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FACULTY OF CHEMICAL ENGINEERING AND TECHNOLOGY

DEGREE IN INDUSTRIAL TECHNOLOGY ENGINEERING

Loreto Taboada Hellín

DIPLOMA THESIS

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UNIVERSIDAD POLITECNICA DE VALENCIA

ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES

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Installation of solar panels on a farm in Murcia (Spain)

DIPLOMA THESIS

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ABSTRACT

This project has the objective of investigating a scope of a photovoltaic solar installation for supplying electricity to a farm located in Ceutí, Murcia, Spain.

The photovoltaic solar installation will include two elements. Primary element will include a photovoltaic generator connected to the electrical network. Secondary, an energy storage element in the form of batteries will be installed to support the generator operation during unavailability of the electrical network.

The investigation of the scope of the photovoltaic installation will cover the technical and economic criteria to elucidate the most appropriate option.

This document will present the components of the installation, the most significant calculations for the design and everything necessary to bring this project to reality.

INDEX

1. INTRODUCTION

Pollution and climate change pose a current and unavoidable problem for our society.

To address this problem, governments and scientists are working on renewable energy plans. That is, they are changing their energy production model based on the burning of fossil fuels to renewable energy sources.

In Spain, according to official data from Spanish electricity network, photovoltaic solar power has tripled in the last 3 years, going from 4,767 MW at the beginning of 2019 to 15,190 MW at the end of 2021. It should be noted that photovoltaic energy has gone from occupying 3.55 % of solar energy to 8.05 % in this period.

One of the reasons for this increase is the nullity of the sun tax.

In Spain between 2015 and 2018, all self-consumption users were required to pay a fee for being connected to the electricity grid. In this way, the amortization period of the photovoltaic installations was longer. Self-consumption was no longer so interesting. At the end of this rate, the installation of solar panels increased by 80 %.

Another important reason as to why the installation of solar panels is becoming a good alternative is the increase in the price of electricity. Since 2020 the price of a kWh in Spain has increased fivefold which represents a significant reduction in the amortization period of photovoltaic installations.

For all these reasons, the installation of solar panels is becoming a good alternative to fossil fuels to curb climate change as well as an option for economic savings.

1.1 Purpose

The object of this project is to size a photovoltaic installation, which allows self-sufficiency to a farm located in the town of Ceutí belonging to the municipality of Murcia (Murcia). The facility will be designed according to be connected to the grid. Also, the possibility of adding batteries to achieve self-consumption will also be proposed.

1.2 Scope

The scope of the project is based on two main ideas.

The design of the photovoltaic installation which includes the development of supporting calculations to carry out the installation and an economic study of the project. The investment of the project and the return time will be calculated.

1.3 Justification

The justification for carrying out the project is the idea of obtaining a future benefit. In other words, energy savings will be reflected in the electricity bill considering solar panels have a useful life of approximately 30 years.

2. GENERAL PART

2.1 Fundamentals of photovoltaic solar energy

The sun is a powerful source of energy that can be converted into electricity using photovoltaic installations, which take advantage of one of the most important renewable resources available: the sun. Solar cells, silicon based, are incorporated into all solar panels and are responsible for the energy transformation that occurs. This transformation is based on the photovoltaic effect, which is essentially the absorption of light energy by electrons in the silicon that results in the generation of an electric current.

Simplified, the solar cells in a panel create an electrical field between its layers, which generates an electric current when the photons of sunlight directly affect the cells. The intensity of the light received determines the amount of electrical flow produced. This current is generated through the junction of two extrinsic semiconductor materials, the n-type material, and the p-type material, which are doped to increase the number of free charge carriers (free electrons or positive holes).

However, electrons cannot easily cross the p-n junction of these two materials, leading to a voltage difference between the layers. This voltage can be used to power an appliance if a circuit is connected to each side of the panel. The resulting electricity is in the form of direct current. To improve its efficiency, an inverter is used to convert this energy into alternating current that is suitable for home use.

There are three types of solar panels available with respect to the structural organisation of the constituting silicon, including monocrystalline, polycrystalline, and amorphous panels. Monocrystalline panels are made from “whole blocks” of silicon, making them highly efficient but expensive. They perform better than others in low radiation conditions and are easily identifiable by their black colour. Polycrystalline panels, on the other hand, are made of non-homogeneous silicon and are less efficient than monocrystalline panels, requiring a greater number of panels to achieve the same power output. They are recognizable by their blue colour. Finally, amorphous solar panels are cheaper and more flexible, but less efficient than the previous types and have a shorter useful life.[1]

2.2 Types of photovoltaic installations

There are four types of photovoltaic installations. The first is the off-grid photovoltaic installation which is a system that operates independently for self-consumption is one that lacks the ability to connect to the electricity grid, either directly or indirectly. This means that the consumer is entirely self-sufficient in terms of energy generation.

On the other hand, we have a type of photovoltaic installation connected to the network.

These installations operate as a generator, just like any other electricity production centre, providing power to an electrical grid. They can be designed either for selling energy to the grid or for self-consumption.

Also, there are the photovoltaic installations for collective self-consumption.

This is photovoltaic installation that generates electricity for the use of several connected consumers.

Finally, there are also hybrid photovoltaic installations. This system combines solar energy with other self-consumption alternatives in the same network. In this sense, many combinations are possible within this type of renewable energy.[1]

2.3 Components of a photovoltaic installation

1. Structure for solar panels

The structure for solar panels is a fundamental piece that often does not receive the attention it deserves.

The supports must provide the photovoltaic modules with a good fixation to the roof, or sufficient weight, in the case of structures without a roof, to withstand the effects of the weather.

The structures also adapt the panels to latitude (looking for the proper inclination), and to the best possible orientation for their production. This is something simple if we install on the ground or flat roof, but not so much in the case of residential roofs.

The structure can be a particularly sensitive element in your installation in regions where it snows, since it must withstand the overloads produced in this situation, something that we must also consider in the design phase of the photovoltaic installation.

Fixed photovoltaic structures are the most used for reliability and accessibility, and they are also cheaper structures. They give the solar panel an orientation and a fixed angle, which must be determined based on the latitude of the installation or that is determined by the roof itself.

A variant are adjustable photovoltaic structures. These are structures that, being fixed, can be configured with various angles of inclination, something especially useful to modify the inclination depending on the season of the year.

Mobile structures are used in cases where you want to maximize the performance of the panels.

These structures have one or two mobile axes, being able to rotate to capture more radiation from the Sun by tracking its trajectory.

However, this mobile capacity requires electricity consumption, and this mechanical complexity exposes them to breakdowns and entails maintenance operations. In addition, the cost is considerably higher.

Regarding the material of the supports there are several options.

One of the best possibilities is aluminium that it is a light and fully recyclable material. On the other hand, its resistance to corrosion makes it a perfect material to work outdoors. In this way, aluminium is a material with great durability and stability against changes in temperature, humidity, solar radiation, etc., all with minimal maintenance.

Another option is galvanized steel structures. The supports that use this material are designed with high-quality hot-dip galvanized steel profiles, with a zinc coating that ensures effective and efficient protection against weather adversities and ensures greater durability and less maintenance.

Galvanized steel is cheaper than aluminium, although it does have some problems. For example, if we drill it once galvanized it will lose its protection. If we invest a little more, we can get stainless steel structures and avoid those problems.

One of the star products both for flat roofs and for installations on the ground is concrete. These are pieces specially designed and manufactured to act as a support for photovoltaic panels, simplifying assembly and lowering costs by eliminating the fixing of the structure itself or its anchoring to the roof. In these structures, it is the mass of the concrete pieces itself that ballasts the panels to counteract the effects of wind and other external agents.[3]

2. Solar panels

Solar panels, also known as solar panels or modules, are facilities specialized in capturing the energy produced by solar radiation to convert it into electricity.

Although there are different types of solar panels on the market.

Photovoltaic solar panels

Panels made up of photovoltaic cells. These cells have very few applications individually (600 mV) for this reason they are associated in series by means of flat tinned copper. These serial cells are encapsulated in an assembly system made up of 5 parts:

First, we have the outer cover, it has a protective function and requires high transparency to transmit radiation. They are usually made of glass.

Then we find the encapsulating layers, this layer prevents direct contact between glass and cell. Some of its functions are electrically isolate the cell from the panel, protect against humidity, dampen vibrations and impacts... The material used is usually silicone, TEDLAR or EVA.

Next is the support frame. It gives mechanical rigidity to the whole and allows insertion in structures that group more modules. The materials used are usually the same as those of the support (aluminium, galvanized steel, stainless steel…)

Finally, we have a watertight box, this box incorporates protection elements such as the protection diode inside. It is the most reliable and long-lasting option. The Bypass diode short-circuits the shaded or damaged areas of the module that produce an inequality of modules with different irradiances, thus minimizing imbalance losses.

As we have previously explained, these types of panels are found in plants no matter the setup.

Thermal solar panels

Solar thermal panels or solar thermal collectors convert solar energy into thermal energy. This type of plate is responsible for collecting the heat emanated by the sun's rays thanks to an internal liquid that heats up when the light falls on it, transmitting the heat generated in a tank or exchanger. Among its most frequent applications we find: the production of hot water for domestic consumption as well as for heating and air conditioning systems.

There are two types of thermal conversion, concentration thermal conversion and low temperature thermal conversion.

To carry out the thermal conversion of concentration, there are 4 types of technologies that can be installed in thermoelectric power plants.

There are parabolic trough power plants. These are made up of mirror concentrators that reflect solar radiation onto a tube containing heat transfer fluid, thus producing steam, and driving a turbine. There are also tower stations, in which a field of heliostats reflect radiation onto a central receiver. In that receiver the transformation takes place, heating a fluid that will generate steam and drive a steam turbine.

We also find parabolic disk power stations. These are made up of a Stirling-dish system consisting of a parabolic mirror with a Stirling-type motor in its focal area. That is where the energy is transformed.

As a last option we find the linear Fresnel concentrators. These power stations are made up of linear mirrors that can rotate around their axis to direct the radiation towards the linear receiver located above.

To carry out the generation of solar thermal energy at low temperature, two options predominate.

The first option is a flat collector. The basis of this system is the greenhouse effect. To achieve this the transparent cover of the collector traps the radiation that bounces off the absorber and increases the overall efficiency.

The second option is vacuum tubes. This set of cylindrical tubes has a selective absorber that sits on a reflector and is surrounded by clear glass cylinders. The collector is made up of many aligned tubes. The main characteristic of these tubes is that a vacuum has been created inside, which prevents thermodynamic losses.

Hybrid solar panels

As its name implies, hybrid solar panels are the result of the combination of a thermal and a photovoltaic system.

These hybrid plates work simultaneously generating electricity and heat, since they use the entire spectrum of existing light. Normally, hybrid plates use the front part to generate electricity, while the back part collects the heat emitted thanks to a heat exchanger.

Although the installation of hybrid solar panels is related to small surfaces, they can be installed in larger capacity spaces such as hotels, residential complexes, industrial buildings, and the like.

In this project we study photovoltaic solar panels.[1]

3. Charge controller

A solar charge regulator is an electronic device used to control the state of charge of batteries. The purpose is to ensure that it is fully and correctly recharged, thus prolonging its useful life as much as possible.

The solar charge regulator is installed between the photovoltaic field and the batteries and is responsible for controlling the flow of energy that circulates between the two elements. This control of the transit of energy is produced thanks to the control of the parameters of intensity (I) and voltage (V) throughout the time that each charge stage lasts.

There are two types: the PWM charge regulator and the MPPT. It is convenient to know the characteristics of each system to know which is the most suitable for our photovoltaic installation.

PWM charge controller.

The device is responsible for regulating the flow of electricity between the solar panels and the batteries by using pulse modulation, ensuring that the batteries are not overcharged. It is important to note that the device must have the same nominal voltage as the solar panels and batteries. For instance, if we have a 12V battery, we should use a 12V panel to charge it. The solar panel operates at a voltage that corresponds to the battery's charging stage, which is not necessarily the maximum intensity that the panel can provide. Consequently, not all solar production is utilized, but it is a more cost-effective approach. If we need more load power, we can connect more 12 V panels but in parallel so as not to add voltage.

MPPT charge controller.

MPPT or Maximum Power Point Tracking regulators are power maximisers since they can adapt the capture of photovoltaic energy to the battery voltage. In this way, a higher performance in energy production can be obtained. MPPT technology is different from PWM in that it uses a DC-DC voltage converter to handle different voltages between the low voltage of the batteries and the high voltage of the panels. This allows the regulator to convert the incoming energy into the same output energy. In this way, photovoltaic production can be increased by 30% compared to PWM charge regulators, although it also has a higher price.

To choose the most suitable for our photovoltaic solar installation, several aspects must be considered. The first is the type of solar panels that the module has, as well as the installation size. The larger it is, the more recommendable is the use of an MPPT controller.[2]

4. Optimizers

A power optimizer for photovoltaic systems is a device whose function is to reduce the losses of a photovoltaic solar system, thus increasing the efficiency of the system.

The idea is that each of the panels has an optimizer, these being connected to the inverter.

Power optimizers can be connected in series or parallel, and they provide power to a standard or dedicated inverter. The optimizer works on each panel, which increases the accuracy of identifying the point of maximum power. This means that when a photovoltaic panel's efficiency is reduced by shading factors, connecting it to a power optimizer can help mitigate this limitation.

In solar systems that have a power optimizer, the current conversion is done in the inverter, while with microinverters, each one of them is responsible for the current conversion (which generates an increase in losses during the conversion).[4]

5. Investor

To convert the direct current (DC) coming from the photovoltaic generators into alternating current (AC) for consumption in the home, we need a DC/AC current converter device called an inverter.

Inverters are mainly characterized by the input voltage from the batteries, the maximum power it can provide and its efficiency or power performance.

One of the functions that any solar inverter must fulfil is to regulate the value of the output voltage, as it must be equal to the voltage used by the electricity grid (220 V RMS and 50 Hz frequency). This is basically achieved in three different ways:

- regulating the voltage before the inverter (DC/DC converters)
- regulating the voltage in the inverter itself through a control system (varying the phase angle, through pulse width modulation (PWM))
- or regulating the inverter output (using an autotransformer) [4]

6. Wiring (connection systems)

When designing the solar field, I can carry out the distribution of panels in series, in parallel or a combination of both.

Serial connection

The connection of solar panels in series is made by joining each of the panels to the next, as if we were building a chain. In this configuration, the positive pole of one plate is connected to the negative pole of the next, and so on with all those that make up the set.

In this type of connection, in series, it is possible to increase the voltage of the set, while maintaining the current intensity.

Panel connection in parallel

The connection of solar panels in parallel is made by joining the positive poles together, and the negative poles also together on the other side. Therefore, all the cables that are connected to the positive pole of the plates are joined to a larger cable that supports the work of those who reach it. All the negative poles of the plates are attached the same to another conductive wire.

This method of connecting the solar panels achieves that the electrical current intensity of the set is the sum of all the intensities of each one of the plates that make up the set. Instead, the tension remains constant.

Connection of solar panels in series-parallel

Different sets of boards by joining several boards in series, and then connecting those groups of "series boards" in parallel. This is how the adequate voltage and intensity is achieved to choose the solar inverter that gives us the best result for the entire installation.

As we see in the three examples, the different ways of connecting the solar panels provide us with the same electrical power. However, depending on the type of connection of the solar panels that we choose, we have varied the output voltage or intensity. This is how we adapt each one of them to the needs of our photovoltaic installation.

The junction box of a solar panel is usually located at the back of the plate. It is the meeting point for the connectors of the different photovoltaic cells that make up the panel, where the safety diodes and the external connection cables of the board are installed. These connection cables are used to join a panel with its neighbours, to get a set of solar panels.[3]

7. Protections

The protection elements of the photovoltaic installation will be designed to protect people against all types of contact, both direct and indirect.

In addition, all installations must be protected against overloads, short circuits and overvoltage’s. The batteries, if they exist, must be specially protected by means of electromagnetic circuit breakers, fuses, or any element capable of fulfilling this type of function.

In accordance with all this, we will have the different protection elements of the photovoltaic installation described below.

Circuit breakers

These elements offer protection against short circuits and overcurrent’s quite reliably. Its design is designed to withstand DC voltages of 1000 V. This value is imposed by the number of existing panels.

Fuses

Like the previous ones, the fuses protect against overcurrent's that may occur. They must be chosen based on the type of current that you have and the system voltage. In installations where there are no stings in parallel, it is not necessary to put fuses.

Disconnectors

Disconnectors that close the circuit when overcurrent's occur.

Surge arrester

The arresters are elements that refer to earth the overvoltage's derived from atmospheric phenomena. They are devices in charge of protecting both the solar panels and the inverter. They are connected in parallel to the electrical installation to guarantee that the discharges are derived to earth.[5]

8. Grounded

The grounding of installations with solar panels is one of the aspects that causes the most controversy, generally due to the absence of specific technical regulations for this type of project. Grounding includes both equipment grounding (protective ground) and live conductor grounding (system ground).

In Spain, the grounding of a solar panel installation is free at discretion.

When it is decided to ground exposed metal parts (as protection against storms, against indirect contact, etc.). Photovoltaic solar panels have, in the frame, a specific hole for grounding.

In addition, the system must be grounded at a single point, called the system ground. If this is not the case, there is the possibility of current flowing through the protective conductors, causing the operation of charge controllers and inverters to become unreliable. In addition, these currents could interfere with the operation of the fault detection and overcurrent protection devices.

A practical and simple solution consists of electrically joining the terminals of the active (or central) grounded conductors, with terminals of protective conductors (joined to the ground electrode through the main ground conductor). In short: unite all lands.

Finally, remember that it must be considered that in photovoltaic installations connected to the grid, the grounding of the photovoltaic system must be independent of the grounding of the neutral.[5]

9. Batteries

Batteries that store electricity can be monobloc, AGM, stationary, gel or lithium. As you can see, there are several types of batteries that you can connect to your photovoltaic system and thus store the energy that you produce more.

Monoblock batteries.

This type of battery is designed for small photovoltaic installations where the price-quality ratio is balanced. Open lead acid batteries are of inferior technology. These have a lifespan of 300 charge cycles, which means that if you charge and discharge once a day, the battery will last less than a year.

AGM batteries.

AGM (Absorbent Mat Glass), have gas valves for the best recombination of these. Thus, energy losses are avoided, the internal pressure is regulated more easily and for this reason, there is a greater use that translates into greater performance. AGM batteries are suitable for high currents in a short space of time because their internal resistance is very low. They have a short life cycle: 500 charge and discharge cycles.

Gel electrolyte batteries.

This type of battery presents a high-quality cyclical operation, which makes it ideal for medium/large installations whose purpose of operation is long periods. These have a longer useful life, withstanding 1,200 cycles. In addition, up to 60 % are discharged.

Stationary batteries.

This type of photovoltaic solar battery is perfect for installations with continuous daily consumption and for long periods. They have superior technology and offer 3,000 charge and discharge cycles. In addition, up to 80% can be downloaded. These are useful for large homes or homes disconnected from the electrical network.

Lithium batteries.

Lithium batteries allow full discharge, that is, 100 % of their power. For example, a 200 Ah lithium battery can be charged to 100 %, unlike others such as AGM or gel, they do not allow charges higher than 80/90 %, so they are not fully discharged.

This feature makes the charging process faster than other types of batteries. In addition, it allows several discharge processes (up to 6000 cycles at 90 %).[6]

3.REGULATIONS IN SPAIN AND MURCIA

3.1 Photovoltaic legislation in Spain

Depending on the type of photovoltaic system that we are going to install, one or another regulation must be considered. Photovoltaic systems are classified into three types: Stand-alone photovoltaic systems (SFA), photovoltaic power plants (CFV) and self-consumption systems (SFCA).[7]

In our case we will deal with self-consumption systems. According to the Ministry for the Ecological Transition and the Demographic Challenge, self-consumption of electricity is "the consumption by one or more consumers of electricity from production facilities close to those of consumption and associated with them".[8] In other words, it is about producing or generating your own electrical energy through solar panels from the same place where you are going to consume it, either in your home or in your business.

The self-consumption regulatory framework is perfectly defined and falls under Law 24/2013, of December 26, on the Electricity Sector.

The fundamental regulation on self-consumption appears contained in RD 244/2019 that regulates the economic, technical, and administrative conditions that govern self-consumption.

The main modalities of self-consumption that currently exist are two: with surpluses and without surpluses.

The modalities without surpluses are those in which the system does not allow the injection of energy into the distribution network, that is, they have anti-discharge systems.

On the other hand, the modalities with surpluses are those that have a system that, in addition to allowing self-consumption, can inject the surplus energy into the network.

If you opt for this last option, you can opt for several self-consumption modalities depending on the power you decide to contract:

- Installations with powers of less than 100 kW: in this case it is possible to benefit from a simplified compensation system. At the end of the month, the retailer will compensate you for the energy produced and not consumed that you have poured into the network.

- Installations with more than 100 kW: if your installation exceeds 100 kW you cannot benefit from simplified compensation. You will consume the generated energy and the surplus will have to be sold in the market. You would act as a producer of renewable energy, and you must face tax and administrative procedures.

The Royal Decree leaves the price of the surplus to negotiation between the user and the marketer itself. It is the latter that decides the price, which is very possibly like the cost of the kW in the wholesale market. In addition, they are free to offer different offers to offer greater advantages and benefits to customers.[9]

3.2 Photovoltaic self-consumption in Murcia

In the Region of Murcia, we can find three types of subsidies to install solar panels:

-Aid from the Government of the Region of Murcia.

-European Next Generation Funds

-Tax rebates and tax deductions.[10]

Self-consumption facilities in the Region of Murcia are legalized based on RD 244/2019. However, they are subject to the following specific procedures:

- Resolution of the General Directorate of Industry, Energy and Mines approving the technical instruction for the application in the Region of Murcia of RD 1699/2011.

- Law 8/2004 of December 28 on administrative, tax, rate, and public function measures.

- Decree 47/2003 of May 16, which approves the regulations for the registration of industrial establishments in the Region of Murcia.

For taxpayers with habitual residence in the Autonomous Community of Murcia, a deduction is recognized in the full regional income tax quota for investment in installations of renewable energy resources of 10 % of the investments made in the execution of installation projects of energy resources from the following renewable energy sources: solar thermal and photovoltaic and wind.

To apply the deduction certain requirements must be met. The features of this help are:

-Amount and maximum limit: 10 % of the investment made in solar thermal, photovoltaic and wind energy installations.

- Limit of applicable deduction: 1,000 €

-Maximum base of the deduction: it is constituted for the acquisition of renewable installations, without the maximum amount exceeding 10,000 €.

-Requirements and other conditions:

- Maximum base of the deduction: it is constituted for the acquisition of renewable installations, without the maximum amount exceeding 10,000 €.

- The application requires the prior recognition of the regional administration.

- The application requires that the verified amount of the taxpayer's patrimony, at the end of the period, exceeds the value shown by its verification at the beginning. [11]

4. EXPERIMENTAL PART

4.1 Location of the farm

In this work the photovoltaic installation is carried out in a poultry farm in Ceutí, a town in Murcia (Spain).

The exact address is: C. Archena, 30562 Ceuti, Murcia, Spain.

The geographic coordinates are: -Latitude: 38.06996

-Longitude: -1.26393

This location has very favourable weather conditions. With excellent weather and access to plenty of sunshine, it has become a prime destination for solar panel installations. On the figure 1 we found the location of Murcia, in Spain.

FIGURE 1 MAP OF SPAIN

FIGURE 2 MAP OF MURCIA

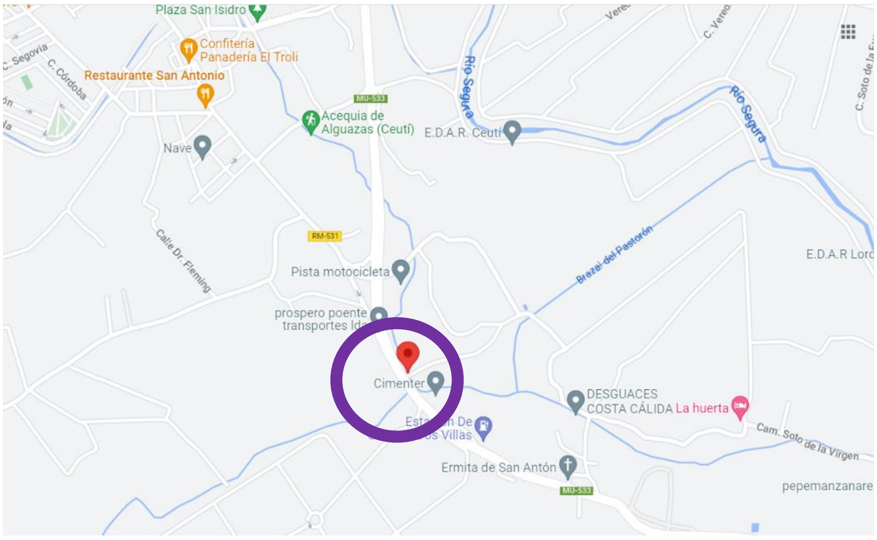


FIGURE 3 MAP OF CEUTÍ

Spain has the perfect conditions to be at the forefront of solar energy development on the continent and to be one of the international leaders in the photovoltaic industry.

In the following figure we observe the annual amount of solar energy in kWh/m^2 in all European countries. We see without any problem how Spain is one of the countries that receive the largest amount.

