Design of a photovoltaic solar installation for the irrigation of the Vallada cultivation area (Valencia)

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Thesis to obtain the Master of Science Degree in

Mechanical Engineering

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Acknowledgments

This master thesis is the culmination of a 6-year academic study period (4 years of degree and 2 years of master). It aims to apply the knowledge acquired in the specialty of Power Generation of the MUII. Therefore, it constitutes the opportunity to demonstrate the learning of these concepts to a real case, giving rise to a document which content is similar to what can be found in a project prepared by a company or an individual who is already an engineer.

Naturally, its elaboration has not been brief, nor simple, having in addition that it has been elaborated in a non-mother language and a foreign and demanding university such as the IST, even more so with the difficulties in its development due to the limitations caused by the pandemic that started more than 1 year ago.

Therefore, I would like to thank, first of all and in a particularly effusive way, the time, patience, help and encouragement to my tutors, Mr. Paulo Jose da Costa Branco, professor at the Department of Electrotechnical and Computer Engineering at IST Lisbon and main tutor, and João Carlos de Campos Henriques, professor in the Department of Engenharia Mecânica del IST, who was my first contact at the IST when I started looking for a tutor for the thesis, for his patience, understanding, encouragement and interest in being aware of the result of the development of this work throughout my stay in Lisbon. I would also like to dedicate a heartfelt and appreciation message to Mr. Modesto Pérez Sánchez, professor of the Department of Hydraulic Engineering and the Environment of the UPV who also helped me in the development and supervision of this work from my home university. They have facilitated my work as much as they could, trying to explain the fundamental concepts necessary for its development and being available as much as they have been able to.

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Therefore, this document is not only a way of showing myself my ability to make an effort and to address challenges, but also a dedication to all those people who, to a greater or lesser extent, have been there to support me, both academically and in other aspects of my life.

Resumen

Las energías renovables tienen un futuro prometedor, puesto que en las próximas décadas desplazarán a las fuentes de energía no renovables en la generación de energía a nivel mundial. Este tipo de tecnologías permiten obtener energía de forma limpia y, pese a que el ciclo de vida de este tipo de instalaciones naturalmente tiene un cierto impacto ambiental, este resulta ser mucho menor que el generado en la obtención de energía por medio de otras fuentes de energía tradicionales, como son el petróleo y el carbón.

De entre las múltiples aplicaciones que este tipo de energías tienen, la que atañe el presente TFM se conoce como bombeo solar fotovoltaico, que consiste en el empleo de una instalación fotovoltaica para la obtención de la energía requerida en el funcionamiento de un sistema de bombeo en este caso empleado para el abastecimiento de un terreno de cultivo en la zona de Vallada (Valencia).

En este sentido, este TFM tiene como objetivo emplear los resultados de un TFM anterior, en el que se analizó la viabilidad y la optimización de la recuperación energética por medio de la instalación de bombas funcionando como turbinas (PATs) como sustitución de las válvulas reguladoras de presión (PRV) previamente empleadas en la instalación hidráulica presente en la zona de cultivo anteriormente mencionada, con el fin de diseñar, calcular y proyectar la instalación fotovoltaica requerida para el abastecimiento energético de los sistemas de bombeo.

De esta forma, se desarrollarán diferentes alternativas (si resulta más rentable no utilizar las PATs, si se escoge finalmente instalarlas y alcanzar el autoabastecimiento mediante baterías, si se decide emplear la red eléctrica para alimentar parte de la demanda a lo largo de los meses del año en lugar del empleo de bancos de baterías, etc) y, de entre ellas, se escogerá y justificará la óptima desde el punto de vista técnico-económico.

Resum

Les energies renovables tenen un futur prometedor, ja que en les pròximes dècades desplaçaran a les fonts d'energia no renovables en la generació d'energia a nivell mundial. Este tipus de tecnologies permeten obtindre energia de forma neta i, a pesar que el cicle de vida d'este tipus d'instal·lacions naturalment té un cert impacte ambiental, este resulta ser molt menor que el generat en l'obtenció d'energia per mitjà d'altres fonts d'energia tradicionals, com són el petroli i el carbó.

D'entre les múltiples aplicacions que este tipus d'energies tenen, la que afecta el present TFM es coneix com a bombament solar fotovoltaic, que consistix en l'ocupació d'una instal·lació fotovoltaica per a l'obtenció de l'energia requerida en el funcionament d'un sistema de bombament en aquest cas empleat per a l'abastiment d'un terreny de cultiu en la zona de Vallada (València) .

En aquest sentit, aquest TFM té com a objectiu emprar els resultats d'un TFM anterior, en el que es va analitzar la viabilitat i l'optimització de la recuperació energètica per mitjà de la instal·lació de bombes funcionant com a turbines (PATs) com a substitució de les vàlvules reguladores de pressió (PRV) prèviament empleades en la instal·lació hidràulica present en la zona de cultiu anteriorment mencionada, a fi de dissenyar, calcular i projectar la instal·lació fotovoltaica requerida per a l'autoabastiment energètic dels sistemes de bombament.

D'aquesta forma, es desenvoluparan diferents alternatives (si resulta més rendible no utilitzar les PATs, si es tria finalment instal·lar-les i aconseguir l'autoabastiment per mitjà de bateries, si es decidix emprar la xarxa elèctrica per a alimentar part de la demanda al llarg dels mesos de l'any en lloc de l'ocupació de bancs de bateries, etc) i, d'entre elles, es triarà i justificarà l'òptima des del punt de vista tecnicoeconòmic.

Abstract

Renewable energies have a promising future, since in the coming decades they will displace non-renewable energy sources in power generation worldwide. This type of technology allows obtaining energy in a clean way and, despite the fact that the life cycle of this type of facilities naturally has a certain environmental impact, it turns out to be much less than that generated in obtaining energy through other sources of energy. traditional energy, such as oil and coal.

Among the many applications that this type of energy has, the one that concerns the present TFM is known as photovoltaic solar pumping, which consists of the use of a photovoltaic installation to obtain the energy required in the operation of a pumping system in this case used to supply a farmland in the Vallada area (Valencia).

In this sense, this TFM aims to use the results of a previous TFM, in which the feasibility and optimization of energy recovery was analysed through the installation of pumps operating as turbines (PATs) as a replacement for regulating valves. pressure (PRV) previously used in the hydraulic installation present in the aforementioned cultivation area, in order to design, calculate and project the photovoltaic installation required for the energy self-sufficiency of the pumping systems.

In this way, different alternatives will be developed (if it is more profitable not to use the PATs, if it is finally chosen to install them and achieve self-sufficiency by means of batteries, if it is decided to use the electricity grid to supply part of the demand throughout the months of the year instead of using battery banks, etc.) and, from among them, the optimal one from the technical-economic point of view will be chosen and justified.

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Memory

Chapter 1. Introduction

1.1 Importance of RR.EE. Evolution and current situation

The exploitation of mineral resources to obtain materials and energy (mechanical, thermal, electrical) on a large scale since the first industrial revolution and especially since the beginning of the 20th century has allowed, together with advances in medicine and social rights, the intense development of technology and population growth and quality of life worldwide.

As is known, this growth and development have been based on the use of resources of mineral origin (burning coal, oil, natural gas) almost exclusively for decades, as well as on the use of production methods and products that are not very respectful with the environment, such as aerosols. This has caused the appearance and aggravation of multiple problems on the planet, such as acid rain, photochemical smog, eutrophication, the destruction of the ozone layer and the disappearance of animal species, as a consequence of polluting emissions originating in the combustion of these resources and the excessive exploitation of their deposits.

Consequently, at the end of the 19th century and the beginning of the 20th century, the first wave of environmentalism or movement for the conservation of the earth and its resources took place, which sought to highlight the importance of respect for the environment and the responsible and sustainable exploitation of the resources of the planet, but it was in the 1960s and 70s that a more widespread ecological awareness emerged in society and institutions, and since then it has gained a strong momentum, especially in recent years. This has led to a greater involvement of the population in caring for the environment, for example in the increasingly widespread use of public means of transport and in contributing to the recycling of household waste. The following figure is intended to schematically illustrate the chronology of some of the main milestones towards sustainable development:

1958	First carbon dioxide measurements by Charles keeling. (Hawaii)
1972	Club of Rome´s Report: *Limits to Growth*
1972	United Nations Conference on the Human Environment (Stockholm)
1979	First World Conference about Climate Change (Stockholm)
1980	World Conservation Strategy (IUCN, UNEP and WWF)
1985	Vienna Convention for the Protection of the Ozone Layer
1987	Montreal Protocol on Substances that Deplete the Ozone Layer
1987	Brundtland Report: *Our Common Future*
1988	Creation of the *Intergovernmental Panel on Climate Change* (IPCC)
1990	Creation of the *World Business Council on Sustainable Development*
1992	United Nations Framework Convention on Climate Change (New York)
1992	UNCED. *Rio Declaration. Agenda 21.* (Rio de Janeiro)
1997	III Conference of the UU.NN about Climate Change. (Kyoto). Kyoto Protocol
1998	European Community signs the Kyoto Protocol on 29th April
2002	UU.NN World Summit on Sustainable Development. (Johannesburg)
2005	Entry into force of the Kyoto Protocol without USA on 16th February
2007	IPCC Synthesis Report (Valencia); Nobel Peace Prize for IPCC and Al Gore
2015	US announces the Clean Energy Plan to reduce CO_2 emissions by 32% (2030)
2015	XXI Conference of the UU.NN. 195 countries sign Paris Agreement. (Paris)
2018	XXIV Conference of the UU.NN. Paris Agreement implementation guidelines

Figure 1. Chronogram of some of the most important milestones towards sustainable development. Source: Own, based on Castilla-La Mancha media

Together with the policies promoted by governments and multiple international organizations aimed at reducing dependence on conventional energy sources and the emissions of polluting substances for the environment, the development and implementation of renewable energies constitutes the other fundamental pillar in the ecological transition at a global level aimed at achieving a more responsible and respectful use of the planet and its resources by human beings.

There are several technologies that have emerged as an alternative to the use of fossil fuels (hydraulic, wind, solar photovoltaic, geothermal, tidal, solar thermal) and which have allowed a notable reduction in polluting emissions in the countries where they represent a relevant percentage of global electricity production. These countries are currently mainly European, as well as the USA (where renewable energies contributed 17.1% of electricity generation in 2017), Australia (which managed to reach 21% of energy production from renewable sources in 2018), China (where renewable energies reached 38.3% of energy capacity in 2018) or Brazil (in 2018, hydroelectric energy represented 62.7% of the country's total installed capacity). The following graph represents the consumption of renewable energies of the main earth regions from 1999 to 2019:

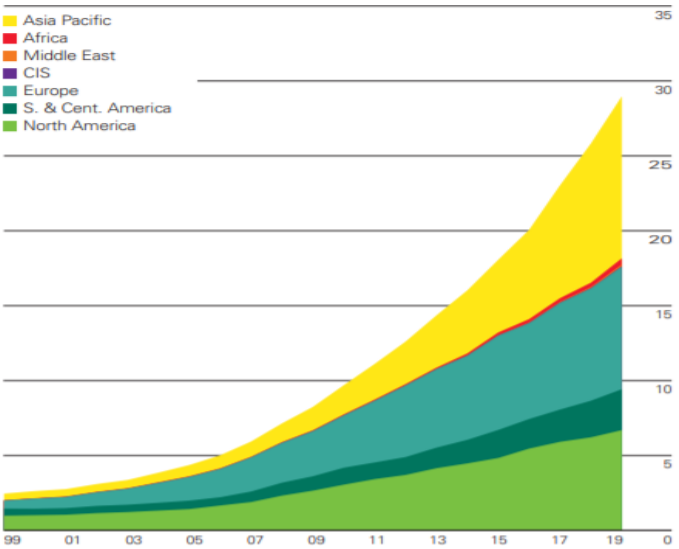


Figure 2. Renewables consumption by region (in Exajoules). Source: BP

Moreover, the graph shown below illustrates the growth, both in absolute and relative terms, of the global power generation capacity of the different renewable energies in recent years (data available until 2018):

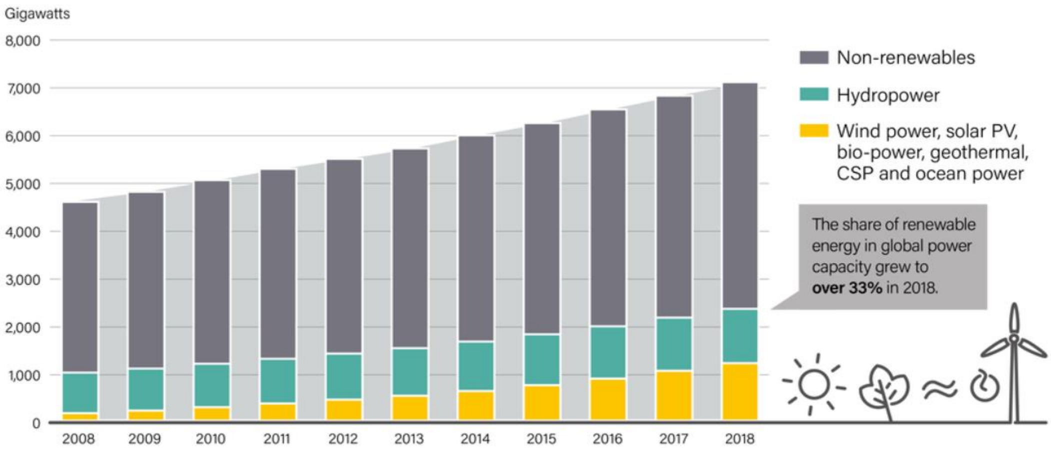


Figure 3. Global power generation capacity (by source) between 2008 and 2018. Source: Ren21

At the same time, the following figure indicates that, despite the fact that hydraulic continues to be the main source in terms of installed (accumulated) power among the different renewables, in recent years, specifically since 2016, the photovoltaic energy in first place, and wind power in second place, are the sources that accumulate the highest installed power generation capacity. Specifically, in 2018, of the approximately 185 gigawatts added, 105 correspond to solar photovoltaic; similarly, around 115 of the 205 gigawatts of installed power from renewable sources in 2019 come from photovoltaics.

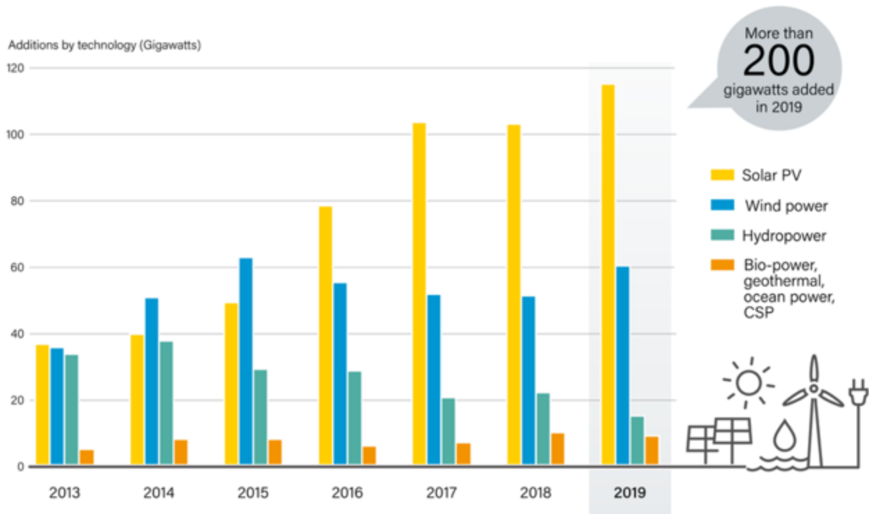


Figure 4. Annual additions of renewable power capacity, by technology and total, between 2013-2019 Source: Ren21

This highlights the importance that renewable sources have acquired in energy generation for years, as well as the dependence that will be on them in the near future. For this reason, it is necessary to continue investing and researching in mathematical forecasting models for the generation of wind and solar photovoltaic energies, as well as in energy storage systems that allow an adequate and efficient use of these variable renewable energy sources.

To conclude, it is equally relevant to illustrate the importance that renewable energies have acquired not only in contributing to energy generation but also in their penetration into the labour market, by employing an increasing number of employees. Precisely, the following graph reflects the employability figures that the main renewable energy sources have achieved in recent years:

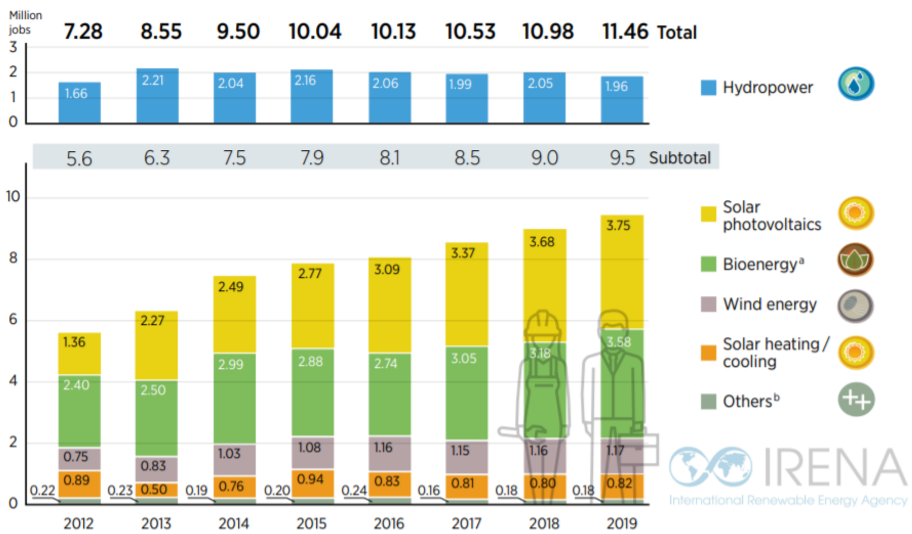


Figure 5. Global renewable energy employment by technology (2012-2019). Source: IRENA

In the case of the EU, the contribution of all the renewable sources in each member state to their energy consumption is not homogeneous, but rather represents a percentage that may be very different among some of them. As can be seen in the attached graph, Spain ranks in an intermediate position in clean energy consumption with respect to the other countries of the European Union, and its percentage (18,4%) is close to that one of the EU average in 2019 (19,7%). This data is encouraging to reach the objective of 20% in 2020.

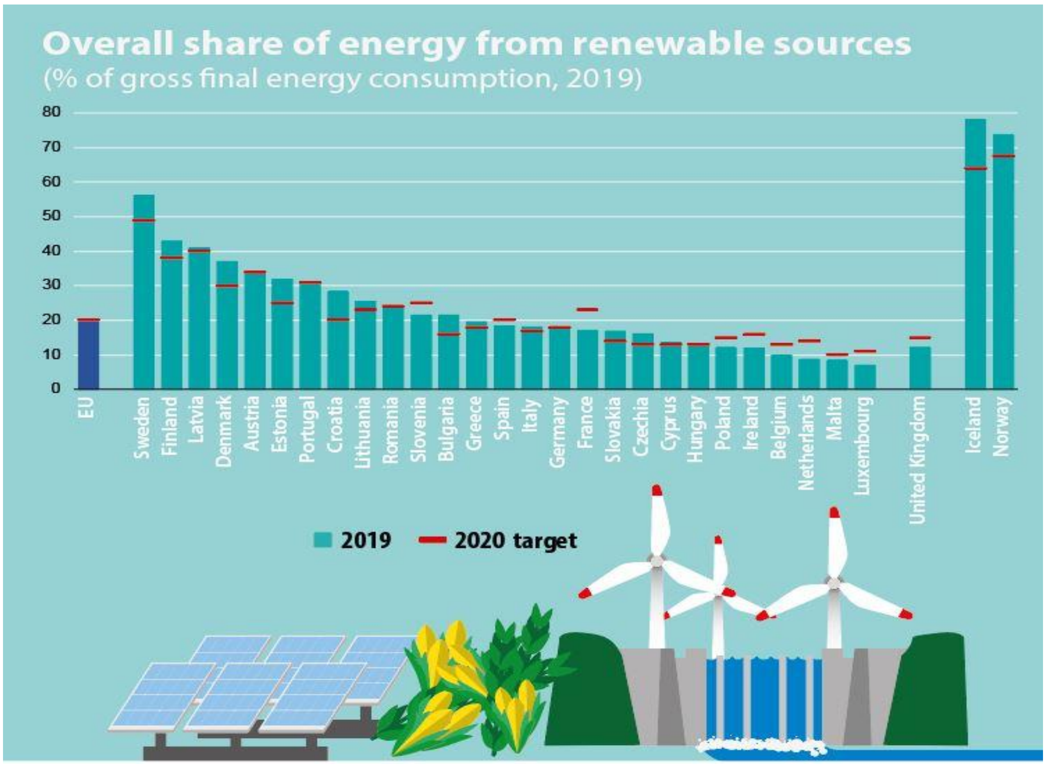


Figure 6. Share of energy from RR.SS in the EU member states in 2019. Source: Eurostat

This graph also reflects that the northern European countries are those in which a greater percentage of their final energy consumption comes from renewable sources, with Sweden being in first place with 56,4%, followed by Finland (43,1%), Latvia (41%), Denmark (37,2%) and Austria (33,6%), while in southern Europe this percentage is lowest, with Netherlands (8,8%), Malta (8,5%) and Luxembourg (7%) in the bottom positions.

1.2 Origins and development of pv energy

The beginnings of photovoltaic solar energy go back to the year 1839, when the French physicist Alexandre Edmond Becquerel, who was only 19 years old, verified that the current rose in one of the platinum electrodes of the electrolytic cell he was experiencing with when said electrode was exposed to the sun.

The next milestone in the development of photovoltaic use of solar energy occurred in 1873 when the English electrical engineer Willoughby Smith discovered the photovoltaic effect in solids, specifically in selenium.

Just 4 years later, in 1877, William Grylls, professor of natural philosophy at King College (London) and his student Richard Evans developed the first selenium photovoltaic cell.

Although the efficiency that could be obtained was tremendously low, thus ruling out any practical application, it did make it clear that it was possible to generate an electric current through a solid if solar radiation impinged on it. This concept was the germ that gave rise to the subsequent development of photovoltaic panels and the large-scale use of photovoltaic solar energy some decades later.

The first time that a photovoltaic cell was achieved to a minimally acceptable efficiency was in 1883, when Charles Fritts created a solar cell based on selenium and a thin layer of gold as a cover. Specifically, the efficiency achieved was 1%, still too low to be used in electricity generation, also taking into account its high cost.

Although the origin of the silicon photovoltaic cell dates back to 1940, when Russell Ohl developed the first cell of this type (and which he attempted in 1946), its true impetus, which gave rise to modern silicon cells and the possibility of a practical application of the photovoltaic effect in the generation of electricity, occurred in 1954, when Gerald Pearson of Bell Laboratories, while experimenting with semiconductors, found by chance that silicon increased its sensitivity to light by carrying certain impurities, manufacturing in this way a first silicon cell with greater efficiency than any of the previous selenium-based cells. Subsequently, Daryl Chapin and Calvin Fuller, physicists who also worked in the Bell Labs, perfected this invention and produced silicon solar cells capable of providing enough electrical energy to achieve practical applications for them.

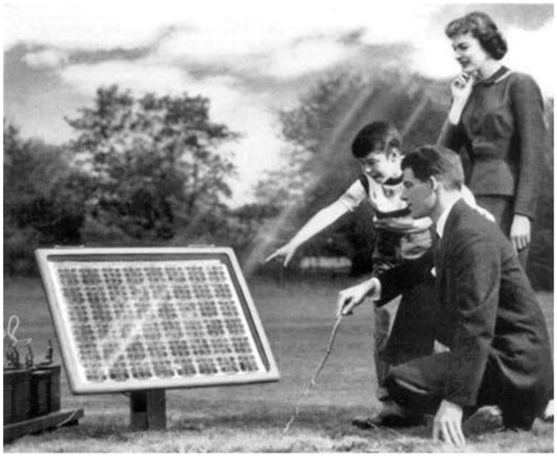


Figure 7. Advertising of the silicon photovoltaic cell manufactured by Bell Laboratories. Source: IB Solar

And why did silicon-based cells turn out to be so much more efficient than selenium-based ones? The answer to this is found in the following graph, which shows the relationship between the absorption coefficient of the material and the wavelength of the incident radiation. It shows how, for practically the entire spectrum of light, the absorption coefficient is higher in the case of silicon compared to selenium (and it is always so in the case of amorphous silicon). On the other hand, it is interesting to comment that, despite the fact that germanium has the best absorption coefficient for all wavelengths, photovoltaic cells are not manufactured with this material because they turn out to have a much higher cost.

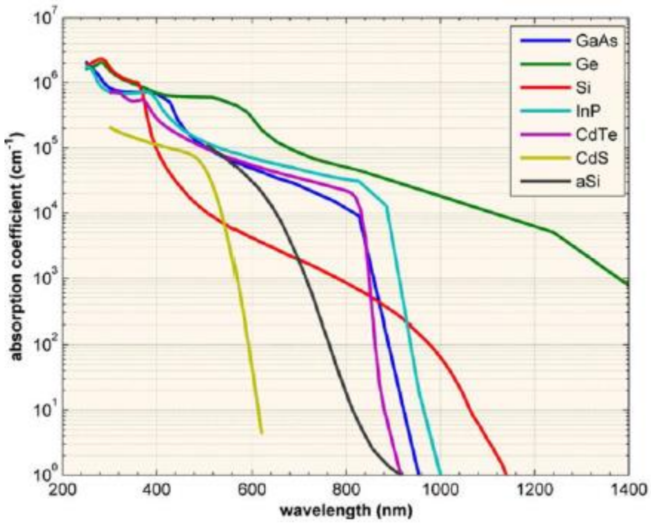
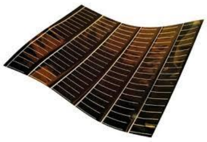
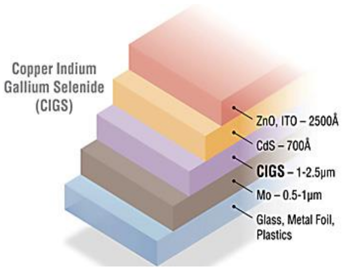
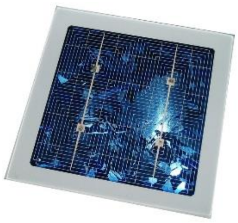
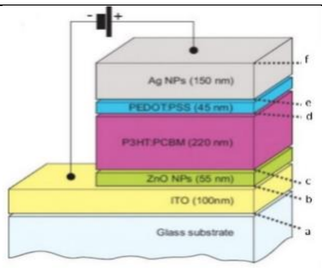
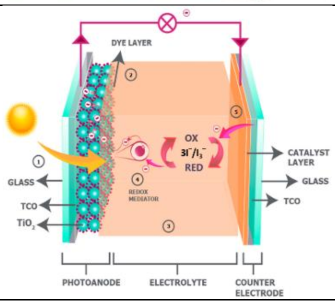


Figure 8. Relation between the absorption coefficient (α) and the wavelength of radiation. Source: PV Education

All this development has led to the availability of a wide range of photovoltaic cell typologies today, with already notable efficiencies (an average of around 15%), while research continues on new and better configurations that allow to increase these efficiencies, extend their useful life and have a lower impact on the environment. In this sense, the following table is intended to clearly and schematically represent the cell technologies existing today and their specific characteristics:

Generation	PV Cell	Picture	Efficiency (%)	Characteristics
I (Wafer based)	Monocrystalline Silicon		14-18 (some models can reach around 22%)	• Semiconductor grade silicon • Made by cutting a block of silicon that has been grown from a single crystal through a process called "*Czochralski process*". • Oldest technology • Not good performance at high temperatures, but occupies significantly less volume to generate the same amount of power. • More expensive compared to thin film. • Represent (nowadays) the major part of solar cell production worldwide (see page 21 from Fraunhofer Institute´s photovoltaics report 2019)
	Polycrystalline Silicon		12-15	• Photovoltaic grade silicon • Made by coupling a certain number of different crystals in a single cell through a more economical process than that one of monocrystalline silicon. • Has neither got good performance at high temperatures. • More expensive compared to thin film. • Most economical choice
II (Thin film)	Amorphous Silicon (a-Si)		5-8	• No definite arrangement of atoms/structure • Good performance at both low and high temperatures

				• Has one of the lowest efficiencies but is also one of the most environmentally friendly pv technologies. • Requires less installation time but much larger space (for the same energy production) • Flexible
	Cadmium Telluride (CdTe)		9-11	• The only thin film technology with lower costs than crystalline silicon solar cells • Very toxic technology due to the Cd (heavy metal) • High optical absorption coefficient and chemical stability • Flexible
	Copper Indium Selenide (CIS) and Copper Indium Gallium Selenide (CIGS)		11-17 (More than 20 in labs)	• High optical absorption coefficient (very thin film (required) • Good efficiency • Flexible
	Nano crystal based		8-12	• Known as Quantum Dots (QD), these are solar cells over which a coating of nanocrystals (typically based on Si, CdTe or CIGS) is placed • Excellent thermal stability and offer multitude of possible designs. • Require less installation time but larger space than an equivalent Si cell installation
III	Polymer based		≈ 10 (up to 17)	• Very flexible due to the presence of polymer substrate, reason why it has a wide range of product designs. • Not good performance at high temperatures • Low installation time
	Dye sensitized		10-12	• Consists of four components: semiconductor electrode, a dye sensitizer, a redox mediator and a counter electrode. • Not good performance at high temperatures • Highly flexible, transparent and low cost • Poor optical absorption of sensitizers

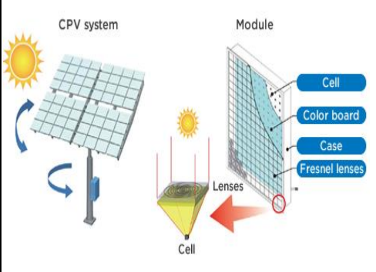
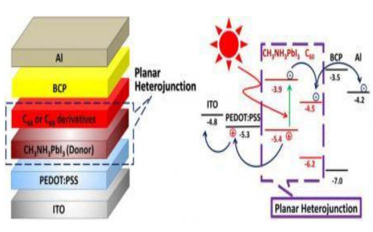
	Concentrated		≈ 40	• It´s principle is based on optics. • Produces a large amount of heat energy, which is further driven by a heat engine. • Classified into low, medium and high concentrated solar cells. • High efficiencies, absence of moving parts and speedy response time
	Perovskite		≈ 24	• Excellent thermal stability • Cheap to produce and simple to manufacture. • High potential of achieving higher efficiencies. • Current issues are stability and durability.

Table 1. Characteristics of the different technologies of photovoltaic panels

It is also interesting to analyse the evolution in the performance of different photovoltaic technologies in the last 45 years. The graph below illustrates this progress, although it should be noted that these percentages of efficiency refer to the cells (not to the panels, which always have somewhat less efficiency) and under laboratory test conditions.

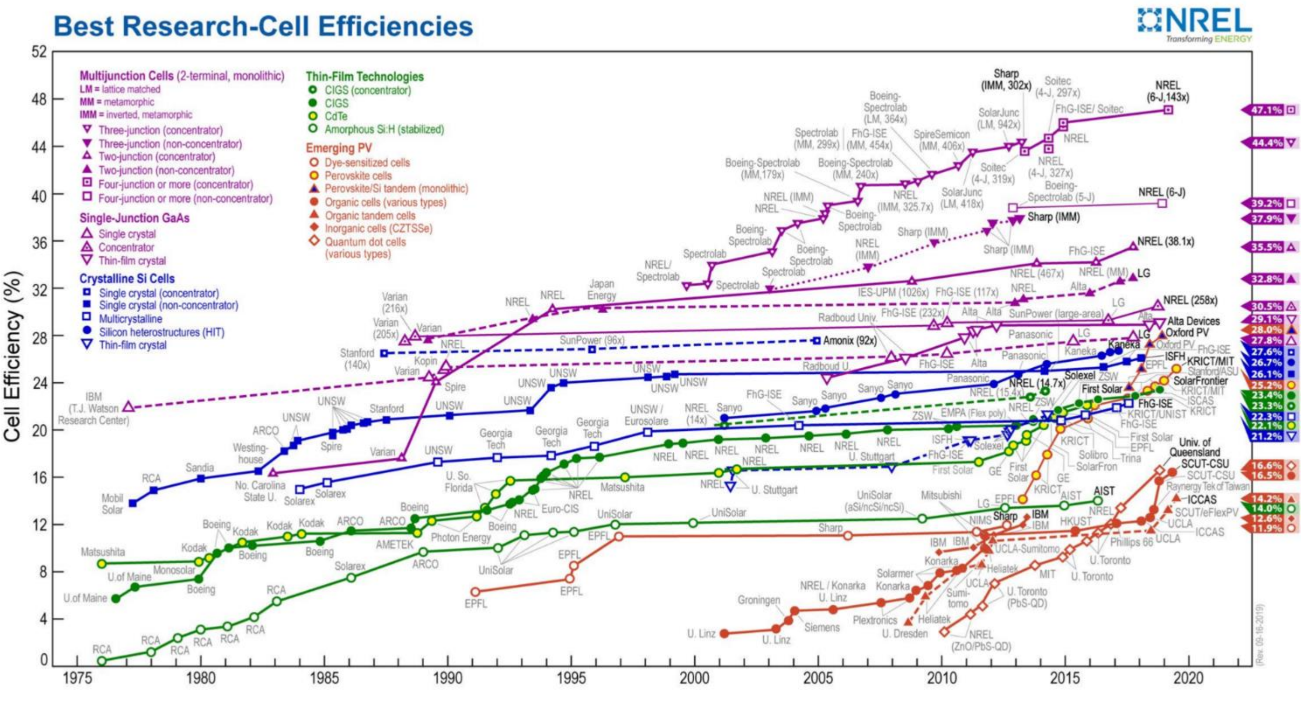


Figure 9. Efficiency records in different solar cell technologies. Source: NREL

1.3 Evolution in implantation, current situation and perspectives of PVE

It is possible to visualize in a simple and direct way the growth that this energy source has experienced in the world in the last decade by observing the graph shown below:

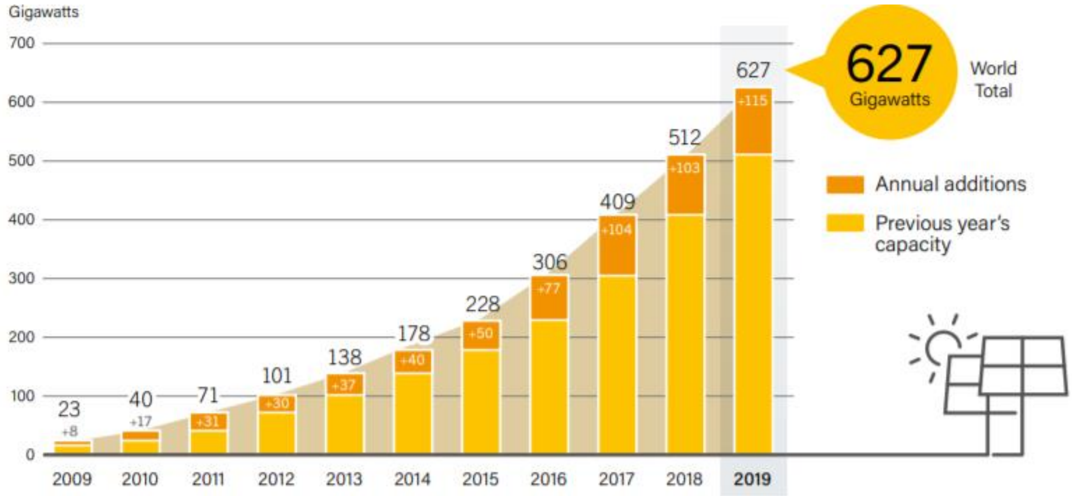


Figure 10. Solar PV global capacity and annual additions (2009-2019). Source: Ren21

On it, the clear upward trend in the development and implementation of photovoltaic energy worldwide can be seen, since it has been growing for several years, especially in the last five.

Obviously, not all countries increase their photovoltaic potential in the same proportions. Those countries with greater economic capacity, greater extension and with more areas of high solar irradiance have a much greater capacity to increase their photovoltaic park.

In this way, the graph shown above can be represented as shown below, which shows the participation of the main countries in the growth of photovoltaic energy:

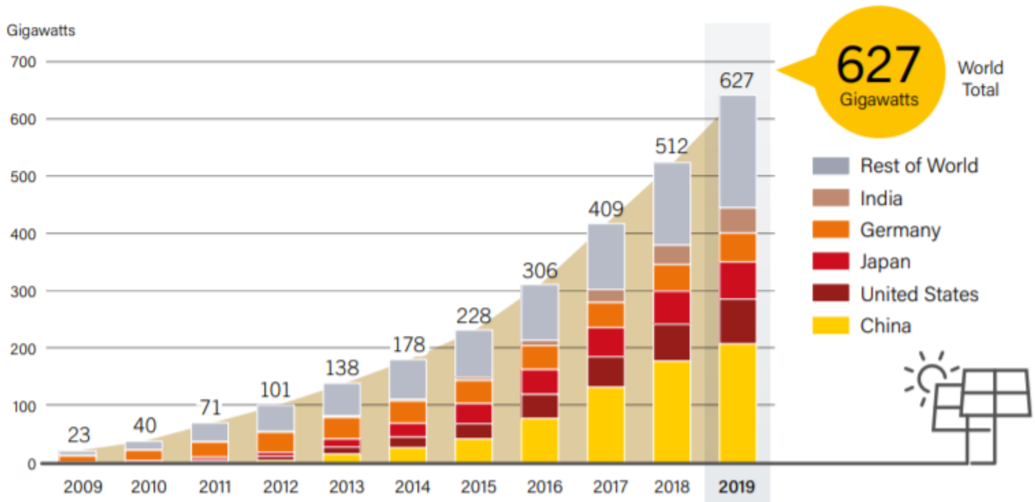


Figure 11. Solar PV global capacity by country and region (2009-2019). Source: Ren21

On it, the clear dominance of China over the rest of the countries is observed, with the USA and Japan in second and third place, respectively. These are the countries where the biggest PV fields projects are being developed, together with India, which will soon overtake Germany if its capacity continues to increase at the rate of last years.

