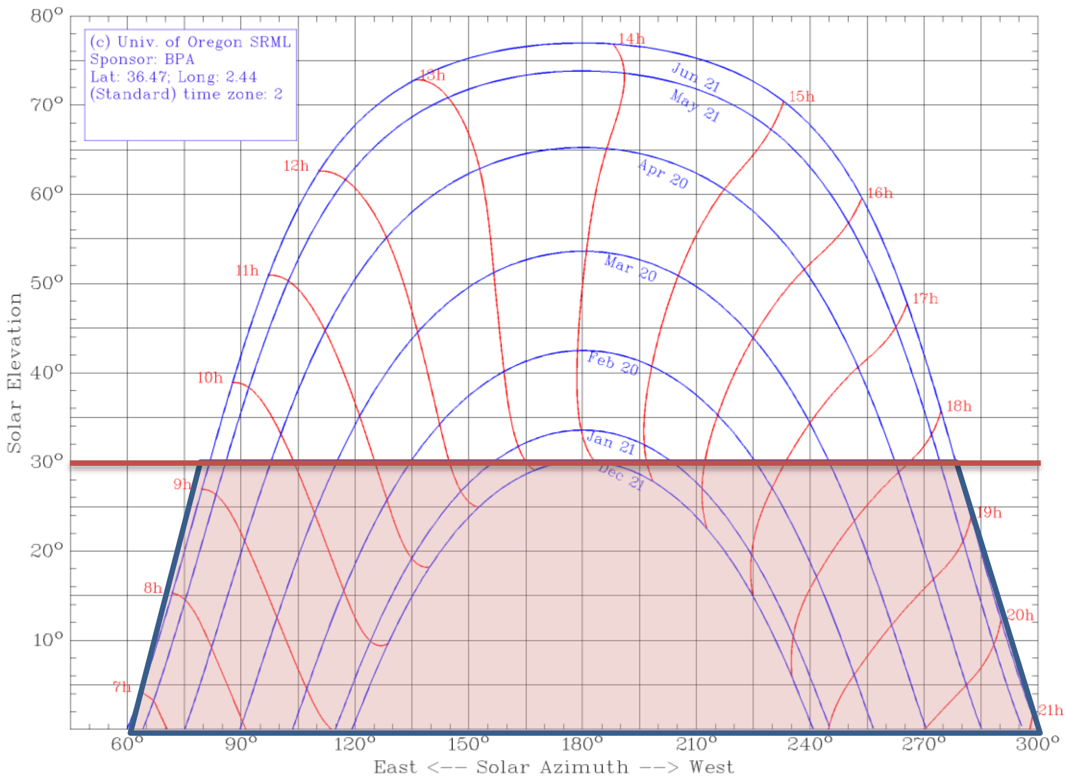


Figure 70. Permanent losses due shadow (Summer season)

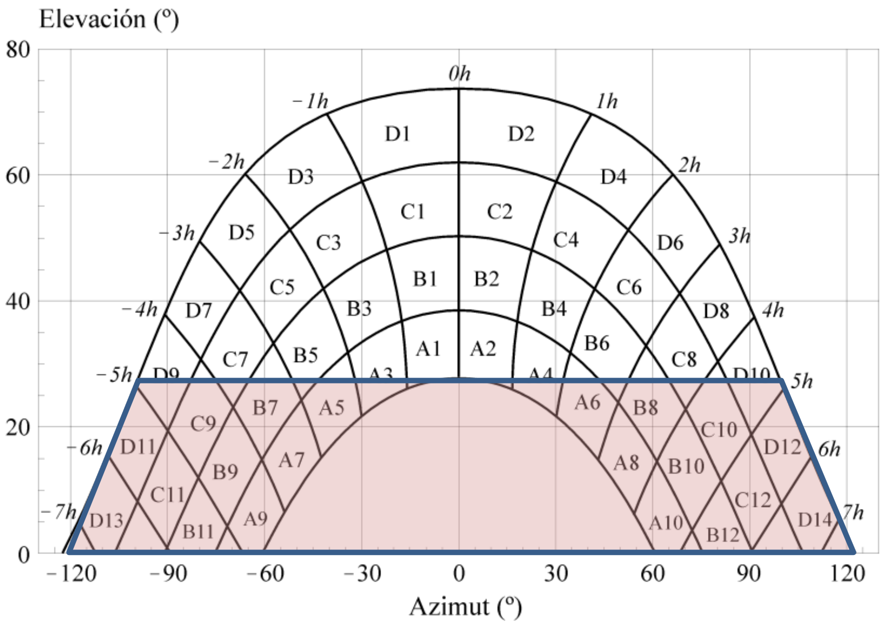


Figure 71. Permanent losses due to shadow

Tabla V-1

$\beta = 35°$ $\alpha = 0°$	A	B	C	D
13	0,00	0,00	0,00	0,03
11	0,00	0,01	0,12	0,44
9	0,13	0,41	0,62	1,49
7	1,00	0,95	1,27	2,76
5	1,84	1,50	1,83	3,87
3	2,70	1,88	2,21	4,67
1	3,15	2,12	2,43	5,04
2	3,17	2,12	2,33	4,99
4	2,70	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	0,00	0,02	0,10	0,40
14	0,00	0,00	0,00	0,02

Table 14. Table of acimuth and elevation

$$\big(D_{13} + D_{11} + (0.5 * D_9) + (0.5 * C_{13}) + C_{11} + C_9 + (0.75 * B_{11}) + B_9 + (0.75 * B_7) + A_9 + A_7 + (0.75 * A_5) + (0.25 * A_3)\big) + (D_{14} + D_{12} + (0.5 * D_{10}) + (0.5 * C_{14}) + C_{12} + C_{10} + (0.75 * B_{12}) + B_{10} + (0.75 * B_8) + A_{10} + A_8 + (0.75 * A_6) + (0.25 * A_4))$$

$$\big(0.03 + 0.44 + (0.5 * 1.49) + (0.5 * 0) + 0.12 + 0.62 + (0.75 * 0.01) + 0.41 + (0.75 * 0.95) + 0.13 + 1 + (0.75 * 1.84) + (0.25 * 2.7)\big) + (0.02 + 0{,}4 + (0{,}5 * 1{,}33) + (0.5 * 0) + 0.1 + 0.52 + (0.75 * 0.02) + 0.42 + (0.75 * 0.99) + 0.11 + 0.98 + (0.75 * 1.79) + (0.25 * 2.7)) = 12.26\%$$

We make the weighted sum for all the boxes of the diagram in which the shadow is projected with the values in the table, obtaining losses of around 12.26% for the row of panels located in the lower part of the south faces of the roof which would be the worst scenario.

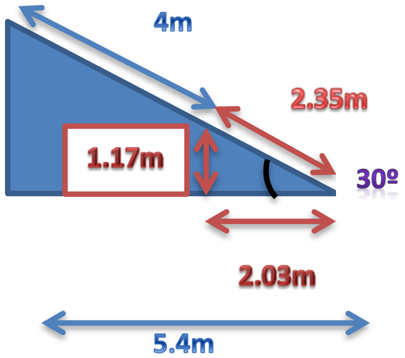


Figure 72. Southern face of the roof

Having in count that we the hypotenuse of the triangule measures 6.35 meters, we are able to install a total of three rows of solar panels since their standard height is 2 meters. So now we can calculate the losse due to shadows for the middle row.

First we rest 4 meters to the biggest hypotenuse in other to make room for the two upper rows of panels.

$$6.35m - 4m = 2.35m$$

The angle is still 30º so we just have to procced in the same way as we did before. Then the height of the second row of panels will be 1.17 meters.

The absolute height this time will be the rest between 3.17 meters minus 1.17 meters.

$$3.17m - 1.17m = 2m$$

We can also calculate the distance between the panel and the object that produces the shadow adding the 2.03 meters to the 5.4 meters of the length of the face in other to obtain the elevation angle of this object. So, the distance between the two of them is 7.43 meters.

Using trigonometry once again, we now are able to know the elevation angle of the element with respect to our second row of solar panels. That elevation is 15º.

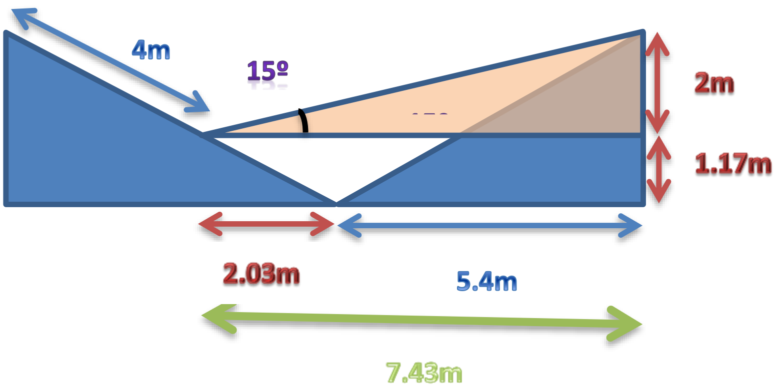


Figure 73. Southern face of the roof

Now that we know the elevation angle, we draw a line in the chart and apply the table as before to work out the losses this row of panels will have.

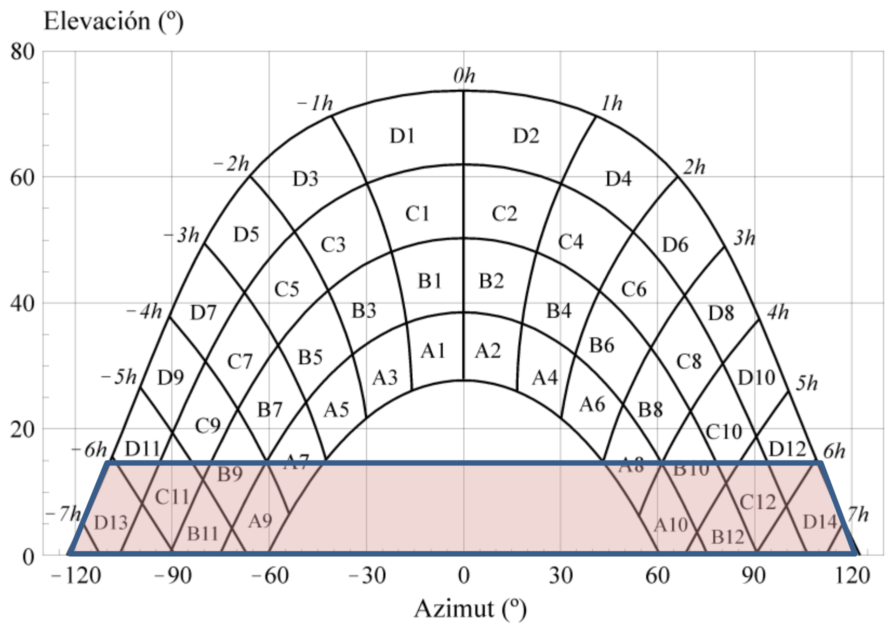


Figure 74. Southern face of the roof

Tabla V-1

$\beta = 35°$ $\alpha = 0°$	A	B	C	D
13	0,00	0,00	0,00	0,03
11	0,00	0,01	0,12	0,44
9	0,13	0,41	0,62	1,49
7	1,00	0,95	1,27	2,76
5	1,84	1,50	1,83	3,87
3	2,70	1,88	2,21	4,67
1	3,15	2,12	2,43	5,04
2	3,17	2,12	2,33	4,99
4	2,70	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	0,00	0,02	0,10	0,40
14	0,00	0,00	0,00	0,02

Table 15. Southern face of the roof

$$(D_{13} + (0.25 * D_{11}) + (0.25 * C_{13}) + (0.75 * C_{11}) + (0.5 * B_{11}) + (0.5 * B_9) + A_9 + (0.5 * A_7)) + (D_{14} + (0.25 * D_{12}) + (0.25 * C_{14}) + C_{12} + (0.75 * B_{12}) + (0.5 * B_{10}) + A_{10} + (0.5 * A_8))$$

$$(0.03 + (0.25 * 0.44) + (0.25 * 0) + (0.75 * 0.12) + (0.5 * 0.01) + (0.5 * 0.41) + 0.13 + (0.5 * 1)) + \left(0.02 + (0.25 * 0.4) + (0.25 * 0) + 0.1 + (0.75 * 0.02) + (0.5 * 0.42) + 0.11 + (0.5 * 0.98)\right) = 2.12\%$$

We made the weighted sum for all the boxes of the diagram in which the shadow is projected with the values in the table, obtaining losses of around 2.12% for the row of panels located in the middle possition of the south faces of the roof.

That means that the upper row won't have a shadow due to the structure of the roof.

6. PROPOSAL AND ANALYSIS OF PHOTOVOLTAIC INSTALLATIONS

6.1. Consumption analysis

In this section we are going to study the energy that the company needs. In order to achieve this, we will analyse all the data we posses from different perspectives.

a) Total Consumption

- Monthly

Firstly, we have to analyse how much energy the company needs each month. For that purpose, we have created a table in which we compare the total amount of the demand from January to December as we can see below.

Month	Total (KWh)
Enero	**49185**
Febrero	**40536**
Marzo	**43821**
Abril	**37909**
Mayo	**39004**
Junio	**45610**
Julio	**51751**
Agosto	**56992**
Septiembre	**65886**
Octubre	**67570**
Noviembre	**61531**
Diciembre	**73847**

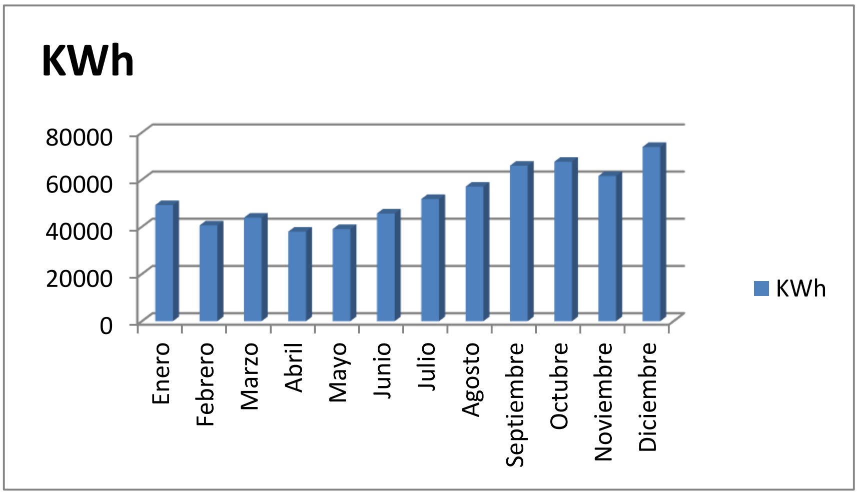


Table 16, Figure 75. Total KWh per month

The graph shows that the month in which the demand is lower correspond to April and may. On the other hand, the month with a higher consumption of energy are September, October and December. The average consumption per month is 52803.5KWh.

- Daily

We will include also a daily consumption along the year but we won't include the table because there are too many values.

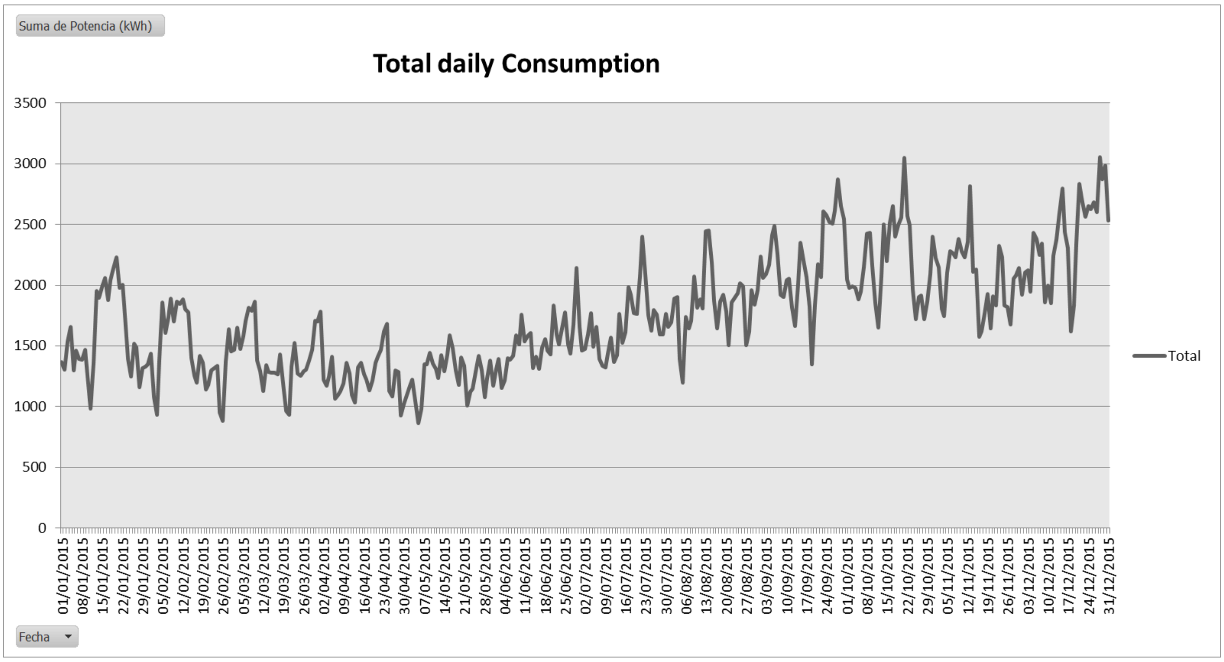


Figure 76. Total KWh per day

This graph is just a more detailed perspective of te previous one. The average total daily consumption is 1736KWh.

- Hour

Now we will check the consumption that the auction centre has along the year in the different hours of the day. This is relevant for our project because we need to size the number of panels and batteries if we finally decide to install them.

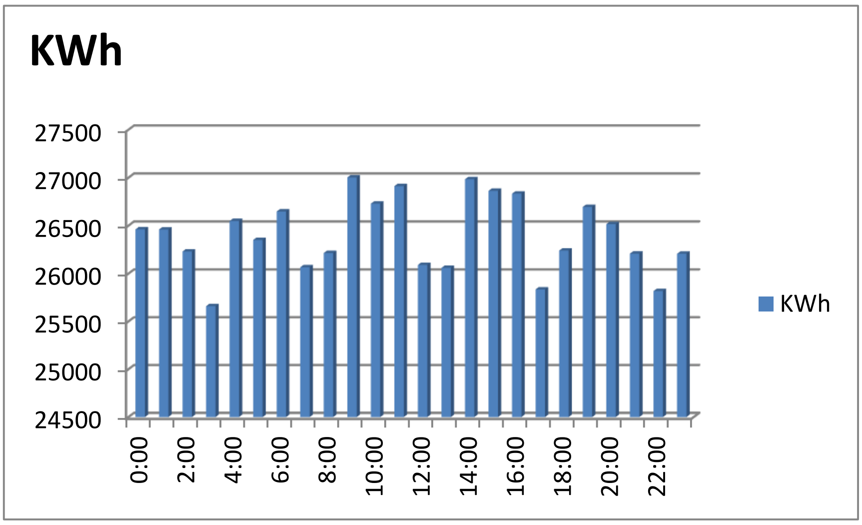


Table 17, Figure 77. Total KWh per hour

From this second graph we can conclude that the quantity of energy we need is more or less stable along the whole day. Probably the falls in consumption represent the changes of working shitfs.

b) Average consumption

- Daily

This graph shows how much energy is requiered on an average hour per day. This value along the whole year is 72KWh.

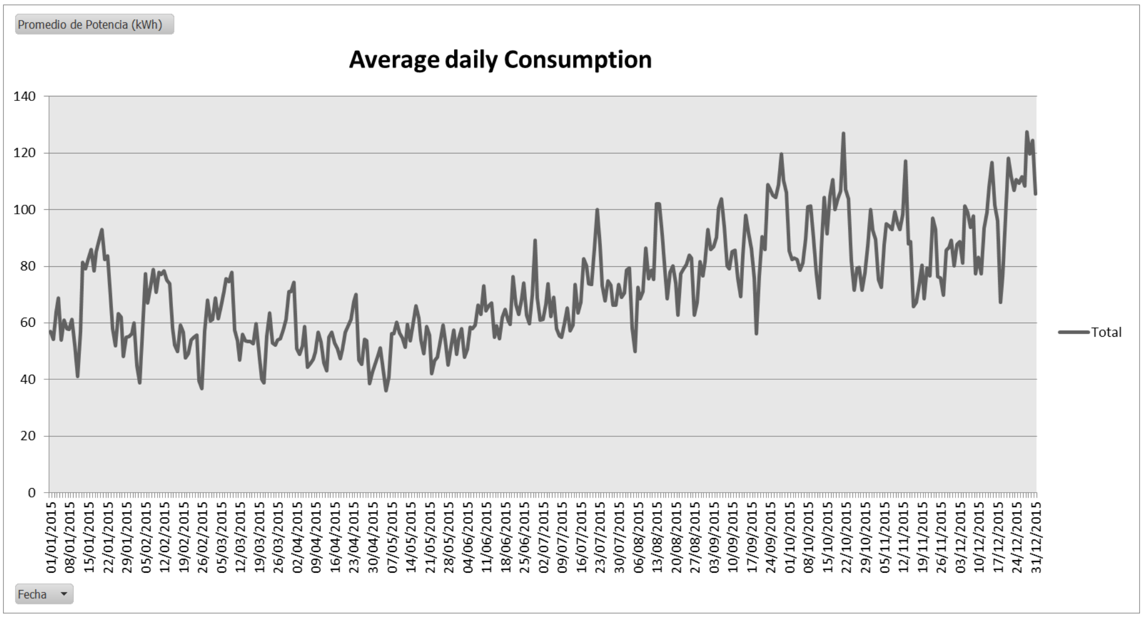


Figure 78. Average KWh per day

- Hour

This graph shows the average consumption for each hour along the year. Here we can see more clearly the hours that the action center demans more energy and the hours when it is fully working.

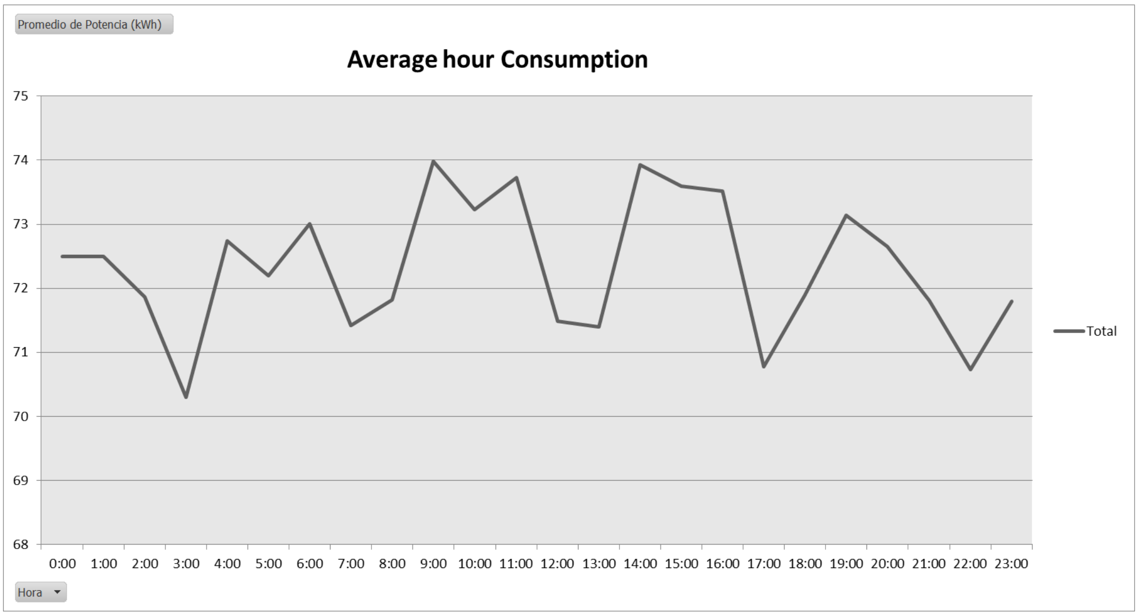


Figure 79. Average KWh per hour

c) Maximum consumption

In this section we are going to analyse the maximum consumption that the auction centre needs from different perspectives.

- Monthly

Now we will check the maximum electricity that the centre uses each month because it is obvious that we don´t produce nor consume the same amount of energy along the year.

Months	Max. (KWh)
Enero	157
Febrero	136
Marzo	138
Abril	104
Mayo	114
Junio	138
Julio	164
Agosto	178
Septiembre	178
Octubre	182
Noviembre	171
Diciembre	182

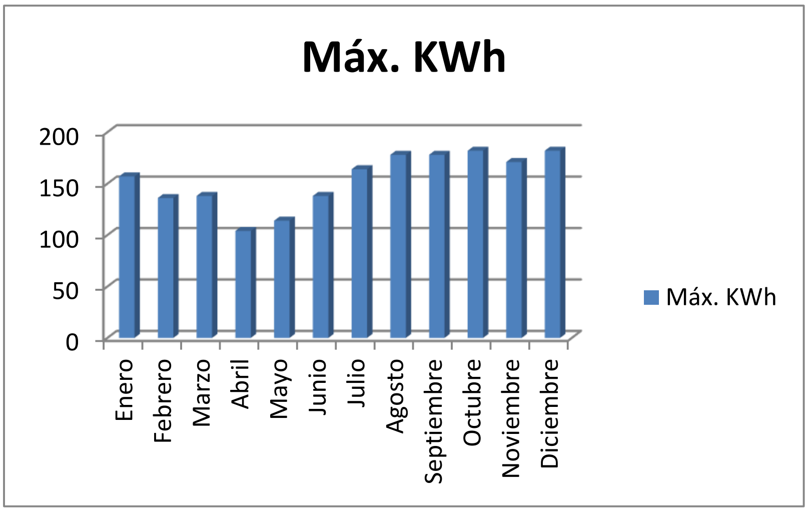


Table 18, Figure 80. Maximum KWh per month

We realize that the time when more energy is required are the months in which we have less hours of sun light which are from September to December. So we will need to have it in count in a future for the kind of installation that is more suitable for our case. So probably we will have to consider if some batteries will be necessary for this project. The highest peak is up to 182KWh which means that is the maximum amount of power we will need for our system unless we want to also charge the batteries.

- Daily

Again this is just a more accurate representation of the previous graph in which we can see more clearly when the peaks are and how much they last.

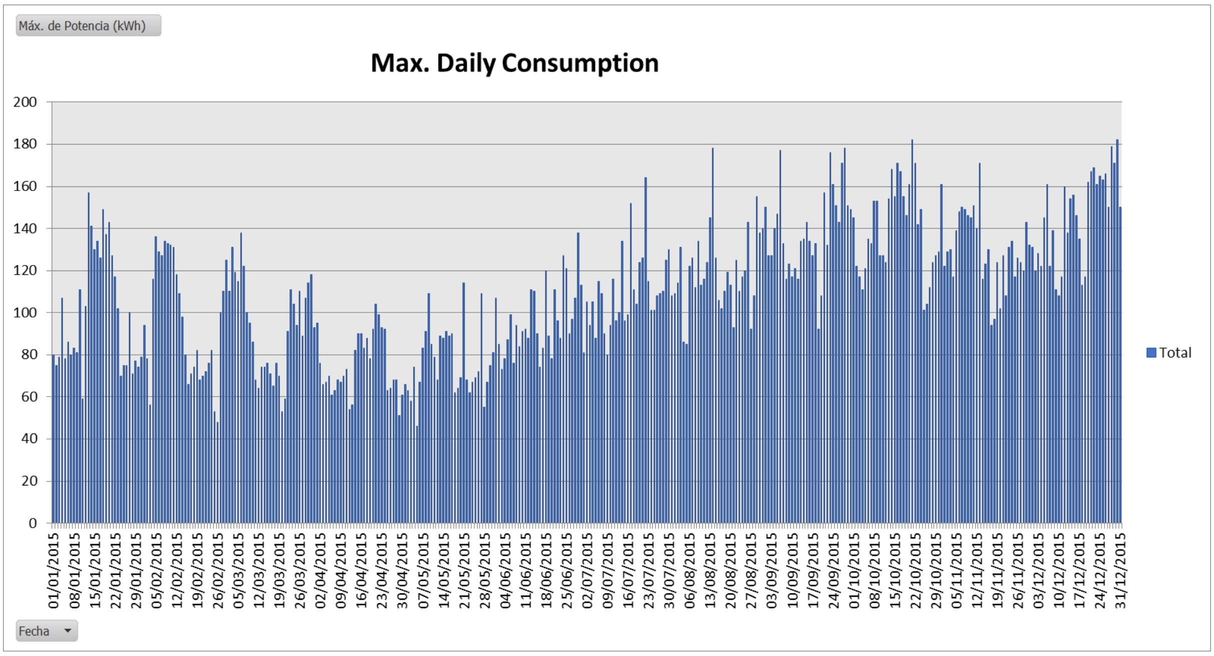


Figure 81. Maximum KWh per day

- Hour

Now we will check the maximum electricity that the centre uses in the different moments of the day to be able to decide how much power our panels will need to produce in the peak of consumption and how many batteries will be needed too in case we decide to install them.

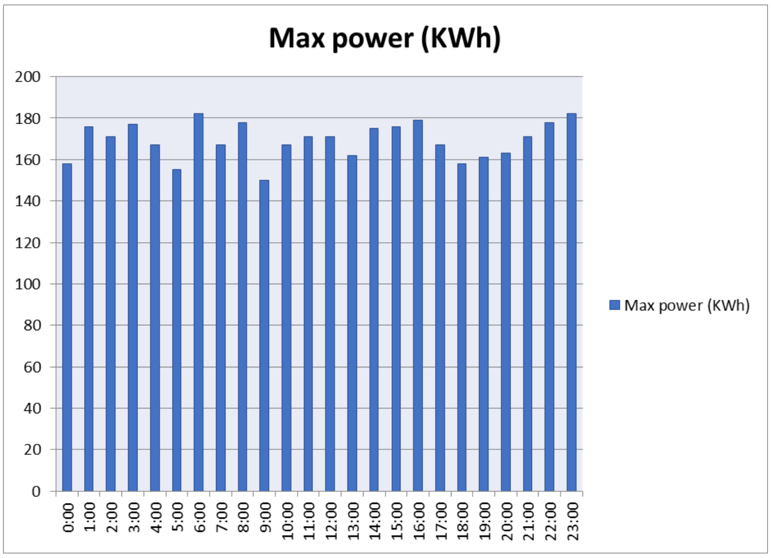


Table 19, Figure 82. Maximum KWh per hour

As we can see, the maximum amount of electricity we need is 182 KWh which is the highest peak.

With the data we had related to the amount of times per year that we need each quantity of electricitywe conclude that the mean each is around 74 KWh. More than 138KWh represents just a 3% of the total and less than that the 97%.

d) Representative data

Now we are going to analyse some important features of our auction centre. In order to do this, we will take some samples from the most relevant periods of time along the year. These ones are December and April since they are the months in which the demand is the highest and the lowest.

- December

Let´s check then what is the highest demand each day to have a general idea of the maximum power we would need.

Typical week on December	Max. Power KWh
21/12/2015	167
22/12/2015	169
23/12/2015	161
24/12/2015	165
25/12/2015	163
26/12/2015	166
27/12/2015	150
Total general	**169**

Table 20. Max power per day during a week of December

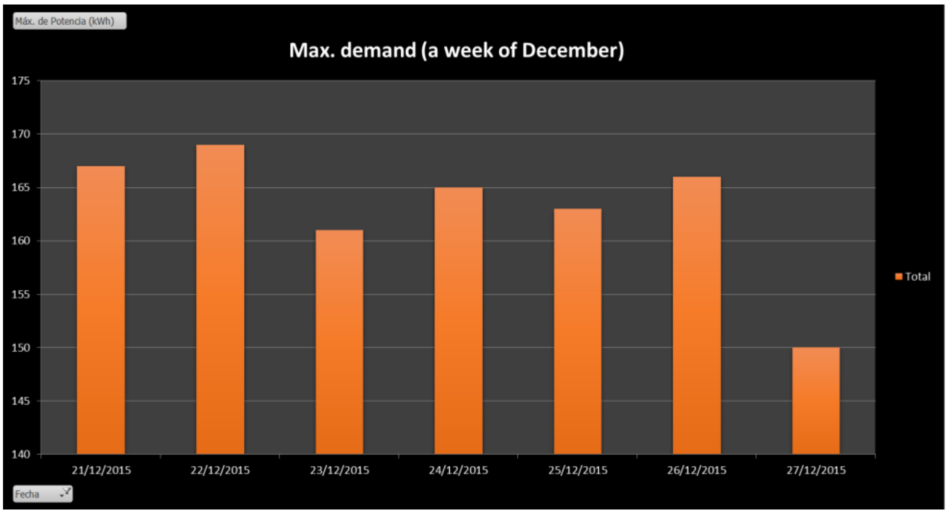


Figure 83. Total KWh per day from 21/12/2015 - 27/12/2015

We can see the peaks are almost the highest values of the demand of all year. Now we will check it hourly to have a more detailed idea.

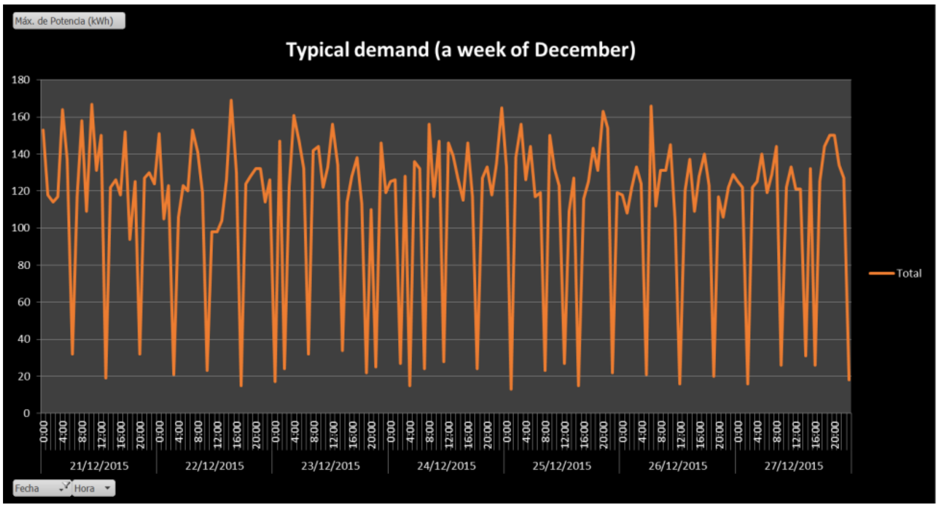


Figure 84. KWh per day from 21/12/2015 - 27/12/2015

We appreciate a great difference between the highest values and the lowest ones. To have a deeper knowledge of this, we can also zoom in to check how a weekday would be in the period when more electricity is needed.

Typical Weekday on December	Power KWh
21/12/2015	**167**
0:00	153
1:00	118
2:00	114
3:00	117
4:00	164
5:00	137
6:00	32
7:00	117
8:00	158
9:00	109
10:00	167
11:00	131
12:00	150
13:00	19
14:00	122
15:00	126
16:00	118
17:00	152
18:00	94
19:00	125
20:00	32
21:00	127
22:00	130
23:00	124

Table 21. Max power per hour during a weekday of December

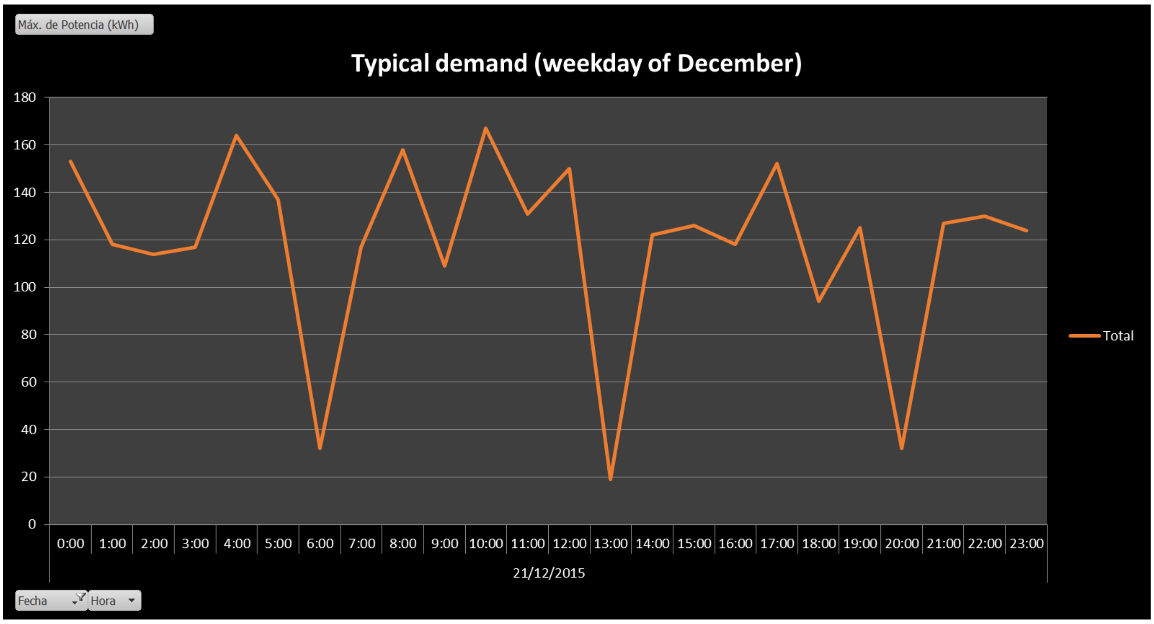


Figure 85. KWh per hour (21/12/2015)

The consumption on a weekday is around 140KWh. With some peaks that can reach up to 172KWh and some great fall in the demand at 2:00, 13:00 and 20:00.