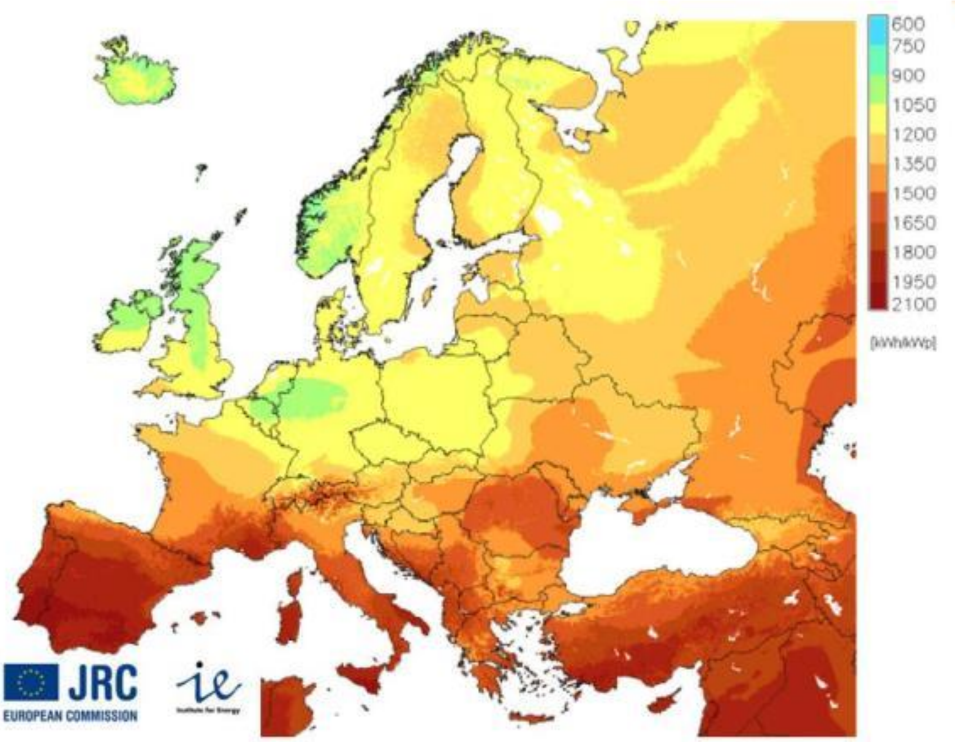


FIGURE 4 ANNUAL SOLAR ENERGY IN EUROPE (kWh/m^2) [12]

If we study solar radiation in Spain, we can also see (figure 3) how Murcia is one of the most favourable locations.

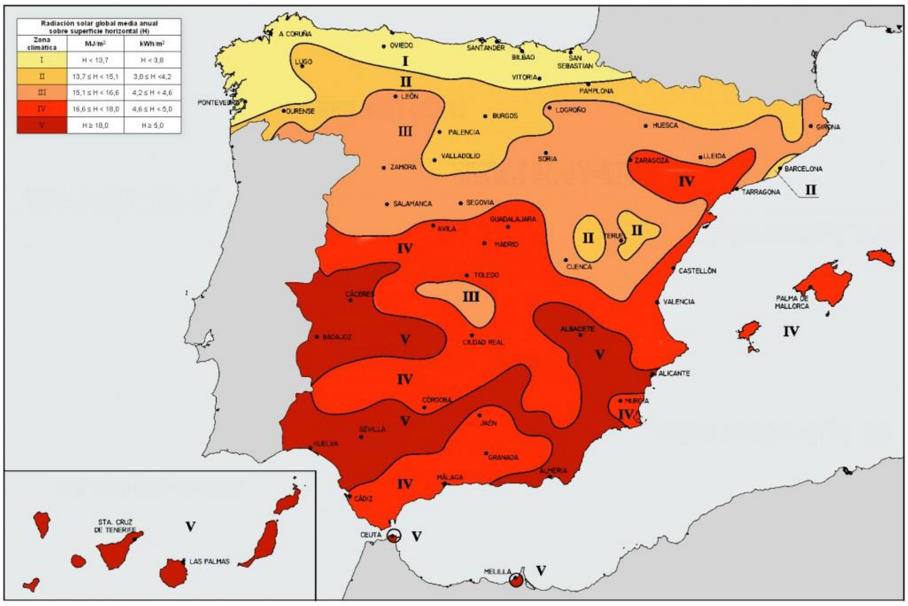
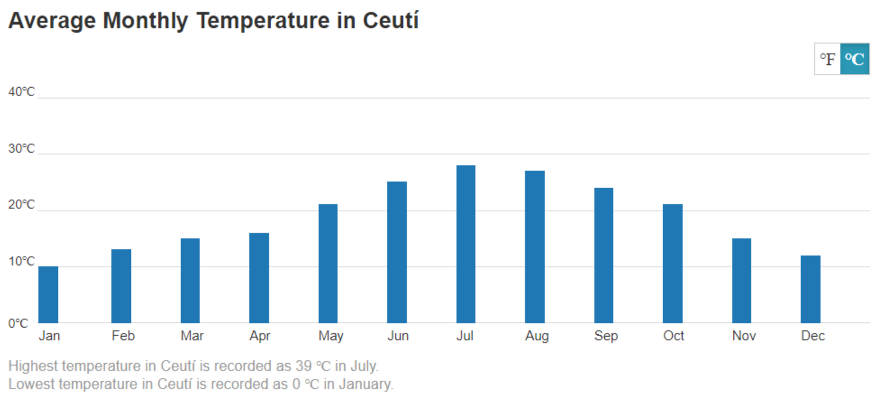


FIGURE 5 ANNUAL AVERAGE SOLAR RADIATION IN SPAIN

Regarding the temperature, the minimum during the year is 0ºC, and the maximum 39ºC. [13]



Highest temperature in Ceutí is recorded as 39 °C in July.
Lowest temperature in Ceutí is recorded as 0 °C in January.

FIGURE 6 AVERAGE MONTHLY TEMPERATURE IN CEUTÍ [13]

It is an area with little rain and precipitation is almost non-existent during the summer. September, on the other hand, is the month with the highest precipitation (1.5 mm/day).

Another aspect to highlight is the high number of hours of sunlight throughout the year. The number of hours of sunshine refers to the time when the sun is visible. That is, without any obstruction of visibility by clouds, fog, or mountains. In December, the sun shines the least. On the other hand, with 12 h/day, July is the sunniest month in the region of Murcia. [14]

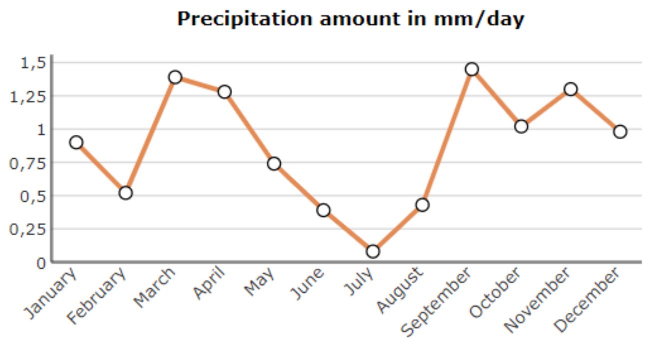


FIGURE 7 PRECIPITATION AMOUNT IN mm/day [14]

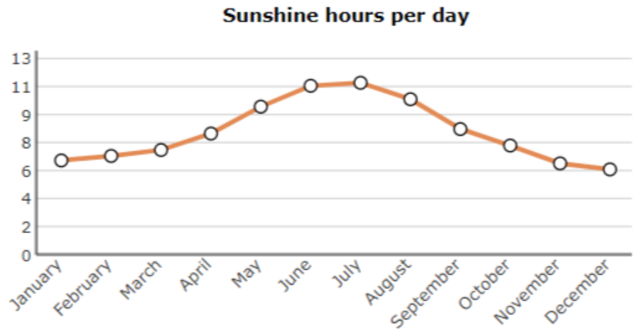


FIGURE 8 SUNSHINE HOURS PER DAY [14]

4.2 Building

The house for which is being designed the installation is an industrial warehouse of dimensions 60×5.90×2.90 m with a roof inclination of 0 ° (flat roof).

The farm is made up of 3 industrial buildings, approximately the same size (one is bigger than the others). This project will only be calculated for one of those buildings. It is intended to obtain an estimate of the consumption of the warehouse according to the hours of use of the installed electrical appliances and then compare it with the real one.

FIGURE 9 LOCATION OF THE FARM

FIGURE 10 INSIDE THE FARM

4.3 Estimate and real consumption

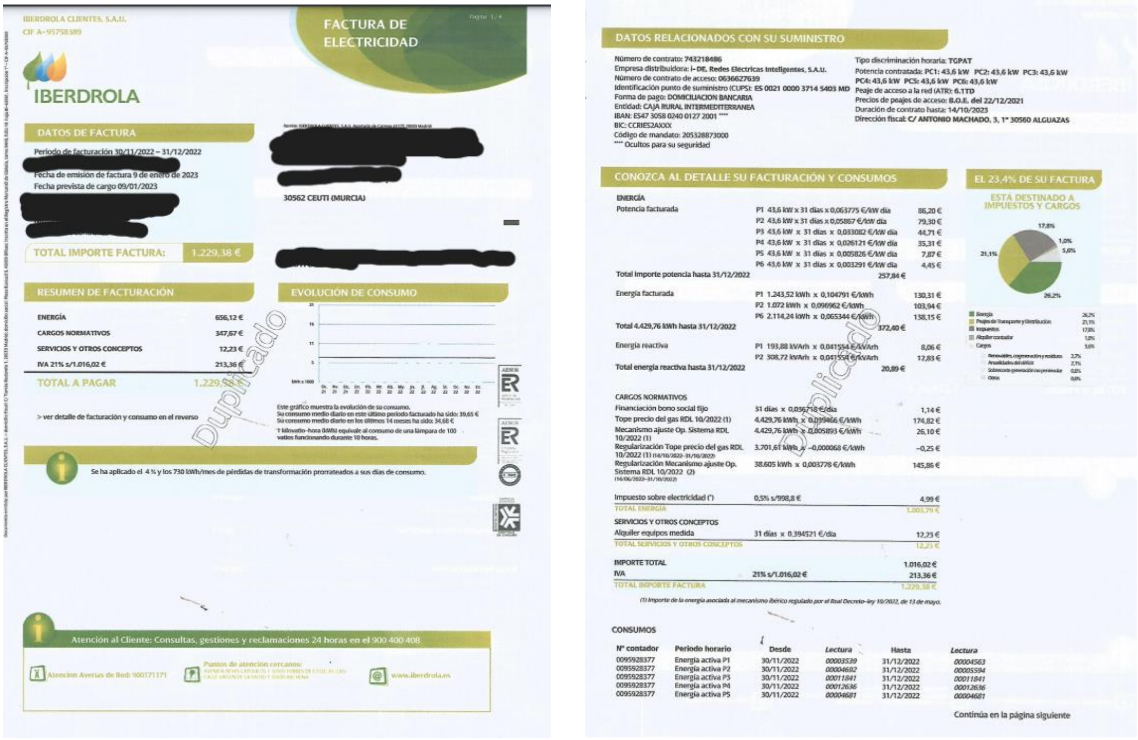
To estimate consumption, the most unfavourable conditions are assumed.

TABLE 1 ESTIMATE CONSUMPTION OF THE FARM

DEVICE	POWER (kW)	HOUR OF USE (h/day)	ENERGY (kWh/day)
light bulbs	0.011x70=0.77	8	6.16
feed hopper motors	1.250x2=2.5	1.5	3.75
industrial fans	2x3=6	12	72
egg collection and grading	22	2.5	55
feed mill	33.55	1.15	38.58
garbage conveyor motors	3x6=18	0.072	1.296
Water Pump	2x2=4	11	44

TOTAL ENERGY: 220.79 kWh/day
TOTAL CONSUPTION IN A MONTH: 6624 kWh
TOTAL CONSUMPTION IN A YEAR: 79 483 kWh

Once the consumption is estimated, it is compared with the real one. We obtain this through an electricity bill where we can find a graph with the electricity consumption during the last year.



IBERDROLA CLIENTES, S.A.U.
CIF A-95758389

FACTURA DE ELECTRICIDAD

Página 1/4

IBERDROLA

DATOS DE FACTURA

Periodo de facturación 30/11/2022 – 31/12/2022
[redacted]
Fecha de emisión de factura 9 de enero de 2023
Fecha prevista de cargo 09/01/2023
[redacted]

[redacted]
30562 CEUTI (MURCIA)

[redacted]

TOTAL IMPORTE FACTURA:	1.229,38 €

RESUMEN DE FACTURACIÓN

ENERGÍA	656,12 €
CARGOS NORMATIVOS	347,67 €
SERVICIOS Y OTROS CONCEPTOS	12,23 €
IVA 21% s/1.016,02 €	213,36 €
TOTAL A PAGAR	1.229,38 €

> ver detalle de facturación y consumo en el reverso

EVOLUCIÓN DE CONSUMO

Este gráfico muestra la evolución de su consumo.
Su consumo medio diario en este último periodo facturado ha sido: 39,65 €
Su consumo medio diario en los últimos 14 meses ha sido: 34,68 €
1 kilovatio-hora (kWh) equivale al consumo de una lámpara de 100 vatios funcionando durante 10 horas.

Se ha aplicado el 4 % y los 730 kWh/mes de pérdidas de transformación prorrateados a sus días de consumo.

Atención al Cliente: Consultas, gestiones y reclamaciones 24 horas en el 900 400 408

Atencion Averias de Red: 900171171

Puntos de atencion cercanos:

www.iberdrola.es

DATOS RELACIONADOS CON SU SUMINISTRO

Número de contrato: 743218486
Empresa distribuidora: i-DE, Redes Eléctricas Inteligentes, S.A.U.
Número de contrato de acceso: 0636627639
Identificación punto de suministro (CUPS): ES 0021 0000 3714 5403 MD
Forma de pago: DOMICILIACION BANCARIA
Entidad: CAJA RURAL INTERMEDITERRANEA
IBAN: ES47 3058 0240 0127 2001 ****
BIC: CCRIES2AXXX
Código de mandato: 205328873000
**** Ocultos para su seguridad

Tipo discriminación horaria: TGPAT
Potencia contratada: PC1: 43,6 kW PC2: 43,6 kW PC3: 43,6 kW PC4: 43,6 kW PC5: 43,6 kW PC6: 43,6 kW
Peaje de acceso a la red (ATR): 6.1TD
Precios de peajes de acceso: B.O.E. del 22/12/2021
Duración de contrato hasta: 14/10/2023
Dirección fiscal: C/ ANTONIO MACHADO, 3, 1º 30560 ALGUAZAS

CONOZCA AL DETALLE SU FACTURACIÓN Y CONSUMOS

ENERGÍA			
Potencia facturada	P1 43,6 kW x 31 días x 0,063775 €/kW día		86,20 €
	P2 43,6 kW x 31 días x 0,05867 €/kW día		79,30 €
	P3 43,6 kW x 31 días x 0,033082 €/kW día		44,71 €
	P4 43,6 kW x 31 días x 0,026121 €/kW día		35,31 €
	P5 43,6 kW x 31 días x 0,005826 €/kW día		7,87 €
	P6 43,6 kW x 31 días x 0,003291 €/kW día		4,45 €
Total importe potencia hasta 31/12/2022		257,84 €	
Energía facturada	P1 1.243,52 kWh x 0,104791 €/kWh		130,31 €
	P2 1.072 kWh x 0,096962 €/kWh		103,94 €
	P6 2.114,24 kWh x 0,065344 €/kWh		138,15 €
Total 4.429,76 kWh hasta 31/12/2022		372,40 €	
Energía reactiva	P1 193,88 kVArh x 0,041554 €/kVArh		8,06 €
	P2 308,72 kVArh x 0,041554 €/kVArh		12,83 €
Total energía reactiva hasta 31/12/2022		20,89 €	
CARGOS NORMATIVOS			
Financiación bono social fijo	31 días x 0,036718 €/día		1,14 €
Tope precio del gas RDL 10/2022 (1)	4.429,76 kWh x 0,039466 €/kWh		174,82 €
Mecanismo ajuste Op. Sistema RDL 10/2022 (1)	4.429,76 kWh x 0,005893 €/kWh		26,10 €
Regularización Tope precio del gas RDL 10/2022 (1) (14/10/2022–31/10/2022)	3.701,61 kWh x −0,000068 €/kWh		−0,25 €
Regularización Mecanismo ajuste Op. Sistema RDL 10/2022 (2) (14/06/2022–31/10/2022)	38.605 kWh x 0,003778 €/kWh		145,86 €
Impuesto sobre electricidad (*)	0,5% s/998,8 €		4,99 €
TOTAL ENERGÍA			1.003,79 €
SERVICIOS Y OTROS CONCEPTOS			
Alquiler equipos medida	31 días x 0,394521 €/día		12,23 €
TOTAL SERVICIOS Y OTROS CONCEPTOS			12,23 €
IMPORTE TOTAL			1.016,02 €
IVA	21% s/1.016,02 €		213,36 €
TOTAL IMPORTE FACTURA			1.229,38 €

(1) Importe de la energía asociada al mecanismo ibérico regulado por el Real Decreto-ley 10/2022, de 13 de mayo.

EL 23,4% DE SU FACTURA

ESTÁ DESTINADO A IMPUESTOS Y CARGOS

Energía	26,2%
Peajes de Transporte y Distribución	21,1%
Impuestos	17,8%
Alquiler contador	1,0%
Cargos	5,6%
Renovables, cogeneración y residuos	2,7%
Anualidades del déficit	2,7%
Sobrecoste generación no peninsular	0,2%
Otros	0,0%

CONSUMOS

Nº contador	Periodo horario	Desde	Lectura	Hasta	Lectura
0095928377	Energía activa P1	30/11/2022	00003539	31/12/2022	00004563
0095928377	Energía activa P2	30/11/2022	00004692	31/12/2022	00005594
0095928377	Energía activa P3	30/11/2022	00011841	31/12/2022	00011841
0095928377	Energía activa P4	30/11/2022	00012636	31/12/2022	00012636
0095928377	Energía activa P5	30/11/2022	00004681	31/12/2022	00004681

Continúa en la página siguiente

FIGURE 11 ELECTRICAL BILL OF THE FARM

EVOLUCIÓN DE CONSUMO

Este gráfico muestra la evolución de su consumo.
Su consumo medio diario en este último periodo facturado ha sido: 39,65 €
Su consumo medio diario en los últimos 14 meses ha sido: 34,68 €
1 kilovatio-hora (kWh) equivale al consumo de una lámpara de 100 vatios funcionando durante 10 horas.

FIGURE 12 MONTHLY EVOLUTION OF CONSUMPTION IN THE FARM

With the data in this graph, we get the average monthly consumption, this is approximately 6750 kWh. The annual consumption would be 81 000 kWh. In this way, calculations are considered correct because the estimated and the actual consumption are very similar. The results only vary by 3 kW given approximation errors.

The installation will be dimensioned based on the monthly average of consumption. The objective is not to oversize the installation when designing it.

4.4 Solar gain

Before beginning to dimension the installation, we must know the irradiation data of the place. The information is obtained with the official PVGIS application, developed by the European Union.[15]

Also, we must choose the inclination of the structure where the solar panels are going to be placed. This is conditioned by the geographical area in which the solar panels are installed. In fact, in most provinces the optimal average inclination angle is between 30 and 40°. We know that to optimize its performance throughout the year, the inclination must be very similar to the latitude where the installation is located, in this case 38.06°. On the other hand, the azimuth angle should be 0 °. This means that since the installation is in the northern hemisphere, the panels will be fully oriented to the south.

Therefore, although the results are similar, we choose the optimal angle proposed, that is, an inclination of 36°.

Once the slope is chosen, the PVGIS application is used to calculate the annual slope of photovoltaic production in kWh for a maximum installed power of 1 kWp. A system loss of 14 % is also considered.

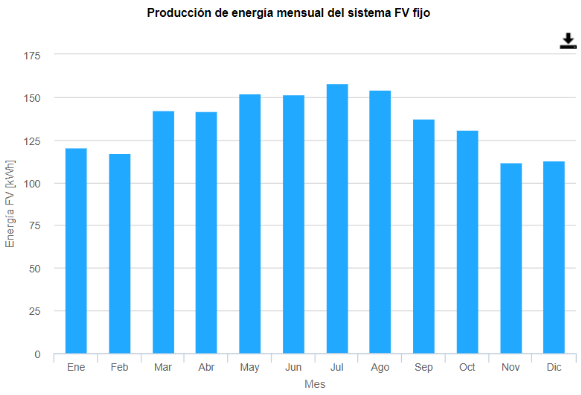
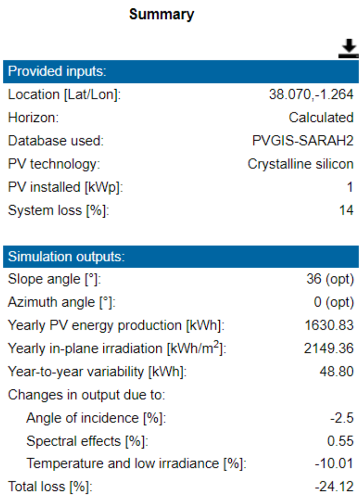


FIGURE 13 MONTHLY ENERGY PRODUCTION OF THE FIXED PV SYSTEM [15]

The application indicates an annual production of photovoltaic energy of 1630.83 kWh. And an irradiance of 2149.36 kWh/m^2.



Summary

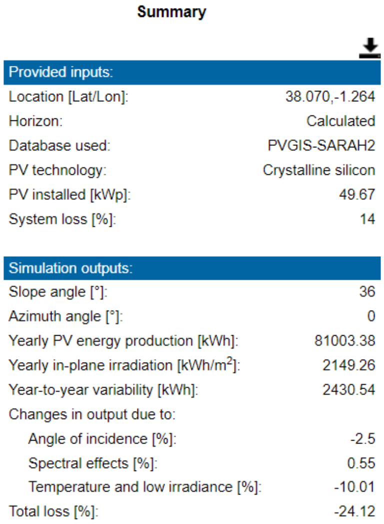
Provided inputs:	
Location [Lat/Lon]:	38.070,-1.264
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	36 (opt)
Azimuth angle [°]:	0 (opt)
Yearly PV energy production [kWh]:	1630.83
Yearly in-plane irradiation [kWh/m^2]:	2149.36
Year-to-year variability [kWh]:	48.80
Changes in output due to:	
Angle of incidence [%]:	-2.5
Spectral effects [%]:	0.55
Temperature and low irradiance [%]:	-10.01
Total loss [%]:	-24.12

FIGURE 14 PRODUCTION PHOTOVOLTAIC ENERGY (1 kWp) [15]

The power peak required for the installation is obtained by relating this production to the annual energy demand of the home.

$$Peak\ power\ to\ install = \frac{Annual\ energy\ demand\ of\ the\ farm}{Yearly\ photovoltaic\ energy\ production} = \frac{81000}{1630.83} = 49.67\ kWp$$

To repeat the simulation with PVGIS, we first approximate the peak power to 49.67 kWp, an annual production of 81003.38 kWh is calculated.



Summary

Provided inputs:	
Location [Lat/Lon]:	38.070,-1.264
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	49.67
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	36
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	81003.38
Yearly in-plane irradiation [kWh/m^2]:	2149.26
Year-to-year variability [kWh]:	2430.54
Changes in output due to:	
Angle of incidence [%]:	-2.5
Spectral effects [%]:	0.55
Temperature and low irradiance [%]:	-10.01
Total loss [%]:	-24.12

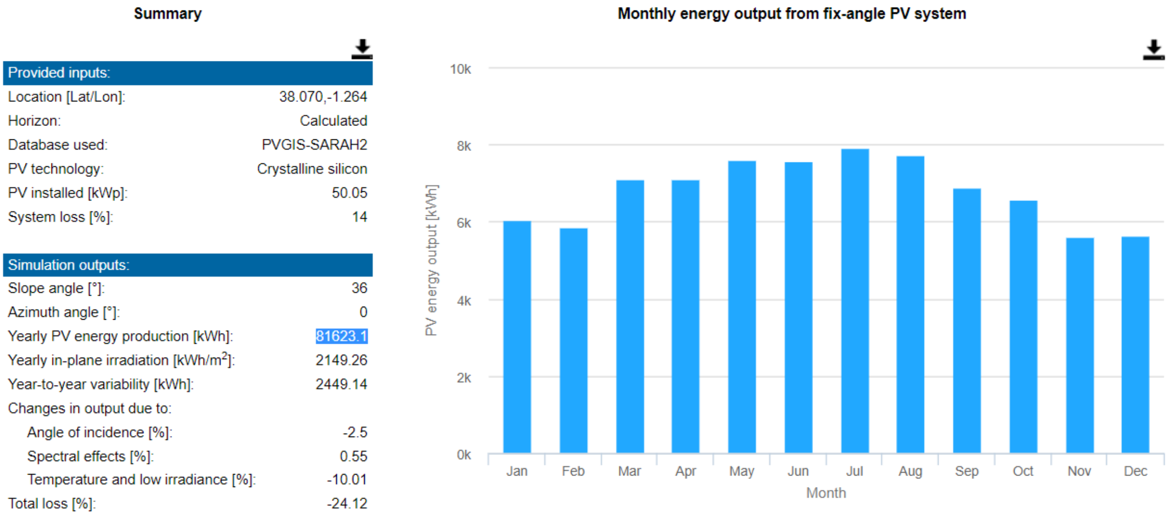
FIGURE 15 PRODUCTION PHOTOVOLTAIC ENERGY (49,67 kWp) [15]

Once the maximum power is established, we calculate the number of panels needed.