On the other hand, it is interesting to comment how, from the perspective of the installed system capacities per inhabitant, Australia, Germany, Japan and Belgium are the countries that lead this ranking.

In the European case, Germany is the leading country in electricity generation from photovoltaic installations, followed by Italy and UK.

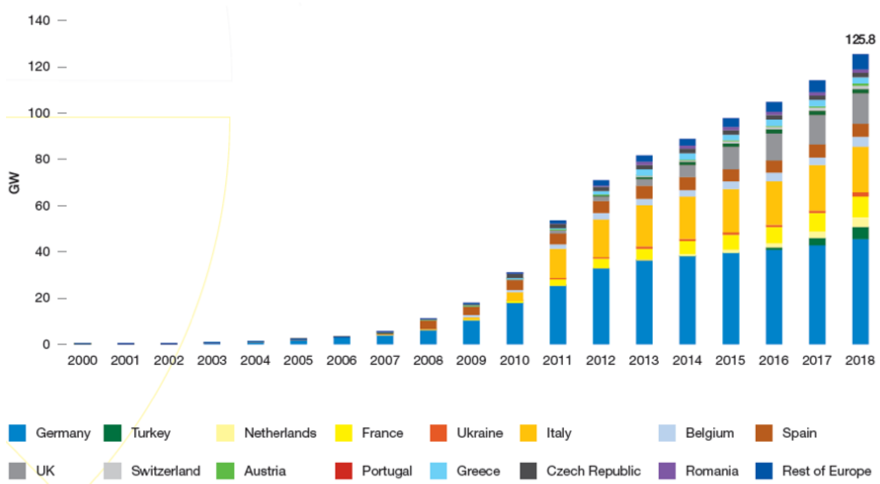


Figure 12. European total solar PV installed capacity (2000-2018). Source: SolarPower Europe

Lastly, in the case of Spain, the birth of photovoltaic energy dates back to 1984, when Iberdrola installed the first grid-connected photovoltaic plant in San Agustín de Guadalix. This 100 kWp connection was the only one the peninsula had for almost 10 years. From this moment on, in successive years photovoltaic energy grew timidly and slowly in Spain until 2007, and especially in the following year 2008, there was a very notable growth in installed photovoltaic power. However, and despite a rebound in 2010, from 2009 to 2018 the growth of this energy source was again almost non-existent, mainly due to the change in the incentive system and the arrival of the economic crisis. Then, last year 2019, Spain once again provided a great boost to photovoltaics by carrying out a large-scale photovoltaic power installation. All this can be seen in the graph shown below:

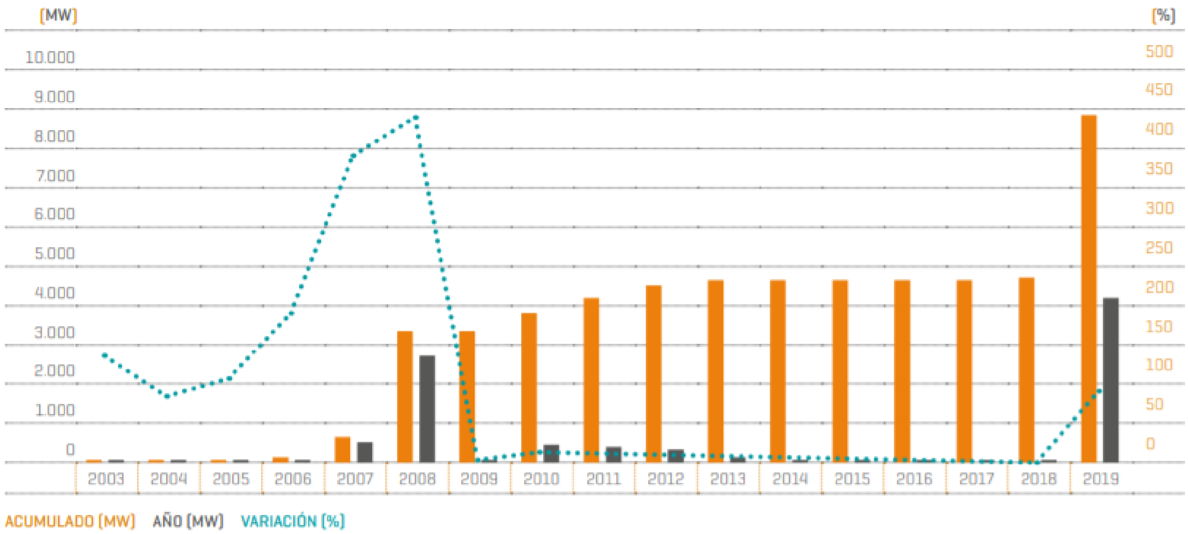


Figure 13. Installed and accumulated photovoltaic solar power in Spain (2003-2019). Source: REE

The distribution of installed (accumulated) photovoltaic power by autonomy is reflected in the following graph. It is possible to visualize how Andalusia (with 20%), Castilla La Mancha (with 19.6%) and Extremadura (with 14%) are the autonomous regions that contribute the most in terms of installed power:

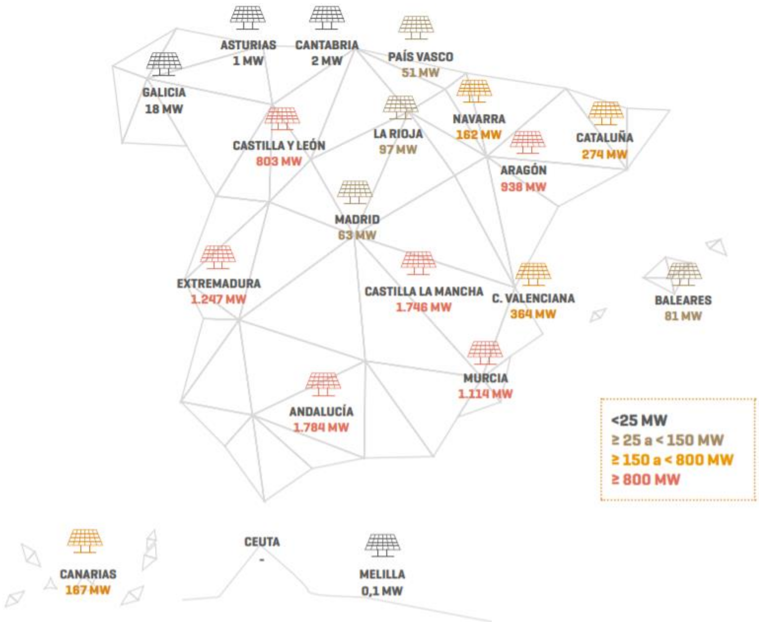


Figure 14. Installed and accumulated photovoltaic solar power in Spain, per autonomous region (2003-2019). Source: REE

On the other hand, the future of renewable energies is promising: renewables are expected to generate 50% of electricity worldwide by 2050. Thanks to the progressive reduction in the price of photovoltaic panels, the increase in the performance achieved by the different photovoltaic technologies and other factors mentioned above, such as the ecological awareness of society and the policies aimed at promoting the development and implementation of renewable energies to the detriment of the most polluting sources, the weight of photovoltaic energy has experienced notable growth in recent years (as can be seen in figure 4 of this document), making it one of the main renewable sources currently and one of the sources with the best future prospects (if not the most).

This predicted growth in the weight of photovoltaic energy in the energy mix in the coming years can be seen in the following graph, which shows the expected participation in electricity generation of the different technologies (renewable and non-renewable) until said year 2050:

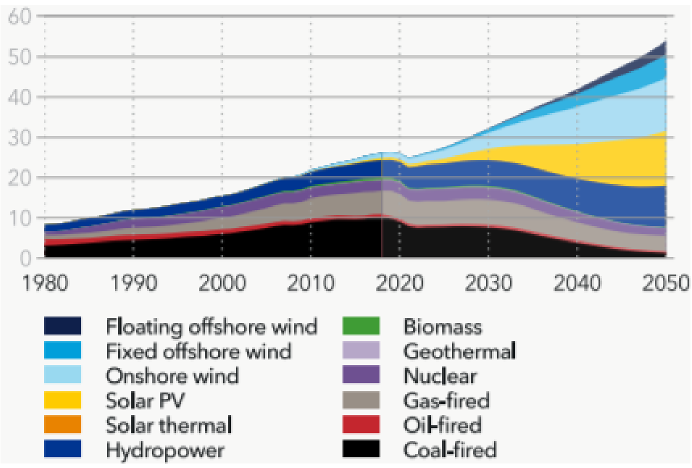


Figure 15. World electricity generation by power station type (in PWh/year). Source: DNG-GL

1.4 Applications of PV energy

There are many ways in which photovoltaic solar energy is used for electricity production, such as photovoltaic parks, the installation of panels on building roofs, the operation of electric vehicles (cars, small boats, etc.), charging of batteries for phones or calculators or powering satellites.

Table 2. Several applications of PV energy. Source: Own

Among all of them, in this document, it is intended to develop a project based on an application known as “photovoltaic solar pumping”, which, as its name indicates, consists of the use of photovoltaic panels to generate the necessary current for a pumping system to carry out the irrigation of a certain growing area or allow the supply of water for human consumption, livestock or industrial facilities.

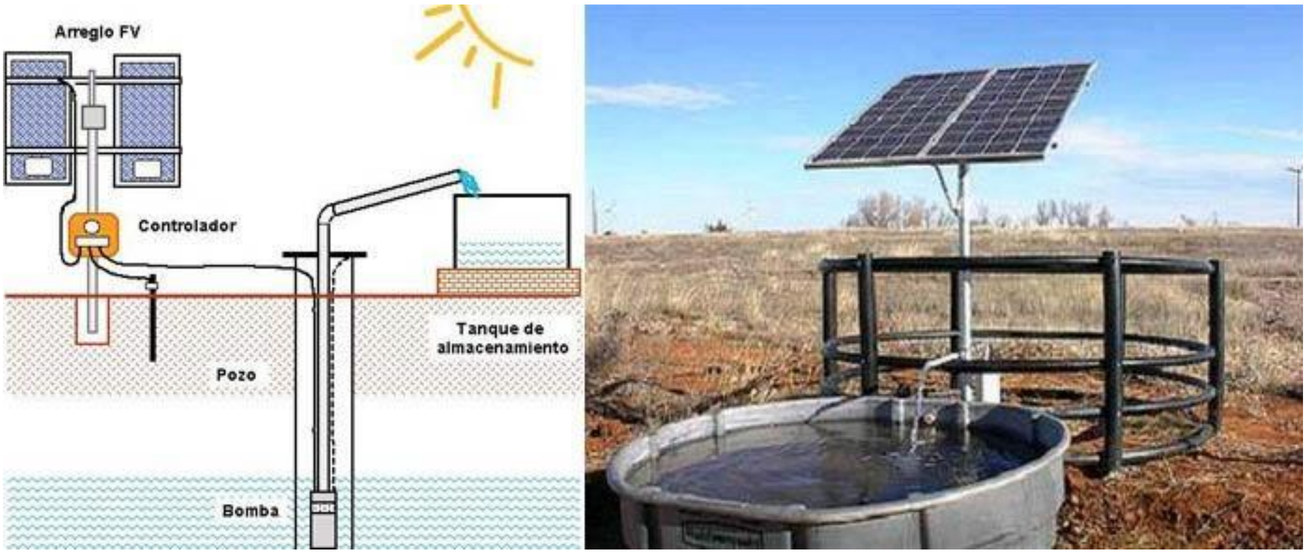


Figure 16. Example of a photovoltaic solar pumping system. Source: AutoSolar

This electrical supply system is especially necessary for those growing areas that, due to their geographical location, cannot have access to the electricity grid or that access is too precarious. However, its use is becoming more and more common also among those users who are not in the circumstances outlined above, since although it requires a large initial investment, it offers numerous advantages compared to other energy supply options. In this sense, the reduction in the cost of photovoltaic panels, at the same time as the progressive increase in their performance and the rise in the price of fossil fuels, are promoting and making their implementation more attractive and profitable. Moreover, the combination of micro-hydropower systems (with the use of PATs, what will be discussed later) and solar/wind systems provides an energy improvement in these water systems from a more sustainable point of view.

This type of irrigation system continues to be perfected and extended today, which is fundamental in a country like Spain that needs to use its water resources in a particularly responsible and sustainable way, since it has an important agricultural sector, which consumes a relevant part of these resources (according to the European Environment Agency, between 50-60% of water consumption is used for agriculture, whereas this percentage rises to around 70% percent in the case of Spain), at the same time that due to its geographical location, it does not have abundant rainfall in most of its territory.

A very attractive aspect of these systems in countries like Spain is that those months in which the irradiation is greater and, therefore, it is possible to obtain photovoltaic energy on a larger scale, are in turn those in which the temperatures are higher and therefore the demand for water increases, both for human consumption and for crops. In this way, in those critical months these systems are especially useful, since their characteristics are used to the maximum. In addition, they are durable, reliable and versatile systems.

As for the types of solar pumping, there are three existing ones:

- **Pumping to a tank or gravitational solar irrigation**: In this case, the water (or part of it) is pumped to a tank or elevated tank in order to be able to use this volume of water at a later time to irrigate the crops. In this way, the function of the tank is to serve as a battery, since it does not only allow to deliver the required flow and pressure at the different points of the irrigation system without the need to start the pumping system thanks to the potential energy, if not that in addition a system of pumps working as turbines (PAT) could be used and thus carry out a certain energy recovery.

- **Direct solar irrigation**: The direct solar irrigation system consists of the direct pumping of water to the consumption points, that is, without the water flow being previously driven to a water tank. Therefore, this system, which is the same as the previous one but with the absence of the water tank, can only be used during sunny hours, in addition to having a lower performance on days in which the irradiation is lower, although these tend to coincide with the lower demand for water from crops.

- **Irrigation system connected to the network**: It is a hybrid system, since it allows obtaining energy from both the electric generator and the electric grid if necessary. This, in turn, allows that if there is a surplus of energy, it can be injected into the network and, therefore, obtain an economic benefit.

1.5 Components of PV systems

Each photovoltaic installation has its own particular characteristics depending on the needs it must satisfy, the location in which it is located, the budget available and current legislation. However, all of them have a series of common elements; these are the following:

1.5.1 General components of PV systems

1.5.1.1 PV module

The photovoltaic module is the essential and fundamental component of any photovoltaic installation, since it is the part that is responsible for the necessary conversion of solar energy to electrical energy. These elements are associated in series and in parallel based on the electrical needs of the system, forming, together with the wiring, connection boxes, diodes and corresponding support structures, what is known as a photovoltaic generator.

Figure 17. PV generator integrated by the interconnection of pv modules. Source: Portal Energía

In turn, the photovoltaic modules or panels are made up of a series-parallel association of solar cells, as well as several layers, each of one has its specific function.

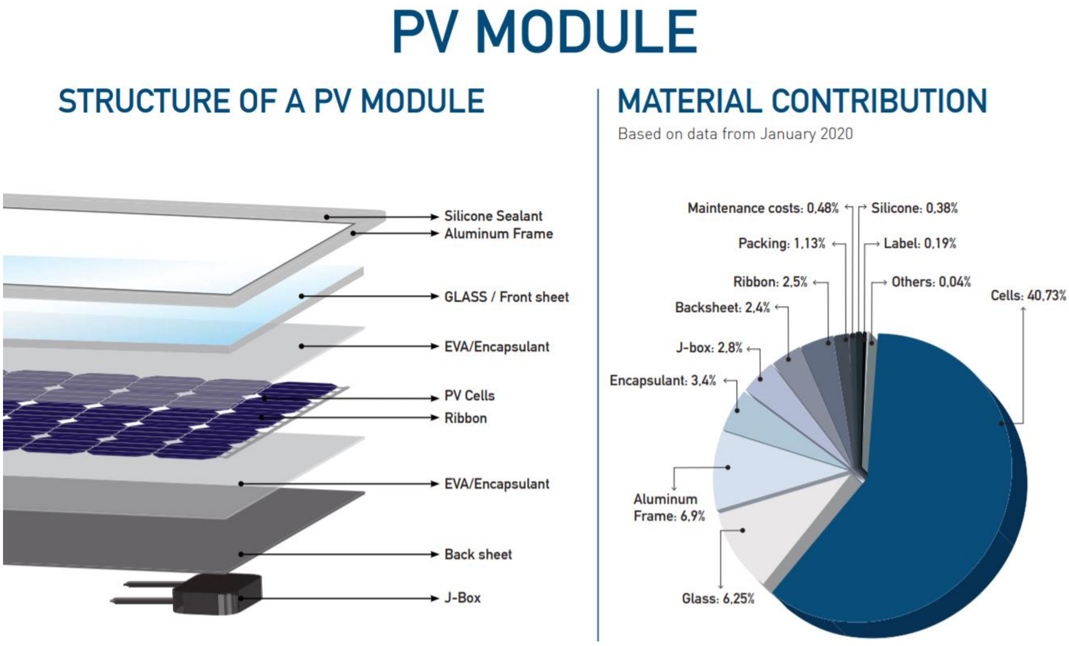


Figure 18. Configuration and components of a PV module. Source: Ecoprogetti

The current and voltage obtained by a module depend on the number of cells in series (N_S) and branches of cells in parallel (N_p) interconnected in it. In the case of the photovoltaic generator as a whole, equivalently, the current and voltage obtained depend on the number of modules in series ($N_{S,G}$) and branches of modules in parallel ($N_{P,G}$) interconnected in the generator.

The manufacturer of the modules provides in its catalogues the values of these parameters measured under standard test conditions (STC), which are the following:

- Irradiance of 1000 W/m^2
- Cell temperature of 25 °C
- Air spectral mass of 1.5
- Perpendicular incidence of solar radiation on the catchment surface

However, the level of incident radiation, as well as the working temperature of the cells (depending on the ambient temperature and irradiance), have a direct effect on these electrical parameters and therefore the energy that can be obtained from the panels and their performance, as can be seen. in the following graphs:

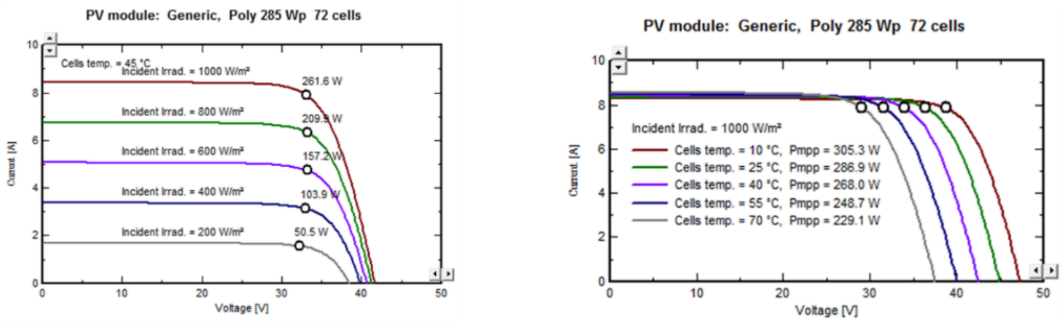


Fig. 1. Current vs Voltage graph with varying (a) Incident Irradiation (b) Temperature

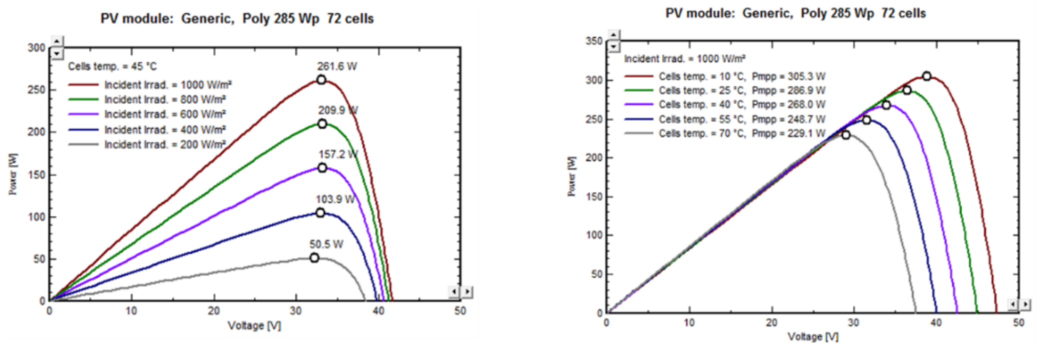


Fig. 2. Power vs Voltage graph with varying (c) Incident Irradiation (d) Temperature

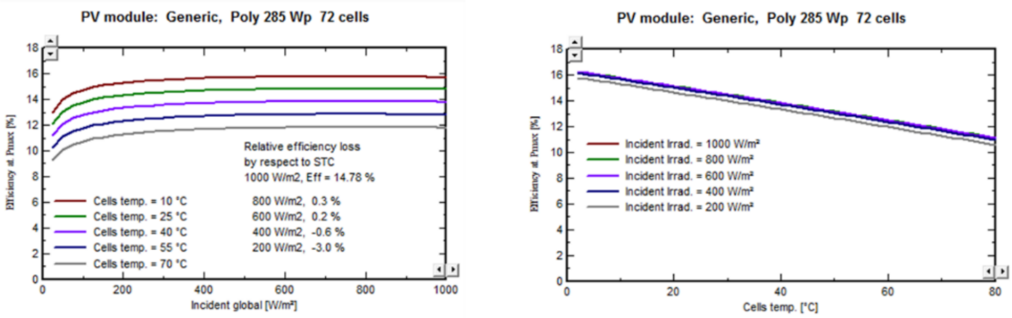


Fig. 3. (e) Efficiency vs global solar (f) Efficiency vs cells temperature

Figure 19. Effect of incident irradiation and temperature on several parameters

Table 1 of this document shows the characteristics of the different photovoltaic panel technologies. These systems provide direct current.

1.5.1.2 Structure/Solar tracking system

The support structure is a metallic auxiliary element, which can be made of galvanized steel, aluminium or stainless steel, whose function is to provide firmness and stability to the photovoltaic module. Its design depends on the weight that the panels must support, the intensity of the wind that they must support and the type of anchoring used.

In turn, these structures can be equipped with a solar tracking system, whose function is to move and orient the surface of the photovoltaic panels towards the sun to increase the energy received and, thus, allow a greater conversion of the same. in electrical energy. These monitoring systems can work by means of photosensitive sensors or a computer program, and their actuation can be achieved by means of an electric motor or by means of a hydraulic system (in the case of higher weights). The following table illustrates the types of existing trackers, as well as the increase in solar collection that they allow to achieve:

Solar Tracking System	Picture	Characteristics
Azimuthal		• The movement can be performed on a rotating crown or on a pillar. • The panels have a fixed elevation angle. • Simple and robust configuration • Annual collection between 121-126% of the maximum value without monitoring
Horizontal		• The rotating horizontal axis is north-south oriented. • Most effective in summer and in low latitudes • Robust structure and few shadows between panels • Annual collection of around 115% of the maximum value without monitoring
Polar axis		• The north-south axis has an angle of inclination equal to the local latitude, and the speed of rotation is equal to the rotation of the earth, although in the opposite direction • Annual collection of around 125% of the maximum value without monitoring
Two axes		• By allowing a very precise orientation of the panels, it is possible to keep their surface perpendicular to solar radiation. • An annual capture of between 128-132% of the maximum value is reached without monitoring, but it is the most complex and expensive system both in assembly and maintenance

Table 3. Configurations of solar tracking system. Source: Ibáñez (s.a.); Sánchez (s.a.)

1.5.1.3 Solar inverter

The inverter is the component which function is to carry out the conversion of the direct current obtained from the photovoltaic generator (or extracted from the batteries) into alternating current (230 or 400 V).

Figure 20. A commercial inverter. Source: Movergy

Investors can be classified:

- **According to the number of phases of AC voltage that they can generate at their output**:
  - Monophasic: A single voltage phase is generated. These inverters are used in low power installations.
  - Triphasic: As the name suggests, these inverters generate a three-phase voltage. In this case, these are inverters which main application is in medium and high power installations.

- **Depending on the type of connection**:
  - Off grid or Stand alone: These pv systems are not connected to the electricity grid and therefore require battery storage with enough capacity to guarantee the necessary electricity supply even in the most unfavourable months of the year, so that it allows to meet the requirements of the installation that must be fed. Off-grid systems are much more expensive than on-grid systems due to the high costs of the batteries (which have to be replaced every 10 years on average) and off-grid inverters. That is why these configuration is mainly used in remote areas that are far from the electricity grid. Apart from this, at certain times of the year the batteries are at high levels of discharge (or what is the same, low level of charge) and this coincides with days of low radiation, so it is difficult to ensure the maintenance of the energy needs just by using these storage systems without entailing an oversizing of the installation and unaffordable costs. Therefore, in these systems it is common to have a backup generator. On the other hand, thanks to the reduction of the cost that batteries are experiencing these last years (and will continue in the future) these systems are becoming more popular even in cities and towns.

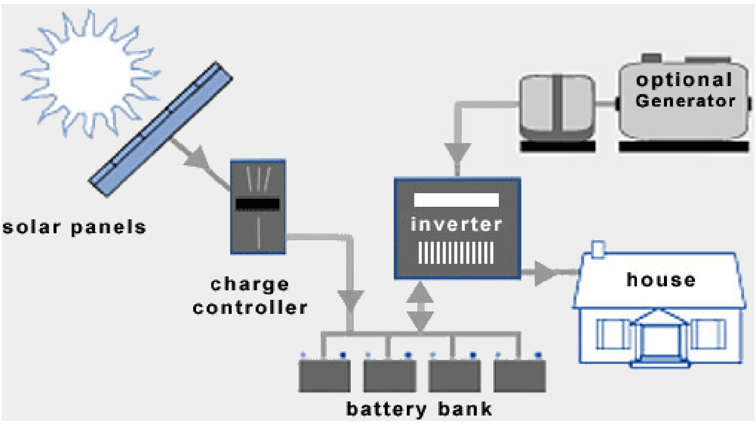


Figure 21. Scheme of an off-grid solar system. Source: Researchgate

- On grid or Grid tie: This configuration is by far the most common and widely used worldwide both for private homes and factories or any other type of application. Even though it is possible to add batteries at a larger stage if needed, in principle these systems do not need to use these components. Furthermore, in this case inverters are connected to the public electricity grid, therefore any excess solar power generated can be injected into the electricity grid and obtain additional incomes. On the other side, it is possible to obtain electricity from the grid if needed, so it can be also conceived as a battery but without the need for maintenance or replacements, and with much better efficiency rates. In the grid connection inverters, the maximum power point tracker (MPPT) and the DC / AC converter are included, and in the case of autonomous inverters, the battery charge and discharge regulator can also be found.

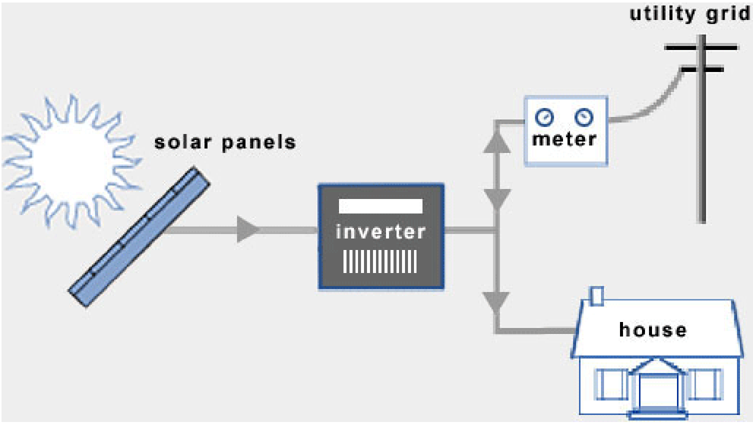


Figure 22. Scheme of an on-grid solar system. Source: Researchgate

- Hybrids: Hybrid solar systems are less expensive than off-grid solar systems, since they don´t need a backup generator. They combine the best from off-grid and on-grid configurations.

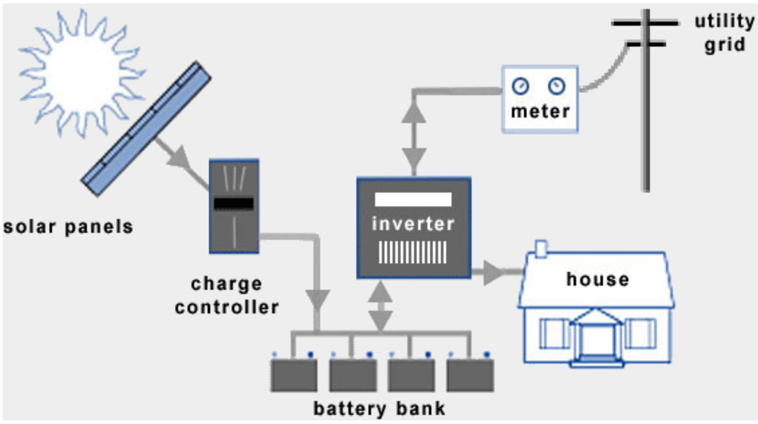


Figure 23. Scheme of a hybrid solar system. Source: Researchgate

- **Depending on the configuration of the photovoltaic system**:
  - Central investors: The different strings that make up the photovoltaic field are connected in parallel to a single converter, which has a power approximately equal to the photovoltaic system that is connected to it. These are equipment used in large facilities, such as industrial estates or large photovoltaic parks, with more than 100 kWp. Their cost per kWh is low, they are robust and have high efficiencies, but present a notable decrease in said performance due to incompatibilities between the modules, as well as because of their partial shading, and their

failures affect the entire installation. In addition, the sections of the wiring are large as a result of the high currents that must flow. Most of these inverters are triphasic.

- Multi-string inverters: It is a middle term between central and string inverters. These are inverters to which different MPPTs are connected, one for each string. This allows optimizing the working point of each string. String inverters require a minimum number of panels per string, which varies depending on the business model. It is possible to connect a different type of modules, and the production problems of a module due to shading or faults affect the entire string, but not the installation as a whole.
- String inverters: These are small power inverters, so that each string of the photovoltaic installation is connected to one of these inverters. This configuration allows reducing the cost of DC wiring (smaller section) and the associated safety problems, since they need to carry a much lower current. In addition, they allow a great modularity, so that each string can have a different number or type of panels, and problems due to partial shading or breakdowns affect only said string, and not the entire installation as in the case of the central inverter. This type of inverter is used mainly in small installations in buildings.
- Micro-investors: Finally, this type of inverter, used in low-power installations, is smaller and is integrated into the photovoltaic module. They are highly modular and easy to install. In addition, as they are installed individually, that is, one for each panel, this allows to optimize their working point and achieve that it works at its maximum power point, thus presenting high efficiencies. A great advantage that they present is that any production problem affects only the module in which the inverter is installed. On the contrary, they present the highest cost per kWh of all possible configurations.

- **According to the type of wave**:
  - Square wave: It is the simplest and most economical configuration, but also the one with the lowest efficiencies. The signal consists of a step. These inverters are typical of low-medium power applications.
  - Modified wave: They have a lower harmonic content than square wave ones, and an electronics that is more complex, giving rise to a waveform that allows to achieve better performances. On the other hand, they are more expensive, but have the best relation cost-quality.
  - Pure sine wave: The electronics of this type of inverter is the most complex and allows efficiencies that can exceed 90%. Naturally, this configuration in turn has the highest cost of the three possible. Only some induction motors and control apparatus or medical equipment require a pure sine waveform. Furthermore, in case of high power installations, low distortion waves are needed, so these inverters are used frequently.

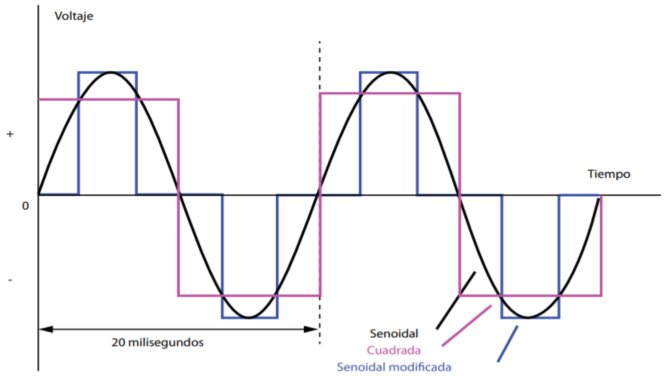


Figure 24. Square, modified and pure sine waves. Source: Editores-srl

The main electrical parameters of these components are the following:

- **Nominal voltage** (V). Voltage that needs to be applied to the input terminals of the inverter.
- **Nominal power** (VA). Power supplied by the inverter continuously.
- **Active power** (W). Real power supplied by the inverter taking into account the phase shift between voltage and current.
- **Overload capacity**. Inverter ability to supply a power higher than the nominal and time that can maintain this situation.
- **Power factor**. Ratio between active power and apparent power at inverter output. In the ideal case, where there are no losses due to reactive current, its maximum value is 1, that is, these conditions are unbeatable for the inverter power supply.
- **Efficiency or performance**. Relationship between the output and input powers of the investor
- **Self-consumption**. It is the power, as a percentage, consumed by the inverter compared to the rated output power.
- **Harmonics**. An ideal harmonic is a wave frequency multiple of the fundamental frequency. Take into account that, only at fundamental frequency, active power is produced.
- **Harmonic distortion**. Total Harmonic Distortion or THD (Total Harmonic Distortion) is the parameter that indicates the percentage of harmonic content of the inverter output voltage waveform.
- **Current ripple**. Small variation that occurs on the value of the alternating current wave when rectifying or inverting a signal from DC to AC

As established in Section 5 of the "*Documento Básico HE Ahorro de Energía*", the inverters must comply with:

- The community directives for "*Seguridad Eléctrica en Baja Tensión y Compatibilidad Electromagnética*"
- The basic characteristics of the investors will be the following:
    - principle of operation: current source
    - auto-switched
    - automatic monitoring of the generator maximum power point
    - will not work in island or isolated mode (it must have an automatic grid disconnection system in case the inverter detects that it is operating in island mode)
- Its power will be at least 80% of the generator's real peak power photovoltaic.
- It must be protected against AC short circuits, grid voltage below 80% of nominal voltage or above 110%, grid frequency out of range (49-51 Hz), overvoltages (use of varistors) and have galvanic isolation between the photovoltaic generator and the grid (use of transformer) if the installation has a nominal power equal or lower than 100 kW, according to the "*Real Decreto 1699/2011*", in the case of being grid connection inverters. Since in this project the nominal power is higher, it is not mandatory to install a transformer.

1.5.1.4 Cabling

The cabling of a photovoltaic installation, responsible for the transport of electrical current, is divided into DC cabling and AC cabling, depending on the segment in which it is located. Its design complies with the calculation regulations and various security measures. In this sense, the calculation of the sections of the different sections of the installation cabling will be different, and will be based on specific standards, depending on whether they are conductors through which DC or AC circulates. These calculation procedures, as well as the standards that must be met (both dimensioning and safety) are indicated in chapter 3 of this document.

1.5.1.5 Channellings

1.5.1.5.1 Protection tubes

Protection tubes are used to protect cables within building materials or the terrain they run through. As happens with cabling, it is necessary to differentiate the protection tubes corresponding to DC cables and AC cables.

1.5.1.5.2 Wire mesh cable tray

In this case, it is intended to choose the commercial model of wire mesh cable tray responsible for conducting the section of string cabling (cabling between modules to the output of the string they form when connected in series). The reasons why this type of tray is chosen are the following:

-It allows greater air circulation between the conductors that it houses and therefore greater ventilation, which in turn allows reducing the operating temperature of the wiring compared to conventional or perforated trays

-Installation of this type of tray is simpler, since the weight is lower, which in turn results in less material required for its preparation

1.5.1.5.3 Ditches

The cabling between the strings and the junction boxes, between junction boxes and inverters, and from inverters to the current injection points must be buried in the ground. Therefore, and based on what is stated in the REBT, specifically the ITC-BT-21, section "Installation of insulated cables", it is established that the conductors directly buried should be located in a trench built for such use, so that the cable is at a minimum depth of 60 cm on the sidewalk (or 80 cm in road) as well as that "the bed of the trench that will receive the cable will be smooth and will be free of sharp edges, edges, stones, etc. ... A layer of mine sand will be placed on it. or washed river, with a minimum thickness of 0.05 m, on which the cable will be placed. Above the cable will be another layer of sand or screened earth about 0.10 m thick. Both layers will cover the total width of the trench, which will be enough to maintain 0.05 m between the cables and the side walls. "

1.5.1.6 DC protections

As they belong to the DC zone, these devices protect the section between the photovoltaic generator and the inverters.

1.5.1.6.1 Junction box

Two of the three DC protection devices are integrated into the DC junction box. Therefore, the junction box fulfils a double function:

- On the one hand, it allows grouping the set of lines that come from the output of the strings that make up the photovoltaic generator (or, as in this case, a part of them). This is achieved thanks to the presence of two main elements:

    - Flat strips of steel: These are rigid rectangular metal elements, generally made of copper (although they can be made of aluminium or some alloy of this material) which function is to allow the connection of the wiring from the strings in the connection panel. Therefore, they must endure the sum of the currents contributed by each of these strings.

  - Cable glands: These are devices designed to secure the end of a cable to the equipment to which it is connected (in this case, the junction box) by appropriate means, in such a way as to ensure a hermetically sealed joint that prevents the entry of water or dust inside said equipment.