On the other hand, we can zoom in to check how a weekdend day would be in the period when more electricity is needed as well.

Typical Weekend day on December	Power (KWh)
0:00	125
1:00	122
2:00	16
3:00	122
4:00	125
5:00	140
6:00	119
7:00	129
8:00	144
9:00	26
10:00	122
11:00	133
12:00	121
13:00	121
14:00	31
15:00	132
16:00	26
17:00	125
18:00	144
19:00	150
20:00	150
21:00	134
22:00	127
23:00	18

Table 22. Max power per hour during a weekend day of December

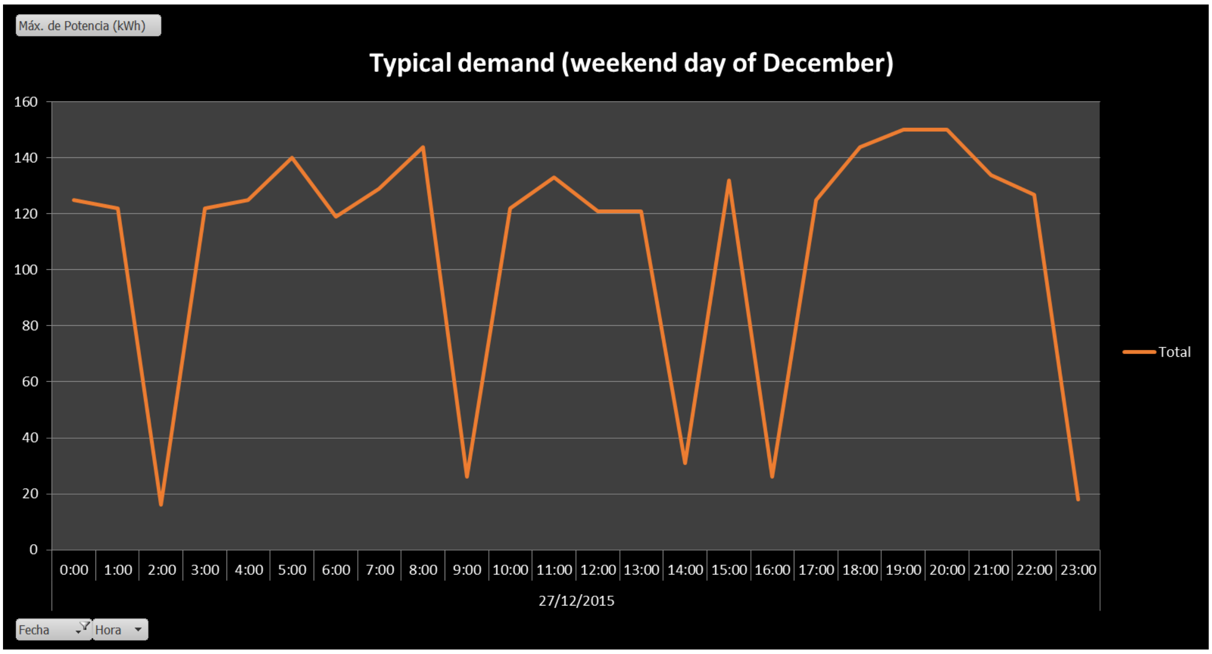


Figure 86. KWh per hour (27/12/2015)

We conclude the the average value in this period of time is around 120KWh, lower than in a weekday, with smaller consumption peaks but more falls.

Comparing those different days, we could say that the peaks are higher on a weekday than on a weekend day. There are also some falls in the consumption probably due to a swift of the working shifts.

- April

Once we have studied the behaviour of the month with a higher demand, we will do the same process for the month with the lowest one which is April.

First, we will check the highest demand each day to have a general idea of the maximum power we would need in this month.

Typical week on December	Max. Power (KWh)
06/04/2015	61
07/04/2015	63
08/04/2015	68
09/04/2015	67
10/04/2015	70
11/04/2015	73
12/04/2015	54
Total general	**73**

Table 23. Max power per day during a week of April

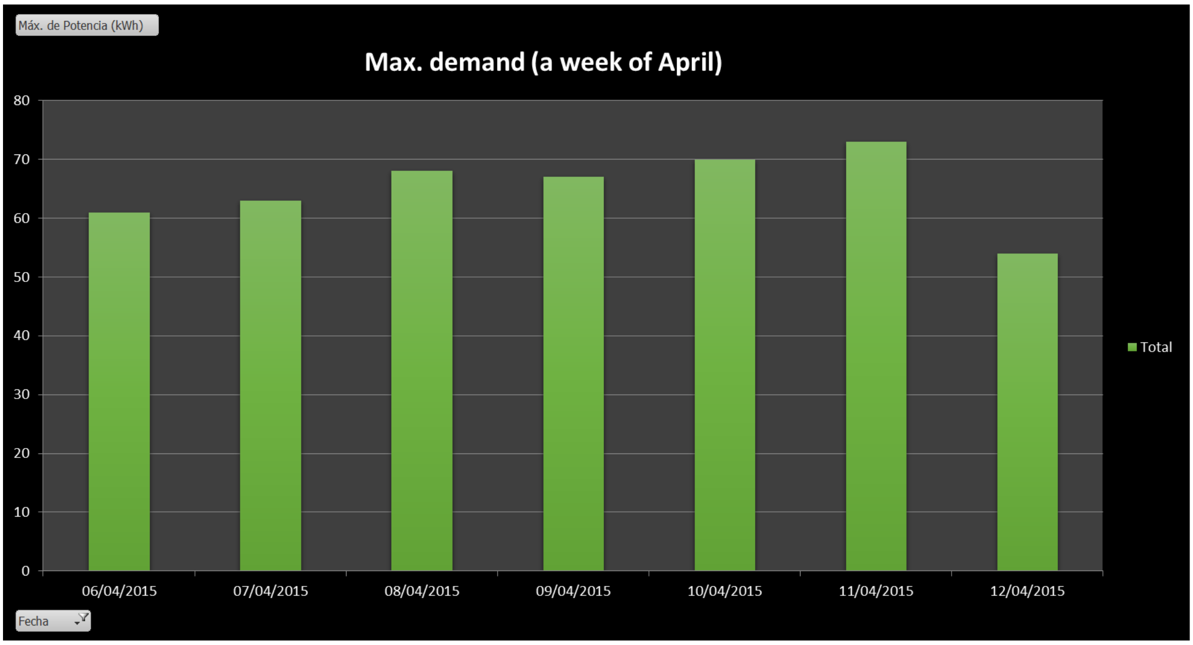


Figure 87. Total KWh per day from 06/04/2015 - 12/04/2015

We can see that the maximum power needed is not even half of the power we need on December. Anyway, we will check it hourly to have a more detailed idea.

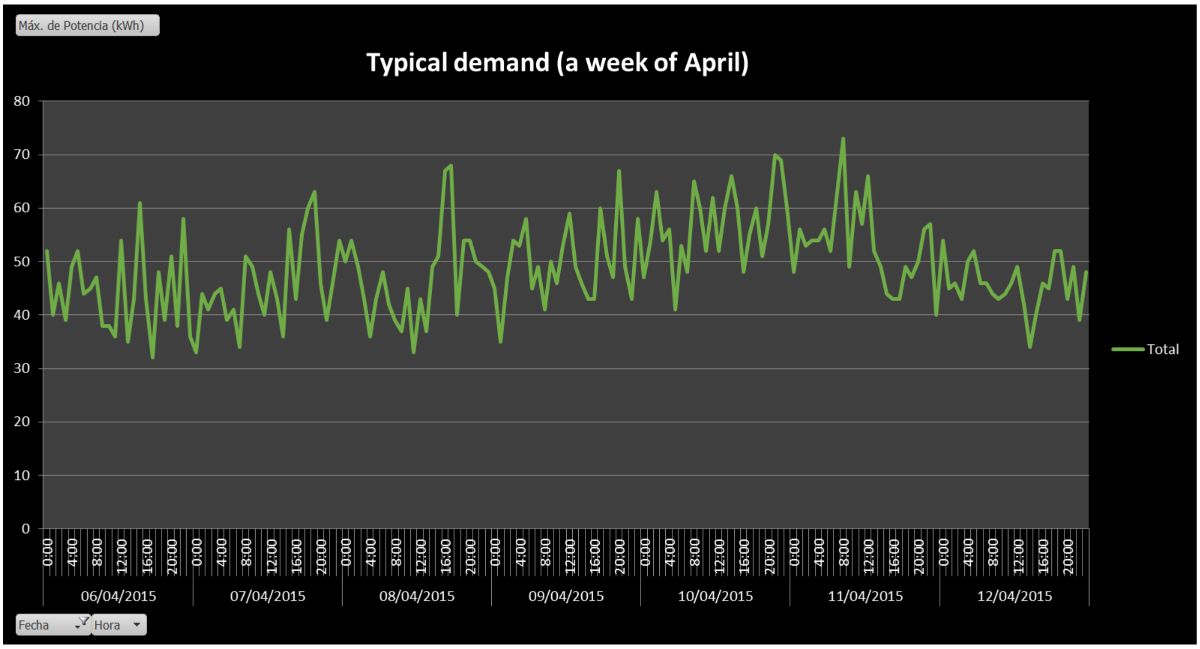


Figure 88. Total KWh per hour from 06/04/2015 - 12/04/2015

In this month we can not appreciate a great difference between the highest values and the lowest ones so we could say it is very stable along a week. To have a deeper knowledge of this, we can also zoom in to check how a weekday would be in the period when less electricity is needed.

Typical Week day	Power (KWh)
06/04/2015	**61**
0:00	52
1:00	40
2:00	46
3:00	39
4:00	49
5:00	52
6:00	44
7:00	45
8:00	47
9:00	38
10:00	38
11:00	36
12:00	54
13:00	35
14:00	43
15:00	61
16:00	43
17:00	32
18:00	48
19:00	39
20:00	51
21:00	38
22:00	58
23:00	36

Table 24. Max power per hour during a weekday of April

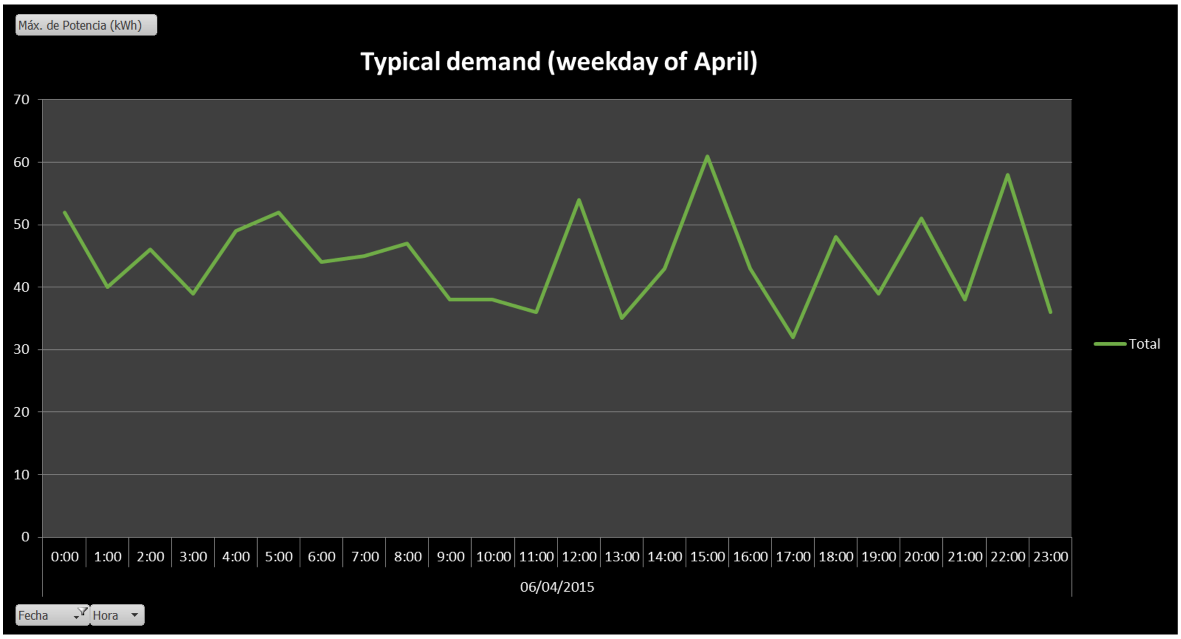


Figure 89. KWh per hour (06/04/2015)

The consumption on a weekday is around 45KWh. With some peaks that can reach up to 61KWh and some small falls in the demand.

We can zoom in to check how a weekdend day would be in the period when less electricity is needed as well.

Typical Weekend day	Power (KWh)
12/04/2015	**54**
0:00	54
1:00	45
2:00	46
3:00	43
4:00	50
5:00	52
6:00	46
7:00	46
8:00	44
9:00	43
10:00	44
11:00	46
12:00	49
13:00	42
14:00	34
15:00	40
16:00	46
17:00	45
18:00	52
19:00	52
20:00	43
21:00	49
22:00	39
23:00	48

Table 25. Max power per hour during a weekend day of April

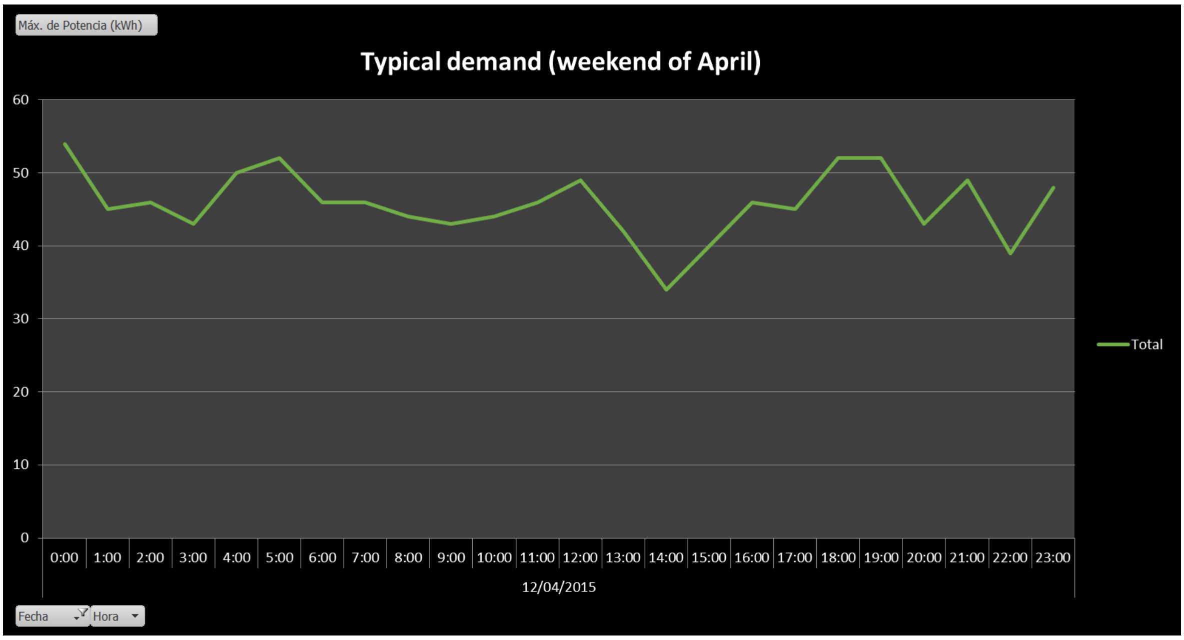


Figure 90. KWh per hour (12/04/2015)

We conclude the the average value in this period of time is around 45KWh as well.

Comparing these different days of the week, we could say that both fo them are really similar and do not vary much shich means it is a much more stable consumption period.

6.2. Reasons to install fotovoiltaic panels

In Spain the situation is currently becoming unsustainable for some citizens, due to the escalation that has been taking place in the price of electricity for months. Every day new historical highs are registered and in the last 5 months the electricity bill has multiplied by three and, what is more worrying, from the Spanish Union of Photovoltaic Companies (UNEF), they warn that this continuous and distressing the rise is still far from disappearing and it will hardly be smoothed out until well into 2022, in the best of possible scenarios.

For this reason, the province of Almería is advancing rapidly towards these other cheaper energies, which represent renewables: solar, wind, hydro or mini-hydro, biomass or geothermal open a window of hope of surrendering to a market of energy that has been triggered by the impulse of rising costs, such as gas or taxes that penalize CO_2 emissions.

a) Economy

Nowadays, consumers are increasingly opting for self-consumption, that is, individually or collectively producing the energy that is needed and right there where it is consumed.

According to HomeServe, a British multinational and international leader in home care and maintenance, there is a strong increase in demand for photovoltaic panel installations, which in the case of Almería has almost quadrupled in the last two years.

The increase in interest in replacement is fundamentally due to an economic solution to curb the incessant increase in the price of electricity. Added second to some concern about the impact that fossil fuel power generation has on the environment, or its consequence on climate change.

In the last six months the electricity market has tripled the cost for the user; From the little more than € 40 for each MW • h-1 that were paid last March, it has risen to € 150 in September, with a strong impact on domestic economies which, in Almería, already account for around ten percent of the cost of living.

In addition, the fact that the plates have more and more sales and is a growing market, makes it easier for companies to choose to invest in improvements in this technology and in the serial production of the same, thus lowering the costs for the end user with a better and better product.

b) Environment

In the present scenario, the alternative resides in an increase in the contribution of renewable energies, whose base (sun, wind or vegetable waste), are radically less expensive than fossil fuels, and with the advantage of being practically renewable resources inexhaustible.

However, clear discrepancies have already emerged in alternative energy production or distribution models: on the one hand, large projects promoted by energy groups or investment funds, which design and build large solar or wind plants and market their productions through distribution networks; on the other, the self-consumption model (understood as one where electricity is produced at the same point where it will finally be consumed). It is the one promoted by consumers themselves, companies, communities (classified in these cases as energy communities) or some public administrations to lower their energy costs.

The scientific community, both nationally and internationally, is in favor of renewables in general and self-consumption in particular, for economic reasons, but also because of the need to reduce the environmental impact of conventional energies on the planet.

Even more determined by this model are the environmental groups, who defend self-consumption as the most efficient solution for the planet and for the economy, as it is a clean production that is carried out in the environment in which it will be consumed and therefore avoids the large losses that are recorded in large distribution networks.

The messages from each other and the impacts that the increases in electricity bills are having on households have triggered interest in these alternatives, with the sun being the main source of wealth.

c) Location

The province of Almería, given its very specific climatic characteristics, could generate all its energy with solar panels. In fact, a report prepared by the EDP Solar group, a world leader in renewable energy, highlights the high capacity of the province of Almería for the use of solar energy. Not only the productive potential stands out, but also the reduction in the amortization periods of the investments in the installation of photovoltaic panels. According to this study, the province of Almería could have 99.4 percent to install solar panels for the production of electricity.

6.3. Deciding our fotovoiltaic facility

Once all the options for choosing solar panels have been explained in detail in this report, in this chapter we have to make the decision about the most suitable for the auction warehouse in Santa Mª del Águila (El Ejido, Almería)

So now it is time to explain which reasons will make us decide whether we choose a panel or another one, the amount of panels, how we will install them and all the issues that we have been talking about in the precious chapters.

As we have mentioned multiple times, the province of Almería is an ideal place to mount solar panels due to the enormous amount of hours of sunlight along the year and the energy that the incidence of those rays has.

Apart from that, the number of hours per day is also quite good and stable along the year, varying from 9 hours and 38 mins on December 21st, to 14 hours and 41 minutes on June 21st.

In our case, the electricity we need each month is more or less the same, consumption its just a bit lower in April and higher at the end of the year but there is not a huge difference.

The roof of the building could be also used to mount our panels directly on it. This will make the structure more robust since the wind in the region sometimes has a really high speed.

The orientation of the auction center is north-south with a small angle to the east. These are also good new since in the north emisphere we should try to make our panels point to the south. This small angle pointing a bit to the east will make the panels produce some more energy during the first hours of the day and a bit less during the evening.

We can seize the fact that the roof also has an inclination of 30 degrees which makes it a really good elevation having in count the latitud in which the warehouse is. Actually, it is the elevation recommended for the summer season.

The warehouse has a roof which may be divided into 4 sections, each one of them has a inclined face pointin to the north, a incline face pointing to the south and a flat one paralell to the grounf floor.

In order to decide the type of panel we will use for this project we will compare the different characteristic they have. The high quality ones are really expensive and they not give a sufficient amount of power to consider them in comparison to the other cheaper versions, we would only consider buying these ones if it was the case that the temperatures are really high since their temperature coefficient is what makes a a real difference. Among the cheaper ones, the ones with a divided cell are more interesting due to the fact that we reduce losses in the whole string of panels in case of any type of shadow that can partially cover our panel and it really represents a great quantity to have into account.

Conventional monocrystalline panels are really cheap but the energy they produce is significantly lower and the space is limited. Among the other options, SHINGLED panels have a really interesting technoly that reduces losses due to temperature and also due to the time degradation. However, once again they are slightly overpriced so the best option remaining would be the mono PERC half cell MMB since the power we can obtain is one of the topones and losses due to degradation and temperature are acceptable. It is the most profitable option we could choose.

If we make some calculations once we have chosen the panels we are going to use, we have a total surface available of 11908.8 m^2. We already said that the best orientation would be the one that faces to the south. Having in count the panels we have chosen ar 2 meters high and 1.01 meters long and the faces of the roof that point to the south are 5.77 meters and 180 meters long, we could make, approximately, fit 3 rows of 183 panels each per section. If each panel produces 410W we can calculate the power we would produce per section this way:

$$3\, rows * 180\, panels * 410 = 221{,}4KW$$

This means that just a section of panels is more than enough to suply electricity to the whole auction centre 97% of the times in which our system is fully working. Hence, we should put the panels in the souther section in order to not have any shadows due to other panels or the sections in front of it.

In addition to the above, a first approach to profitability can be assessed thanks to the preliminary figures of solar potential if we relate this quantity with the actual electricity consumption of the center (633 MWh/year):

$$\frac{633\,\frac{MWh}{year}}{1770\,\frac{kWh}{kW}} = 357{,}6KW$$

Which determines that roof has place enough to allocate modules to fulfil the complete yearly demand of the center, altought not in a dynamic sense but accumulated.

About the batteries, we could consider adding a bunch of them. Normally during the day we will have an exceed of prodction that we can sell for a small quantity of money. However, using batteries would be more profitable beacause we could save the excedents of production to power the warehouse in the evening when the light is gone but the price of electricity is still high. We should size this for the 21st December which is the day in which the demand is higher and the shortest the day is.

With this system we would be able to save money from 8:00 in the morning until midnight which is the period of the day in which the electricity is the most expensive in Spain and use electricity from the grid at night when its the cheaper.

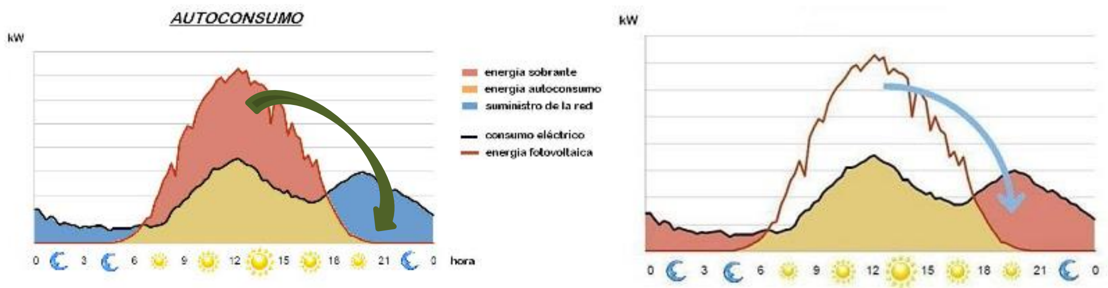


Figure 91. Consumption Graph

Source: https://autoconsumofv.com (02/20)

In the image we can see a normal demand and the production of electricity from solar panels. The yellow area corresponds to the electricity we are producing and consuming, which means is for free for us. The blue area is the electricity we take from the grid, which is the one we would have to pay. And the red area is the excess of production we have. The idea of adding batteries would be to reduce the blue area by acumulating the energy in excess (red area) to use it when we are not producing electricity.

If the mean of the electricity we use is 75KW and the 21st of December there are 6 hours since the sunset at 18:00 until midnight, we can calculate the amount of energy we would need.

$$75KW * 6\text{h} = 450KWh$$

We can round it to 500KWh to be sure we will have enough energy in case the demand is higher but anyways we could also use the grid as a backup.

Anyways, first we could install just the panels and then, make a deeper study with more precise data after some time using the panels to check if adding the batteries would be propper with the amount of energy we produce in excess.

6.4. Proposed Installation

Now that we have analysed all the main issues to find a propper solution is time to gather them all and decide how our installation will look like.

For this purpose we will use the program SAM which is a powerful tool to make all the calculations that we need.

In first place, we add the data of the location related to the weather that we had already obtained from PVGIS as is shown in the screenshot below.

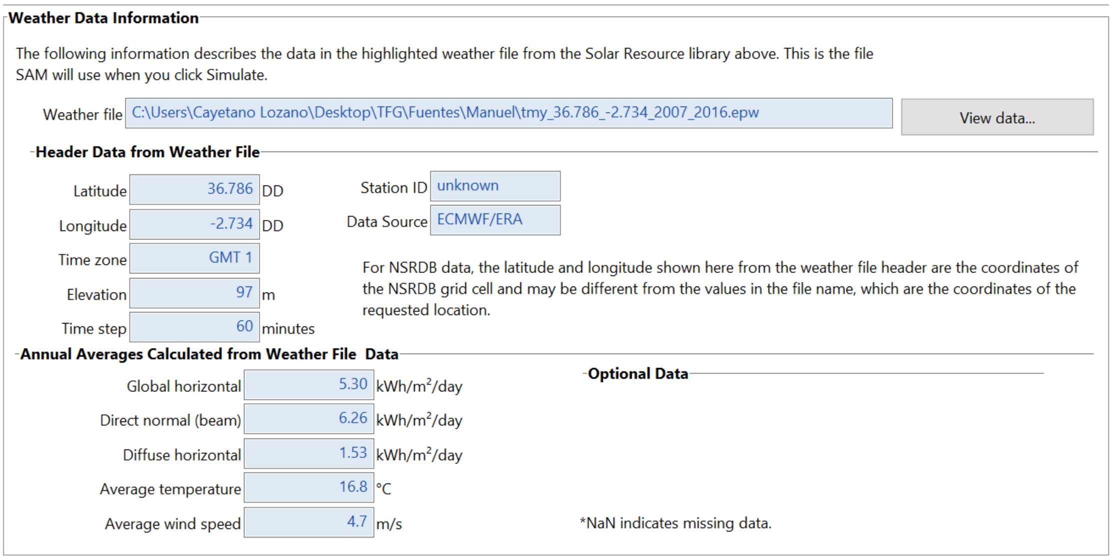


Figure 92. Anual weather conditions downloaded from PVGIS

After this data has been uploaded to the program, we can also add the consumption data of the auction center that we had in our Excel document to have a perfectly accurate study of the enery we need.

Monthly Load Summary

	Energy (kWh)	Peak (kW)
Jan	49,185.00	157.00
Feb	40,536.00	136.00
Mar	43,821.00	138.00
Apr	37,909.00	104.00
May	39,004.00	114.00
Jun	45,610.00	138.00
Jul	51,751.00	164.00
Aug	56,992.00	178.00
Sep	65,886.00	178.00
Oct	67,570.00	182.00
Nov	61,531.00	171.00
Dec	73,847.00	182.00
Annual	633,642.00	182.00

Table 26. Auction center consumption downloaded from Excel

Knowing all the information that we have being exposing it is time to choose the panel we will use for our system. The one we have chosen is Trina Solar TSM-410DEG15M(II). The reason why we didn't take a divided cell one is because we will just use parts of the available roof in which no shadow can be projected. So it makes no difference in production but it does in the costs.

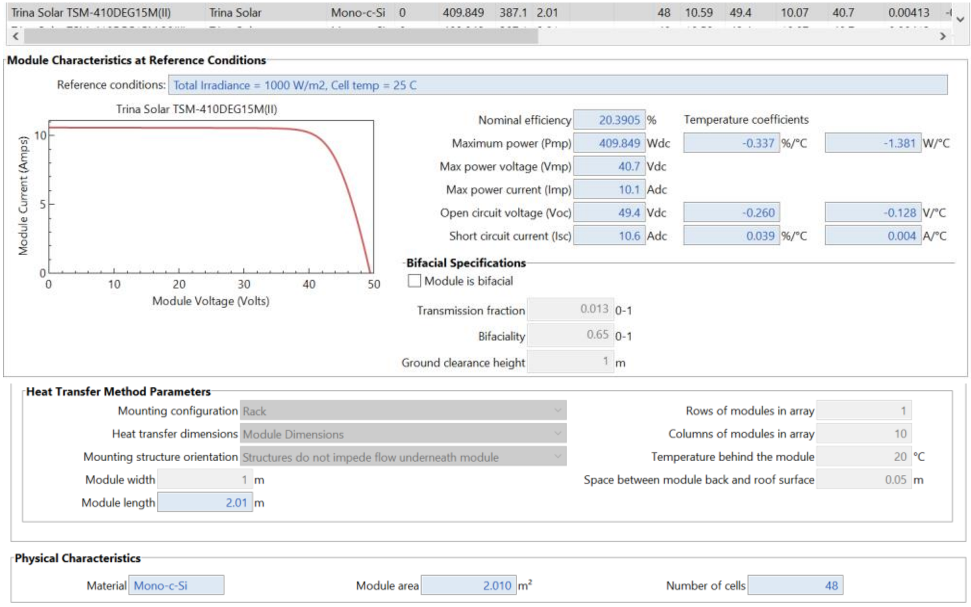
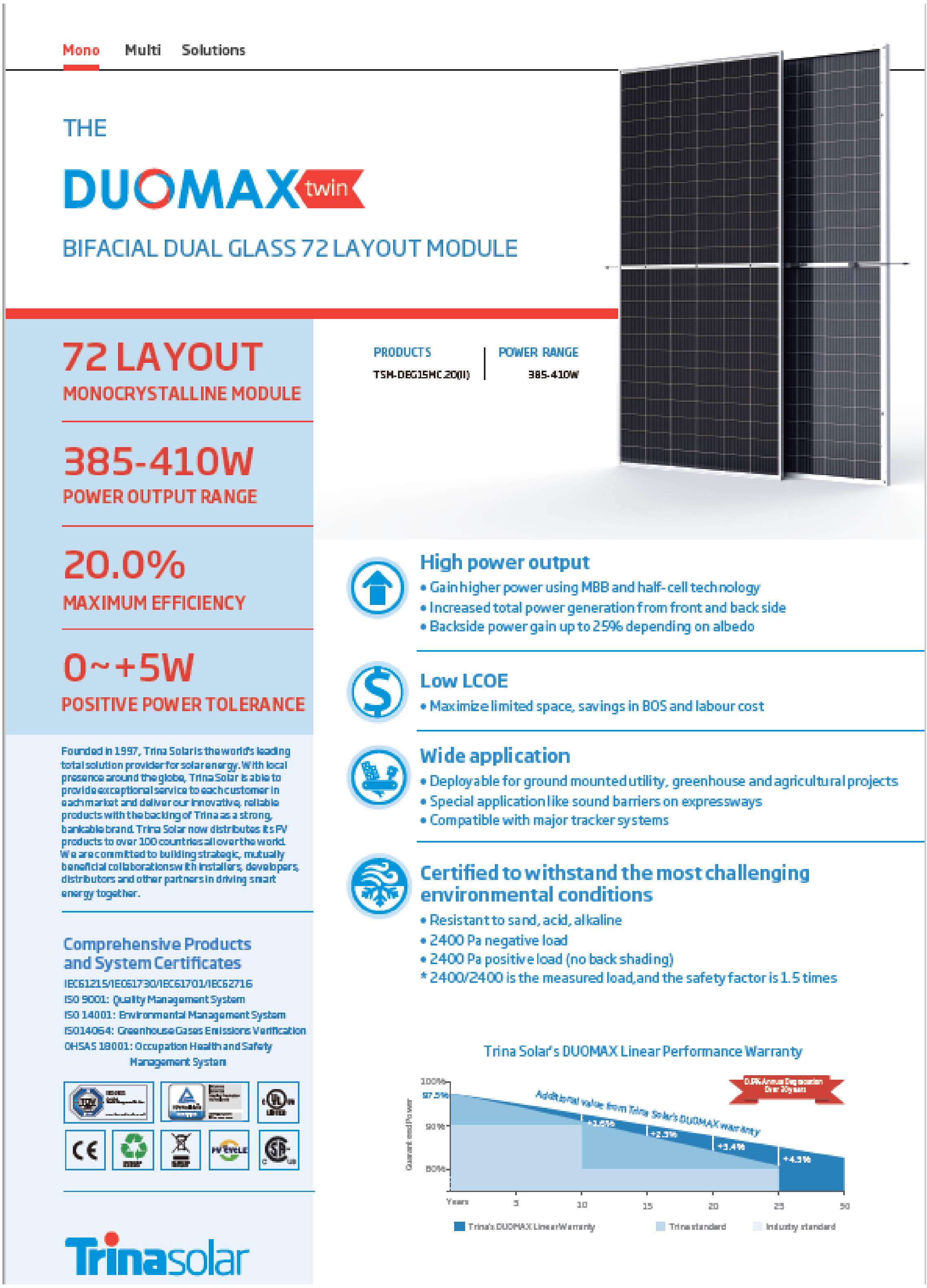


Figure 93. Module characteristics

The size of the panel is 1 meter width and 2.01 meters length. We will be able to make 3 rows of panels in the incline surfaces and 2 in the horizontal ones. Anyway, for our purpose we will just consider those faces pointing south and the horizontal ones. We discard then using the faces wich point to the north.

The datasheet of a similar model was added to the project in case we need to make calculations with some other parameters.



Mono Multi Solutions

THE

DUOMAX twin

BIFACIAL DUAL GLASS 72 LAYOUT MODULE

PRODUCTS	POWER RANGE
TSM-DEG15MC.20(II)	385-410W

72 LAYOUT
MONOCRYSTALLINE MODULE

385-410W
POWER OUTPUT RANGE

20.0%
MAXIMUM EFFICIENCY

0~+5W
POSITIVE POWER TOLERANCE

Founded in 1997, Trina Solar is the world's leading total solution provider for solar energy. With local presence around the globe, Trina Solar is able to provide exceptional service to each customer in each market and deliver our innovative, reliable products with the backing of Trina as a strong, bankable brand. Trina Solar now distributes its PV products to over 100 countries all over the world. We are committed to building strategic, mutually beneficial collaborations with installers, developers, distributors and other partners in driving smart energy together.