Knowing that the chosen model of solar panels has a power of 550 W since the chosen model is the LUXEN 530-550 W MONOCRYSTALLINE.

$$\text{Number of solar panels} = \frac{established\ peak\ power}{solar\ panel\ power} = \frac{49667.96}{550} = 91\ panels$$

Approximating the number of panels to 91 gives a final maximum power of 50.05 kWp and a final annual production of 81623.1 kWh.



Summary

Provided inputs:	
Location [Lat/Lon]:	38.070,-1.264
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	50.05
System loss [%]:	14

Simulation outputs:	
Slope angle [°]:	36
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	81623.1
Yearly in-plane irradiation [kWh/m^2]:	2149.26
Year-to-year variability [kWh]:	2449.14
Changes in output due to:	
Angle of incidence [%]:	-2.5
Spectral effects [%]:	0.55
Temperature and low irradiance [%]:	-10.01
Total loss [%]:	-24.12

FIGURE 16 MONTHLY ENERGY OUTPUT FROM SIX-ANGLE PV SYSTEM [15]

5. RESULTS

5.1 Solar panels

The solar panel chosen is Series 5 LNVU-530-550M.

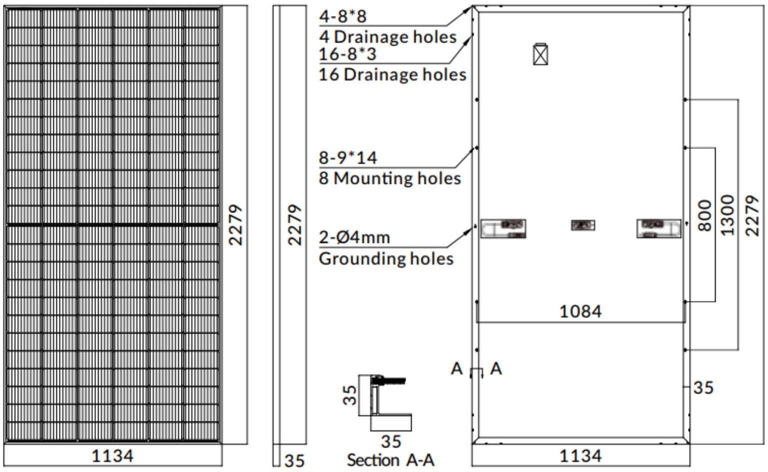
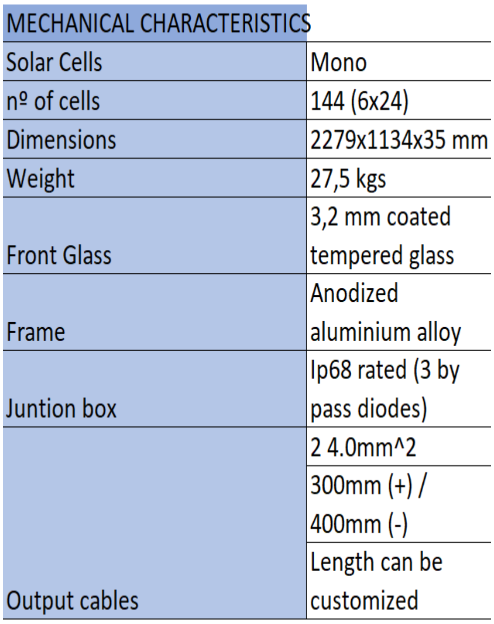


FIGURE 17 SOLAR PANEL DIMENSIONS [16]

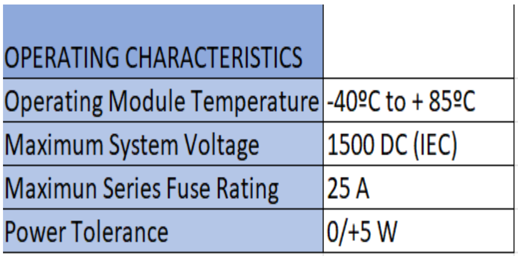
The following tables show some general characteristics of this solar panel model.

TABLE 2 MECHANICAL CHARACTERISTICS PV PANEL [16]



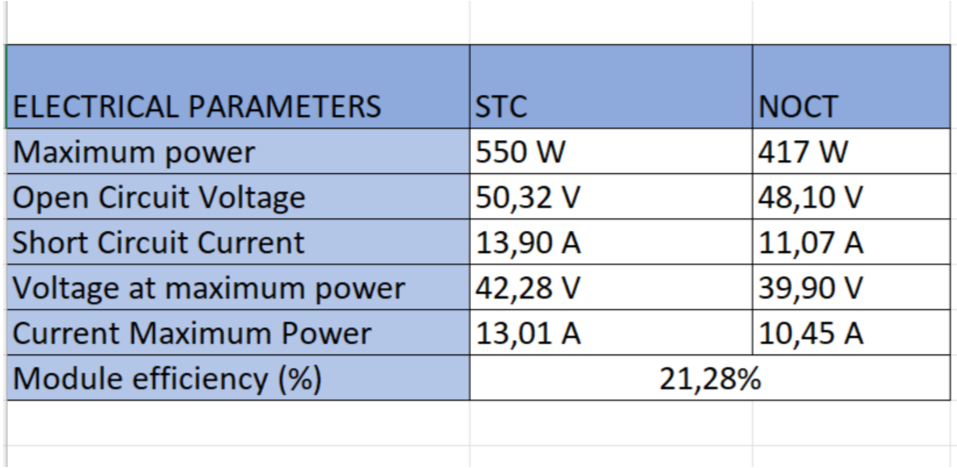
MECHANICAL CHARACTERISTICS	
Solar Cells	Mono
nº of cells	144 (6x24)
Dimensions	2279x1134x35 mm
Weight	27,5 kgs
Front Glass	3,2 mm coated tempered glass
Frame	Anodized aluminium alloy
Juntion box	Ip68 rated (3 by pass diodes)
Output cables	2 4.0mm^2
	300mm (+) / 400mm (-)
	Length can be customized

TABLE 3 OPERATING CHARACTERISTICS PV PANEL [16]



OPERATING CHARACTERISTICS	
Operating Module Temperature	-40ºC to + 85ºC
Maximum System Voltage	1500 DC (IEC)
Maximun Series Fuse Rating	25 A
Power Tolerance	0/+5 W

TABLE 4 ELECTRICAL PARAMETERS PV PANEL [16]



ELECTRICAL PARAMETERS	STC	NOCT
Maximum power	550 W	417 W
Open Circuit Voltage	50,32 V	48,10 V
Short Circuit Current	13,90 A	11,07 A
Voltage at maximum power	42,28 V	39,90 V
Current Maximum Power	13,01 A	10,45 A
Module efficiency (%)	21,28%	

STC: Irradiance 1000 W/m², cell temperature 25ºC, AM1.5G

NOCT: Irradiance 800 W/m², ambient temperature 20ºC, wind speed 1m/s, AM1.5G

Electrical performance & Temperature dependence:

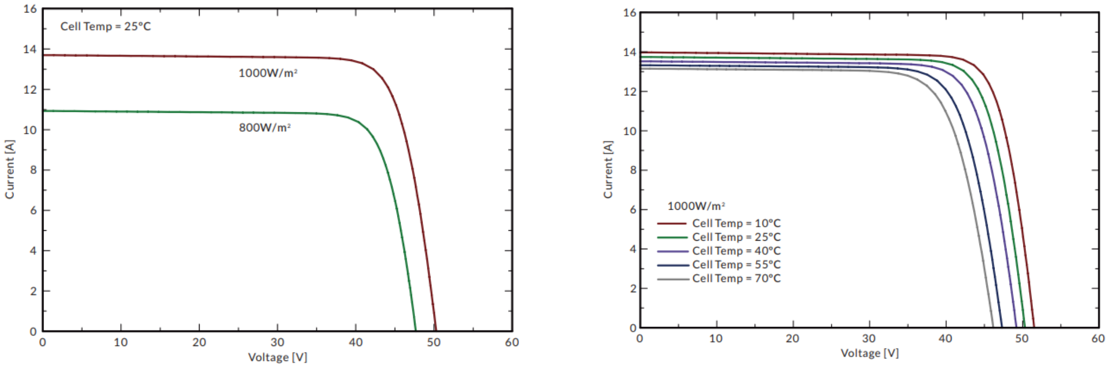


FIGURE 18 CURRENT-VOLTAGE & POWER-VOLTAGE CURVES [16]

5.1.1 Structure for solar panels

The support structure for the solar panels chosen is from Vico Export. The most adequate one is the 14.1 V model with adjustable open inclined support for flat roof.

According to the technical sheet:

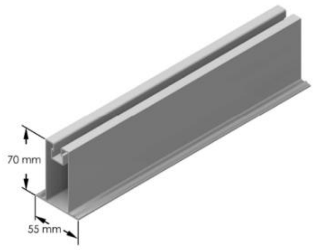
The kit system permits the modules to be positioned vertically, with an adjustable inclination ranging from 30º to 50 º. The maximum allowable module size is 2279x1150 mm, and a 20mm gap must be left between each module to accommodate the S11 pressers that secure the panels together. The material used is EN AW 6005A T6 aluminium profiles and the A2-70 stainless steel hardware. A document on wind speeds indicates it supports winds of up to 150 km/h and the installation is located 93 meters above sea level so snow overloading will not suppose any problems for the structure.[17]

The structure pack includes the following components:

- *Triangle for support* ***(14.1V)***

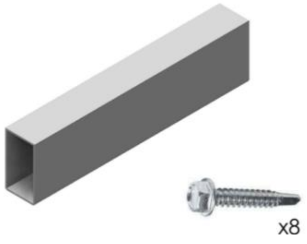
- *Central presser to fix panels to each other* ***(S11)***

- *Profile for module guide* ***(G2)***



- *Adjustable side presser for fixing panels at start and end* ***(S10)***

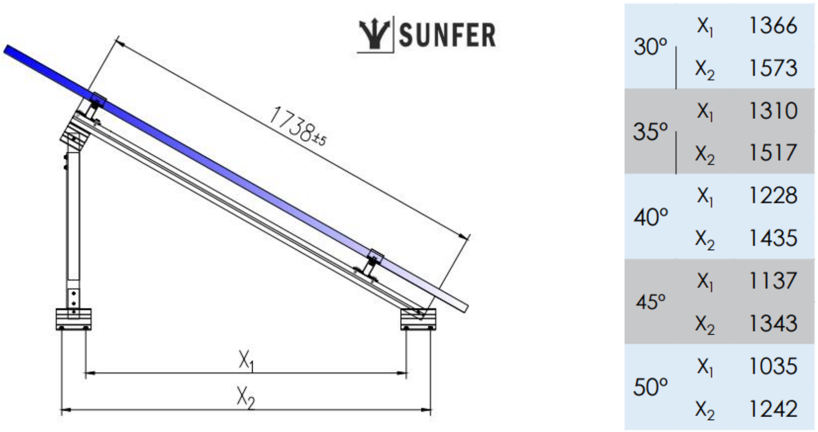
- *Connection for profile G2* ***(UG2)***



- *Bracing for inclined supports* ***(S09)***

FIGURE 19 COMPONENTS OF THE SUPPORTS PACK [17]

The solar panels must have an inclination of 36 degrees as indicated above. So, for our project we should fix with the following dimensions:



30º	X_1	1366
	X_2	1573
35º	X_1	1310
	X_2	1517
40º	X_1	1228
	X_2	1435
45º	X_1	1137
	X_2	1343
50º	X_1	1035
	X_2	1242

FIGURE 20 DIMENSIONS OF THE SUPPORT FOR DIFFERENT ANGLES [17]

TABLE 5 DIMENSIONS OF THE SUPPORT FOR 36º

36º	X1	1293,6
	X2	1500,6

The support kits have a capacity of three modules each.

5.1.2. Shadow calculations

As the installation has two rows of solar panels, to avoid shadows, we will calculate the minimum distance between them.[18]

To perform this calculation, we use the following formula:

$$d = L \cdot \frac{\sin B}{\tan 61 - Lat} + \cos B$$

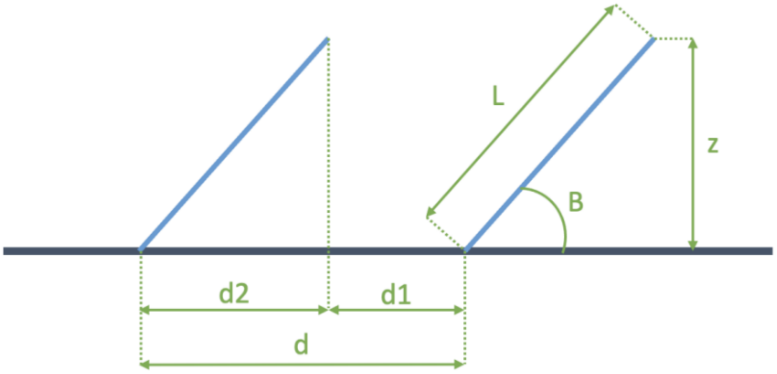


FIGURE 21 FORMULE FOR THE MINIMUM DISTANCE BETWEEN PANELS

B=36º; L=1,134; z= sen (36) ×2,279= 1,34; Lat.= 38,07.

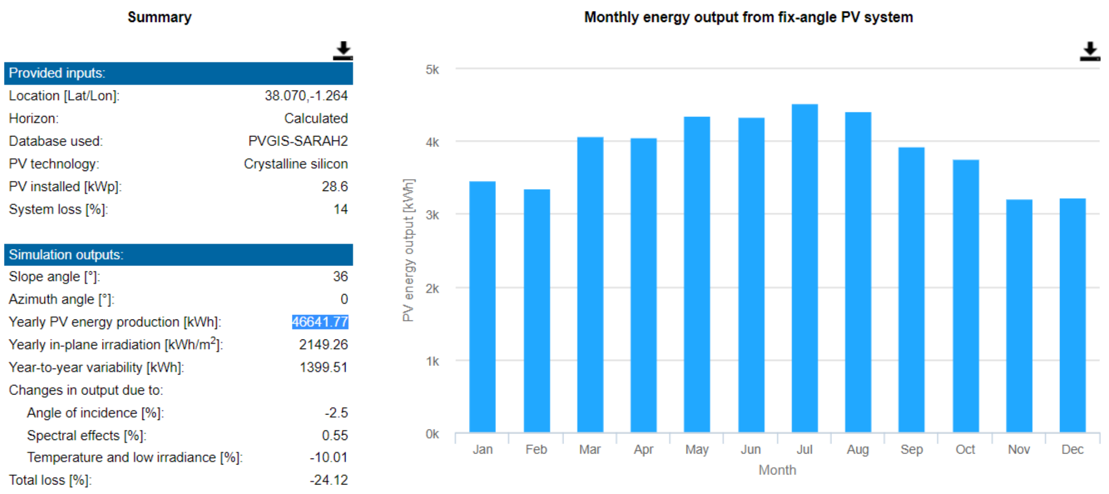
$$d = 1{,}134.\frac{\sin 36}{\tan(61 - 38{,}07)} + 1{,}134.\cos 36 = 2{,}57\, m$$

Therefore, 2,57 metres is the minimum distance between the panels. It is also important that there are no objects on the roof that could shade the panels.

Depending on the capacity of the industrial building, the solar panels will be arranged in two series connected in parallel. However, given the size of the panels, it is logistically unfeasible to install the panels required for a full supply of photovoltaic energy. The maximum number of panels we can install is 52. So, two parallel rows with 26 panels each one. That is, 9 kits will be needed for each series. So, 18 kits will be used for the project.

$$Established\ peak\ power = solar\ panels \times solar\ panel\ power = 52 \times 550$$
$$= 28600\ W = 28,6\ kWp$$

So, trying the simulation with PVGIS, approximating the peak power to 28,6 kWp, an annual production of 46641,77 kWh is calculated.



Summary

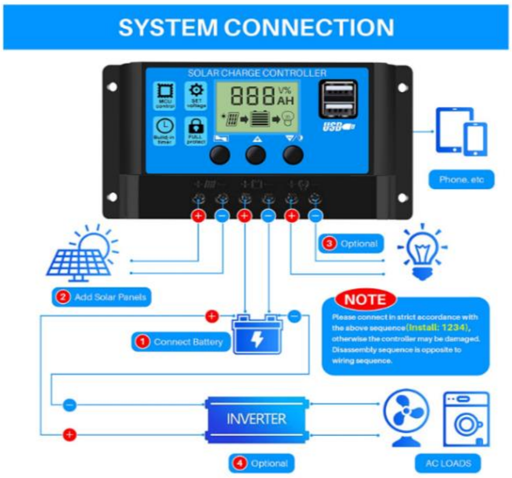
Provided inputs:	
Location [Lat/Lon]:	38.070,-1.264
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	28.6
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	36
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	46641.77
Yearly in-plane irradiation [kWh/m²]:	2149.26
Year-to-year variability [kWh]:	1399.51
Changes in output due to:	
Angle of incidence [%]:	-2.5
Spectral effects [%]:	0.55
Temperature and low irradiance [%]:	-10.01
Total loss [%]:	-24.12

FIGURE 22 MONTHLY ENERGY OUTPUT FROM FIX-ANGLE PV SYSTEM (28,6 kWp) [15]

$$46641{,}77 \times \frac{100}{81000} = 57{,}58\,\%$$

The installation will be capable of covering 57, 58 % of the average annual demand.

5.1.3. Charge regulator



Please connect in strict accordance with the above sequence(Install: 1234), otherwise the controller may be damaged. Disassembly sequence is opposite to wiring sequence.

FIGURE 23 CHARGE REGULATOR SYSTEM CONNECTION [19]

The charge regulator selected is Thlevel Solar Charge Controller 12V/24V. Intelligent Solar Panel Solar Charge Regulator with LCD Display and Suitable for Lead Batteries. [19]

The most important information about the charge regulator chosen, are the following characteristics:

→Smart

-Intelligent PWM charging mode

-Adjustable charge / discharge control parameters

-The solar charge controller is only suitable for lead-acid batteries: OPEN, AGM, GEL, not suitable for nickel hydride, lithium, lithium ion or other batteries.

→Rated Discharge Current

-30 A

-Battery voltage: 12V / 24V automatic

-Full 3-stage PWM charge management (bulk, ABS, float).

→Large LCD Screen

-Solar Charge Controller dynamically displays all operating data and operating conditions, you can conveniently switch working modes and parameter settings.

→Dual MOS Multiple Protection

-Solar charge controller have over current and short circuit protection, reverse protection, open circuit protection, low voltage, and overload protection.

5.1.4. Inverter

FIGURE 24 INVERTER SUN2000-30KTL-M3 [20]

Generally, the size of your inverter should be like the DC power of your solar panel system; If you are installing a 6 kW system, you can expect the proposed inverter to be around 6000 W, plus or minus a few percent.

Inverter manufacturers typically list sizing guidelines for the array capacity their inverters can be paired with on their product specification sheets. For that reason, as the peak power of the installation is 28,6 kWp, so we will choose an inverter whose maximum recommended PV power is higher than this. The chosen model is SUN2000-30KTL-M3 (also because Huawei are cheaper than Fronius models).

The Huawei SUN2000-30KTL-M3 grid-connected inverter is suitable for installation in residential or industrial applications that are powered by three-phase current. This inverter is one of the intermediate models in Huawei's range of three-phase grid-tie inverters. The Huawei SUN2000-30KTL-M3 inverter with an efficiency of 98.4% has a power rating of 30kW and 33 kVA, as well as a rated output current of 43.3 A and a maximum output current of 47.9 A, making this inverter an excellent choice for grid-tie installations in businesses, industrial buildings and places that require power of this calibre.[20]

Some important technical specification of the SUN2000-30KTL-M3 Network Inverter:

-Number of MPP trackers: 4

-Maximum input current: 27 A (per MPPT) / 20 A (per Input)

-DC input voltage range: 200-1000 V

-AC rated power: 30 kW

- Rated AC Grid Frequency: 50 Hz/ 60 Hz

- Rated Output Current: 43.3 A

- Max. Output Current: 47.9 A

-Weight: 43 kg

-Dimensions: 640 x 530 x 270 mm

5.1.5. Optimizers

The power optimizer is usually optional. In case of using, it in our installation we would choose the SolarEdge P505 model. [21]

FIGURE 25 SOLAREDGE P505 [21]

5.1.6. Wiring

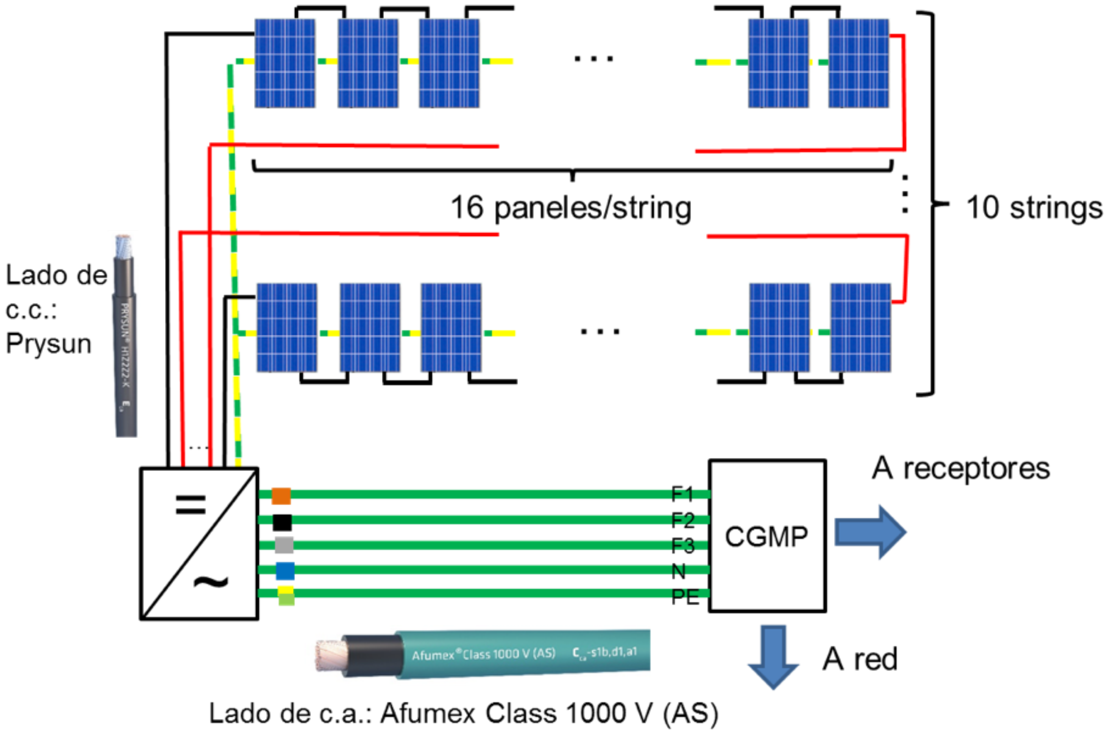


FIGURE 26 CONNECTION SYSTEM

The REBT regulation, fully approved in 2002 and partially modified since then, is the most important requirement for calculating electrical installations in Spain.

The Low Voltage Electrotechnical Regulation (REBT) is a mandatory regulation that prescribes the conditions for the assembly, operation and maintenance of low voltage installations, and Royal Decree 842/2002 establishes the technical conditions that low voltage electrical installations must meet. [22]

The facilities must be designed and executed to guarantee the safety of people and equipment.

Some of the aspects regulated by the REBT are the following:

-Electrical installation requirements

-Safety measures when designing the facility.

-Adaptations in the installation according to power and intensity

-Safety aspects for photovoltaic installations

-Materials and design to be used according to installation.

-The conductor of a power line is required to satisfy the thermal, voltage drop and short circuit thermal criterion.

-Thermal criterion:

Thermal criteria dictate that the cable cross section must be large enough to ensure that the insulation temperature does not exceed limits during normal operation. The standard establishes that the maximum temperature allowed is 70°C for cables with PVC insulation and 90°C for those with XLPE insulation. If the temperature is constantly kept above the limit, the aging process of the cable is accelerated, which can degrade the dielectric and mechanical properties of the insulating material and cause defects that can eventually lead to short circuits.

-Voltage drop criterion

The line must maintain a voltage drop below a specific value throughout its route, depending on the type of line. In accordance with the regulations for photovoltaic installations, both the section from the solar panels to the inverter and the section from the inverter to the connection point must not have a voltage drop greater than 1.5 %. Energy losses are caused by the flow of current through the cable and limiting these losses is important to guarantee the correct operation of the devices powered by the line.

-Short-circuit thermal criterion

Short circuits occur when two conductors of different voltage come into direct contact without load, causing a very high current peak due to the low resistance between the two points, which can easily melt the cables. Electrical circuits are designed to allow only a limited amount of current to flow through them, if a short circuit occurs, as a much greater current is flowing than allowed, the temperature of the conductors will increase until the protections are activated. It is important that the conductor temperature does not exceed certain limits, which are established by regulations depending on the type of insulation of the cable.

The current limitation is calculated based on the resistance or impedance of the load to which it is connected.

If the total resistance or impedance of the circuit becomes a very small value, then, according to Ohm's law, an abnormally high current will flow through the circuit, called the short-circuit current. [5].

Two sections must be sized in our installation. The first section is for direct current connecting the solar panels to the inverter, while the second section is for alternating current connecting the inverter to the connection point.

5.2 Direct current section

For this section of the installation, we will use a PV ZZ-F type cable.