- On the other hand, it has the function of housing the fuses and surge arresters, as well as the string cut-off switches.

1.5.1.6.1.1 Protection against overcurrents and short circuits

As established by the UNE-HD 60364-7-712 standard, “the protection devices against overcurrents on the direct current side will be either gPV fuses (standard designation that refers to the fuses commonly used in PhotoVoltaic installations, and which action is usually faster than that of general purpose fuses gG) […], or devices in accordance with the UNE-EN 60947-3 standard , or in accordance with standard UNE-EN 60898-2 ".

A fuse is an electrical device made of a conductive material, which has a relatively low melting point, and allows the connection of two sections of an electrical circuit. Its purpose is to interrupt the passage of electrical current between both parts in case of excessive current, since in this situation high temperatures are reached that melt the metal sheet that is housed inside a small porcelain container, opening the circuit and thus avoiding the partial or total deterioration of the elements of the electrical line located downstream. These single-use devices, which therefore must be replaced after having performed their function only once, are in turn housed inside a structural element known as a fuse holder.

A protection fuse is installed for each string of photovoltaic modules.

1.5.1.6.1.2 Protection against overvoltages. Surge arresters

In the photovoltaic generator, the appearance of overvoltages of greater or lesser importance can occur. Normally these overvoltages have their origin in atmospheric effects, either direct or indirect, as well as defects in the networks, as ITC-BT-23 indicates.

Although the commercial inverter model installed has its own internal protections against overvoltages, it is advisable to install these protection elements at the input of said equipment. With this, by slightly increasing the cost of the components purchased, the protection of the installation is increased and it is avoided that, in the first instance, said internal protections of the inverters are activated, which would be highly detrimental when stopping their operation.

Surge protection devices are responsible for absorbing excess voltage through a discharge to earth of very high currents. With this, it is possible to protect the equipment installed downstream of the protection device, which would otherwise have a voltage (much higher) than the nominal one, which could cause a partial failure of them (reduction of their performance) or directly its disablement.

There are different technologies that can act as limiters, being the varistors one of the most widely used. These are non-linear resistors whose value decreases with the voltage applied between their ends, so that when the voltage applied to them exceeds a certain limit, its value becomes very low, allowing a very high current to flow through them and discharging said current to ground.

1.5.1.6.2 Protection against direct and indirect contacts. DC side grounding

As mentioned previously, this is the third protection existing in the DC part, but unlike fuses and varistors, it is not housed in the junction box.

For its dimensioning and characterization, the ITC-BT-08, ITC-BT-18, ITC-BT-24, UNE-HD 60364-4-41:2018 and the UNE-HD 60364-5-54:2015 standards must be used. Precisely, the ITC-BT-18 defines the grounding or connection to earth as "the direct electrical connection, without fuses or any protection, of a part of the electrical circuit or a conductive part not belonging to it by means of an earth connection with an electrode or group of electrodes buried in the ground. By means of the installation of grounding, it should be ensured that in the set of facilities, buildings and nearby surface of the land there are no dangerous potential differences and that, at the same time, allow passage to ground from fault currents or discharge currents of atmospheric origin ".

The purpose of earthing an electrical installation is to avoid damage to people and equipment due to the appearance of fault currents.

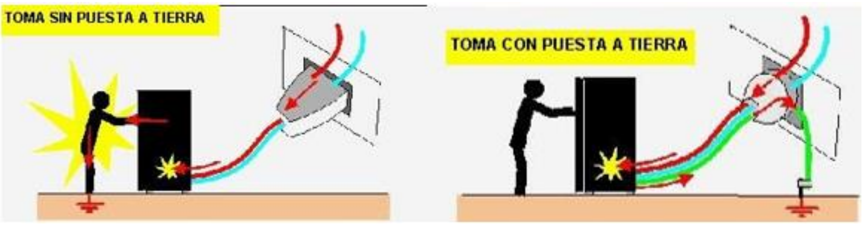


Figure 25. Comparison of current flow in case of existing and non-existing grounding of the masses. Source: Areatecnologia

The type of system that constitutes the projected photovoltaic installation, with all the active conductors isolated from ground, is called by the REBT as **IT system**. This implies that the PV generator will be grounded in floating mode. This configuration allows to achieve adequate levels of protection against direct and indirect contacts.

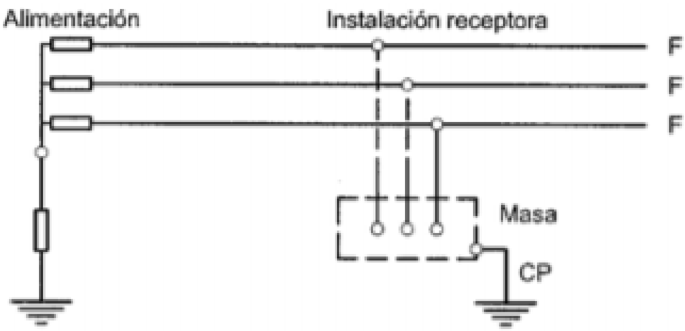


Figure 26. Grounding system according to IT scheme. Source: ITC-BT-08

1.5.1.7 AC Protection devices

These protections correspond to the part of the installation in which alternating current circulates.

1.5.1.7.1 Protection against overcurrents and short circuits

In the case of protection against this type of inconveniences for the AC zone, the most common is to use magnetothermal switches (on the DC side are the fuses), and in this project it has been decided to proceed in the same way. A type C magnetothermal switch will be placed, since it is the most used one in this type of installation.

1.5.1.7.2 Protection against direct and indirect contacts

To achieve the protection of people against direct and indirect contacts, the device known as differential switch is installed on the AC side. Its function is to detect residual differential currents and open the circuit. On the other hand, these components are dimensioned basing on the characteristics of the magnetothermal switches.

1.5.1.7.3 AC side grounding

In the AC part, a **TT scheme** is used, with the masses of the equipment protected by the same protection device joined to the same protection conductor, and the neutral grounded.

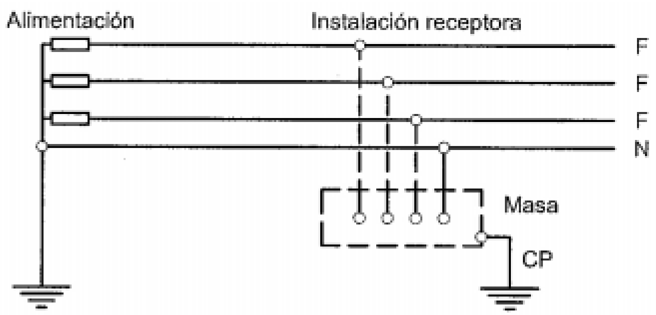


Figure 27. Grounding system according to TT scheme. Source: ITC-BT-08

1.1.1 Other components of PV systems

1.1.1.1 Batteries

The function of (secondary) batteries is clear: carry out a conversion of electrical energy into chemical energy for storage, thereby allowing a subsequent reconversion and its use in those periods of time in which, for various reasons, it is not possible to supply the electrical needs of the system by direct power supply through solar panels.

There are various technologies for energy storage in batteries. These are set out below:

- **Lead acid batteries**: They are the most abundant type of batteries on the market, in part because of their low cost and good performance, as well as their relatively long useful life. However, they have a low energy density and are highly polluting due to the presence of lead.
- **Nickel-cadmium batteries**: They have a higher energy density than the previous ones, as well as a higher resistance to overcharges and over-discharges and a longer useful life, but they are more expensive and there is less availability in the market.
- **Nickel-metal hydride batteries**: High energy density and lower environmental impact, but high self-discharge rate
- **Lithium ion batteries**: Very high energy density, little maintenance required and low self-discharge rate, although they are very expensive and they degrade quickly, which also worsens the fact that they present an explosion hazard due to the reaction between lithium and hydrogen.

Batteries must have a protection system against overloads due to excessively high currents from the photovoltaic generator, as well as against overdischarges, which normally consists of what is known as the charge regulator, and also against short circuits by means of fuses.

Furthermore, it is generally recommended that the nominal battery voltage be 12 V for PV systems with $P < 1.5$ kW, 24 V for 1.5 kW $< P < 5$ kW, and 48 V or 120 V for $P > 5$ kW. On the other hand, they must guarantee a maximum discharge depth of less than 80% in applications that do not require habitual deep discharges, and less than 60% in applications with habitual over-discharges, such as public lighting systems.

On the other hand, when this component is going to be selected, it must be verified that it has an appropriate nominal storage capacity and that it guarantees a sufficient useful life so that its acquisition is profitable.

1.1.1.2 Engine-pump

It is the system in charge of providing the necessary impulse to the required flow at the requested points of a hydraulic network. There are various types of pumps (volumetrics and turbopumps) and electric motors that drive them (squirrel cage rotor, wound rotor, synchronous, etc.). These pumps can work, in turn, with direct current or alternating current.

Figure 28. A commercial water pump. Source: Zozhi

1.1.1.3 Water tank

As indicated above, the water tank allows the supply of water in the different points of the cultivation system at any time without the need to use the pumping equipment, as well as some energy recovery in case of having the necessary equipment.

Figure 29. A water tank for cultivation. Source: Ilurco

1.1.1.4 Pipes

This is the part of the installation responsible for conducting the water flow to the irrigation points, whether it is drip, sprinkler or gravity irrigation. They are usually made of polyethylene or PVC. Although, as with many elements of any type of installation, the dimensioning of the pipes requires a rigorous and detailed calculation, this work is not going to delve into it since this part of the installation already exists and does not need to be dimensioned.

Chapter 2. Description of the case study

2.1 Description of the location area of the facilities

The land on which the irrigation network, the pumping systems and the ponds are located, as well as on which it is intended to project and locate the photovoltaic installation necessary for its self-sufficiency, is located in the municipality of Vallada. This municipality, which is located in the region of "La Costera", province of Valencia, is about 75 km from Valencia, capital of the Valencian Community and third city in Spain in terms of population and gross domestic product (GDP), and is close to other larger towns, such as Játiva and Onteniente.

Its municipal area, with an area of 6,123 ha., limits to the north with Enguera, to the east with Montesa, to the south with Aielo de Malferit and Onteniente and to the west with Mogente. Of these 6123 ha of the municipality, 2793 correspond to forest land and another 1000 (approximately) correspond to irrigated farmland.

This small municipality has a population of 3036 people (according to the census of the National Institute of Statistics of Spain) as of 2018. The coordinates to locate the town are 38 ° 53'44.2 "N 0 ° 41'25.3" W and its Postal code is 46691. As for the communication routes, it has the A-35 highway that connects Valencia, Alicante, Albacete and Madrid, as well as a bus line from Játiva and a railway connection that offers commuter, regional train services and long distance.

As for the climate, it is classified as Mediterranean / continental, with temperatures that are usually between 8 °C in January and 24 °C in August, and the average annual rainfall is around 439 m^3.

On the other hand, its economy is based on two fundamental pillars:

- Firstly, the municipality is dedicated to the furniture, wicker, rattan, reed and basketry industry, its main clients being other European countries.
- Secondly, agriculture also plays a fundamental role in the economy and the maintenance of jobs for the population. In this case, olive trees, cereals, almond trees and fruit trees predominate as dry crops. Citrus and different varieties of fruit trees occupy irrigated crops.

The geographical location is the one shown below (its geographical context is shown in greater detail in the plan 1 in Document 5):

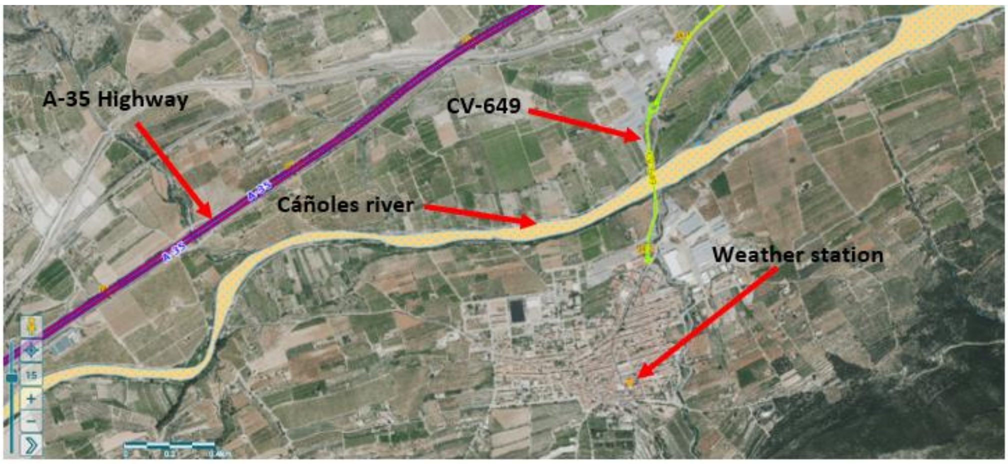


Figure 30. Geographical location of Vallada. Source: Adaptation from "Instituto Cartográfico Valenciano"

2.2 Available data and existing facilities

According to the data provided by the irrigation company to which the cultivation area in question belongs (Sociedad de Riego Canyoles I), in said land there are:

- 383 ha, 405 intakes and 43,98 km of pipes of various materials and diameters. In this sense, the table below shows the construction material and the diameter used in the irrigation network, as well as the total length of every diameter of every material, where PN means "Nominal Pressure" that is the maximum water pressure for which the pipe or fitting is designed:

Material	Diameter (mm)	Total length (m)
Asbestos cement (FIB)	FIB 200	1805,81
	FIB 250	2101,21
	FIB 300	2598,30
	FIB 350	5701,30
	FIB 400	2867,76
	FIB 450	204,20
	FIB 500	126,12
Polyvinylchloride (PVC)	PVC 63 PN6	2233,09
	PVC 75 PN6	977,97
	PVC 90 PN6	1144,88
	PVC 125 PN6	2428,71
	PVC 140 PN6	2952,57
	PVC 160 PN6	1975,10
	PVC 180 PN6	1616,33
Polyethylene (PE)	PE 40 PN 16	2169,54
	PE 50 PN 16	1539,71
	PE 63 PN 16	3413,77
	PE 75 PN 16	1547,37
	PE 90 PN 16	1353,29
	PE 110 PN 16	3981,36
	PE 125 PN 16	1242,51

Table 4. Total lengths and diameters of every material used in the conductions

On the other hand, the following graph shows how most of the pipes, specifically 95%, have a length of 150 m or less, with the remaining 5% corresponding to pipes between 150 and 510 m.

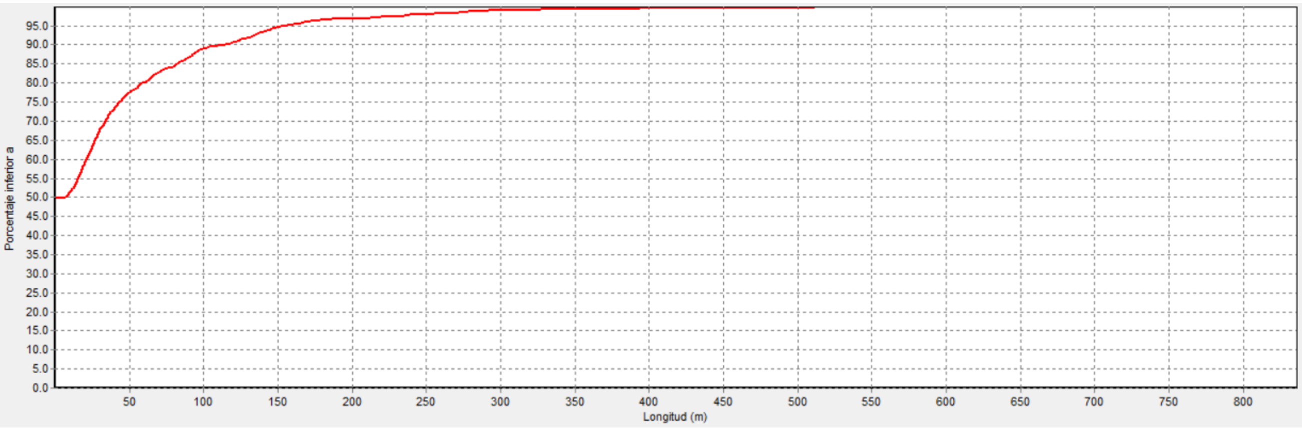


Figure 31. Distribution of lengths in the irrigation network

- Drip irrigation system. The change in the type of irrigation from flooding to drip irrigation occurred as a consequence of the increase in the area devoted to the cultivation of citrus fruits, which consume a greater amount of water than that of other rainfed crops (almond and olive trees), and by the lower efficiency in the use of water resources in this irrigation system. The following table aims to collect the most common types of irrigation, as well as their advantages and disadvantages:

Type of irrigation	Picture	Characteristics	Advantages	Disadvantages
Furrow irrigation		• Also called gravity or surface irrigation, it consists of the circulation of water through channels that separate the crop lines. • A reservoir of adequate dimensions is required to store the volume of water required by the crop based on its needs and climatic conditions. • The infiltration capacity of the land must be known to prevent its flooding • It is the gravity that carries out the distribution of the water flow throughout the cultivated land.	• It is a simple and inexpensive system. • Since gravity is used to distribute the water flow, energy consumption is low. • Acts on the roots of plants exclusively, and is ideal for small growing areas	• It is not an adequate system for uneven terrain, since the water could not follow its course and advance adequately and, therefore, not be properly distributed in the channels that feed the crop lines. • • As a significant part of the terrain becomes considerably wet, this can lead to the growth and proliferation of weeds • • A large amount of water is required, and it also has high evaporation losses
Drip irrigation		• It is mainly used in areas with little rainfall. • The water distribution in the main lines is usually done with PVC or PE pipes, these connections being flexible or rigid PE pipes in the secondary branches. • It is used in both greenhouse and outdoor growing areas. • It is a type of low pressure irrigation	• Allows roots to grow optimally. • Prevents fluctuations in humidity almost completely. • Allows fertilizers to be applied directly to water. • Thanks to its irrigation precision, it allows to greatly reduce the volume of water used. • Considerably reduces the possibility of weed growth. • System with good adaptation to irregular and complex terrain (slopes, rocky areas, sandy terrain, etc.) • Irrigation can be automated	• If water is not properly filtered through the system due to some type of blockage, the system can become clogged, leading to uneven watering and even cracking hazards. • The initial investment required for its installation and start-up, as well as the complexity of its design, are greater than in

				the case of flood irrigation
Sprinkler irrigation	 	• The water is conducted through underground pipes until it is expelled under pressure by means of sprinklers, so that the plants are watered in the same way as they would in a fine rain. • There are three types: stationary sprinklers, mobile sprinklers and self-propelled sprinklers.	• This system makes it possible to precisely adjust the power of the irrigation, as well as its distribution, for a uniform irrigation in the field of cultivation. • It is also possible to use it on flat land or that present positive or negative slopes. • Water consumption is also lower than in the case of flood irrigation. • Although the water comes out with more pressure than in the two previous systems, it does not cause any damage to the crops or the ground, and this pressure is perfectly adjustable. • Very efficient system that covers large areas, which makes it widely used. • Irrigation can be automated • Long useful life	• They have the highest installation and maintenance cost, as well as the greatest complexity in design and installation

Table 5. Types of irrigation: characteristics, advantages and disadvantages

- There are two branched networks of pipes. The first of them, the oldest, consists of the water extraction well known as "Pozo Canyoles I" that provides a maximum water flow of around 0,1 m^3/s that is pumped to a reservoir located at a height of 360 m and with a capacity of around 5000 m^3. The second, much more recent, consists of a water extraction point known as "Pozo el Tollo" that pumps a maximum flow of around 0,1 m^3/s to a reservoir located at a level similar to the previous one (371 m) but of much greater capacity, specifically 17,000 m^3.

- By default, both branched networks of pipes work independently, each one with its well and its reservoir, although if necessary it is possible to allow the communication of both basins, so that one of them can also supply water to the different irrigation points of the other pipe network.

- The pumps are submerged and therefore self-priming and not susceptible to the cavitation problem common in jet pumps. These are usually centrifugal pumps. In the present case study, both the pump located in the " Pozo Canyoles I " and the one in the " Pozo el Tollo " are semi-axial type pumps. As is logical, these commercial pumps are suitable to boost the flow rates that are requested over the months and with the required height.

- Finally, the Sociedad de Regantes Canyoles I also provides an Excel file with the data on the monthly water consumption of the different intakes between 2001 and 2017. With this, it is possible to construct the following graph, which accurately collects the total annual consumption (bars) and the evolution of the area dedicated to cultivation (line).

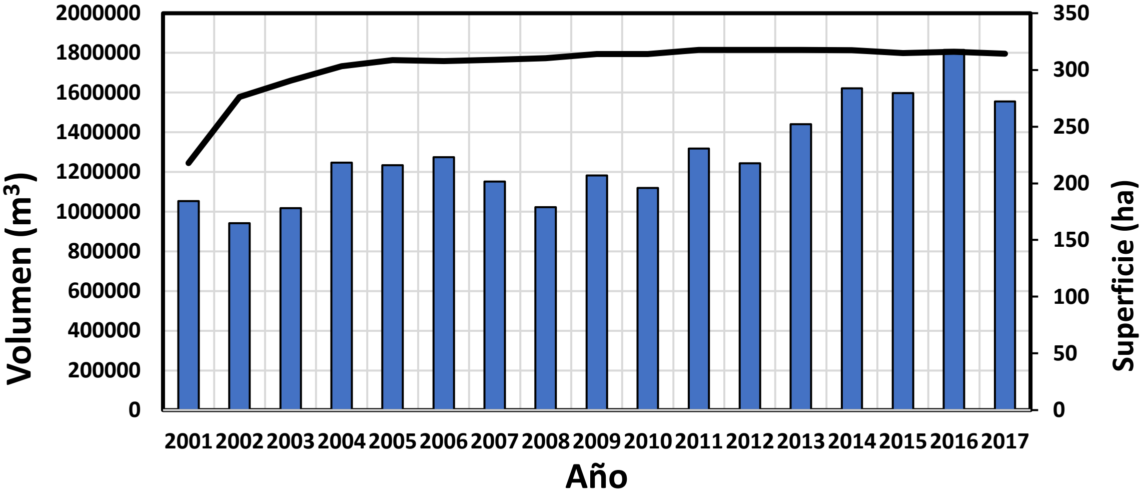


Figure 32. Total annual consumption and evolution of the total irrigated cultivation area

This file also contains the total monthly consumption corresponding to an average year, necessary to establish a reference year with which to carry out the study of the water needs of the area, as well as the amount per one of the total monthly consumption of this same period and the theoretical consumption of the two types of crops (orange and olives). This is represented in the graph shown below:

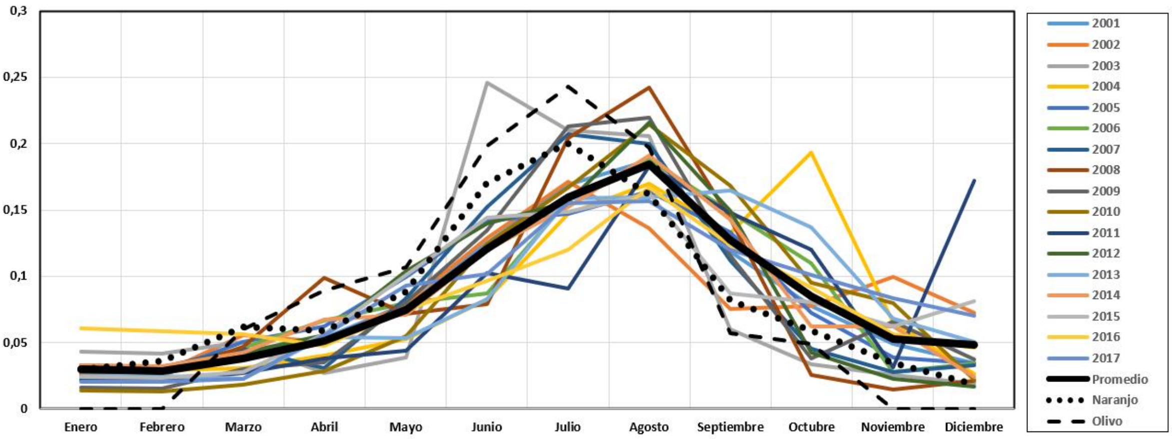


Figure 33. Total monthly consumption of an average year, monthly consumptions in amount per one and theoretical consumption of the orange trees and olive trees

There is also access to data on the required monthly volume of water and the number of hectares associated with each of the 405 intakes.

To represent the distribution of the main pipes on the map, the procedure is as follows:

- A digital terrain elevation model (DEM) of the desired area is downloaded, in this case Vallada. For this, the database available in the Instituto Geográfico Nacional (IGN) of Spain has been used.

- Then, this DEM is opened through a software prepared for this type of files, such as QGIS and ArcGIS, the corresponding extraction of the raster is carried out and the file is saved in .dxf format.

- Finally, this file is opened through AutoCAD, the DEM is represented and the hydraulic network can be traced on it.

In addition, it is also possible to carry out this work by using Google Earth in combination with Global Mapper.

2.3 Results of the previous study

Before entering fully into the considerations and the calculation and design procedure that will be applied in this project, it is convenient to indicate and comment on certain results and conclusions obtained by Héctor Montero Ortiz in his TFM, since they are of great relevance when addressing the development strategy of this work. In this sense, the following points stand out:

- In function of the energy sale price, 3 scenarios were proposed: one neutral; an optimistic one, in which an increase in the sale price of energy was considered 20% higher than in the neutral case; and a pessimistic scenario in which the sale price of energy was taken 20% lower. Using as financial indicators the NPV, the IRR and the Return Period (Payback), the convenience of the installation of between 1 and 10 groups of countries was estimated, both by sectors separately and jointly and for each of these scenarios, as well as for the two objective functions proposed, one that only considers the maximization of the recovered energy (E) and another that also takes into account the economic implications of the increase in groups of installed PATs (E/PSR). The following table reflects the optimal results for each scenario:

Scenario	Number of groups of PATs	Objective function	Sector
Neutral	2	E/PSR	2
Optimistic	3	E/PSR	Both
Pessimistic	2	E/PSR	2

Table 6. Results of the feasibility analysis according to scenario. Source: Adapted from Héctor Montero

In view of the results, it was decided to proceed with the studio considering a total of two groups of PATs and the second objective function.

- Subsequently, the energy recovery was analysed through the installation of these two groups of PATs, the 2004 and 2070 lines, characterized by the circulation of large volumes of water and by high heights (pressures) respectively, those chosen for this purpose. These lines are represented below:

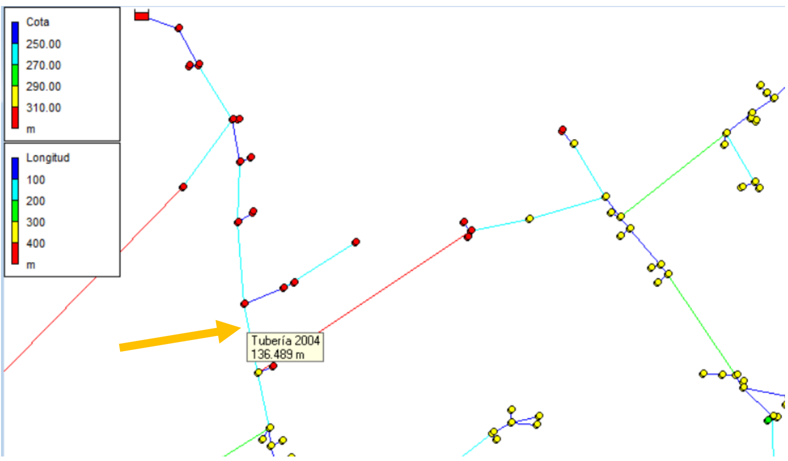


Figure 34. Line 2004

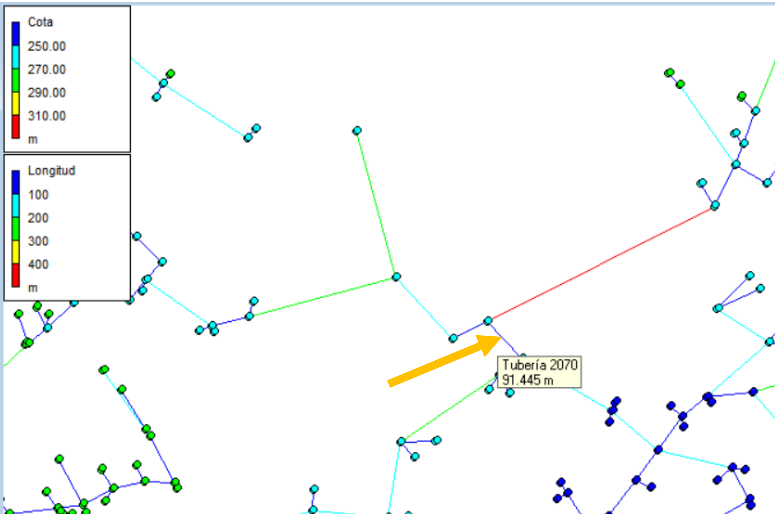


Figure 35. Line 2070

- On the other hand, both in the case of the group of PATs installed on the 2004 line and the one located on the 2070 line, there are 3 PATs that make it up, each of them being 3,25 kW in the group of the former. mentioned line and 1,71 kW in the case of the second. The connection of these 3 PATs is as follows:

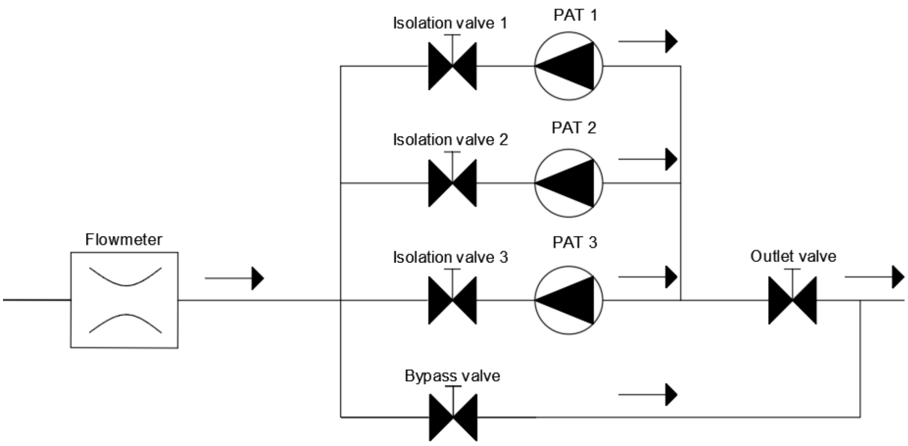


Figure 36. Configuration of PATs in parallel. Source: Adapted from Pérez-Sánchez et al

- The following table contains relevant information, obtained after the energy recovery study of the two groups of PATs of the aforementioned lines. It displays the recovered energy, as well as the percentage that it represents of the total recoverable, and the percentage that is turbine for its recovery.

Line	**Theoretical energy recovered (kWh)**	**Energy finally recovered (kWh)**	**% Energy recovery**	**Total volume (m^3)**	**Turbinate volume (m^3)**	**% Turbinate volume**
2004	68833,97	29004,31	42,14	898102,95	743505,38	82,79
2070	39571,14	12665,42	32,01	281048,97	245013,57	87,18
Total	108405,10	41669,72	38,44	1179151,91	988518,95	83,83

Table 7. Energy recovery and turbinate volume in lines 2004 and 2070

- Finally, knowing the costs of the PATs (9336,1 €), their installation (25555,88€) and the manholes in which they will be located (15872,8€), as well as the unit operating cost (0,0145 €/kWh), the fixed discount rate (2,5%), the energy recoverable annually (41,67 MWh/año) and the sale price of the electricity considered in the scenario neutral (0,0842 €/kWh), the financial indicators mentioned in the first point of this section are applied, obtaining the following results:

Number of groups of PATs	NPV (€)	IRR (%)	Payback (years)
2	16445,65	4,33	19

Table 8. Real case feasibility analysis

2.4 Software used in the project and other useful applications

Word: Microsoft Word is a computer program created by the Microsoft company that allows text processing. Once the text has been written in its entirety, it is time to proceed to convert the .docx file to .pdf.

Excel: Microsoft Excel is a program created by Microsoft to carry out various calculations, representation of graphs and tables, which uses a programming language known as Visual Basic. Therefore, it has been used for the development of all the calculations presented in this document, that is, both those related to the energy needs of the growing area and the components that make up the photovoltaic installation (panels, inverters, wiring, elements protection, etc.) and parameters necessary for the economic evaluation of the project.

AutoCAD: AutoCAD is Computer-Aided-Design software used for 2D drawing and 3D modelling developed by Autodesk. This program has been used to represent the different components that make up the photovoltaic installation designed in this study, as well as to know the data required in some calculations carried out in Excel.

EPANET: It is a free software developed by the Environmental Protection Agency (EPA) of the USA. Its purpose is to allow analysis of the behaviour of pressurized drinking water distribution systems and the monitoring of the water quality in them. It has made it possible to know the main parameters of the hydraulic network that make up the two irrigation sectors (height, length of the pipes, flows and pressures at the nodes) with which the initial calculations have been carried out.

Arquímedes: It is a software developed by CYPE that allows measurements, budgets, certifications and specifications to be made. Therefore, it has been used to carry out the detailed development of each of the components that make up the budget presented in Document 4.

PVGIS: It is a free online software developed by the European Union that provides free access to several data and tools, such as hourly, daily and monthly values of both solar radiation and PV performance, and PV potential for different technologies and configurations of grid connected and stand-alone systems. The radiation and temperature data used in this document have been obtained from this site.

MS Project: Microsoft Project is a project management software developed and marketed by Microsoft which role is to assist project managers in developing plans, assigning resources to tasks, tracking project progress, managing budgets, and analysing workloads. It allows to obtain the critical path of a project, facilitating the levelling of resources and providing great visibility on the activities of the critical chain. For this reason, it has been used in this final master's work to determine the estimated duration and evolution of each of the tasks that make up the execution of the works required for the realization of the projected photovoltaic installation.

In addition to the aforementioned software, there are other programs that allow calculations related to the design of a photovoltaic installation to be carried out, in addition to in some cases offering commercial catalogues of different components based on the parameters specified by the user. If you have access to them (many are paid and require a user identification code) they allow you to speed up the development of projects, especially those of large dimensions and complexity, and carry out more accurate and well-founded calculations. Some of these programs are listed below:

PVSyst: It is a software that allows to carry out the study, dimensioning and analysis of the simulation results of photovoltaic systems. Thanks to its meteorological database, it has daily solar radiation data that allows the size of the facilities to be sized according to their location. In addition, it allows the installation to be projected in 3D and in its calculations it takes into account the daily evolution of the projected shadows as a function of the solar path. It offers four design options (grid-connected, stand alone, pumping and DC grid pv systems). It is a very complete and reliable program that can be combined with others for optimal results, but it is not free.

Sisifo: It is a simulation web service developed by the "*Instituto de Energía Solar*" of the Polytechnic University of Madrid in collaboration with the European Commission that allows the design of pv plants connected to the grid, as well as pv irrigation systems, using models and showing targeted results. to guarantee their quality and economic viability.

Diafem: Free software developed by the "*Agencia Andaluza de la Energía*" in collaboration with the University of Jaén that allows the design of isolated electrification projects, both photovoltaic and mini-wind, as well as mixed.

SAM: The System Advisor Model (SAM) is a free and complete (for a limited number of uses) techno-economic software model that can model many types of renewable energy system (pv systems, concentrating solar power systems, wind power, marine energy wave and tidal systems, biomass etc.).

Document 2.

Statement of requirements

2.1 Introduction: purpose of the statement

This document determines the conditions to which the Contractor and the various work units must adhere to carry out the works and facilities described in this project, named as “Design of a photovoltaic solar installation for the irrigation of the Vallada cultivation area (Valencia), as well as determine the Contractor's obligation to comply with the instructions issued by the Director of the work to solve the difficulties that arise during the same.

2.2 General conditions

2.2.1 Documents

The documents related to the calculation and selection of the necessary components (Document 3), the disposition of said components in the field destined for their installation (Document 5) and the conditions that must be followed to guarantee health and safety as much as possible. of the workers (Document 8) are the basis for the execution of the installation designed in this project. In addition, Documents 4 and 6 allow to know their economic and environmental viability, respectively.

2.2.2 Quality of workmanship

Specialized labour will be available for each specific job, and in possession of the mandatory authorization or qualification issued by the competent Body. The installation must be carried out to the satisfaction of the Director of the Works.

In each case, the quality of the workforce will be in accordance with the difficulty of the work to be carried out, and the Director of the work may, if he deems it necessary, demand the presentation of the professional card, and how many tests he deems necessary to prove compliance. of this condition.

2.2.3 Start date of the works and expected execution period

The start and end dates of the execution of the established works are indicated in the diagram attached in Annex II. On the other hand, as indicated in said Annex, the start date does not take into account the period of time necessary to obtain the necessary permits for the start-up of the works (prior administrative authorization, building license, license of activity, occupation of land) and that can last for several weeks. The successful tenderer must start the works once a maximum of 15 days have elapsed after the final award date (that is, a maximum of 15 days after obtaining all the necessary permits), giving the Technical Direction of the Work account of the day of inauguration of the works.

2.2.4 Provisional reception

Once the works have been completed in their entirety, and arrived the time when the Contractor requests it, they will be provisionally received by the Employer.

For this provisional reception to be formalized, the assistance of a representative of the Property (Employer), the Engineer Director of the Works and the Contractor or their representative will be necessary. From this formal meeting, a Minute will be drawn up in triplicate, which must be signed by each of the three above-mentioned legal assistants in the event of the agreement of each party indicated with the work carried out.