Comprehensive Products and System Certificates

IEC61215/IEC61730/IEC61701/IEC62716
ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO14064: Greenhouse Gases Emissions Verification
OHSAS 18001: Occupation Health and Safety Management System

Trinasolar

High power output
- Gain higher power using MBB and half-cell technology
- Increased total power generation from front and back side
- Backside power gain up to 25% depending on albedo

Low LCOE
- Maximize limited space, savings in BOS and labour cost

Wide application
- Deployable for ground mounted utility, greenhouse and agricultural projects
- Special application like sound barriers on expressways
- Compatible with major tracker systems

Certified to withstand the most challenging environmental conditions
- Resistant to sand, acid, alkaline
- 2400 Pa negative load
- 2400 Pa positive load (no back shading)

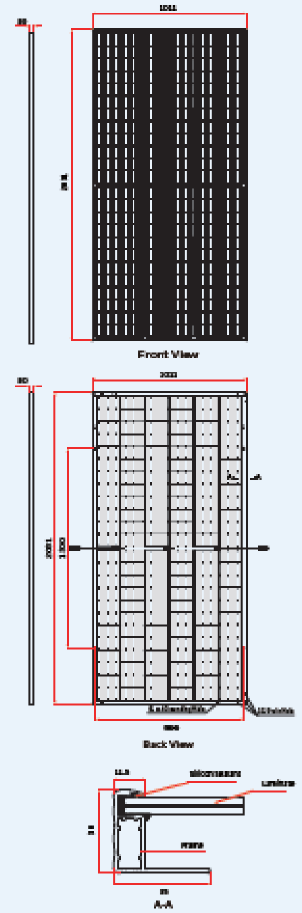
* 2400/2400 is the measured load,and the safety factor is 1.5 times

Trina Solar's DUOMAX Linear Performance Warranty

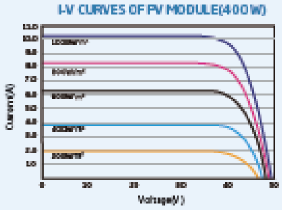
DUOMAX twin

72LAYOUT MODULE

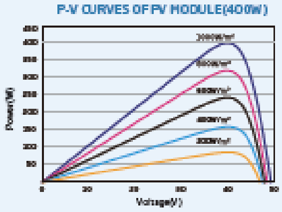
DIMENSIONS OF PV MODULE(mm)



I-V CURVES OF PV MODULE(400W)



P-V CURVES OF PV MODULE(400W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	385	390	395	400	405	410
Power Output Tolerance-P_{MAX} (W)	0 ~ +5					
Maximum Power Voltage-V_{MPP} (V)	39.9	40.2	40.5	40.8	41.1	41.4
Maximum Power Current-I_{MPP} (A)	9.66	9.71	9.76	9.81	9.86	9.91
Open Circuit Voltage-V_{OC} (V)	48.3	48.5	48.7	48.9	49.1	49.3
Short Circuit Current-I_{SC} (A)	10.21	10.25	10.29	10.33	10.37	10.41
Module Efficiency η_m (%)	18.7	19.0	19.2	19.5	19.7	20.0

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

BI-FACIAL OUTPUT - Backside Power Gain

10%	Power Output(W)	424	429	435	440	446	451
	Module Efficiency(%)	20.6	20.9	21.2	21.4	21.7	22.0
15%	Power Output(W)	443	449	454	460	466	472
	Module Efficiency(%)	21.6	21.9	22.1	22.4	22.7	23.0
25%	Power Output(W)	481	488	494	500	506	513
	Module Efficiency(%)	23.4	23.8	24.1	24.4	24.6	25.0

ELECTRICAL DATA (NMOT)

Maximum Power-P_{MAX} (Wp)	290	294	298	302	305	309
Maximum Power Voltage-V_{MPP} (V)	37.5	37.7	38.0	38.2	38.5	38.8
Maximum Power Current-I_{MPP} (A)	7.77	7.81	7.85	7.89	7.92	7.97
Open Circuit Voltage-V_{OC} (V)	45.4	45.6	45.8	46.0	46.2	46.4
Short Circuit Current-I_{SC} (A)	8.24	8.27	8.30	8.33	8.36	8.39

NMOT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline
Cell Orientation	144 cells (6 × 24)
Module Dimensions	2031 × 1011 × 30mm (79.96 × 39.80 × 1.18 inches)
Weight	31.4 kg (69.2 lb)
Front Glass	2.5 mm (0.10 inches), High Transmission, AR Coated Heat Strengthened Glass
Encapsulant material	POE/EVA
Back Glass	2.5 mm (0.10 inches), Heat Strengthened Glass (White Grid Glass)
Frame	30mm (1.18 inches) Anodized Aluminium Alloy
J-Box	IP68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), Portrait: 280/280 mm (11.02/11.02 inches) Landscape: 1900/1900 mm (74.80/74.80 inches)
Connector	MC4 EVO2 / TS4*

*Please refer to regional datasheet for specified connector.

TEMPERATURE RATINGS

NMOT (Nominal Module Operating Temperature)	41°C (±3°C)
Temperature Coefficient of P_{MAX}	- 0.37%/°C
Temperature Coefficient of V_{OC}	- 0.29%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1500V DC (IEC)
	1500V DC (UL)
Max Series Fuse Rating	20A

(Do not connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

10 year Product Workmanship Warranty
30 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 32 pieces
Modules per 40' container: 704 pieces

Trinasolar

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Version number: TSM_EN_2019_A www.trinasolar.com

With the previous calculations we made before we know that:

1- **Southern face** ➔ 3*180=**540 panels**
2- **Upper rows south faces** ➔ 3*180=**540 panels**
3- Middle rows south faces ➔ 3*180= 540 panels
4- **Flat faces** ➔ 4*2*180 = **1440 panels**
5- Lower rows south faces ➔ 3*180=540 panels
6- North faces ➔ 3*180= 540 panels

The ones in bold are the sections we are considering to mount solar panels.

Now we will choose the invertir that is more convenient for our objective. I chose the model PVS-175-TL-POWER-MODULE-1-US [800V] because of paramenters such as its high efficiency, Its Paco value and the Mppt which both fit perferfectly to the panels we are going to mount.

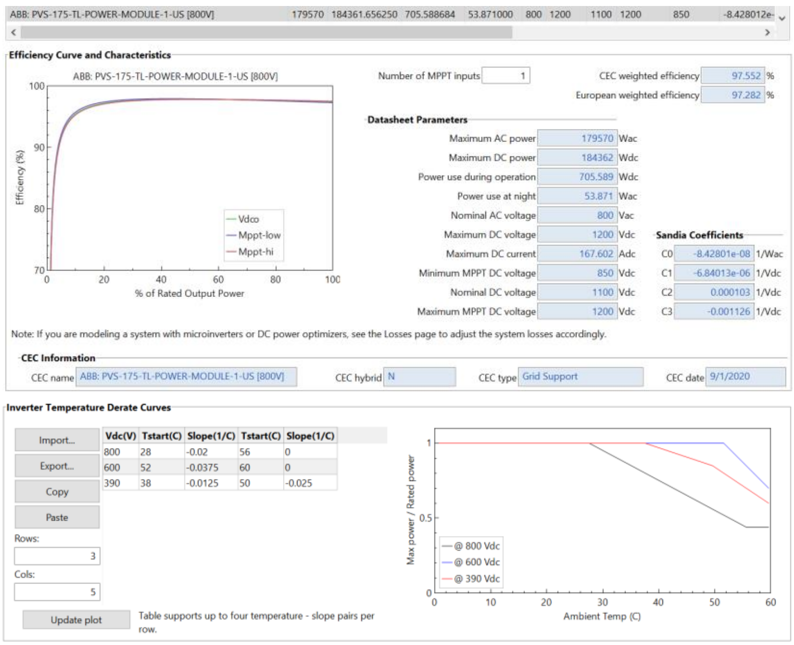


Figure 94. Inverter Characteristics

We will also add the datasheet of the inverter.

FIMER

Solar inverter PVS-175-TL

The PVS-175-TL is FIMER's innovative three-phase string inverter, delivering a six-in-one solution to enhance and optimize solar power generation for ground mounted utility scale applications.

175 kW

String inverter - PVS-175-TL

High power density
This new high-power string inverter with the highest power density within the 1500 Vdc segment, delivers up to 185 kVA at 800 Vac. This not only maximizes the ROI for ground-mounted utility-scale applications but also reduces Balance of System costs (i.e. AC side cabling) for small to large scale, free field ground mounted PV installations.

Design flexibility
The inverter comes equipped with 12 MPPT, the highest available in the market, assuring maximum PV plant design flexibility and increasing yields also in case of complex installations.

Installer friendly design
Quick and easy installation, thanks to plug and play connectors, as the existing PV module's mounting systems can be used to install the inverters, thus saving time and cost on site preparation and hire of plant.
The fuse and combiner free design eliminates the need for external components, such as separate DC combiner boxes and AC first level combiners, thanks to the integrated DC disconnect and AC wiring compartment with optional AC disconnect.
The Advanced Cooling Concept preserves the lifetime of the system and minimizes O&M costs thanks to internal heavy-duty inverter cooling fans. These can be easily removed during scheduled maintenance cycles whilst the power module can be easily replaced without removing the wiring box.

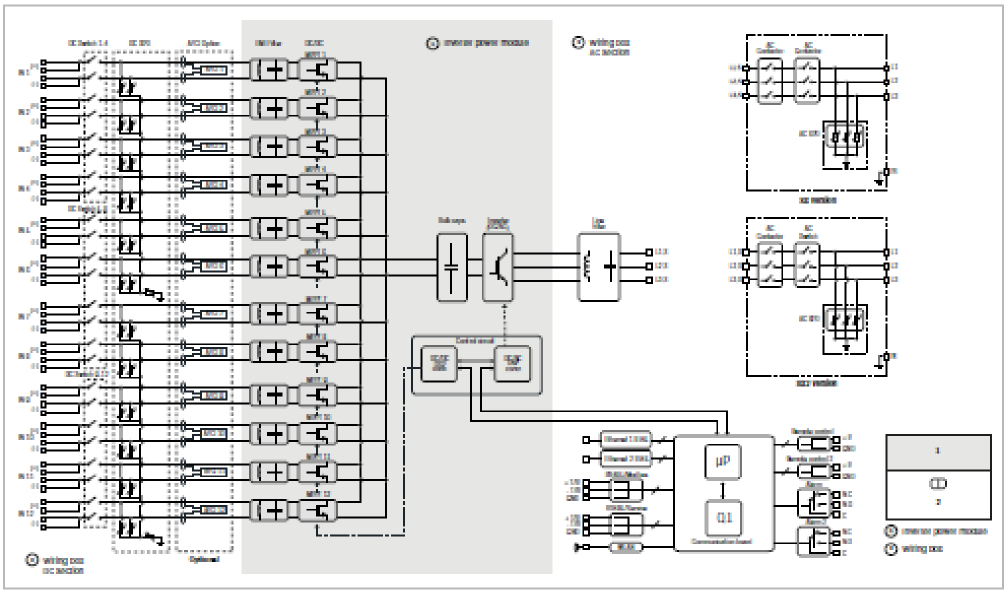
Advanced communication for O&M
Standard wireless access from any mobile device makes the configuration of inverter and plant easier and faster. Improved user experience thanks to a built-in User Interface (UI) enables access to advanced inverter configuration settings.
The Installer for Solar Inverters mobile APP and configuration wizard enable a quick multi-inverter installation and commissioning thus reducing the time spent on site.

Fast system integration
Industry standard Modbus (RTU/TCP)/SUNSPEC protocol enables fast system integration.
Two Ethernet ports enable fast and future-proof communication for PV plants.

Protect your assets
Monitoring your assets is made easy, as every inverter is capable to connect to Aurora Vision cloud platform and thanks to the state-of-the-art cybersecurity and Arc Fault Detection option, your assets and profitability are secure in the long term.

Highlights
- Up to 185 kW power rating, highest in class
- All-in-one combiner and fuse free design
- Separate power module and wiring compartment for fast swap and replacement
- Easy access to consumables for fast inspection and replacement
- 12 MPPT and wide input voltage range for maximum energy yield
- WLAN interface for commissioning and configuration
- Remote monitoring and firmware upgrade via the Aurora Vision cloud platform (logger free)
- Free of charge standard access to Aurora Vision cloud

PVS-175-TL string inverter block diagram



String inverter - PVS-175-TL

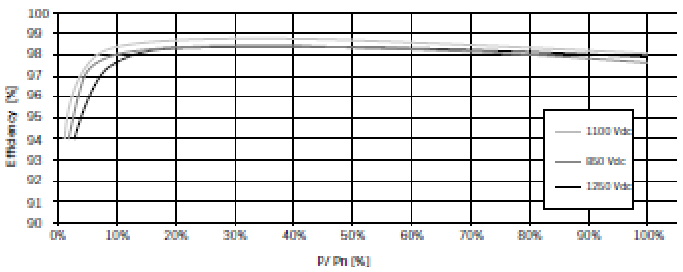
Technical data and types

Type code	PVS-175-TL
Input side	
Absolute maximum DC input voltage ($V_{max,abs}$)	1500 V
Start-up DC input voltage (V_{start})	750 V (650...1000 V)
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0.7 x Vstart...1500 V (min 600 V)
Rated DC input voltage (V_{dcr})	1100 Vdc
Rated DC input power (P_{dcr})	188000 W @ 30°C - 177000 W @ 40°C
Number of independent MPPT	12
MPPT input DC voltage range ($V_{MPPTmin}...V_{MPPTmax}$) at P_{acr}	850..1350 V
Maximum DC input current for each MPPT ($I_{MPPTmax}$)	22 A
Maximum input short circuit current for each MPPT (I_{SCmax})	30 A
Number of DC input pairs for each MPPT	2 DC inputs per MPPT
DC connection type	PV quick fit connector [1]
Input protection	
DC Series Arc Fault Circuit Interrupter [2]	Type I acc. to UL 1699B with single-MPPT sensing capability
Reverse polarity protection	Yes, from limited current source
Input over voltage protection for each MPPT	Type 2 with monitoring
Photovoltaic array isolation control (insulation resistance)	Yes, acc. to IEC 62109-2
Residual Current Monitoring Unit (leakage current protection)	Yes, acc. to IEC 62109-2
DC Load Breaking Disconnect Switch (rating for each MPPT)	20 A/1500 V - 50 A/1000 V
Fuse rating	N/A, No fuses
String current monitoring	MPPT-level current sense
Output side	
AC Grid connection type	Three phase 3W+PE (TN system)
Rated AC power (P_{acr} @ $\cos\varphi=1$)	175 000 W @ 40°C
Maximum AC output power ($P_{ac,max}$ @ $\cos\varphi=1$)	185 000 W @≤ 30°C
Maximum apparent power (S_{max})	185 000 VA
Rated AC grid voltage ($V_{ac,r}$)	800 V
AC voltage range	(552...960) [3]
Maximum AC output current ($I_{ac,max}$)	135 A
Rated output frequency (f_r)	50 Hz/60 Hz
Output frequency range ($f_{min}...f_{max}$)	45...55 Hz/55...65 Hz [3]
Nominal power factor and adjustable range	> 0.995, 0...1 inductive/capacitive with maximum S_{max}
Total current harmonic distortion	< 3%
Max DC current injection (% of In)	< 0.5%*In
Maximum AC Cable outer diameter / multi core	1 x 53 mm (1 x M63 cable gland)
Maximum AC Cable outer diameter / single core	3 x 32 mm (3 x M40 cable gland)
AC connection type [4]	Copper Busbar for lug connections with M10 bolts (included)
Output protection	
Anti-islanding protection	According to local standard
Maximum external AC overcurrent protection	200 A
Output overvoltage protection - replaceable surge protection device	Type 2 with monitoring
Operating performance	
Maximum efficiency (η_{max})	98.7%
Weighted efficiency (EURO/CEC)	98.4%
Communication	
Communication interfaces	1xRS485, 2x Ethernet (RJ45) [5]
Local user interface	4 LEDs, Web User Interface, Mobile APP
Communication protocol	Modbus RTU/TCP (Sunspec compliant)
Commissioning tool	FIMER Installer for solar inverters mobile app/Embedded Web User Interface
Remote monitoring services	Aurora Vision, Plant Portfolio Platform
Advanced features	Built-in Export Limitation control algorith/Integrated data logging for iverters and accessories / Remote FW update

Technical data and types

Type code	PVS-175-TL
Environmental	
Operating ambient temperature range	-25...+60°C/-13...140°F with derating above 40°C/133 °F
Relative humidity	4%...100% condensing
Sound pressure level, typical	65dB(A) @ 1m
Maximum operating altitude without derating	2000 m / 6560 ft
Physical	
Environmental protection rating	IP 65 (IP54 for cooling section)
Cooling	Forced air
Dimension (H x W x D)	867x1086x419 mm / 34.2"x42.7"x16.5" for, -SX model 867x1086x458 mm / 34.2"x42.7"x18.0" for, -SX2 model
Weight	–76 kg / 167,5 lbs for power module; –77 kg / 169,7 lbs for Wiring box Overall max –153 kg / 337,2 lbs
Mounting system	Mounting bracket (vertical support only)
Safety	
Isolation level	Transformerless
Marking	CE
Safety and EMC standard	IEC/EN 62109-1, IEC/EN 62109-2, EN 61000-6-2, EN 61000-6-4, EN 61000-3-11, EN 61000-3-12, EN 301 489-1, EN 301 489-17, EN 300 328, EN 62311,
Grid standard [6]	CEI 0-16, UTE C 15 712-1, JORDAN IRR-DCC-MV and IRR-TIC, BDEW, VDE-AR-N 4110, VDE-AR-N 4120, P.O. 12.3, DRRG D.4, AS/ NZS4777.2
Available product variants	
Inverter power module	PVS-175-TL-POWER MODULE
24 quick fit connector pairs (2 each MPPT) + DC switches + SPD Type 2 (DC & AC)	WB-SX-PVS-175-TL
24 quick fit connector pairs (2 each MPPT) + DC switches + AC disconnection switch + SPD Type 2 (DC & AC)	WB-SX2-PVS-175-TL
Optional available	
DC Series Arc Fault Circuit Interrupter	Type I acc. to UL 1699B [2] with single-MPPT sensing capability
AC Plate, Single Core Cables	Plate with 4 individual AC cable glands: 3 x M40: Ø 22...32mm, 1 x M32: Ø 18...25mm
AC Plate, Multi Core Cables	Plate with 2 individual AC cable glands: 1 x M63: Ø 37...53mm, 1 x M32: Ø 18...25mm
Pre-Charge [7]	Night time operation with restart capability
Anti-PID [8]	Based on night time polarization of the array

Efficiency curves of PVS-175-TL



1) Multicontact MC4-Evo2. Cable couplers may accept up to 10mm² (AWG8)
2) Available as an option. Performance in line with the relevant requirements of the Draft IEC 63027 standard
3) The AC voltage and frequency range may vary depending on specific country grid standard
4) Use of aluminum cables is possible via bi-metallic cable lugs
5) As per IEEE 802.11 b/g/n standard, 2.4 GHz
6) Check your sales channel for availability of the applicable grid standard for your country
7) The inverter cannot verify the photovoltaic array isolation resistance before connection during Night time. When this accessory is present, the inverter must be installed and operate in "restricted areas (access limited to qualified personnel)" according to IEC 62109-2
8) Cannot operate simultaneously with the night mode

Remark. Features not specifically listed in the present data sheet are not included in the product

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fimer.com

PVS-175-TL_EN REV. C 09-06-2021

For the battery, we will determine some values in order to make a good usage of it. So we will limit the state of charge between 15% and 95%. Furthermore, we wiil let the battery discharge as much as the system needs it because the sooner we start using that energy, the less we will need form the net. This is important since th taxes for the first period and the second one are more expensive than the one over the night so we will be able to save more money.

There is also a maximum rate of charge and this charge to make the battery last longer.

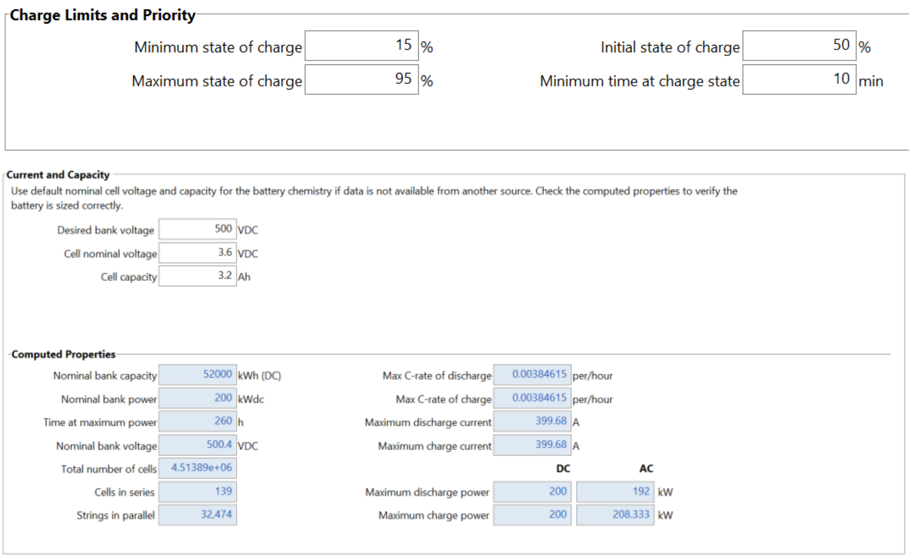


Figure 95. Battery characteristics

6.4.1. Technical Calculations

➢ Case 1. Off-Grid

For the first scenario, we are going to analyse how many batteries we would need in case we would like our auction center to be completely autonomous. This would be an Off-Grid installation.

For this purpose, we will use the máximum surface we have available in order to be able to feed the whole capacity of the batteries we need.

As we explained beofre, using the southern face of the roof pointing to the south we would be able to mount 3 rows of panels with 180 modules each one. This makes a total of 540 panels.

Then we will use just the highest row of the other faces pointing to the south, which wpuld also be 3 rows of 180 panels each. Which also adds 540 panels more.

And finally, we would mount 2 rows of panels on each section of the horizontal faces. Which is a total of 1440 additional panels.

With this amount of energy, we can produce we will have enough power to feed the batteries. So after some trial using SAM and analysing the plots we have worked out that we would need a battery of 34MWh to be able to be totally independent from the grid.

To know how will connect the panels, we will first get to know how many panels we can use in parallel using the next formula:

$$\frac{V_{DCO}}{V_{DC}} = \frac{1100V}{49.4V} = 22.27$$

Where V_{DCO} is the DC voltage of the inverter and V_{DC} is the DC voltage of the modules. So we are just able to add a máximum of 22 panels in serie per string. Now that we now this, we will add as many panels in series as we can in order to make fit the máximum amount of modules possible. So if we divide 540 which are the panels, which fit in a section, by 22 we obtain that we can have up to 24 panels in pararel per string for the south faces and 65 on the horizontal sections. Hence this is the way we have connected the panels as we can see below.

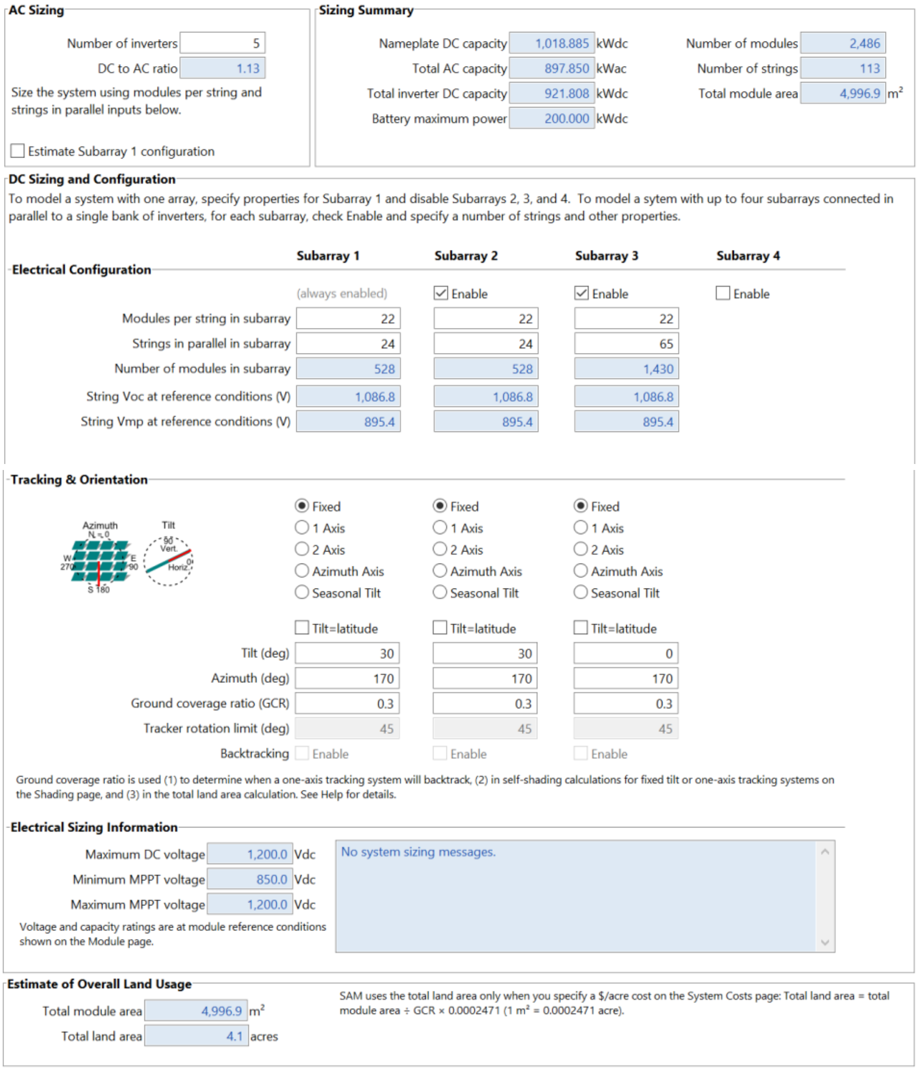


Figure 96. System design for 1MWh of production

Depending on the power we have on our system, we will need more or less inverters. For 1MWh we will need 5 inverters since our objective is that the DC to AC ratio is less than 1.2 to reduce the losses.

We also set up the fixed structure with its elevation and azimuth of each section as we have studied in the previous chapters.

Finally, we will set 200KW as the power that the battery must have since as we have since in previous tables for the demand, the highest peak is 182KWh so we will oversize it a bit just in case.

For the capacity of the batteries, we will add 32KW which will be enough to be able to create a totally isolated system.

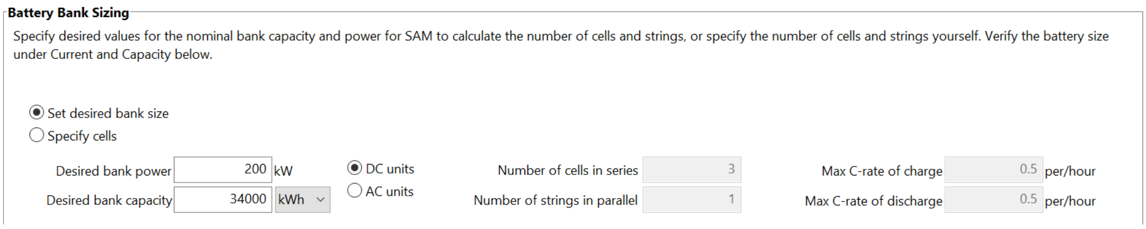


Figure 97. System design for 52MWh of battery capacity

Then, we will simulate the results and analyse them.

Metric	Value
Annual energy (year 1)	1,674,201 kWh
Capacity factor (year 1)	18.8%
Energy yield (year 1)	1,643 kWh/kW
Performance ratio (year 1)	0.81
Battery roundtrip efficiency	92.14%
Battery charge energy from system	100.0%
Levelized COE (nominal)	22.50 ¢/kWh
Levelized COE (real)	17.96 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$-51,505
Net savings with system (year 1)	$260,680
Net present value	$-1,307,879
Simple payback period	22.3 years
Discounted payback period	NaN
Net capital cost	$9,143,574
Equity	$3,657,430
Debt	$5,486,144

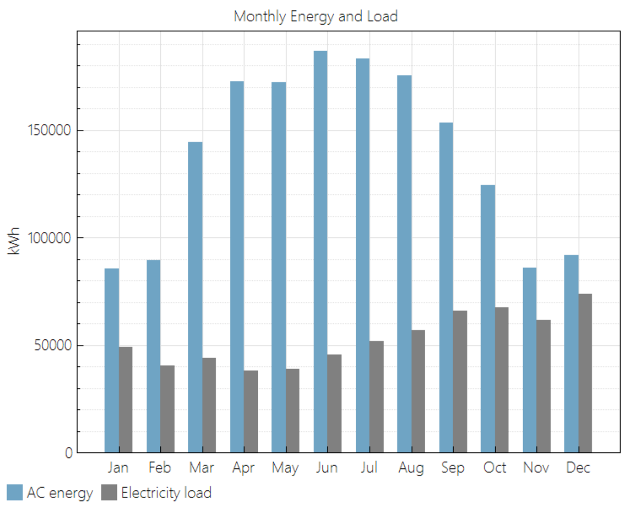


Table 27, Figure 98. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 1674MWh per year once we have calculated the losses, the total cost of the facility which is 9,143,574€ and the simple payback period that is 22.3 years.

With respect to the plot, it is obvious that the energy we produce is much more than the one we need. In the part of the year with a higher radiation this value is around four times the demand in the same period while, in the winter seasson when the demand is the highest, our production is still way over it. This means we are wasting too much energy that we are producing and we will have to sell most of it to the electricity company.

Now we have taken a graph in wich we can see along the year the percentage of the capacity of the battery each hour in dark green, the production per hour in light green, the amount KW used from the battery in blue, and in red the part of the consumption which is taken directly from the panels.

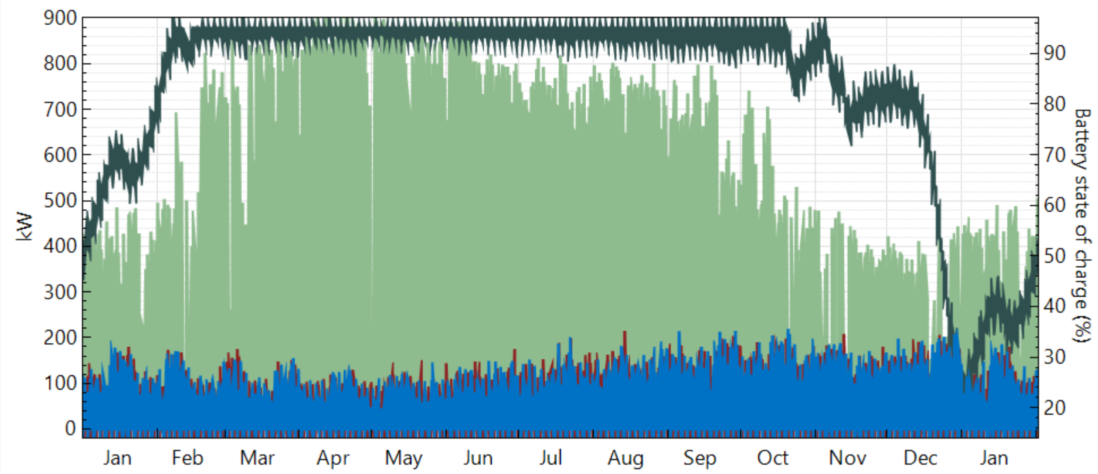


Figure 99. Annual battery percentage, consumption from battery, consumption from panels and panels production.

Now we will zoom in this plot in two different parts that are very representative as we did in a previous chapter. First, we will check the behaviour that our system has in a week of April and then in a week of December which are the months in which the production and demand are completely opposite. The drastical loss of the percentage of the capacity from September to December is produced because of a higher consumption, typical of these dates since the auction centre is fully working, and a lower irradiation season.

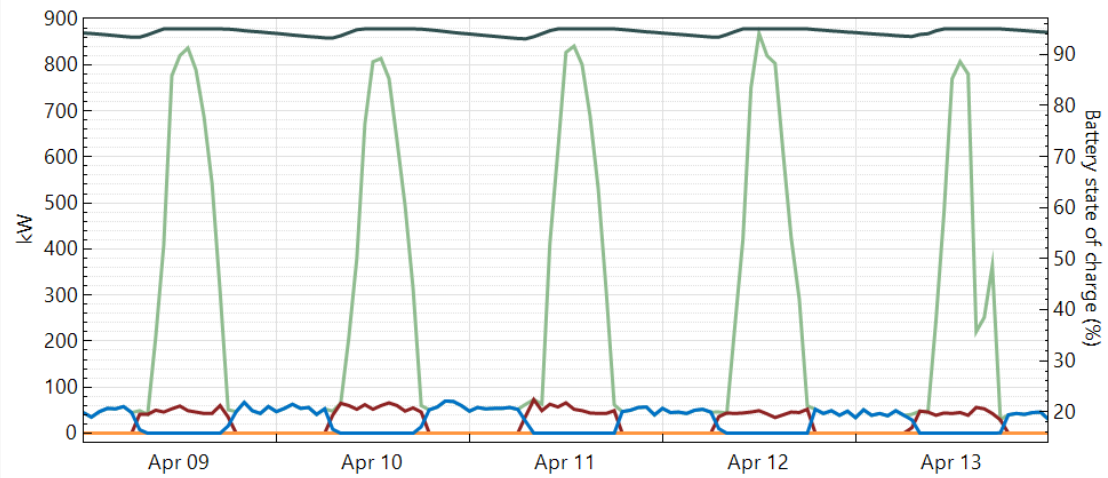


Figure 100. Battery percentage, consumption from battery, consumption from panels and panels production along a week of April

As we can see the battery percentage does not go down 90% in this period, the peaks of production feed the battery completely and the consumption of the auction center is fully covered by the batteries when there is no solar energy from the panels.

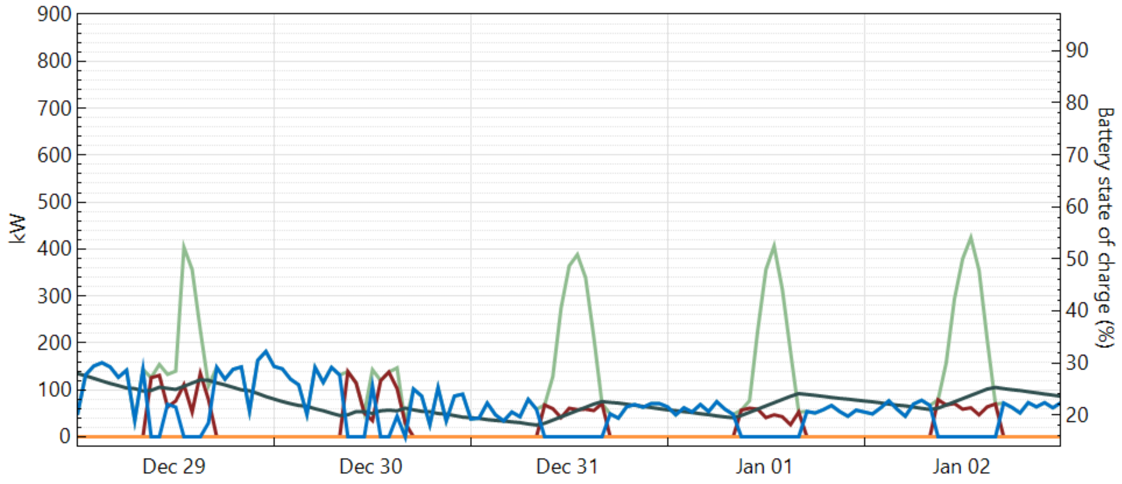


Figure 101. Annual battery percentage, consumption from battery, consumption from panels and panels production along a week of December

Along this week, the battery percentage is almost at the minimum, the peaks of production feed the battery but not as much as in the previous figure. Yet, the consumption of the auction center is fully covered by the batteries when there is no solar energy from the panels. We could even say that the 30th of December was cloudy and yet the battery was able to feed all the auction center by itself.

To conclude, a plot for an average day each month was added to have another view of the data.