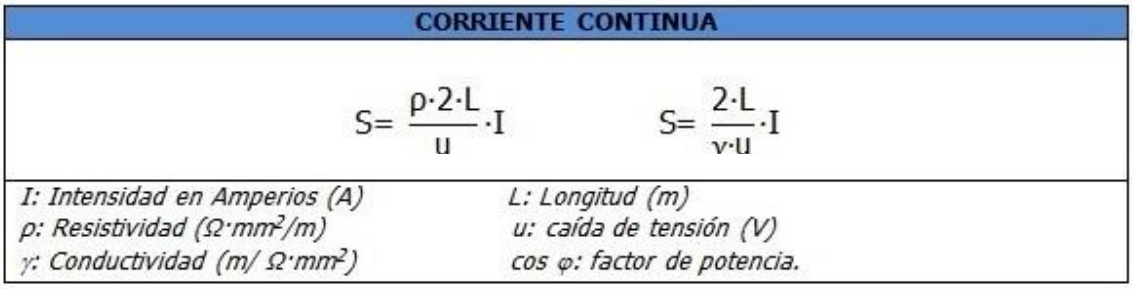
The structure of the cables is made of copper, specially made for photovoltaic installations, since they are single-pole cables with double insulation and great resistance to the elements, which are specially designed for this type of project.[24]

We will have two cables (one for the positive pole, another for the negative). The cables will not spread the fire and with smoke emission and reduced opacity.

FIGURE 27 CABLE TOPSOLAR [24]

The general formula for calculating continuous cable section is:

TABLE 6 FORMULE FOR CC CABLE SECTION [5]



CORRIENTE CONTINUA	
$S=\frac{\rho\cdot 2\cdot L}{u}\cdot I$	$S=\frac{2\cdot L}{\gamma\cdot u}\cdot I$
I: Intensidad en Amperios (A) *ρ: Resistividad (Ω·mm²/m)* *γ: Conductividad (m/ Ω·mm²)*	*L: Longitud (m)* *u: caída de tensión (V)* *cos φ: factor de potencia.*

We will calculate the minimum cable section to meet the different criteria.

To build the continuous run, two parallel circuits must be used that run from each array of solar panels to the inverter inputs. Before starting, it is important to know the length of the line, which is around 60 m.

-Thermal criterion

The concept of thermal dimensioning is based on the principle that, under normal operating conditions, the conductor should not exceed a certain temperature. However, there are many factors that can affect heating, which is why standardized installation conditions are used. Tables are available that provide the admissible current (I_T) for specific cross-sections and insulation types of conductors. The current flowing through the installation (I_L) must always be lower than the admissible current in these conditions (I_Z). When the installation conditions are not in accordance with the standardized ones, certain coefficients (k) must be applied to correct the values obtained in the table.

$$I_L \leq I_Z = I_T \cdot k$$

FIGURE 28 THERMAL CRITERION EXPRESSION no 1 [5]

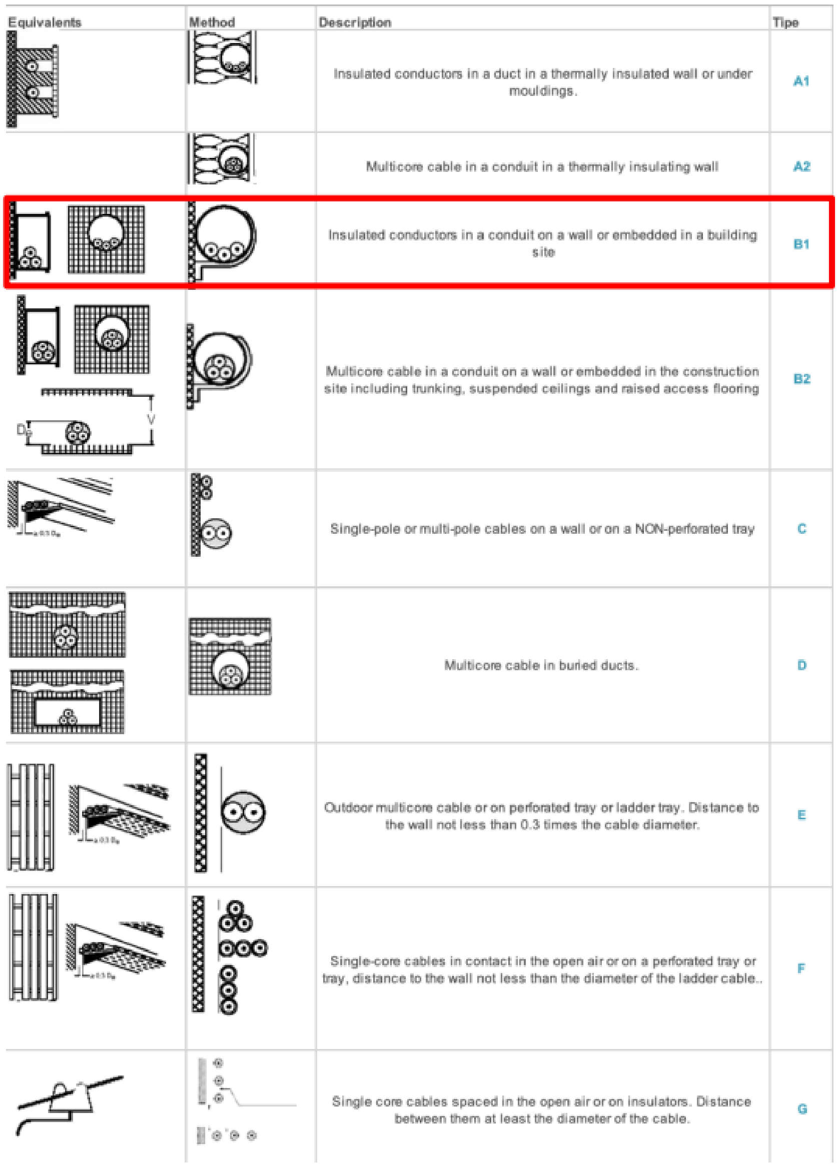
In the technical specifications of the solar panels appears the maximum current power (Imp) that they can support. This maximum current power in STC conditions will be 13.01 A. However, according to the ITC-BT-40 of the Electrotechnical Regulation for BT, it is indicated: "The connection cables must be sized for a current of not less than 125% of the maximum current of the generator”. In this way, to obtain the maximum current that flows through the installation, we must increase the incidence through the panels by multiplying it by 1.25.

I_L= 1,25×13,01= 16.26 A

To find in the tables, the correct values of allowable current and correction factors. The installation method of the cables should be known first. In this case, the cables are installed in a conduit on the roof. Therefore, the installation method B1 according to UNE 20460-5-523 [20]

FIGURE 29 EXAMPLE OF THE METHOD INSTALLATION OF CONDUCTORS IN A CONDUIT OVER THE ROOF

TABLE 7 DIFFERENT METHODS INSTALLATIONS [23]



Equivalents	Method	Description	Tipe
		Insulated conductors in a duct in a thermally insulated wall or under mouldings.	A1
		Multicore cable in a conduit in a thermally insulating wall	A2
		Insulated conductors in a conduit on a wall or embedded in a building site	B1
		Multicore cable in a conduit on a wall or embedded in the construction site including trunking, suspended ceilings and raised access flooring	B2
		Single-pole or multi-pole cables on a wall or on a NON-perforated tray	C
		Multicore cable in buried ducts.	D
		Outdoor multicore cable or on perforated tray or ladder tray. Distance to the wall not less than 0.3 times the cable diameter.	E
		Single-core cables in contact in the open air or on a perforated tray or tray, distance to the wall not less than the diameter of the ladder cable..	F
		Single core cables spaced in the open air or on insulators. Distance between them at least the diameter of the cable.	G

The correction coefficients (*k*) are obtained from additional tables:

If the ambient temperature does not coincide with the normalized temperature in the table (30°C), the temperature coefficient (k_T) must be applied. In our case, the ambient temperature on the roof of the installation is around 45°C. Therefore, for XLPE insulated cable, the temperature coefficient is 0.87.

The grouping coefficient (k_A) is applied when there is more than one bundle of cables running in parallel in a trunking system. In our installation, two circuits are grouped together due to the two parallel rows of solar panels. As a result, the clustering coefficient is 0.80.

TABLE 8 COEFFICIENT KT [23]

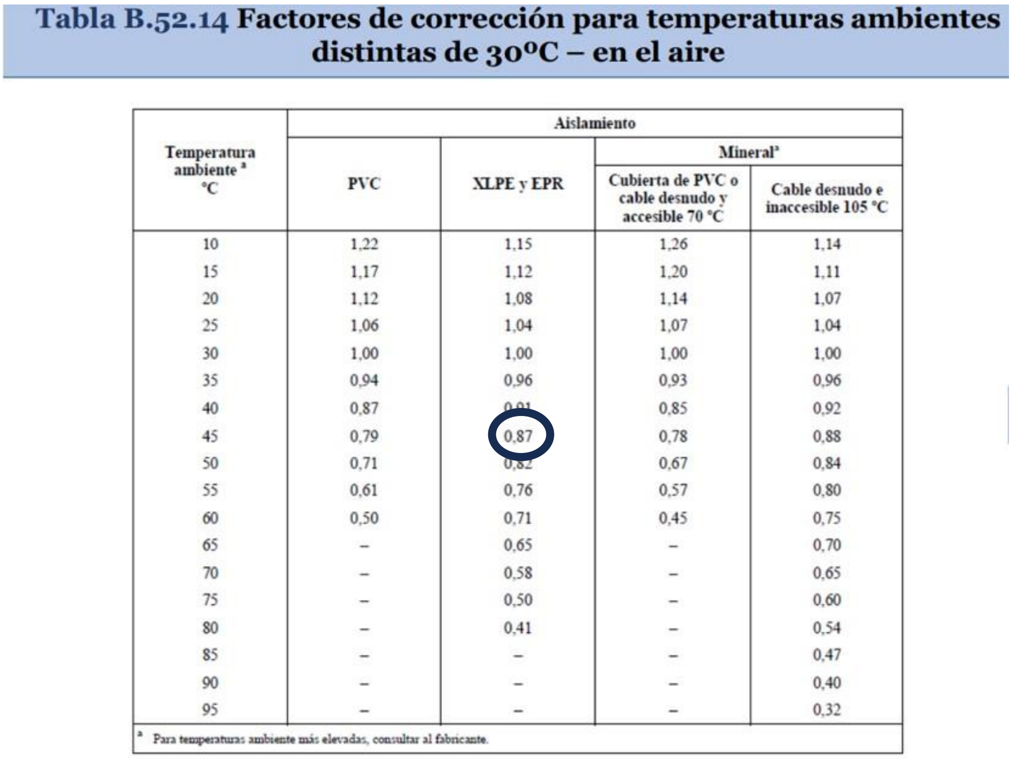


Tabla B.52.14 Factores de corrección para temperaturas ambientes distintas de 30ºC – en el aire

Temperatura ambiente [a] °C	Aislamiento			
	PVC	XLPE y EPR	Mineral[a]	
			Cubierta de PVC o cable desnudo y accesible 70 °C	Cable desnudo e inaccesible 105 °C
10	1,22	1,15	1,26	1,14
15	1,17	1,12	1,20	1,11
20	1,12	1,08	1,14	1,07
25	1,06	1,04	1,07	1,04
30	1,00	1,00	1,00	1,00
35	0,94	0,96	0,93	0,96
40	0,87	0,91	0,85	0,92
45	0,79	0,87	0,78	0,88
50	0,71	0,82	0,67	0,84
55	0,61	0,76	0,57	0,80
60	0,50	0,71	0,45	0,75
65	–	0,65	–	0,70
70	–	0,58	–	0,65
75	–	0,50	–	0,60
80	–	0,41	–	0,54
85	–	–	–	0,47
90	–	–	–	0,40
95	–	–	–	0,32

[a] Para temperaturas ambiente más elevadas, consultar al fabricante.

TABLE 9 COEFFICIENT K_A [23]

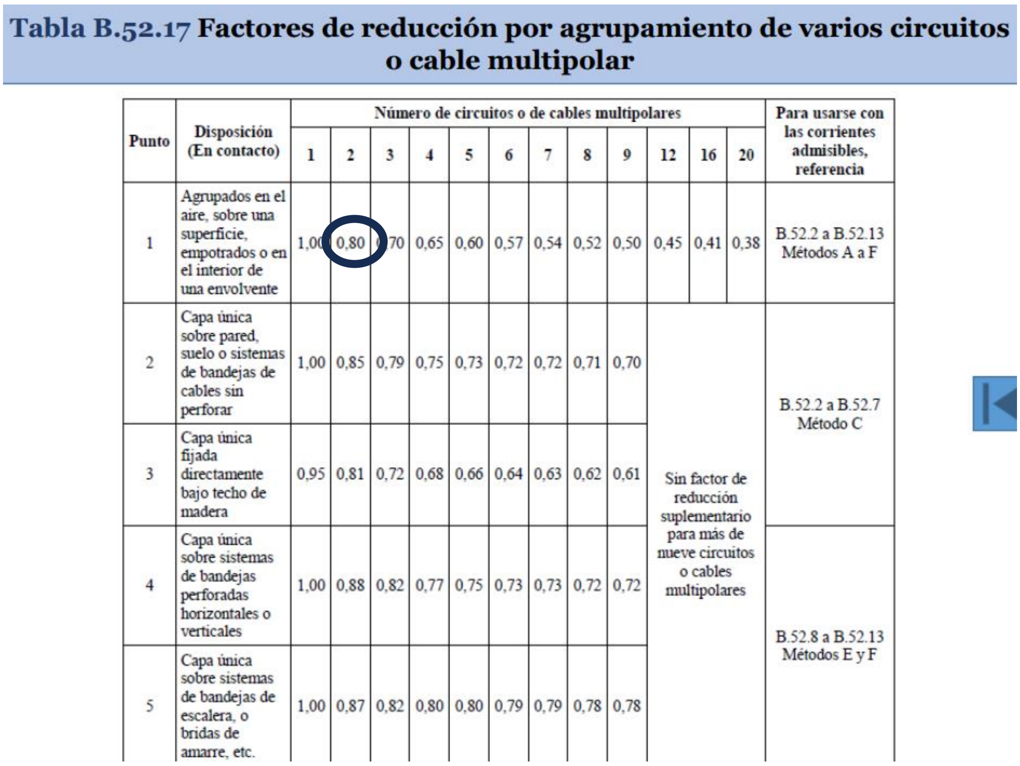


Tabla B.52.17 Factores de reducción por agrupamiento de varios circuitos o cable multipolar

Punto	Disposición (En contacto)	Número de circuitos o de cables multipolares												Para usarse con las corrientes admisibles, referencia
		1	2	3	4	5	6	7	8	9	12	16	20	
1	Agrupados en el aire, sobre una superficie, empotrados o en el interior de una envolvente	1,00	0,80	0,70	0,65	0,60	0,57	0,54	0,52	0,50	0,45	0,41	0,38	B.52.2 a B.52.13 Métodos A a F
2	Capa única sobre pared, suelo o sistemas de bandejas de cables sin perforar	1,00	0,85	0,79	0,75	0,73	0,72	0,72	0,71	0,70	Sin factor de reducción suplementario para más de nueve circuitos o cables multipolares			B.52.2 a B.52.7 Método C
3	Capa única fijada directamente bajo techo de madera	0,95	0,81	0,72	0,68	0,66	0,64	0,63	0,62	0,61				
4	Capa única sobre sistemas de bandejas perforadas horizontales o verticales	1,00	0,88	0,82	0,77	0,75	0,73	0,73	0,72	0,72				B.52.8 a B.52.13 Métodos E y F
5	Capa única sobre sistemas de bandejas de escalera, o bridas de amarre, etc.	1,00	0,87	0,82	0,80	0,80	0,79	0,79	0,78	0,78				

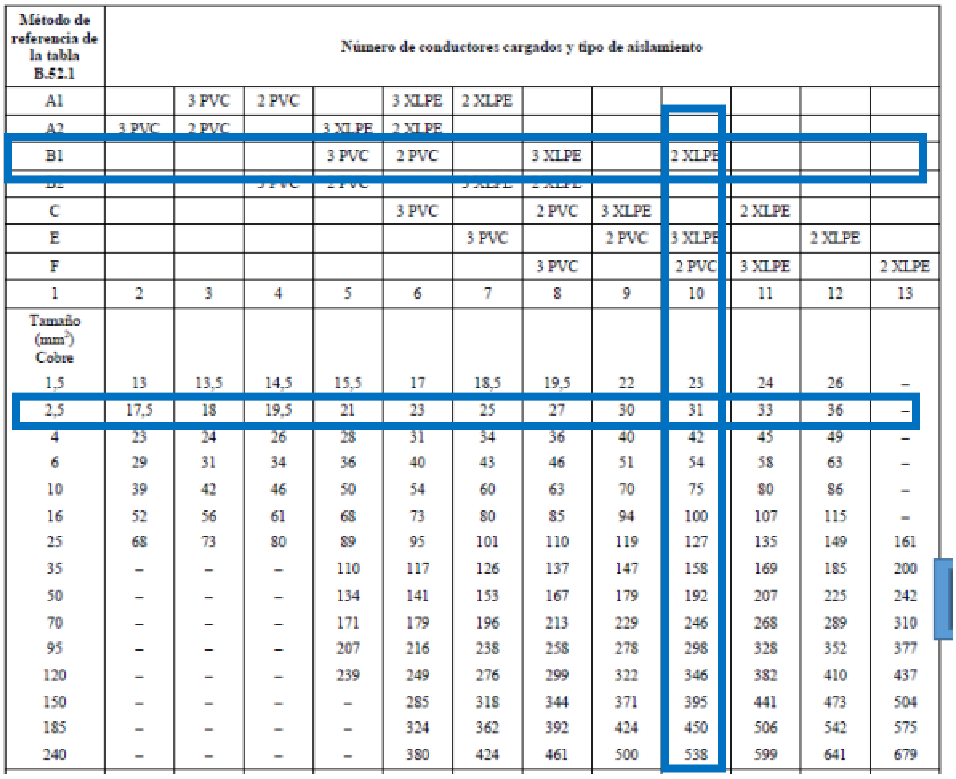
Finally, there is a soil thermal resistivity coefficient (k_{RT}) that is used when the cables are buried, and the soil thermal resistivity is not equal to 2.5 Km/W. However, in this situation, this coefficient is not applicable.

Thus, we obtain the correction coefficient k: $k = k_T \times k_A = 0.87 \times 0.80 = 0.696$

In this way we can calculate the admissible current: $\frac{IL}{k} = \frac{16.26}{0.696} = 23.36\ A \leq I_T$

To guarantee the correct operation of the installation, it is necessary that the maximum admissible current of the cable is greater than or equal to 23.36 A. Therefore, the section that gives us a value immediately higher than this must be found in the table. To do this, we must consider that it is a type B1 installation and that the cable used is a phase and neutral conductor with XLPE (2XLPE) insulation.[23]

TABLE 10 ADMISSIBLE CURRENTS no 1 [23]



Método de referencia de la tabla B.52.1	Número de conductores cargados y tipo de aislamiento											
A1		3 PVC	2 PVC		3 XLPE	2 XLPE						
A2	3 PVC	2 PVC		3 XLPE	2 XLPE							
B1				3 PVC	2 PVC		3 XLPE		2 XLPE			
B2			3 PVC	2 PVC		3 XLPE	2 XLPE					
C					3 PVC		2 PVC	3 XLPE		2 XLPE		
E						3 PVC		2 PVC	3 XLPE		2 XLPE	
F							3 PVC		2 PVC	3 XLPE		2 XLPE
1	2	3	4	5	6	7	8	9	10	11	12	13
Tamaño (mm^2) Cobre												
1,5	13	13,5	14,5	15,5	17	18,5	19,5	22	23	24	26	–
2,5	17,5	18	19,5	21	23	25	27	30	31	33	36	–
4	23	24	26	28	31	34	36	40	42	45	49	–
6	29	31	34	36	40	43	46	51	54	58	63	–
10	39	42	46	50	54	60	63	70	75	80	86	–
16	52	56	61	68	73	80	85	94	100	107	115	–
25	68	73	80	89	95	101	110	119	127	135	149	161
35	–	–	–	110	117	126	137	147	158	169	185	200
50	–	–	–	134	141	153	167	179	192	207	225	242
70	–	–	–	171	179	196	213	229	246	268	289	310
95	–	–	–	207	216	238	258	278	298	328	352	377
120	–	–	–	239	249	276	299	322	346	382	410	437
150	–	–	–	–	285	318	344	371	395	441	473	504
185	–	–	–	–	324	362	392	424	450	506	542	575
240	–	–	–	–	380	424	461	500	538	599	641	679

In conclusion, the nominal operating current of 16.26 A results in an allowable current of 31 A and a minimum cross section of 2.5 mm^2 for the cable with XLPE insulation (2XLPE), fulfilling the condition that the allowable current must not exceed the rated operating current.

-Voltage drop criterion

Regarding the voltage drop criterion, the IDAE's Technical Specifications for Grid-Connected Installations (PCT-C-REV - July 2011) establishes the following in its section 5.5.2. Regarding the voltage drop in direct current (DC) wiring: " 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 section sufficient for the voltage drop to be less than 1.5%". Therefore, the calculation will be made according to this criterion to ensure that the voltage drop on the DC side never exceeds 1.5 %.[5]

Considering that each solar panel has a maximum power voltage (Vmp) of 42.28 V and considering that in each row of solar panels there are 26 panels connected in series, we can determine what the voltage in each row will be:

U_L= Vmp x nº of solar panels connected in serie = 42.28 × 26 = 1099,28 V

Therefore, the maximum voltage drop that can occur on the section will be:

$$\Delta U = \frac{1.5}{100} \times 1099{,}28 = 16{,}49 \text{ V}$$

The voltage drop in a monophasic line can also be calculated by means of the following expression:

- ΔU= Voltage drops
- L = Cable length
- I_L = Current flowing through the installation
- S = Cable section
- ρ_T= Copper resistivity at temperature T

$$\Delta U \leq \frac{L \cdot I_L \cdot \rho_T}{S} \cdot 2$$

FIGURE 30 VOLTAGE DROP EXPRESSION [5]

We can solve the equation to determine the minimum section of the cable that ensures that the voltage drop does not exceed 1.5 %. However, before doing so, it is crucial to know the resistivity value of copper, as it varies with temperature. We can calculate the temperature using the following formula:

- *T*: Estimated temperature of the conductor
- T_0: Ambient temperature of the conductor
- T_{max}: Maximum permissible conductor temperature according to insulation

$$T = T_0 + (T_{max} - T_0) \times \left(\frac{I_L}{I_Z}\right)^2$$

FIGURE 31 EXPRESSION OF ESTIMATED TEMPERATURE OF THE CONDUCTOR [5]

Another option is to consider the conductor temperature as the maximum value allowed according to the type of cable insulation. This allows us to take the most extreme case and have a wider margin when sizing. In this case, the cable has cross-linked polyethylene insulation, and according to UNE-HD 60364, 4-43, the maximum permissible temperature in continuous service is 90ºC. So, we can calculate the resistivity of the copper with the following formula: [5]

$$\gamma_{\mathrm{Cu}90} = \frac{1}{\rho}$$

To know the conductivity, we use the following table:

TABLE 11 CONDUCTIVITY FOR DIFFERENT MATERIALS [5]

Material	γ_{20}	γ_{70}	γ_{90}
Cobre	56	48	44
Aluminio	35	30	28
Temperatura	20ºC	70ºC	90ºC

In our case, $\gamma_{\mathrm{Cu}90} = 44 \frac{m}{\Omega \cdot \mathrm{mm}^2}$. So, $\rho_{90^\circ} = \frac{1}{56} = 0.2272 \frac{\Omega \cdot \mathrm{mm}^2}{m}$.

We can also use another formule to calculate the resistivity of the copper:

- ρ_T= Resistivity at temperature T
- ρ_{20}= Resistivity at temperature 20ºC = 0.01724 $\frac{\Omega \cdot \mathrm{mm}^2}{m}$
- α = Temperature coefficient of copper = 0.00393 $°\mathrm{C}^{-1}$
- T_C= Characteristic temperature of copper = 234.5 °C

$$\rho_T = \rho_{20} \cdot (1 + \alpha \cdot \Delta T) = \rho_{20} \cdot \frac{T_C + T}{T_C + 20}$$

FIGURE 32 EXPRESSION OF THE RESISTIVITY [5]

$$\rho_{90^\circ\mathrm{C}} = 0.01724 \cdot \frac{234.5 + 90}{234.5 + 20} = 0.02198 \frac{\Omega \cdot mm^2}{m}$$

FIGURE 33 EXPRESSION OF THE RESISTIVITY AT 90 ºC [5]

Of the cases we choose, $\rho_{90^\circ} = 0.2272 \frac{\Omega \cdot \mathrm{mm}^2}{m}$. Since it is more restrictive.

With all the data obtained, the minimum section can be determined so that the voltage drop does not exceed 1.5 %.

$$S \geq \frac{L \cdot I_L \cdot \rho_T}{\Delta U} \cdot 2$$

FIGURE 34 EXPRESSION OF MINIMUM SECTION [5]

$$S \geq \frac{60 \times 16{,}26 \times 0{,}2272}{16{,}49} \times 2 = 13{,}44 \text{ mm}^2$$

Therefore, the next normalised cross-section larger than 13,44 mm^2 is 16 mm^2.

-Short-circuit thermal criterion

This criterion follows the same approach as the thermal criterion, but in this case, the current used will be the short-circuit current provided by the technical specifications of the solar panel under STC conditions. For this model, said current has a value of 13,90 A that increasing in a 125 % is:

$$I_K = 1{,}25 \times 13{,}90 = 17.375 \text{ A}$$

The installation method and the correction coefficients remain the same that in the thermal criterion.