In the event that the works are in good condition and have been executed in accordance with the technical specifications found in this project, such signature will be carried out and the warranty period will begin. If, on the other hand, the works are not in a state to be received, it will be stated in the Minutes and the defects observed that have led to their disagreement will be specified, as well as the instructions to the Contractor by the Technical Directorate that are considered indispensable to remedy these defects origin of the nonconformity.

Once the estimated term to correct these problems has expired, a new survey will be carried out under the same conditions. If on this second occasion there is no conformity of the work carried out by the Contractor by the Employer, the contract may be terminated with loss of the deposit. In any case, the cost incurred in carrying out these repair works will be remedied by the Contractor.

2.2.5 Definitive measurement of jobs

Once the provisional reception of the works has been formalized, in addition to starting the warranty period established in 1 year, it will proceed immediately, by the Directorate of the Work, to its general and definitive measurement, for what that the assistance of the Contractor or a representative thereof is established as necessary.

2.2.6 Warranty period

The warranty period for the completed works will be the one agreed by contract between the Property and the Contractor and will begin to run from the date of signing the Provisional Acceptance Certificate. After this guarantee period, the definitive reception of the works will be carried out. If this reception is favourable and is formalized, the Contractor will be relieved of all responsibility for conservation, reform or repair.

2.2.7 Conservation expenses for works received provisionally

The maintenance costs incurred during the aforementioned warranty period, which establishes the end of the provisional reception and the beginning of the final reception, will be borne by the Contractor.´

2.2.8 Hidden vice

The project must be unalterable, unless the Director Engineer had well-founded reasons to believe in the existence of hidden defects in the works executed. In this case, he may order the execution of the demolitions that he considers necessary for the recognition of the works that he believes are defective, as long as the definitive reception of said works has not been formalized.

The costs of demolition and reconstruction originated will be borne by the Contractor, in the event of these defects, and by the Promoter if not.

2.2.9 Final reception

Once the guarantee period established by contract between the Property and the Contractor has expired, it will be definitively received. If the works are in the desired state according to the specifications established in this project, the final acceptance certificate will be signed by the Contractor or his representative and the Direction of the Works, each receiving a copy of the same. of these parts. In this way the Contractor will be relieved of all administrative responsibility, remaining the civil liability. Otherwise, it will proceed in an identical manner to that drawn up in the provisional reception, establishing a period in which the Contractor will defray the necessary expenses to carry out the reforms that allow to solve the non-conformities detected, so that if after this period, no have reached the established prescriptions, the contract may be terminated with loss of deposit (unless it is deemed convenient to grant a last and non-extendable period).

2.2.10 Penalties for delay of works

If the Builder has not completed the works and does not have them ready for use or commissioning within the established period, it will proceed, except for justified cause of force majeure, to reduce the settlements, bonds or emoluments in the amounts established in the clauses of the contract signed between the Property and the Contractor, for which the objective opinion of the Technical Management will also be taken into account.

2.2.11 Defective works

The Contractor, of course, must use the materials specified in these Specifications and that comply with the most current and demanding regulations in terms of efficiency, safety and environmental impact, as well as in the amount indicated and carry out the works specified and contracted in this document relating to the necessary works and the installation of this equipment.

From this it follows that, until the final reception of the works takes place, the Contractor will be solely responsible for the execution of the works, the materials and equipment acquired and the appearance of problems or defects that may arise in the course of the materialization of this project, either due to the acquisition of materials used or installed equipment other than those indicated or due to the deficient execution of the pertinent works, without the fact that the Direction of the Works (Director Engineer) has not alerted about this, as long as the Direction has in turn carried out the supervision tasks and the necessary indications.

In this sense, if the Technical Directorate perceives defects in the execution of the works or the acquisition of equipment other than those indicated in the Statement and that do not meet the necessary conditions, it may, before the final reception, impose the performance of the tasks and/or necessary purchases deemed as necessary, being these expenses borne by the Contractor.

If the repair works cannot be carried out, the economic amount estimated by the Construction Management will be discounted. In addition, in the event of new defects in subsequent works or the acquisition of materials other than those indicated, the contract may be terminated, without prejudice to compensation that may be due from the Contractor.

2.2.12 Direction of the work

The Engineer will be the exclusive Director of the Works. Therefore, he/she will have the power to direct the evolution of the execution of the works, and will have to carry out the technical-economic interpretation of the project, establishing on the other hand the measures and modifications that he/she deems appropriate for its correct development and implementation within the deadlines established in the contract, as well as the relevant safety and health measures to guarantee the safety of the operators in the performance of their work.

In addition, the Technical Director (Engineer) will attend the works as many times as necessary for their supervision and the resolution of problems that may arise, will approve the partial certifications of the work, will carry out the layout of the work and its corresponding record, will check the provisional and final status of the works prior to their corresponding receptions and will sign the final certificate of the work.

2.2.13 Obligations of the Contractor (Builder)

It is stipulated that the Contractor shall:

- The expenses caused by the tests and trials that the Technician in charge of the work makes of the materials, machines or various elements that make up the work, as long as they are subject to current practice, will be borne by the Contractor.

- The Contractor will be responsible for compliance with all current provisions on work accidents.

- If the contract does not comply with any of the conditions stipulated in the opinion of the Technical Director of the Work, whose orders must be attended by the Contractor, the Concessionaire reserves the right to terminate the Contract that will be signed based on these specifications.

- The Contractor must enable the roads and access roads, as well as install the work booth with the habitability conditions required to examine the project documents and hold the necessary meetings at all times.

- The Contractor may not subcontract partially or totally the project works without prior written authorization from the Directorate.

- The Contractor shall prepare the partial work certifications and the final settlement proposal.

- The Contractor must keep the Book of Orders and Monitoring of the Work in which all incidents arising during the useful life of the aforementioned installation will be recorded, including each visit, review, etc.

- It will be the responsibility of the Contractor to arrange insurance for accidents at work and for damage to third parties occurring during the work.

- It will be the obligation of the Contractor to take charge of the necessary personnel in the opinion of the Technical Directorate.

- When by division or causes it is necessary to assess incomplete works, the prices of the general budget of the Project will be applied, or in its case the previously accepted budget, without the valuation of each unit of work being able to be attempted in any other way than that established in the budget. . In none of these cases will the Contractor be entitled to any claim based on the insufficiency of the prices indicated or on omissions of any of the elements that constitute the referred prices.

- The Contractor will be responsible for any damages that may occur due to the negligence or carelessness of his personnel, in which case he/she will indemnify the affected owners.

- Compliance with the Municipal Ordinances and Provisions in force, and in general with any law applicable to the project category (Installations for the generation and distribution of electrical energy).

- The Contractor will have to make a Safety and Health Study that complies with the current legislation on Safety and Health at work and that will include the indications carried out by the Engineer Director of the Work.

2.3 Conditions of use, maintenance and safety

The preventive and corrective maintenance tasks of the facilities and their associated guidance costs are found at the end of Document 3.

On the other hand, maintenance must also be carried out by personnel trained for it and with the relevant safety guarantees. In this sense, qualified personnel belonging to electrical installation companies should not manipulate the electrical installation of the project while it is in operation. In addition, the material that needs to be replaced will be replaced by identical equipment, not allowing the variation in the commercial model installed in the first instance unless authorized by the Technical Directorate, as well as the elimination of any protection element, either from the part of direct or alternating current, without being replaced by an identical component.

The reviews will be carried out with the frequency and during the period stipulated in the contract and will be carried out by companies authorized to carry out this type of supervision and maintenance tasks.

2.4 Materials and equipment to acquire

As previously indicated, it is the Contractor's obligation, among other things, to acquire commercial components and equipment with the established characteristics and in the quantities set for their installation. In this sense, the equipment and materials available in the photovoltaic installation described in this project are listed and briefly described below, and the quantities of each of them are indicated:

2.4.1 Photovoltaic modules

As indicated in the document relating to the calculation of the different components that make up the designed photovoltaic installation, when determining the commercial model of the photovoltaic module, a comparative analysis was carried out between several commercial models based on different criteria (quantity, cost and surface occupied) to determine which was the optimum, that is, the one with the lowest value of these parameters.

Finally, it was decided to select the commercial model *ERA Solar ESPSC400*. Since 1560 modules are required in the photovoltaic field that powers Sector 1 and 760 in the one that powers Sector 2, the photovoltaic installation consists of a total of 2320 modules of 400 Wp, resulting in a peak installed power of 928 kW. It is therefore a medium-high power photovoltaic installation.

These modules also have a high performance, up to 20,17% in STC, approximate dimensions of 1,98x1m and a current and voltage in their MPP of 9,6 A and 41,7 V, respectively. They also have great reliability and a frame made of high quality aluminium.

The orientation and inclination of the photovoltaic generator must be those described in the project (α=0° and β=35°, respectively).

In Annex III the commercial catalogue of this equipment can be found, as well as the catalogues of the rest of the components of the installation.

2.4.2 Inverters

The conversion of direct current from the photovoltaic generator into alternating current for use in pumping systems (or when possible, for sale on the grid) will be carried out by means of a series of three-phase inverters from the *Ingeteam* brand, model *INGECON Sun 3 Play 100 TL*. A total of 10 of them will be needed, with 6 being located in the installation corresponding to Sector 1 and 4 in Sector 2. As in case of the modules, a comparative analysis was carried out in this case.

They have a nominal output power of up to 110 kW if they are connected to a 440 Vac network (in this case the pumps are 400 Vac, so that its nominal power is up to 100 kW). Its recommended power range at the input is 101,2 to 145 kWp. On the other hand, the maximum voltage and current at the input are 1100 V and 185 A, respectively, giving the output 400 V and 145 A. They have a power factor of 1, a consumption of 20 W in stand-by and a degree of protection of IP65. Furthermore, they have a really good maximum efficiency, of 99,1% (98,5 if European efficiency) at STC.

On the other hand, it is also relevant to indicate that the catalogue of this product indicates that the type of grid to which the inverter must be connected must be TT or TN: "These units must be connected to a three-phase star grid with grounded neutral. They cannot be connected to IT networks or delta networks grounded on one of their lines ".

These inverters will be installed in the same cabin as the DC junction boxes and AC measurement and protection boxes, and next to the transformer and pumping rooms of the sectors.

2.4.3 Support structure

Considering the dimensions of the solar panels, their inclination and their arrangement with respect to the horizontal, an appropriate commercial model must be chosen. In this sense, it has been decided to select the pre-assembled *CVA915XL* model, from the company *SUNFER*.

Each of the structures can hold up to 20 panels in 1 row. Therefore, having 2320 panels, and being all strings of 20 modules in series, 116 of these structures will be needed. These structures are completely made of high quality aluminium (EN AW 6005A T6), with A2-70 stainless steel screws, they are easy to assemble and they must be anchored to the ground by means of mass concrete footings, of approximate dimensions 49,5 cm (width) x 46 cm (height) x 28 cm (thickness).

2.4.4 Cabling

In the case of wiring, different sections are distinguished:

- The wiring that connects the strings with the junction boxes. The commercial model *Exzhellent Solar XZ1FA3Z-K (AS) 1,8 kV DC*, from *General Cable* company, has been chosen. The necessary sections have been two, specifically 25 mm^2 and 35 mm^2, requiring in turn about 47,695 m and 14,550 m of each, respectively. This makes the cost of wiring the highest after that of photovoltaic modules. In general, this expense is usually notably lower than that of investors, this being the second or third expense, depending on the price of the structures.
- The wiring that connects the connection boxes with the inverters. Sections of 6, 10 and 70 mm^2 have been needed, and in length respectively of each one of them. The chosen commercial model has been the *ENERGY RV-K FOC 0,6/1 kV*, again from the *General Cable* company.
- The wiring that connects the inverters with the protection and measurement boxes will be the same commercial model, but in this case each of the multiconductor cables will have three phase conductors with 185 mm^2 section and 95 mm^2 neutral () and 150 and 70 mm^2 () respectively.

When calculating the necessary standard sections in each section of the installation, the provisions of ITC-BT-40 of R.D 842/2002 (REBT) and UNE 20460-5-523 standard have been followed. In this way, the criteria of maximum allowable voltage drop, establishing maximum drops of 1,5%, 1,2% and 0,3% in the three sections described above, and of maximum allowable current, have been used.

The different lines must be marked with the standard colours: phases in brown, black and grey; neutral in blue and protection cable, for grounding, in yellow-green.

2.4.5 Wire mesh cable tray

The wire mesh cable tray has the function of serving as a support for the wiring that covers the length between the ends of the string, that is, from the cable that leaves the furthest panel of the string to the opposite end of it. In this way, since there are 116 strings of 20 m each, 2320 meters will be needed.

For its selection, the model *CSU4518110*, from the *Schneider Electric* company, has been chosen. It is a model made of ZnAL (Zinc-Aluminium), known as zinc$^+$, specifically recommended for outdoor installations. The dimensions are 35x100x3000, in millimetres (height, width and length, respectively). They are sold in packages with a total length of 24 m, that is, 8 of these mesh trays are included in each package. Therefore, 97 of this packages will be acquired.

2.4.6 Protection tubes

Three different protection tubes have been used for underground electrical conduits. Specifically, 5592,38 m of protection tube of 90 mm of external diameter, 2992,36 m of protection tube of 110 mm of external diameter and m of protection tube of 250 mm of external diameter. The 90 and 110 mm tubes are used with the wiring between the strings and the connection boxes, and the 250 between the protection and measurement boxes to the rooms where the transformers and pumps are located.

The chosen company has been *IBK cables*, and the models are, respectively, the *MOTD90L*, *MOTD110L* and *MOTD250L*. These are red halogen-free HDPE pipes (a different colour can be requested) that comply with the UNE EN 61386.2.4 standard, withstand temperatures between -25 and 100 °C and a crushing load of up to 450 N, as well as a normal impact of 20, 28 and 40 J respectively.

2.4.7 DC junction boxes and protection elements

The DC junction boxes are the elements that are responsible for grouping the lines coming from the strings of the photovoltaic generator, ensuring their attachment and proper connection and housing the protection elements against overcurrents, short circuits and overvoltages described in the corresponding chapter of the Document 1 and calculated in Document 3. Each of these components is detailed below:

2.4.7.1 Flat strips and cable grands for connecting the cables

As described in Document 1, in each junction box there are two components which function is to group the set of wiring lines from the panels that make up the photovoltaic generator. These are the cable glands and the flat strips of copper (or steel).

Cable glands are used for preventing the entry of water or dust into the junction box through the gap between the box and the cable. As for the latter, they function as a common connection point between the different lines of the strings. Therefore, they must be able to withstand the sum of the currents provided by each of these strings. A total of 116 cable glands (one per string) of *Hummel* company and 20 copper strips will be used, since there are 2 for each box, one corresponding to the positive pole and the other to the negative pole.

As there are boxes of 17, 15, 5 and 4 strings in parallel, and since the short-circuit current of the modules is equal to 10,36A, the current that the respective plates must withstand is 176,12 A, 155,4 A, 51,8 A and 41,44 A.

2.4.7.2 Fuses and fuse holders

The fuses have the mission of protecting against overcurrents and short circuits, as explained above. A fuse will be placed for each pole. Therefore, there will be 232 cylindrical gPV fuses (4x2x17 + 2x2x15 + 2x2x5 + 2x2x4) from the *DF Electric* company. These fuses will be of 15 A of nominal intensity, 30 kA of breaking capacity and nominal voltage of 1500 V. These values, like those of any other component of the installation, are obtained from the development of a series of calculations, described in Document 3. For the calculation of this component, the instructions of ITC-BT-22 have been followed, which in turn requires compliance with UNE-HD 60364-4-43: 2013.

On the other hand, fuse holders from the same company, model *PML*, will be selected to be used with the aforementioned 10x85 cylindrical fuses. Likewise, being single-pole, 232 fuse holders will be needed. Its commercial catalogue is in the same way in Annex III.

2.4.7.3 Surge arresters

Surge arresters have the mission of grounding excess voltage that may appear in the installation as a consequence of direct or indirect causes. Although the inverters already have this type of protection included, it is recommended that these devices be installed before the inverters to increase the level of security.

The commercial model *DG M YPV 1200 FM*, of the company *DEHNguard*, has been chosen. There will be one for each DC junction box, that is a total of 10. It has a nominal discharge current I_n=20 kA at 8/20 µs, a maximum discharge current I_{max}=40 kA at 8/20 µs, a voltage protection level $U_p \leq 4$ kV, a nominal voltage U_c =1000 V and a maximum working voltage of 1170 V.

2.4.7.4 String cut-off switches

These are switches that allow each string to be sectioned individually, so that a failure in one of the strings cannot lead to the failure of a different string. Thus, 116 string cut-off switches will be needed. At the same time, a general DC cut-off switch must also be placed for each box (then 10 in total) that allow the joint and manual disconnection of all the strings associated with the same connection box.

2.4.8 Protection against direct and indirect contacts. DC side grounding

The earth connections will be buried at least 0,5 m, although it is recommended that the conductor is buried at least 0,8 m, and this will be done in this case. On the other hand, the ring through which the rods will be interconnected creating an earth network will be made of bare copper and with a minimum section of 25 mm^2, although the most common is that it is 35 mm^2 and this will be the section finally used. Electrodes formed by vertically driven rods in the ground will be connected to the ring. The most common electrode is 2 meter long vertical ground rod, and this is the length of the selected commercial model. In this project, the model *T101820*, of the *Sofamel* company, has been selected.

On the other hand, 16 mm^2 grounding cables, model *H07-VK-1x16*, of the *KLK* brand, will also be needed, as calculated in the corresponding section, which will be connected to the masses of the strings of the photovoltaic installation, which are the aluminium frames and their support structures. The colour of the insulating cover will be yellow-green and they will be made of copper.

As previously indicated, the connection scheme followed in this case must be IT. The ITC-BT-08 includes information on this scheme, as well as the TT and TN. In turn, the UNE-HD 60364-4-41 standard expresses the requirements that must be met in this type of diagrams, and the ITC-BT-18 and ITC-BT-24.

2.4.9 AC protection and measurement boxes and their elements

In a similar way to that of the DC junction boxes, the AC measurement and protection panels (map panels for short) have the function, on the one hand, of serving as a connection point for the wiring lines that arrive in this case from the inverters already through which alternating current circulates, and on the other hand to store the protection elements against overcurrents and short circuits, as well as against direct and indirect contacts. In turn, a unidirectional energy meter (wattmeter) will be installed inside it to know how much energy coming from the corresponding section of the photovoltaic field feeds each pump. It will be necessary, on the other hand, an energy meter in this case bidirectional (wattmeter), between the network and the LVP, to know the energy flow both between the network and the pumping systems and between the photovoltaic generator and the network.

These m.a.p. panels are an intermediate point between the inverters and the Low Voltage Panel (LVP). Subsequently, the power line to the pumps leaves the CBT at 400 V.

As for the protection elements, two are distinguished:

2.4.9.1 Magnetothermal switch

Its function is to protect against overcurrents and short circuits. The *DPX³* model, from the *Legrand* company, will be installed. They have a nominal current (I_n) of 160 A, a breaking capacity ($P_{ms\ b}$) of 16 kA and a magnetic tripping current of the protection device between 800 and 1600 A (that is, between 5 I_n and 10 I_n, since it is a type C magnetothermal switch). As there will be 1 per inverter, 10 of these switches will be used.

2.4.9.2 Differential switch

Its function is to protect against direct and indirect contacts, deriving residual currents to earth. Since the model described above already includes the differential protection function, it is not necessary to purchase and install another additional component.

2.4.10 AC side grounding

The criterion is identical to that of DC side grounding, both in relation to the minimum depth to which the ground connections must be inserted (0,8 m) and the section of the bare copper cable (35 mm^2) that must interconnect the network. of rods of 2 m in length. In this case, the TT scheme is applied.

As in the DC side, the model *T101820*, of the *Sofamel* company, has been selected.

2.4.11 Monitoring elements

The following describes the 3 components that, together, allow to know the energy flows between the photovoltaic installation and the pumps (self-consumed energy), the photovoltaic installation and the network (sale of surplus energy) and the network and pumps (purchase of energy), as well as real-time electricity generation data from the photovoltaic field, power and current generated by the inverter, power factor, etc. and regulate the connection/disconnection of the power circuits.

2.4.11.1 Triphasic wattmeter

It is a device that allows knowing the energy flows present at the point where it is installed. In this way, a three-phase wattmeter, model *EM24*, from the *Carlo Gavazzi* company, will be installed for each of the inverters. Therefore, 10 of them will be needed. These are three-phase inverters compatible with Ingeteam models, others such as the *iEM3000* from *Schneider Electric* or the *Chint Three-phase 3G DTSU666-D* from *Huawei* (compatible with *Huawei* and *SolaX* inverters) have been found, but when in doubt as to whether the software It could be configured to make it compatible with Ingeteam inverters, it has been decided to choose the aforementioned model.

2.4.11.2 Communications card

In turn, an *INGECON SUN EMS Board* communication card, from the *Ingeteam* brand, will be installed in each inverter, so it will be necessary to buy 10 of these cards. This allows, via Wi-Fi, Ethernet or RS-485, to exchange information in real time with its corresponding wattmeter and to optimally adjust energy production and consumption.

2.4.11.3 AC current control

To control the circulation of the alternating current, components known as thyristors will be used. It is a family of electronic components made up of semiconductor elements that use internal feedback to produce switching. Specifically, *SC-ACR400 / 100kW-LA* models from the *Semicode* company will be used. These are compact thyristor units in W3C configuration plus the SC6006 control card that use SCR (Silicon Controlled Rectifier) technology to regulate alternating current.

2.5 Technical conditions. Regulations in force applied to the project

The most relevant rules and regulations that apply to this project are shown below:

- **Código Técnico de la Edificación CTE. "Documento Básico. Seguridad Estructural. Acciones de la Edificación", DB-SE-AE**. Standard that regulates the safety conditions of the support structure.
- **Ley 31/1995**, dated November 8, on the Prevention of Occupational Risks. Law whose purpose is to promote the safety and health of workers by establishing the guarantees and responsibilities necessary to guarantee the adequate level of protection of their health.
- **Real Decreto 1627/1997**, dated October 24, establishing the minimum health and safety provisions in construction sites.
- **Real Decreto 842/2002**, dated August 2, approving the "*Reglamento Electrotécnico de Baja Tensión*" (REBT), which determines the conditions that the electrical installation of the project must meet.
- **Ley 24/2013**, dated December 26, of the electricity sector.
- **Norma UNE-EN 50618: 2015**, dated March 18, which establishes the parameters to be met by electrical cables for photovoltaic systems. The IEC 60529: 1991 standard is an identical international equivalent.
- **Norma UNE-EN 60364-7-712: 2017**, dated February 15, which sets the requirements for electrical installations or special low-voltage sites. Photovoltaic (PV) solar power systems.
- **Norma UNE-EN 61215-1:2017**, dated June 7, which establishes the test requirements for the qualification of the design and approval of photovoltaic modules for land use.
- **Norma UNE-EN 60529:2018**, dated April 25, which sets the degrees of protection provided by the envelopes.
- **Real Decreto 244/2019**, dated April 5, which regulates the administrative, technical and economic conditions for self-consumption of electrical energy.
- **Ordenanzas Municipales**

In relation to equipment used in the project:

- All equipment installed must incorporate CE marking.
- The photovoltaic modules will incorporate the CE marking, according to Directive 2016/95/CE of the European Parliament and of the Council, of 12 December 2006, on the approximation of the laws of the Member States on the electrical equipment intended to be used within certain voltage limits.
- In addition, they must comply with the **"*Norma UNE-EN 61730*"**: Photovoltaic Module Safety Conditions, harmonized for Directive 2006/95/CE, and the **"*Norma UNE-EN 50380*"**: Information on data sheets and nameplates. Characteristics for photovoltaic modules. Additionally, they must meet the **"*Norma UNE-EN 61215*"**: Crystalline Silicon Photovoltaic (PV) Modules for Land Use. Design Qualification and Type Approval. They must have an IP65 protection degree and their frames, made of aluminium or stainless steel, must be grounded.
- The characterization of the inverters must be done according to the standards: **UNE-EN 62093**: Components of accumulation, conversion and energy management of photovoltaic systems.
  Design qualification and environmental tests, **UNE-EN 61683**: Photovoltaic systems. Power conditioners. Procedure for performance measurement, and according to IEC 62116. Testing procedure of islanding prevention measures for utility interactive photovoltaic inverters.
- The nominal power of the inverters must be at least 65% of the nominal power of their corresponding section of the photovoltaic generator and, at the same time, said nominal power will not exceed 1,3 times the peak power of that section of the photovoltaic generator to maintain optimal production.

Furthermore, its efficiency must be at least 90% in STC and must comply with the **IEC 61000-6-2** and **IEC 6100-6-4** regulations, as well as the specific national regulations.

- The conductors will have the adequate section to avoid voltage drops and overheating. Specifically, for any working condition, the conductors of the direct current part will have enough section so that the voltage drop is less than 1,5% (1,2% between the photovoltaic generator and the junction boxes, and 0,3% between the junction boxes and the inverters, since no specific values are specified) and those of the alternating current part will have a section such that the voltage drop is less than 1,5%, having in both cases as reference voltages corresponding to junction boxes. This is done in accordance with ITC-BT-40
- The positives and negatives of each group of modules will be conducted separately and protected according to current regulations.
- It must have the necessary length so as not to generate efforts in the various elements or the possibility of being hooked by the normal traffic of people.
- All DC wiring will be double insulated and suitable for use outdoors, in the air or in the ground, in accordance with the UNE 21123 standard and with a minimum insulation of 1000V.

On the other hand, the regulations regarding the prevention of occupational risks are detailed in the document related to the Safety and Health Study.

Document 3.

Calculations for the dimensioning of the photovoltaic installation

3.1 Determination of the water needs of the sectors

As indicated in the previous chapter, the Sociedad Canyoles I provides information on the volume of water demanded by each of the intakes throughout the months of an average year; furthermore, it also provides the average annual volume consumed jointly by both sectors, both between 2001 and 2017 and between 2011 and 2017. These values are shown below:

Average year by years (2001-2017)	1284394,882
Average year since 2011 (to 2017)	1513044,835
Average year by average in irrigation intakes	1570661,276

Table 9. Average annual volumes, according to the criteria chosen to obtain them

Since what is intended here is to know the water needs that each sector demands separately, and that will have to be satisfied by its reservoir and corresponding pumping group, the reference value corresponding to the average annual volume per average in intakes is used, since in addition the data of each of the shots are available for each month on average, as previously commented, and that on the other hand results in an average higher than the previous ones. It results in a higher and more conservative value that will give rise to higher energy needs, so that the resulting photovoltaic installation (with or without the combination of other sources that provide electrical energy) will be able to meet the needs with greater guarantees.

However, the following clarification should be made: the exact volume with is somewhat lower, and is the result of the introduction of the data in EPANET. This is due to the fact that certain intakes that have consumption data do not have an associated area, as is the case of connection 8, or the opposite, such as connections 51 and 52, in which the cultivation area is indicated but there is no monthly water consumption. This is the one finally indicated per month and for both sectors separately, as well as the sum of both sectors and difference that these values suppose with respect to those provided in the Excel file:

Sector 1											
January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
17559,25	**17096,65**	**16843,79**	**22006,13**	**30572,47**	**49246,11**	**66026,67**	**78757,31**	**60598,12**	**43535,99**	**26921,23**	**23016,16**
Sector 2											
January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
29803,47	**28812,83**	**42232,41**	**55387,13**	**80258,48**	**129859,85**	**173216,54**	**193444,08**	**125363,74**	**85655,63**	**55794,59**	**67545,62**
Total											
January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
47362,72	**45909,48**	**59076,19**	**77393,26**	**110830,96**	**179105,96**	**239243,21**	**272201,38**	**185961,86**	**129191,62**	**82715,81**	**90561,77**
Difference											
January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
2008,04	**1944,65**	**2786,61**	**2246,68**	**3969,68**	**5472,63**	**10156,47**	**7745,15**	**5250,16**	**3792,50**	**2186,11**	**3548,35**

Table 10. Total monthly consumption of the intakes of each sector in an average year

It is important to highlight that the data of the demand flows provided already takes into account the net crop needs, that is, the crop needs considering the historical data of average monthly rains. If this had not been the case and the volume of water required per monthly intake was not known, it would have been possible to use the information provided by the *Agencia Estatal de Metereología* (AEMET) in terms of climatology (humidity, temperatures, hours of sunshine and wind characteristics), as well as from other sources for data related to the soil and the characteristics of the crops considered, and the support of software such as Cropwat for calculating the crop water requirements and irrigation needs.

On the other hand, although it is true that the volumes consumed monthly are those mentioned above for each sector, the hourly data of the flows consumed will be used (that is, the flow demanded by each sector to its respective water tank in each hour of each month of the year) because this data is available in an EPANET file. Although it results in a much larger volume of data and that makes its treatment and subsequent corresponding calculation to determine the reservoirs filling regulation strategy and the sizing of the corresponding photovoltaic installation more complex, much more accurate and therefore reliable and rigorous results are achieved.

3.2 Determination of the required pumping parameters. Commercial pump selection

It is known that the maximum flow provided by both wells is 0,1 $\frac{\mathrm{m}^3}{\mathrm{s}}$, and it is the one that will be used to optimize the strategy for filling the reservoirs through the pumping systems.

On the other hand, the other parameter necessary to determine the power of the commercial pump to select is the head at which it must be able to provide said flow.

As is known, Bernoulli's equation allows us to know the terms that make up the energy of the fluid along its path. By posing this equation between the points of interest, it is possible to precisely know the necessary pumping head. This equation is the one cited below:

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2 \cdot g} + h_b - \sum h_l = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2 \cdot g} \rightarrow E_1 + h_b - \sum h_l = E_2$$

Equation 1. Bernoulli´s equation

Where:

- $\boldsymbol{z}$**:** Geometric elevation of the fluid. Represents the potential energy that it possesses due to having an elevation above the reference level (m)
- $\boldsymbol{\frac{p}{\gamma}}$**:** This is the fluid pressure height, equal to the pressure divided by the specific weight of the fluid. The sum of this term and the previous one gives rise to what is known as the piezometric height of the fluid (m)
- $\boldsymbol{\frac{v}{2 \cdot g}}$**:** Kinetic height. In water installations this term is usually negligible
- $\boldsymbol{h_b}$**:** This is the head that the pump must provide to the fluid to overcome the losses in the pipes.
- $\sum \boldsymbol{h_l}$**:** Sum of the total fluid losses in the pipes.
- $\boldsymbol{E}$**:** Represents the energy available in the fluid. It is the sum of the piezometric height and the kinetic height.

Regarding the calculation of losses, the following has been done:

- To calculate the head losses due to the roughness of the walls, there are three different methods:
  - Hazen-Williams method: It is only valid for water, and its application is in the turbulent regime.

$$h_f = 10{,}674 \cdot L \cdot D^{-4{,}871} \cdot \left(\frac{Q}{C_{HW}}\right)^{1{,}852}$$

Equation 2. Hazen-Williams method to calculate head losses

  - Darcy-Weisbach method: It is the most widely used method, and it is the one used by EPANET in its calculations. It is very exact, and can be used with any liquid and regime (laminar, turbulent or transitory).

$$h_f = \frac{8 \cdot f \cdot L}{\pi^2 \cdot g \cdot D^5} \cdot Q^2$$

Equation 3. Darcy-Weisbach method to calculate head losses

- Chezy-Manning method: Used when there are free sheet flow rates.

$$h_f = 10{,}294 \cdot L \cdot n^2 \cdot D^{-5{,}33} \cdot Q^2$$

Equation 4. Chezy-Manning method to calculate head losses

At the same time, in the Darcy-Weisbach formula, which as previously indicated is the one used in this case, the friction factor is given by:

$$f = \frac{0{,}25}{\left[\log_{10}\left(\frac{\varepsilon}{3{,}71 \cdot \mathrm{D}} + \frac{5{,}74}{{R_e}^{0{,}9}}\right)\right]^2}$$

Equation 5. Obtention of the friction factor for the D-W formula

Where, in turn, the Reynolds number is expressed as:

$$R_e = \frac{v \cdot \mathrm{D}}{\nu}$$

Equation 6. Reynolds number

Where:

- $\boldsymbol{h_f}$: Head losses (m)
- $\boldsymbol{g}$: Acceleration of gravity on the surface of the earth (m/s^2)
- $\boldsymbol{L}$: Pipe length (m)
- $\boldsymbol{D}$: Pipe diameter (m)
- $\boldsymbol{Q}$: Flow ($\frac{\mathrm{m}^3}{s}$)
- $\boldsymbol{C_{HW}}$: Hazen-Williams roughness coefficient (dimensionless)
- $\boldsymbol{f}$: Darcy-Weisbach friction factor (dimensionless)
- $\boldsymbol{n}$: Chezy-Manning roughness coefficient (dimensionless)
- $\boldsymbol{\varepsilon}$: Absolute roughness of the internal wall of the pipe (m)
- $\boldsymbol{R_e}$: Reynolds number (dimensionless)
- $\boldsymbol{v}$: Fluid velocity in the conduction (m/s)
- $\boldsymbol{\nu}$: Fluid kinematic viscosity ($\frac{\mathrm{m}^2}{\mathrm{s}}$)

- To calculate localized losses, also known as minor losses or local losses and which are due to turbulences that originate in elbows and other elements or connections of the hydraulic network, it was decided to increase the real lengths of the pipes in 15%. It is not an exact calculation, but it is approximate enough to justify not spending time considering each of the elbows, valves and TEs individually in the calculation of these losses. These lengths are, thus, the ones used in the D-W formula for the friction losses.

The procedure for calculating this height is detailed below, both for the system that must provide the water pumping in sector 1 and that located in sector 2:

Sector 1 (Canyoles I)

This sector is the oldest of the two that make up the cultivation area studied, as well as the smallest, both by total length of its pipes and by cultivation area covered, as well as the one with the lowest monthly water needs (an average of 30.6% with respect to the total). In this case, the pumping system is responsible for driving the water from the well to the reservoir located at a higher level, with a capacity of 5000 m^3. The approximate measurements of this raft are 46x28x4 m.

Figure 37. Aerial view of the well and the water reservoir in Sector 1

The characteristics of pumping in this sector are:

$\frac{p_1\left(\frac{N}{m^2}\right)}{\gamma\left(\frac{N}{m^3}\right)}$	0
$\frac{v_1^2\left(\frac{m}{s}\right)^2}{2\cdot g\left(\frac{m}{s^2}\right)}$	0
Losses in pipes $\left(\frac{s^2}{m^5}\right)$	2590,18
$\frac{p_2\left(\frac{N}{m^2}\right)}{\gamma\left(\frac{N}{m^3}\right)}$	0
$\frac{v_2^2\left(\frac{m}{s}\right)^2}{2\cdot g\left(\frac{m}{s^2}\right)}$	0
Height difference (m)	99,75

Table 11. Characteristics of pumping at Sector 1

Thus, the resistance curve of Sector 1 is:

$$H^r{}_{Sector\ 1} = 99{,}75 + 2590{,}18 \cdot Q^2{}_{Sector\ 1}$$

Sector 2 (El Tollo)

Sector 2 is the main sector of the cultivation area, since in addition to having higher irrigation needs it also covers most of the cultivation area. It consists of a reservoir with a much greater capacity than that of sector 1 (17000 m^3), which was built, as was the well from which the water stored in said reservoir is extracted, to meet the growing water needs of the growing area by citrus growing becomes the majority. It has a shape that resembles an isosceles triangle of about 85 m on each side and 100 m at the base. Its approximate area is 4400 m^2, so its depth is around 4m.