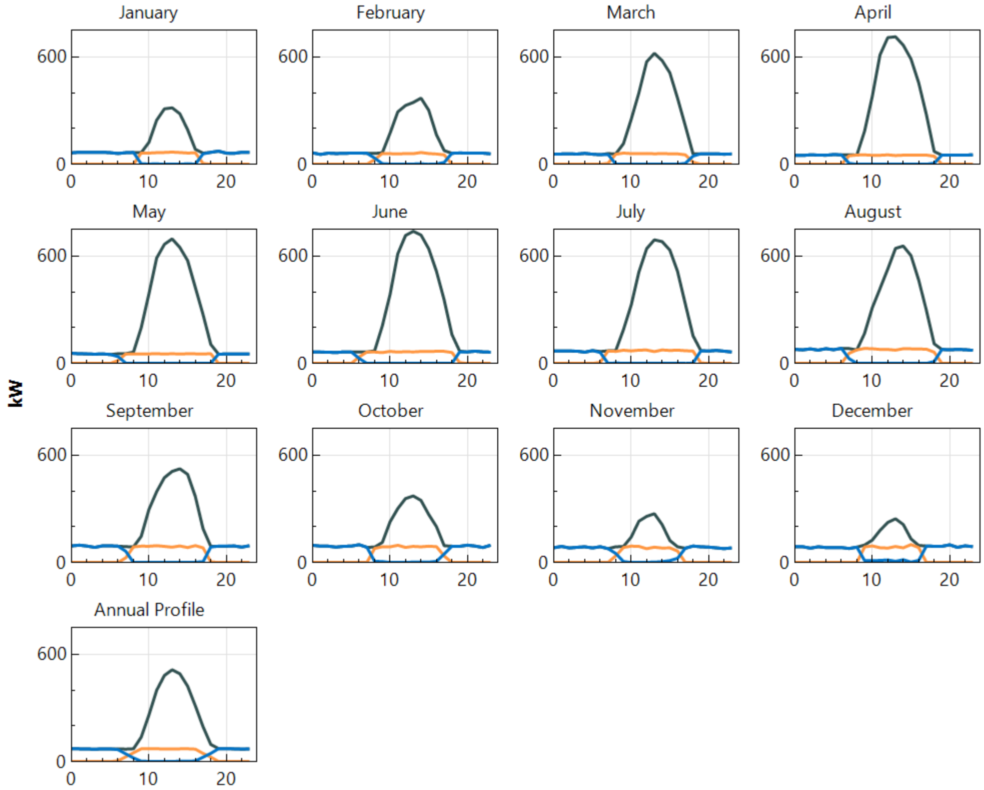


Figure 102. Daily average consumption from battery (Blue), consumption from panels (Yellow) and panels production (Green) each month

We perfectly distinguish that the production exceeds the consumption each month. We can completely cover the demand even after a long period of low irradiation and high consumption with the battery we installed.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

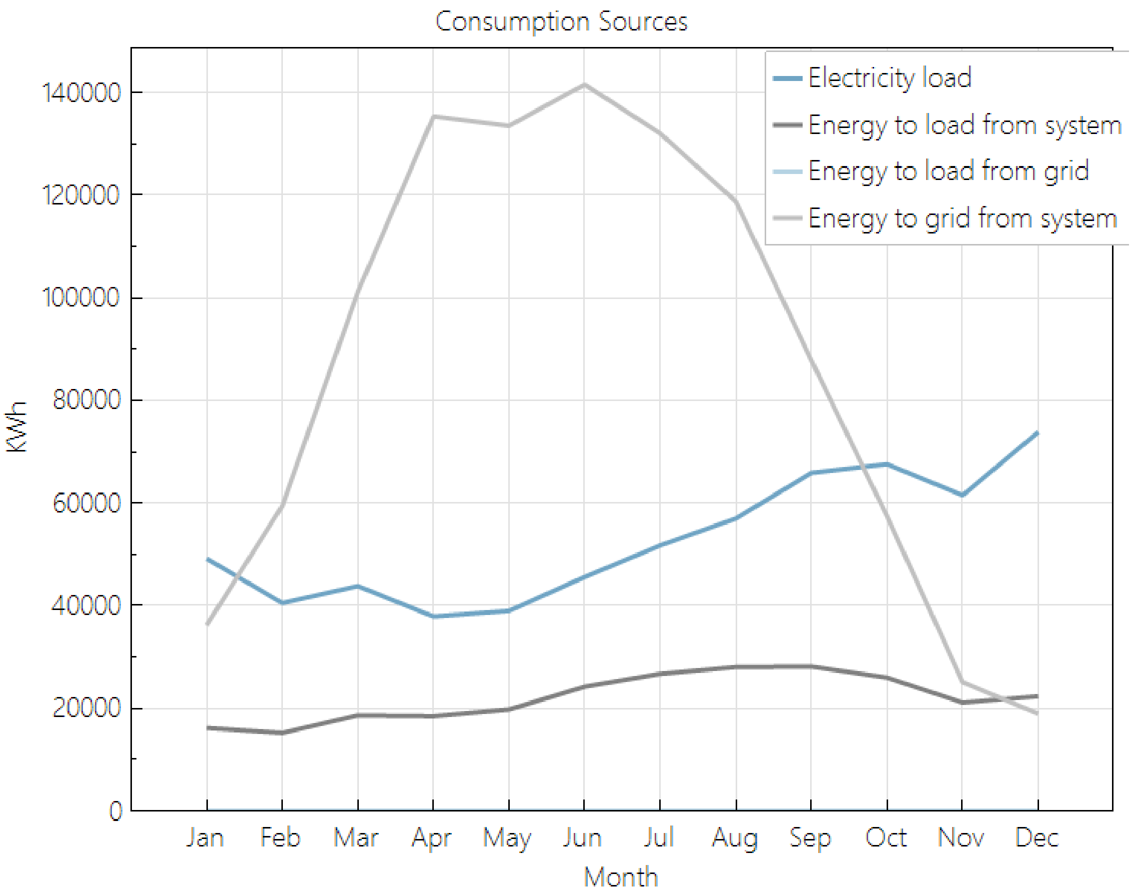


Figure 103. Consumption sources for case 1

We can conclude that the majority of energy we produce is not used by our system so we are wasting it. As the line for the electricity from the grid does not appear, this means that all the energy we need is taken from the system and the batteries.

➢ Case 2

This time we will try with a more realistic case in which we will use the same configuration for the panels but we will still try to use a big battery with the intention to provide energy in case we had some cloudy days in a row.

So we will just set the settings for a battery with 5MWh of capacity and then run the simulation.

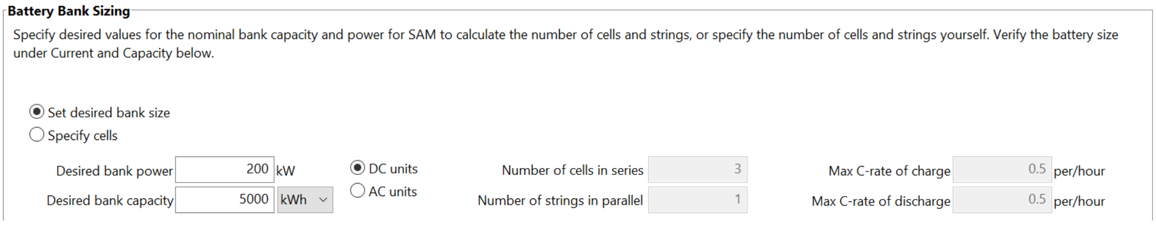


Figure 104. System design for 5MWh of battery capacity

Metric	Value
Annual energy (year 1)	1,665,592 kWh
Capacity factor (year 1)	18.7%
Energy yield (year 1)	1,635 kWh/kW
Performance ratio (year 1)	0.81
Battery roundtrip efficiency	91.37%
Battery charge energy from system	100.0%
Levelized COE (nominal)	7.91 ¢/kWh
Levelized COE (real)	6.32 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$-35,432
Net savings with system (year 1)	$244,607
Net present value	$851,099
Simple payback period	8.8 years
Discounted payback period	15.8 years
Net capital cost	$2,910,604
Equity	$1,164,242
Debt	$1,746,362

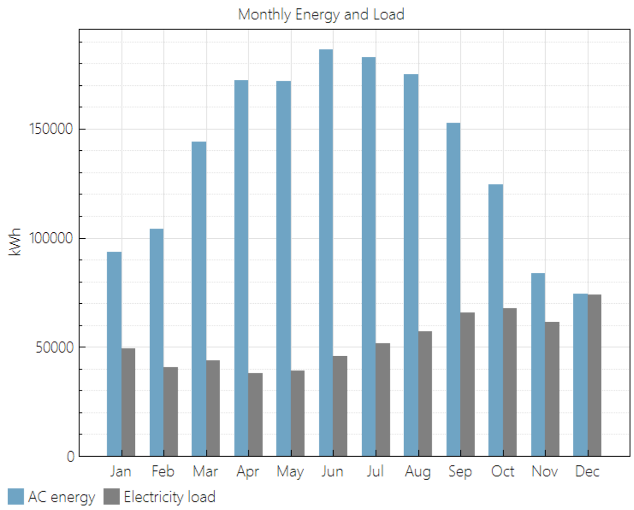


Table 28, Figure 105. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 1665MWh per year once we have calculated the losses, the total cost of the facility which is 2,910,604€ and the simple payback period that is 8.8 years.

With respect to the plot, the energy we produce is still much more than the one we need. So we have similar conclusions to the previous case for the energy we produce. Let´s check if the battery this time is worth it.

Now we have taken a graph in wich we can see along the year the percentage of the capacity of the battery each hour in dark green, the production per hour in light green, the amount KW used from the battery in blue, and in orange the part of the consumption which is taken from the grid.

This means that with this battery capacity we would be able to suply energy along the whole year to the auction centre except for some specific moments of November and December in which it may be cloudy so combined with the low irradiation and the bigger demand we won’t be able to cover them. However, this is just a tiny percentage of the total consumption. We also appreciate how the battery level of charge varies much more everyday.

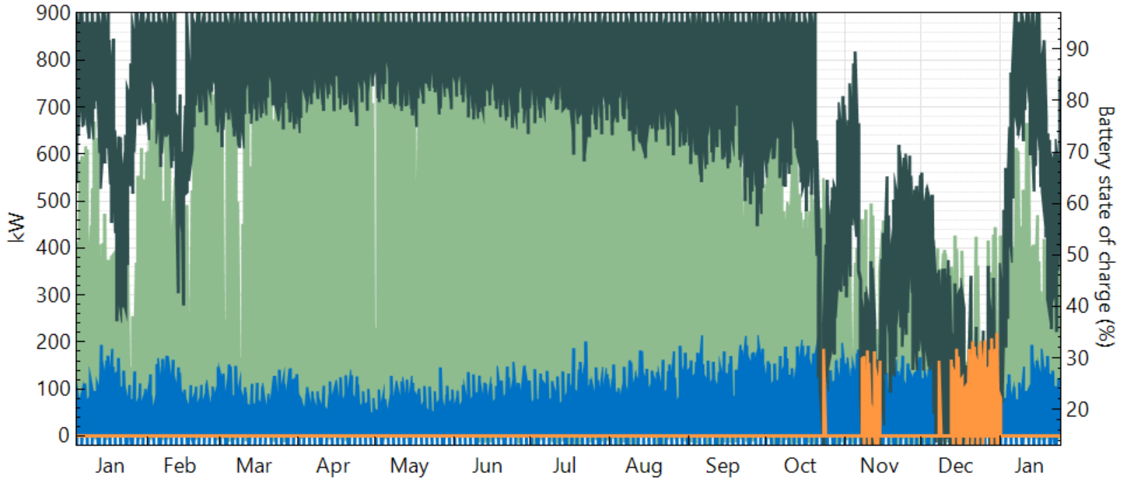


Figure 106. Annual battery percentage, consumption from battery, consumption from panels and panels production.

Now we will zoom in this plot in two different parts that are very representative as we did in a previous case. First, we will check the behaviour that our system has in a week of April and then in a week of December, which are the months in which the production and demand are completely opposite.

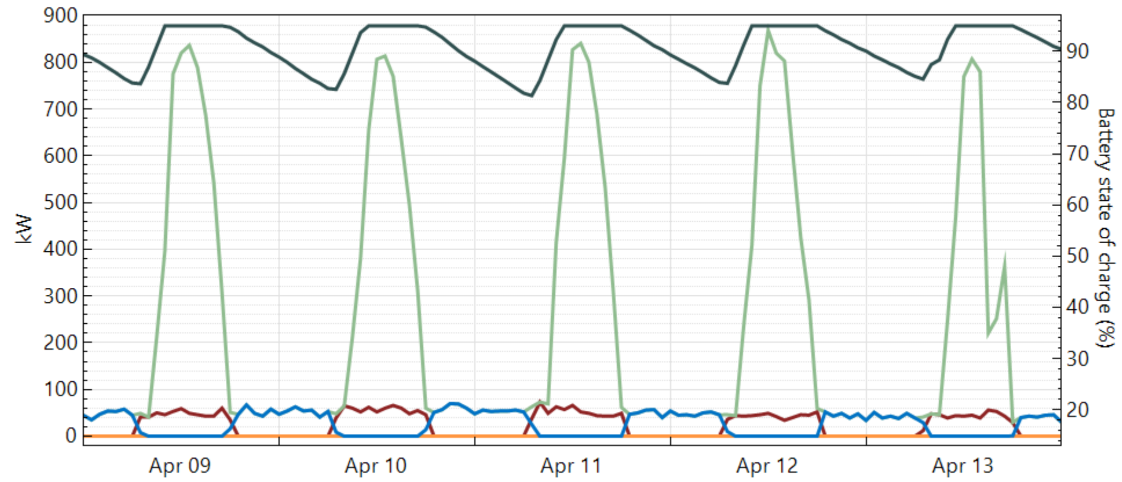


Figure 107. Battery percentage, consumption from battery, consumption from panels and panels production along a week of April

As we can see the battery percentage does not go down 85% in this period, the peaks of production feed the battery completely and the consumption of the auction centre is fully covered by the batteries when there is no solar energy from the panels.

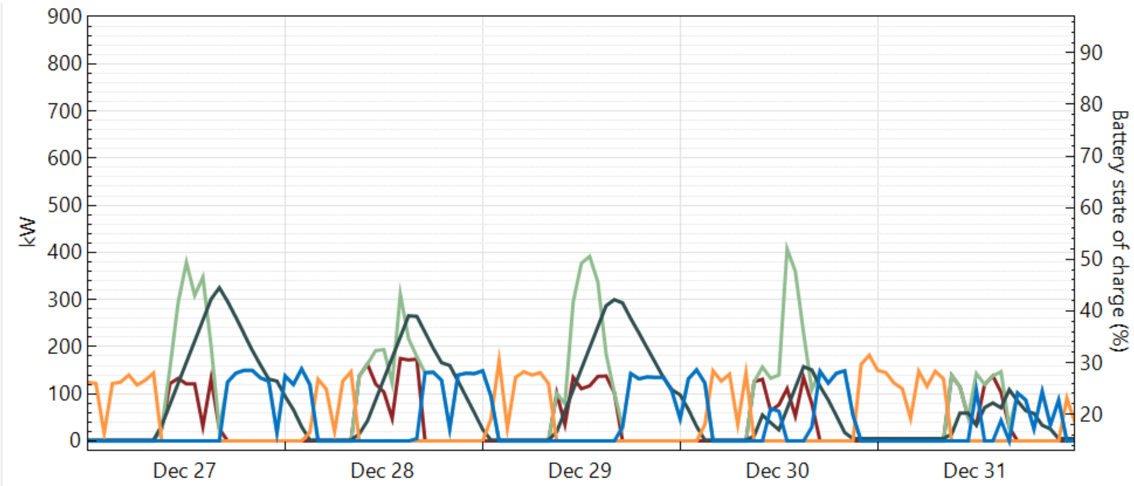


Figure 108. Annual battery percentage, consumption from battery, consumption from panels and panels production along a week of December

Along this week, the battery percentage is being restored up to 50% during the day with the excess of production but since the demand is too high the battery is not enough to feed the system durong the whole night so we need to make use of the grid for a few hours. To conclude, a plot for an average day each month was added to have another view of the data.

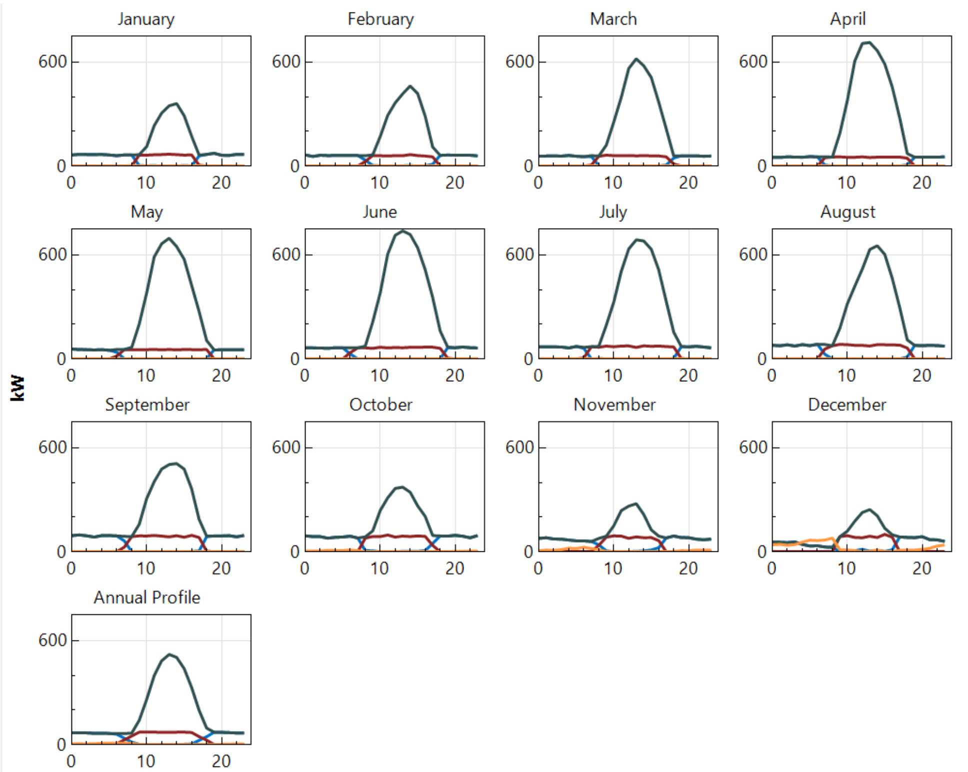


Figure 109. Daily average consumption from battery (Blue), consumption from panels (Red), panels production (Green) and consumption from grid (Yellow) each month

We perfectly distinguish that the production exceeds the consumption each month as in case 1. We are almost able to completely cover the demand even after a long period of low irradiation and high consumption with the battery we installed. Just November and December would be motnhs in which we would have to use the power from the grid.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

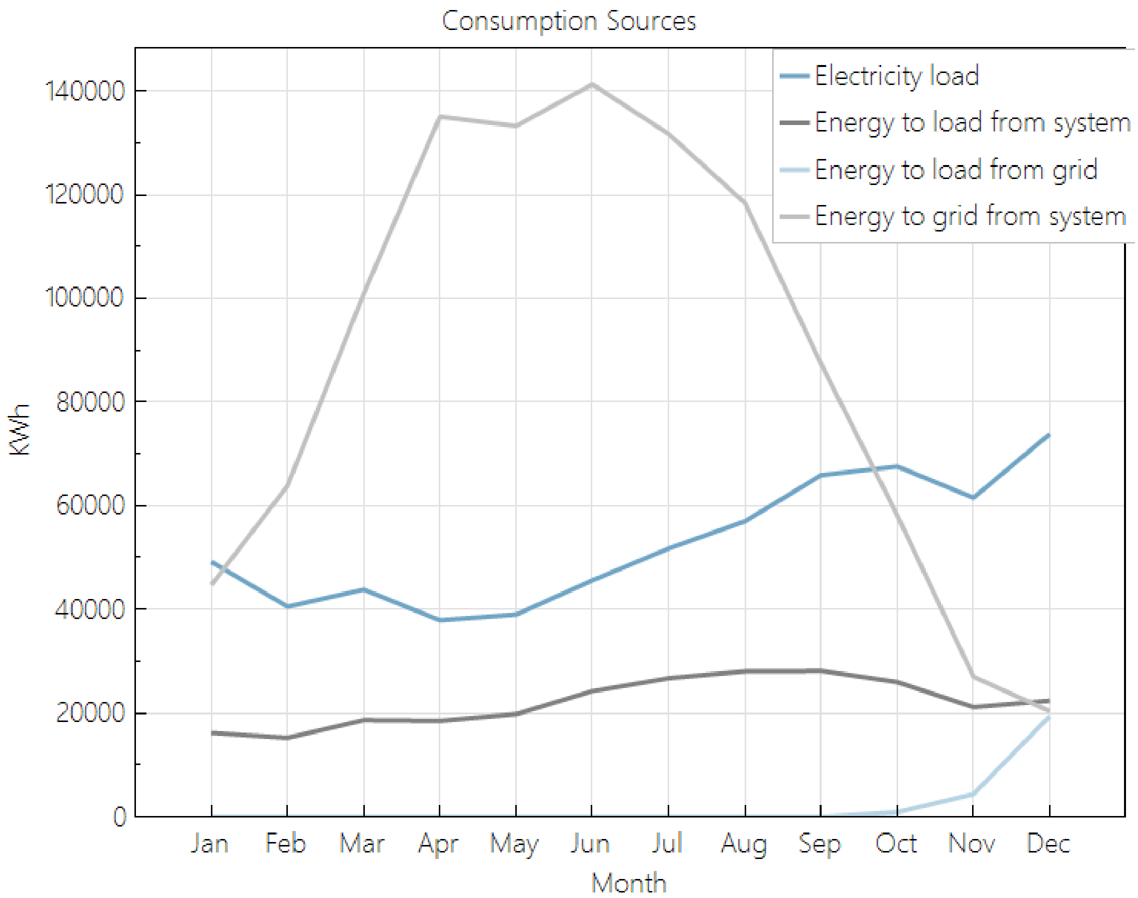


Figure 110. Consumption sources for case 2

We can conclude that the majority of energy we produce is not used by our system so we are wasting it. As the line for the electricity from the grid does not appear, this means that all the energy we need is taken from the system and the batteries.

➢ Case 3

This time we will try the same configuration for the panels but we will change the battery for a smaller one to save some costs due to the batteries which are the most expensive part of the project.

So we will just set the settings for a battery with 2MWh of capacity and then run the simulation.

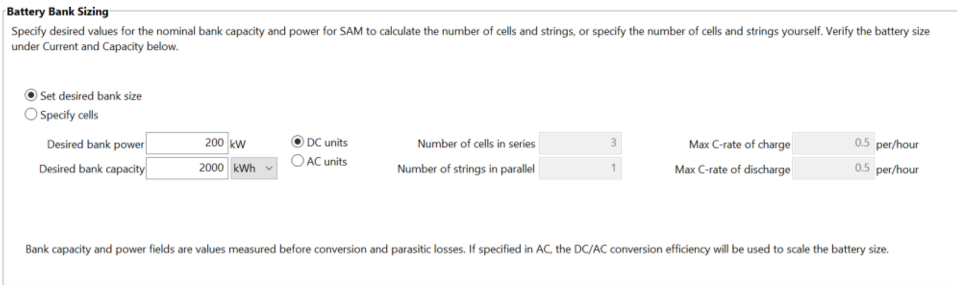


Figure 111. System design for 2MWh of battery capacity

Metric	Value
Annual energy (year 1)	1,662,350 kWh
Capacity factor (year 1)	18.6%
Energy yield (year 1)	1,632 kWh/kW
Performance ratio (year 1)	0.81
Battery roundtrip efficiency	90.54%
Battery charge energy from system	100.0%
Levelized COE (nominal)	6.81 ¢/kWh
Levelized COE (real)	5.43 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$-23,802
Net savings with system (year 1)	$232,978
Net present value	$925,643
Simple payback period	7.3 years
Discounted payback period	11.4 years
Net capital cost	$2,265,601
Equity	$906,240
Debt	$1,359,360

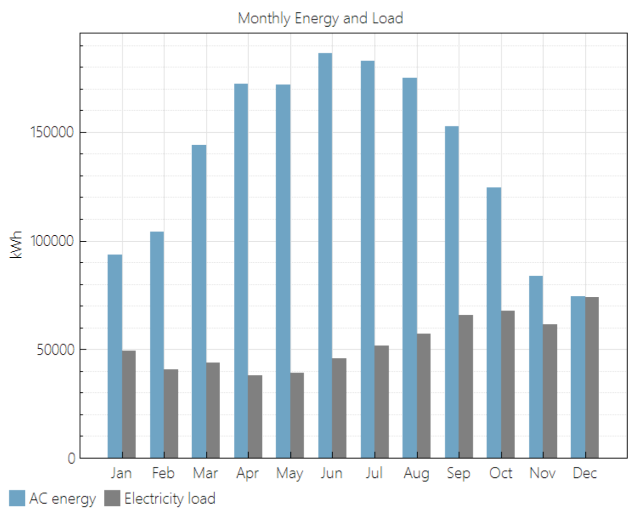


Table 29, Figure 112. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 1662MWh per year once we have calculated the losses, the total cost of the facility which is 2,265,601€ and the simple payback period that is 7.3 years.

With respect to this plot, we have the same conclusions to the previous case for the energy we produce since we didn´t change that parameter. Let´s check if the battery capacity is better now.

Now we have taken a graph in wich we can see along the year the percentage of the capacity of the battery each hour in dark green, the production per hour in light green, the amount KW used from the battery in blue, and in orange the part of the consumption which is taken from the grid.

This means that with this battery capacity we would be able to suply energy along the whole year to the auction centre except for some specific moments from Setember and December in which it may be cloudy so combined with the low irradiation and the bigger demand we won't be able to cover them. Still, this is just a small percentage of the total consumption.

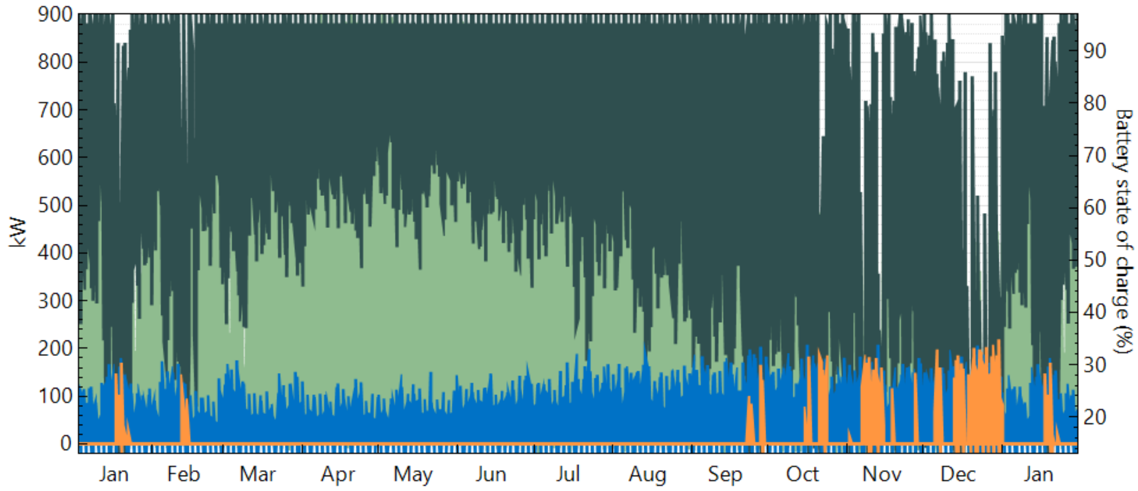


Figure 113. Annual battery percentage, consumption from battery, consumption from panels and panels production.

Now we will zoom in this plot in two different parts that are very representative as we did in a previous case. First, we will check the behaviour that our system has in a week of April and then in a week of December, which are the months in which the production and demand are completely opposite.

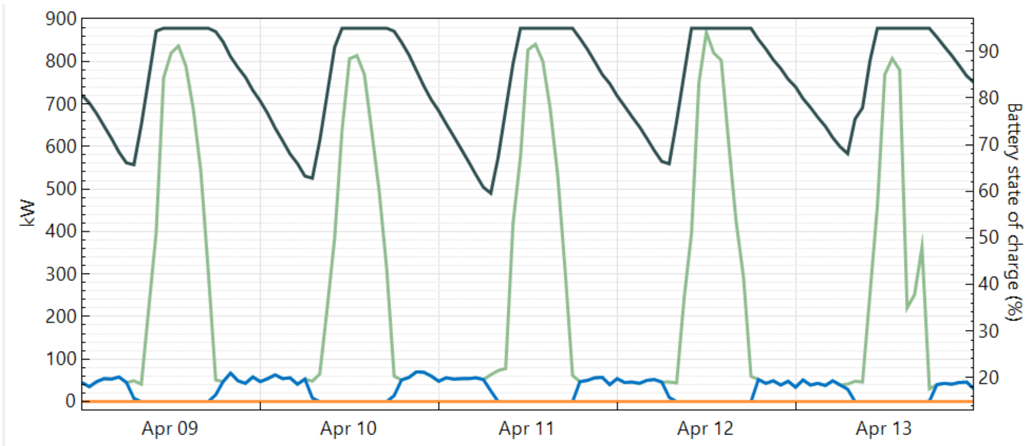


Figure 114. Battery percentage, consumption from battery, consumption from panels and panels production along a week of April

As we can see the battery percentage goes down to 65% in this period after covering the demand during the night, the peaks of production feed the battery completely and the consumption of the auction centre is fully covered by the batteries when there is no solar energy from the panels.

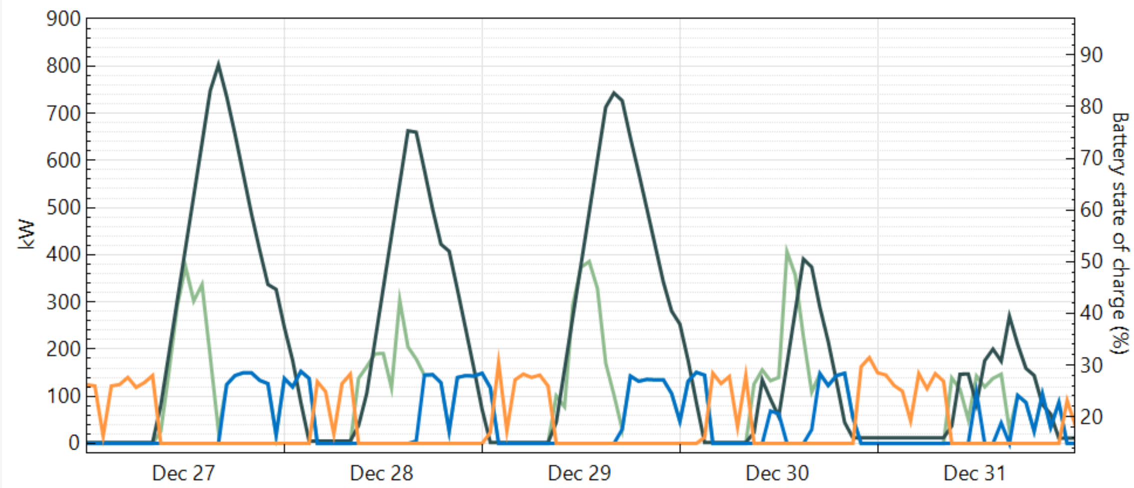


Figure 115. Annual battery percentage, consumption from battery, consumption from panels and panels production along a week of December

Along this week, the battery percentage is being almost fully restored during the day with the excess of production but since the demand is too high the battery has not enough capacity to feed the system during the whole night so we need to make use of the grid for a few hours.

To conclude, a plot for an average day each month was added to have another view of the data.

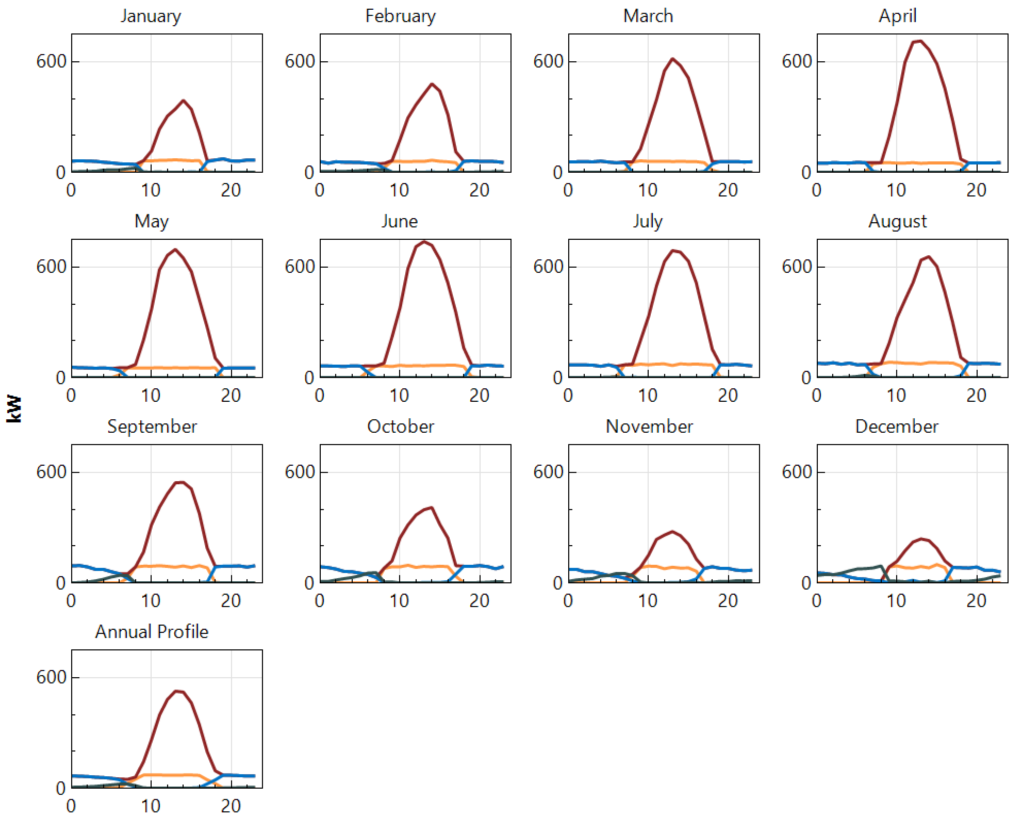


Figure 116. Daily average consumption from battery (Blue), consumption from panels (Yellow) and panels production (Green) each month

We perfectly distinguish that the production exceeds the consumption each month as in cases 1 and 2. We are almost able to completely cover the demand even after a long period of low irradiation and high consumption with the battery we installed. Just some exceptional moments in which the demand is too high would be periods in which we would have to use the power from the grid.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

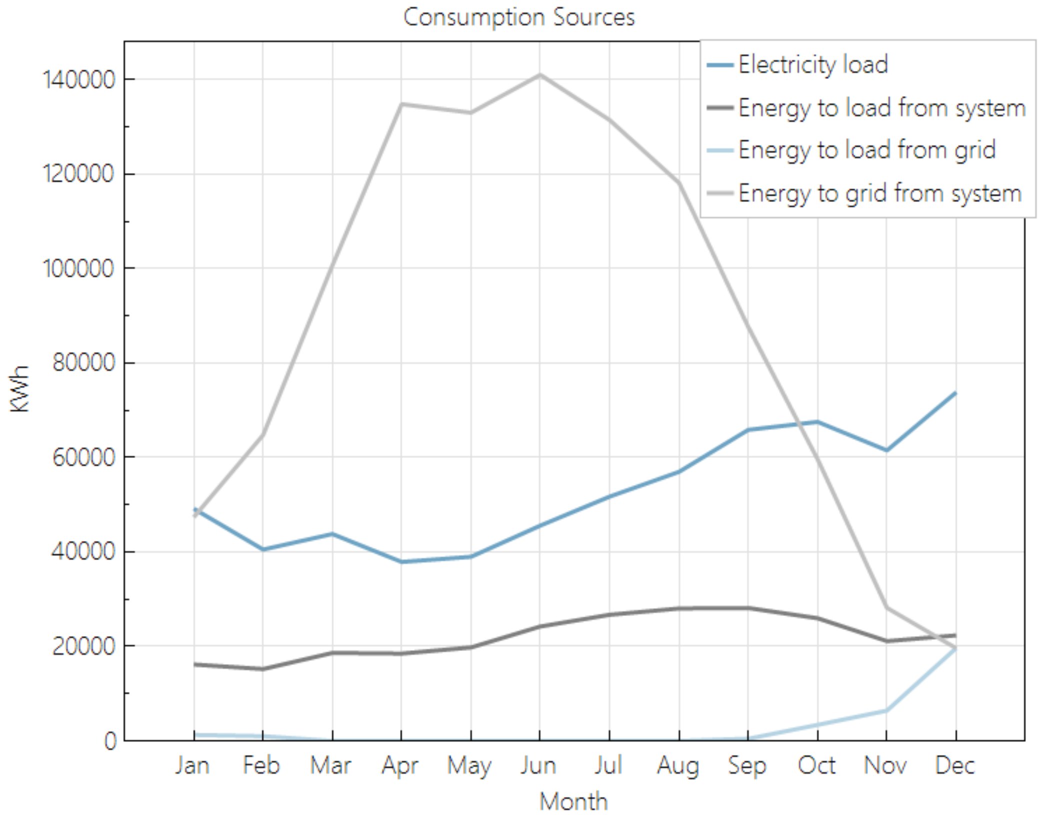


Figure 117. Consumption sources for case 3

We could still say that the majority of energy we produce is not used by our system so we are wasting it once again. As the line for the electricity from the grid just appears from September, this means that all the rest of the energy we need is taken from the system and the batteries.

➢ Case 4

For this purpose, we will use the same configuration as previously but we will remove the panels which were on the horizontal surface.

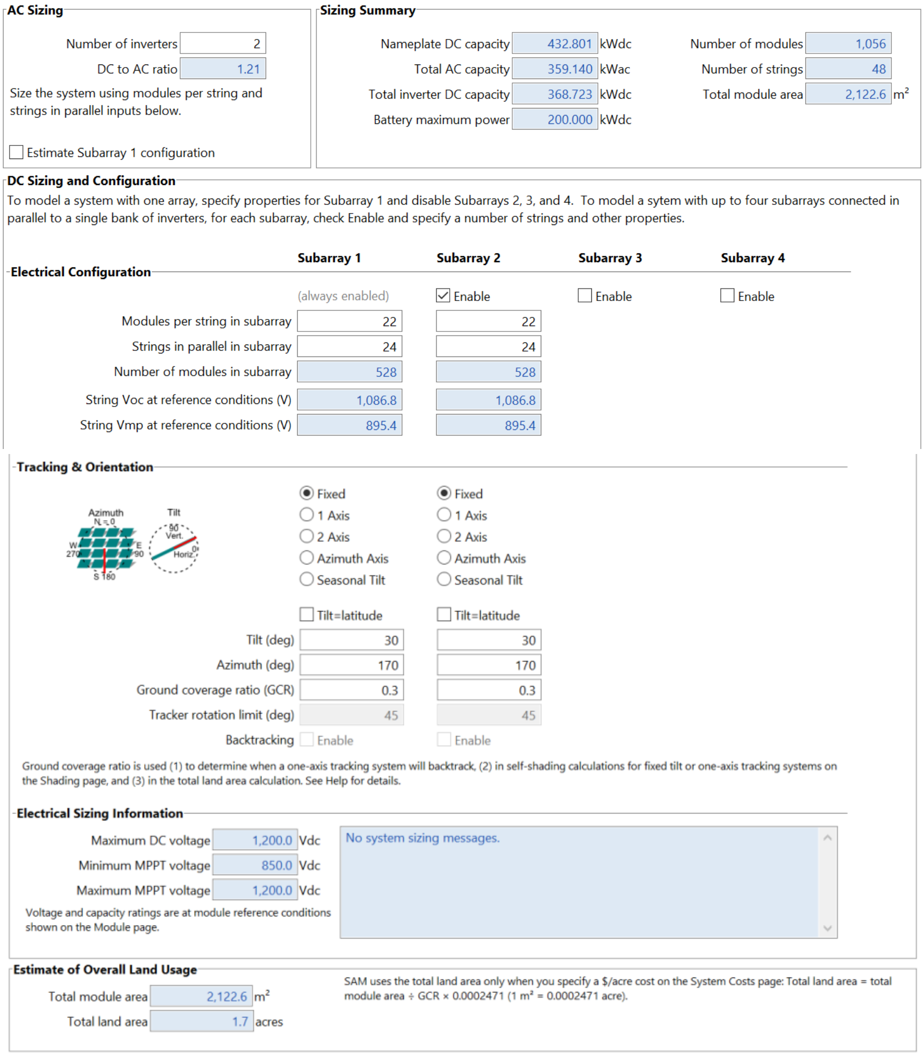


Figure 118. System design for 433KWh of production

For 0,432MWh we will need 2 inverters since our objective is that the DC to AC ratio is less than 1.2 to reduce the losses.