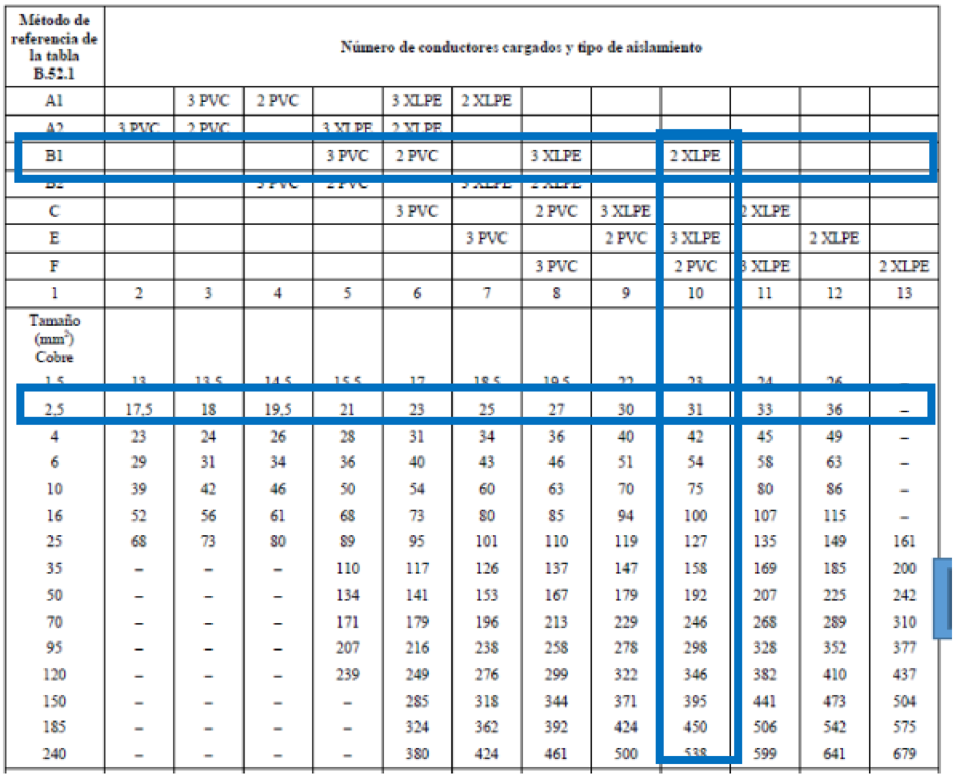
$$\frac{I_k}{k_T \cdot k_A} \leq I_T$$

FIGURE 35 EXPRESSION OF MAXIMUM ADMISSIBLE CURRENT [5]

$$\frac{17.375}{0{,}80\,.0{,}87} \leq I_T \rightarrow 24{,}96 \leq I_T$$

Following the same procedure as with the thermal criterion and considering that the maximum admissible current of the cable must be greater than or equal to 24.96, we look again in the table for the section that provides us with an admissible current value immediately higher than this. It is important to note that the installation is type B1 and that there are two charged conductors with XLPE insulation (2XLPE).[23]

TABLE 12 ADMISSIBLE CURRENTS no 2 [23]



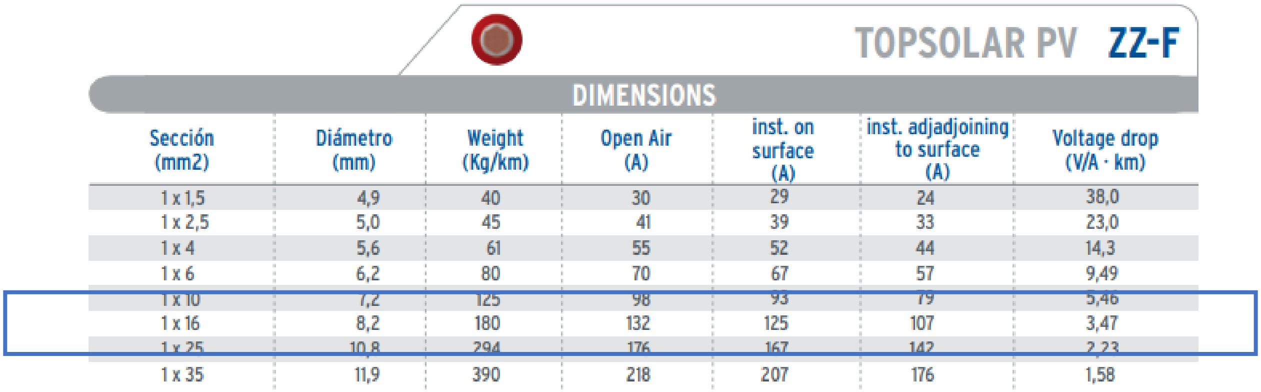
Método de referencia de la tabla B.52.1	Número de conductores cargados y tipo de aislamiento											
A1		3 PVC	2 PVC		3 XLPE	2 XLPE						
A2	3 PVC	2 PVC		3 XLPE	2 XLPE							
B1				3 PVC	2 PVC		3 XLPE		2 XLPE			
B2			3 PVC	2 PVC		3 XLPE	2 XLPE					
C					3 PVC		2 PVC	3 XLPE		2 XLPE		
E						3 PVC		2 PVC	3 XLPE		2 XLPE	
F							3 PVC		2 PVC	3 XLPE		2 XLPE
1	2	3	4	5	6	7	8	9	10	11	12	13
Tamaño (mm^2) Cobre												
1,5	13	13,5	14,5	15,5	17	18,5	19,5	22	23	24	26	–
2,5	17,5	18	19,5	21	23	25	27	30	31	33	36	–
4	23	24	26	28	31	34	36	40	42	45	49	–
6	29	31	34	36	40	43	46	51	54	58	63	–
10	39	42	46	50	54	60	63	70	75	80	86	–
16	52	56	61	68	73	80	85	94	100	107	115	–
25	68	73	80	89	95	101	110	119	127	135	149	161
35	–	–	–	110	117	126	137	147	158	169	185	200
50	–	–	–	134	141	153	167	179	192	207	225	242
70	–	–	–	171	179	196	213	229	246	268	289	310
95	–	–	–	207	216	238	258	278	298	328	352	377
120	–	–	–	239	249	276	299	322	346	382	410	437
150	–	–	–	–	285	318	344	371	395	441	473	504
185	–	–	–	–	324	362	392	424	450	506	542	575
240	–	–	–	–	380	424	461	500	538	599	641	679

Therefore, according to this last criterion, the section of the cable must be equal to or greater than 2,5 mm^2.

Comparing the results, the minimum section with which the three criteria are met is the 16 mm^2 section.

So, this are some of the technical specifications of the cable chosen that it is: Topsolar ZZ-F/H1Z2Z2-K with a section of 16 mm^2.

TABLE 13 CABLE DIMENSIONS SPECIFICATIONS [24]



TOPSOLAR PV ZZ-F

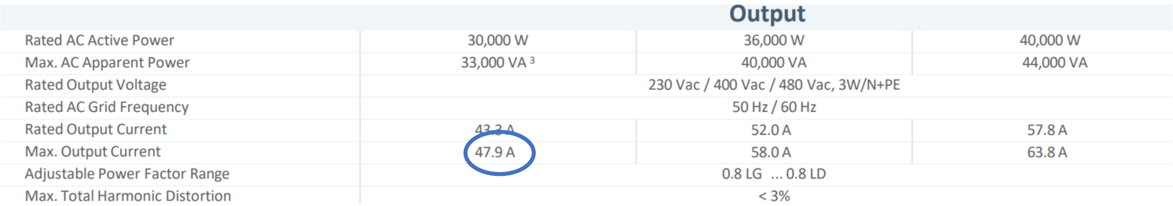
DIMENSIONS

Sección (mm2)	Diámetro (mm)	Weight (Kg/km)	Open Air (A)	inst. on surface (A)	inst. adjadjoining to surface (A)	Voltage drop (V/A · km)
1 x 1,5	4,9	40	30	29	24	38,0
1 x 2,5	5,0	45	41	39	33	23,0
1 x 4	5,6	61	55	52	44	14,3
1 x 6	6,2	80	70	67	57	9,49
1 x 10	7,2	125	98	93	79	5,46
1 x 16	8,2	180	132	125	107	3,47
1 x 25	10,8	294	176	167	142	2,23
1 x 35	11,9	390	218	207	176	1,58

5.3 Alternating current section.

The wiring of the AC part extends from the output of the inverter to the control panel and protection of the farm. The line consists of three phases plus a neutral conductor (3F+N) and is made up of unipolar copper conductors with PVC insulation. The connection is triphasic. The length of this section is approximately 15 m. In addition, it is important to consider some characteristics of the investor for the application of the three criteria. [5]

TABLE 14 OUTPUT CHARACTERISTICS OF THE INVESTOR [20]



Output			
Rated AC Active Power	30,000 W	36,000 W	40,000 W
Max. AC Apparent Power	33,000 VA [3]	40,000 VA	44,000 VA
Rated Output Voltage	230 Vac / 400 Vac / 480 Vac, 3W/N+PE		
Rated AC Grid Frequency	50 Hz / 60 Hz		
Rated Output Current	43.3 A	52.0 A	57.8 A
Max. Output Current	47.9 A	58.0 A	63.8 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD		
Max. Total Harmonic Distortion	< 3%		

-Thermal criterion:

Once again, to meet this criterion, the following condition must be met:

$$I_L \leq I_Z = I_T \cdot k$$

FIGURE 36 THERMAL CRITERION EXPRESSION no 2 [5]

In this case, the maximum current at the output of the inverter, established by its technical specifications, is 47,9 A. As stipulated in the ITC-BT-40 of the Low Voltage Electrotechnical Regulation (REBT), this value is increased by 125 %.[23]

$$I_L = 1{,}25 \times I_{AC} = 1{,}25 \times 47{,}9 = 59{,}87 \text{ A}$$

Regarding the installation method, the cable is installed as a single pole in a wall tube (installation method B1 according to the UNE 20460-5-523 standard).

The ambient temperature of cables in the air can be approximated to 30ºC, in addition, there is no bundling since it is only a three-phase circuit, and it is not buried. For these reasons, the correction factors all have a value equal to one and the installation conditions coincide with the standard ones. It is not necessary to apply any correction factor.

$$\frac{I_L}{k_T \cdot k_A \cdot k_{RT}} \leq I_T$$

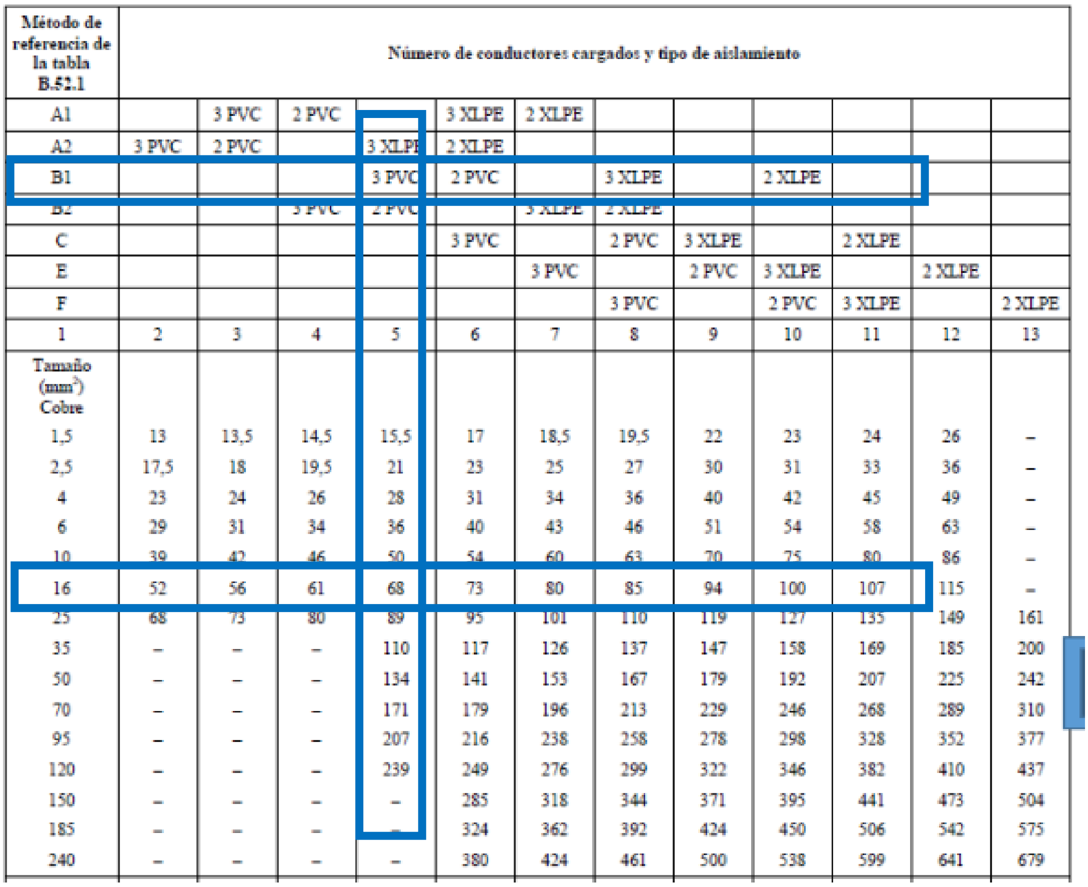
FIGURE 37 MAXIMUM ADMISSIBLE CURRENT EXPRESSION AC [5]

$$\frac{59{,}87}{1 \times 1 \times 1} \leq I_T$$

$$59,87 \leq I_T$$

Bearing in mind that the maximum admissible current of the cable must be greater than or equal to 59,87 A, we look in the table for the section that gives us a value immediately higher than this, considering that the installation is type B1 and that the line used is three-phase. with PVC insulation (3PVC).[20]

TABLE 15 ADMISSIBLE CURRENTS no 3 [23]



Método de referencia de la tabla B.52.1	Número de conductores cargados y tipo de aislamiento											
A1		3 PVC	2 PVC		3 XLPE	2 XLPE						
A2	3 PVC	2 PVC		3 XLPE	2 XLPE							
B1				3 PVC	2 PVC		3 XLPE		2 XLPE			
B2			3 PVC	2 PVC		3 XLPE	2 XLPE					
C					3 PVC		2 PVC	3 XLPE		2 XLPE		
E						3 PVC		2 PVC	3 XLPE		2 XLPE	
F							3 PVC		2 PVC	3 XLPE		2 XLPE
1	2	3	4	5	6	7	8	9	10	11	12	13
Tamaño (mm^2) Cobre												
1,5	13	13,5	14,5	15,5	17	18,5	19,5	22	23	24	26	–
2,5	17,5	18	19,5	21	23	25	27	30	31	33	36	–
4	23	24	26	28	31	34	36	40	42	45	49	–
6	29	31	34	36	40	43	46	51	54	58	63	–
10	39	42	46	50	54	60	63	70	75	80	86	–
16	52	56	61	68	73	80	85	94	100	107	115	–
25	68	73	80	89	95	101	110	119	127	135	149	161
35	–	–	–	110	117	126	137	147	158	169	185	200
50	–	–	–	134	141	153	167	179	192	207	225	242
70	–	–	–	171	179	196	213	229	246	268	289	310
95	–	–	–	207	216	238	258	278	298	328	352	377
120	–	–	–	239	249	276	299	322	346	382	410	437
150	–	–	–	–	285	318	344	371	395	441	473	504
185	–	–	–	–	324	362	392	424	450	506	542	575
240	–	–	–	–	380	424	461	500	538	599	641	679

Consequently, it is determined that for an operating current of 59,87 A, the allowable current is 68 A and a thermal section of 16 mm^2 is required.[21]

-Voltage drop criterion

In accordance with point 5 of the ITC-BT 40 of the REBT [25], it is established that the voltage drop between the inverter output and the general control and protection panel must not exceed 1.5 % for the rated current. Considering that the voltage between phases is 400 V, the maximum voltage drop that can occur is:

$$\Delta U = \frac{1.5}{100} \cdot 400 = 6\,V$$

FIGURE 38 MAXIMUM VOLTAGE DROP AC [5]

Furthermore, it is important to consider that in a three-phase line, the voltage drop can be calculated using the following equation:

$$\Delta U = \sqrt{3} \cdot (R \cdot I \cdot \cos\varphi + X \cdot I \cdot \sin\varphi)$$

FIGURE 39 VOLTAGE DROP EXPRESSION AC no.1 [5]

5Being:

$$I_a = I \cdot \cos\varphi = \frac{P}{\sqrt{3} \cdot U}$$
$$I_r = -I \cdot \sin\varphi = \frac{-Q}{\sqrt{3} \cdot U}$$

FIGURE 40 THREE-PHASE EXPRESSIONS [5]

It is obtained:

$$\Delta U = \frac{1}{U} \cdot (R \cdot P + X \cdot Q)$$

FIGURE 41 VOLTAGE DROP EXPRESSION AC no.2 [5]

For conductor sections that are not too large, up to 95 mm^2 in copper conductors, the term related to resistance is practically more relevant than the one related to reactance. Therefore, it is possible to do without this last term and the final expression obtained is the following:

$$\Delta U = \frac{R \cdot P}{U} = \frac{L \cdot \rho_T \cdot P}{S \cdot U} = \frac{L \cdot \rho_T \cdot I_L}{S}$$

FIGURE 42 FINAL VOLTAGE DROP EXPRESSION AC [5]

In this case, unlike in the direct current section, the conductor temperature is calculated to obtain the resistivity of the copper at that temperature.

$$T = T_0 + (T_{max} - T_0) \times \left(\frac{I_L}{I_Z}\right)^2$$

FIGURE 43 EXPRESSION OF ESTIMATED TEMPERATURE OF THE CONDUCTOR AC [5]

$$T = 30 + (70-30) \times \left(\frac{59.87}{68}\right)^2 = 61\ ^\circ C$$

By approximating the conductor temperature to 61°C we calculate the resistivity of the copper.

$$\rho_{61} = 0{,}01724 \times \frac{234{,}5+61}{234{,}5+20} = 0{,}02\ \frac{\Omega\cdot\text{mm}^2}{m}$$

With this information, we can now determine the minimum section required for the cable, so that the voltage drop does not exceed 1.5 %.

$$S \geq \frac{L \cdot \rho_T \cdot I_L}{\Delta U}$$

FIGURE 44 EXPRESSION OF MINIMUM SECTION AC [5]

$$S \geq \frac{15.\times 0{,}02 \times 59.87}{6}$$

$$S \geq 2.99\ \text{mm}^2$$

Consequently, the next normalized cross section that is greater than 2.99 mm^2 is 4 mm^2.

Therefore, the minimum section of 16 mm^2 established by the thermal criteria will be selected to work with a wider safety margin.

Once we have the information about the cross section of the phase conductors, we can calculate the cross section of the neutral conductor. According to the ITC-BT-014 [26], when the section is greater than 16 mm^2, the section of the neutral conductor will be equal to that of the phase conductors multiplied by two. Therefore, in this case, the neutral conductor will also have a section of 16 mm^2.[23]

5.4 Earthing installations

As defined in the ITC-BT-18 [27], the groundings are established to limit the voltage that, with respect to the ground, the metallic masses may present at a given moment, ensure the actuation of the protections and eliminate or reduce the risk of a breakdown in the electrical materials used.

According to the electrical technology book, a grounding is the electrical connection without fuses or any protection, of part of the electrical circuit (usually neutral point) or of a conductive part that does not belong to it, with an electrode or group of electrodes buried in the ground. floor. The objective is to ensure that dangerous potential differences do not appear in the set of facilities, buildings, and the surrounding surface of the ground, and at the same time allow fault currents or discharge currents of atmospheric origin to pass to earth.[5]

The grounding arrangements can be used together or separately.

The choice and installation of the materials that ensure the grounding must be such that:

-The value of the grounding resistance is in accordance with the protection and operating standards of the installation

-Earth fault currents and leakage currents can flow without danger, particularly from the point of view of thermal, mechanical, and electrical stresses.

-The solidity or mechanical protection is ensured regardless of the estimated conditions of external influences.

An elementary grounding installation is made up of:

-A mass (M) of the installation, whose potential is not initially defined and wants to be fixed to the same potential as ground

-A metallic electrode E, buried in the ground

-A conductor C, which electrically connects the mass M with the electrode E:

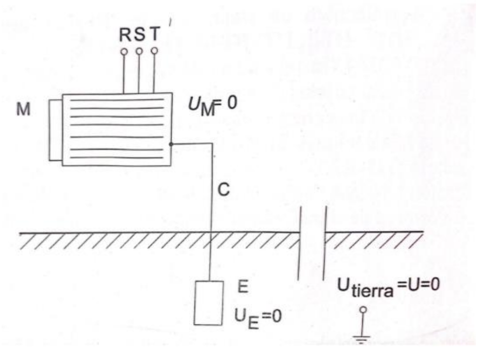


FIGURE 45 TYPICAL PARTS OF A GROUNDING INSTALLATION [5]

5.4.1 Earth ground

According to the ITC-BT-01 [28], the grounding system is an electrode, or set of electrodes, in contact with the earth and that ensures the electrical connection with it. Electrodes must be easy to install, made of materials that are resistant to moisture and chemical action, and that cannot cause galvanic corrosion. They can take many forms, ranging from spades to plates or rings. As a rule, they should be buried at least 0.5 m deep.

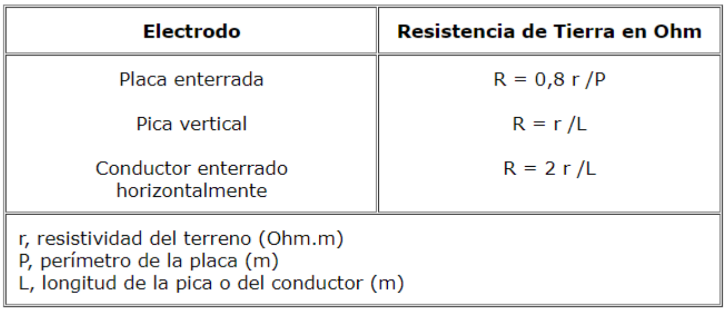
The grounding of the photovoltaic installation is independent of the neutral of the distribution company and of the masses of other homes. There will be two independent ground connections, one for the DC grounds and another for the AC grounds.

The electrode will be sized so that its earth resistance, in any foreseeable circumstance, is not greater than the value specified for it, in each case.

The grounding will be vertical spikes whose resistance can be calculated with the following expression:

TABLE 16 FORMULES FOR ESTIMATING EARTH RESISTANCE AS A FUNCTION OF SOIL RESISTIVITY AND ELECTRODE CHARACTERISTICS [5]

Tabla 5. Fórmulas para estimar la resistencia de tierra en función de la resistividad del terreno y las características del electrodo



Electrodo	Resistencia de Tierra en Ohm
Placa enterrada	R = 0,8 r /P
Pica vertical	R = r /L
Conductor enterrado horizontalmente	R = 2 r /L
r, resistividad del terreno (Ohm.m) P, perímetro de la placa (m) L, longitud de la pica o del conductor (m)	

We need to know the value of resistivity. For this we estimate it with the following tables:

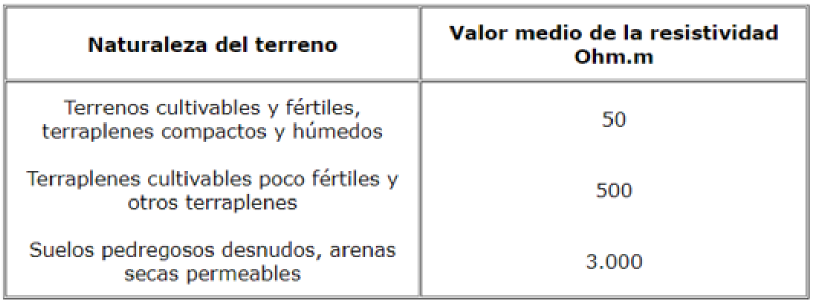
TABLE 17 GUIDE VALUES FOR RESISTIVITY AS A FUNCTION OF TERRAIN [5]

Tabla 3. Valores orientativos de la resistividad en función del terreno

Naturaleza terreno	Resistividad en Ohm.m
Terrenos pantanosos	de algunas unidades a 30
Limo	20 a 100
Humus	10 a 150
Turba húmeda	5 a 100
Arcilla plástica	50
Margas y Arcillas compactas	100 a 200
Margas del Jurásico	30 a 40
Arena arcillosas	50 a 500
Arena silícea	200 a 3.000
Suelo pedregoso cubierto de césped	300 a 5.00
Suelo pedregoso desnudo	1500 a 3.000
Calizas blandas	100 a 300
Calizas compactas	1.000 a 5.000
Calizas agrietadas	500 a 1.000
Pizarras	50 a 300
Roca de mica y cuarzo	800
Granitos y gres procedente de alteración	1.500 a 10.000
Granito y gres muy alterado	100 a 600

TABLE 18 APPROXIMATE MEAN VALUES OF RESISTIVITY AS A FUNCTION OF TERRAIN [5]

Tabla 4. Valores medios aproximados de la resistividad en función del terreno.