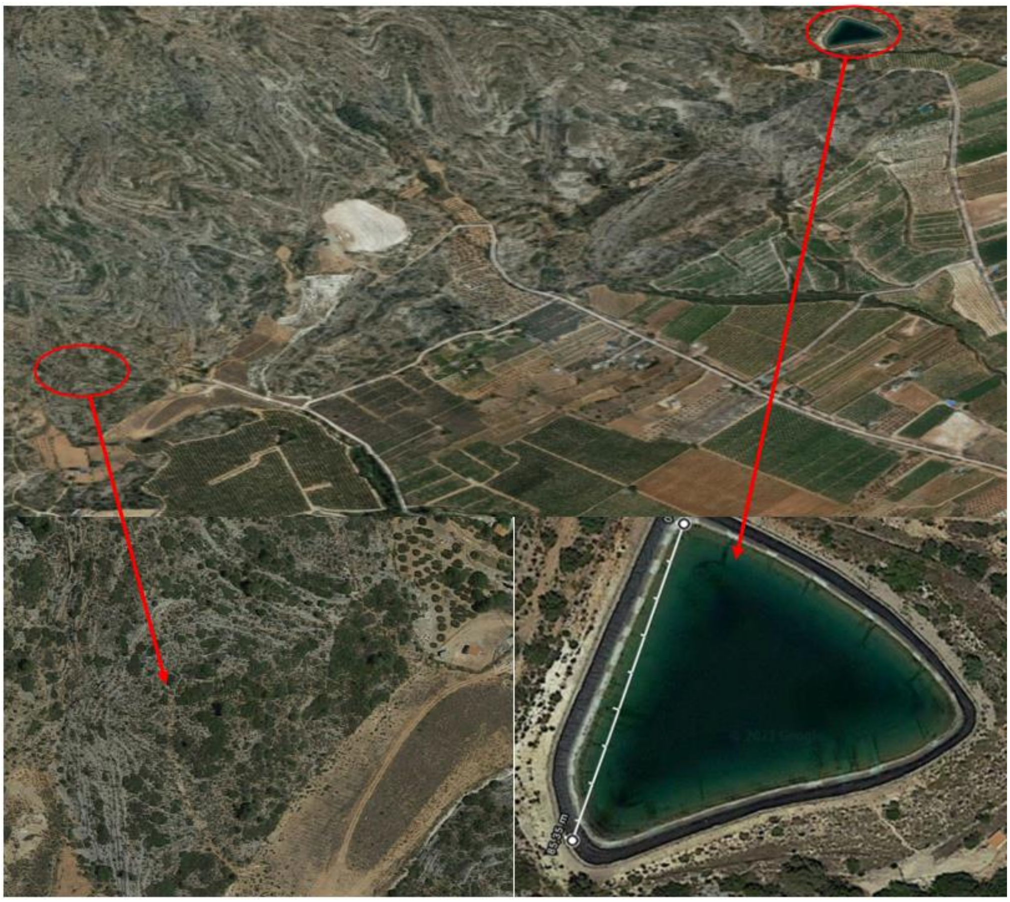


Figure 38. Aerial view of the well and the water reservoir in Sector 2

Whereas the characteristics of pumping in this sector are:

$\dfrac{p_1\left(\frac{N}{m^2}\right)}{\gamma\left(\frac{N}{m^3}\right)}$	0
$\dfrac{v_1^2\left(\frac{m}{s}\right)^2}{2\cdot g\left(\frac{m}{s^2}\right)}$	0
Losses in pipes $\left(\frac{s^2}{m^5}\right)$	92,58
$\dfrac{p_2\left(\frac{N}{m^2}\right)}{\gamma\left(\frac{N}{m^3}\right)}$	0

$\dfrac{v_2^2\left(\frac{\mathrm{m}}{s}\right)^2}{2\cdot g\left(\frac{\mathrm{m}}{s^2}\right)}$	0
Height difference (m)	63,07

Table 12. Characteristics of pumping at Sector 2

In this case, the resistance curve of Sector 2 is:

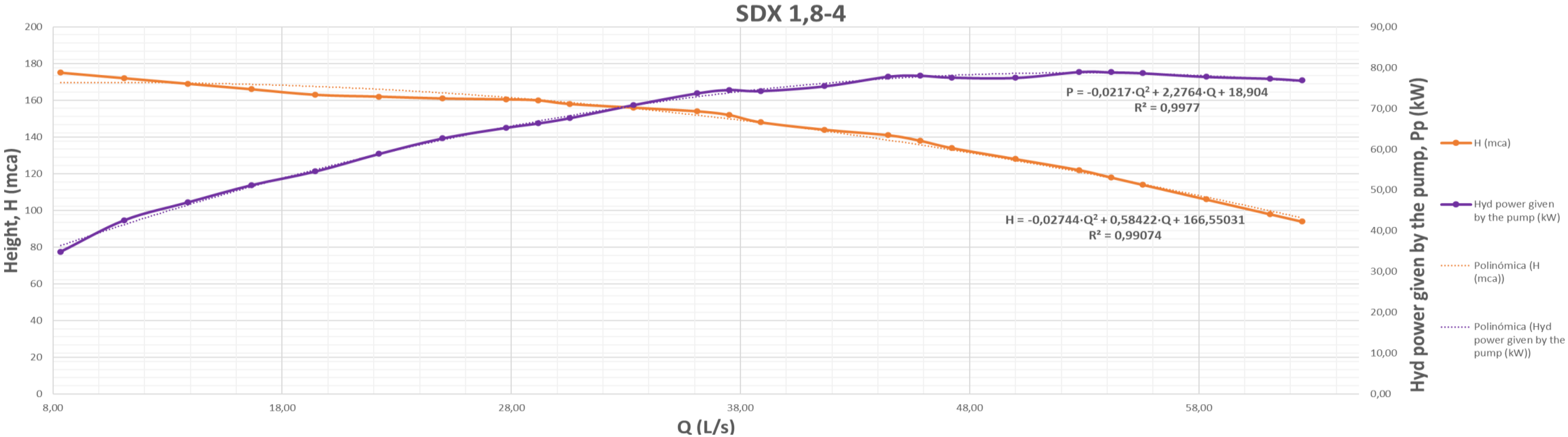
$$H^{r}{}_{Sector\ 2} = 63{,}07 + 92{,}58 \cdot Q^2{}_{Sector\ 2}$$

As can be seen, while in both sectors, due to the characteristics of the existing wells, the maximum extractable flow from them is the same, and therefore the maximum flow that each of the two pumping systems must also provide, in the case of Sector 1, the maximum required pumping head is much higher, around 200% of that of sector 1. This is due to two factors: on the one hand, the greater height difference between the water extraction point and the higher point of the network, and on the other hand, the smaller diameter and the greater length of the conduit that make the losses to overcome are much higher.

Once the maximum flow to be pumped is known (of around 0,1 m^3/s, as said before), as well as the necessary head to be provided by the pump (with that maximum flow, it would be of 125,65 m and 63,99 m for Sector 1 and 2, respectively), the commercial model that satisfies them must be chosen. In this sense, after comparing two commercial models, the following has been decided:

- In Sector 1, install two pumps in parallel, **model SDX 1,8-4**.
- In Sector 2, install two pumps in parallel, **model SDX 1,8-2**. Although it is true that in this case a commercial model has been found that, with a single pump, provided a maximum flow of 360 $\frac{m^3}{h}$ and a maximum head above 64 m, in this case it has also been decided to install two pumps in parallel of a lower-range model to avoid that, in the event of a pump failure, this does not affect the pumping, preventing it entirely, but rather that it can continue pumping at least 50% of the requested demand.

The characteristic curves of these commercial models, which are built with stainless steel and which motors are triphasic, have been represented in Excel both for the single models and for their parallel association in each sector, at their nominal speed (2900rpm-50Hz) and with 40 Hz. The operating frequency range is from 40 to 50 Hz. Their corresponding catalogues are attached in Annex IV:



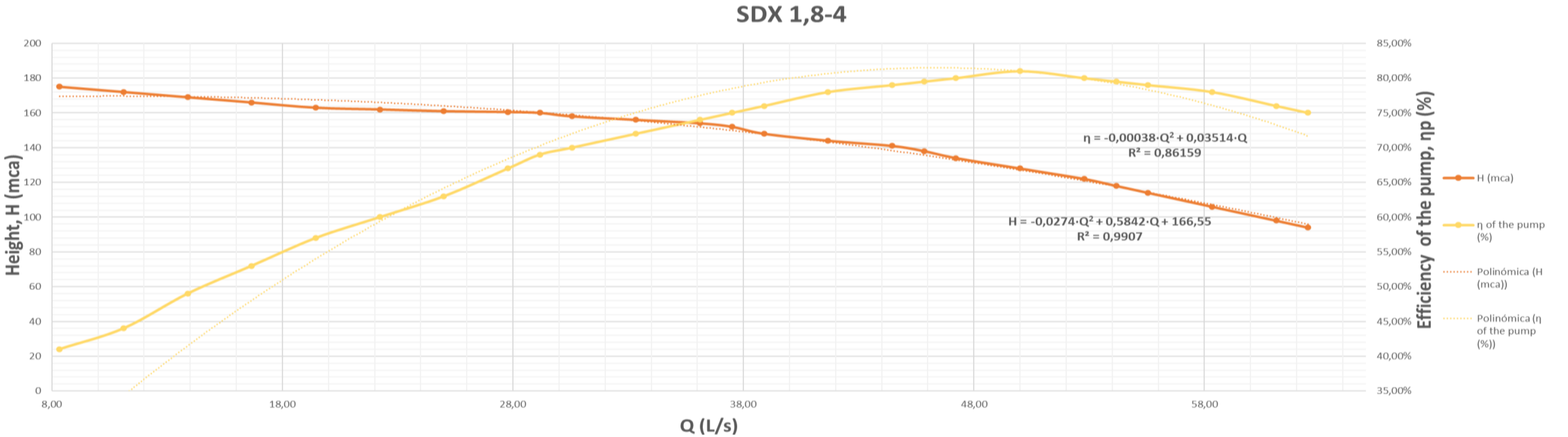
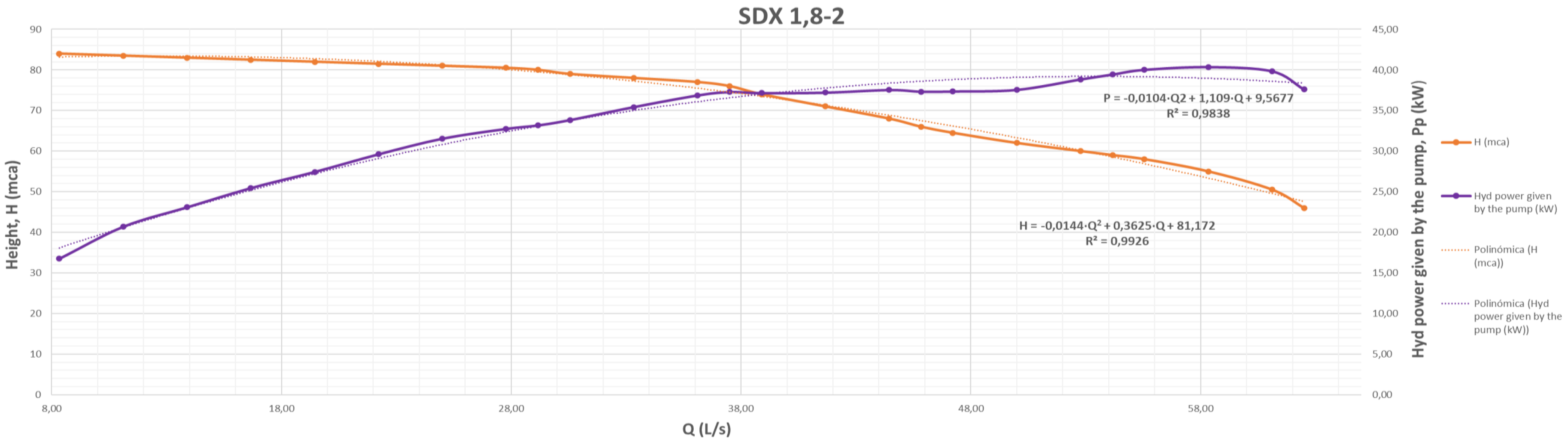


Figure 39. Q-H, Q-P and Q-η curves of selected model for Sector 1, in individual mounting. Source: Own, adapted from Bombas Ideal



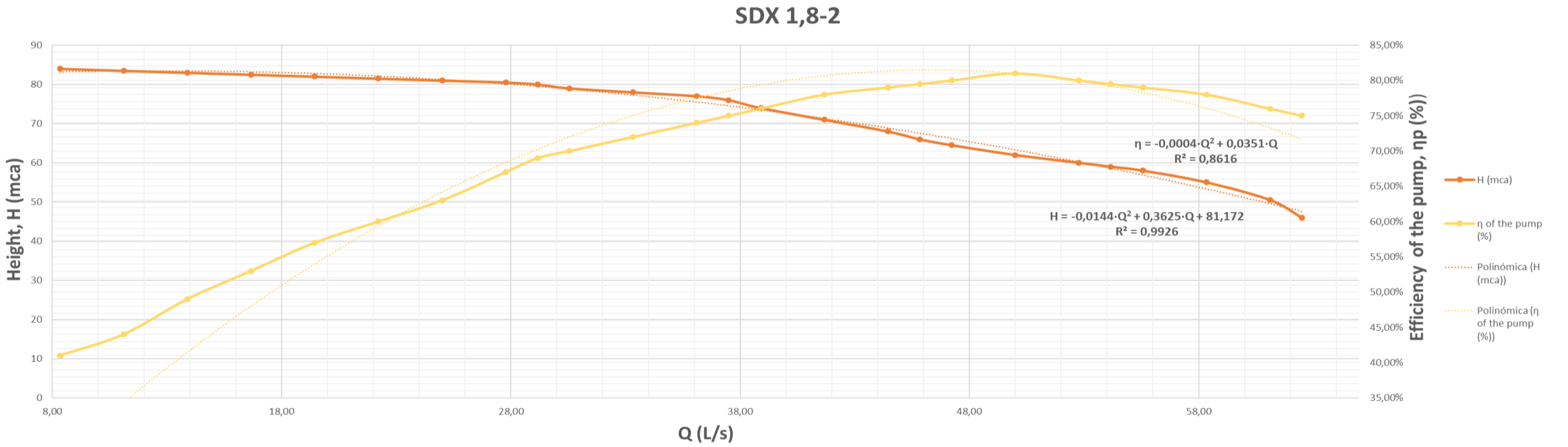


Figure 40. Q-H, Q-P and Q-η curves of selected model for Sector 2, in individual mounting. Source: Own, adapted from Bombas Ideal

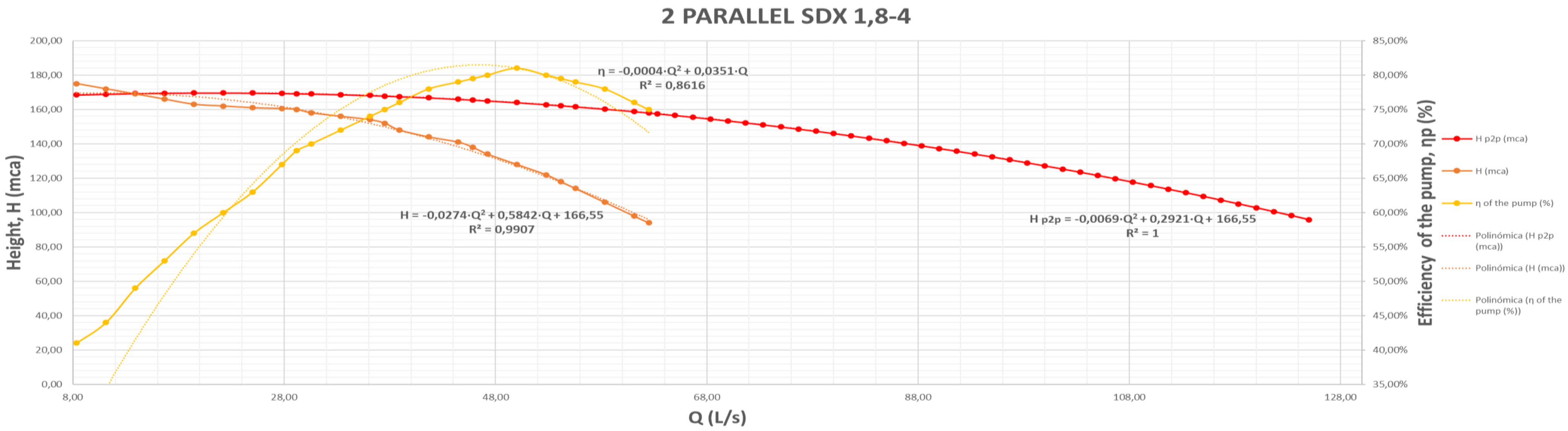


Figure 41. Q-H and Q-η curves of selected model for Sector 1, in parallel mounting. Source: Own, adapted from Bombas Ideal

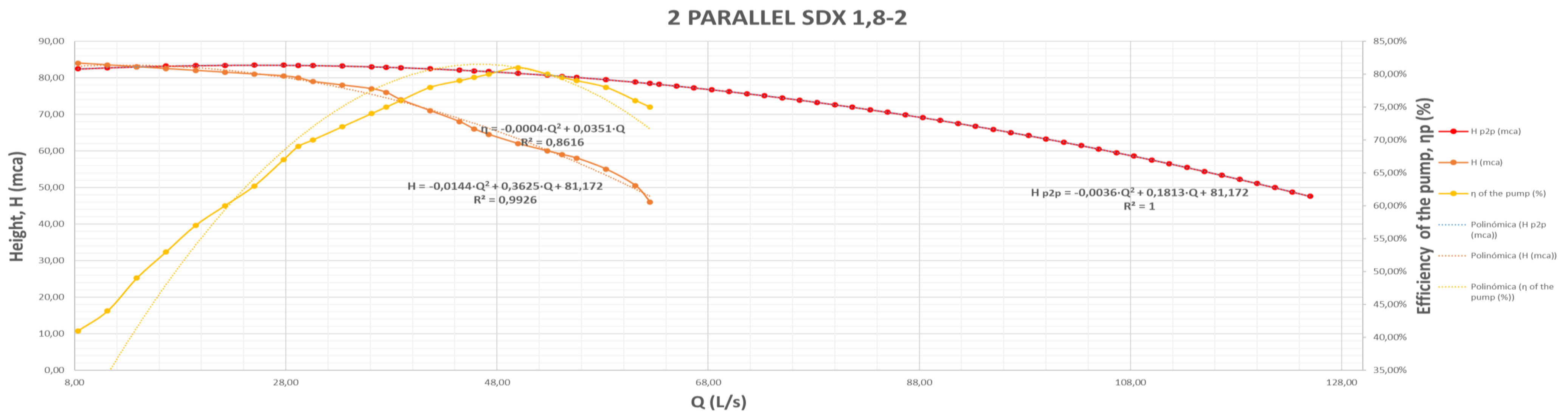


Figure 42. Q-H and Q-η curves of selected model for Sector 2, in parallel mounting. Source: Own, adapted from Bombas Ideal

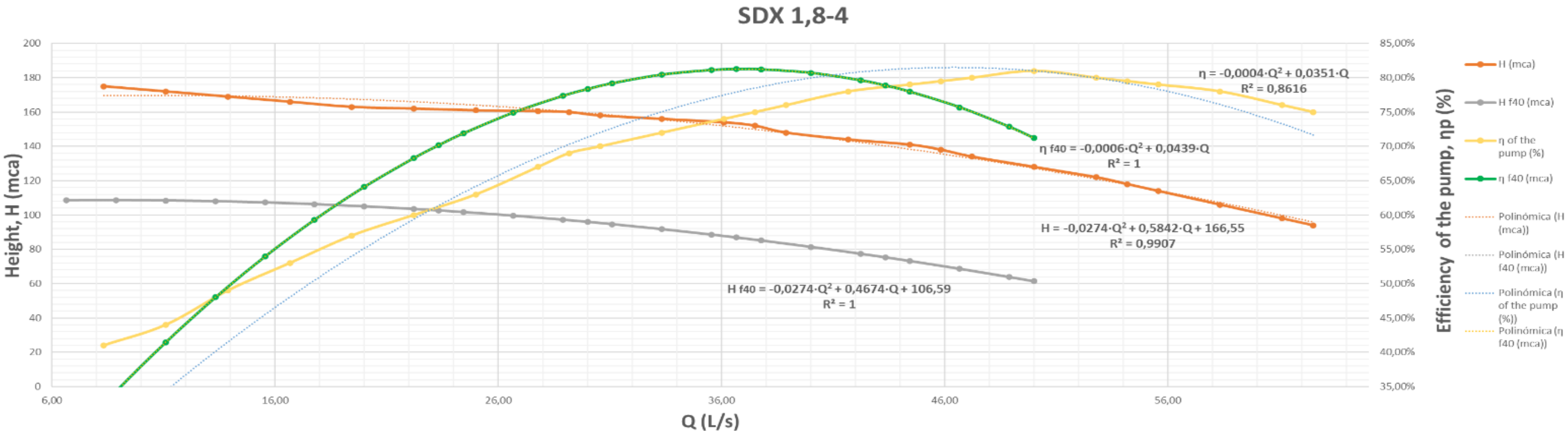


Figure 43. Q-H and Q-η curves of selected model in Sector 1, at 50 and 40 Hz. Source: Own, adapted from Bombas Ideal

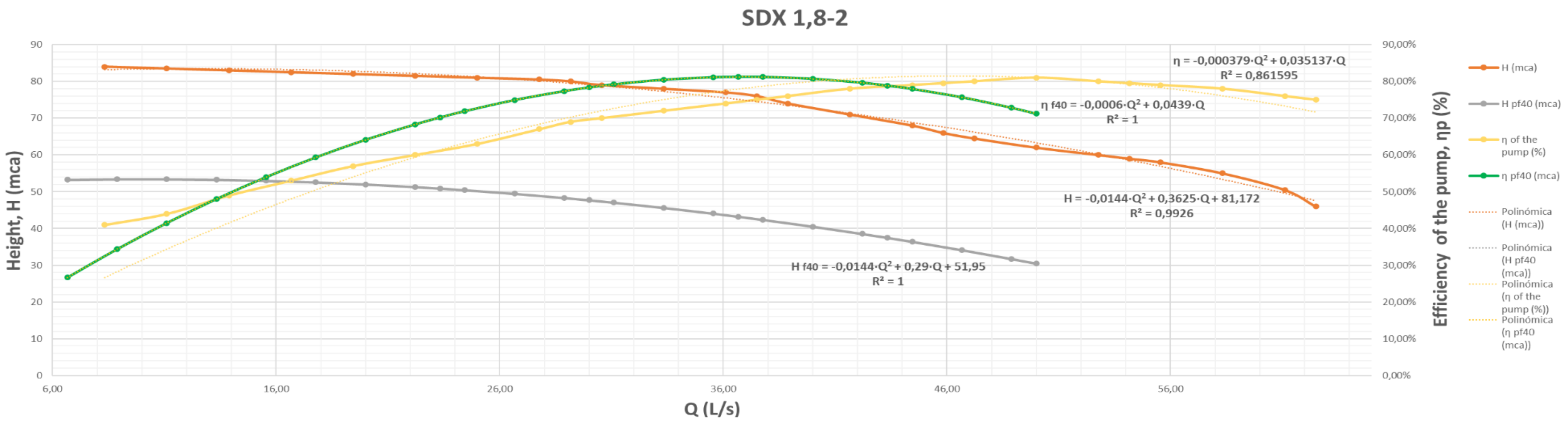


Figure 44. Q-H and Q-η curves of selected model in Sector 2, at 50 and 40 Hz. Source: Own, adapted from Bombas Ideal

The number at the end of the models names indicates the number of stages of the pumps (4 and 2 respectively). When choosing commercial pumps, firstly it was verified that they could meet the Q-H ratio required by the installation, and then attention was paid to the fact that, for their curves at 50 Hz, said operating point is at the last third of them, so that if it is necessary to reduce their turning frequency, the operating point approaches the maximum performance.

The choice of a submersible type of pump is clear: the depth of the well is greater than 35 m. If this depth was between 8 and 35 m, a jet pump for deep wells would have been selected, in which the ejector would be located below the water level and would have two tubes directed to the well, while for depths less than 8 m, a jet pump for shallow wells would have been chosen, so that the ejector would be located in the body of the pump and there would be a single tube directed to the well. The useful life of this type of device is between 15 and 20 years. These pumps will substitute the existing ones.

On the other hand, it is necessary to have a set of accessories in the pumping groups for their correct operation and work control, such as the flow meter, the pressure switch, the air vents which function is to empty the volumes of air that can accumulate in high points of the pipeline and that hinder the correct flow of water through it, and the filters that prevent the entry of solids of certain dimensions into the pumps and, with it, the obstructions and damage that would occur in them in case of contrary.

In addition, these pumps are not going to operate 24 hours a day, nor are they going to do so by driving the same flow and providing the same head constantly. Given the need to vary the flow that each pumping group supplies, it is possible to follow two strategies: carry out a regulation at a fixed speed, or at a variable speed.

In the first case, valves which degree of opening is regulated to modify the circulation flow are used. It is a more inefficient method, in which the head also changes,

The second case, which turns out to be a more economical and efficient option, consists of using a frequency inverter. In this way, by requiring a lower flow than the one previously driven, it is possible to keep the pressure (head) constant and, therefore, the power consumed is also reduced.

In this project the second strategy is chosen, so it will be necessary to look for a suitable frequency inverter from among those commercial models found in the different internet catalogues. In this sense, considering the operating point at a constant head, the performance increases when the frequency (and therefore the flow) decreases. However, it should be clear that below a certain frequency value, the pump is not capable of delivering the requested head.

3.3 Approach to possible alternatives

Before calculating the energy needs of the pumping groups, it is necessary to propose different alternatives that allow, with the greatest safety and lowest possible cost, to supply them. In this sense, the following possibilities have been proposed:

- **Self-supply only through solar panels**: In this case, the energy needs would be satisfied only through the photovoltaic system. Therefore, energy recovery by the PATs would not be considered, thereby losing not only the use of energy that would otherwise be dissipated by PRV, but also the reduction of greenhouse gases associated with the generation of the corresponding amount of energy in case it was obtained through non-renewable energy sources, such as coal. For this reason, it seems an undesirable scenario, in which an opportunity to optimize the obtaining of energy resources is being consciously lost. On the other hand, electricity generation is subject to certain restrictions, such as variable weather conditions, which leads to a lack of uniformity in electricity generation, or the limitation of available space for the installation of the panels.

- **Self-supply through solar panels + PATs**: This is the option that, at least a priori, is more attractive and the one that is intended to be achieved, since it achieves energy self-sufficiency, without having other expensive elements that require high maintenance and taking advantage of recoverable energy to reduce either the electricity tariff in case of grid connection, or the number of solar panels in case of not using said grid connection. As in the previous case, its difficulty lies mainly in the availability of the required space and in the climatological variability.

- **Self-supply through solar panels + PATs with or without batteries and with or without generator sets**: This scenario is undesirable and unlikely. It would try to achieve the self-sufficiency of the system through the installation of auxiliary groups, either batteries or generators. It is not desirable because they are expensive groups and they significantly complicate the maintenance of the installation.

- **Self-supply through solar panels + PATs and energy from the network**: In this case, the maximum degree of self-supply capacity would be installed and the consumptions not satisfied by the pv installation would be fed by the electricity of the grid. PATs generation is also taken into account.

- **Connection to the network of the pumping groups**: Finally, the situation arises in which the energy needs are not covered by means of the different installed elements that have been raised in the previous cases. Therefore, the connection of the pumps to the electrical network would be established so that in this way the energy requirements are met. It is the easiest solution but it would naturally have the costs associated with the electricity rate.

On the other hand, the strategy is clear: during peak hours, when the price of electricity consumed from the grid is higher, an attempt will be made to pump the maximum possible flow by means of the energy provided by the photovoltaic installation if the remaining capacity of the corresponding water tank is sufficient, so that in off-peak hours, when the cost is much lower, the energy from the network is used in case it is necessary to pump more water.

However, and as a consequence of the particularities of the water needs and of the water pumping and storage systems of each sector, the strategy differs from one to the other. In this way, with the hours in which solar radiation is available (the irradiance threshold from which it is usually considered that the received one is enough to allow the water pumping is usually between 200 and 400 W/m^2, so in this project, 300 W/m^2 has been taken as the minimum value to consider that the pumping can be carried out by photovoltaic energy) and the pumping flow of the installation of Sector 1, not only the water needs of the same can be supplied, but there is also a considerable number of hours per year in which, as no pumping is required, this solar resource can be used to generate electricity that would be poured into the grid (after conversion to alternating current) for sale, thereby generating profits while the tank is able to keep irrigation needs satisfied. On the other hand, it should be emphasized that it has been established, as a regulation strategy, not to pump during those hours in which the radiation was lower than the previously indicated minimum value, to let the tank empty and to pump again at those times when enough radiation is received until it reaches its maximum capacity, at which point it stops pumping again until its capacity is around 15% of its maximum. Therefore, in this sector, if so decided, it would be possible to supply the energy and water needs by pumping water from the well during a fraction of the annual hours in which sufficient irradiance is received without requiring the injection of electricity from the electrical network, being able to sell the energy surpluses.

In the case of Sector 2, regulation is not so simple. Due to the high water needs, in this case it is not only not possible to meet the energy and water demands not even pumping all the annual hours with sufficient radiation, but also during the months of highest consumption (May-September) it is required a certain contribution of electricity from the network to pump during the night hours. In this case, it has also been decided to pump using photovoltaic energy once 15% of the capacity of the corresponding reservoir has been reached and until it is filled, and on the other hand the energy from the network has been used when the stored volume was already scarce, 10% of capacity, during night hours.

The value of 15%, in both cases, has been set in order to ensure that the remaining capacity of the reservoirs was sufficient to supply the water needs for at least the next 6 hours in the event that solar radiation was not available in those hours (passage of a cloud or rainy day).

In this way, the "*Sociedad de Riego Canyoles 1*" intends to obtain a study on the technical-economic feasibility of the installation of a photovoltaic system that, to a greater or lesser extent, achieves self-sufficiency of the energy needs of the pumping systems. Apart from the economic and environmental benefits, by installing a photovoltaic solar pumping system, aid could be obtained for the modernization of irrigation systems, based on the provisions of ORDER 27/2018 of November 28, 2018, of the *Consellería de Agricultura, Mendioambiente, Cambio Climático and Desarrollo Rural*, by which "the regulatory bases for granting aid to irrigation communities and other irrigation entities are approved, in relation to the promotion of the rational use of water ".

In Annex I the graphs that represent the temporal evolution of the stored volume in each reservoir, as well as the incident irradiance in the photovoltaic installation as a function of its coordinates and the position of the photovoltaic module, can be found.

3.4 Calculation of the power required at the input of the pump motor

To recap, there is:

- In Sector 1 it has been decided to install two pumps in parallel, model SDX 1,8-4. The operating point at which the pumping group will work, obtained by intersecting the Q-H motor curve that defines the parallel association of two equal machines (see corresponding graph) and the resistance curve of the installation, is Q = 100,94 L/s; H = 126,14 m.
- In Sector 2 it has been decided to install two pumps in parallel, model SDX 1.8-2. The operating point at which the pumping group will work, obtained by intersecting the Q-H motor curve that defines the parallel association of two equal machines (see corresponding graph) and the resistance curve of the installation, is Q = 98,74 L/s; H = 63,97 m.

Once the operating point corresponding to each sector is known, either through the analytical expression obtained by representing the power corresponding to each operating point of the commercial pump according to the Q-H curve attached to its catalogue, or through the traditional power formula, the physical power (or received by the fluid) can be obtained:

$$P_f = \frac{\gamma \cdot \mathrm{Q} \cdot \mathrm{H}}{1000}$$

Equation 7. Power received by the fluid

Where:

- $\boldsymbol{P_f}$: Power received by the fluid (kW)
- γ: Specific gravity of the water fluid. It has been taken from 9810 $\frac{N}{m^3}$
- $\boldsymbol{Q}$: Flow to be driven by the pump ($\frac{m^3}{s}$)
- $\boldsymbol{H}$: Height to be supplied by the pump (m)

If in this formula, and successive formulas for obtaining the power in previous stages, the values of Q and H corresponding to the association of the pumps in parallel are entered, the total power is obtained. If values per pump are used, the power should be doubled accordingly.

Next, according to the hydraulic performance obtained for the operating point and which curve as a function of the pumped flow has also been represented for the parallel association of the two selected commercial models, the summed power is obtained on the axis of the two pumps (or power that both pumps must provide, jointly).

$$P_p = \frac{\gamma \cdot \mathrm{Q} \cdot \mathrm{H}}{\eta_h \cdot 1000} = \frac{P_f}{\eta_h}$$

Equation 8. Power to provide by a pump

Being:

- $\boldsymbol{P_p}$: Power that the pump(s) must provide (kW)
- $\boldsymbol{\eta_h}$: Hydraulic performance of the pump (-)

After this, knowing the performance of the electric motor coupled to the pump, the power consumed by said motor is determined. This is the total power that is required at the input of both pump motors.

$$P_e = \frac{\gamma \cdot \mathrm{Q} \cdot \mathrm{H}}{\eta_h \cdot \eta_e \cdot 1000} = \frac{P_f}{\eta_h \cdot \eta_e} = \frac{P_f}{\eta_g} = \frac{P_p}{\eta_e}$$

Equation 9. Electric power consumed by an electric engine

In which:

- $\boldsymbol{P_e}$: Electric power consumed by the engine(s) (kW)
- $\boldsymbol{\eta_e}$: Electric performance of the engine (-)
- $\boldsymbol{\eta_g}$: Global performance of the motor-pump system (-)

The results of these calculations are represented in the table below, for both sectors and considering the parallel association of the pumps:

Sector 1 (Canyoles I)

Q (L/s)	H (m)	P_f (kW)	η_h (%)	P_p (kW)	η_e(%)	η_g(%)	P_e (kW)
100,94	126,14	124,91	80,56	155,05	86	69,28	180,29

Table 13. Operating point, performances and powers of the pumping groups of Sector 1

Sector 2 (El Tollo)

Q (L/s)	H (m)	P_f (kW)	η_h (%)	P_p (kW)	η_e(%)	η_g(%)	P_e (kW)
98,74	63,97	61,96	80,87	76,63	86	69,54	89,10

Table 14. Operating point, performances and powers of the pumping groups of Sector 2

3.5 Determination of the optimal position of the photovoltaic modules

3.5.1 Obtention of the incident solar irradiance

Now that the power that must be provided to the motors is known, it is necessary to determine the configuration and particularities of the photovoltaic installation as a whole, trying to optimize said configuration to try to maximize the obtaining of photovoltaic energy, use the least number of components and make the most of the available terrain, all this to increase the benefits obtained by the implementation of the photovoltaic system.

To do this, the first step consists in obtaining the hourly irradiance levels in the area where the photovoltaic park is wanted to be located, for each month of the year. In that sense, to obtain these (and other) data in the area, the Photovoltaic Geographical Information System (PVGIS) website is accessed (although it would be also possible to obtain these data from other sources, such as the "*Instituto Nacional de Meteorología*" or official autonomic institutions, PVGIS has been selected since it is the most precise and widely used source in Europe). It is an application developed by the European Commission Joint Research Center in 2001 and which has been improved and updated in subsequent years, the purpose of which is to provide reliable data on solar energy, radiation and photovoltaic performance of autonomous installations and connected to the net. This web page offers a user manual to learn more about the calculation procedure of this tool.

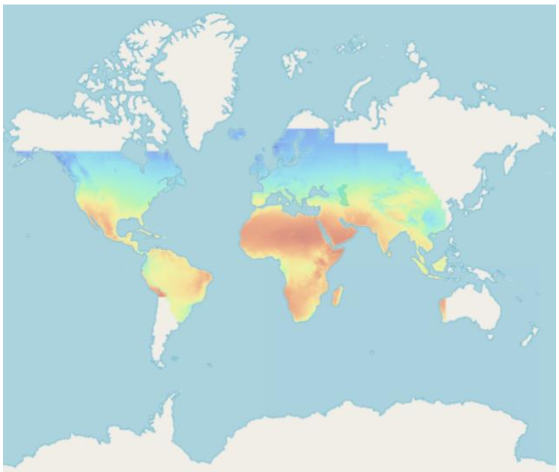


Figure 45. World regions for which PVGIS provides data

The first step to determine the available solar energy is, naturally, to know the coordinates of the location where the installation of the photovoltaic system would take place. In this case, these coordinates of the limits of the pv installation are:

Corner	Latitude	Length
Superior (North)	38° 54' 53.748" (38.91493°)	0° 42' 17.388" (-0.70483°)
Lower (South)	38° 54' 50.112" (38.91392°)	0° 42' 11.448" (-0.70319°)
Right (East)	38° 54' 53.892" (38.91497°)	0° 42' 12.492" (-0.70347°)
Left (West)	38° 54' 50.184" (38.91394°)	0° 42' 16.740" (-0.70465°)

Figure 46. Coordinates of the limits of the pv installation

The average values used for obtaining the hourly irradiance and temperature data correspond to average coordinates:

- **Latitude: 38°54'52"N (38.914°)**
- **Length: 0°42'14.4"W (-0.704°)**
- **Elevation: 318 m**

On the other hand, the irradiance values obtained throughout each of the months of the year also depend on two factors that define the position of the photovoltaic modules: their **orientation** or azimuth **α** and their **inclination β**.

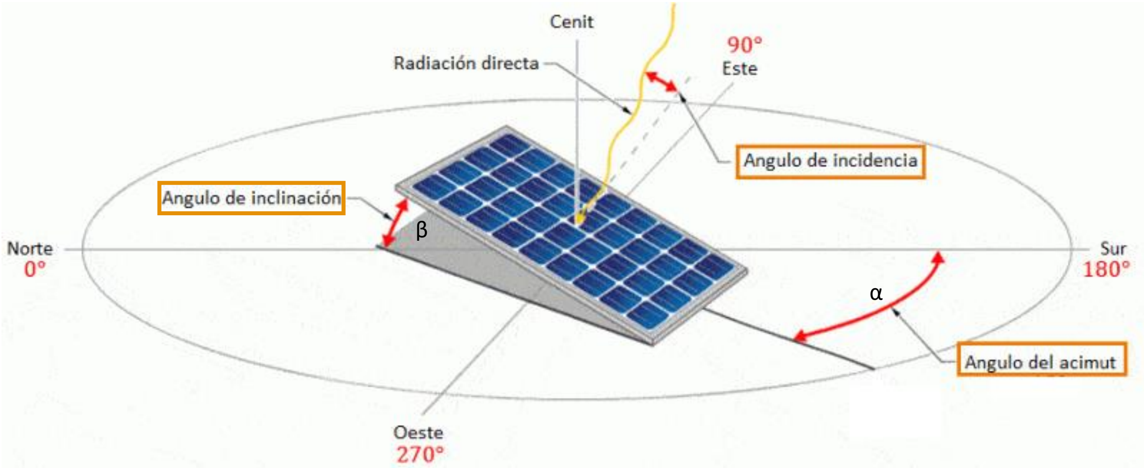


Figure 47. Characteristic parameters of the position of the photovoltaic module. Source: SunFields Europe

Azimuth is defined as the angle formed between the reference direction (North) and the line formed between the observer and the observed point in the same plane as the reference direction. Since in the Northern hemisphere, where the terrain on which the photovoltaic installation calculated and designed in this thesis is projected, the panels must be oriented towards the South to optimally take advantage of the incident solar radiation, it is sought that the azimuth angle is 0, that is α_{opt}= 0°, so that the installed panels have said optimal orientation that maximizes the radiation captured.