For the capacity of the batteries, we will try with 2KW to check how the change of power produce affects the system.

Metric	Value
Annual energy (year 1)	748,645 kWh
Capacity factor (year 1)	19.7%
Energy yield (year 1)	1,730 kWh/kW
Performance ratio (year 1)	0.78
Battery roundtrip efficiency	90.75%
Battery charge energy from system	100.0%
Levelized COE (nominal)	8.57 ¢/kWh
Levelized COE (real)	6.83 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$38,998
Net savings with system (year 1)	$170,178
Net present value	$808,794
Simple payback period	5.7 years
Discounted payback period	7.9 years
Net capital cost	$1,284,965
Equity	$513,986
Debt	$770,979

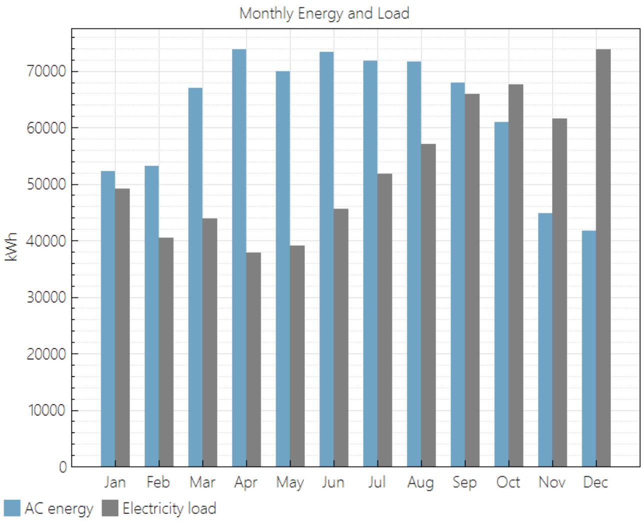


Table 30, Figure 119. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 748KWh per year once we have calculated the losses, the total cost of the facility which is 1,284,965€ and the simple payback period that is 5.7 years.

With respect to the plot, this time is more fitted the production with respect to the consumption monthly. Our excess of production is from March to August while the one with higher production is from September to December. We could make this fit a bit better with a higher elevation of the panels since it is more propper for winter season. This would make the installation more expensive and less robust.

Now we have taken a graph in wich we can see along the year the percentage of the capacity of the battery each hour in dark green, the production per hour in light green, the amount KW used from the battery in blue, and in orange the part of the consumption which is taken from the grid.

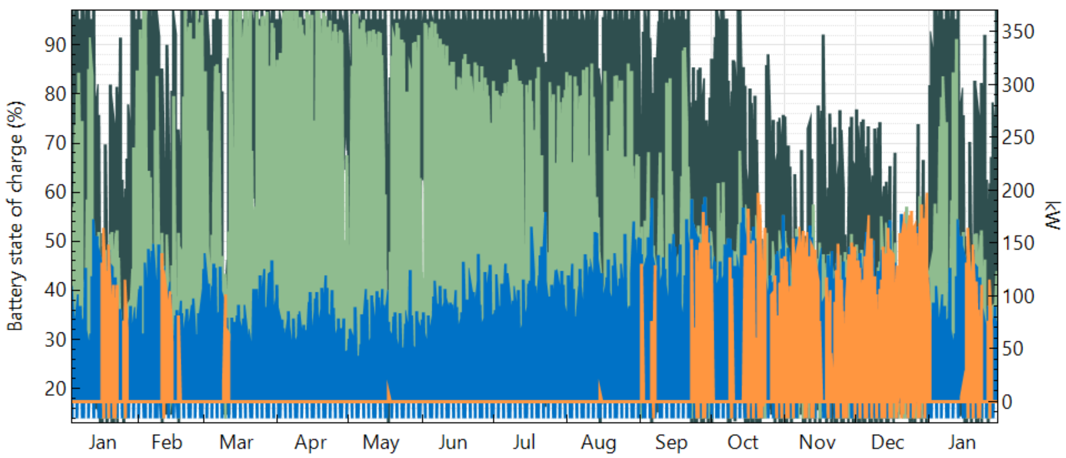


Figure 120. Annual battery percentage, consumption from battery, consumption from panels and panels production.

The percentage of energy we need to take from the grid is considerably higher tha in the previous cases.

Now we will zoom in this plot in two different parts that are very representative as we did in a previous case. Once again, we will check the behaviour that our system has in a week of April and then in a week of December.

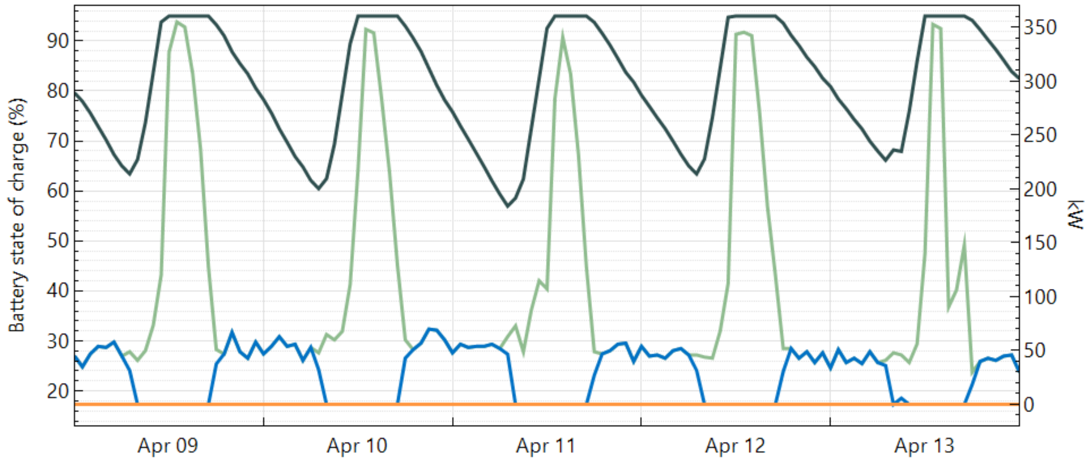


Figure 121. Battery percentage, consumption from battery, consumption from panels and panels production along a week of April

As we can see the battery behaves in the same way as in the previous case since the production we have here is more than enough to fill up the batteries.

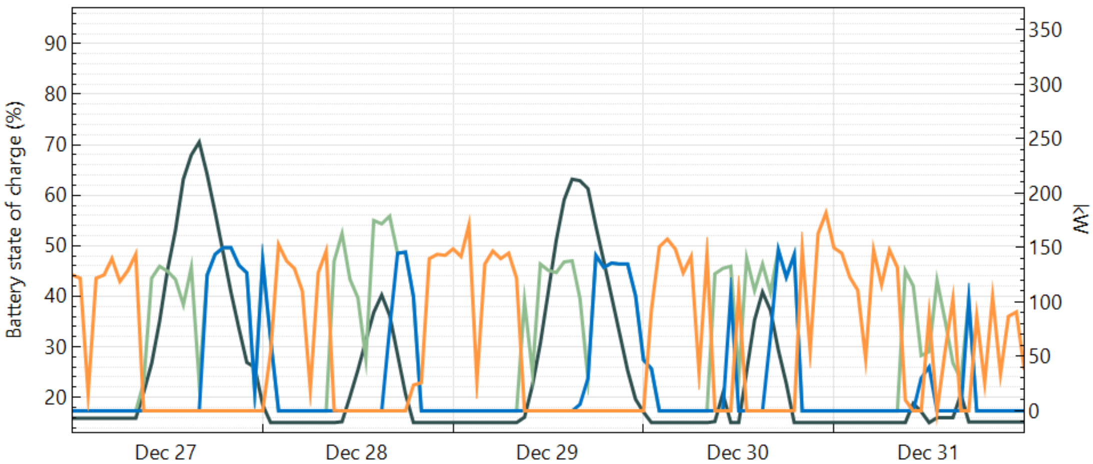


Figure 122. Annual battery percentage, consumption from battery, consumption from panels and panels production along a week of December

Along this week, the battery percentage is filled up during the day but the battery capacity is not enough for the whole night.

To conclude, a plot for an average day each month was added to have another view of the data.

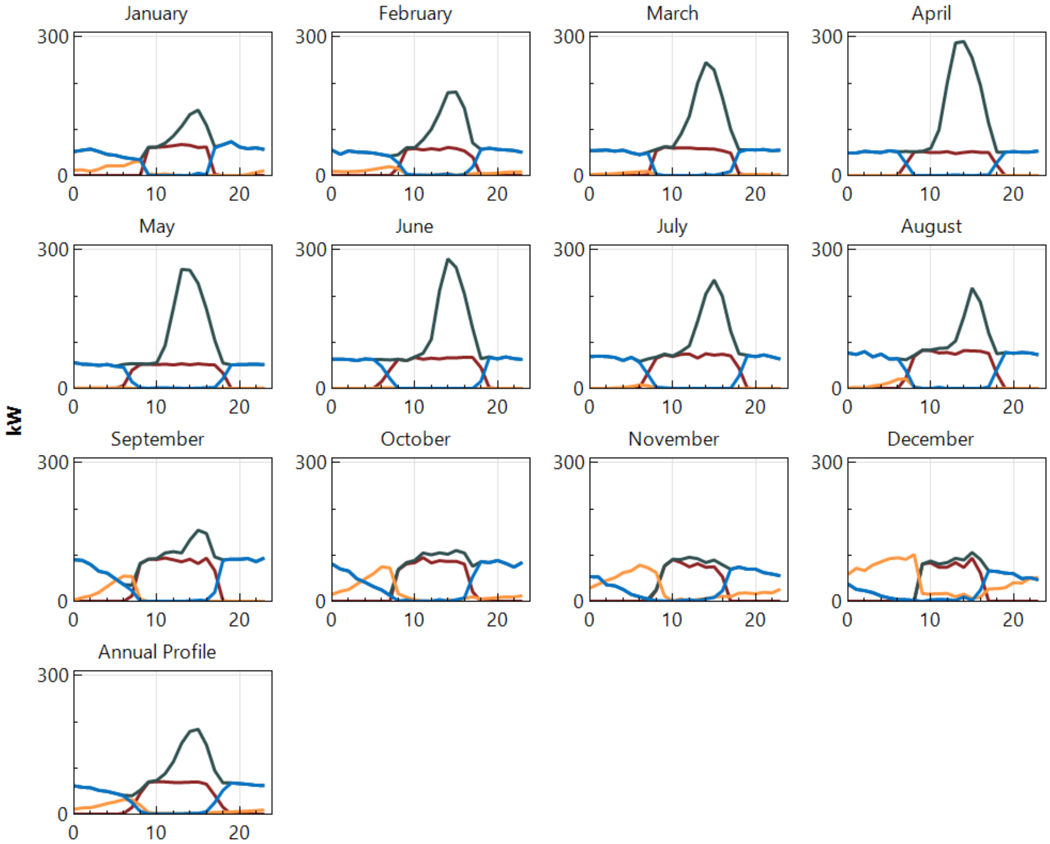


Figure 123. Daily average consumption from battery (Blue), consumption from panels (Yellow) and panels production (Green) each month

We perfectly distinguish that the production exceeds the consumption each month as in cases 1,2 and 3. We start to need more often the energy from the grid. Even when there is a cloudy day, the battery may not be enough supply for the whole night even in August.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

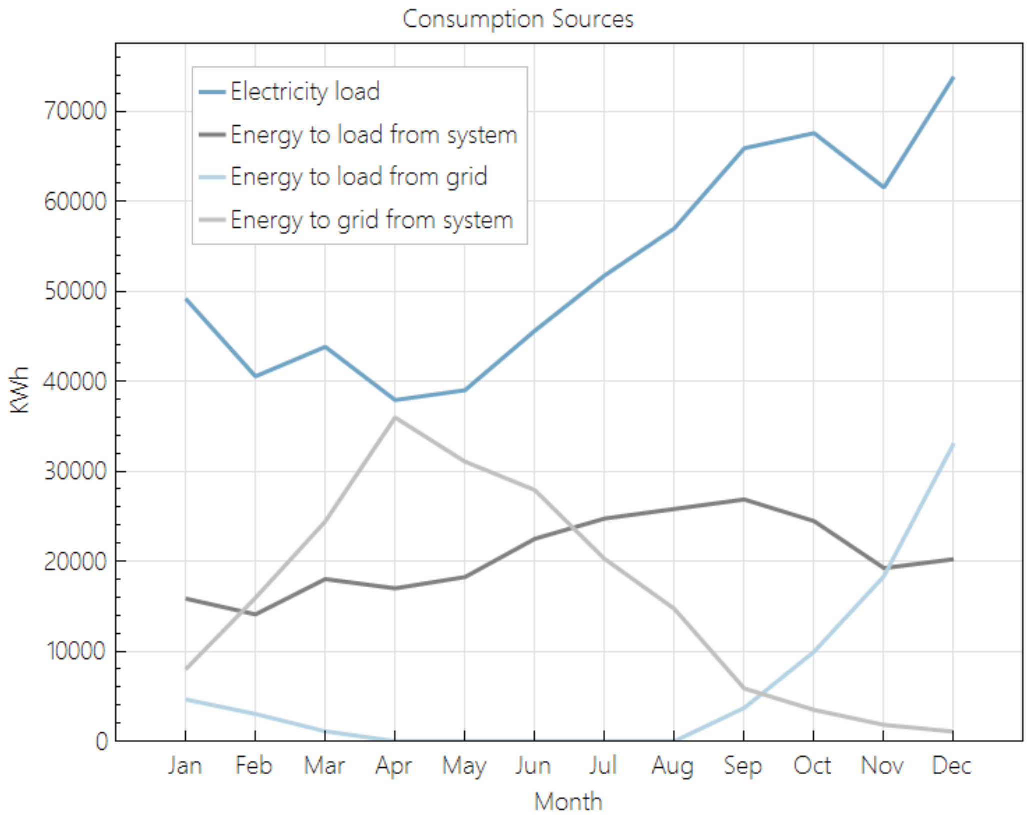


Figure 124. Consumption sources for case 4

We could say that this time the energy we produce is not as wasted as before since there was a great reduction in the electricity we send to the grid.Obviously it is the highest in the motnhs with a greater irradiation when the consumption is also lower.

As the line for the electricity from the grid just appears from August, this means that all the rest of the energy we need is taken from the system and the batteries. In this case, we alredy have to use a considerable amount of electricity from the grid in the last months of the year.

- **Case 5**

This time we will use the same configuration for the panels but we will change the battery for a smaller one to save some costs due to the batteries which are the most expensive part of the project.

So we will just set the settings for a battery with 1MWh of capacity and then run the simulation.

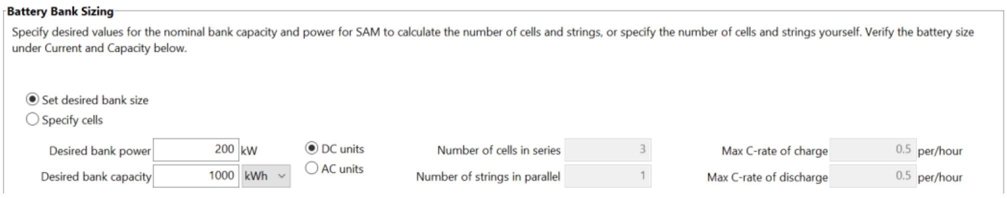


Figure 125. System design for 500KWh of battery capacity

Metric	Value
Annual energy (year 1)	751,173 kWh
Capacity factor (year 1)	19.8%
Energy yield (year 1)	1,736 kWh/kW
Performance ratio (year 1)	0.79
Battery roundtrip efficiency	89.72%
Battery charge energy from system	100.0%
Levelized COE (nominal)	7.09 ¢/kWh
Levelized COE (real)	5.65 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$55,496
Net savings with system (year 1)	$153,679
Net present value	$812,934
Simple payback period	5.3 years
Discounted payback period	7.0 years
Net capital cost	$1,070,305
Equity	$428,122
Debt	$642,183

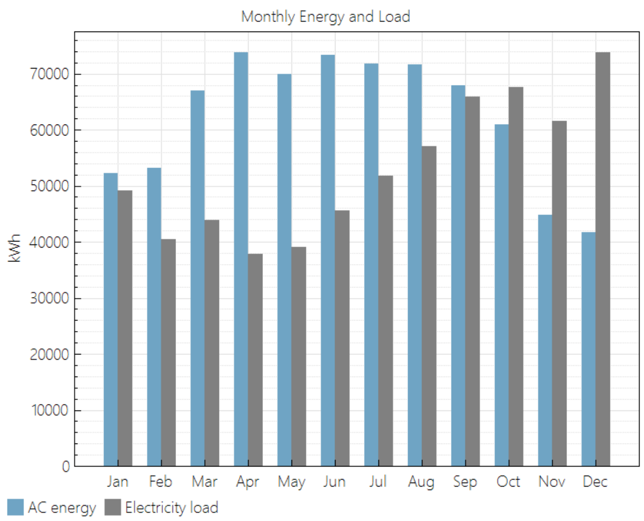


Table 31, Figure 126. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 751KWh per year once we have calculated the losses, the total cost of the facility which is 812,934€ and the simple payback period that is 5.3 years.

With respect to this plot, we have the same conclusions to the previous case for the energy we produce since we didn´t change that parameter. Let´s check the battery capacity.

Now we have taken a graph in which we can see along the year the percentage of the capacity of the battery each hour in dark green, the production per hour in light green, the amount KW used from the battery in blue, and in orange the part of the consumption which is taken from the grid.

This means that with this battery capacity we would be able to suply energy to the system for some hours after the sunset. Just the months with lower demand and a higher radiation would be fully covered unless some exceptional cloudy days.

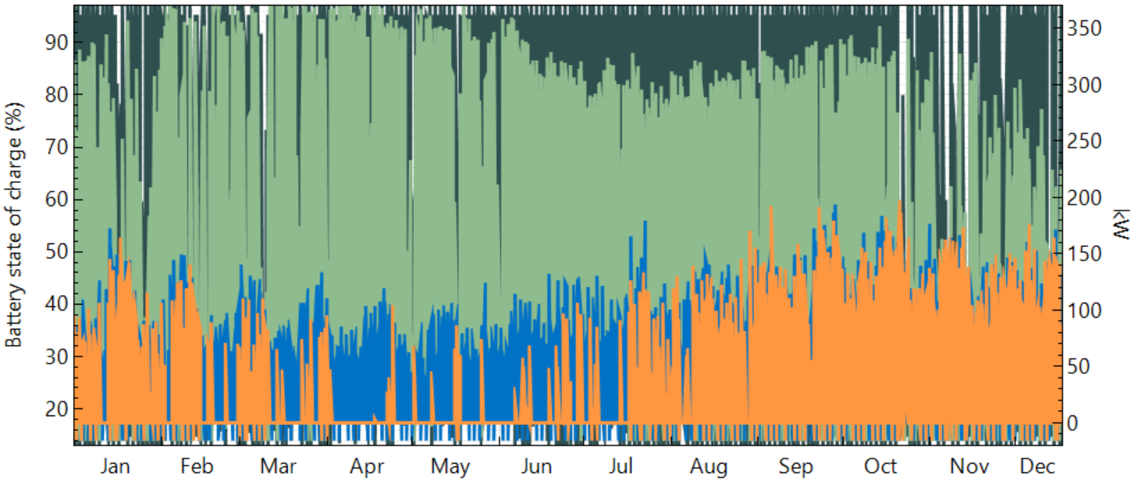


Figure 127. Annual battery percentage, consumption from battery, consumption from panels and panels production.

Now we will zoom in this plot in two different parts that are very representative as we did in a previous case. First, we will check the behaviour that our system has in a week of April and then in a week of December, which are the months in which the production and demand are completely opposite.

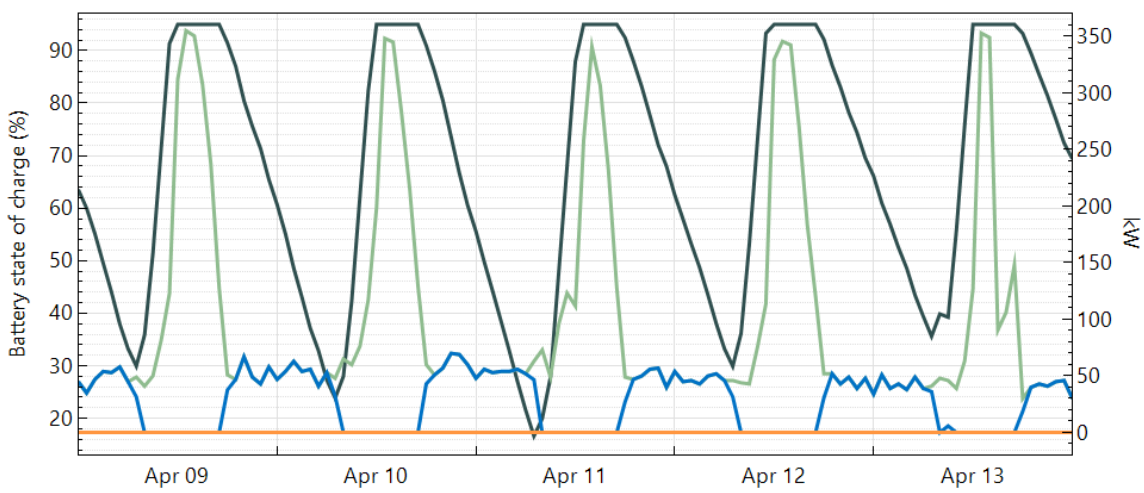


Figure 128. Battery percentage, consumption from battery, consumption from panels and panels production along a week of April

As we can see, even with the best conditions the battery consumes all its capacity to feed the auction centre during the night. When there is sun light, the battery fully recovers.

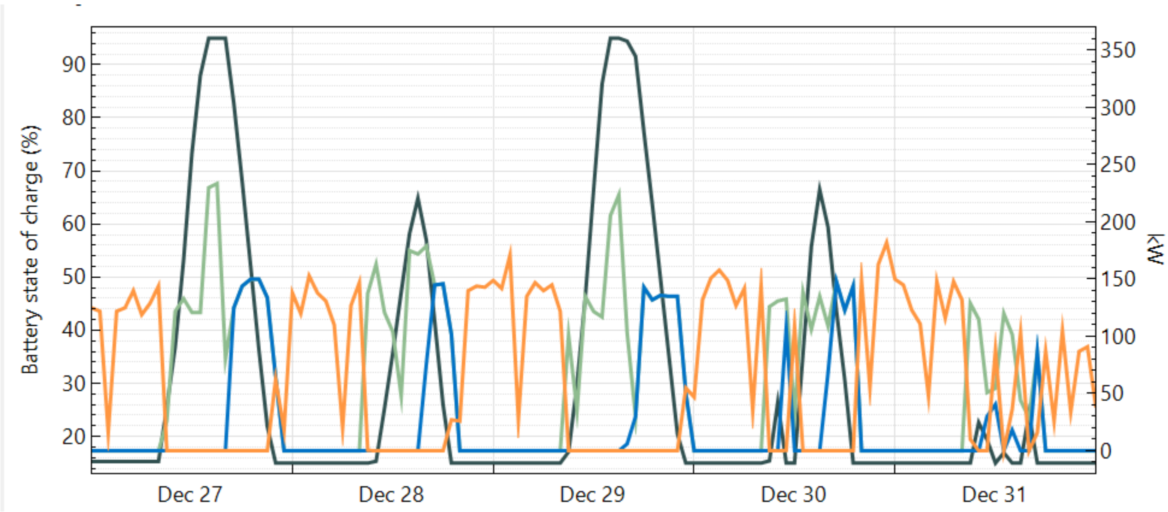


Figure 129. Annual battery percentage, consumption from battery, consumption from panels and panels production along a week of December

Along this week, however, the battery percentage is being almost fully restored during the day with the excess of production but since the demand is too high the battery has not enough capacity to feed the system during the whole night so we need to make use of the grid for a few hours.

To conclude, a plot for an average day each month was added to have another view of the data.

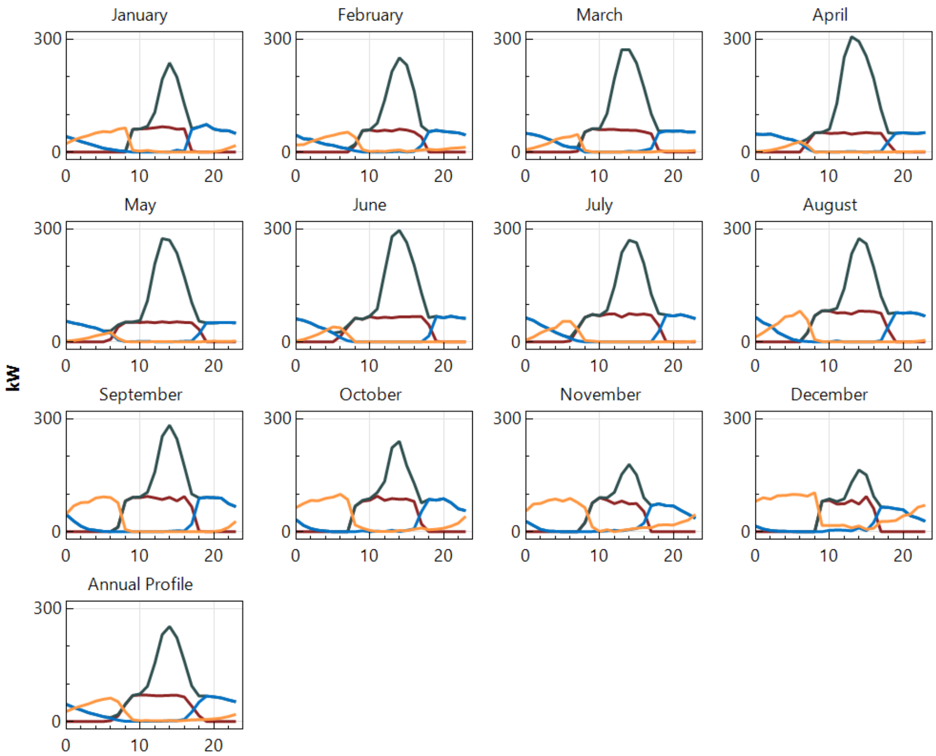


Figure 130. Daily average consumption from battery (Blue), consumption from panels (Yellow) and panels production (Green) each month

We perfectly distinguish that the production exceeds the consumption each month as in all the previous cases which is basically to feed the battery. With this system, we would be really dependent from the grid. Basically, we are saving money when the Price of the electricity is the highest and buying it when it is the cheapest.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

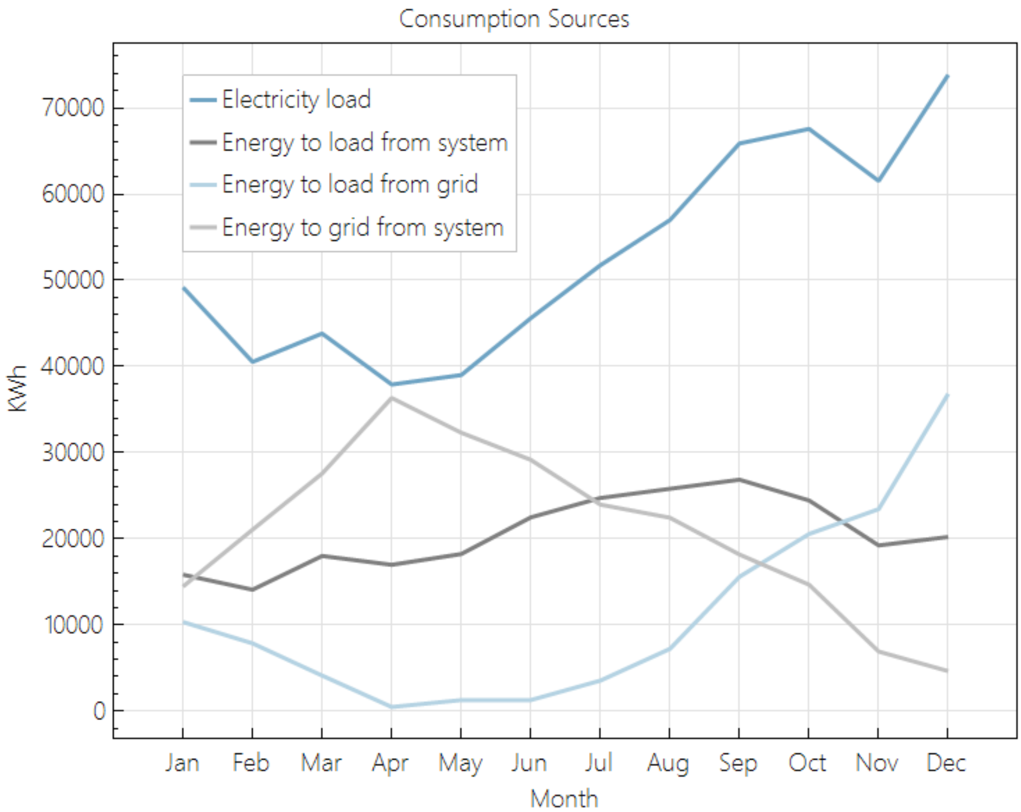


Figure 131. Consumption sources for case 5

We could say that, this time, the energy we produce a bit more wasted since we do not have such a capacity to keep all that energy. So our system either has not enough batteries or we need to reduce the production.

For this case, we already need a supply from the grid along all year mostly in the last motnhs of the year.

➢ Case 6

This time, we will try to use the same configuration for the panels but we will remove the battery. So we will just set the settings for a battery with 0KWh of capacity and then run the simulation.

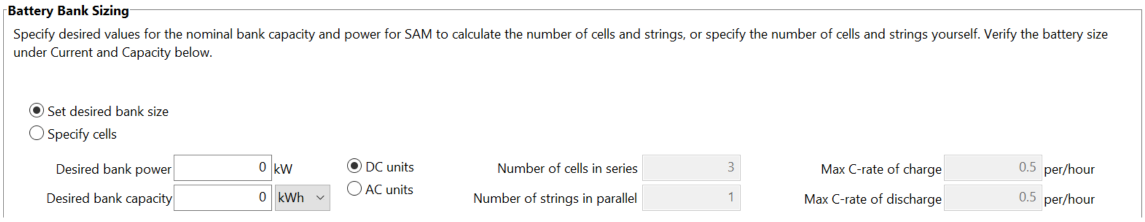


Figure 132. Battery configuration for cases 6 and 7

Metric	Value
Annual energy (year 1)	779,033 kWh
Capacity factor (year 1)	20.5%
Energy yield (year 1)	1,800 kWh/kW
Performance ratio (year 1)	0.82
Battery roundtrip efficiency	NaN
Battery charge energy from system	NaN
Levelized COE (nominal)	4.58 ¢/kWh
Levelized COE (real)	3.65 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$85,724
Net savings with system (year 1)	$123,452
Net present value	$732,157
Simple payback period	4.6 years
Discounted payback period	5.7 years
Net capital cost	$724,162
Equity	$289,665
Debt	$434,497

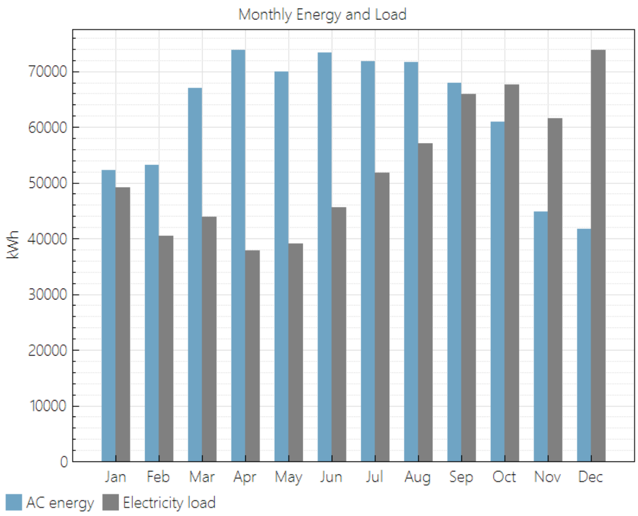


Table 32, Figure 133. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 779KWh per year once we have calculated the losses, the total cost of the facility which is 724,162€ and the simple payback period that is 4,6 years.

With respect to this plot, we have the same conclusions to the previous case for the energy we produce since we didn´t change that parameter. What we want to know i show not having a battery affects the system.

Now we have taken a graph in which we can see along the year the production per hour in red and the part of the consumption which is taken from the grid in blue.

This means that with this configuration we would only be able to suply energy to the system during the hours in which the panels are producing energy.

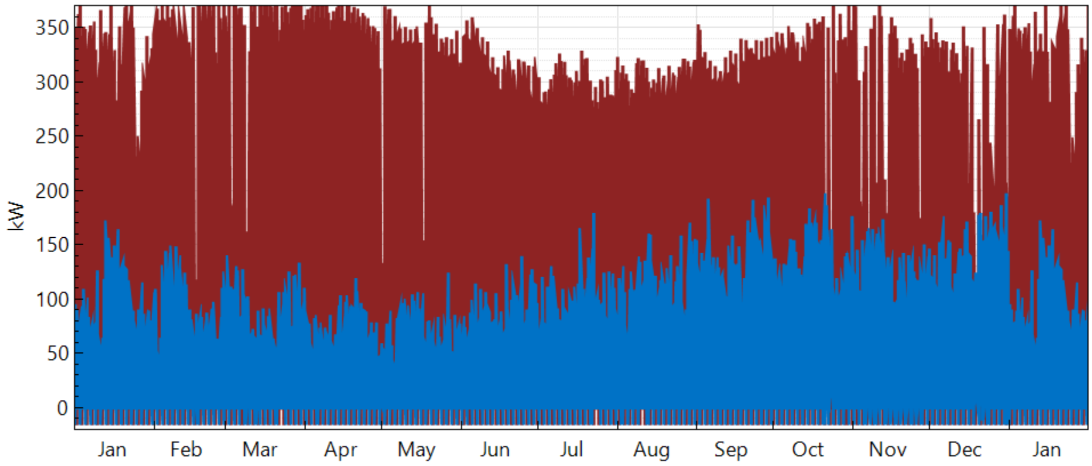


Figure 134. Consumption from panels and panels production.

As we are doing for all the cases, we will zoom in this plot in two different parts that are very representative as we did in a previous case.

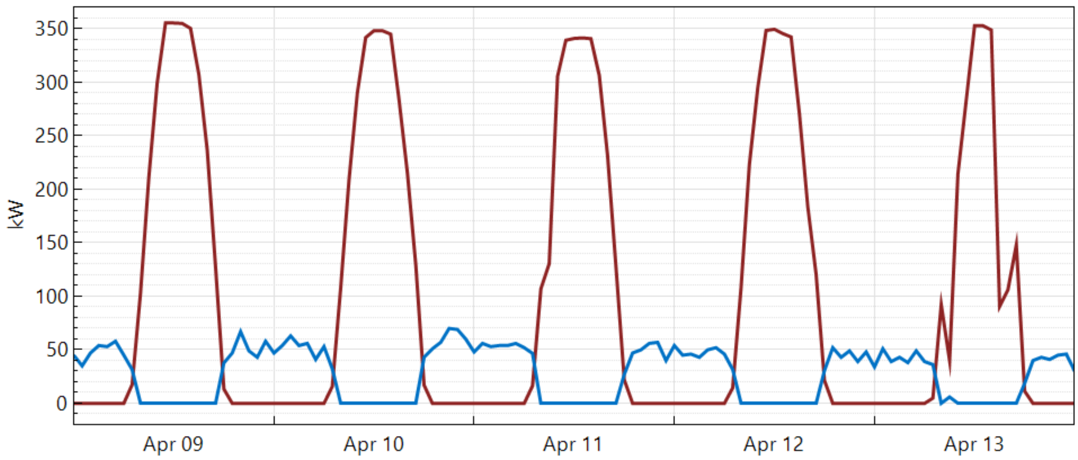


Figure 135. Consumption from panels and panels production along a week of April

As expected, in April we have a excess of production that, instead of storing in the batteries, we would have to sell to the net.