Naturaleza del terreno	Valor medio de la resistividad Ohm.m
Terrenos cultivables y fértiles, terraplenes compactos y húmedos	50
Terraplenes cultivables poco fértiles y otros terraplenes	500
Suelos pedregosos desnudos, arenas secas permeables	3.000

In this case the soil has a resistivity of 100 Ω.m. As it is a marl soil so the spikes will have a length of 2 meters each.

$$R_{\text{pat}} = \frac{100}{2} = 50\ \Omega$$

5.4.2 Protective conductors

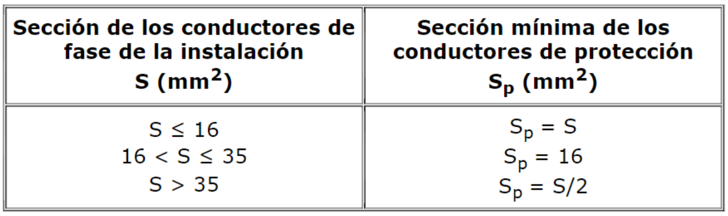
The protection conductors are used to electrically connect the masses of an installation with certain elements of an installation, to ensure protection against indirect contacts.

In the grounding circuit, the protective conductors will join the masses to the ground conductor.

The section of the protection conductors will be indicated in table 2 (according to the REBT ITC-BT-18 of section 3.4):

TABLE 19 RELATION BETWEEN SECTIONS OF PROTECTIVE CONDUCTORS AND PHASE CONDUCTORS [5]

Tabla 2. Relación entre las secciones de los conductores de protección y los de fase



Sección de los conductores de fase de la instalación S (mm^2)	Sección mínima de los conductores de protección S_p (mm^2)
$S \leq 16$	$S_p = S$
$16 < S \leq 35$	$S_p = 16$
$S > 35$	$S_p = S/2$

As the phase conductors of the installation have a cross-section of 16 mm^2

$$S_p = 16\ mm^2$$

5.4.3 Main earth terminal

According to ITC-BT-18 (point 3.3) [27]. In every grounding installation, a main ground terminal must be provided, this is a connection device, to which the ground conductors, the protection conductors, the main equipotential connection conductors, and the functional earth conductors must be attached, if it is necessary.

A device must be available on the ground conductors, located in an accessible place, which allows the resistance of the corresponding ground connection to be measured. This device must be removable using an appropriate tool. In addition, it must guarantee mechanical safety and ensure electrical continuity.

In this project, it will be placed in the vicinity of the control and protection panel.

5.4.4 Earth conductor

These conductors establish the connection between the electrode or group of electrodes and the primary ground terminal. The criteria used to determine its cross section is the same as that applied to protective conductors, since they are mechanically protected and protected against corrosion. As a result, both will have an identical cross section of 16 mm^2.[5]

5.5 Protections

This section addresses the necessary requirements to ensure the safety of users in low voltage electrical installations. These requirements are based on the ITC-BT-24 [29] regulation of the Low Voltage Electrotechnical Regulation (REBT). The established protections are of vital importance due to the risk posed by the passage of electric current through the human body. This phenomenon can cause various physiological effects that vary according to the duration of the discharge (the consequences become worse as the duration increases) and the rms value of the current (the higher the rms value, the more severe consequences).

The UNE-IEC/TS 60479-1 standard provides a set of graphs that enable the assessment of physiological effects caused by electric currents based on their rms value and duration.

These graphs allow the identification of four distinct zones.

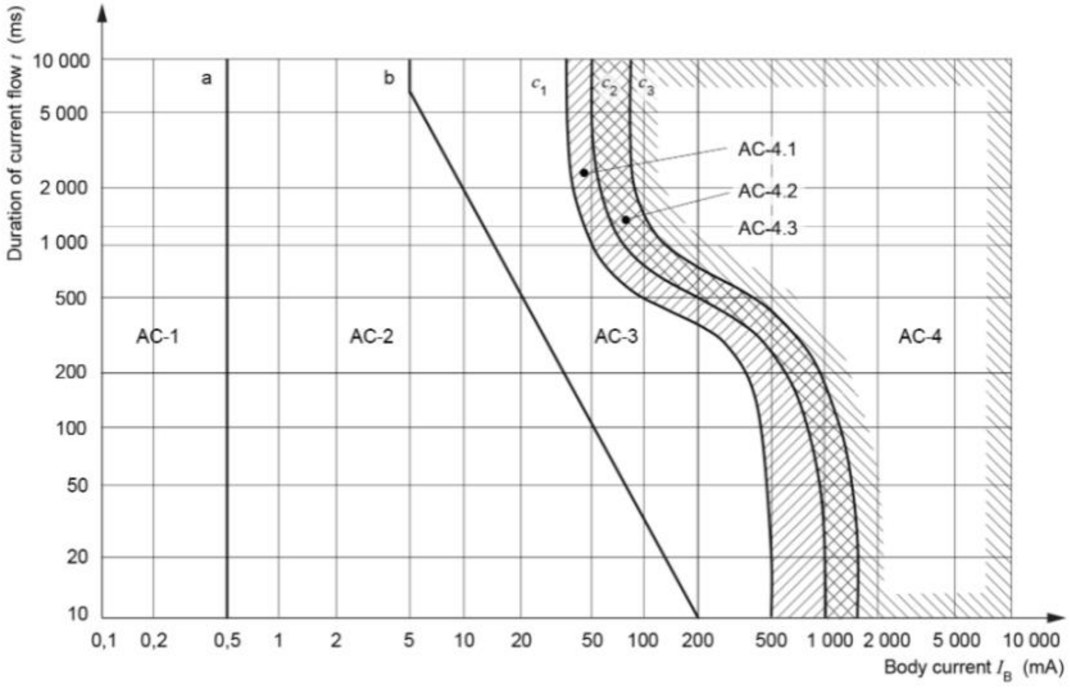


FIGURE 46 EFFECTS OF CURRENT TON THE HUMAN [5]

- Zone 1 corresponds to currents below the sensitivity threshold (0.5 mA), which do not produce any physiological effect.

- Zone 2 includes electric shocks that the person feels but does not expect any physiological effect.

- Zone 3 includes shocks that can cause muscle stiffness, shortness of breath, rhythm disturbances, and even TCA, but do not cause fibrillation.

- Finally, in zone 4, in addition to the effects of zone 3, ventricular fibrillation can also occur.

The determination of criteria based on these zones is complicated because the current that passes through the human body in case of contact is influenced by multiple factors, which are not necessarily related to the electrical installation itself. Therefore, the following safety standards are established, which are based on the conventional contact voltage (U_L) limit and the contact voltage-time curve.

The conventional touch voltage limit refers to the maximum voltage value that can be sustained indefinitely without representing a risk to users. According to the REBT, this limit is set at 50 V, except in areas with high conductivity such as humid or wet environments, where it is reduced to 24 V.

This curve specifies for each value of contact stress, the maximum time that the human body can be subjected to that stress, so that damage is minimised.

An installation is considered safe if, in the event of a touch voltage higher than the conventional limit voltage appearing in any part accessible to people, it is guaranteed that it will be eliminated by the protections in less time than the time established by the safety curve.

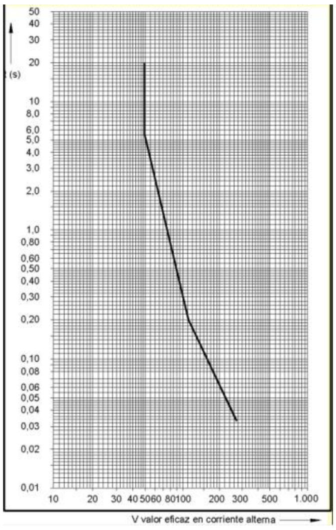


FIGURE 47 SAFETY CURVE (CONTACT VOLTAGE-TIME) [5]

There are two categories of contacts: direct contacts and indirect contacts.

5.5.1 Protections against direct contacts

Direct contact occurs when a person or animal comes into contact with a part of the electrical installation, materials or equipment which in normal operation is live (live part). The same safety measures are required both in the case of direct contact on the direct current (DC) side and on the alternating current (AC) side.

Protection systems against direct contact are classified into three categories:

-Protection by insulation of live parts

Active parts must be covered with insulation that cannot be removed except by destroying it. It must also be able to withstand all mechanical, thermal, electrical, and chemical stresses that may occur during use. Therefore, the necessary insulating material shall be used in our installation.

-Protection by barriers and enclosures

It is necessary to ensure that the active parts of the installation are protected behind barriers or inside enclosures that cannot be accessed without the use of a key or tool.

-Protection by exclusive use of very low voltages

This protection system is allowed provided that certain conditions are met (UNE-HD 60364):

-the rms value may not exceed a certain value, marked according to the conditions under which the installation is to be used.

-the power source complies with certain requirements

-requirements are fulfilled in the execution of the installation

There are also systems that protect against accidental direct contact. These protection systems would be by means of out-of-reach protection, by interposition of obstacles or by complementary protection using high-sensitivity differentials. [5]

5.5.2 Protections against indirect contacts

Indirect contact occurs when a person or animal comes into contact with a metallic element which under normal conditions should not be under voltage, but which, due to a fault, is circumstantially under voltage.

In this scenario, different measurements must be implemented on the direct current (DC) side compared to the alternating current (AC) side.

-Direct current section (DC)

Protection shall be achieved using Class II equipment or by reinforced insulation. Electrical equipment is Class II when it has double insulation or reinforced insulation and has passed tests set out in the relevant standards.

The interconnection wiring of the modules, made of copper (Cu), complies with the UNE 500086-2-1 standard as established in ITC-BT-21.

-Alternating current section (AC)

To ensure protection against indirect contacts on the AC side, the installation of a residual current circuit breaker is required.

When an insulation fault occurs, a current is generated which flows through the faulty phase, the earth connection of the earths and the earth connection of the neutral of the distribution transformer. This results in a touch voltage which is equal to

$$U_L = R_A \times I_d$$

Being:

U_L= Contact voltage (V)

R_A = Grounded resistance (Ω)

I_d = Fault current (A)

With $I_d = \frac{Udn}{RA+RB+Rd}$

The maximum contact voltage that can appear occurs in the case of frank fault ($R_d = 0$).

However, according to the regulations, (REBT ITC-24) any fault current that generates voltages above the conventional limit (50 V) must cause the automatic disconnection of the power supply in less than the permitted time. To achieve this, a differential switch is used, which detects residual currents and triggers disconnection when they exceed a set value.

The following formula shall be used to determine which rated difference current shall be installed in the installation:

$$I_{\Delta N} \times R_A \leq U_L$$

Knowing that

$I_{\Delta N}$ = Device rated difference current

$$I_{\Delta N} \leq \frac{UL}{RA} = \frac{50}{50} = 1 \text{ A} = 1000 \text{ mA}$$

This implies that any switch with a residual current equal to or less than 1000 mA is suitable for this installation. In general, a value of $I_{\Delta N} = 30$ mA is installed. In this way, the value of R_A is considerably lower than the $R_{A,adm}$, ensuring compliance even under unfavourable conditions and limiting contact voltages.

In addition, it is crucial that the residual current circuit breaker has a rated current higher than the current that normally flows through the installation, this ensures its proper performance.

$$I_n > I_L = 16{,}26 \text{ A}$$

Thus, the first standardised rated current value that meets this requirement is 25 A. Therefore, the earth leakage circuit breaker selected for the installation shall be $I_n = 25$ A, class AC, 2-pole and with a sensitivity of 30 mA.[5] [30]

5.5.3 Protection of the installation against overcurrent's and overvoltage's

It is necessary to ensure the protection of the installation's circuits against possible overcurrent's and overvoltage's.

To safeguard the installation, various devices will be implemented to ensure its protection in accordance with the standards established in the REBT ITC-BT-22 and ITC-BT-23 regulations.

Overcurrent's can be caused by overloads, short circuits, or electrical discharges from the atmosphere.

A circuit is overloaded when it is subjected to a current greater than the admissible current (I_Z) without there being any type of fault in the installation.

To protect installations against this, protective devices are used. These must ensure that the permissible current limit of a conductor is complied with the basic principle is that the protection system should operate in a shorter time than is necessary for the conductor to reach its maximum permissible temperature in the event of an overload. Fuses or circuit breakers can be used to achieve this protection.

On the other hand, the most frequent causes of short circuits in LV installations are insulation faults, faults in the connected loads or connection faults in the installation.

In order to protect the installation against short circuits, a protective device shall be installed at the point of origin of each circuit. It must have adequate breaking capacity to interrupt short-circuit currents and prevent damage to conductors and connections. It is important to note that these devices only protect the section of the installation downstream of them.

A separate study shall be carried out to determine the devices to be installed on the DC line and the AC line, as they will not be the same in both cases.

-DC section:

In the following points, the selection of the necessary overload and overvoltage protections will be carried out.

-Protection against overload:

For overload and short-circuit protection in the DC section, a fuse system is used in each array of solar panels. This ensures the protection of the line connecting the solar panels to the inverter.

The UNE-HD 60364,4-43 standard establishes a criterion for verifying overload protection; a protective device is considered to effectively protect a conductor if both of the following conditions are met:

1. $I_B \leq I_n \leq I_Z$
2. $I_2 \leq 1{,}45\ I_Z$

- I_B = 13,01 A. The circuit current's capacity is determined based on the load forecast, considering the maximum power current of the solar panel model for which it has been designed.
- I_Z = 26,5 A. Admissible current of the cable to be protected.
- I_n = Fuse rated current.
- I_2 = Current that ensures the effective operation of the device.

1. $13{,}01\ \text{A} \leq I_n \leq 26{,}5\ \text{A}$
2. $I_2 \leq 1{,}45 \times 26{,}5 = 38{,}425\ \text{A}$

The 16A nominal current fuse is chosen.

To check whether the second condition is fulfilled, first select the type of fuse to be installed. In this case, the type gPV will be chosen. The letter g indicates that the fuse can cut off all currents above its conventional fusing current up to the corresponding breaking capacity, while the letter PV indicates that it is used for photovoltaic applications.

For this type of fuse according to UNE-EN 60269, $I_2 = 1{,}6\ I_n$

$$I_2 = 1{,}6 \times 15 = 24\ \text{A} \leq 38{,}425\ \text{A}$$

The fuse model chosen that meets the necessary conditions to protect the line against overloads is the 15A 1000 V DC 10x38 gPV fuse (article: 5504037) of the autosolar brand, which has a breaking capacity of 33 kA.

Now we have to check whether the selected fuse model also serves as short-circuit protection in our installation.

According to UNE-HD 60364, short-circuit protection is ensured if the following conditions are met:

1. *Breaking power of the fuse* $> I_{ccmax}$
2. $I_{ccmin} > I_a \rightarrow (I^2t)\mathit{fuse} \leq (I^2t)\mathit{cable} = k^2 \times S^2$

I_{ccmax} = 13,90 A, established by the solar panel model.

1. 30 kA > 13,90 A

For a cable section of 16 mm^2 and a k value of 143 (insulation XLPE), for a cut off time of 5 seconds:

2. $I_{cable} = \sqrt{\frac{k^2 \times S^2}{t}} = \sqrt{\frac{143^2 \times 16^2}{5}} = 1023{,}224$ A

The permissible current capacity of the cable is 1023,224 A.

Analysing the graph characteristic of the fuses:

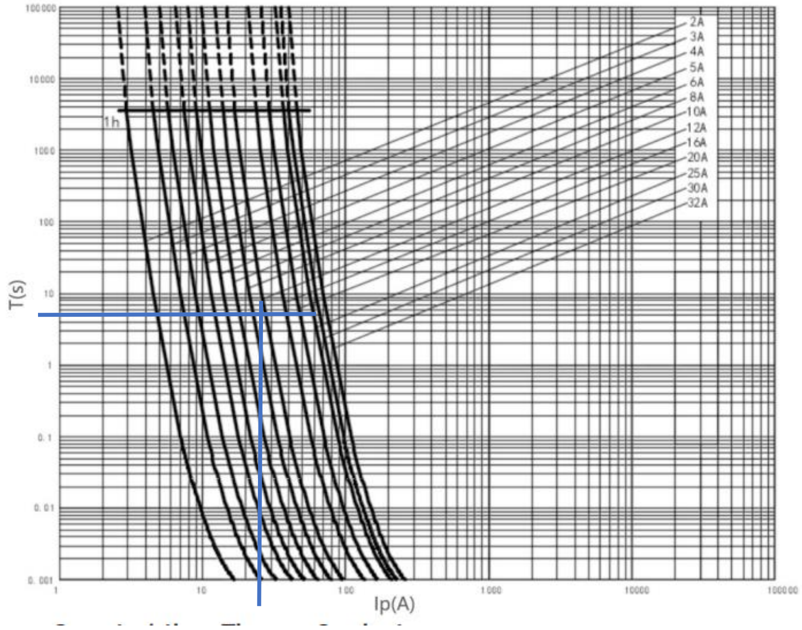


FIGURE 48 FUSE CHARACTERISTICS GRAPH [5]

For a time of 5 seconds the fuse would melt at 37 A, being a lower value than the admitted by the cable. So, the second condition is also fulfilled.

Therefore, selecting this fuse protection against overcurrent on the line is ensured.

- Protection against overvoltage:

To protect the installation against possible overvoltage, an overvoltage protection device shall be included. The voltage of this device shall be adjusted considering the maximum input voltage of the inverter, which is 1100 V. Therefore, a surge arrester with a rated voltage of 1100 V shall be installed.

The device to be installed will be the Weidmüller 8076 4P 25-50 kA voltage discharger [28].

-AC section

The following protection elements are installed inside a PVC control box:

A 2-pole class AC residual current circuit breaker with $I_n = 63$ A and a sensitivity of 30 mA shall be used to ensure protection against indirect contacts, as explained in previous sections.

A magneto-thermal switch that protects the installation against overloads and short circuits. It will be considered the two protection conditions against overloads:

1. $I_B \leq I_n \leq I_Z$
2. $I_2 \leq 1{,}45\ I_Z$

The first condition indicates that either 50 A or 60 A circuit breakers can be used. To prevent tripping of the circuit breaker due to transient current peaks that are not caused by faults, a 50 A circuit breaker shall be used. As long as the first condition is accomplished, the second will also be fulfilled.

It will be installed a thermal magneto switch bipolar 50 A from SCHNEIDER ELECTRIC. It's type C (so its trip margins are $5I_n$-$10I_n$) and it has a breaking power of 6 kA. [31]

The C-curve circuit breaker is selected because the inrush currents in a B-type circuit breaker would quickly trip the circuit breaker. However, type C circuit breakers are used to protect lines with a certain consumption. Here we can find the curves of the 3 types of switches. [5]

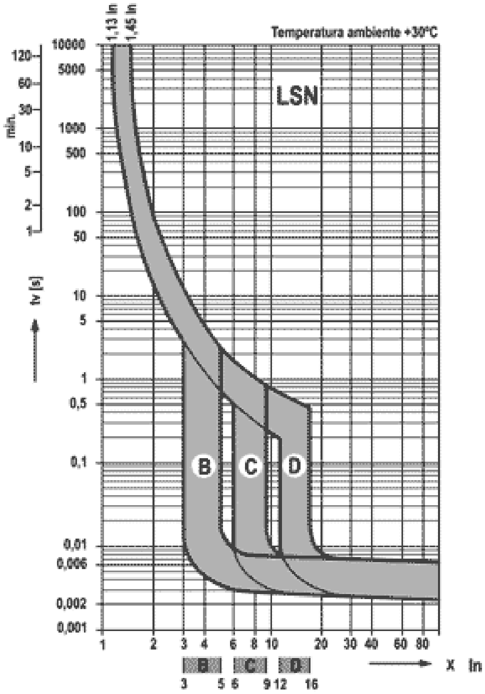


FIGURE 49 CHARACTERISTIC CURVES MAGNETO-THERMAL SWITCH [5]

FIGURE 50 Thermal magneto switch bipolar 50A from SCHNEIDER ELECTRIC [31]

6. WITH BATTERIES

This project is being created for a self-sufficient system; therefore, batteries are not necessary. However, the chosen inverter is suitable for the connection through which higher self-consumption can be achieved. This would mean that adding batteries would lead to more savings. However, we are also talking about a higher investment as the project becomes more expensive with the addition of this device. If batteries are eventually connected to the system, they must be compatible with the selected investor. In this case with the SUN2000-30KTL-M3 Network Inverter. So, the battery selected is LUNA2000-5/10/15-S0.

This battery model consists of 3 modules connected in series to offer a useful capacity range of 5 kWh up to 15 kWh. The direct parallel connection of up to 2 identical LUNA2000 towers also allows a maximum capacity of 5 to 30 kWh.[32]

FIGURE 51 LUNA2000-5/10/15-S0 BATTERY [32]

By the way, if we wanted to use a Fronius inverter it would be the Fronius TAURO Eco 50-3-P solar inverter.

Some of its specifications are as follows:

TABLE 20 SPECIFICATIONS OF FRONIUS TAURO Eco 50-3-P SOLAR INVERTER [33]

TECHNICAL DATA:

- AC nominal output (Pac,r): 50 kW
- Max. PV generator power (Pdc max): 75 kWpeak
- DC input voltage range (Udc min – Udc max): 580 – 1000 V
- Number of DC connections (PV1 / PV2 / PV3): 1 / 1 / –
- DC Connection terminals: Cable diameter 25 – 95 mmÂ², Cable lug or V clamps, Cable gland – 6 x M40
- Protection class: IP 65
- Dimensions (h x w x d): 755 x 1109 x 346 mm
- Weight: 74 kg

INTERFACES:

- Wi-Fi and 2x Ethernet LAN RJ45 for Fronius Solar.web, Modbus TCP Sunspec, Fronius Solar API (JSON)
- USB type A socket
- Wired Emergency Shutdown (WSD)
- 2x RS485
- 6 digital inputs / 6 digital I/Os
- Integrated Datalogger and Webserver

In this case with the Fronius Tauro ECO 50 kW Network Inverter, the battery selected is BYD Battery Box premium HVM.

This battery model consists of 3 to 8 HVM modules connected in series to offer a useful capacity range of 8,3 kWh up to 22.1 kWh.

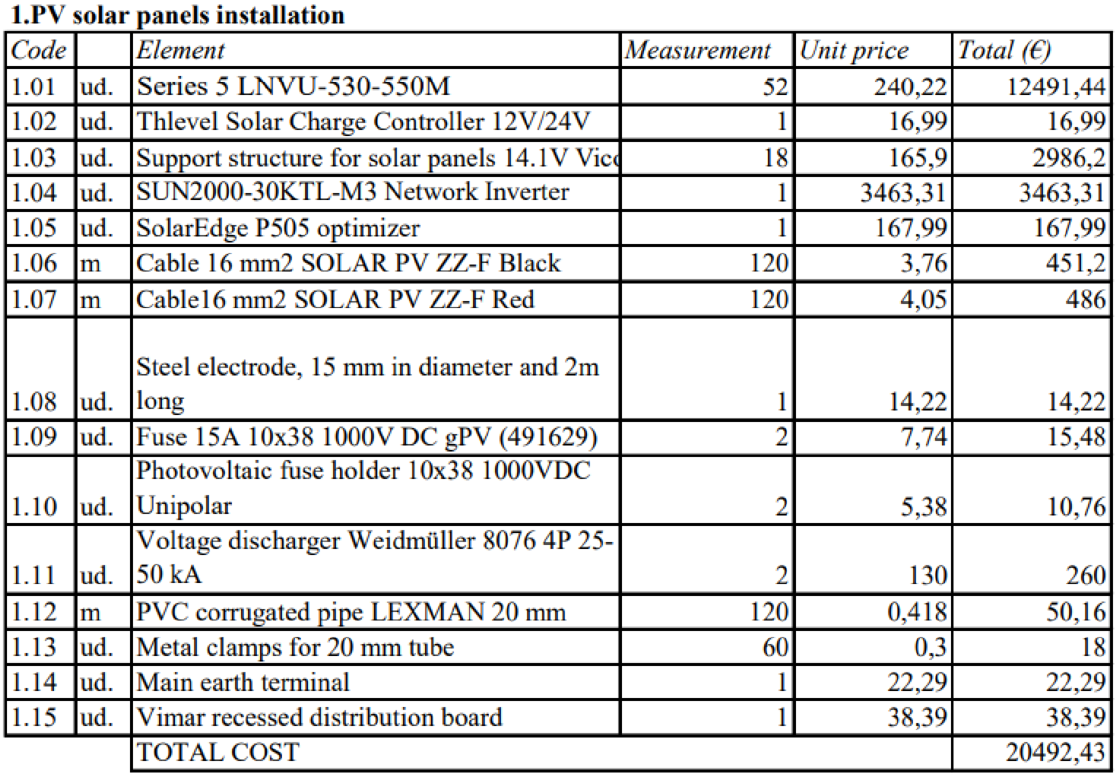
In addition, direct parallel connection of up to 3 HVM towers with the same number of modules is possible from the outset, enabling 66,3 kWh to be achieved.[33]

7. ECONOMIC STUDY

7.1 Budget

The value of the final budget is thirty-nine thousand nine hundred and sixty-five thousand sixty-five and seventy-two euros.