For its part, the inclination of a module is interpreted as the angle that its surface forms with the horizontal terrain. This factor is key, since it largely determines the solar energy capture that can be achieved. As is logical, since the height of the sun in the celestial vault varies throughout the year, and the more it will vary the closer it is to the poles, the optimal inclination of these modules is also different in each month of the year. The following image conveniently illustrates this circumstance and allows to intuit that the highest optimal angles correspond to those months with less irradiance (October-March), while the smaller angles, closer to 0°, are given for the months in which the irradiance is higher (April-September).

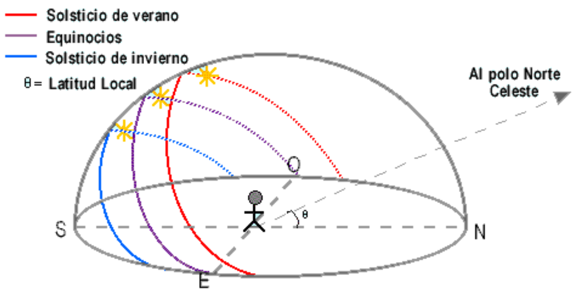


Figure 48. Solar trajectory at different times of the year (North hemisphere). Source: University of Cantabria

For this reason, photovoltaic systems with 1 or 2-axis solar tracking offer a substantial improvement in the annual capture of solar energy, although their cost is higher and their maintenance is more complex. However, as usually happens in isolated type solar installations, in this case it is initially decided to choose an installation with a fixed structure, without solar tracking on any axis. In this way, a compromise solution must be reached that allows the energy received to be maximized by maintaining a fixed angle of inclination throughout the year and, in turn, satisfying energy needs.

3.5.2 Criteria for the selection of the optimal inclination angle

Once the irradiance levels are known at the location of interest and for the different inclinations considered in the study, the next step is to apply a method or criterion that allows determining the optimal angle of inclination of the photovoltaic panels, so that maintaining this angle throughout the year, the dimensioned photovoltaic system guarantees the coverage of energy needs. In order to obtain this optimal angle of inclination, four possible criteria are contemplated:

- **Criterion of the critical month**: The purpose of this criterion is to establish the optimum angle of inclination of the photovoltaic modules in such a way as to guarantee the necessary energy supply in the worst month, in terms of radiation received. This criterion consists of three steps, which are the following:

  - Firstly, the quotient between the average hourly energy per month required by the pumping system and the value of hourly irradiance received in the corresponding month is calculated for each of the inclinations considered in the study and each month of the year.
  - Next, the maximum quotient for each of the inclinations must be identified. In this way, the critical month is the one that groups a greater number of the highest value of these ratios for the different inclinations.
  - Finally, the optimal inclination is the one that corresponds, within the month identified as critical, with the smallest value of its quotients.

  In this way, what this criterion does is, in the first place, to know the month for which it is more difficult to satisfy the energy needs (since the quotient between said needs and the incident radiation is higher) and, once known, to determine the inclination that allows a greater capture of solar energy (that is why the quotient is, in this case, the lowest).

  The results of the application of this method give $\beta_{opt} = 20°$ as the optimum angle.

- **Criterion of maximum annual energy capture**: For its part, this criterion consists of two steps:
  - The first step is to know the annual mean value of daily radiation for each inclination.
  - The second one consists in proceeding, in a similar way to the previous criterion, to calculate the quotient between the average needs, in this case annual, of daily energy, and said annual average values of daily radiation. In this way, the smallest quotient corresponds to the optimum inclination of the photovoltaic modules.

	H (β) Average year										
	0º	**10º**	**20º**	**30º**	**35º**	**36º**	**40º**	**50º**	**60º**	**70º**	**80º**
Year	4,852	5,237	5,507	5,648	5,669	**5,670**	5,658	5,536	5,277	4,887	4,383

Table 15. Annual mean value of daily radiation for each inclination

  In this way, it is observed how the optimal angle of inclination (according to this criterion) that allows a greater annual energy capture is 36º, since it provides the maximum annual average value of daily radiation captured. On the other hand, you can check how this value is the same that PVGIS provides as the optimal inclination.

  Therefore, in this case, $\beta_{opt} = 36°$

- **Statistical criterion:** The following formula is based on statistical analysis of annual solar radiation on surfaces with different inclinations located in places of different latitudes and provides the optimal inclination as a function of the latitude of the place:

$$\beta_{opt} = 3{,}7 + 0{,}69 \cdot |\Phi|$$

Equation 10. Obtention of the optimum inclination angle by the statistical criterion

Where :
  - $|\boldsymbol{\Phi}|$: Latitude of the place, in absolute value (°)

According to this criterion, the optimal angle would be: $\beta_{opt} = 3{,}7 + 0{,}69 * |38{,}9| \rightarrow \beta_{opt} = 30{,}5°$

- **Design period criterion**: This criterion is set out in the "*Pliego de Condiciones Técnicas de Instalaciones Aisladas de Red*" (IDAE):

Design period	Optimal inclination
December (winter)	Latitude +10°
July (summer)	Latitude -20°
Annual	Latitude -10°

Figure 49. Optimal inclination of the photovoltaic panel depending on the design period. Source: IDAE

In this case, the optimal inclination would be: $\beta_{opt} = 38{,}9 - 10 \rightarrow \beta_{opt} = 28{,}9°$

The criterion finally chosen has been the second one (maximum annual energy capture), so the optimal inclination angle established for this project is $\beta_{opt} = 36°$. However, the calculations are approached using **β= 35°**,. This is due to the inclination angles with which the commercial models of support structures for photovoltaic modules are offered (from 5°, to 30 or 35°, usually, 5 in 5). The radiation levels received on an annual average are really close (around 99.97%) and their monthly variation is also minimal (around 1% at most), so it does not affect the installation.

3.6 Radiation on the generator with a position different from the optimum

As is logical, if the photovoltaic generator is not configured with its optimal position (orientation and inclination), the incident radiation will not be captured optimally either and thus the resulting electricity generation will not be the maximum potentially obtainable either. The acceptable limit values for this type of loss are developed in the corresponding section (see Losses considered in the pv system. Performance Ratio). For its part, in this section we proceed to detail the process to determine the real radiation values based on the position of the panels:

- First, it is necessary to determine the Irradiation Factor, which expression is:

$$IF \begin{cases} 1 - \left[1{,}2 \cdot 10^{-4} \cdot \left(\beta - \beta_{opt}\right)^2 + 3{,}5 \cdot 10^{-5} \cdot \alpha^2\right] & if\ \beta \in (15{,}90)° \\ 1 - \left[1{,}2 \cdot 10^{-4} \cdot \left(\beta - \beta_{opt}\right)^2\right] & if\ \beta < 15° \end{cases}$$

Equation 11. Irradiation factor of the incident irradiance

Where:
  - $\boldsymbol{IF}$: Irradiation factor (-)
  - $\boldsymbol{\beta}$: Inclination angle of the pv panels (°). In this case, the value of β is adopted as the β_{opt} established for the project (that is, 36°)

- $\boldsymbol{\beta_{opt}}$: Optimal inclination angle of the pv panels (°)
- $\boldsymbol{\alpha}$: Orientation angle of the pv panels (°)

- Next, the Ratio Factor must be calculated:

$$K = \frac{H_{dm}(0, \beta_{opt})}{H_{dm}(0)}$$

Equation 12. Ratio factor of the incident irradiance

Being:
- $\boldsymbol{K}$: Ratio factor (-)
- $\boldsymbol{H_{dm}(0, \beta_{opt})}$: Monthly mean values of daily irradiation, for the optimal position, that is optimal orientation ($\alpha = \alpha_{opt}$) and optimal inclination ($\beta = \beta_{opt}$) ($\frac{\text{Wh}^2}{\text{m}}$)
- $\boldsymbol{H_{dm}(0)}$: Monthly mean values of daily irradiation, with optimal orientation ($\alpha = \alpha_{opt}$) but horizontal surface ($\beta = 0°$) ($\frac{\text{Wh}^2}{\text{m}}$)

- Finally, the real radiation is obtained by means of the following equation:

$$H_{dm,i}(\alpha, \beta) = IF \cdot K \cdot H_{dm}(0) = IF \cdot H_{dm}(0, \beta_{opt})$$

Equation 13. Real incident irradiation

In which:
- $\boldsymbol{H_{dm,i}(\alpha, \beta)}$: Monthly mean values of daily irradiation, with an orientation angle α and an inclination angle β ($\frac{\text{Wh}^2}{\text{m}}$)

Since in this case there is no difficulty or impediment in orienting the solar panels in an optimal way (that is, with azimuth $\alpha = \alpha_{opt} = 0°$), and the optimum inclination angle of the panels has been adopted, the IF has a value of 1, so the values of $H_{dm,i}(\alpha, \beta)$ are the same as $H_{dm}(0, \beta_{opt})$ for each month. Therefore, the values provided by PVGIS do not need to be modified.

3.7 Calculation of the power to install in the photovoltaic generator

Now, the performance of the inverter must be used to determine the power required at the input of said component. Initially, the inverter (and battery if used) performance used values are chosen by estimation, using usual values. This is because in order to calculate in the first instance the energy that the photovoltaic installation must provide, it is necessary to use these parameters. As will be developed in the following points, the photovoltaic generator must then be dimensioned according to the position (orientation and inclination) and the arrangement of the panels (the separation that is left between rows of panels in their 4 directions).

The performance initially considered was 97,5% until the most appropriate commercial model was subsequently selected, at which point the calculations were redone.

$$P_{inv} = \frac{P_e}{\eta_{inv}}$$

Equation 14. Power at the input of the inverter (without batteries)

In which:

- $\boldsymbol{P_{inv}}$: Power required at the inverter input (kW)
- $\boldsymbol{\eta_{inv}}$: Inverter energy efficiency (-)

And in case of those systems in which batteries are installed to store part of the energy produced, the formula that would allow knowing the value of the power required at the output of the photovoltaic generator would be:

$$P_{inv} = \frac{P_e}{\eta_{inv} \cdot \eta_{bat}}$$

Equation 15. Power at the input of the inverter (with batteries)

Being:

- $\boldsymbol{\eta_{bat}}$: Battery energy efficiency (-)

Finally, by setting a PR of the photovoltaic solar generator until the losses of the wiring sections (and others) are known, the power that must be installed in the photovoltaic field is known. The initial value chosen has been 0,75, which is a common value in installations without batteries (0,7-0,8 generally, achieving values of 0,85 or even more in some cases). To establish this starting value of PR, the following percentages of the different losses that take place in these energy systems, and which are developed in the corresponding section in this document, have been estimated:

- Orientation and tilt losses: 3,5% (the panels face south, then the orientation is optimal, and the slope is almost identical to optimal)
- Shadow losses: 7,5%
- Cell temperature losses: 2,5% These losses were already considered before, so they are not included now
- Losses due to mismatch effect: 2%
- Losses due to dust: 1,5%
- Angular and spectral losses: 1,5%
- Losses due to non-compliance with nominal power: 5%
- Ohmic losses in the DC section: 1,5% (voltage drop limit value according to ITC-BT-40)
- Losses in the MPPT system: 1,5%
- Losses in the DC/AC converter: 2,5%. These losses were already considered before, so they are not included now (<u>the complete PR would be 70%</u>)
- Ohmic losses in the AC section: 1,5% (voltage drop limit value according to ITC-BT-40)
- Other losses: 2,5%

So, the power of the pv generator is given by the following expression:

$$P_{pv\ gen} = \frac{P_{inv}}{PR}$$

Equation 16. Required power at the output of the pv generator

Where:

- $\boldsymbol{P_{pv\ gen}}$: Required power of the pv generator (kW)
- $\boldsymbol{PR}$: Performance Ratio of the installation (-)

When the inverter is selected, and the new losses obtained with the commercial section of the DC and AC cabling are taking into account, a new PR is calculated (this time including the efficiency of the inverter but not the losses due to temperature, they are applied apart to know the power that the module is capable of delivering). This PR is estimated at the end of this Document and applied in the Document 4 to obtain the new annual profits/expenses.

The results of these calculations are represented in the table below, for both sectors and considering the parallel association of the pumps:

Sector 1 (Canyoles I)

P_e (kW)	η_{inv} (%)	P_{inv} (kW)	PR (%)	$P_{pv\ gen}$ (kW)
180,29	99,1	181,93	75	242,58

Table 16. Performances and powers required at the photovoltaic system of Sector 1

Sector 2 (El Tollo)

P_e (kW)	η_{inv} (%)	P_{inv} (kW)	PR (%)	$P_{pv\ gen}$ (kW)
89,10	99,1	89,91	75	119,88

Table 17. Performances and powers required at the photovoltaic system of Sector 2

3.8 Photovoltaic generator sizing

After determining the power that the photovoltaic generator to install must have in each sector, as well as the optimal orientation and inclination of the panels, it is time to establish the arrangement of the panels on the surface in which they are going to be located and select the comercial model that is considered most appropriate, as well as the total number of panels theoretically necessary and the one finally set. These calculations will be addressed in this section.

3.8.1 Commercial PV panels compared

For the selection of the panel, the power it is capable to generate, its performance, dimensions and price have been taken into account, all with the aim of maximizing the electrical production of the solar field and, therefore, the economic benefit, as well as occupy the least possible surface and spend as few money as possible.

With this objective, in this section, after comparing some commercial models, the dimensions and functional characteristics of three of them are detailed below:

Mechanical data			
Parameter	**Panel 1**	**Panel 2**	**Panel 3**
Length (m)	1,623	1,979	1,960
Width (m)	1,048	1,002	992
Thickness (mm)	35	40	40
Mass (Kg)	18,5	22,5	22,1
Front Glass (mm)	3,2	3,2	3,2
Framework	Anodized aluminium	Aluminium hollow-chamber on each side	Anodized aluminium

Table 18. Mechanical data of the comercial pv panels compared

Panel characteristics			
Parameter	**Panel 1**	**Panel 2**	**Panel 3**
Rated power-Pmax (W)	335	400	330

Nominal Power Tolerance (W)	4,99	-	5
Voltage at point Pmax-VMPP (V)	37,05	41,7	37,7
Current at point Pmax-IMPP (A)	9,05	9,60	8,76
Open Circuit Voltage-VOC (V)	45,15	49,8	45,8
Short Circuit Current-ISC (A)	9,49	10,36	9,22
Module efficiency ηm (%)	19,70%	20,17%	17,00%
Nominal Operation Celule Temperature -NOCT (ºC)	45	45	42
Variation of maximum generator power (% / ºC)	-0,37%	-0,57%	-0,38%
Temperature factor of open circuit voltage (% / ºC)	-0,28%	-0,38%	-0,33%
Short-circuit current temperature factor (% / ºC)	0,05%	0,03%	0,07%

Table 19. Characteristics of the comercial pv panels compared

Where:

- **Panel 1**: Seraphim Eclipse SRP-335-E01B-HV (unit price: 151,84 €)
- **Panel 2**: ERA Solar ESPSC400 (unit price: 135,65 €)
- **Panel 3**: Suntech STP330 (unit price: 135,18 €)

3.8.2 Minimum distance between rows of modules

In addition to the azimuthal angle and inclination, which, as previously indicated, determine the position of the photovoltaic module, the separation between said modules is another determining factor when it comes to maximizing solar irradiance capture. By optimizing this parameter, what is sought is to minimize the shadows that some photovoltaic panels (or another type of element or obstacle) can project on others that are in their vicinity. These shadows have a lower incidence in summer, since the path of the sun is much more vertical.

On the other hand, depending on whether the placement of the panels is portrait or landscape, the shadows generated will be greater or less respectively, but it will also influence the use of the available space, in this case being greater and less, respectively.

Figure 50. Portrait vs Landscape disposition of the solar panels. Source: Conermex

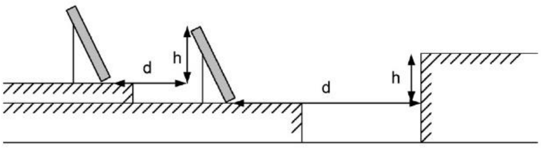
In this way, both the *Código Técnico de la Edificación* (CTE) and the *Pieglos de Condiciones Técnicas* of the *IDAE* specify that "the distance d, measured on the horizontal, between a row of collectors and an obstacle of height h, which can produce shadows on the installation, you must guarantee a minimum of 4 hours of sunshine around noon of the winter solstice". Said distance between rows of modules must be greater than the value d, provided by the following equation:

$$d = \frac{h}{\tan(61º - \Phi)}$$

Equation 17. Minimum required distance between rows of modules (I)

Where:

- $\boldsymbol{d}$: Distance between rows of modules (m)
- $\boldsymbol{h}$: Height of the module or obstacle, or the difference in heights between the top of one row and the bottom of the next (m)
- $\boldsymbol{\Phi}$: Latitude of the place (°)



At the same time, since:

$$k = \frac{1}{\tan(61^\circ - \Phi)}$$

Equation 18. Obtention of the "k" factor for the distance between modules

And

$$h = L \cdot \sin\beta$$

Equation 19. Relation between the height of the module and the inclination angle

Where:

- $\boldsymbol{L}$: Length of the side of the pv module with β inclination with respect to the horizontal (m). This will be the longest side of the panel, if portrait configuration is adopted, whereas it will be the shortest in case landscape configuration is chosen. Obviously, $\beta = \beta_{opt}$ in these calculations

Thus, the formula of distance *d* can be also expressed this way:

$$d = k \cdot h = k \cdot (L \cdot \sin\beta)$$

Equation 20. Minimum required distance between rows of modules (II)

On the other hand, to know the horizontal projection that the photovoltaic panel makes on the ground, the following expression is used:

$$b = L \cdot \cos\beta$$

Equation 21. Horizontal projection of the module

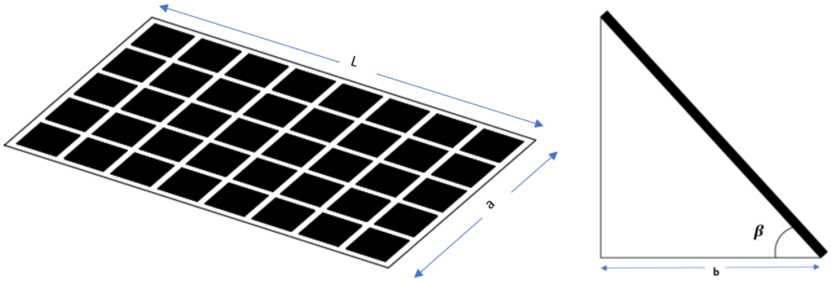


Figure 51. Nomenclature used in the dimensions of photovoltaic panels. Source: Own

Therefore, depending on whether the panels are installed in portrait or landscape configuration, the values of these parameters, as well as the area required by each of them, will be slightly different.

On the other hand, it is also relevant to know both the area occupied by the projection of the panels on the ground (A_s) and the surface necessary to maintain the minimum distance between rows of panels (A_{bm}). These areas, as well as the sum of both and representing the surface that each panel requires for its installation (A_t), are also reflected in the following table:

Parameter	Panel 1		Panel 2		Panel 3	
	Portrait config	Landscape config	Portrait config	Landscape config	Portrait config	Landscape config
β (°)	35					
Φ (°)	38,92					
L (m)	1,62	1,05	1,98	1,00	1,96	0,99
h (m)	0,93	0,60	1,14	0,57	1,12	0,57
k (-)	2,46	2,46	2,46	2,46	2,46	2,46
d (m)	2,29	1,48	2,80	1,42	2,77	1,40
b (m)	1,33	0,86	1,62	0,82	1,61	0,81
a (m)	1,05	1,62	1,00	1,98	0,99	1,96
A_s (m^2)	1,39	1,39	1,62	1,62	1,59	1,59
A_{bm} (m^2)	2,40	2,40	2,80	2,80	2,75	2,75
A_t (m^2)	3,80	3,80	4,43	4,43	4,34	4,34

Table 20. Geometric parameters related to the arrangement of photovoltaic panels

It has been decided to arrange the panels in a **portrait configuration**.

3.8.3 Comparison of the commercial modules and selection of the best option

In first place, it is necessary to determine the maximum power that each module is capable of providing at each operating moment based on the irradiance and temperature of the place. For this, the following function is used, which expresses the variation of the maximum power that the module is capable of delivering in STC and which is provided in its corresponding commercial catalogue when the temperature and irradiance values are different from these standard values:

$$P_{m\,mod} = P_{m\,mod\,(STC)} \cdot \frac{G_{loc}(\alpha,\beta)}{G_{STC}} \cdot \left[1 + \frac{\gamma_p}{100} \cdot \left(T_{cel} - T_{cel\,(STC)}\right)\right]$$

Equation 22. Maximum deliverable power by a photovoltaic module

Being:

- $\boldsymbol{P_{m\,mod}}$: Maximum power that the module is capable of delivering depending on the irradiance received and the ambient temperature (W)
- $\boldsymbol{P_{m\,mod\,(STC)}}$: Maximum power that the module is capable of delivering in STC (W)
- $\boldsymbol{G_{loc}(\alpha,\beta)}$: Effective irradiance received by the solar collector surface according to its orientation and inclination (W/m^2)
- $\boldsymbol{G_{STC}}$: Irradiance under standard test conditions (STC). Its value is equal to 1000 W/m^2
- γ_p: Coefficient of variation of the maximum power of the module with its temperature (%/°C)
- $\boldsymbol{T_{cel\,(STC)}}$: Temperature of the photovoltaic cell in STC (°C). Its value is equal to 25 °C.
- $\boldsymbol{T_{cel}}$: Temperature of the photovoltaic cell depending on the ambient temperature of the site and the irradiance received (ºC). The value of this parameter is obtained by means of the following formula:

$$T_{cel} = T_{loc} + \frac{NOCT - 20}{800} \cdot G_{loc}(\alpha,\beta)$$

Equation 23. Temperature of the cells of a photovoltaic module

Where, in turn:

- $\boldsymbol{T_{loc}}$: Ambient temperature of the location (°C)
- $\boldsymbol{NOCT}$: Nominal Operating Cell Temperature of photovoltaic cells= 45 °C. Conditions: Irradiance: 800 W/m^2; AM 1,5 G spectral distribution; ambient temperature: 20 °C; wind speed: 1 m / s

At the same time, the minimum number of modules that must be installed to achieve the required power is given by:

$$N_T = \frac{P_{pv\,gen}}{P_{m\,mod}}$$

Equation 24. Number of total required modules

Taking into account the 3 commercial panels previously selected for their comparison, this has been carried out as follows: for each hour of each day, the maximum power that the module is capable of delivering is different due to the variation in irradiance and the temperature, so the number of modules theoretically necessary to achieve to produce the corresponding necessary power in each one of the sectors is remarkably different. In this sense, for each hour of the year in which the irradiance threshold considered as a minimum (300 W/m^2) is reached and water pumping is required, it has been calculated, for each of the 3 commercial panels compared and in the two sectors of the study, the number of panels necessary to reach this power. In addition, the acquisition cost of said number of panels and the occupied surface have also been calculated. Due to the large amount of data (a matrix of 8760x12 for each sector), only the results of these calculations for two days of the year (January 1st and July 15th, due to their irradiance and temperature disparities) are attached, as an illustration, for both sectors:

Sector 1 (Canyoles I)

Hour (h)	$P_{pv\,gen}$ (kW)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)
0													
1													
2													
3													
4													
5													
6													
7													
8													
9	242,58	116,60	2081	315969,68	7903,04	140,75	1724	233863,19	7632,96	115,47	2101	284021,58	9120,87
10	242,58	182,34	1331	202093,05	5054,76	216,61	1120	151929,68	4958,77	180,99	1341	181281,74	5821,55
11	242,58	205,45	1181	179317,73	4485,10	241,98	1003	136058,45	4440,76	204,10	1189	160733,78	5161,69
12	242,58	142,92	1698	257816,68	6448,52	169,96	1428	193710,34	6322,43	141,63	1713	231570,19	7436,48
13	242,58	176,22	1377	209077,48	5229,45	208,07	1166	158169,65	5162,43	174,85	1388	187635,39	6025,59
14	242,58	135,67	1789	271633,71	6794,11	161,50	1502	203748,55	6650,06	134,40	1805	244007,12	7835,87
15	242,58	104,41	2324	352865,70	8825,89	125,02	1941	263299,56	8593,73	103,32	2348	317412,03	10193,15
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Table 21. Maximum deliverable power and number of modules required each hour depending on the conditions of irradiance and temperature, cost and occupied surface. January 1st. Sector 1

Hour (h)	$P_{pv\,gen}$ (kW)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)
0													
1													
2													
3													
4													
5													
6													
7													
8	242,58	148,28	1636	248402,88	6213,06	172,27	1409	191132,96	6238,31	146,89	1652	223323,97	7171,67
9	242,58	203,58	1192	180987,92	4526,87	232,59	1043	141484,51	4617,85	202,13	1201	162355,98	5213,79
10	242,58	250,63	968	146976,76	3676,19	281,64	862	116931,59	3816,48	249,40	973	131534,03	4223,99
11	242,58	277,10	876	133007,90	3326,80	307,72	789	107029,03	3493,28	276,12	879	118826,74	3815,92
12	242,58	288,22	842	127845,49	3197,68	317,69	764	103637,75	3382,59	287,36	845	114230,48	3668,32
13	242,58	280,47	865	131337,71	3285,02	309,61	784	106350,78	3471,14	279,53	868	117339,71	3768,16
14	242,58	252,44	961	145913,92	3649,60	280,93	864	117202,90	3825,34	251,21	966	130587,74	4193,60
15	242,58	209,03	1161	176281,02	4409,15	235,48	1031	139856,70	4564,73	207,57	1169	158030,10	5074,87
16	242,58	149,73	1621	246125,35	6156,09	171,90	1412	191539,92	6251,59	148,29	1636	221161,02	7102,21
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19													
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23													

Table 22. Maximum deliverable power and number of modules required each hour depending on the conditions of irradiance and temperature, cost and occupied surface. July 15th. Sector 1

Sector 2 (El Tollo)

Hour (h)	$P_{pv\,gen}$ (kW)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)
0													
1													
2													
3													
4													
5													
6													
7													
8													
9	119,88	116,60	1029	156238,73	3907,85	140,75	852	115575,08	3772,21	115,47	1039	140456,18	4510,51
10	119,88	182,34	658	99907,76	2498,90	216,61	554	75150,93	2452,82	180,99	663	89626,99	2878,22
11	119,88	205,45	584	88671,93	2217,86	241,98	496	67283,14	2196,03	204,10	588	79488,19	2552,63
12	119,88	142,92	839	127389,98	3186,28	169,96	706	95769,96	3125,80	141,63	847	114500,85	3677,00
13	119,88	176,22	681	103399,98	2586,24	208,07	577	78270,92	2554,65	174,85	686	92736,22	2978,07
14	119,88	135,67	884	134222,58	3357,18	161,50	743	100789,06	3289,61	134,40	892	120584,13	3872,35
15	119,88	104,41	1149	174458,99	4363,57	125,02	959	130089,79	4245,95	103,32	1161	156948,62	5040,14
16													
17													
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Table 23. Maximum deliverable power and number of modules required each hour depending on the conditions of irradiance and temperature, cost and occupied surface. January 1st. Sector 2

Hour (h)	$P_{pv\,gen}$ (kW)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)	$P_{m\,mod}$ (W)	N_T (-)	Cost (€)	S (m^2)
0													
1													
2													
3													
4													
5													
6													
7													
8	119,88	148,28	809	122834,92	3072,35	172,27	696	94413,44	3081,52	146,89	817	110445,33	3546,76
9	119,88	203,58	589	89431,11	2236,85	232,59	516	69996,17	2284,58	202,13	594	80299,30	2578,68
10	119,88	250,63	479	72729,20	1819,10	281,64	426	57787,54	1886,10	249,40	481	65023,50	2088,12
11	119,88	277,10	433	65744,77	1644,41	307,72	390	52904,09	1726,71	276,12	435	58805,04	1888,42
12	119,88	288,22	416	63163,57	1579,85	317,69	378	51276,27	1673,58	287,36	418	56506,91	1814,62
13	119,88	280,47	428	64985,59	1625,42	309,61	388	52632,78	1717,86	279,53	429	57993,94	1862,38
14	119,88	252,44	475	72121,86	1803,91	280,93	427	57923,19	1890,53	251,21	478	64617,95	2075,10
15	119,88	209,03	574	87153,58	2179,89	235,48	510	69182,27	2258,01	207,57	578	78136,35	2509,22
16	119,88	149,73	801	121620,24	3041,97	171,90	698	94684,75	3090,38	148,29	809	109363,86	3512,03
17													
18													
19													
20													
21													
22													
23													

Table 24. Maximum deliverable power and number of modules required each hour depending on the conditions of irradiance and temperature, cost and occupied surface. July 15th. Sector 2

In the previous tables the results for panel 1 are in red, for panel 2 in green, and for panel 3 in blue.

The irradiance and ambient temperature during these hours of operation, as well as the corresponding cell temperature, are as follows:

Hour (h)	Irradiance G(i) (W/m^2)	Ambient temperature T_{loc} (°C)	Cell temperature T_{cel} (°C)
9	340,99	8,74	19,40
10	549,44	10,36	27,53
11	628,67	11,97	31,62
12	429,85	13,59	27,02
13	536,86	13,68	30,46
14	407,24	13,77	26,50
15	310,01	13,87	23,55

Table 25. Irradiance, ambient temperature and cell temperature. January 1st

Hour (h)	Irradiance G(i) (W/m^2)	Ambient temperature T_{loc} (°C)	Cell temperature T_{cel} (°C)
8	464,78	23,35	37,88
9	656,20	24,47	44,98
10	829,65	25,62	51,55
11	934,26	26,78	55,98
12	982,66	27,93	58,64
13	954,18	28,31	58,12
14	848,34	28,69	55,20
15	689,27	29,06	50,60
16	478,74	27,99	42,95

Table 26. Irradiance, ambient temperature and cell temperature. July 15th

Once these results are obtained, it can be found that, in the most unfavourable hour (lower irradiance and / or very high temperatures), the values of these parameters are, for each commercial panel and each sector (and in total), the following:

Sector 1 (Canyoles I)

	Panel 1	Panel 2	Panel 3
Max number of required panels (-)	2530	2193	2560
Max cost of panels (€)	384.143,82	297.483,74	346.071,04
Max occupied surface (m^2)	9608,22	9709,45	11113,48

Table 27. Maximum number of required panels, cost and occupied area in Sector 1

Sector 2 (El Tollo)

	Panel 1	Panel 2	Panel 3
Max number of required panels (-)	1165	1084	1266
Max cost of panels (€)	189.794,38	147.046,23	171.142,94
Max occupied surface (m^2)	4747,14	4799,38	5495,96

Table 28. Maximum number of required panels, cost and occupied area in Sector 2

Total

	Panel 1	Panel 2	Panel 3
Max number of required panels (-)	3695	3277	3826
Max cost of panels (€)	573.938,19	444.529,97	517.213,98
Max occupied surface (m^2)	14355,36	14508,83	16609,45

Table 29. Total maximum number of required panels, cost and occupied area

At this point the final choice of panel 2 seems obvious, but it is not, since several factors must be weighed:

Panel 3 is ruled out from the outset, since it is the one that gives rise not only to the largest number of modules required to achieve the necessary power, but also to the largest surface area necessary for its installation. As for the other two panels, panel 1 requires more units than panel 2, and the cost is also much higher. The surface occupied by the total of panels 2 is higher, but slightly. In this way, with panel 2 it is possible to reach the total power of the photovoltaic field with a smaller number of panels and a significantly lower investment, being in fact the smallest of all of them and with a significant difference. It is a panel that, with a very close unit price to the smallest one, produces a considerably higher power (16,41% compared to panel 1 and 18,89% compared to panel 3). This means that with a significantly lower number of panels, the required generator power is reached, what also reduces the necessary wiring between panels and the probability of failure or shading of any of them.

Although it is true that all of the aforementioned are advantages of panel 2, a disadvantage must be taken into account, which in hot climates such as Valencia´s between the months of June and September is relevant, and is the factor of loss of the maximum power with temperature. This factor is 54% higher than that of the other panels, which will mean that, if the panels determined as strictly necessary are installed, the power of the photovoltaic generator is lower in these months than that which would be obtained with the installation of the number of panels types 1 and 3, and therefore it would be required either to install a few more panels or to request a greater injection of current from the network.

Therefore, with all this, it has finally been decided to select **panel 2 (ERA Solar ESPSC400)** for its installation in the photovoltaic solar field.

3.9 Inverter calculations

The calculation of the parameters that define the operation of the inverter and its subsequent commercial selection are addressed in this section. After choosing the commercial panel and establishing the number of panels that must (and can) be used, the necessary parameters can now be calculated to be able to choose a specific commercial inverter also based on the type of photovoltaic system configuration chosen, so it is an iterative process. The values shown correspond to the performance of the comercial inverter.

First, it is necessary to set the number of modules that can be connected in series to this component. To do this, the following equations establish the limits of the interval of this number of modules:

$$N_{S\,max} = \frac{V_{DC\,inv\,max}}{V_{OC\,mod\,(Tmin\,mod)}};\ N_{S\,min} = \frac{V_{MPPT\,min}}{V_{M\,mod\,(Tmax\,mod)}}$$

Equation 25. Maximum and minimum number of modules that can be connected in series to one inverter

And, at the same time:

$$V_{OC\,mod\,(Tmin\,mod)} = V_{OC\,mod} + \beta_V \cdot (T_{\min mod} - 25°C) \cdot V_{OC\,mod}$$

Equation 26. Maximum voltage that can be reached in the module

$$V_{M\,mod\,(Tmax\,mod)} = V_{M\,mod} + \beta_V \cdot (T_{\max mod} - 25°C) \cdot V_{OC\,mod}$$

Equation 27. Minimum voltage that can be reached in the module

In which:

- $\boldsymbol{N_{S\,max}}$: Maximum number of modules that can be connected in series to the inverter. The result, if it is decimal, is rounded to the next lower integer.

- $\boldsymbol{V_{DC\ inv\ max}}$: Maximum voltage value that can be admitted at the input of the inverter (V)
- $\boldsymbol{V_{OC\ mod\ (Tmin\ mod)}}$: Maximum voltage value that can be reached in the module (V). It coincides with the open circuit voltage of the module with 1000 W/m^2, but the lowest temperature expected for the module.
- $\boldsymbol{V_{OC\ mod}}$: Open circuit voltage of the module (V) in STC.
- $\boldsymbol{T_{min\ mod}}$: Lowest temperature expected for the module ($°C$)
- $\boldsymbol{N_{S\ min}}$: Minimum number of modules that can be connected in series to the inverter. The result, if it is decimal, is rounded to the next higher integer.
- $\boldsymbol{V_{MPPT\ min}}$: Minimum voltage value that can be admitted at the input of the inverter MPPT system (V)
- $\boldsymbol{V_{M\ mod\ (Tmax\ mod)}}$: Minimum voltage value that can be reached in the module (V). It coincides with the voltage of the module at its maximum power point with 1000 W/m^2, but the highest temperature expected for the module.
- $\boldsymbol{V_{M\ mod}}$: Voltage of the module at its maximum power point (V)
- $\boldsymbol{T_{max\ mod}}$: Highest temperature expected for the module ($°C$)
- $\boldsymbol{\beta_V}$: Temperature coefficient of open circuit voltage of the module (% / °C)

Whereas the maximum number of modules that can be connected in parallel to the inverter is given by the expression shown below:

$$N_{P\ max} = \frac{I_{DC\ inv\ max}}{I_{SC\ mod\ (Tmax\ mod)}}$$

Equation 28. Maximum number of modules that can be connected in parallel to one inverter

And, at the same time:

$$I_{SC\ mod\ (Tmax\ mod)} = I_{SC\ mod} + \alpha_I \cdot (T_{\max mod} - 25°C) \cdot I_{SC\ mod}$$

Equation 29. Maximum current that can be provided by the module

Being:

- $\boldsymbol{N_{P\ max}}$: Maximum number of modules that can be connected in parallel to the inverter.
- $\boldsymbol{I_{DC\ inv\ max}}$: Maximum current value that can be admitted at the input of the inverter (A)
- $\boldsymbol{I_{SC\ mod\ (Tmax\ mod)}}$: Maximum current value that can be provided by the module (A). It coincides with the short circuit current of the module with 1000W/m^2, but the highest temperature expected for the module.
- $\boldsymbol{\alpha_I}$: Temperature coefficient of short circuit current of the module (% / °C)
- $\boldsymbol{I_{SC\ mod}}$: Short circuit current of the module (A)

In addition to the maximum number of modules that can be connected in series and parallel, and related to this, it is necessary to set limits on both the maximum voltage and the open circuit voltage and the short-circuit current that can reach the inverter, and that they must respect the capacity values of this component established in their commercial datasheet:

$$V_{M\ string} = N_S \cdot V_{M\ mod} \in \ (V_{MPPT\ min}, V_{MPPT\ max})$$

Equation 30. Maximum voltage of the string

$$V_{OC\ string} = N_S \cdot V_{OC\ mod} < V_{M\ adm\ inv}$$

Equation 31. Open circuit voltage of the string

$$I_{SC\ sos} = N_P \cdot \mathrm{I}_{SC\ mod} < I_{M\ adm\ inv}$$

Equation 32. Short circuit current of the set of strings in parallel

Where:

- $\boldsymbol{V_{M\ string}}$: Maximum voltage of the string (V)
- $\boldsymbol{V_{OC\ string}}$: Open circuit voltage of the string (V)
- $\boldsymbol{N_S}$: Number of modules that are finally connected in series in the string that leads to the inverter.
- $\boldsymbol{V_{M\ adm\ inv}}$: Maximum allowable voltage of the inverter (V)
- $\boldsymbol{I_{SC\ sos}}$: Short circuit current of the set of strings (A)
- $\boldsymbol{N_P}$: Number of strings that are finally connected in parallel to the inverter.