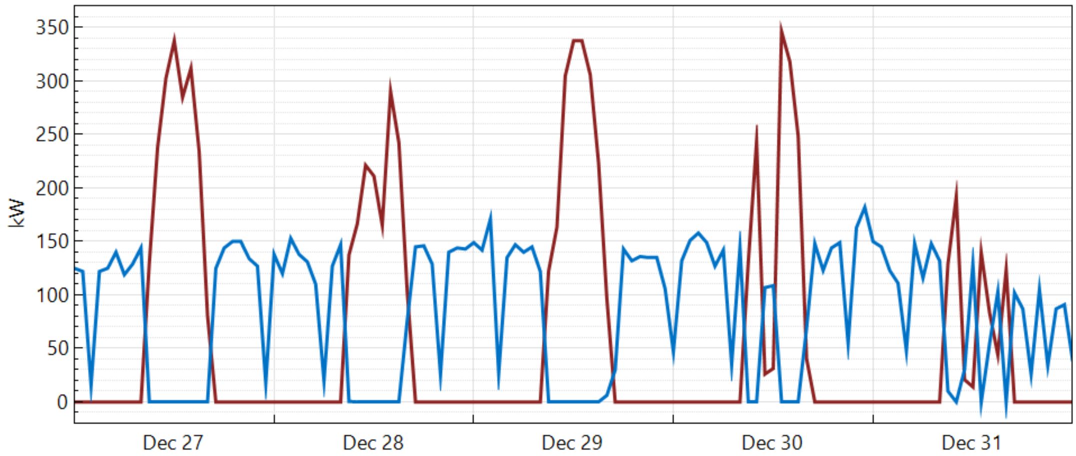


Figure 136. Consumption from panels and panels production along a week of December

Same behaviour occurs in December but with a lower difference between production and consumption.

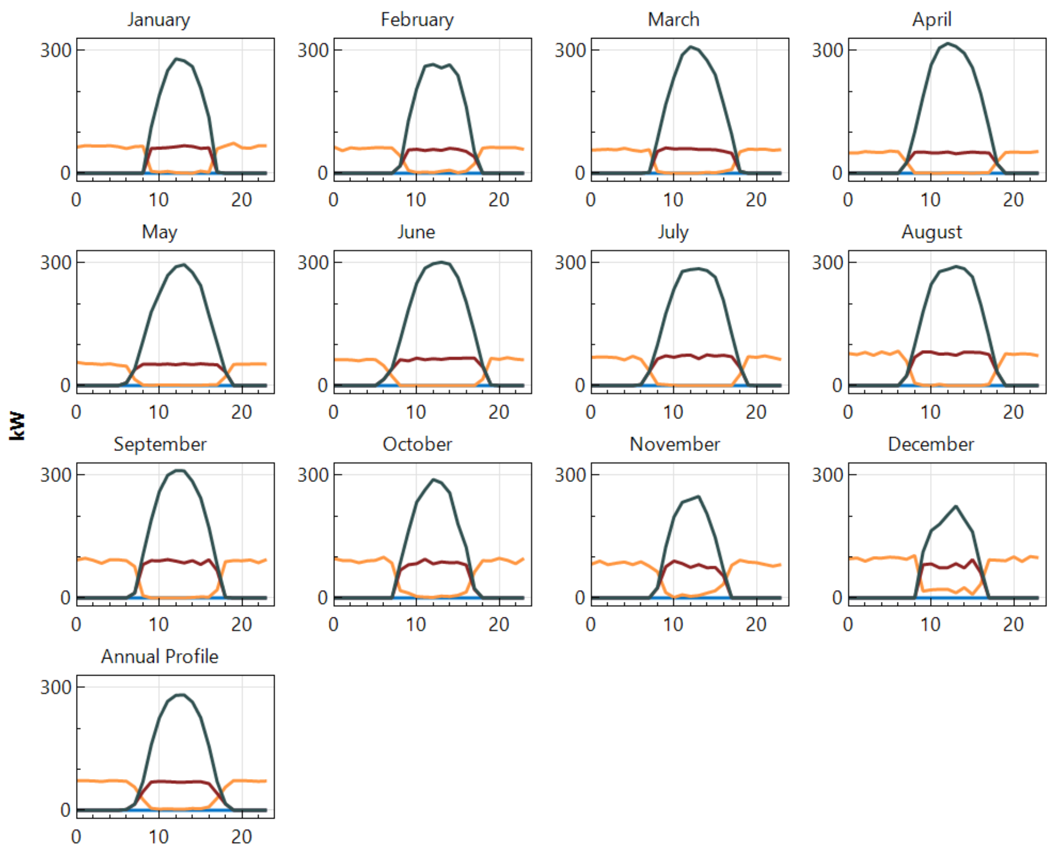


Figure 137. Consumption from panels (Red), consumption from grid (Yellow) and panels production (Green) each month

Having this system allows us to save energy just during sunlight hours, energy from the grid would have to be used the rest of the day.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

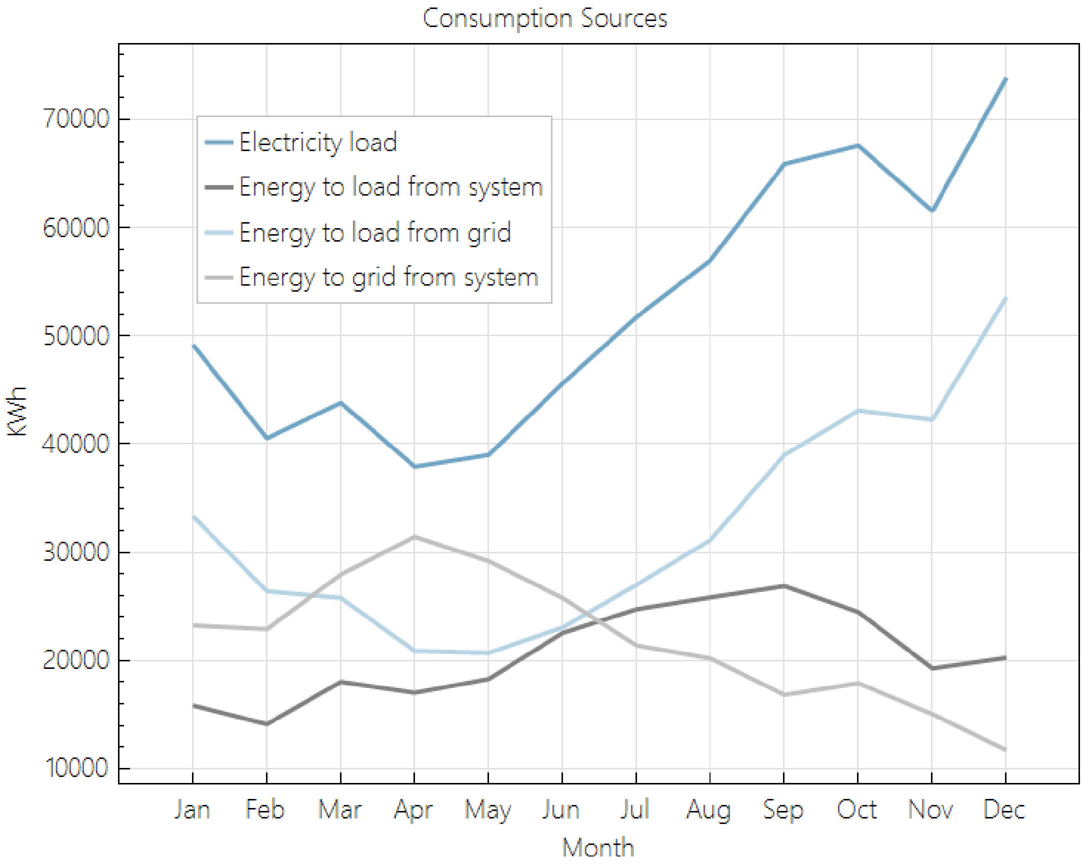


Figure 138. Consumption sources for case 6

As we do not have batteries to keep our energy, we will need to use the grid along all the year and we will only be able to save electricity and money when the system is producing energy. Yet, we are wasting so much energy that we are throwing to the grid.

➢ Case 7

For this purpose, we will use the same configuration as previously but we will remove the panels which were on the higher row of the faces pointing south.

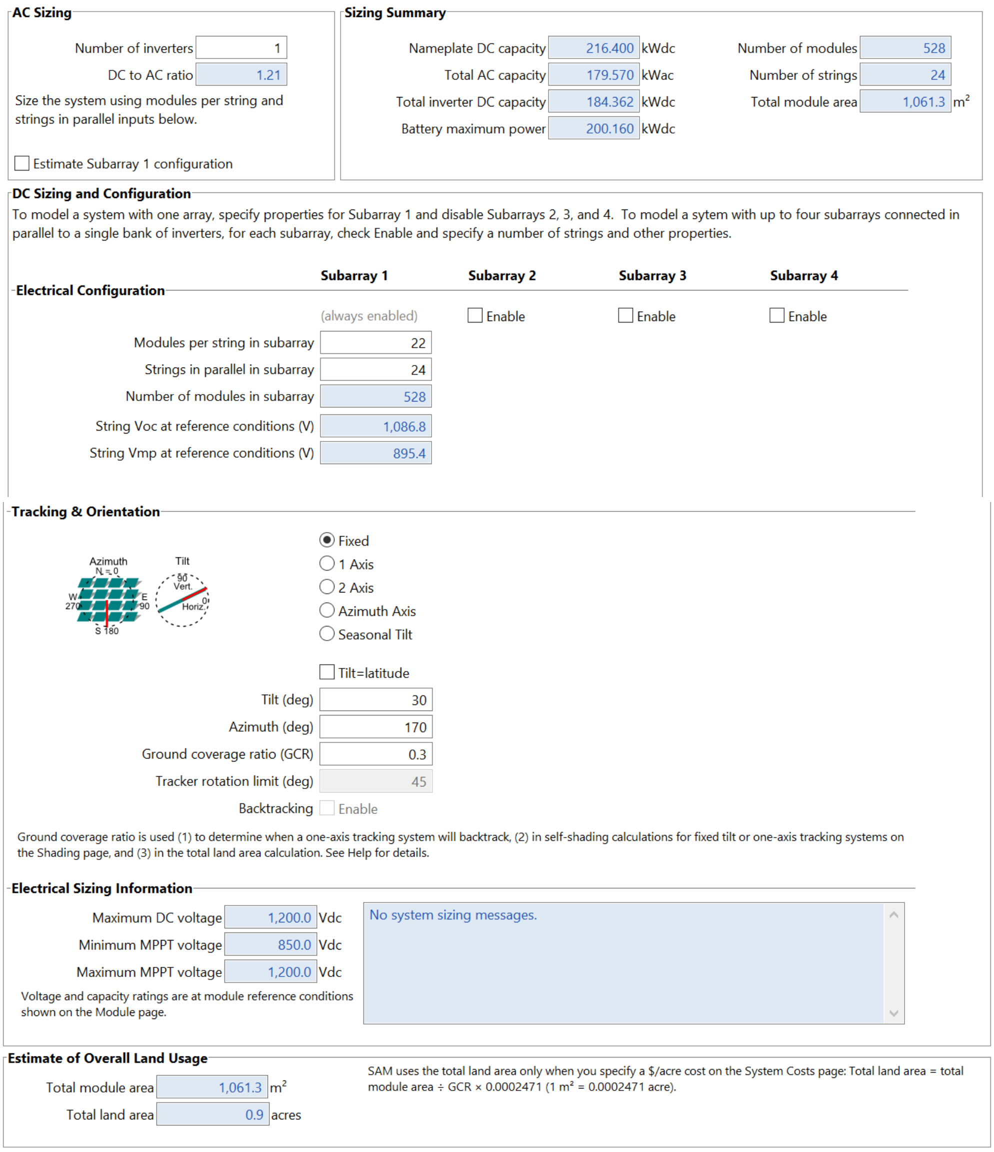


Figure 139. System design for 216KWh of production

Now we will run the simulation and analyse the data obtained.

Metric	Value
Annual energy (year 1)	389,516 kWh
Capacity factor (year 1)	20.5%
Energy yield (year 1)	1,800 kWh/kW
Performance ratio (year 1)	0.82
Battery roundtrip efficiency	NaN
Battery charge energy from system	NaN
Levelized COE (nominal)	4.58 ¢/kWh
Levelized COE (real)	3.65 ¢/kWh
Electricity bill without system (year 1)	$209,176
Electricity bill with system (year 1)	$124,649
Net savings with system (year 1)	$84,527
Net present value	$559,136
Simple payback period	3.6 years
Discounted payback period	4.1 years
Net capital cost	$362,081
Equity	$144,832
Debt	$217,249

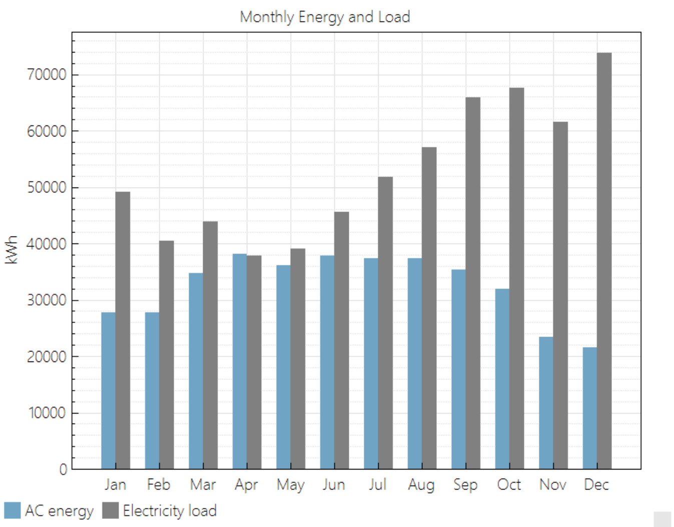


Table 33, Figure 140. Simulation summary and plot of energy produced/energy demanded

Some important data we extract from this are: the anual energy we can obtain with this system, which is 390KWh per year once we have calculated the losses, the total cost of the facility which is 362,081€ and the simple payback period that is 3,6 years.

What we have done now is fit the production during the day to the consumption. By doing this, we don't waste energy that otherwise we would have to give to the grid in exchange of a tiny amount of money.

Now we have taken a graph in which we can see along the year the production per hour in orange and the part of the consumption which is taken from the grid in blue.

This means that with this configuration we would only be able to suply energy to the system during the hours in which the panels are producing energy but now both values are more fitted.

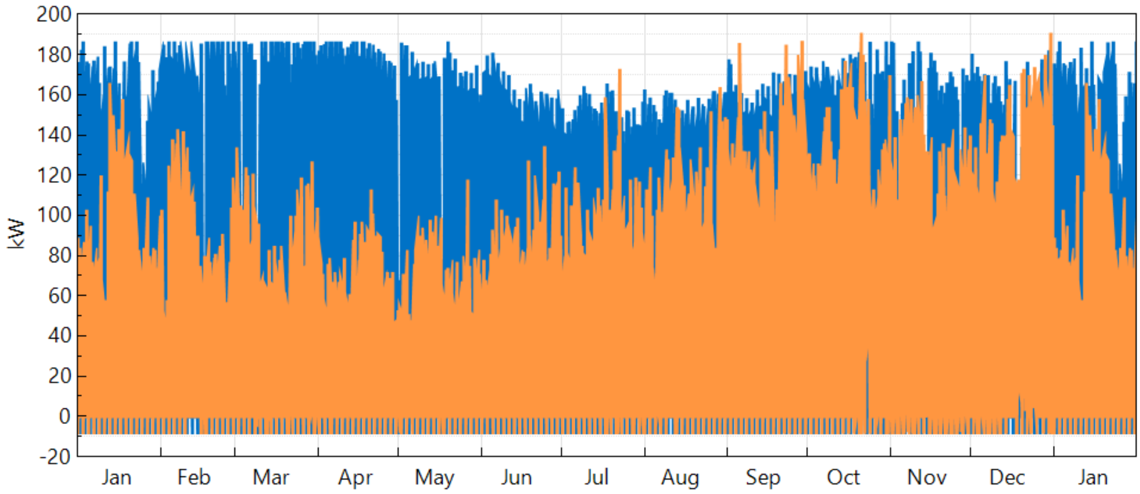


Figure 141. Consumption from panels and panels production.

As we are doing for all the cases, we will zoom in this plot in two different parts that are very representative as we did in a previous case.

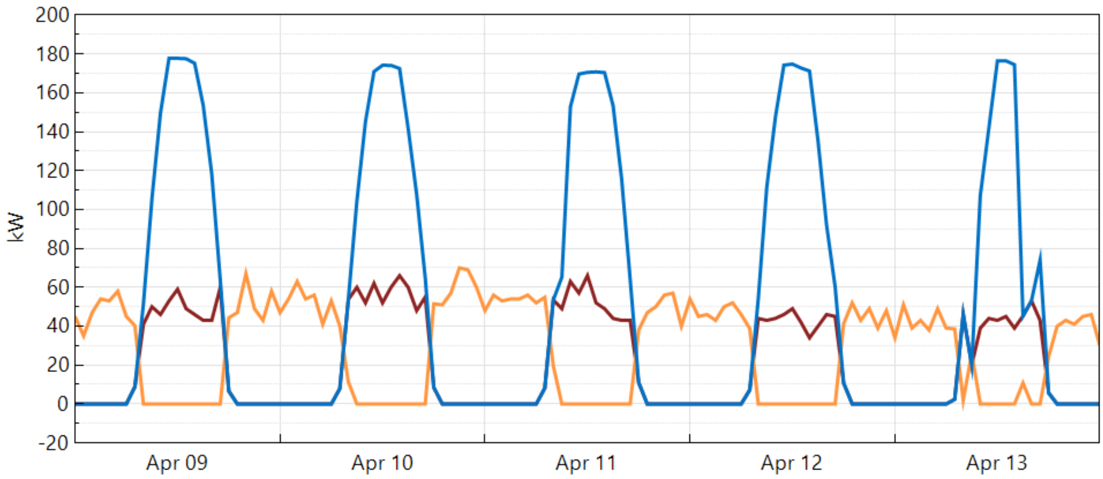


Figure 142. Consumption from panels and panels production along a week of April

As expected, in April we have a excess of production that, instead of storing in the batteries, we would have to sell to the net but this time is an aceptable amount.

Same behaviour occurs in December but with a lower difference between production and consumption. This time both consumption and production are at the same level which is ideal.

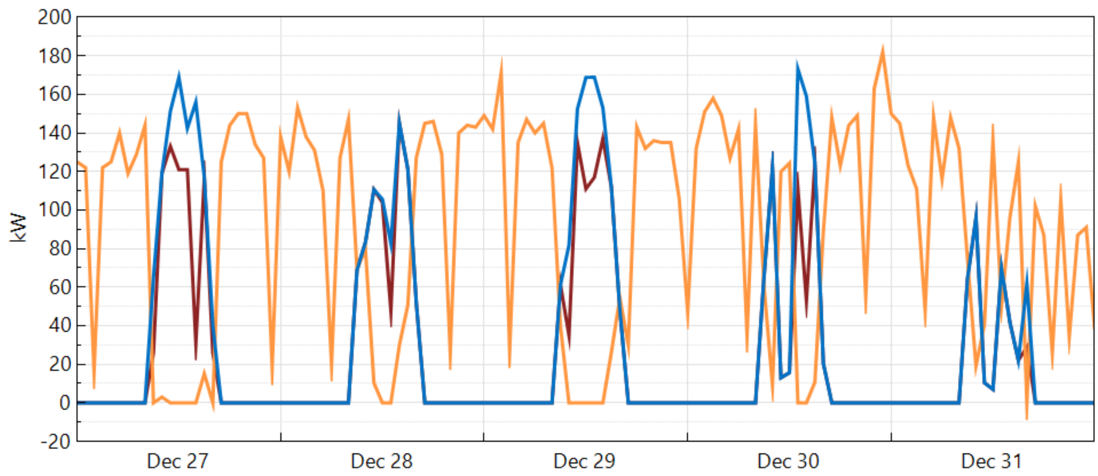


Figure 143. Consumption from panels and panels production along a week of December

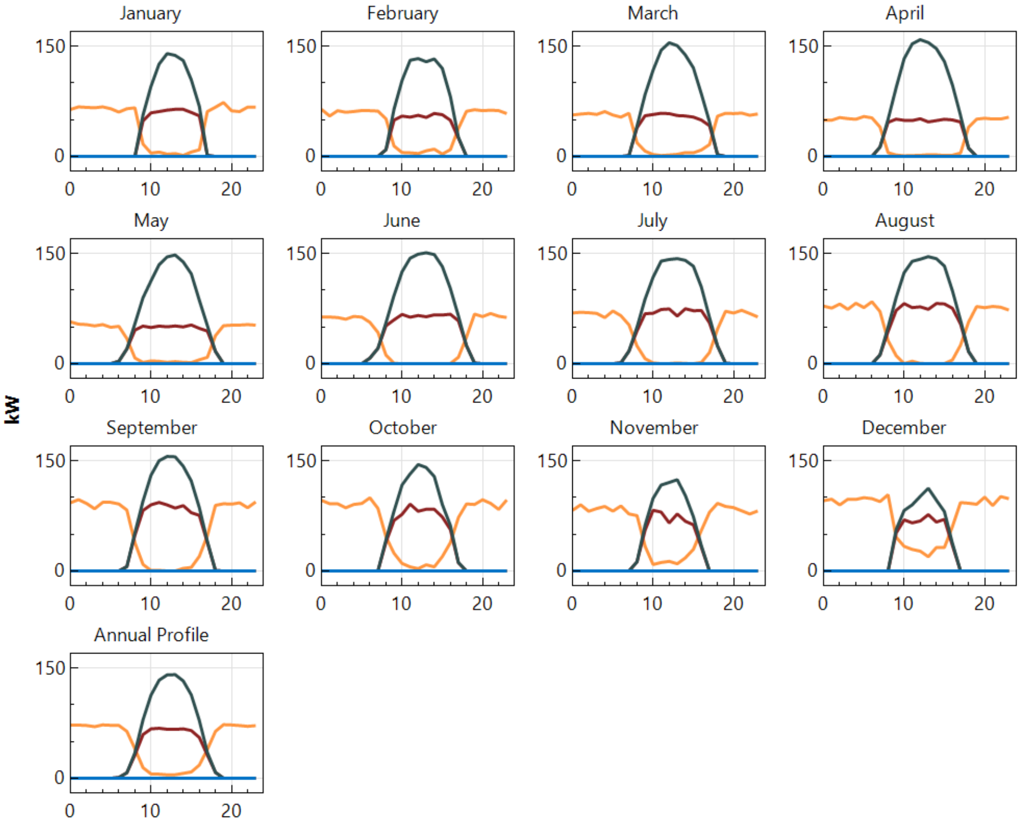


Figure 144. Consumption from panels (Red), consumption from grid (Yellow) and panels production (Green) each month

Having this system allows us to save energy just during sunlight hours, energy from the grid would have to be used the rest of the day.

Now, we will analyse plot in which we are able to compare the electricity that we need for the aution centre (Dark blue), the energy we take from the system (Dark gray), the excess of energy we produce se we need to give it to the grid (Light gray), and the consumption from the grid (Light blue).

The electricity load minus the energy to load from system and the energy to load from grid makes the energy taken from the batteries.

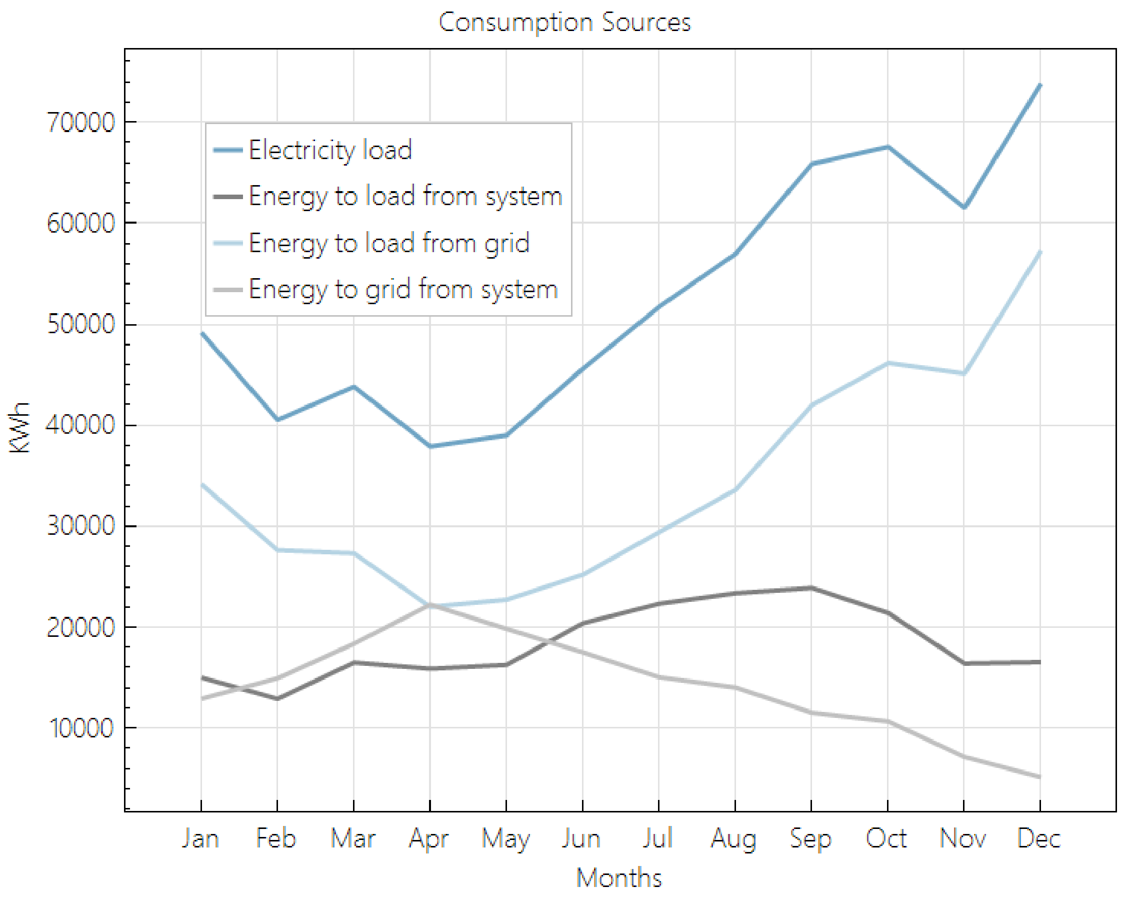


Figure 145. Consumption sources for case 7

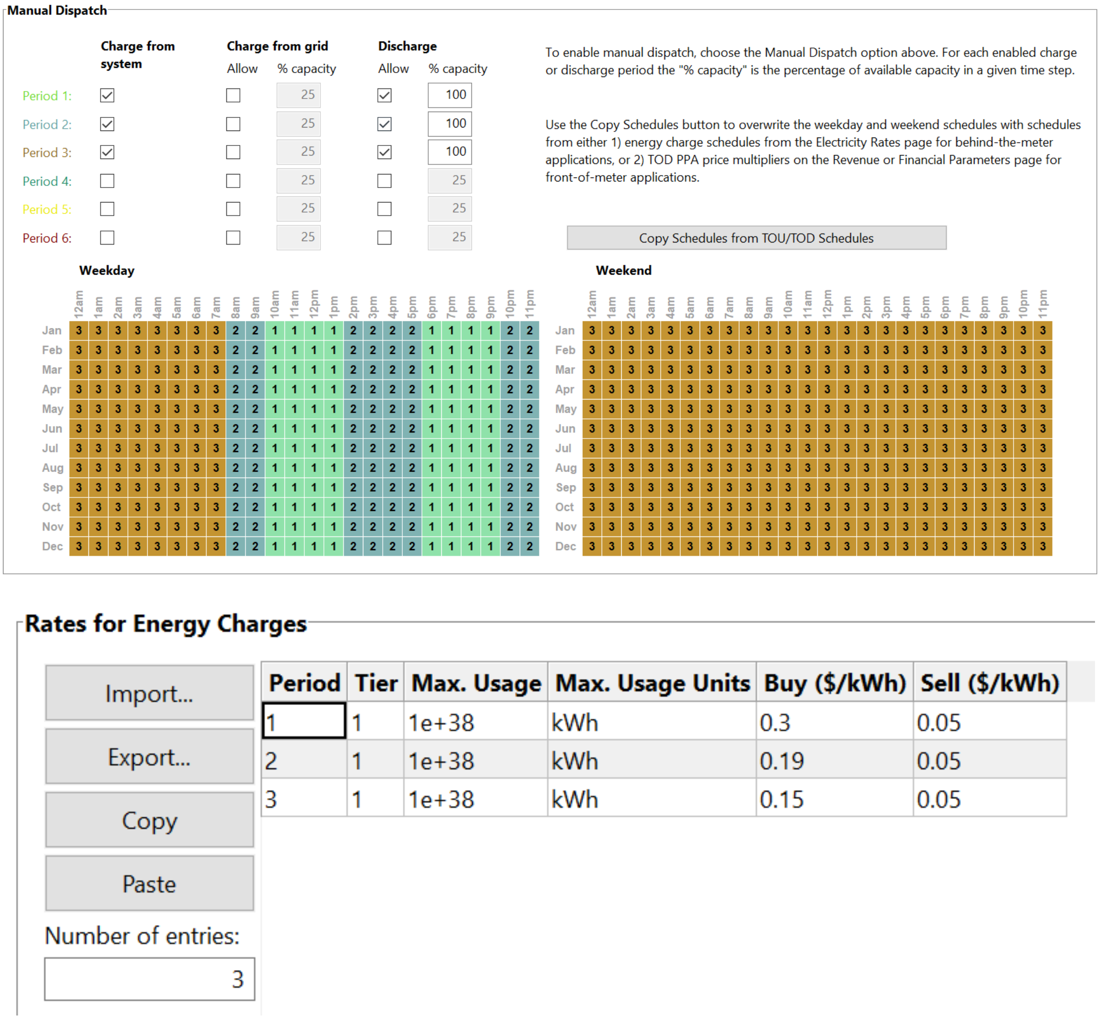
As we do not have batteries to keep our energy, we will need to use the grid along all the year and we will only be able to save electricity and money when the system is producing energy. We are not producing that much extra energy so the production fits better to the consumption.

6.4.2. Profitability

When installing solar panels the main benefits come from the money we are able to save thanks that we are producing the electricity that we need for ourselves. We could also earn a small percentage due to the energy we are selling when we have an excess of production.

In Spain, since June three main pareiods where stablished. The first one, which is the most expensive, goes from 10:00 until 14:00 and from 18:00 to to 22:00. The second one, which is the medium, goes from 8:00 to 10:00, from 12:00 to to 16:00 and from 22:00 to 00:00. The last one, which is the cheapest, goes from 00:00 until 8:00.

This is an important factor because it esencial to decide when it is more convenient to use the electricity, how to make use of it and, whether it is worth it to include batteries or not and how many in case we do.



Weekday

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Feb	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Mar	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Apr	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
May	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Jun	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Jul	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Aug	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Sep	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Oct	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Nov	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2
Dec	3	3	3	3	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2

Weekend

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Feb	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Mar	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Apr	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
May	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jun	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Jul	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Aug	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Oct	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Nov	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Dec	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Rates for Energy Charges

Period	Tier	Max. Usage	Max. Usage Units	Buy ($/kWh)	Sell ($/kWh)
1	1	1e+38	kWh	0.3	0.05
2	1	1e+38	kWh	0.19	0.05
3	1	1e+38	kWh	0.15	0.05

Figure 146. Prices of electricity per period

The profitability analysis is intended to determine the viability of carrying out the designed project This is determined by calculating and analyzing the payback period of the investment, that is, the year in which cashflow starts to be positive. The payback or return period represents the time it will take to recover the initial investment according to the calculations made with the cash flows, and is calculated as the time for which the accumulated cash flows are equalized with the initial investment.

➢ Case 1. Off-Grid

For case 1 we are using the next components:

- Total amount of 2486 modules which have a cost of 417,742.69€
- 5 Inverters which cost is 122,226.15€
- Batteries which capacity for 34MWh cost 7,152,669€

Adding the indirect costs and some other variables we have a total amount of 9,143,574€ which would never be profitable.

Direct Capital Costs

Module	2,486 units	0.4 kWdc/unit	1,018.9 kWdc	0.41 $/Wdc	$ 417,742.69
Inverter	5 units	179.6 kWac/unit	897.9 kWac	0.12 $/Wdc	$ 122,266.15

	$	$/Wdc	$/m²	
Balance of system equipment	0.00	0.24	0.00	$ 244,532.30
Installation labor	0.00 +	0.15 +	0.00 =	$ 152,832.69
Installer margin and overhead	0.00	0.16	0.00	$ 163,021.53

Battery DC capacity 34,000.0 kWh × 206.67 $/kWh + 200.0 kW × 629.47 $/kW = $ 7,152,669.00

Subtotal $ 8,253,064.50

Contingency

Contingency 4 % of subtotal $ 330,122.56

Total direct cost $ 8,583,187.00

Indirect Capital Costs

	% of direct cost	$/Wdc	$	
Permitting and environmental studies	0	0.11	0.00	$ 112,077.30
Engineering and developer overhead	0 +	0.44 +	0.00 =	$ 448,309.22
Grid interconnection	0	0.00	0.00	$ 0.00

Land Costs

Land area 4.116 acres

Land purchase	$ 0/acre +	0 +	0.00 +	0.00 =	$ 0.00
Land prep. & transmission	$ 0/acre	0	0.00	0.00	$ 0.00

Sales Tax

Sales tax basis, percent of direct cost 82 % Sales tax rate 0.0 % $ 0.00

Total indirect cost $ 560,386.50

Total Installed Cost

The total installed cost is the sum of the direct and indirect costs. Note that it does not include any financing costs from the Financial Parameters page.

Total installed cost $ 9,143,574.00

Total installed cost per capacity $ 8.97/Wdc

Figure 147. Summary of costs Case 1

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

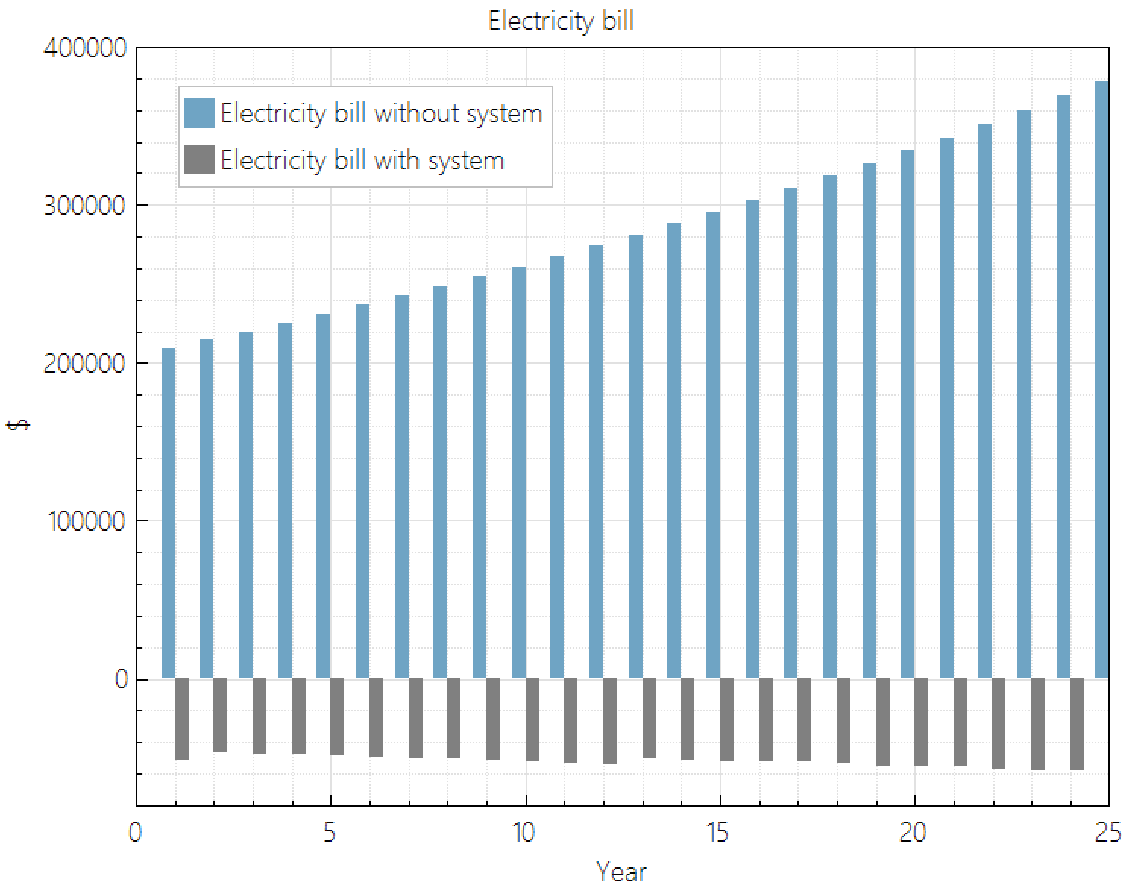


Figure 148. Electricity bill for case 1

After analysing this, we could say that note ven we are not paying for the electricity anymore, but we are being paid anual for it.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

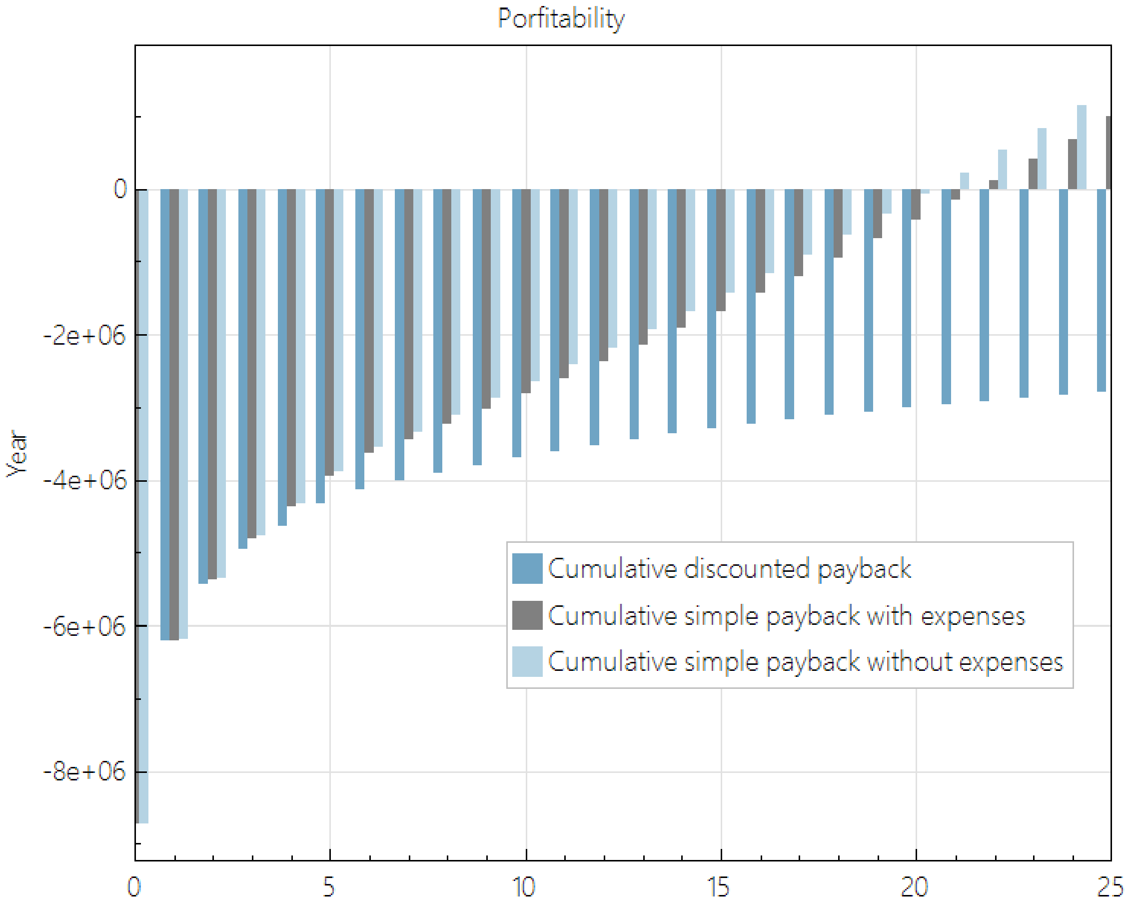


Figure 149. Profitability for case 1

As we check, the system would start to be profitable only after the year 21 after the installation was completed.