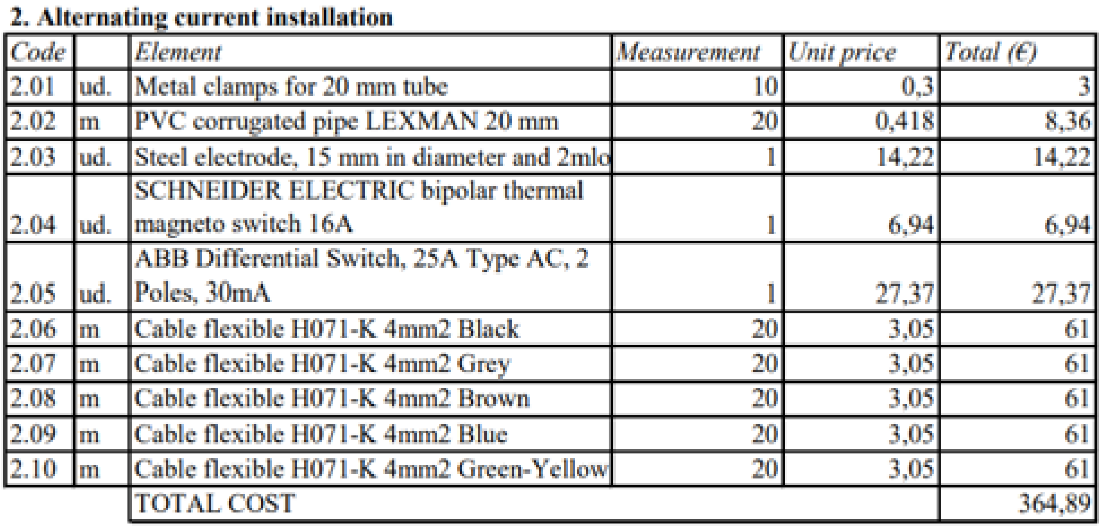
TABLE 21 COST OF SOLAR PANELS INSTALLATION



1.PV solar panels installation

Code		*Element*	*Measurement*	*Unit price*	*Total (€)*
1.01	ud.	Series 5 LNVU-530-550M	52	240,22	12491,44
1.02	ud.	Thlevel Solar Charge Controller 12V/24V	1	16,99	16,99
1.03	ud.	Support structure for solar panels 14.1V Vic	18	165,9	2986,2
1.04	ud.	SUN2000-30KTL-M3 Network Inverter	1	3463,31	3463,31
1.05	ud.	SolarEdge P505 optimizer	1	167,99	167,99
1.06	m	Cable 16 mm2 SOLAR PV ZZ-F Black	120	3,76	451,2
1.07	m	Cable16 mm2 SOLAR PV ZZ-F Red	120	4,05	486
1.08	ud.	Steel electrode, 15 mm in diameter and 2m long	1	14,22	14,22
1.09	ud.	Fuse 15A 10x38 1000V DC gPV (491629)	2	7,74	15,48
1.10	ud.	Photovoltaic fuse holder 10x38 1000VDC Unipolar	2	5,38	10,76
1.11	ud.	Voltage discharger Weidmüller 8076 4P 25-50 kA	2	130	260
1.12	m	PVC corrugated pipe LEXMAN 20 mm	120	0,418	50,16
1.13	ud.	Metal clamps for 20 mm tube	60	0,3	18
1.14	ud.	Main earth terminal	1	22,29	22,29
1.15	ud.	Vimar recessed distribution board	1	38,39	38,39
		TOTAL COST			20492,43

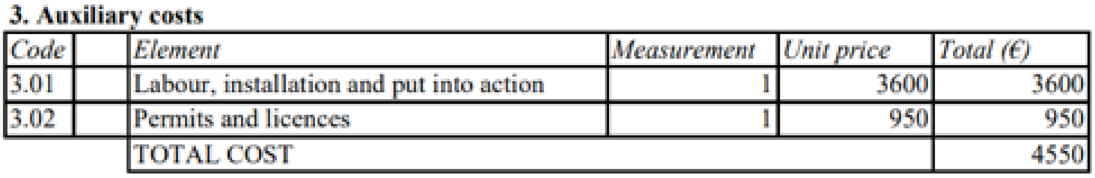
TABLE 22 COST OF ALTERNATING PART INSTALLATION



2. Alternating current installation

Code		*Element*	*Measurement*	*Unit price*	*Total (€)*
2.01	ud.	Metal clamps for 20 mm tube	10	0,3	3
2.02	m	PVC corrugated pipe LEXMAN 20 mm	20	0,418	8,36
2.03	ud.	Steel electrode, 15 mm in diameter and 2mlo	1	14,22	14,22
2.04	ud.	SCHNEIDER ELECTRIC bipolar thermal magneto switch 16A	1	6,94	6,94
2.05	ud.	ABB Differential Switch, 25A Type AC, 2 Poles, 30mA	1	27,37	27,37
2.06	m	Cable flexible H071-K 4mm2 Black	20	3,05	61
2.07	m	Cable flexible H071-K 4mm2 Grey	20	3,05	61
2.08	m	Cable flexible H071-K 4mm2 Brown	20	3,05	61
2.09	m	Cable flexible H071-K 4mm2 Blue	20	3,05	61
2.10	m	Cable flexible H071-K 4mm2 Green-Yellow	20	3,05	61
		TOTAL COST			364,89

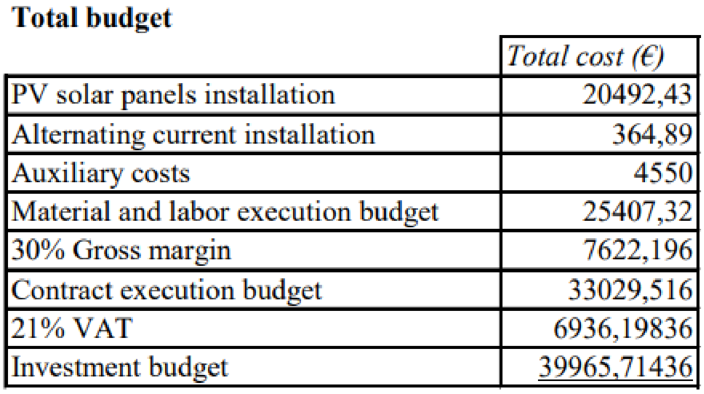
TABLE 23 AUXILIARY COSTS



3. Auxiliary costs

Code		*Element*	*Measurement*	*Unit price*	*Total (€)*
3.01		Labour, installation and put into action	1	3600	3600
3.02		Permits and licences	1	950	950
		TOTAL COST			4550

TABLE 24 TOTAL BUDGET



Total budget

	Total cost (€)
PV solar panels installation	20492,43
Alternating current installation	364,89
Auxiliary costs	4550
Material and labor execution budget	25407,32
30% Gross margin	7622,196
Contract execution budget	33029,516
21% VAT	6936,19836
Investment budget	39965,71436

7.2 Financing and aids

1. Next Generation state aid for self-consumption

   These grants come from the European Funds and are limited in amount, so it is advisable to apply for them before they run out. Although they are state subsidies, they are managed directly by the Region of Murcia.

   These aids are:

   - For installations larger than 10 kWp, subsidies range between 450 € and 300 €/ kWp installed.

   - In municipalities with less than 20,000 inhabitants on non-urban land and 5,000 on urban land, additional subsidies of 55 €/kWp for the installation and 15 €/kWh for the battery must be added to the amounts.

   We have a project without batteries, so we assume a subsidy of 450 €/kWp and 55 €/kWh. This would involve aid of 14443 € (12870+1573). So, our cost will be now 25522,72 €.

2. Income Tax (IRPF) Deductions

   We will be able to deduct 20 % of the total amount invested in the photovoltaic installation in our main residence from our Income Tax Return. This deduction can also be made for self-consumption electricity installations, as established in article 9.1.a of Law 24/2013, of 16 December, on the Electricity Sector, and its implementing regulations (self-consumption electricity supply method). It is a basic requirement to be able to apply for this deduction in the IRPF that the installation is located in our main residence.

   Our project doesn't comply with this requirement.

3. IBI bonuses

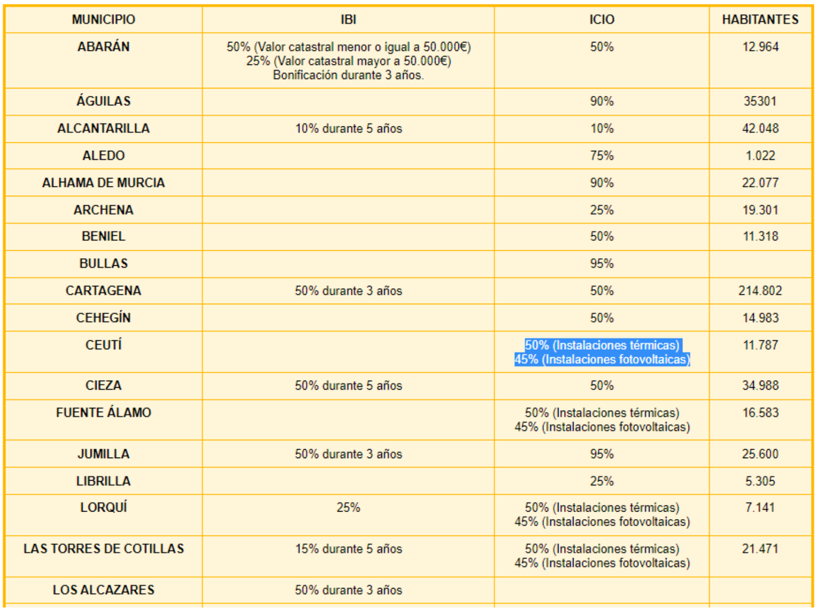
   The Real Estate Tax (IBI) is a municipal tax established by each local council that affects all owners of real estate.

   In our case the project doesn't have this bonus.

4. ICIO bonuses

The Tax on Constructions, Installations and Works (ICIO) is an indirect tax that is payable on any construction, installation or work for which a building or urban planning licence has been required.In the following table, looking for Ceutí we have some benefits.

TABLE 25 PERCENTAGE (%) OF ICIO IN LOCAL COUNCILS OF MURCIA [34]



MUNICIPIO	IBI	ICIO	HABITANTES
ABARÁN	50% (Valor catastral menor o igual a 50.000€) 25% (Valor catastral mayor a 50.000€) Bonificación durante 3 años.	50%	12.964
ÁGUILAS		90%	35301
ALCANTARILLA	10% durante 5 años	10%	42.048
ALEDO		75%	1.022
ALHAMA DE MURCIA		90%	22.077
ARCHENA		25%	19.301
BENIEL		50%	11.318
BULLAS		95%	
CARTAGENA	50% durante 3 años	50%	214.802
CEHEGÍN		50%	14.983
CEUTÍ		50% (Instalaciones térmicas) 45% (Instalaciones fotovoltaicas)	11.787
CIEZA	50% durante 5 años	50%	34.988
FUENTE ÁLAMO		50% (Instalaciones térmicas) 45% (Instalaciones fotovoltaicas)	16.583
JUMILLA	50% durante 3 años	95%	25.600
LIBRILLA		25%	5.305
LORQUÍ	25%	50% (Instalaciones térmicas) 45% (Instalaciones fotovoltaicas)	7.141
LAS TORRES DE COTILLAS	15% durante 5 años	50% (Instalaciones térmicas) 45% (Instalaciones fotovoltaicas)	21.471
LOS ALCAZARES	50% durante 3 años		

For our project will we obtained 45 %. ($45 \times \frac{4450}{100} = 2002{,}5$).
The total cost would then be 23520,22 € (25522,72-2002,5). [34]

7.3 Results

7.3.1 Analysis of the efficiency of the installation

We already know the budget for the installation and the applicable subsidies. We then ask ourselves how long it would take to recover the initial investment.

First, we consider the payments where we find the actual amount that the customer must pay for the installation, the fixed costs in the electricity bill set by the company and the estimate of the energy that must be purchased from the company (since in our case it is not self-sufficient).

Regarding the energy purchased, it has been calculated that approximately 70 % of the energy generated annually by the photovoltaic panels is used in the farm. Therefore, the amount of energy to be purchased will be approximately the total annual consumption, minus 70 % of the energy generated by the solar panel system.

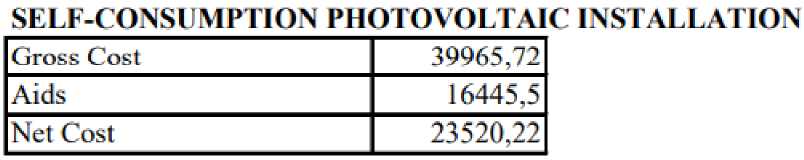
Estimates of these payments may vary over time.

In addition, based on the trend of previous years, it is estimated that there will be a 3% increase in the cost per kilowatt hour (kWh). Regarding the fixed costs, these have been obtained from the household electricity bill.

Regarding savings, the amount of money that the owner of the installation could save for each kilowatt hour (kWh) produced and consumed by the installation is considered.

7.3.2 Evaluation of economic profitability

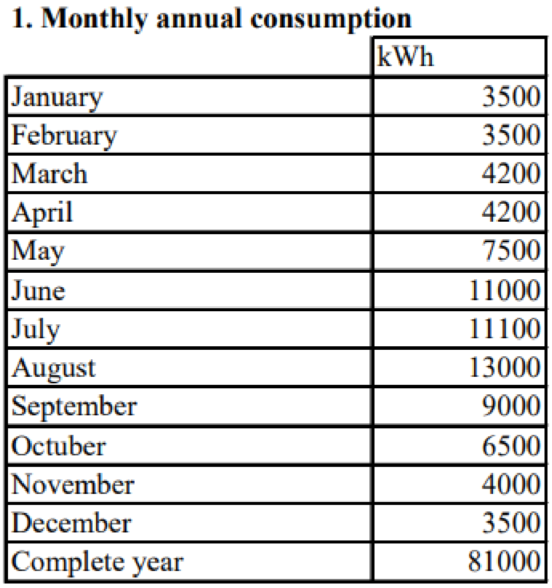
TABLE 26 NET COST OF THE INSTALLATION



SELF-CONSUMPTION PHOTOVOLTAIC INSTALLATION

Gross Cost	39965,72
Aids	16445,5
Net Cost	23520,22

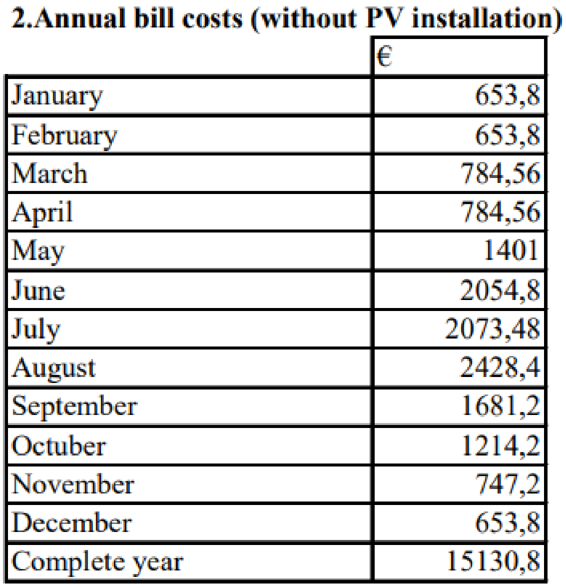
TABLE 27 ANNUAL CONSUPMTION WITHOUT PV INSTALLATION



1. Monthly annual consumption

	kWh
January	3500
February	3500
March	4200
April	4200
May	7500
June	11000
July	11100
August	13000
September	9000
Octuber	6500
November	4000
December	3500
Complete year	81000

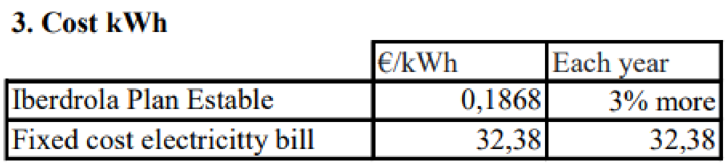
TABLE 28 ANNUAL BILL COST WITHOUT PV INSTALLATION



2.Annual bill costs (without PV installation)

	€
January	653,8
February	653,8
March	784,56
April	784,56
May	1401
June	2054,8
July	2073,48
August	2428,4
September	1681,2
Octuber	1214,2
November	747,2
December	653,8
Complete year	15130,8

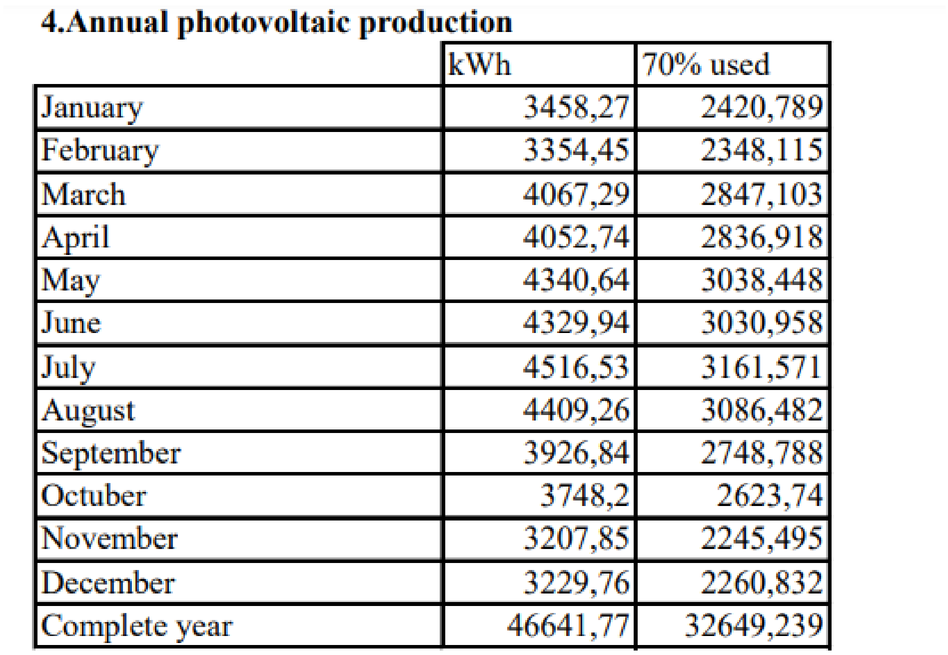
TABLE 29 COST OF KW PER HOUR AND FIXED COST OF ELECTRICITY BILL



3. Cost kWh

	€/kWh	Each year
Iberdrola Plan Estable	0,1868	3% more
Fixed cost electricitty bill	32,38	32,38

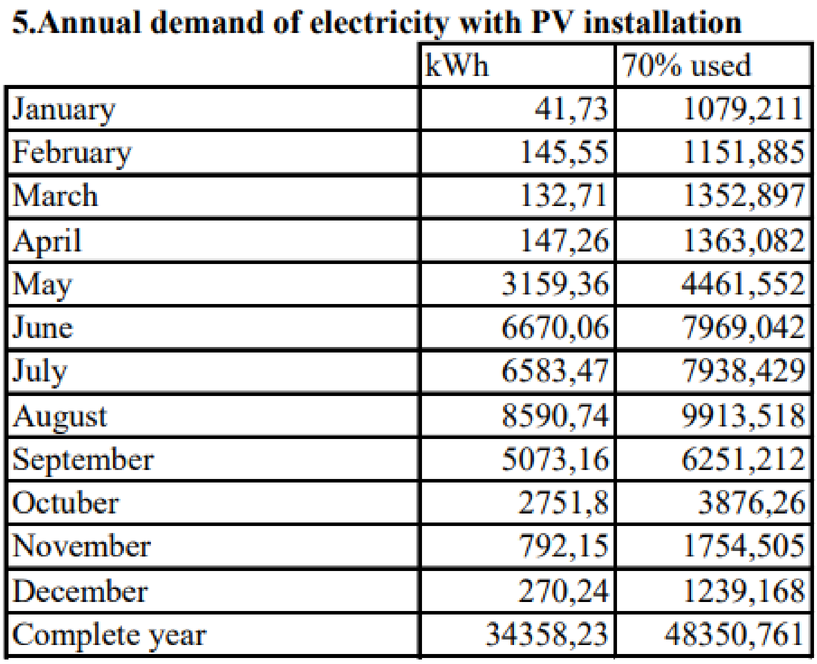
TABLE 30 ANNUAL PHOTOVOLTAIC PRODUCTION IN THE INSTALLATION



4.Annual photovoltaic production

	kWh	70% used
January	3458,27	2420,789
February	3354,45	2348,115
March	4067,29	2847,103
April	4052,74	2836,918
May	4340,64	3038,448
June	4329,94	3030,958
July	4516,53	3161,571
August	4409,26	3086,482
September	3926,84	2748,788
Octuber	3748,2	2623,74
November	3207,85	2245,495
December	3229,76	2260,832
Complete year	46641,77	32649,239

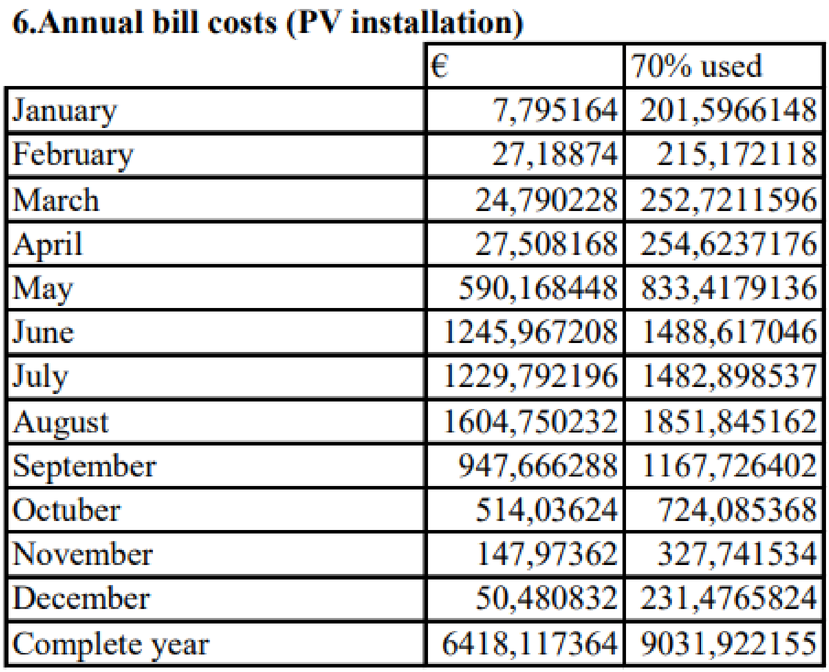
TABLE 31 ANNUAL CONSUPMTION OF ELECTRICITY WITH THE PV INSTALLATION



5.Annual demand of electricity with PV installation

	kWh	70% used
January	41,73	1079,211
February	145,55	1151,885
March	132,71	1352,897
April	147,26	1363,082
May	3159,36	4461,552
June	6670,06	7969,042
July	6583,47	7938,429
August	8590,74	9913,518
September	5073,16	6251,212
Octuber	2751,8	3876,26
November	792,15	1754,505
December	270,24	1239,168
Complete year	34358,23	48350,761

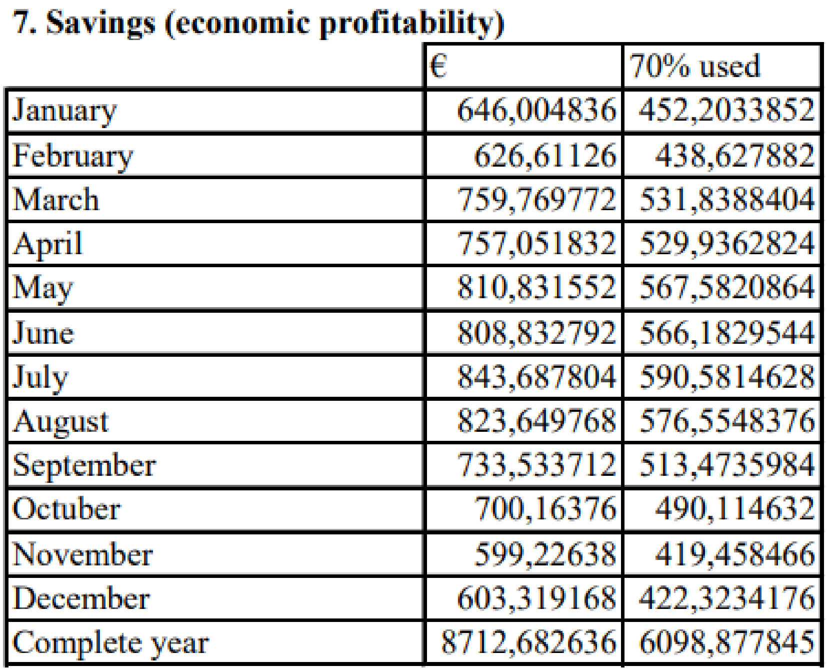
TABLE 32 ANNUAL BILL COST WITH PV INSTALLATION



6.Annual bill costs (PV installation)

	€	70% used
January	7,795164	201,5966148
February	27,18874	215,172118
March	24,790228	252,7211596
April	27,508168	254,6237176
May	590,168448	833,4179136
June	1245,967208	1488,617046
July	1229,792196	1482,898537
August	1604,750232	1851,845162
September	947,666288	1167,726402
Octuber	514,03624	724,085368
November	147,97362	327,741534
December	50,480832	231,4765824
Complete year	6418,117364	9031,922155

TABLE 33 ANNUAL SAVINGS BECAUSE THE PV INSTALLATION



7. Savings (economic profitability)

	€	70% used
January	646,004836	452,2033852
February	626,61126	438,627882
March	759,769772	531,8388404
April	757,051832	529,9362824
May	810,831552	567,5820864
June	808,832792	566,1829544
July	843,687804	590,5814628
August	823,649768	576,5548376
September	733,533712	513,4735984
Octuber	700,16376	490,114632
November	599,22638	419,458466
December	603,319168	422,3234176
Complete year	8712,682636	6098,877845