On the other hand, it is relevant to analyse the possible alternatives proposed when choosing the most appropriate inverter configuration:

- A possible configuration would result in choosing a large commercial inverter with connection capacity for a large number of photovoltaic modules, to establish a central inverter-type connection for all photovoltaic modules, that is, for those that supply the pumping system of the sector and as those that feed the sector 2.
- In a similar way, it was also thought to establish a central inverter, this time separately, one of them corresponding to the photovoltaic system of sector 1 and the other central inverter connected to the photovoltaic field that feeds the pumping system of the sector 2.
- A third possibility would be to carry out a multi-string type configuration for all the photovoltaic panels of the complete photovoltaic installation.
- Finally, it was proposed to use two individual multi-string systems, each one associated with the photovoltaic installation of the corresponding sector. This is the chosen scenario.

The configuration of grid connection inverters chosen is the 'multi-string' type, due to the reduction of the safety and reliability problems associated with this type in comparison with a central inverter. Furthermore, said configuration presents greater modularity. Additionally, it should be mentioned that the production problems (shading, breakdown, etc.) of each module affect the entire string, but not the installation as a whole. Finally, it is necessary to clarify that those strings which are connected to the same inverter must have the same number if panels connected in series. There will be two individual multi-string inverter systems, as said before.

Once the inverter configuration to be established has been determined, a comparison of the performance of 3 different commercial models has been carried out in a similar way as was done in the case of photovoltaic modules, in order to choose the model that meet the requirements demanded by the photovoltaic system at the lowest possible cost. The table that contains the most relevant technical data of these 3 commercial models is shown below:

Inverter characteristics			
	Inverter 1	**Inverter 2**	**Inverter 3**
Input parameters (DC)			
Recommended maximum power of the photovoltaic field (kWp)	159,5	120	37,8
MPPT voltage range (V)	627-850	450-820	580-850
Maximum voltage (V)	1100	900	1000
Maximum current (A)	185	258	47,7

Number of connections (-)	24	8	6
Output parameters (AC)			
Nominal output power (kW)	110	100	27
Nominal output voltage (V)	440	400 (±10%)	400 (+20% - 30%)
Output frequency (Hz)	50 - 60	50 - 60	50 - 60
Harmonic current distortion, THD (%), referet to nominal power	<3%	<3%	<2%
Nominal output current (A)	145	145	39
Power factor cos Φ (-)	1 (adjustable)	0.95 inductive - 0.95 capacitive (adjustable)	0 - 1 inductive / capacitive
Other technical parameters			
Nominal maximum efficiency (%)	99,1	97,1	98,3
European Performance (%)	98,5	96,5	98
Standby consumption (W)	20	<40	20
Dimensions (mm)	905x720x315	1700x1440x1040	725x510x225
Weight (kg)	78	1125	35,7
Permissible ambient temperature range (ºC)	-25°C / +60°C	-20°C / +50°C	-25°C / +60°C
Degree of protection (-)	IP65[1]/NEMA 4	IP54	IP66
Maximum height (m) from which the output power starts to reduce	1000	1000	2000

Table 30. Characteristics of the comercial inverters compared

Where:

- **Inverter 1**: Ingeteam INGECON SUN 3Play 100TL PRO (unit price: 9144,99 €)
- **Inverter 2**: Freesun LVT FS0100_T (unit price: 11860,55 €)
- **Inverter 3**: Fronius Eco 27.0-3-S (unit price: 3358,29 €)

[1]The IPxy degree of protection depends on the digits it has. The picture below shows the protection that each digit refers to:

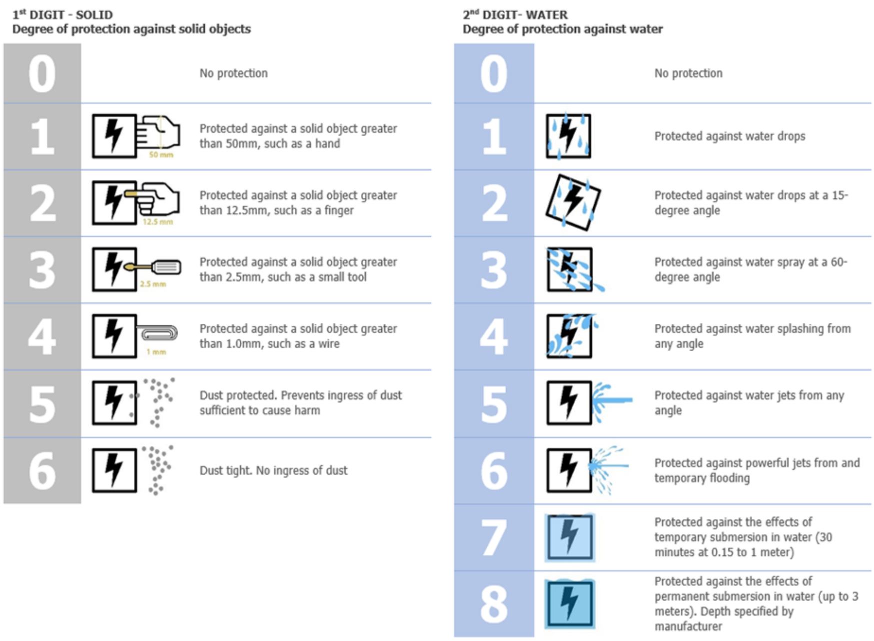


Figure 52. Degrees of Ingress Protection (IP). Source: Northcliffe.org

On the other hand, using the equations previously described, these limit values are represented in the table shown below:

Parameter	Inverter 1 (Ingeteam INGECON SUN 3Play 100TL PRO)	Inverter 2 (Freesun LVT FS0100_T)	Inverter 3 (Fronius Eco 27.0-3-S)
$V_{DC\ inv\ max}$ (V)	1100	900	1000
$V_{MPPT\ min}$ (V)	627	450	580
$V_{OC\ mod}$ (V)	49,8	49,8	49,8
$T_{min\ mod}$ (°C)	18,65	18,65	18,65
$V_{M\ mod}$ (V)	41,7	41,7	41,7
$T_{max\ mod}$ (°C)	63,35	63,35	63,35
β_V (% / °C)	-0,38%	-0,38%	-0,38%
$V_{OC\ mod\ (Tmin\ mod)}$ (V)	51,00	51,00	51,00
$V_{M\ mod\ (Tmax\ mod)}$ (V)	34,44	34,44	34,44
$N_{S\ max}$ (-)	21,57	17,65	19,61
$N_{S\ max\ ent}$ (-)	21	17	19
$N_{S\ min}$ (-)	18,20	13,07	16,84
$N_{S\ min\ ent}$ (-)	19	14	17
$I_{DC\ inv\ max}$ (A)	185	258	47,7
α_I (% / °C)	0,03%	0,03%	0,03%
$I_{SC\ mod}$ (A)	10,36	10,36	10,36
$I_{SC\ mod\ (Tmax\ mod)}$ (A)	10,48	10,48	10,48
$N_{P\ max}$ (-)	17,65	24,62	4,55
$N_{P\ max\ ent}$ (-)	17	24	4

Table 31. Values for the configuration of the string connections to the compared inverter commercial models

Next, it is necessary to define a certain number of modules to be installed in order to know what their optimal configuration should be in relation to the commercial inverter to which they are connected (or inverters, if more than one is required) prior connection to the DC connection box.

This will allow to choose the commercial inverter that best suits the number of panels needed, in addition to its voltage and current parameters. Just as an example, if 40% and 80% of the maximum number of modules needed were installed in Sector 1, this maximum number being the one corresponding to the most unfavourable time and that was determined in the previous section, and taking into account that each of the strings that reaches its corresponding inverter must have the same number of modules connected in series, the results obtained are shown in the following tables:

Sector 1			880
Parameter	Inverter 1 (Ingeteam INGECON SUN 3Play 100TL PRO)	Inverter 2 (Freesun LVT FS0100_T)	Inverter 3 (Fronius Eco 27.0-3-S)
$N_{S\ max\ ent}$ (-)	21	17	19
$N_{S\ min\ ent}$ (-)	19	14	17
$N_{P\ max\ ent}$ (-)	17	24	4
N_s (-)	20	16	18
N_p (-)	16	20	2
$V_{M\ string}$ (V)	834	667,2	750,6
Meets the condition 1?	SI	SI	SI
$V_{OC\ string}$ (V)	996	796,8	896,4
Meets the condition 2?	SI	SI	SI
$I_{SC\ sos}$ (A)	165,76	207,2	20,72
Meets the condition 3?	SI	SI	SI
$M_{per\ inv}$ (-)	320	320	36
N_{inv} (-)	2,75	2,75	24,44
$M_{comp\ inv}$ (-)	640	640	864
$M_{l\ inv}$ (-)	240	240	18
$N_{s\ l\ inv}$ (-)	20	15	18

$N_{p\,l\ \mathrm{inv}}$ (-)	12	16	1
$N_{inv\ \mathrm{fin}}$ (-)	3	3	25
Unit price (€/ud)	9144,99	11860,55	3358,29
Total cost (€)	27434,97	35581,65	83957,25

Table 32. Number of panels per string and number of strings per inverter model, quantity and total cost of inverters for 40% of the maximum estimated number of modules

Sector 1			1755
Parameter	**Inverter 1 (Ingeteam INGECON SUN 3Play 100TL PRO)**	**Inverter 2 (Freesun LVT FS0100_T)**	**Inverter 3 (Fronius Eco 27.0-3-S)**
$N_{S\,max\,ent}$ (-)	21	17	19
$N_{S\,min\,ent}$ (-)	19	14	17
$N_{P\,max\,ent}$ (-)	17	24	4
N_s (-)	19	16	17
N_p (-)	14	21	3
$V_{M\,string}$ (V)	792,3	667,2	708,9
Meets the condition 1?	SI	SI	SI
$V_{OC\,string}$ (V)	946,2	796,8	846,6
Meets the condition 2?	SI	SI	SI
$I_{SC\,sos}$ (A)	145,04	217,56	31,08
Meets the condition 3?	SI	SI	SI
$M_{per\ \mathrm{inv}}$ (-)	266	336	51
N_{inv} (-)	6,60	5,22	34,37
$M_{comp\ \mathrm{inv}}$ (-)	1596	1680	1734
$M_{l\,\mathrm{inv}}$ (-)	160	75	19
$N_{s\,l\ \mathrm{inv}}$ (-)	20	15	19
$N_{p\,l\ \mathrm{inv}}$ (-)	8	5	1
$N_{inv\ \mathrm{fin}}$ (-)	7	6	35
Unit price (€/ud)	9144,99	11860,55	3358,29
Total cost (€)	64014,93	71163,3	117540,15

Table 33. . Number of panels per string and number of strings per inverter model, quantity and total cost of inverters for 80% of the maximum estimated number of modules

Operating identically with other percentages, and in Sector 2 naturally in the same way, comparing the results, the **inverter 1 (Ingeteam INGECON SUN 3Play 100TL PRO)** has been selected for the pv installation. Despite the fact that in some cases the number of necessary inverters was one unit higher than the number of required inverters if they corresponded to the Inverter 2, in all the cases studied the total cost managed to be lower than both the cost of the necessary inverters 2 and 3. On the other hand, it should be noted that Inverter 3, due to its more limited features, was only capable to receive the connection of a much smaller number of panels, resulting in a much higher number of units needed and, in turn, in a higher cost.

3.9.1 Evaluation of alternatives in the sizing of the photovoltaic system

Once the commercial models of the photovoltaic module and the inverter are known, it is necessary to decide what will be the final number of modules to install and, consequently, also of inverters. At this point, it is necessary to take into account a series of conditioning factors that must be weighed in order to make an informed decision.

Therefore, at this point we have proceeded as follows, for each of the sectors:

- First, an Excel sheet has been generated in which the necessary power to install in the photovoltaic field has been set, as well as the maximum power that the module (panel 2) is capable of delivering and the number of modules theoretically necessary to reach this power in every hour of operation.
- Next, a series of tables have been generated in which the following parameters have been represented:
    - Percentage of modules installed.

- Number of modules installed.
- Acquisition cost of the modules.
- Extra (+) or missing (-) panels with respect to the required quantity.
- Percentage of the necessary energy produced by the installed modules compared to the necessary.
- Benefits obtained from the sale of surpluses. These benefits also take into account the sale of energy at times when irradiance is less than 300 W/m^2 and when it is higher than that value but pumping is not taking place.
- Expenses derived from the purchase of unmet needs.
- Total cost, sum of the cost of the necessary panels and the costs of purchasing electricity each hour.

After this, and as indicated in the section corresponding to the calculation of the parameters that define the inverter and the optimal configuration of the strings which current they receive, it has been proceeded for each of these percentages to determine the number of necessary inverters of the chosen model, in addition to calculating the cost of their purchase.

Then, with these investment expenses in the purchase of panels and inverters, as well as the annual incomes obtained from the sale of surplus energy and the annual expenses due to the purchase of the necessary energy, the cash flows, updated cash flows and updated accumulated cash flows are obtained for the next 25 years (with a k=2,5%), since it is the time horizon that has been taken for the project and that is a usual value. This is intended to visualize, in the absence of the complete economic study (developed in Document 4) with the NPV, TIR and PP in which other expenses and incomes are taken into account, such as pumps and PATs and the sale of energy that they recover, as well as the annually saved money, and other expenses such as cabling and protection elements against overvoltages and overcurrents, the evolution of expenses/income in the following years since the materialization of the project according to its initial dimensions. Thus, it is intended to select a suitable number of panels (and their corresponding inverters).

It is worth mentioning that at this point it has been tried to be as rigorous as possible. For this, not only the progressive annual reduction in the power generated by the panels has been taken into account (1% annual for 10 years and 0,67% annual for 15 years; see corresponding catalogue) and therefore the reduction in the energy sold and the increase in the purchase of energy, but also the evolution of the sale price of energy.

In this context, 0,05 €/kWh has been taken as the energy sale price. It is a price somewhat lower than the average of last 10 years that, according to the Statista website[1] , is around 0,0553 €/kWh. However, the price considered in this document has taken into account the small (but existing) additional expenses in the sale of energy. These are, on the one hand, the cost of representation, which takes into account the expense incurred by requiring a representative in the electricity market to manage the sale of the customer's energy by negotiating its sale price to obtain the maximum benefit in the transaction, and on the other hand, the generation access toll which reason is the corresponding payment that must be made to the electricity distribution company for using its facilities to transport electricity. The expenses considered have been 0,00082 €/kWh and 0,0005 €/kWh, respectively. As explained in the economic analysis section, an increase in the sale price of the surplus electricity, as well as in the purchase rate, of 2% per year, similar to the CPI of 2,2%, is considered.

These economical parameters have also been applied in the economic analysis of the Document 4.

These tables have been prepared for different percentages of the number of modules determined as necessary at the worst hour. These tables are provided in the following pages:

[1] https://es.statista.com/estadisticas/993787/precio-medio-final-de-la-electricidad-en-espana/

% of installed modules (%)	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Number of installed modules (-)	0	220	439	658	878	1097	1316	1536	1755	1974	2193
Acquisition cost of the modules (€)	0	-29843,33	-59551,0085	-89258,687	-119102,017	-148809,6955	-178517,374	-211616,34	-238068,3825	-267776,061	-297483,7395
Surface occupied by the modules (m^2)	0	974,04	1943,66	2913,28	3887,32	4856,94	5826,55	6800,60	7770,22	8739,83	9709,45
Acquisition cost of the inverters (€)	0	-9144,99	-18289,98	-18289,98	-27434,97	-36579,96	-45724,95	-54869,94	-64014,93	-64014,93	-73159,92
Profits obtained from the sale of surplus (€)	0	4375,644821	8753,02	13129,53	18019,24	24442,12	31686,14	39349,13	47230,82	55247,97	63337,64
Expenses derived from the purchase of unmet needs (€)	-27904,22	-21953,47	-16029,76	-10106,06	-5057,59	-2468,09	-1147,72	-458,88	-128,79	-11,50	0
Initial investment (€) year 0	0	-38988,32	-77840,9885	-107548,667	-146536,987	-185389,6555	-224242,324	-266486,28	-302083,3125	-331790,991	-370643,6595
Cash flow (€) year 1	-27904,22	-17841,11	-7524,57	2791,11	12730,89	21704,93	30210,09	38492,17	46628,43	54683,88	62704,26
Cash flow (€) year 2	-27904,22	-18104,40	-7772,40	2558,76	12500,12	21435,82	29881,75	38094,09	46154,83	54131,28	62070,89
Cash flow (€) year 3	-27904,22	-18367,69	-8020,23	2326,40	12269,35	21166,72	29553,41	37696,01	45681,24	53578,69	61437,51
Cash flow (€) year 4	-27904,22	-18630,99	-8268,06	2094,04	12038,58	20897,62	29225,07	37297,93	45207,64	53026,09	60804,13
Cash flow (€) year 5	-27904,22	-18894,28	-8515,88	1861,69	11807,81	20628,52	28896,73	36899,85	44734,05	52473,50	60170,76
Cash flow (€) year 6	-27904,22	-19188,42	-8825,42	1536,77	11450,01	20187,10	28345,00	36224,36	43927,47	51531,41	59090,85
Cash flow (€) year 7	-27904,22	-19481,67	-9133,19	1214,51	11095,85	19750,63	27799,69	35556,83	43130,45	50600,49	58023,76
Cash flow (€) year 8	-27904,22	-19774,05	-9439,20	894,87	10745,30	19319,05	27260,72	34897,18	42342,89	49680,64	56969,35
Cash flow (€) year 9	-27904,22	-20065,56	-9743,48	577,84	10398,32	18892,31	26728,03	34245,33	41564,69	48771,73	55927,49
Cash flow (€) year 10	-27904,22	-20356,21	-10046,04	263,38	10054,87	18470,37	26201,55	33601,19	40795,76	47873,67	54898,06
Cash flow (€) year 11	-27904,22	-20558,90	-10265,58	27,00	9789,20	18139,27	25786,01	33091,60	40186,90	47162,39	54082,72
Cash flow (€) year 12	-27904,22	-20760,95	-10483,86	-207,50	9526,12	17811,71	25375,04	32587,68	39584,86	46459,09	53276,52
Cash flow (€) year 13	-27904,22	-20962,37	-10700,89	-440,12	9265,62	17487,63	24968,60	32089,39	38989,57	45763,68	52479,38
Cash flow (€) year 14	-27904,22	-21163,18	-10916,68	-670,87	9007,67	17167,02	24566,64	31596,66	38400,97	45076,09	51691,19
Cash flow (€) year 15	-27904,22	-21363,38	-11131,24	-899,80	8752,24	16849,82	24169,12	31109,44	37818,98	44396,23	50911,88
Cash flow (€) year 16	-27904,22	-21562,97	-11344,59	-1126,90	8499,31	16536,02	23775,99	30627,68	37243,53	43724,04	50141,35
Cash flow (€) year 17	-27904,22	-21761,95	-11556,74	-1352,19	8248,85	16225,57	23387,21	30151,33	36674,57	43059,43	49379,51
Cash flow (€) year 18	-27904,22	-21960,35	-11767,70	-1575,71	8000,85	15918,45	23002,74	29680,32	36112,03	42402,33	48626,28
Cash flow (€) year 19	-27904,22	-22158,15	-11977,48	-1797,46	7755,26	15614,61	22622,53	29214,60	35555,84	41752,66	47881,57
Cash flow (€) year 20	-27904,22	-22355,37	-12186,09	-2017,46	7512,08	15314,02	22246,54	28754,12	35005,94	41110,35	47145,30
Cash flow (€) year 21	-27904,22	-22552,02	-12393,55	-2235,72	7271,27	15016,66	21874,72	28298,83	34462,27	40475,32	46417,37
Cash flow (€) year 22	-27904,22	-22748,09	-12599,87	-2452,28	7032,82	14722,49	21507,05	27848,68	33924,77	39847,50	45697,72
Cash flow (€) year 23	-27904,22	-22943,60	-12805,06	-2667,14	6796,69	14431,48	21143,47	27403,61	33393,37	39226,82	44986,24
Cash flow (€) year 24	-27904,22	-23138,55	-13009,13	-2880,31	6562,87	14143,59	20783,94	26963,58	32868,00	38613,21	44282,87
Cash flow (€) year 25	-27904,22	-23332,94	-13212,09	-3091,83	6331,32	13858,80	20428,42	26528,52	32348,62	38006,60	43587,52

Table 34. Evaluation of alternatives in the sizing of the photovoltaic system for Sector 1 (I)

Updated (€) year 1	-27223,63	-17405,96	-7341,05	2723,04	12420,38	21175,54	29473,25	37553,34	45491,15	53350,13	61174,89
Updated (€) year 2	-26559,64	-17232,03	-7397,88	2435,46	11897,79	20402,93	28441,88	36258,51	43930,84	51522,94	59079,96
Updated (€) year 3	-25911,84	-17056,23	-7447,58	2160,29	11393,31	19655,41	27443,28	35004,50	42419,57	49753,14	57050,84
Updated (€) year 4	-25279,84	-16878,75	-7490,45	1897,10	10906,36	18932,21	26476,47	33790,09	40955,89	48039,02	55085,54
Updated (€) year 5	-24663,26	-16699,79	-7526,80	1645,46	10436,38	18232,60	25540,50	32614,09	39538,38	46378,93	53182,18
Updated (€) year 6	-24061,72	-16546,11	-7610,13	1325,15	9873,31	17407,27	24441,81	31236,15	37878,52	44435,37	50953,86
Updated (€) year 7	-23474,85	-16389,25	-7683,43	1021,72	9334,55	16615,51	23386,91	29912,73	36284,15	42568,43	48813,37
Updated (€) year 8	-22902,29	-16229,48	-7747,19	734,46	8819,17	15856,04	22374,14	28641,74	34752,78	40775,21	46757,40
Updated (€) year 9	-22343,70	-16067,06	-7801,88	462,69	8326,23	15127,61	21401,89	27421,20	33282,03	39052,91	44782,73
Updated (€) year 10	-21798,73	-15902,24	-7847,95	205,76	7854,85	14429,02	20468,61	26249,20	31869,58	37398,83	42886,27
Updated (€) year 11	-21267,05	-15668,86	-7823,86	20,57	7460,79	13824,75	19652,67	25220,59	30628,24	35944,57	41218,86
Updated (€) year 12	-20748,34	-15436,92	-7795,33	-154,29	7083,20	13244,00	18867,76	24230,76	29433,56	34544,93	39614,07
Updated (€) year 13	-20242,29	-15206,53	-7762,64	-319,27	6721,47	12685,89	18112,73	23278,29	28283,83	33197,91	38069,61
Updated (€) year 14	-19748,57	-14977,76	-7726,03	-474,80	6374,97	12149,57	17386,48	22361,82	27177,41	31901,57	36583,26
Updated (€) year 15	-19266,90	-14750,68	-7685,74	-621,28	6043,12	11634,22	16687,94	21480,00	26112,70	30654,07	35152,90
Updated (€) year 16	-18796,98	-14525,35	-7642,00	-759,11	5725,35	11139,08	16016,10	20631,57	25088,17	29453,60	33776,46
Updated (€) year 17	-18338,51	-14301,85	-7595,03	-888,66	5421,11	10663,37	15369,96	19815,30	24102,35	28298,44	32451,97
Updated (€) year 18	-17891,23	-14080,23	-7545,04	-1010,29	5129,87	10206,36	14748,57	19030,01	23153,80	27186,93	31177,51
Updated (€) year 19	-17454,86	-13860,54	-7492,24	-1124,36	4851,13	9767,37	14151,02	18274,54	22241,16	26117,44	29951,25
Updated (€) year 20	-17029,13	-13642,83	-7436,82	-1231,19	4584,40	9345,70	13576,41	17547,80	21363,11	25088,45	28771,40
Updated (€) year 21	-16613,79	-13427,16	-7378,95	-1331,12	4329,22	8940,72	13023,91	16848,74	20518,37	24098,45	27636,27
Updated (€) year 22	-16208,57	-13213,56	-7318,82	-1424,44	4085,11	8551,78	12492,68	16176,31	19705,70	23146,01	26544,19
Updated (€) year 23	-15813,24	-13002,07	-7256,59	-1511,46	3851,66	8178,28	11981,94	15529,55	18923,93	22229,73	25493,58
Updated (€) year 24	-15427,55	-12792,73	-7192,43	-1592,46	3628,45	7819,64	11490,93	14907,50	18171,91	21348,29	24482,91
Updated (€) year 25	-15051,27	-12585,57	-7126,48	-1667,70	3415,06	7475,31	11018,90	14309,24	17448,54	20500,40	23510,70
Updated accumulated (€) year 1	-27223,63	-56394,28	-85182,03	-104825,63	-134116,61	-164214,12	-194769,07	-228932,94	-256592,16	-278440,87	-309468,77
Updated accumulated (€) year 2	-53783,26	-73626,32	-92579,92	-102390,17	-122218,82	-143811,19	-166327,19	-192674,43	-212661,32	-226917,93	-250388,80
Updated accumulated (€) year 3	-79695,10	-90682,55	-100027,49	-100229,88	-110825,51	-124155,79	-138883,92	-157669,94	-170241,75	-177164,79	-193337,97
Updated accumulated (€) year 4	-104974,95	-107561,30	-107517,94	-98332,77	-99919,15	-105223,57	-112407,45	-123879,85	-129285,86	-129125,77	-138252,42
Updated accumulated (€) year 5	-129638,21	-124261,09	-115044,74	-96687,31	-89482,77	-86990,97	-86866,95	-91265,76	-89747,48	-82746,84	-85070,24
Updated accumulated (€) year 6	-153699,93	-140807,20	-122654,88	-95362,16	-79609,46	-69583,70	-62425,14	-60029,60	-51868,96	-38311,47	-34116,38
Updated accumulated (€) year 7	-177174,77	-157196,45	-130338,31	-94340,44	-70274,91	-52968,18	-39038,23	-30116,88	-15584,81	4256,97	14696,99
Updated accumulated (€) year 8	-200077,07	-173425,94	-138085,50	-93605,98	-61455,74	-37112,14	-16664,08	-1475,14	19167,98	45032,18	61454,38
Updated accumulated (€) year 9	-222420,76	-189493,00	-145887,38	-93143,28	-53129,51	-21984,53	4737,81	25946,07	52450,01	84085,09	106237,11
Updated accumulated (€) year 10	-244219,49	-205395,24	-153735,33	-92937,53	-45274,66	-7555,51	25206,42	52195,27	84319,59	121483,93	149123,39
Updated accumulated (€) year 11	-265486,55	-221064,09	-161559,18	-92916,95	-37813,87	6269,24	44859,09	77415,85	114947,82	157428,49	190342,25
Updated accumulated (€) year 12	-286234,89	-236501,02	-169354,52	-93071,24	-30730,67	19513,24	63726,85	101646,61	144381,38	191973,42	229956,32
Updated accumulated (€) year 13	-306477,18	-251707,55	-177117,16	-93390,51	-24009,20	32199,13	81839,57	124924,91	172665,21	225171,33	268025,93
Updated accumulated (€) year 14	-326225,75	-266685,31	-184843,19	-93865,30	-17634,23	44348,69	99226,05	147286,72	199842,62	257072,90	304609,19
Updated accumulated (€) year 15	-345492,65	-281435,99	-192528,93	-94486,58	-11591,11	55982,91	115913,99	168766,72	225955,32	287726,97	339762,09
Updated accumulated (€) year 16	-364289,63	-295961,34	-200170,92	-95245,69	-5865,76	67121,99	131930,09	189398,29	251043,49	317180,57	373538,55
Updated accumulated (€) year 17	-382628,14	-310263,19	-207765,95	-96134,34	-444,65	77785,36	147300,05	209213,60	275145,84	345479,02	405990,52
Updated accumulated (€) year 18	-400519,38	-324343,41	-215311,00	-97144,63	4685,22	87991,72	162048,62	228243,60	298299,64	372665,94	437168,03
Updated accumulated (€) year 19	-417974,24	-338203,95	-222803,24	-98268,99	9536,35	97759,09	176199,64	246518,14	320540,81	398783,39	467119,28
Updated accumulated (€) year 20	-435003,37	-351846,78	-230240,06	-99500,19	14120,75	107104,80	189776,05	264065,95	341903,92	423871,84	495890,69
Updated accumulated (€) year 21	-451617,16	-365273,94	-237619,01	-100831,31	18449,97	116045,51	202799,96	280914,69	362422,29	447970,29	523526,95
Updated accumulated (€) year 22	-467825,73	-378487,51	-244937,83	-102255,75	22535,08	124597,29	215292,65	297091,00	382127,99	471116,29	550071,14
Updated accumulated (€) year 23	-483638,98	-391489,58	-252194,42	-103767,21	26386,75	132775,57	227274,59	312620,55	401051,91	493346,03	575564,72
Updated accumulated (€) year 24	-499066,53	-404282,31	-259386,85	-105359,66	30015,20	140595,21	238765,52	327528,05	419223,82	514694,32	600047,63
Updated accumulated (€) year 25	-514117,80	-416867,88	-266513,33	-107027,37	33430,25	148070,52	249784,41	341837,28	436672,37	535194,72	623558,33

Table 35. Evaluation of alternatives in the sizing of the photovoltaic system for Sector 1 (II)

% of installed modules (%)	0%	10%	20%	30%	40%	50%	60%	**70%**	80%	90%	100%
Number of installed modules (-)	0	109	217	326	434	542	651	759	868	976	1084
Acquisition cost of the modules (€)	0	-14786,0135	-29436,3755	-44222,389	-58872,751	-73523,113	-88309,1265	-102959,4885	-117745,502	-132395,864	-147046,226
Surface occupied by the modules (m^2)	0	482,59	960,76	1443,36	1921,52	2399,69	2882,29	3360,45	3843,05	4321,21	4799,38
Acquisition cost of the inverters (€)	0	-6716,58	-9144,99	-9144,99	-18289,98	-18289,98	-27434,97	-36579,96	-27434,97	-36579,96	-36579,96
Profits obtained from the sale of surplus (€)	0,00	1248,508082	2497,02	3746,08	5391,50	8121,46	11474,70	15116,58	18970,14	22901,32	26891,49
Expenses derived from the purchase of unmet needs (€)	-20740,93	-21503,62	-17133,25	-12723,39	-9047,03	-7091,88	-6061,81	-5523,73	-5271,86	-5179,69	-5173,537
Initial investment (€) year 0	0	-21502,5935	-38581,3655	-53367,379	-77162,731	-91813,093	-115744,0965	-139539,4485	-145180,472	-168975,824	-183626,186
Cash flow (€) year 1	-20740,93	-20482,63	-14832,53	-9142,00	-3799,91	877,44	5237,52	9386,45	13455,85	17440,82	21397,30
Cash flow (€) year 2	-20740,93	-20710,16	-15028,83	-9306,70	-3944,30	725,31	5062,16	9180,04	13213,43	17160,01	21076,65
Cash flow (€) year 3	-20740,93	-20937,68	-15225,14	-9471,39	-4088,68	573,17	4886,79	8973,64	12971,01	16879,20	20756,00
Cash flow (€) year 4	-20740,93	-21165,20	-15421,44	-9636,09	-4233,07	421,04	4711,43	8767,24	12728,59	16598,39	20435,35
Cash flow (€) year 5	-20740,93	-21392,72	-15617,74	-9800,78	-4377,45	268,91	4536,06	8560,84	12486,17	16317,58	20114,70
Cash flow (€) year 6	-20740,93	-21629,04	-15831,65	-9991,89	-4559,85	59,52	4279,80	8247,86	12110,02	15875,32	19604,47
Cash flow (€) year 7	-20740,93	-21865,11	-16045,05	-10182,23	-4741,15	-148,23	4025,86	7937,94	11737,69	15437,68	19099,67
Cash flow (€) year 8	-20740,93	-22100,93	-16257,95	-10371,83	-4921,38	-354,35	3774,22	7631,05	11369,17	15004,64	18600,26
Cash flow (€) year 9	-20740,93	-22336,51	-16470,36	-10560,68	-5100,54	-558,86	3524,85	7327,16	11004,41	14576,13	18106,18
Cash flow (€) year 10	-20740,93	-22571,84	-16682,28	-10748,80	-5278,63	-761,78	3277,73	7026,23	10643,36	14152,12	17617,38
Cash flow (€) year 11	-20740,93	-22731,26	-16828,64	-10881,85	-5408,35	-913,60	3089,61	6794,81	10364,02	13822,78	17236,71
Cash flow (€) year 12	-20740,93	-22890,51	-16974,65	-11014,35	-5537,29	-1064,26	2903,14	6565,58	10087,41	13496,75	16859,93
Cash flow (€) year 13	-20740,93	-23049,58	-17120,29	-11146,32	-5665,46	-1213,75	2718,31	6338,50	9813,51	13173,99	16487,00
Cash flow (€) year 14	-20740,93	-23208,48	-17265,59	-11277,76	-5792,87	-1362,09	2535,11	6113,56	9542,30	12854,47	16117,87
Cash flow (€) year 15	-20740,93	-23367,20	-17410,53	-11408,68	-5919,52	-1509,30	2353,51	5890,74	9273,74	12538,16	15752,50
Cash flow (€) year 16	-20740,93	-23525,74	-17555,13	-11539,07	-6045,42	-1655,38	2173,50	5670,01	9007,82	12225,02	15390,86
Cash flow (€) year 17	-20740,93	-23684,12	-17699,39	-11668,95	-6170,59	-1800,35	1995,07	5451,36	8744,49	11915,03	15032,91
Cash flow (€) year 18	-20740,93	-23842,32	-17843,31	-11798,33	-6295,02	-1944,21	1818,20	5234,77	8483,75	11608,15	14678,62
Cash flow (€) year 19	-20740,93	-24000,36	-17986,89	-11927,19	-6418,72	-2086,98	1642,87	5020,21	8225,56	11304,35	14327,95
Cash flow (€) year 20	-20740,93	-24158,23	-18130,14	-12055,56	-6541,71	-2228,67	1469,07	4807,66	7969,89	11003,60	13980,86
Cash flow (€) year 21	-20740,93	-24315,94	-18273,05	-12183,44	-6663,99	-2369,28	1296,78	4597,10	7716,73	10705,87	13637,31
Cash flow (€) year 22	-20740,93	-24473,48	-18415,65	-12310,83	-6785,56	-2508,84	1125,99	4388,52	7466,04	10411,13	13297,27
Cash flow (€) year 23	-20740,93	-24630,86	-18557,92	-12437,73	-6906,44	-2647,35	956,68	4181,89	7217,80	10119,35	12960,71
Cash flow (€) year 24	-20740,93	-24788,09	-18699,87	-12564,15	-7026,62	-2784,82	788,84	3977,19	6971,99	9830,49	12627,59
Cash flow (€) year 25	-20740,93	-24945,15	-18841,51	-12690,10	-7146,13	-2921,26	622,46	3774,41	6728,58	9544,54	12297,87

Table 36. Evaluation of alternatives in the sizing of the photovoltaic system for Sector 2 (I)