➢ Case 2.

For case 2 we are using the next components:

- Total amount of 2486 modules which have a cost of 417,742.69€
- 5 Inverters which cost is 122,226.15€
- Batteries which capacity for 5MWh cost 1,159,428.88€

Adding the indirect costs and some other variables we have a total amount of 2,910,603.75€ which would never be profitable.

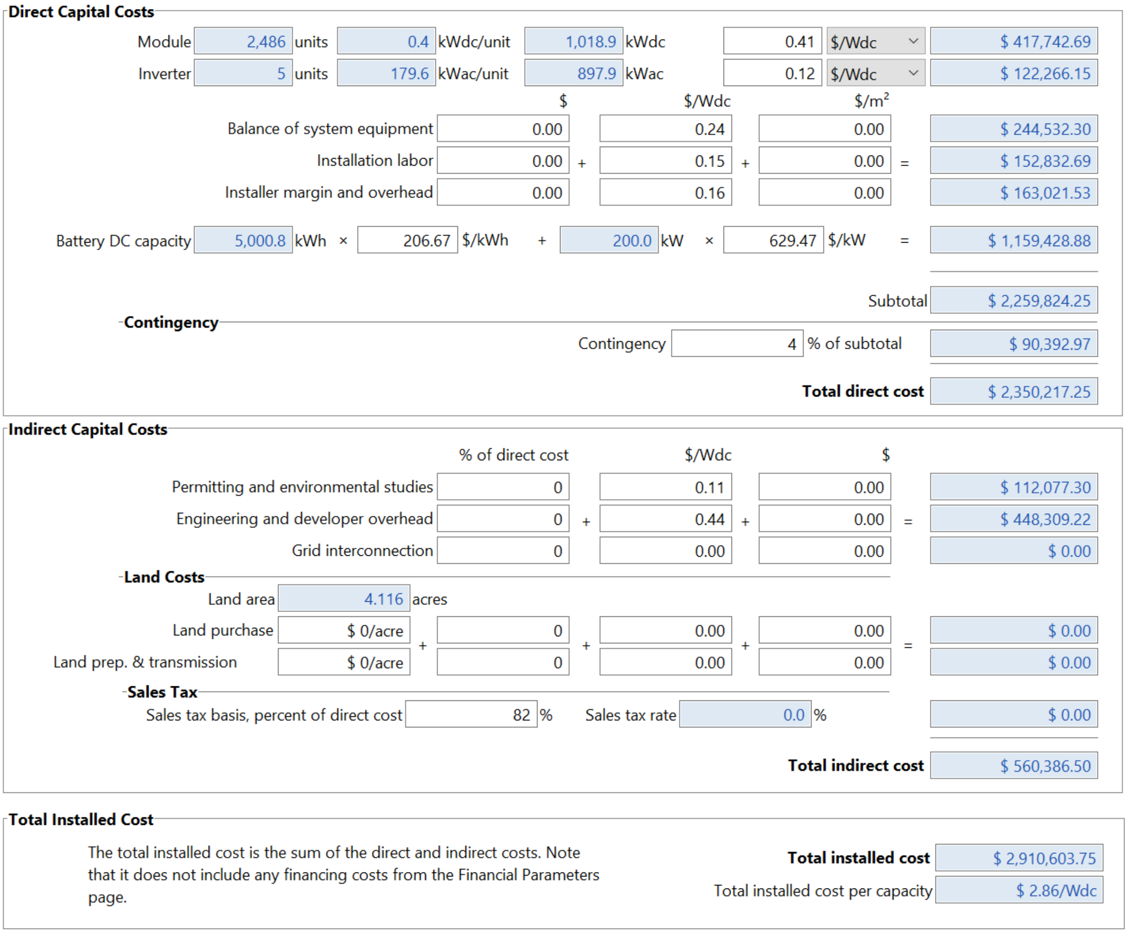


Figure 150. Summary of costs Case 2

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

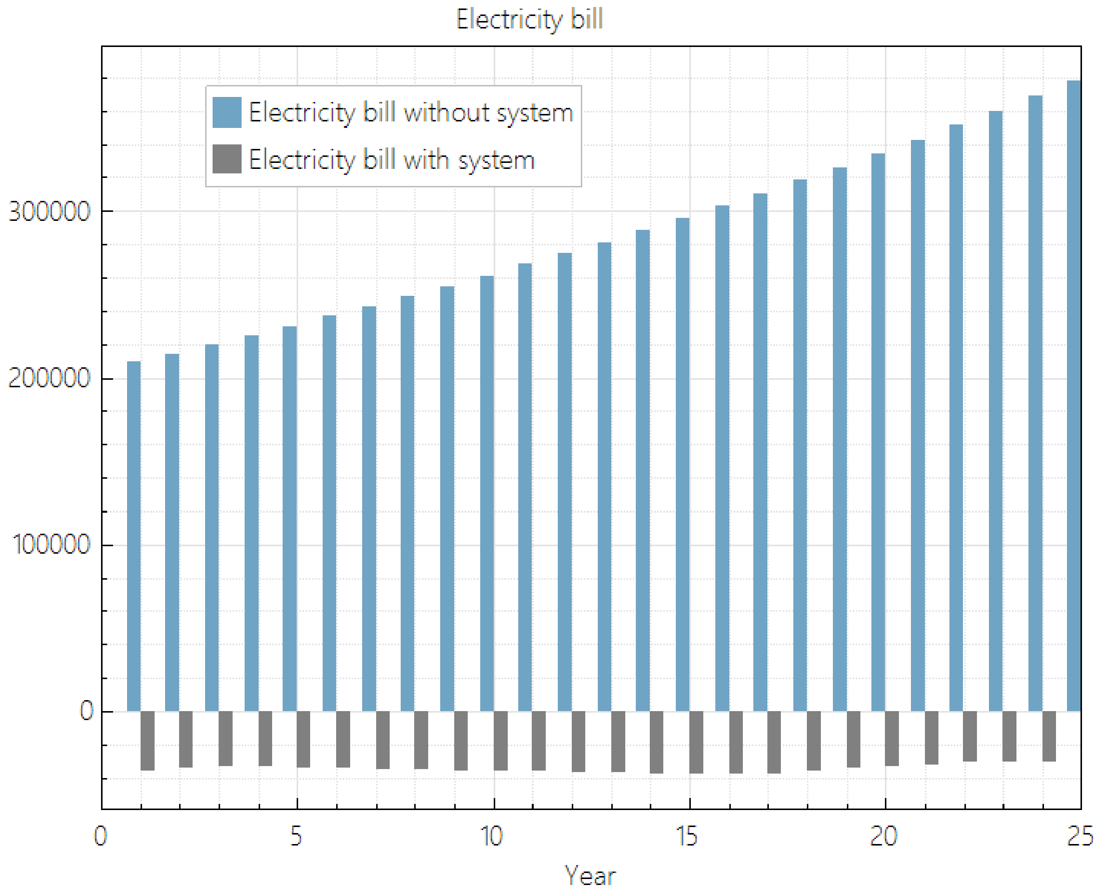


Figure 151. Electricity bill for case 2

After analysing this, we could say that not only we are not paying for the electricity anymore, but we are being paid anually for it as in case 1.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

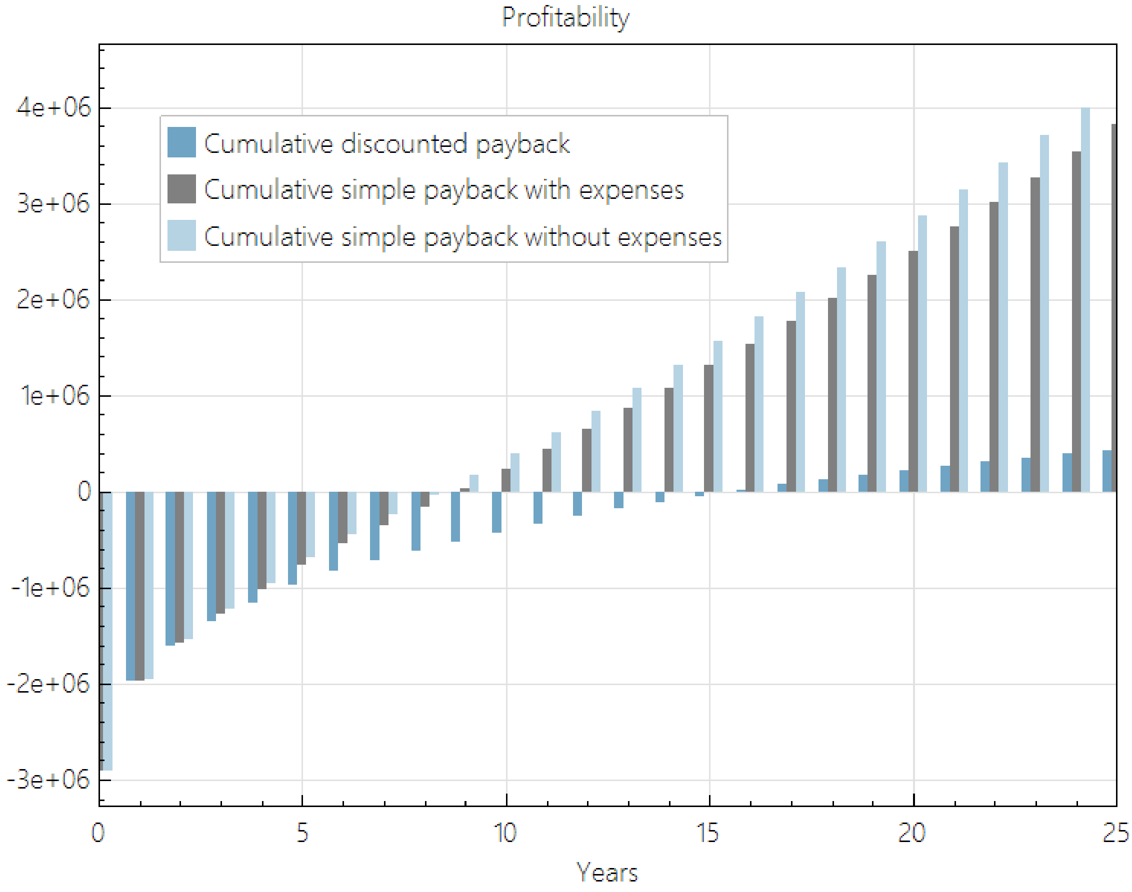


Figure 152. Profitability for case 1

As we check, the system would start to be profitable only after the year 9 after the installation was completed. After 25 years, we would have an accumulative payback of 4,000,000€

➢ Case 3.

For case 3 we are using the next components:

- Total amount of 2486 modules which have a cost of 417,742.69€
- 5 Inverters which cost is 122,226.15€
- Batteries which capacity for 2MWh cost 539.233,69€

Adding the indirect costs and some other variables we have a total amount of 2,265,600,75€ which would never be profitable.

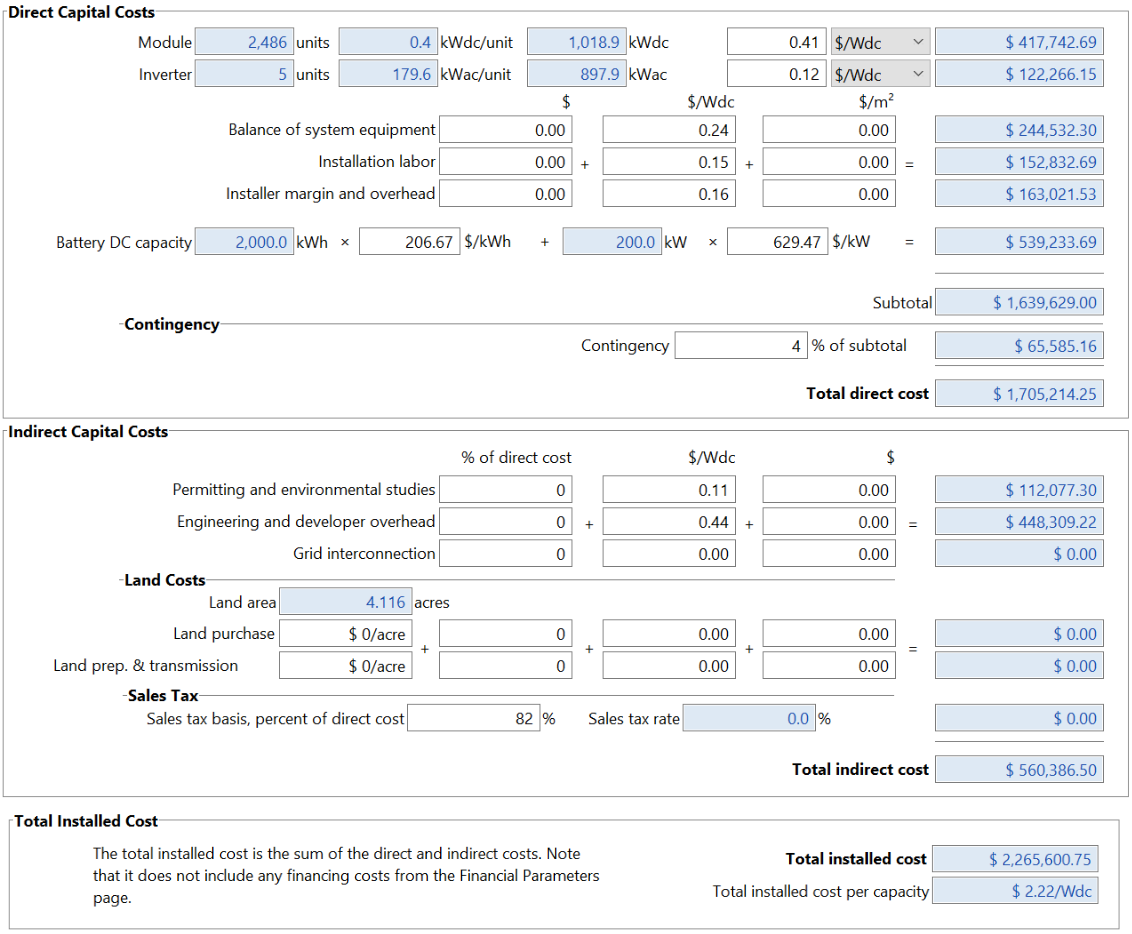


Figure 153. Summary of costs Case 3

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

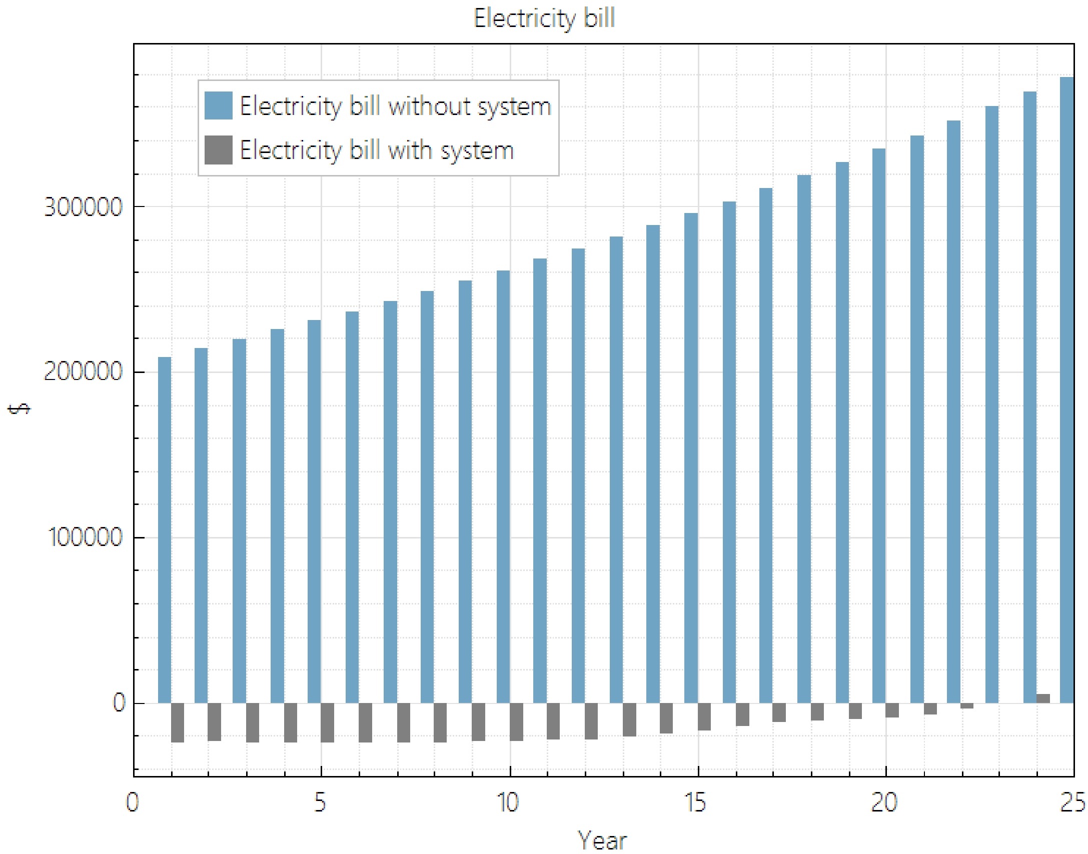


Figure 154. Electricity bill for case 3

After analysing this, we could say that note ven we are not paying for the electricity anymore, but we are being paid anual for it until last year. Each year it is a bit less since the losses due to the degradation of the system increase with time.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

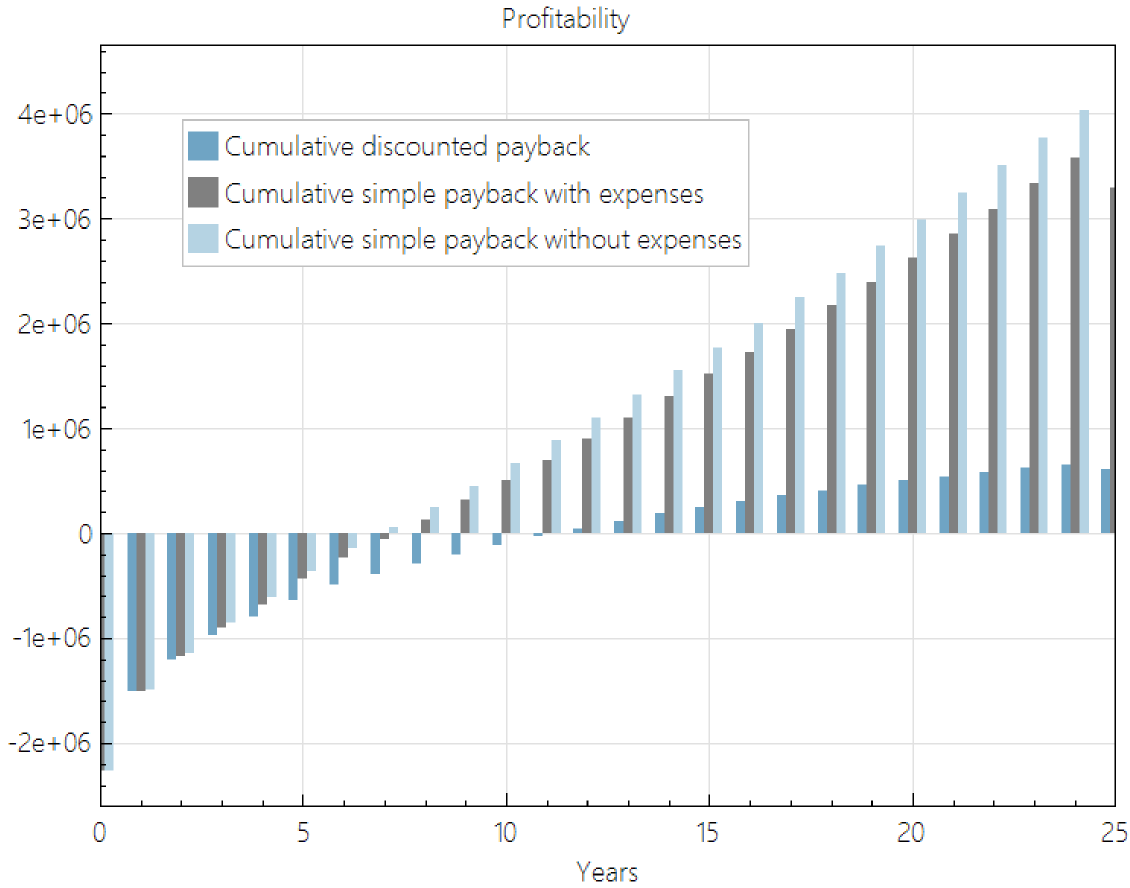


Figure 155. Profitability for case 3

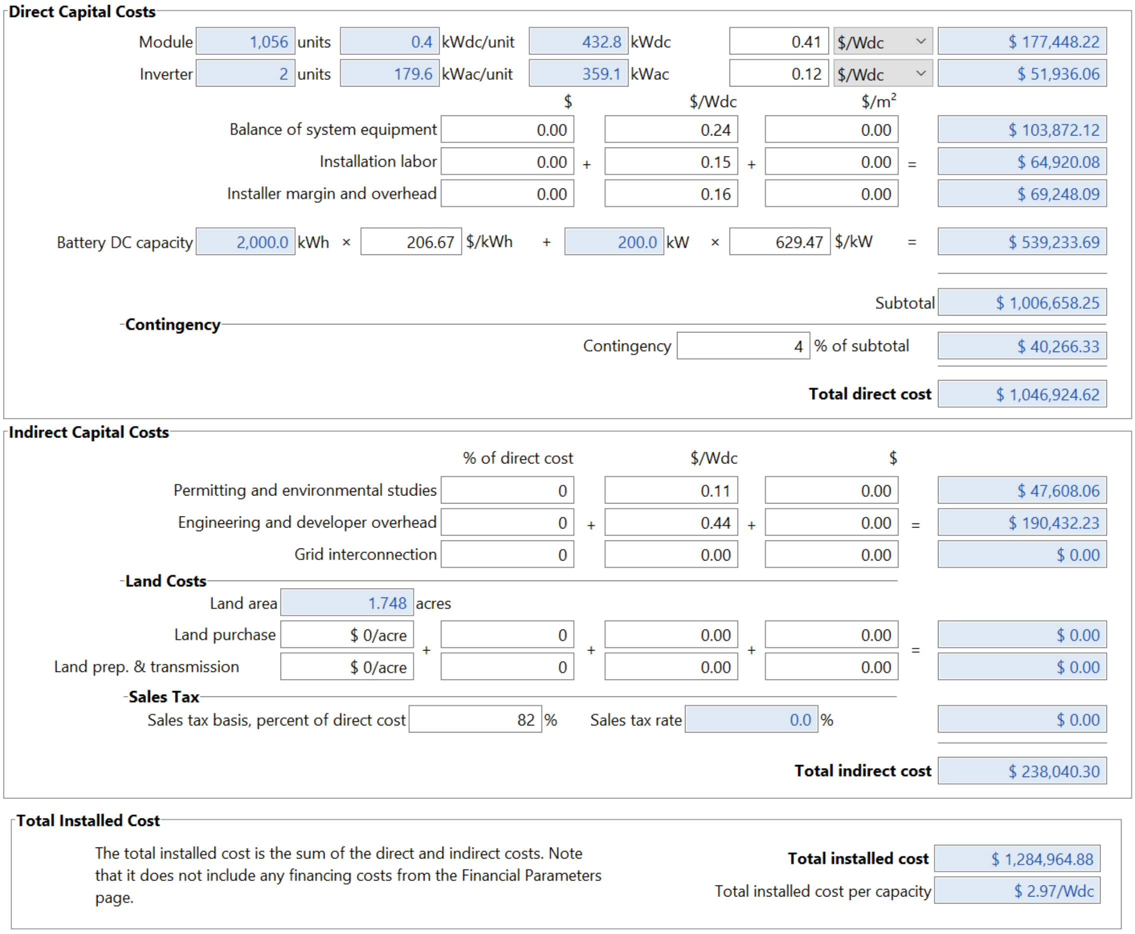
As we check, the system would start to be profitable only after the year 7 after the installation was completed. After 25 years, we would have an accumulative payback of 4,000,000€.

➢ **Case 4.**

For case 4 we are using the next components:

- Total amount of 1056 modules which have a cost of 177,448.22€
- 2 Inverters which cost is 51,936.06€
- Batteries which capacity for 2MWh cost 539.233,69€

Adding the indirect costs and some other variables we have a total amount of 1,284,964,88€ which would never be profitable.



Direct Capital Costs

Module	1,056	units	0.4	kWdc/unit	432.8	kWdc	0.41 $/Wdc	$ 177,448.22
Inverter	2	units	179.6	kWac/unit	359.1	kWac	0.12 $/Wdc	$ 51,936.06

	$	$/Wdc	$/m²	
Balance of system equipment	0.00	0.24	0.00	$ 103,872.12
Installation labor	0.00 +	0.15 +	0.00 =	$ 64,920.08
Installer margin and overhead	0.00	0.16	0.00	$ 69,248.09

Battery DC capacity 2,000.0 kWh × 206.67 $/kWh + 200.0 kW × 629.47 $/kW = $ 539,233.69

Subtotal $ 1,006,658.25

Contingency

Contingency 4 % of subtotal $ 40,266.33

Total direct cost $ 1,046,924.62

Indirect Capital Costs

	% of direct cost	$/Wdc	$	
Permitting and environmental studies	0	0.11	0.00	$ 47,608.06
Engineering and developer overhead	0 +	0.44 +	0.00 =	$ 190,432.23
Grid interconnection	0	0.00	0.00	$ 0.00

Land Costs

Land area 1.748 acres

Land purchase	$ 0/acre +	0 +	0.00 +	0.00 =	$ 0.00
Land prep. & transmission	$ 0/acre	0	0.00	0.00	$ 0.00

Sales Tax

Sales tax basis, percent of direct cost 82 % Sales tax rate 0.0 % $ 0.00

Total indirect cost $ 238,040.30

Total Installed Cost

The total installed cost is the sum of the direct and indirect costs. Note that it does not include any financing costs from the Financial Parameters page.

Total installed cost $ 1,284,964.88

Total installed cost per capacity $ 2.97/Wdc

Figure 156. Summary of costs Case 4

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

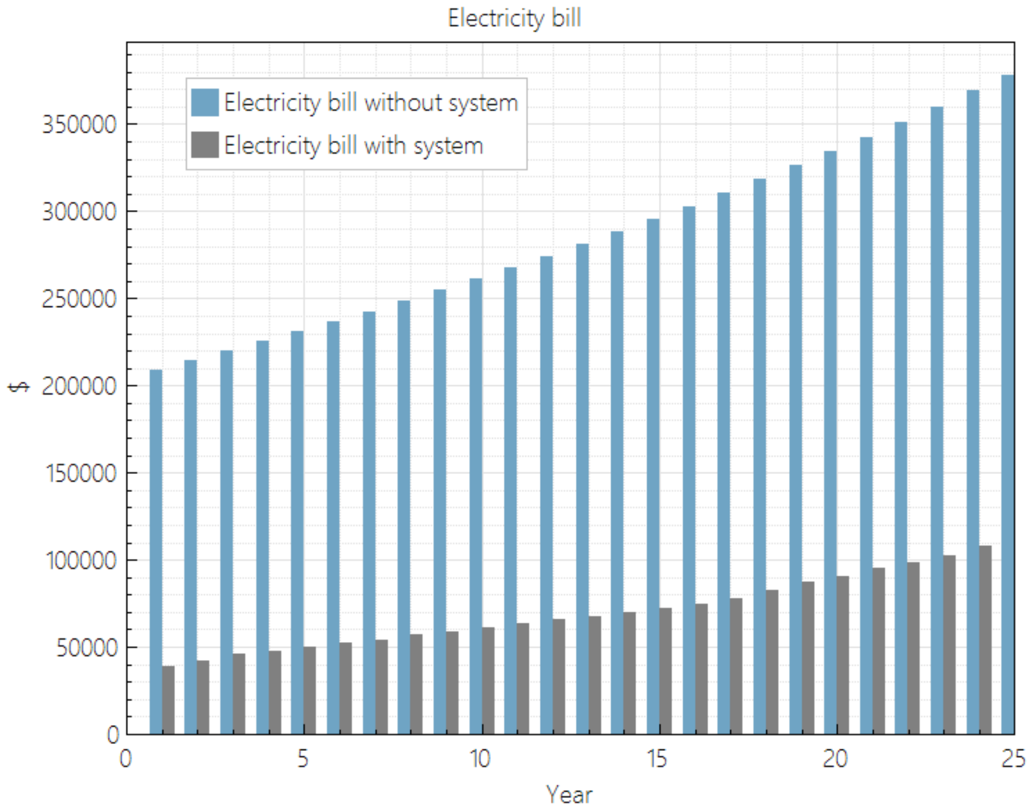


Figure 157. Electricity bill for case 4

After analysing this, we appreciate an enormous save in the bill in comparison to the bill we would have if we had not installed our system.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

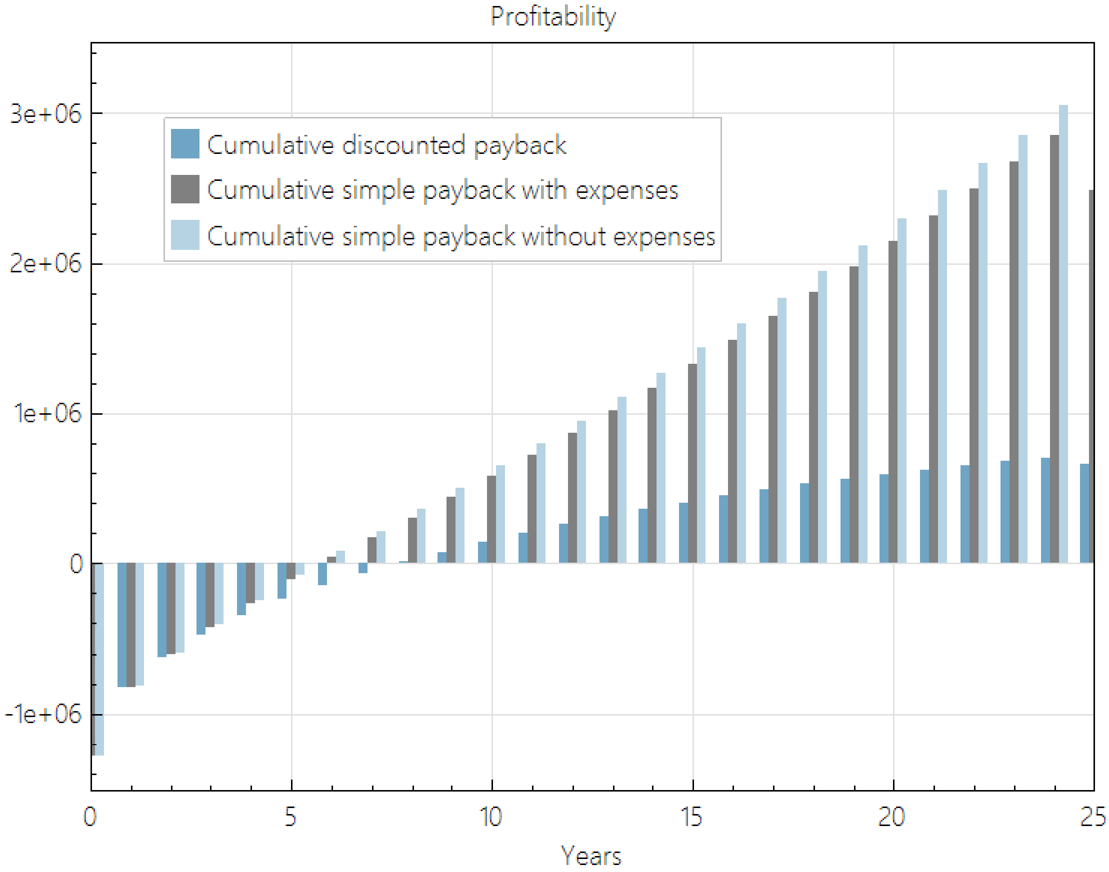


Figure 158. Profitability for case 4

As we check, the system would start to be profitable only after the year 6 after the installation was completed. After 25 years, we would have an accumulative payback of 3,000,000€

➢ Case 5.

For case 5 we are using the next components:

- Total amount of 1056 modules which have a cost of 177,448.22€
- 2 Inverters which cost is 51,936.06€
- Batteries which capacity for 1MWh cost 332.830,06€

Adding the indirect costs and some other variables we have a total amount of 1,070,305.12€ which would never be profitable.

Direct Capital Costs

Module	1,056	units	0.4	kWdc/unit	432.8	kWdc	0.41	$/Wdc	$ 177,448.22
Inverter	2	units	179.6	kWac/unit	359.1	kWac	0.12	$/Wdc	$ 51,936.06

	$		$/Wdc		$/m^2		
Balance of system equipment	0.00		0.24		0.00		$ 103,872.12
Installation labor	0.00	+	0.15	+	0.00	=	$ 64,920.08
Installer margin and overhead	0.00		0.16		0.00		$ 69,248.09

Battery DC capacity 1,000.8 kWh × 206.67 $/kWh + 200.2 kW × 629.47 $/kW = $ 332,830.06

Subtotal $ 800,254.62

Contingency

Contingency 4 % of subtotal $ 32,010.19

Total direct cost $ 832,264.81

Indirect Capital Costs

	% of direct cost		$/Wdc		$		
Permitting and environmental studies	0		0.11		0.00		$ 47,608.06
Engineering and developer overhead	0	+	0.44	+	0.00	=	$ 190,432.23
Grid interconnection	0		0.00		0.00		$ 0.00

Land Costs

Land area 1.748 acres

Land purchase	$ 0/acre	+	0	+	0.00	+	0.00	=	$ 0.00
Land prep. & transmission	$ 0/acre		0		0.00		0.00		$ 0.00

Sales Tax

Sales tax basis, percent of direct cost 82 % Sales tax rate 0.0 % $ 0.00

Total indirect cost $ 238,040.30

Total Installed Cost

The total installed cost is the sum of the direct and indirect costs. Note that it does not include any financing costs from the Financial Parameters page.