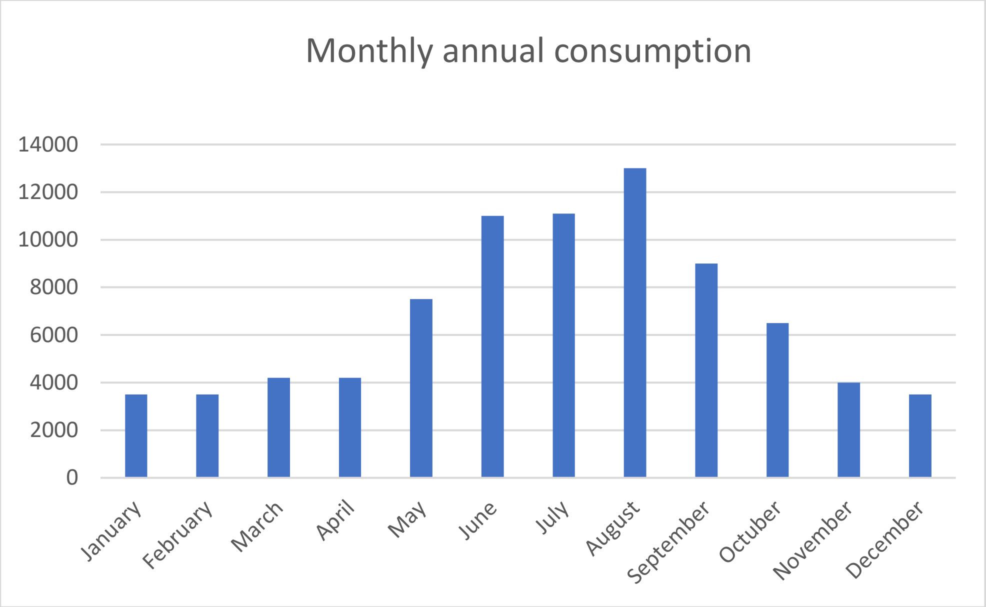


FIGURE 52 ANNUAL CONSUPMTION

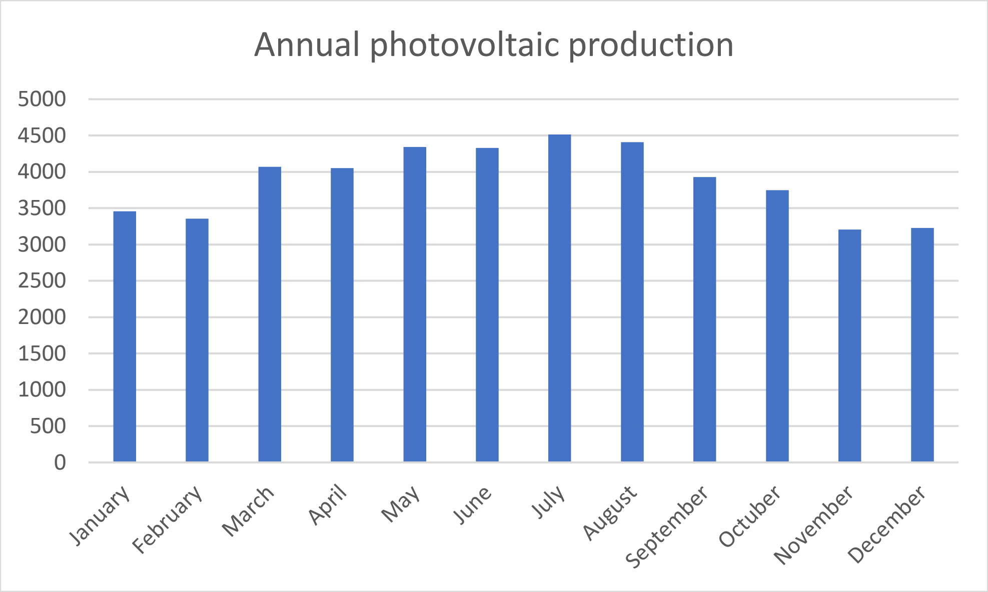


FIGURE 53 ANNUAL PHOTOVOLTAIC PRODUCTION (WORKING AT 100%)

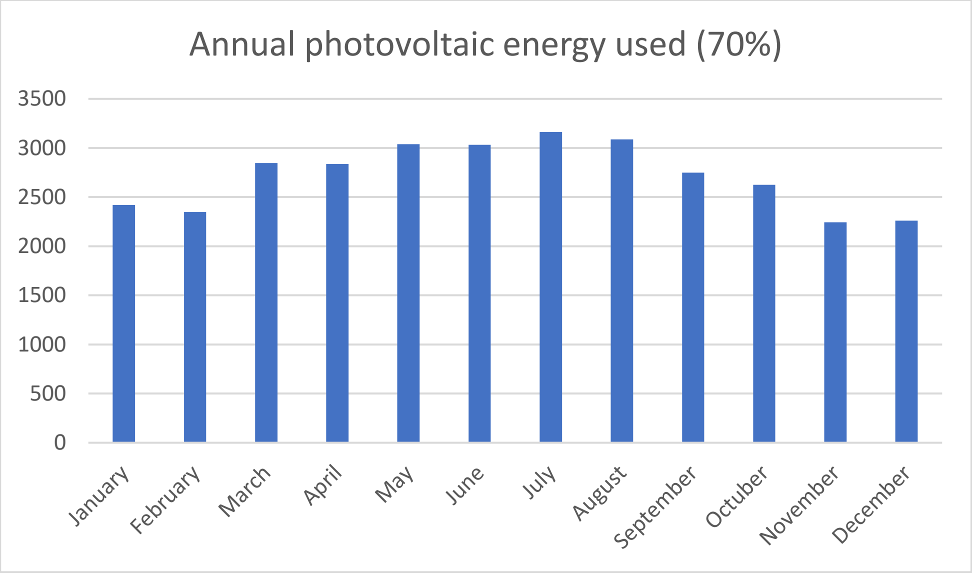


FIGURE 54 ANNUAL PHOTOVOLTAIC PRODUCTION (WORKING AT 70 %)

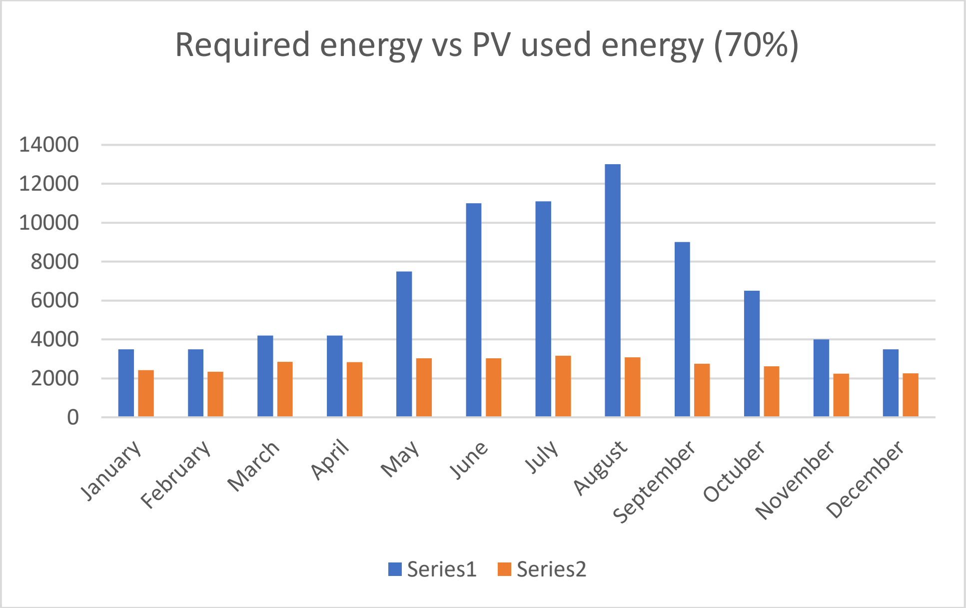


FIGURE 55 ANNUAL DIFFRENCE BETWEEN ENERGY REQUIRED AND ENERGY USED THAT HAS BEEN PRODUCED BY THE PV PANELS (WORKING 70 %)

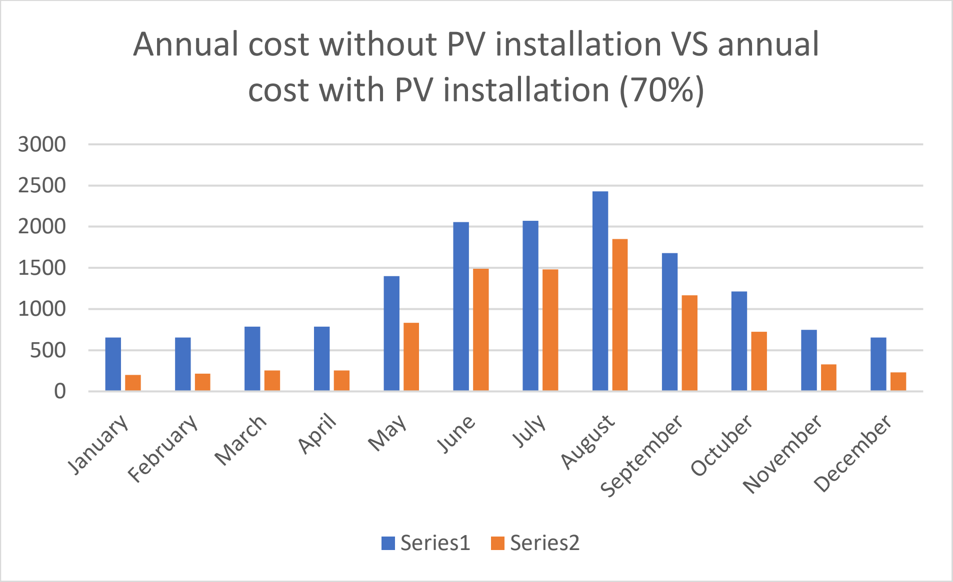
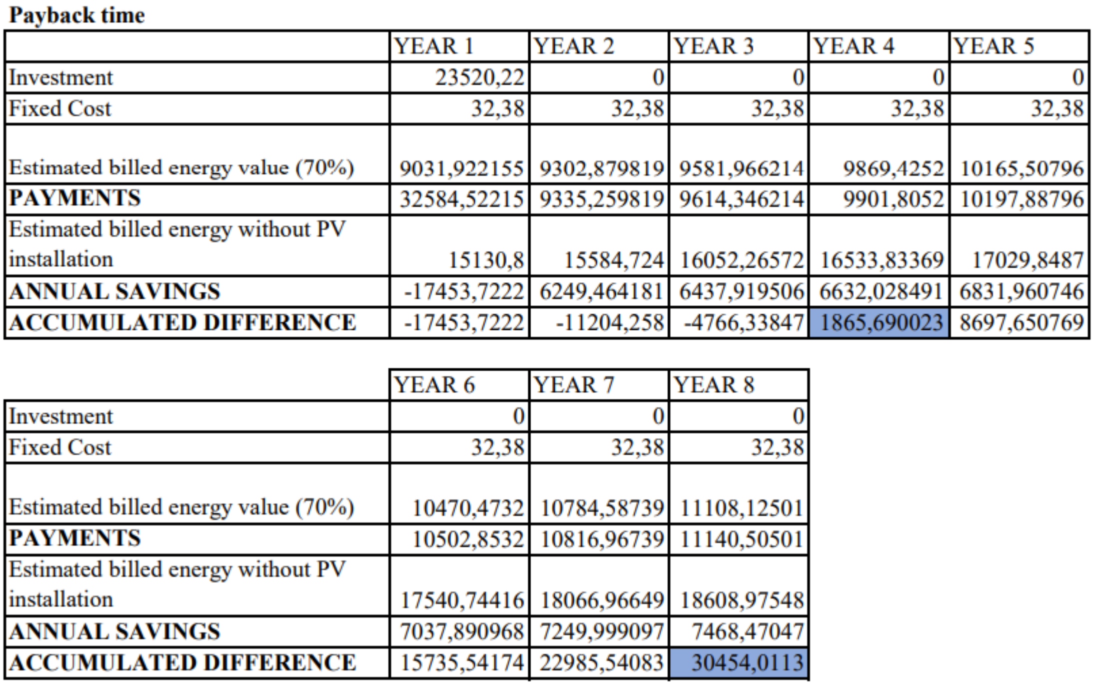


FIGURE 56 ANNUAL DIFFRENCE BETWEEN COST WITHOUT PV INSTALLATION AND COST WITH PV INSTALLATION (WORKING 70%)

7.3.3 Calculation of payback time

TABLE 34 PAYBACK TIME



Payback time

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8
Investment	23520,22	0	0	0	0	0	0	0
Fixed Cost	32,38	32,38	32,38	32,38	32,38	32,38	32,38	32,38
Estimated billed energy value (70%)	9031,922155	9302,879819	9581,966214	9869,4252	10165,50796	10470,4732	10784,58739	11108,12501
PAYMENTS	32584,52215	9335,259819	9614,346214	9901,8052	10197,88796	10502,8532	10816,96739	11140,50501
Estimated billed energy without PV installation	15130,8	15584,724	16052,26572	16533,83369	17029,8487	17540,74416	18066,96649	18608,97548
ANNUAL SAVINGS	-17453,7222	6249,464181	6437,919506	6632,028491	6831,960746	7037,890968	7249,999097	7468,47047
ACCUMULATED DIFFERENCE	-17453,7222	-11204,258	-4766,33847	1865,690023	8697,650769	15735,54174	22985,54083	30454,0113

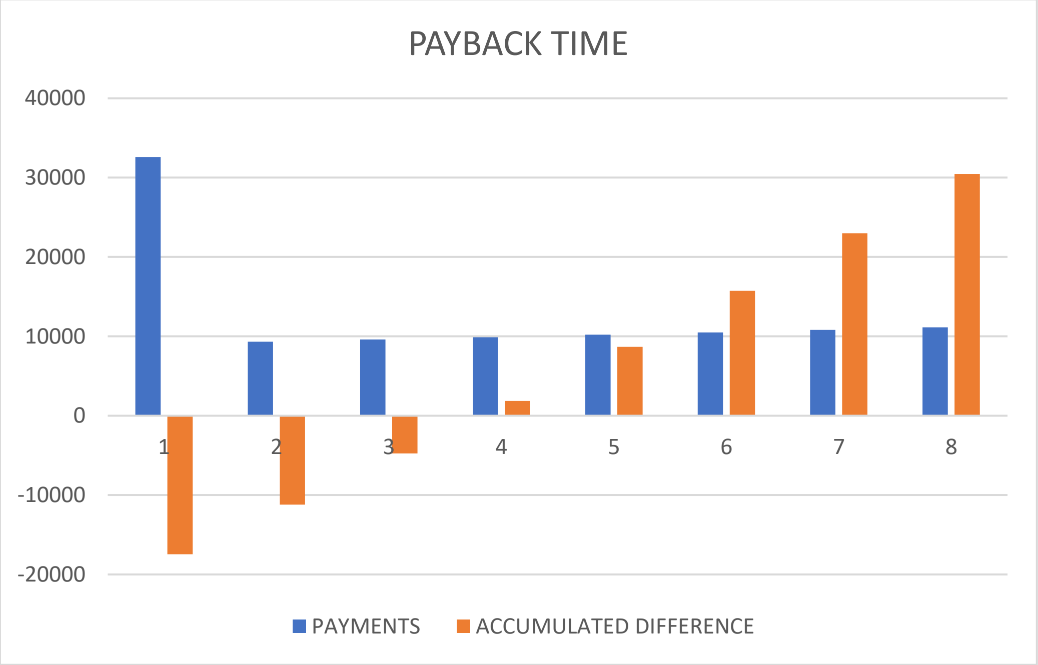


FIGURE 57 EVOLUTION OF SAVINGS AND PAYMENTS TROUGHT THE YEARS

8. CONCLUSION

In conclusion, through this project, focusing on photovoltaic energy, it has been possible to dimension an installation that covers 57.58 % of the electricity consumption of a farm in the town of Ceutí in Murcia. We could also have installed another type of energy source in our project, instead of photovoltaics.

The most suitable components (to obtain the installation in the most economical way possible) have been chosen by means of different justification calculations.

Furthermore, thanks to the economic study of the project, it is known that comparing the cost of electricity without solar panels and with solar panels, the project is profitable (even though only a little more than half of the farm's needs are covered self-sufficiently, and the rest must come from the electricity grid; there is a big difference in money). Profits start to be seen in the 4th year and by the 8th year the initial investment would have been fully recovered.

9.LIST OF SYMBOLS

PNIEC National Integrated Energy and Climate System

GHG Greenhouse Gases

I Intensity

V Voltage

PWM Pulse with modulation

MPPT Maximum Power Point Tracking

DC Direct Current

AC Alternating Current

AGM BATTERIES Absorbent Mat Glass

SFA Stand-alone photovoltaic systems

CFV photovoltaic power plants

SFCA self-consumption systems

PVGIS Photovoltaic Geographical Information System

k_T Temperature coefficient

k_A grouping coefficient

k Correction coefficient

k_{RT} Thermal resistivity coefficient

I_L Current flowing through the installation

XLPE Cross linked polyethylene

PVC Polyvinyl chloride

Vmp Maximum power voltage

ΔU Voltage drops

U_L Contact voltage

L Cable length

S Cable section

ρ_T Resistivity at temperature T

T Estimated temperature of the conductor

To Ambient temperature of the conductor

Tmax Maximum permissible conductor temperature according to insulation

I_T Admissible current for specific cross-sections

α Temperature coefficient of copper

Tc Characteristic temperature of copper

I_k Steady state RMS fault current

I_T maximum admissible current of the cable

I_L Current flowing through the installation

I_{AC} Maximum current at the output of the inverter

R_{pat} Earthing resistance

R_A Grounded resistance

S_p Cross-section of protective conductor

I_d Fault current

$I_{\Delta N}$ Device rated difference current

I_B Operating current

I_Z Admissible current (of the cable to be protected)

I_n Fuse rated current.

I_2 Current that ensures the effective operation of the device.

I_{ccmin} Minimum short-circuit current

I_{ccmax} Maximum short-circuit current

I_{cable} Permissible current capacity of the cable

REBT Low voltage electrotechnical regulations

IRPF Abbreviation for personal income tax

IBI Real Estate Tax

ICIO Tax on constructions, installations and works

STC CONDITIONS Standard test conditions

10.FIGURES

11.TABLES

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13. BIOGRAPHIE

My name is Loreto Taboada Hellín, I am Spanish, and I was born on 2nd March 2001. I have studied a degree in Industrial Technologies Engineering, and I am finishing my studies at the University of Zagreb since I have spent the last semester abroad thanks to the Erasmus+ scholarship.

I have done this project as a final project because I did an internship last summer in a photovoltaic company (Stark Renewable Energy), so I was aware of the steps to follow before installing a solar panel. I also believe that this is a sector that is growing in Spain and will grow much more in the coming years because it is an ideal country to develop this type of renewable energy due to its location.

In addition, I am starting my master's degree next year and I will be specialising in renewable energies to continue advancing and discovering new methods of energy, as this is one of the biggest problems we are currently facing on the planet.

14. ANNEXES

SCRIPT 1

```
function main(workbook: ExcelScript.Workbook) {
    let selectedSheet = workbook.getActiveWorksheet();
    // Set range A1:A4 on selectedSheet
    selectedSheet.getRange("A1:A4").setValues([["1. PV solar panels installation"],["code"],["1.01"],["1.02"]]);
    // Auto fill range
    selectedSheet.getRange("A3").autoFill("A3:A13", ExcelScript.AutoFillType.fillDefault);
    // Set font italic to true for range A2 on selectedSheet
    selectedSheet.getRange("A2").getFormat().getFont().setItalic(true);
    // Set range B3 on selectedSheet
    selectedSheet.getRange("B3").setValue("ud.");
    // Auto fill range
    selectedSheet.getRange("B3").autoFill("B3:B13", ExcelScript.AutoFillType.fillDefault);
    // Set range C2:F2 on selectedSheet
    selectedSheet.getRange("C2:F2").setValues([["element","measurement","unit price","total (€)"]]);
    // Set font italic to true for range C2:F2 on selectedSheet
    selectedSheet.getRange("C2:F2").getFormat().getFont().setItalic(true);
    // Set width of column(s) at range E:E on selectedSheet to 58.5
    selectedSheet.getRange("E:E").getFormat().setColumnWidth(58.5);
    // Set width of column(s) at range D:D on selectedSheet to 70.5
    selectedSheet.getRange("D:D").getFormat().setColumnWidth(70.5);
    // Set width of column(s) at range C:C on selectedSheet to 117.75
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(117.75);
    // This action currently can't be recorded.
    // Set width of column(s) at range C:C on selectedSheet to 123.75
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(123.75);
    // Set range C4 on selectedSheet
    selectedSheet.getRange("C4").setValue("Thlevel Solar Charge Controller 12V/24V\n");
    // Set wrap text to true for range C4 on selectedSheet
    selectedSheet.getRange("C4").getFormat().setWrapText(true);
    // Set wrap text to true for range C4 on selectedSheet
    selectedSheet.getRange("C4").getFormat().setWrapText(true);
```

```
    // Set width of column(s) at range C:C on selectedSheet to 181.5
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(181.5);
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // Set width of column(s) at range C:C on selectedSheet to 195.75
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(195.75);
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // Set width of column(s) at range C:C on selectedSheet to 226.5
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(226.5);
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // This action currently can't be recorded.
    // Auto fill range
    selectedSheet.getRange("A13").autoFill("A13:A18", ExcelScript.AutoFillType.fillDefault);
    // Auto fill range
    selectedSheet.getRange("B13").autoFill("B13:B18", ExcelScript.AutoFillType.fillDefault);
    // Set range B8:B9 on selectedSheet
    selectedSheet.getRange("B8:B9").setValue("m");
    // Set range B14 on selectedSheet
    selectedSheet.getRange("B14").setValue("m");
    // Set range D3:E17 on selectedSheet
```

```
    selectedSheet.getRange("D3:E17").setValues([["52","240,22"],["1","16,99"],["18","165,9"],["1","3463,31"],["1","167,99"],["120","3,76"],["120","4,05"],["1","14,22"],["2","7,74"],["2","5,38"],["2","130"],["120","0,418"],["60","0,3"],["1","22,29"],["1","38,39"]]);
    // Set range F3 on selectedSheet
    selectedSheet.getRange("F3").setFormulaLocal("=PRODUCTO(E3;D3)");
    // Set width of column(s) at range C:C on selectedSheet to 231.75
    selectedSheet.getRange("C:C").getFormat().setColumnWidth(231.75);
    // Auto fill range
    selectedSheet.getRange("F4").autoFill("F4:F17", ExcelScript.AutoFillType.fillDefault);
    // Auto fill range
    selectedSheet.getRange("F3").autoFill("F3:F4", ExcelScript.AutoFillType.fillDefault);
    // Auto fill range
    selectedSheet.getRange("F3:F4").autoFill("F3:F7", ExcelScript.AutoFillType.fillDefault);
    // Auto fill range
    selectedSheet.getRange("F3:F7").autoFill("F3:F12", ExcelScript.AutoFillType.fillDefault);
    // Auto fill range
    selectedSheet.getRange("F3:F12").autoFill("F3:F17", ExcelScript.AutoFillType.fillDefault);
    // Set range F18 on selectedSheet
    selectedSheet.getRange("F18").setFormulaLocal("=SUMA(F3:F17)");
}
```

SCRIPT 2

```
1   function main(workbook: ExcelScript.Workbook) {
2       let selectedSheet = workbook.getActiveWorksheet();
3       // Auto fill range
4       selectedSheet.getRange("B24").autoFill("B24:B26", ExcelScript.AutoFillType.fillDefault);
5       // Set range B27 on selectedSheet
6       selectedSheet.getRange("B27").setValue("m");
7       // Auto fill range
8       selectedSheet.getRange("B27").autoFill("B27:B31", ExcelScript.AutoFillType.fillDefault);
9       // Set width of column(s) at range C:C on selectedSheet to 237
10      selectedSheet.getRange("C:C").getFormat().setColumnWidth(237);
11      // Set range D22:D28 on selectedSheet
12      selectedSheet.getRange("D22:D28").setValues([["10"],["20"],["1"],["1"],["1"],["20"],["20"]]);
13      // Auto fill range
14      selectedSheet.getRange("D28").autoFill("D28:D31", ExcelScript.AutoFillType.fillDefault);
15      // Set range E22:E27 on selectedSheet
16      selectedSheet.getRange("E22:E27").setValues([["0,3"],["0,418"],["14,22"],["6,94"],["27,37"],["3,05"]]);
17      // Auto fill range
18      selectedSheet.getRange("E27").autoFill("E27:E31", ExcelScript.AutoFillType.fillDefault);
19      // Set range F22 on selectedSheet
20      selectedSheet.getRange("F22").setFormulaLocal("=PRODUCTO(D22;E22)");
21      // Auto fill range
22      selectedSheet.getRange("F22").autoFill("F22:F31", ExcelScript.AutoFillType.fillDefault);
23      // Set range F32 on selectedSheet
24      selectedSheet.getRange("F32").setFormulaLocal("=SUMA(F22:F31)");
25      let table = selectedSheet.addTable("A22:F32", true);
26
27  }
```

These scripts have been taken from the first excel, created to calculate the project budget.

I'll explain what script 2 executes in each line. It’s the script to create table “Alternating current installation”.

First, we enter the sheet where we are working. We select box B24, we can see it where it says "Getrange", that is the selected box. Then "AutofillType" appears since that box has been filled by copying the box from another Excel (made the same table with an Excel previously). Where it says "Setvalue" are the values that have been inserted manually.

In row 20 the first Excel formula is made, the product of two boxes. Then the boxes from F22 to F31 are filled automatically also using the product formula.

In row 24, another Excel formula is performed in box F32, this time it is the sum of boxes F22 to F31.

Finally, in row 25 we select all cells and add it in a table.