Total installed cost $ 1,070,305.12

Total installed cost per capacity $ 2.47/Wdc

Figure 159. Summary of costs Case 5

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

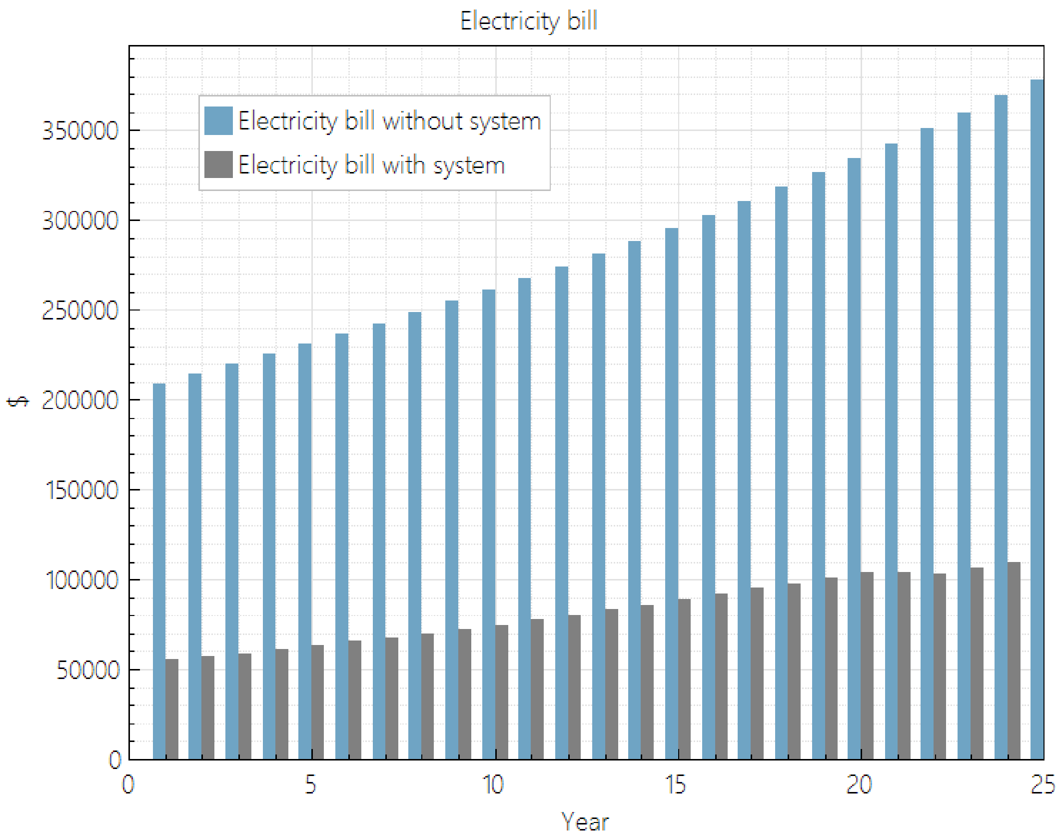


Figure 160. Electricity bill for case 5

After analysing this, we appreciate an enormous save in the bill in comparison to the bill we would have if we had not installed our system.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

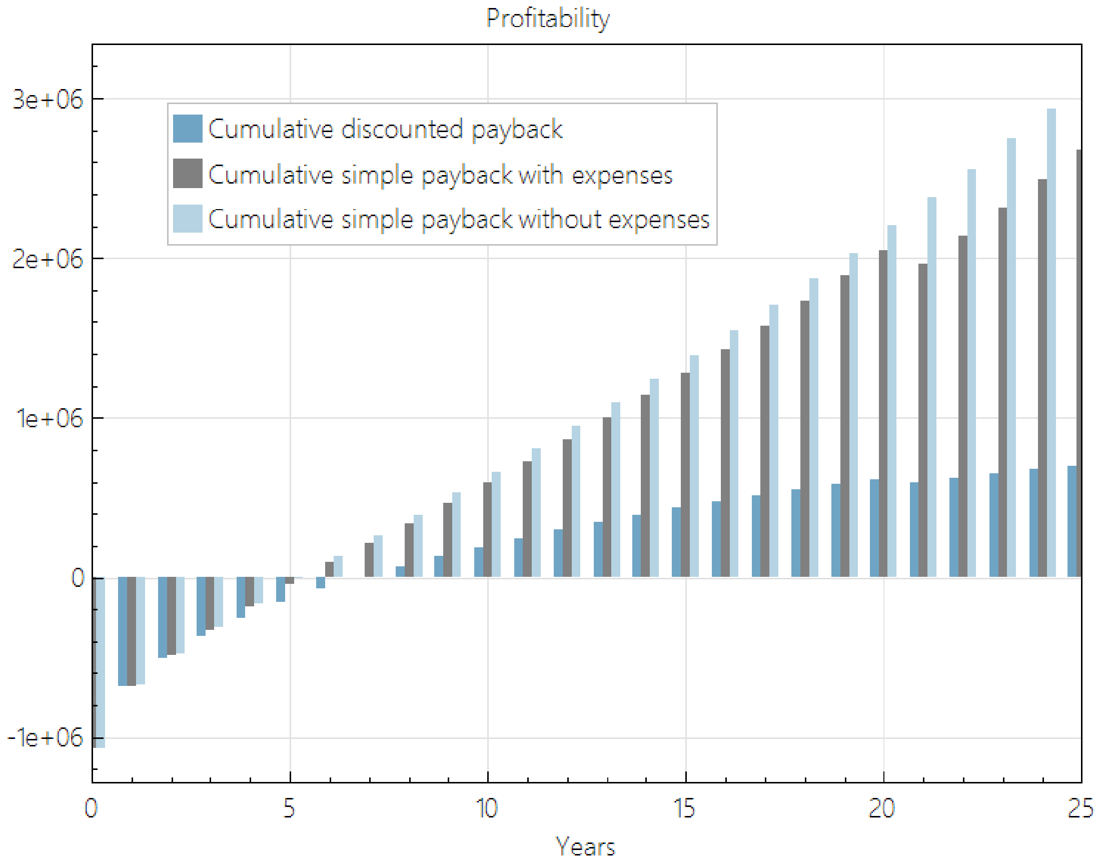


Figure 161. Profitability for case 5

As we check, the system would start to be profitable only after the year 6 after the installation was completed. After 25 years, we would have an accumulative payback of 3,000,000€

➢ Case 6.

For case 6 we are using the next components:

- Total amount of 1056 modules which have a cost of 177,448.22€
- 2 Inverters which cost is 51,936.06€

Adding the indirect costs and some other variables we have a total amount of 724,161.88€ which would never be profitable.

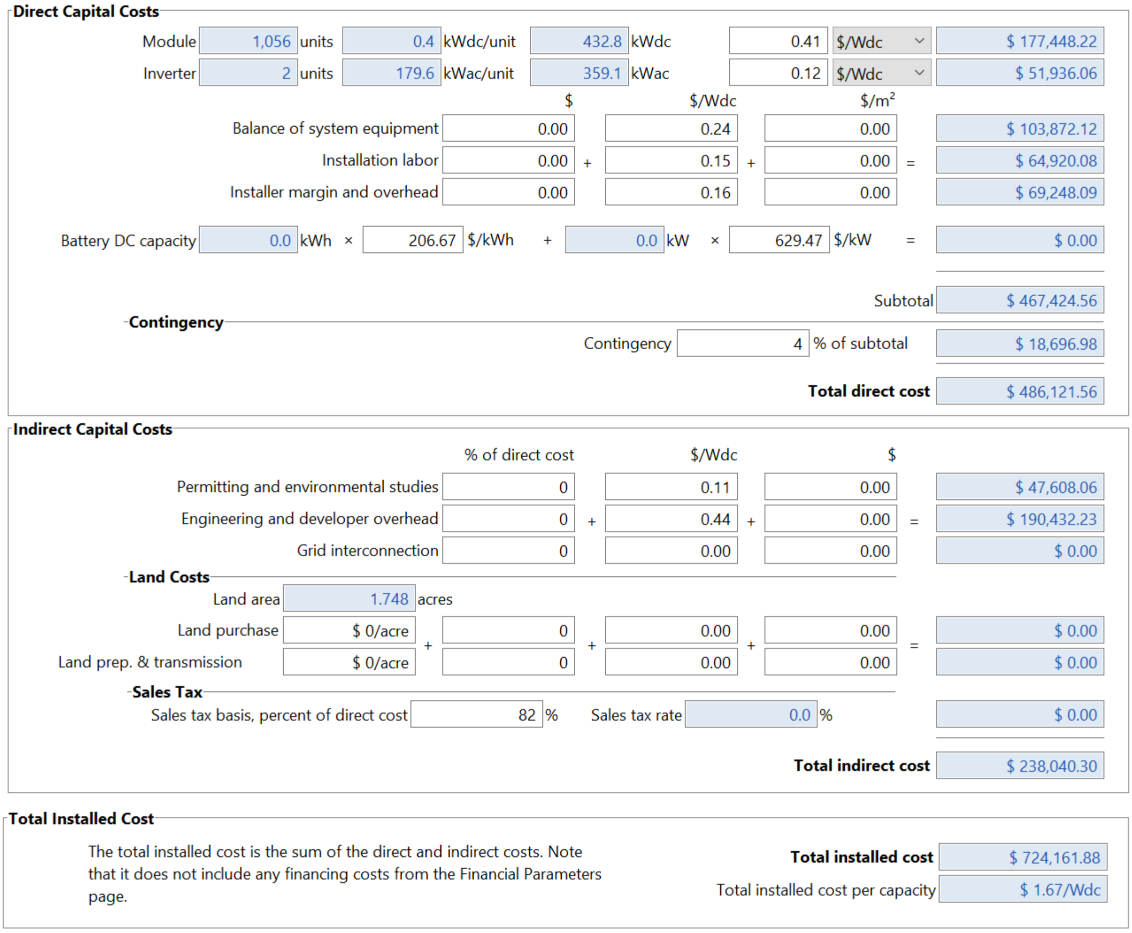


Figure 162. Summary of costs Case 6

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

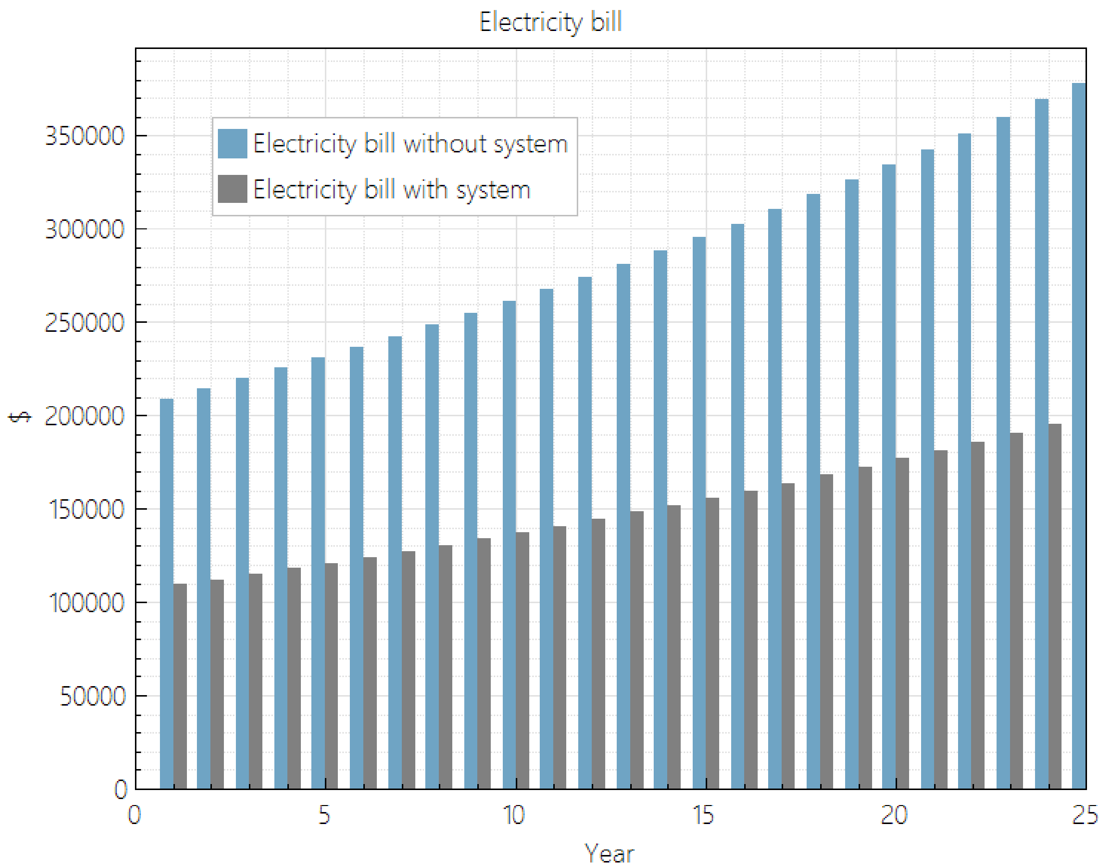


Figure 163. Electricity bill for case 6

After analysing this, we appreciate that we save half of the bill in comparison to the bill we would have if we had not installed our system.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

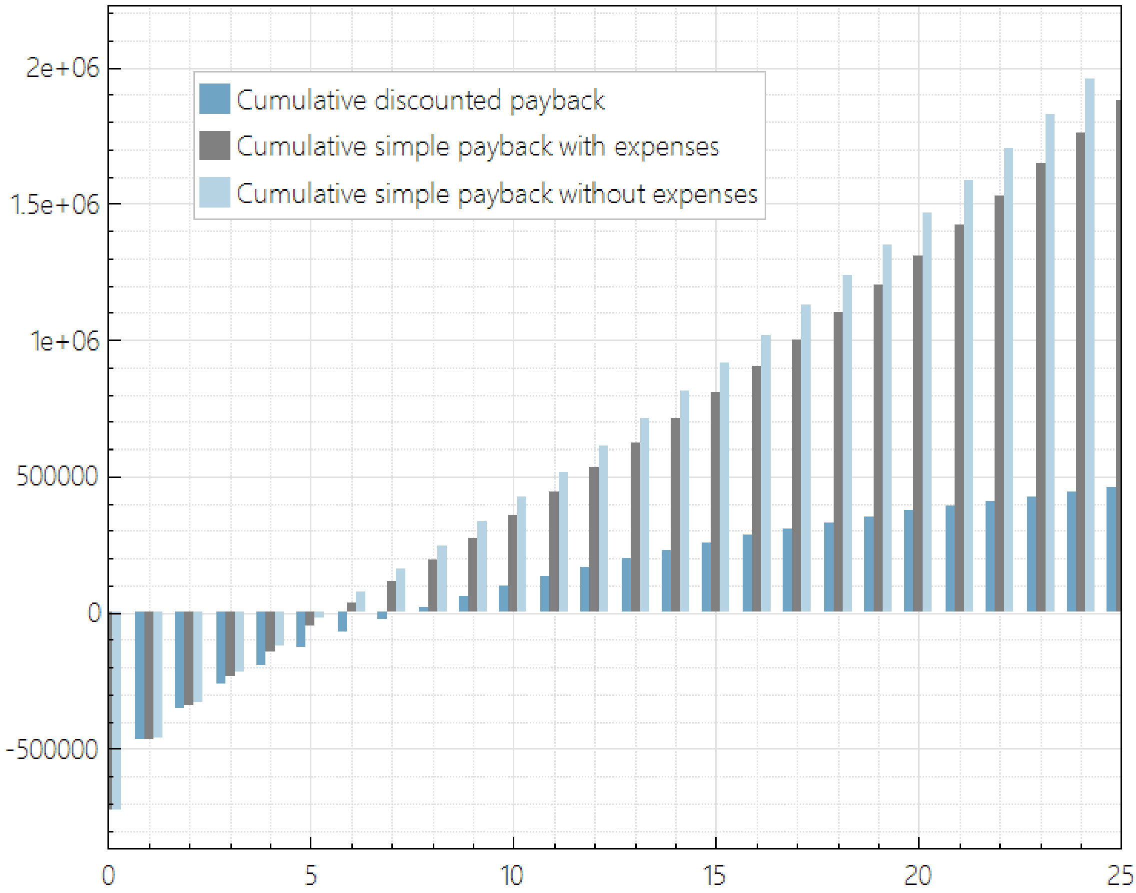


Figure 164. Profitability for case 6

As we check, the system would start to be profitable only after the year 5 after the installation was completed. After 25 years, we would have an accumulative payback of 2,000,000€

➢ Case 7.

For case 7 we are using the next components:

- Total amount of 528 modules which have a cost of 88,724.11€
- 1 Inverters which cost is 25,968.03€

Adding the indirect costs and some other variables we have a total amount of 362,080.94€ which would never be profitable.

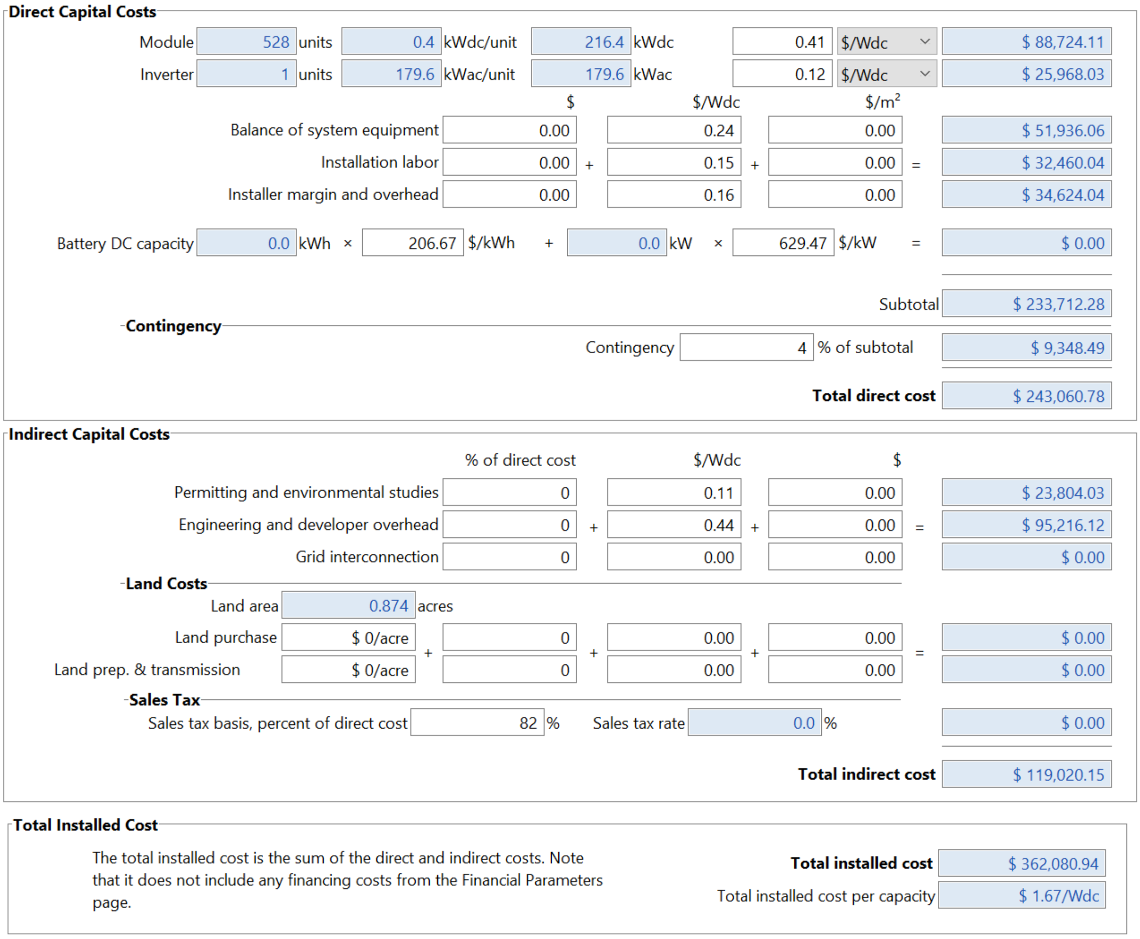


Figure 165. Summary of costs Case 7

We will show now a plot in which, the gray bars, correspond to the electricity bill without our proposed system and, in blue, the electricity bill without that system.

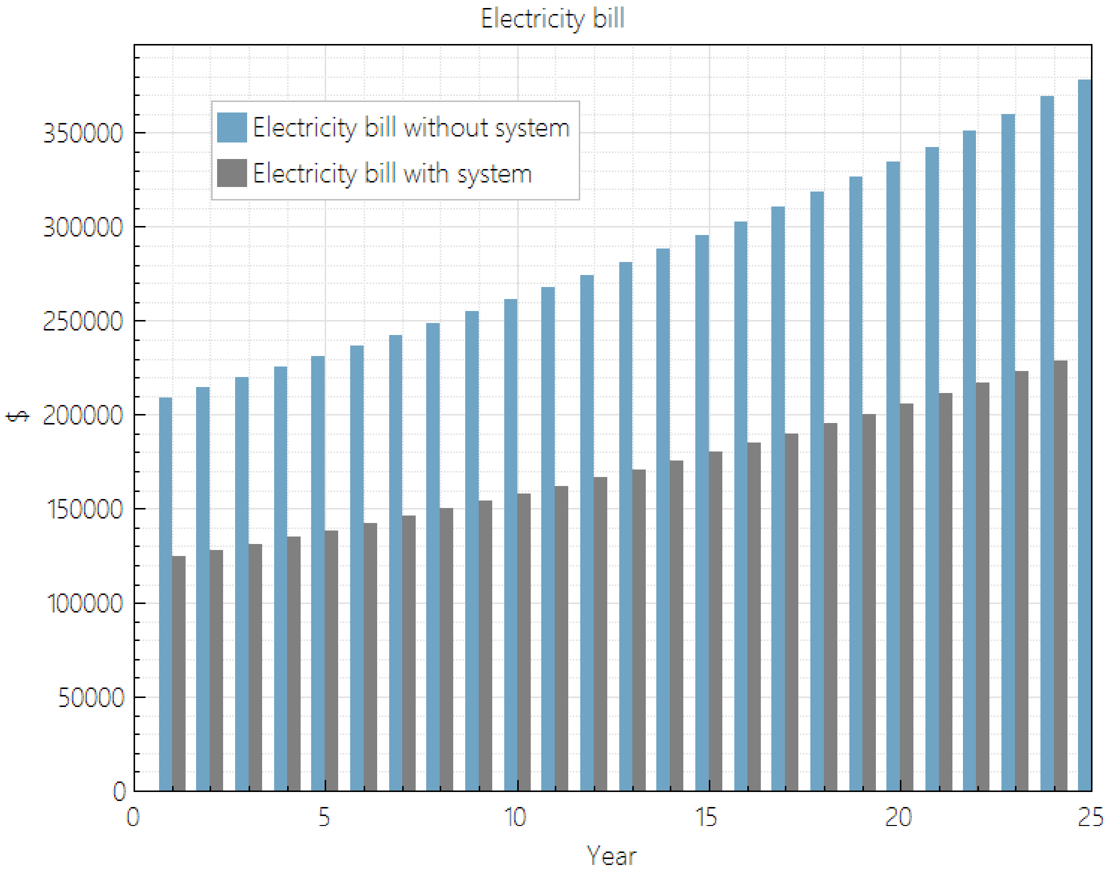


Figure 166. Electricity bill for case 7

After analysing this, we appreciate that we save almost half of the bill in comparison to the bill we would have if we had not installed our system.

The profitability is probably one of the most important factors to decide which case is the one we should mount.

In the next graph, we will be able to see the evolution along the years of the cummulative discounted payback (Dark blue), cummulative simple payback with expenses (Gray) and the cummulative simple payback without expenses (Light blue)

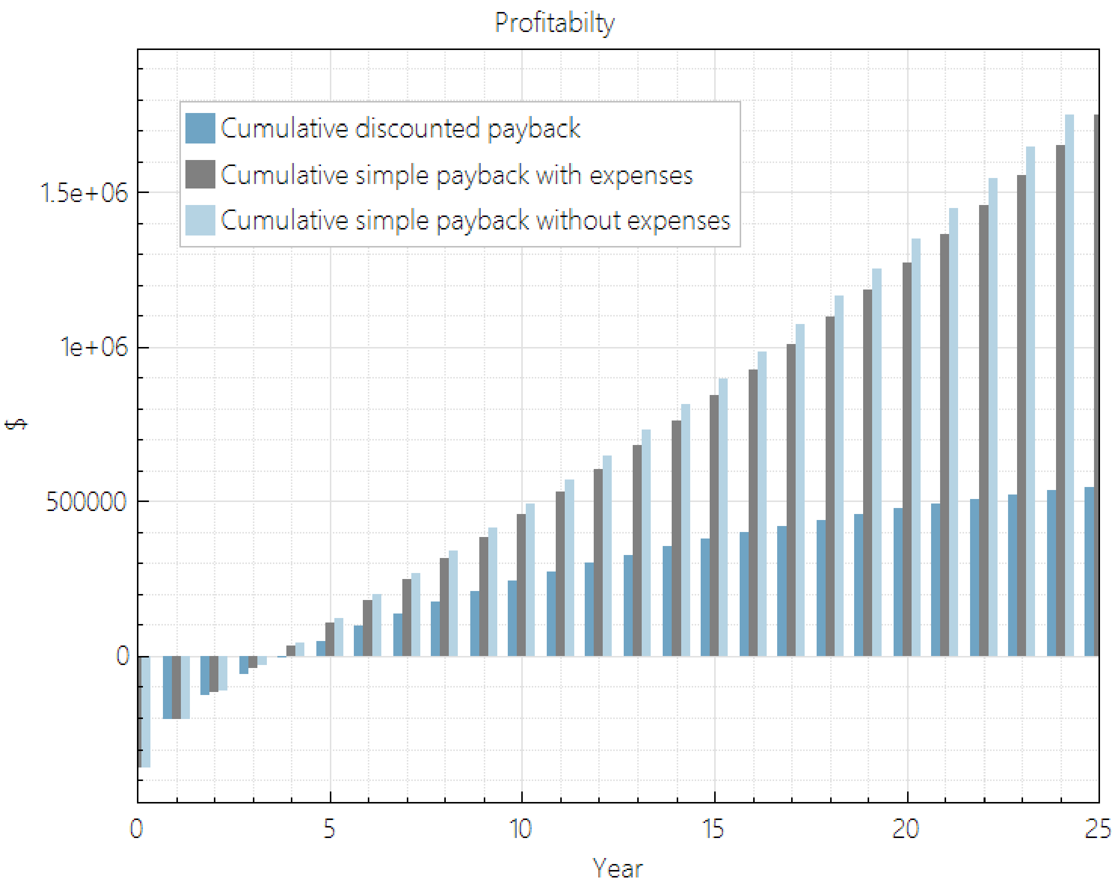


Figure 167. Profitability for case 7

As we check, the system would start to be profitable only after the year 4 after the installation was completed. After 25 years, we would have an accumulative payback of 1,750,000€

Once we have analysed all the cases one by one we can créate a table to compare them all.

Case	Energy generated (KWh)	Batteries capacity (KWh)	Inverters	Price (€)	Profitability (Years)
1	1,018,885	32,000	5	9,143,574	21.6
2	1,018,885	5,000	5	2,910,604	8.8
3	1,018,885	2,000	5	2,265,601	7.3
4	432,801	2,000	2	1,284,965	5.7
5	432,801	1,000	2	1,070,305	5.3
6	432,801	0	2	724,162	4.6
7	216,400	0	1	362,081	3.6

Table 34. Summary of costs of the cases

As we see, the one with the fatest profitability is the one from case number 7 since it is the cheapest in costs and fits propperly to cover the most expensive period of electricity along the year. Hence, this is the solution we must apply.

7. CONCLUSIONS

All in all, our installation will be mounted over the roof of the auction centre since it makes the system more robust and cheaper without great losses. Hence, the panels will have an elevation angle of 30º and an azimuth angle of -170º.

For the panels we will use the model Trina Solar TSM-410DEG15M(II) with a power of 400W per panel. The size of the modules is 2.04 meters high and 1 meter width.

The inverter used for the project will be the model PVS-175-TL-POWER-MODULE-1-US [800V].

Panels will have this configuration: There will be just 22 panels in parallel and 24 in series in the southern face pointing to the south. This makes a total amount of 528 modules with a power of 216,400KW.

No batteries will be used in this proyect. This means the production will just cover the demand during daylight hours which are when the electricity is the most expensive. Some benefits will also come from selling the excess of production.

The total cost of the installation is 362,081€ and the profitability of this configuration is expected to be reached in 3.6 years. After 25 years of usage, the total profit will be 1,750,000€.

After all of this we will have achieved all the objectives proposed when we started the project:

- Application of knowledge related to photovoltaic solar energy.
- Carrying out a study of the energy balance in terms of consumption and potential solar electricity generation of the installation.
- Study of the hourly consumption profile according to the actual use of the auction center and the calculated solar electricity generation hourly profile.
- Adaptation to the existing real problem, in terms of available space and predefined orientations.
- Calculation of facilities, photovoltaic modules, inverters... to carry out a complete photovoltaic project.
- Application of current regulations.
- Cost and profitability analysis.
- Simulation of system performance
- Calculation of the amortization period of the initial investment made.

Conclusiones

Con todo, nuestra instalación se montará sobre el techo del centro de subastas ya que hace que el sistema sea más robusto y económico sin grandes pérdidas. Por tanto, los paneles tendrán un ángulo de elevación de 30º y un ángulo de acimut de -170º.

Para los paneles utilizaremos el modelo Trina Solar TSM-410DEG15M (II) con una potencia de 400W por panel. El tamaño de los módulos es de 2,04 metros de alto y 1 metro de ancho.

El inversor utilizado para el proyecto será el modelo PVS-175-TL-POWER-MODULE-1-US [800V].

Los paneles tendrán esta configuración: Habrá solo 22 paneles en paralelo y 24 en serie en la cara sur apuntando hacia el sur. Esto hace una cantidad total de 528 módulos con una potencia de 216,400KW.

No se utilizarán pilas en este proyecto. Esto significa que la producción solo cubrirá la demanda durante las horas de luz, que es cuando la electricidad es más cara. También se obtendrán algunos beneficios de vender el exceso de producción.

El coste total de la instalación es de 362.081 € y se espera alcanzar la rentabilidad de esta configuración en 3,6 años. Tras 25 años de uso, el beneficio total será de 1.750.000 €.

Después de todo esto habremos logrado todos los objetivos propuestos cuando iniciamos el proyecto:

- Aplicación de conocimientos relacionados con la energía solar fotovoltaica.
- Realización de un estudio del balance energético en términos de consumo y generación potencial de energía solar de la instalación.
- Estudio del perfil de consumo horario según el uso real del centro de subastas y del perfil horario de generación solar calculado.
- Adaptación al problema real existente, en cuanto a espacio disponible y orientaciones predefinidas.
- Cálculo de instalaciones, módulos fotovoltaicos, inversores ... para realizar un proyecto fotovoltaico completo.
- Aplicación de la normativa vigente.
- Análisis de costes y rentabilidad.
- Simulación del rendimiento del Sistema.
- Cálculo del plazo de amortización de la inversión inicial realizada.

8. BIBLIOGRAPHY

- The land use data comes from the Global Land Cover SHARE database, published by the Food and Agriculture Organization of the United Nations.

- Elevation data comes from Shuttle Radar Topography Mission (SRTM), published by NASA's Jet Propulsion Laboratory.

- The names, locations, and time zones of places and some airports come from the GeoNames Geographical Database.

- All data related to the position of the sun (sunrise and sunset) are calculated using astronomical formulas from the book Astronomical Algorithms, 2nd edition, by Jean Meeus.

- All climatological data, including cloud cover, precipitation, wind speed and direction, and solar flux come from NASA's MERRA-2 Modern-Era Retrospective Analysis. This reanalysis combines a variety of wide-area measurements into a modern world weather model to reconstruct the hour-by-hour climate history of the entire world on a 50 km block grid.

- Location of the auction centre:
  https://earth.google.com

- Weather conditions:
  https://es.weatherspark.com

- Orientation charts and shadow calculations:
  https://www.idae.es

  https://www.idae.es/sites/default/files/documentos_5654_FV_pliego_condiciones_tecnicas_instalaciones_conectadas_a_red_C20_Julio_2011_3498eaaf.pdf

- https://www.idae.es/sites/default/files/documentos_5654_FV_pliego_condiciones_tecnicas_instalaciones_conectadas_a_red_C20_Julio_2011_3498eaaf.pdf

- PVGIS tool:
  https://re.jrc.ec.europa.eu/pvg_tools/en/#PVP

- How to connect our panels:
  https://www.youtube.com/watch?v=75zq3antUmo&ab_channel=AutoconsumoSolarF%C3%A1cil

- AENOR. Base de datos normas:

http://www.aenor.es/aenor/normas/buscadornormas/buscadornormas.asp#.V2aEYSi9mAg [fecha de consulta: abril a junio de 2016]

Datasheet:

- Module: https://www.fimer.com/sites/default/files/FIMER_PVS-175-TL_EN_RevC.pdf
- Inverter: https://www.fimer.com/sites/default/files/FIMER_PVS-175-TL_EN_RevC.pdf

UNIVERSIDAD DE ALMERÍA

Resumen/Abstract

This document contains a techno-economical assessment of the installation of a grid-connected system in the roof at an auction centre located in Santa Maria del Aguila (Almeria). As starting point for the design and evaluation of the installation, the following boundary conditions have been considered: the local weather and solar radiation availability, the need of a direct architectural integration of the solar modules in the pre-existing roof and the knowledge of the user hourly electricity load. On this basis, 7 different scenarios of photovoltaic grid connected plants have been created and analysed, both in terms of on-site installation and technical performance and in terms of economic profitability. The options considered consist of different combinations of sizes of storage and solar generation for a grid tied systems, even including a fully autonomous eventual operation.

In all the cases, calculations related to the losses (shadow, non-optimal orientation, etc.) have undertaken for a correct plants settlement. Afterwards, the sizing of corresponding modules arrays, inverters and batteries for each scenario have been carried out since it is requested as input for their detailed performance and economical profitability estimation. System Advisor Model (SAM) by NREL has been used as tool for the dynamic simulation of the 7 proposed plants configurations and for the integration of hourly systems estimations in global plant performance indicators (yearly production and payback period).

As result of the work, the more feasible option for the user is that consisting in a 216.4 kW plant with a cost of 362,081€, reaching a quite reasonable payback time. The rest of the options have been discarded because the period of payback was higher due to the expensive price of the batteries and the fact that the systems were oversized making the facility less profitable.

Keywords: photovoltaic, photovoltaic modules, inverter, orientation, shadows, losses, available roof, Almeria, irradiation, temperature, parallel, series, PVGIS, SAM, panels, energy consumption, photovoltaic production, surplus, profit, savings, profitability.

Este documento contiene una valoración tecno-económica de la instalación de un sistema conectado a red en la cubierta de un centro de subastas ubicado en Santa María del Águila (Almería). Como punto de partida para el diseño y evaluación de la instalación, se han considerado las siguientes condiciones de contorno: la disponibilidad de radiación solar y meteorológica local, la necesidad de una integración arquitectónica directa de los módulos solares en la cubierta preexistente y el conocimiento de la carga de electricidad por hora del usuario. Sobre esta base, se han creado y analizado 7 escenarios diferentes de plantas fotovoltaicas conectadas a red, tanto en términos de instalación in situ y rendimiento técnico como en términos de rentabilidad económica. Las opciones consideradas han sido diferentes combinaciones de tamaños de baterías y generadores solares operando en un modo de conexión a red e incluyendo una eventual operación autónoma del sistema.

En todos los casos se han realizado cálculos relacionados con las pérdidas (sombra, orientación no óptima, etc.) para un correcto asentamiento de las plantas. Posteriormente se ha realizado el dimensionamiento de los correspondientes arreglos de módulos, inversores y baterías para cada escenario ya que se solicita como insumo para su detallado desempeño y estimación de rentabilidad económica. System Advisor Model (SAM) de NREL se ha utilizado como herramienta para la simulación dinámica de las 6 configuraciones de plantas propuestas y para la integración de estimaciones de sistemas horarios en indicadores globales de rendimiento de plantas (producción anual y periodo de recuperación).

Como resultado de la obra, la opción más factible para el usuario es la que consiste en una planta de 216,4 kW con un coste de 362.081 €, alcanzando su amortización en un periodo razonable de tiempo. El resto de opciones se han descartado porque el período de recuperación fue mayor debido al alto precio de las baterías y al hecho de que los sistemas eran sobredimensionados, lo que hacía que la instalación fuera menos rentable.

Palabras clave: fotovoltaica, módulos fotovoltaicos, inversor, orientación, sombras, pérdidas, cubierta disponible, Almería, irradiación, temperatura, paralelo, serie, PVGIS, SAM, paneles, consumo de energía, producción fotovoltaica, excedente, beneficio, ahorro, rentabilidad.