Updated (€) year 1	-20235,05	-19983,06	-14470,76	-8919,03	-3707,23	856,04	5109,78	9157,51	13127,66	17015,43	20875,42
Updated (€) year 2	-19741,51	-19712,22	-14304,66	-8858,25	-3754,24	690,36	4818,24	8737,70	12576,74	16333,14	20061,06
Updated (€) year 3	-19260,01	-19442,71	-14138,05	-8795,13	-3796,75	532,25	4537,87	8332,92	12044,88	15674,01	19274,01
Updated (€) year 4	-18790,25	-19174,62	-13971,06	-8729,82	-3834,95	381,44	4268,32	7942,69	11531,48	15037,32	18513,42
Updated (€) year 5	-18331,96	-18908,05	-13803,81	-8662,46	-3869,03	237,68	4009,22	7566,53	11035,96	14422,36	17778,47
Updated (€) year 6	-17884,83	-18650,66	-13651,58	-8615,97	-3931,94	51,32	3690,46	7112,10	10442,43	13689,23	16904,87
Updated (€) year 7	-17448,62	-18394,36	-13498,14	-8565,96	-3988,57	-124,70	3386,82	6677,92	9874,51	12987,19	16067,89
Updated (€) year 8	-17023,04	-18139,27	-13343,66	-8512,64	-4039,20	-290,83	3097,68	6263,16	9331,21	12315,01	15266,10
Updated (€) year 9	-16607,85	-17885,47	-13188,28	-8456,24	-4084,14	-447,49	2822,45	5867,06	8811,54	11671,52	14498,13
Updated (€) year 10	-16202,78	-17633,08	-13032,17	-8396,95	-4123,66	-595,10	2560,56	5488,88	8314,58	11055,61	13762,67
Updated (€) year 11	-15807,59	-17324,51	-12825,86	-8293,54	-4121,95	-696,30	2354,73	5178,63	7898,88	10534,96	13136,87
Updated (€) year 12	-15422,04	-17020,38	-12621,60	-8189,79	-4117,29	-791,33	2158,65	4881,87	7500,55	10035,59	12536,30
Updated (€) year 13	-15045,89	-16720,64	-12419,41	-8085,77	-4109,84	-880,48	1971,92	4598,08	7118,92	9556,68	11960,00
Updated (€) year 14	-14678,92	-16425,27	-12219,33	-7981,58	-4099,77	-963,99	1794,17	4326,73	6753,35	9097,46	11407,05
Updated (€) year 15	-14320,89	-16134,25	-12021,37	-7877,30	-4087,22	-1042,12	1625,02	4067,35	6403,20	8657,17	10876,56
Updated (€) year 16	-13971,60	-15847,53	-11825,58	-7773,01	-4072,35	-1115,11	1464,13	3819,46	6067,89	8235,08	10367,67
Updated (€) year 17	-13630,83	-15565,09	-11631,95	-7668,78	-4055,28	-1183,18	1311,15	3582,61	5746,84	7830,50	9879,56
Updated (€) year 18	-13298,37	-15286,89	-11440,52	-7564,68	-4036,15	-1246,56	1165,77	3356,36	5439,49	7442,75	9411,43
Updated (€) year 19	-12974,02	-15012,89	-11251,30	-7460,79	-4015,09	-1305,46	1027,66	3140,28	5145,31	7071,18	8962,53
Updated (€) year 20	-12657,58	-14743,07	-11064,29	-7357,16	-3992,22	-1360,09	896,53	2933,97	4863,79	6715,18	8532,11
Updated (€) year 21	-12348,86	-14477,38	-10879,53	-7253,85	-3967,65	-1410,64	772,09	2737,05	4594,43	6374,13	8119,47
Updated (€) year 22	-12047,67	-14215,78	-10697,00	-7150,92	-3941,49	-1457,30	654,05	2549,14	4336,76	6047,46	7723,91
Updated (€) year 23	-11753,83	-13958,24	-10516,72	-7048,43	-3913,86	-1500,24	542,15	2369,87	4090,31	5734,60	7344,80
Updated (€) year 24	-11467,15	-13704,72	-10338,70	-6946,41	-3884,85	-1539,66	436,13	2198,89	3854,64	5435,04	6981,48
Updated (€) year 25	-11187,46	-13455,18	-10162,93	-6844,92	-3854,55	-1575,70	335,75	2035,88	3629,33	5148,23	6633,35
Updated accumulated (€) year 1	-20235,05	-41485,65	-53052,13	-62286,41	-80869,96	-90957,05	-110634,32	-130381,94	-132052,81	-151960,39	-162750,77
Updated accumulated (€) year 2	-39976,56	-61197,87	-67356,79	-71144,66	-84624,20	-90266,69	-105816,08	-121644,24	-119476,07	-135627,25	-142689,71
Updated accumulated (€) year 3	-59236,57	-80640,59	-81494,84	-79939,78	-88420,95	-89734,44	-101278,20	-113311,32	-107431,19	-119953,23	-123415,69
Updated accumulated (€) year 4	-78026,83	-99815,21	-95465,91	-88669,60	-92255,90	-89353,00	-97009,88	-105368,64	-95899,72	-104915,91	-104902,27
Updated accumulated (€) year 5	-96358,78	-118723,26	-109269,72	-97332,07	-96124,93	-89115,32	-93000,66	-97802,11	-84863,76	-90493,55	-87123,81
Updated accumulated (€) year 6	-114243,62	-137373,92	-122921,30	-105948,04	-100056,88	-89064,00	-89310,20	-90690,00	-74421,33	-76804,31	-70218,93
Updated accumulated (€) year 7	-131692,24	-155768,28	-136419,44	-114514,00	-104045,44	-89188,70	-85923,38	-84012,09	-64546,82	-63817,13	-54151,04
Updated accumulated (€) year 8	-148715,28	-173907,54	-149763,10	-123026,64	-108084,65	-89479,53	-82825,70	-77748,93	-55215,61	-51502,12	-38884,94
Updated accumulated (€) year 9	-165323,13	-191793,02	-162951,38	-131482,88	-112168,79	-89927,03	-80003,25	-71881,86	-46404,07	-39830,60	-24386,81
Updated accumulated (€) year 10	-181525,91	-209426,10	-175983,55	-139879,83	-116292,45	-90522,13	-77442,69	-66392,98	-38089,49	-28774,99	-10624,14
Updated accumulated (€) year 11	-197333,49	-226750,61	-188809,41	-148173,37	-120414,40	-91218,42	-75087,96	-61214,35	-30190,60	-18240,03	2512,73
Updated accumulated (€) year 12	-212755,53	-243770,99	-201431,01	-156363,16	-124531,68	-92009,76	-72929,31	-56332,48	-22690,05	-8204,44	15049,03
Updated accumulated (€) year 13	-227801,42	-260491,63	-213850,42	-164448,93	-128641,52	-92890,24	-70957,39	-51734,40	-15571,13	1352,24	27009,04
Updated accumulated (€) year 14	-242480,34	-276916,90	-226069,74	-172430,51	-132741,29	-93854,23	-69163,23	-47407,67	-8817,78	10449,70	38416,09
Updated accumulated (€) year 15	-256801,23	-293051,14	-238091,12	-180307,81	-136828,52	-94896,35	-67538,21	-43340,31	-2414,58	19106,86	49292,65
Updated accumulated (€) year 16	-270772,84	-308898,67	-249916,69	-188080,82	-140900,86	-96011,45	-66074,09	-39520,85	3653,31	27341,94	59660,31
Updated accumulated (€) year 17	-284403,67	-324463,76	-261548,64	-195749,60	-144956,14	-97194,63	-64762,93	-35938,24	9400,15	35172,44	69539,87
Updated accumulated (€) year 18	-297702,04	-339750,64	-272989,16	-203314,28	-148992,29	-98441,19	-63597,17	-32581,88	14839,64	42615,19	78951,30
Updated accumulated (€) year 19	-310676,07	-354763,53	-284240,46	-210775,07	-153007,38	-99746,65	-62569,51	-29441,61	19984,95	49686,37	87913,83
Updated accumulated (€) year 20	-323333,65	-369506,60	-295304,75	-218132,23	-156999,60	-101106,74	-61672,98	-26507,63	24848,74	56401,55	96445,94
Updated accumulated (€) year 21	-335682,51	-383983,98	-306184,28	-225386,09	-160967,24	-102517,38	-60900,89	-23770,58	29443,18	62775,68	104565,41
Updated accumulated (€) year 22	-347730,19	-398199,76	-316881,28	-232537,01	-164908,73	-103974,68	-60246,84	-21221,44	33779,94	68823,13	112289,32
Updated accumulated (€) year 23	-359484,01	-412158,00	-327398,00	-239585,44	-168822,59	-105474,92	-59704,69	-18851,58	37870,24	74557,74	119634,12
Updated accumulated (€) year 24	-370951,16	-425862,72	-337736,70	-246531,85	-172707,44	-107014,58	-59268,56	-16652,69	41724,89	79992,77	126615,60
Updated accumulated (€) year 25	-382138,62	-439317,90	-347899,63	-253376,77	-176561,99	-108590,28	-58932,81	-14616,80	45354,22	85141,01	133248,96

Table 37. Evaluation of alternatives in the sizing of the photovoltaic system for Sector 2 (II)

3.9.2 Number of panels and inverters finally installed, total power and cost

Once the ideal inclination of the commercial pv panel model selected and the minimum separation between rows are established, knowing their dimensions, as well as the direction in which they should be located to have an optimal orientation (α_{opt} = 0°, which being in the northern hemisphere means that the panels are oriented towards the south) it is possible to configure the number of rows of panels in said terrain, as well as the number of panels per row.

As said before, the panels are arranged in a **portrait configuration**, which means that the edges parallel to the ground (perpendicular to the support structure) are the shortest. The panels implemented in the field have a fixed structure, in such a way that a minimum separation between modules has been omitted, so the panels that make up each row are adjacent to each other.

Despite the fact that there are already dirt roads that delimit the space occupied by each irrigation area, it has been considered necessary to establish an extra margin within the area itself destined to the installation of photovoltaic modules on those sides that border said dirt roads of 80 cm, so that the necessary maintenance, repair or replacement operations can be carried out safely and comfortably, and avoid interfering with the traffic that may exist on said roads; on the other hand, in the case of those sides of the perimeter that are bordering the growing area, it has been decided to establish a margin of 70 cm to also facilitate these tasks.

Based on the results of the previous section, it has been decided to install around 70,8% of the total number of panels required in both sectors. Therefore, in Sector 1 1560 panels will be installed (24 more than 70% to correctly adjust the connection of the strings to the inverters and feed the pumps identically) and 6 inverters, and in Sector 2 a total of 760 panels (1 more than 70 % for the same reason) and 4 inverters. This seeks, with a large but reasonable investment, to satisfy the energy needs without the need to purchase energy from the network in a high percentage of the necessary pumping hours and, at the same time, to obtain a profit in the years following the initial investment.

Furthermore, the total area required for each photovoltaic module is known, as well as the number of modules that will be installed for feeding each sector, so it is possible to calculate the surface required for their installation. The results of this simple calculation were reflected in the tables of the previous point. Their sum is 10277,6 m^2.

But beyond knowing the area required by the installation of the modules, it is worth asking: is it possible to install all the necessary modules in each sector, with the land available for that purpose? Or can only a fraction of the total be installed, requiring the assistance of an additional source to complete the necessary energy supply?

To answer this question, the AutoCAD software tool is used. Since for the development of this master thesis there is a .dwg file that represents both the irrigable plots and the surface area of the polygons in which these plots are located, in addition to the pipe networks and a cartographic representation of the terrain , it is possible to determine the area of the plots of land intended for the implementation of the photovoltaic modules required in each sector.

The reasons for choosing these plots of land have been the following:

• It is a land with a not excessive surface, but sufficient to house a large number of photovoltaic panels, as well as other elements of the installation. In this way, the decrease in the arable area and the demand for water in each sector is practically imperceptible, not affecting the water needs that serve as the basis for estimating the energy needs of the installation.

• The land for the installation of these components is located in a perimeter area of the existing plots, so there is direct access through dirt roads on at least one of its sides.

• It has been tried to select a land close to the location of the water extraction wells in order to minimize the length of the wiring as well as the losses due to current circulation. At the same time, care has been taken that this terrain is not too close to the mountains, to avoid further losses due to shading.

This surface is visualized in the following figure:

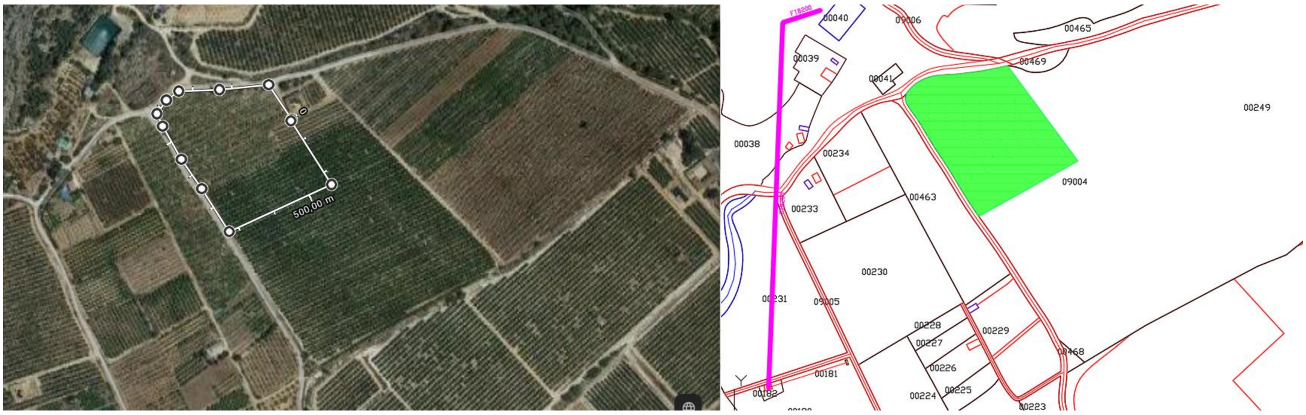


Figure 53. Available surface for the installation of the pv panels that feed the pumping systems of Sectors 1 and 2

Once the available area is known (around 21314,08 m^2), the value of the area occupied by each module is used individually to determine the number of modules that could be installed on said land.

The results of these calculations are as follows:

		Sector 1	Sector 2	Total
Panel 2	Surface finally occupied by the panels (m^2)	9709,45	4799,38	14508,83
	Number of panels that could be installed (u)	2300	1105	2405

Table 38. Surface finally occupied by the panels and number of panels installed in total

3.10 Calculation of the panel structure

The panel support structure must be calculated to ensure that it is able to withstand the stresses applied to it in good conditions, thereby guaranteeing the firmness and stability to the photovoltaic module. Its design depends on the weight of the panels, the intensity of the wind that they must support and the type of anchoring used. The calculations presented here are based on the indications of the DB-SE AE.

Therefore, to carry out this calculation, the geometric parameters, mass and inclination (β_{opt}) of the commercial panel to be installed must be known. The following table summarizes these features:

Panel	
Mass of the panel (Kg)	22,5
Length of the panel (m)	1,979
Width of the panel (m)	1,002
Inclination of the panel β_{opt} (°)	35

Table 39. Parameters of interest of the installed commercial panel

Now it is necessary to determine the total area occupied by the panels of the structure. This procedure is schematized in the next table:

Panel rows parameters	
Disposition of the panels	Portrait
Nº. of rows per structure	1
Nº. of panels per row	20
Total length of the row (m)	20,040
Inclined height of the rows of panels (m)	1,979
Total height (m)	1,135
Projection (m)	1,621
Total area (m²)	39,659

Table 40. Panel rows parameters

Next, it is necessary to know the conditions of the place where the photovoltaic park is located. The considered temperature is the most unfavourable one, that is, the one that increases the density of the air to its maximum (the lowest temperature reached during the year):

Site conditions	
Temperature (ºC)	3,16
Height above sea level (m)	318
Pressure (Pa)	97.538,594
Characteristic constant of the gas	286,94

Table 41. Site conditions

Where the characteristic constant of the gas is obtained from the following expression:

$$p = \rho \cdot R \cdot T$$

Equation 33. Absolut pressure of a gas at a certain temperature and height above sea level

Being:

- $\boldsymbol{p}$: Absolut pressure (N/m^2)
- $\boldsymbol{\rho}$: Density of the gas (kg/m^3)
    - $\rho = 101300 \cdot (1 - 0{,}0000225577 * Hasl)^{5{,}2559}$
- $\boldsymbol{R}$: Characteristic constant of the gas (N·m/kg·K)
- $\boldsymbol{T}$: Temperature of the gas (K)

At the same time, for atmospheric air, the characteristic constant is given by:

$$R = \frac{\mathfrak{R}}{MW} = \frac{8{,}31}{28{,}96 \cdot 10^{-3}} = 286{,}94$$

Equation 34. Characteristic constant of a gas

Where:

- $\boldsymbol{\mathfrak{R}}$: Universal constant of the gases (N·m/mol·K)
- $\boldsymbol{MW}$: Average molecular weight (dry air) (g/mol)

Therefore, the density of air in the most unfavourable conditions is:

$$\rho = \frac{p}{R \cdot T} = \frac{97.538{,}594}{286{,}94 \cdot (273{,}15 + 3{,}16)} = 1{,}23\ kg/m^3$$

To know the dynamic and the static pressure of the wind, the following formulas are applied:

- Dynamic pressure:

$$q_b = 0{,}5 \cdot \rho \cdot {v_b}^2$$

Equation 35. Dynamic pressure on a structure

Where:

- v_b: Wind speed. Zone A

Figure 54. Wind speed and dynamic pressure according to the location of the installation. Source: Dlubal (based on DB SE AE)

- Static pressure:

$$q_e = q_b \cdot C_e \cdot C_p$$

Equation 36. Static pressure on a structure

Where:

- C_e: Exposure coefficient. Grade II (rural, flat land without obstacles or trees of importance) and 3 m height.

	Grado de aspereza del entorno	Altura del punto considerado (m)							
		3	6	9	12	15	18	24	30
I	Borde del mar o de un lago, con una superficie de agua en la dirección del viento de al menos 5 km de longitud	2,4	2,7	3,0	3,1	3,3	3,4	3,5	3,7
II	Terreno rural llano sin obstáculos ni arbolado de importancia	2,1	2,5	2,7	2,9	3,0	3,1	3,3	3,5
III	Zona rural accidentada o llana con algunos obstáculos aislados, como árboles o construcciones pequeñas	1,6	2,0	2,3	2,5	2,6	2,7	2,9	3,1
IV	Zona urbana en general, industrial o forestal	1,3	1,4	1,7	1,9	2,1	2,2	2,4	2,6
V	Centro de negocio de grandes ciudades, con profusión de edificios en altura	1,2	1,2	1,2	1,4	1,5	1,6	1,9	2,0

Table 42. Exposure coefficients. Table 3.4 of the DB SE AE

- C_p: Wind pressure coefficient. The slenderness (total height/total length) is 0,057.

	Esbeltez en el plano paralelo al viento					
	< 0,25	0,50	0,75	1,00	1,25	≥ 5,00
Coeficiente eólico de presión, c_p	0,7	0,7	0,8	0,8	0,8	0,8
Coeficiente eólico de succión, c_s	-0,3	-0,4	-0,4	-0,5	-0,6	-0,7

Table 43. Wind coefficients. Table 3.5 of the DB SE AE

Finally, to know the wind force on the structure and per each clamping piece, as well as the total weight of the panels and the total force that each clamping piece must withstand, (there are 22 per structure) it is necessary to apply the expressions shown below:

- Wind force on the structure:

$$F_{total\,w} = q_e \cdot A_{total}$$

Equation 37. Wind force on a structure

- Wind force per clamping piece:

$$F_{piece\,w} = \frac{F_{total}}{n_{pieces}}$$

Equation 38. Wind force that each clamping piece must withstand

- Total weight of the panels:

$$W_{total\,p} = N_T \cdot W_p$$

Equation 39. Total weight of the panels

- Total force per clamping piece:

$$F_{piece\,t} = \frac{F_{total} + W_{total\,p}}{n_{pieces}}$$

Equation 40. Total force that each clamping piece must withstand

And the results of these calculations are shown in the following table:

Calculation of pressures and forces in the structure and fasteners	
Wind speed (m/s)	26
Dynamic pressure (N/m²)	415,815
Slenderness	0,057
Exposure coefficient	2,1
Wind coefficient (of external pressure)	0,7
Static pressure (N/m2)	611,248
Wind force on the structure (kN)	24,242
No. of clamping pieces (-)	22
Wind force per piece (kN)	1,102
Total weight of the panels (kN)	4,415
Weight of the panels per clamping piece (kN(	0,201
Total force per clamping piece (kN)	1,303

Table 44. Calculation of the dynamic and static pressure, wind force, weight and total force per piece

In conclusion, each clamping piece must withstand around 1,303 kN (132,82 kg), and these forces must be derived to the terrain properly by the footings.

Considering the dimensions of the solar panels, their inclination of 35° and their arrangement with respect to the horizontal, an appropriate commercial model must be chosen. In this sense, it has been decided to select the pre-assembled **CVA915XL** model, from the company SUNFER.

3.11 Calculation of cabling

As mentioned in chapter 1, although the cabling calculation follows common guidelines, the specific procedure and the standards applied are particular and specific depending on whether we speak of direct current (DC) or alternating current (AC) cabling.

In both cases, the sizing of the cabling has been carried out using the two existing selection criteria: the maximum admissible voltage drop criterion and the maximum admissible current criterion. The reason for this has been to size and select the commercial cabling in the last instance based on the criterion that provides a more conservative result, that is, a cabling with a larger section, to guarantee that the transport of electric current is adequate despite unfavourable operating conditions for this occurred and, in turn, reduce losses due to voltage drops, which lead to an increase in temperature that can lead in turn to a faster deterioration of the wiring or even a higher risk of fire.

Both criteria are included in ITC-BT-40 (point 5) of the "*Reglamento Electrotécnico de Baja Tensión* (*REBT*)". These criteria are developed in later sections, depending on the type of current flowing through the cables whose section is to be calculated. The different lines must be marked with the standard colours: phases in brown, black and grey; neutral in blue and protection cable, for grounding, in yellow-green, as specified in Document 2.

Before exposing the procedure for obtaining the standardized section of the cabling of the photovoltaic installation, it is convenient to take into consideration the properties of the different metallic conductors with which the cable industry works; specifically, of two of them, copper and aluminium, since they are by far the most widely used conductors and, therefore, of which there is a greater commercial offer. The characteristics of these metallic conductors, which are also non-magnetic, are shown in the following table:

Material	Advantages	Disadvantages
Copper	• Causes less corrosion and wear problems. • It has a high electrical conductivity. • Easy to weld. • High ductility • Copper conductors require a lower section than aluminium conductors to carry the same current, although they are heavier. • High tensile strength, what reduces signs of wear	• More expensive
Aluminium	• It is a much lighter metal than copper, as it has a density of 2,7 $\mathrm{g/cm^3}$ compared to 8,9 $\mathrm{g/cm^3}$. This also makes it more malleable and makes it easier to work with it. • On the other hand, and although its resistivity is around 1,64 times that of copper at 20ºC, the fact that its density is only 30,34% of that of this metal means that, for the same electrical resistance between the cables, the weight of the aluminium conductor is around half the weight of the copper conductor, although it is true that its section must be greater. • In economic terms, aluminium is more attractive than copper due to its lower price, so in cases where extensive wiring is required, installing aluminium conductors can lead to significant savings	• The mechanical properties of aluminium are inferior to those of copper. • If the installation is not adequate, there is a high risk of fire. • Aluminium cabling systems require more rigorous maintenance than those using copper conductors

Table 45. Main characteristics of the most common types of conductors (copper and aluminium). Source: Electricaplicada

3.11.1 DC Cabling

This set consists of the cables that connect the photovoltaic modules to each other in series and those that connect the output of the different strings that make up the photovoltaic field with their corresponding junction boxes, as well as the cables that connect the output of these junction boxes with the input of the inverters, in parallel, and through which direct current circulates.

3.11.1.1 DC cabling of the strings

In this case, the application of the aforementioned criteria is carried out by means of the equations developed below. The wiring that connects the modules in series will be placed on a wire mesh cable tray (see corresponding catalogue in Annex IV), while the wiring that connects the ends of the strings with their corresponding junction boxes will run underground.

Criterion of the maximum admissible voltage drop

The calculation of the minimum necessary cable section in case of applying this criterion is obtained by the following formula:

$$S_{vd\ DC\ st} = \frac{2 \cdot L_{DC\ st} \cdot I_{mp}}{\sigma_{T^\circ C} \cdot \frac{e_{st}}{100} \cdot N_S \cdot V_{M\ mod}} = \frac{2 \cdot L_{DC\ st} \cdot I_{mp}}{\sigma_{x^\circ C} \cdot \frac{e_{st}}{100} \cdot V_{M\ string}}$$

Equation 41. Section of the cabling of the strings. Maximum voltage drop criterion

Where:

- $\boldsymbol{S_{vd\ DC\ st}}$: Section of the string cable according to the maximum admissible voltage drop criterion (mm^2)
- $\boldsymbol{L_{DC\ st}}$: Cable length of the string (m)
- $\boldsymbol{I_{mp}}$: String current at its maximum power point (A). Since a string consists of a series connection of the modules, this is the current of one module at its maximum power point in STC.
- $\boldsymbol{e_{st}}$: Maximum allowable voltage drop between the photovoltaic generator and the connection point to the Public Distribution Network or to the indoor installation. The ITC-BT-40 specifies that a value of 1,5% has to be adopted (V); thus, a value of 1,2% will be used for those cables that connect the strings and the junction boxes.
- $\boldsymbol{\sigma_{T^\circ C}}$: Conductivity of the material that makes up the cable, at temperature T $(\mathrm{m}/\Omega \cdot \mathrm{mm}^2)$. In order to calculate this conductivity as a function of its temperature, the following equation is applied:

$$\sigma_{T^\circ C} = \frac{\sigma_{20^\circ C}}{[1 + \alpha \cdot (\mathrm{T} - 20)]}$$

Equation 42. Conductivity of the material at a temperature other than 20 °C

  Where:

  - $\boldsymbol{\sigma_{20^\circ C}}$: Conductivity of the material at 20°C. In case of copper conductors, its value is 58 $\mathrm{m}/\Omega \cdot \mathrm{mm}^2$, whereas the value of this parameter is 35,714 m/ Ω ·mm^2 when it comes to aluminium conductors.
  - $\boldsymbol{\alpha}$: Coefficient of variation of conductivity with temperature. Its value for copper and aluminium is 0,00393 $^\circ\mathrm{C}^{-1}$ and 0,00407$^\circ\mathrm{C}^{-1}$ respectively.
  - $\mathbf{T}$: Temperature of the conductor ($^\circ$C)

  Since copper cables will be used, and the maximum temperature that they will reach is 90°C, the value of this parameter is 45,49 (m/ Ω ·mm^2)
- $\boldsymbol{V_{M\ string}}$: String voltage at its maximum power point (V). Since a string consists of a series connection of the modules, this is the voltage of one module at its maximum power point in STC multiplied by the number of modules connected in series.

The reason for doubling the length of the string lies in the fact that there are two cables, one that connects the positive poles and the other that connects the negative poles. This is due to the fact that the current in this section is direct (DC) so it has a single direction of circulation, from the positive to the negative pole (conventional direction, the real direction is from negative to positive), whereas AC current has two directions of circulation, so the electrons "oscillate" on both sides continuously.

Once the section of the cables is calculated, it must be normalized to the immediately higher value. For this, the following table, which shows the nominal sections of the commercial cables, is used:

Normalized sections of commercial cables	
1,5	50
2,5	70
4	95
6	120
10	150
16	185
25	240
35	300

Table 46. Nominal cross section of unipolar conductors. Source: Ingemecánica

Due to the symmetrical arrangement of the modules, the calculations can be halved. Thus, the results of the application of this criterion are the following:

Sector 1									
String	$L_{DC\ st}$ (m)	I_{mp} (A)	σ_T (m/Ω·mm²)	e_{st} (%)	N_s	$V_{M\ string}$ (V)	$S_{vd\ DC\ st}$ (mm²)	$S_{vd\ DC\ st\ norm}$ (mm²)	e_{st} (%) with S norm
S1-1-1	502,25	9,6	45,49	1,2%	20	834	21,18	25	1,017%
S2-1-1	502,25	9,6	45,49	1,2%	20	834	21,18	25	1,017%
S3-1-1	496,85	9,6	45,49	1,2%	20	834	20,96	25	1,006%
S4-1-1	496,85	9,6	45,49	1,2%	20	834	20,96	25	1,006%
S5-1-1	491,45	9,6	45,49	1,2%	20	834	20,73	25	0,995%
S1-2-1	596,19	9,6	45,49	1,2%	20	834	25,15	35	0,862%
S2-2-1	590,8	9,6	45,49	1,2%	20	834	24,92	25	1,196%
S3-2-1	590,8	9,6	45,49	1,2%	20	834	24,92	25	1,196%
S4-2-1	585,09	9,6	45,49	1,2%	20	834	24,68	25	1,184%
S5-2-1	585,09	9,6	45,49	1,2%	20	834	24,68	25	1,184%
S6-2-1	579,38	9,6	45,49	1,2%	20	834	24,44	25	1,173%
S7-2-1	579,38	9,6	45,49	1,2%	20	834	24,44	25	1,173%
S8-2-1	574,6	9,6	45,49	1,2%	20	834	24,23	25	1,163%
S9-2-1	574,6	9,6	45,49	1,2%	20	834	24,23	25	1,163%
S10-2-1	569,82	9,6	45,49	1,2%	20	834	24,03	25	1,154%
S11-2-1	569,82	9,6	45,49	1,2%	20	834	24,03	25	1,154%
S12-2-1	565,04	9,6	45,49	1,2%	20	834	23,83	25	1,144%
S13-2-1	565,04	9,6	45,49	1,2%	20	834	23,83	25	1,144%
S14-2-1	560,26	9,6	45,49	1,2%	20	834	23,63	25	1,134%
S15-2-1	560,26	9,6	45,49	1,2%	20	834	23,63	25	1,134%
S16-2-1	547,35	9,6	45,49	1,2%	20	834	23,09	25	1,108%
S17-2-1	547,35	9,6	45,49	1,2%	20	834	23,09	25	1,108%
S1-3-1	622,73	9,6	45,49	1,2%	20	834	26,26	35	0,900%
S2-3-1	622,73	9,6	45,49	1,2%	20	834	26,26	35	0,900%
S3-3-1	617,95	9,6	45,49	1,2%	20	834	26,06	35	0,894%
S4-3-1	617,95	9,6	45,49	1,2%	20	834	26,06	35	0,894%
S5-3-1	613,07	9,6	45,49	1,2%	20	834	25,86	35	0,887%
S6-3-1	613,07	9,6	45,49	1,2%	20	834	25,86	35	0,887%
S7-3-1	608,29	9,6	45,49	1,2%	20	834	25,66	35	0,880%
S8-3-1	608,29	9,6	45,49	1,2%	20	834	25,66	35	0,880%
S9-3-1	603,5	9,6	45,49	1,2%	20	834	25,45	35	0,873%
S10-3-1	603,5	9,6	45,49	1,2%	20	834	25,45	35	0,873%
S11-3-1	598,57	9,6	45,49	1,2%	20	834	25,25	35	0,866%
S12-3-1	598,57	9,6	45,49	1,2%	20	834	25,25	35	0,866%
S13-3-1	592,91	9,6	45,49	1,2%	20	834	25,01	35	0,857%
S14-3-1	592,91	9,6	45,49	1,2%	20	834	25,01	35	0,857%
S15-3-1	587,17	9,6	45,49	1,2%	20	834	24,76	25	1,189%
S16-3-1	587,17	9,6	45,49	1,2%	20	834	24,76	25	1,189%
S17-3-1	581,66	9,6	45,49	1,2%	20	834	24,53	25	1,178%
S1-4-1	575,74	9,6	45,49	1,2%	20	834	24,28	25	1,166%
S2-4-1	570,9	9,6	45,49	1,2%	20	834	24,08	25	1,156%
S3-4-1	570,9	9,6	45,49	1,2%	20	834	24,08	25	1,156%
S4-4-1	565,97	9,6	45,49	1,2%	20	834	23,87	25	1,146%
S5-4-1	565,97	9,6	45,49	1,2%	20	834	23,87	25	1,146%
S6-4-1	560,31	9,6	45,49	1,2%	20	834	23,63	25	1,134%
S7-4-1	560,31	9,6	45,49	1,2%	20	834	23,63	25	1,134%
S8-4-1	554,56	9,6	45,49	1,2%	20	834	23,39	25	1,123%
S9-4-1	554,46	9,6	45,49	1,2%	20	834	23,39	25	1,122%
S10-4-1	549	9,6	45,49	1,2%	20	834	23,15	25	1,111%
S11-4-1	549	9,6	45,49	1,2%	20	834	23,15	25	1,111%
S12-4-1	543,32	9,6	45,49	1,2%	20	834	22,92	25	1,100%
S13-4-1	543,32	9,6	45,49	1,2%	20	834	22,92	25	1,100%
S14-4-1	537,6	9,6	45,49	1,2%	20	834	22,67	25	1,088%
S15-4-1	537,6	9,6	45,49	1,2%	20	834	22,67	25	1,088%
S16-4-1	531,9	9,6	45,49	1,2%	20	834	22,43	25	1,077%
S17-4-1	531,9	9,6	45,49	1,2%	20	834	22,43	25	1,077%
S1-5-1	615,79	9,6	45,49	1,2%	20	834	25,97	35	0,890%
S2-5-1	611,07	9,6	45,49	1,2%	20	834	25,77	35	0,884%
S3-5-1	611,07	9,6	45,49	1,2%	20	834	25,77	35	0,884%
S4-5-1	606,14	9,6	45,49	1,2%	20	834	25,56	35	0,877%
S5-5-1	606,14	9,6	45,49	1,2%	20	834	25,56	35	0,877%
S6-5-1	600,48	9,6	45,49	1,2%	20	834	25,33	35	0,868%
S7-5-1	600,48	9,6	45,49	1,2%	20	834	25,33	35	0,868%
S8-5-1	594,73	9,6	45,49	1,2%	20	834	25,08	35	0,860%
S9-5-1	594,73	9,6	45,49	1,2%	20	834	25,08	35	0,860%
S10-5-1	589,17	9,6	45,49	1,2%	20	834	24,85	25	1,193%
S11-5-1	589,17	9,6	45,49	1,2%	20	834	24,85	25	1,193%
S12-5-1	583,49	9,6	45,49	1,2%	20	834	24,61	25	1,181%
S13-5-1	583,49	9,6	45,49	1,2%	20	834	24,61	25	1,181%
S14-5-1	577,77	9,6	45,49	1,2%	20	834	24,37	25	1,170%
S15-5-1	577,77	9,6	45,49	1,2%	20	834	24,37	25	1,170%
S16-5-1	572,07	9,6	45,49	1,2%	20	834	24,13	25	1,158%
S17-5-1	572,07	9,6	45,49	1,2%	20	834	24,13	25	1,158%
S1-6-1	520,02	9,6	45,49	1,2%	20	834	21,93	25	1,053%
S2-6-1	520,02	9,6	45,49	1,2%	20	834	21,93	25	1,053%
S3-6-1	514,3	9,6	45,49	1,2%	20	834	21,69	25	1,041%
S4-6-1	514,3	9,6	45,49	1,2%	20	834	21,69	25	1,041%
S5-6-1	508,6	9,6	45,49	1,2%	20	834	21,45	25	1,030%

Table 47. Calculation of the section of the wiring of the strings of the PV installation corresponding to Sector 1. Criterion of the maximum allowable voltage drop

Sector 2									
String	$L_{DC\ st}$ (m)	I_{mp} (A)	σ_T (m/Ω·mm²)	e_{st} (%)	N_S	$V_{M\ string}$ (V)	$S_{vd\ DC\ st}$ (mm²)	$S_{vd\ DC\ st\ norm}$ (mm²)	e_{st} (%) with S norm
S1-1-2	464,52	9,6	45,49	1,2%	20	834	19,59	25	0,94%
S2-1-2	464,52	9,6	45,49	1,2%	20	834	19,59	25	0,94%
S3-1-2	469,3	9,6	45,49	1,2%	20	834	19,79	25	0,95%
S4-1-2	469,3	9,6	45,49	1,2%	20	834	19,79	25	0,95%
S5-1-2	474,08	9,6	45,49	1,2%	20	834	20,00	25	0,96%
S6-1-2	474,08	9,6	45,49	1,2%	20	834	20,00	25	0,96%
S7-1-2	478,86	9,6	45,49	1,2%	20	834	20,20	25	0,97%
S8-1-2	478,86	9,6	45,49	1,2%	20	834	20,20	25	0,97%
S9-1-2	483,64	9,6	45,49	1,2%	20	834	20,40	25	0,98%
S10-1-2	483,64	9,6	45,49	1,2%	20	834	20,40	25	0,98%
S11-1-2	488,41	9,6	45,49	1,2%	20	834	20,60	25	0,99%
S12-1-2	488,41	9,6	45,49	1,2%	20	834	20,60	25	0,99%
S13-1-2	493,19	9,6	45,49	1,2%	20	834	20,80	25	1,00%
S14-1-2	493,19	9,6	45,49	1,2%	20	834	20,80	25	1,00%
S15-1-2	497,97	9,6	45,49	1,2%	20	834	21,00	25	1,01%
S1-2-2	431,21	9,6	45,49	1,2%	20	834	18,19	25	0,87%
S2-2-2	431,21	9,6	45,49	1,2%	20	834	18,19	25	0,87%
S3-2-2	435,99	9,6	45,49	1,2%	20	834	18,39	25	0,88%
S4-2-2	435,99	9,6	45,49	1,2%	20	834	18,39	25	0,88%
S5-2-2	440,77	9,6	45,49	1,2%	20	834	18,59	25	0,89%
S6-2-2	440,77	9,6	45,49	1,2%	20	834	18,59	25	0,89%
S7-2-2	445,55	9,6	45,49	1,2%	20	834	18,79	25	0,90%
S8-2-2	445,55	9,6	45,49	1,2%	20	834	18,79	25	0,90%
S9-2-2	450,33	9,6	45,49	1,2%	20	834	18,99	25	0,91%
S10-2-2	450,33	9,6	45,49	1,2%	20	834	18,99	25	0,91%
S11-2-2	455,1	9,6	45,49	1,2%	20	834	19,19	25	0,92%
S12-2-2	455,1	9,6	45,49	1,2%	20	834	19,19	25	0,92%
S13-2-2	459,88	9,6	45,49	1,2%	20	834	19,40	25	0,93%
S14-2-2	459,88	9,6	45,49	1,2%	20	834	19,40	25	0,93%
S15-2-2	464,66	9,6	45,49	1,2%	20	834	19,60	25	0,94%
S1-3-2	424,78	9,6	45,49	1,2%	20	834	17,92	25	0,86%
S2-3-2	424,78	9,6	45,49	1,2%	20	834	17,92	25	0,86%
S3-3-2	429,56	9,6	45,49	1,2%	20	834	18,12	25	0,87%
S4-3-2	429,56	9,6	45,49	1,2%	20	834	18,12	25	0,87%
S1-4-2	514,37	9,6	45,49	1,2%	20	834	21,69	25	1,04%
S2-4-2	514,37	9,6	45,49	1,2%	20	834	21,69	25	1,04%
S3-4-2	519,15	9,6	45,49	1,2%	20	834	21,90	25	1,05%
S4-4-2	519,15	9,6	45,49	1,2%	20	834	21,90	25	1,05%

Table 48. Calculation of the section of the wiring of the strings of the PV installation corresponding to Sector 2. Criterion of the maximum allowable voltage drop

So, there would be 24 strings with a 35 mm^2 normalized section and 92 strings with a 25 mm^2 normalized section. The last two columns of the tables show the normalized sections of the cables and the corresponding voltage drop for each one, respectively. It can be seen how, as it is logical, the voltage drop is lower than the voltage drop allowed.

The channelling of underground lines or trenches have been designed taking into account the following conditions:

- First, the radius of curvature after the cable is laid will be at least 10 times the external diameter. These radii of curvature of the cables are made in order to avoid mechanical stress in the corners, when it is necessary to make a change of direction (turn).
- Second, road crossings will be perpendicular to the axis of the road or road, trying to avoid them if possible.

The previously indicated lengths of the strings correspond to those obtained when measuring the cable sections in the corresponding CAD file, but with an increase of 2% in order to capture the effect that the realization of the radii of curvature of said buried cables would have in its final length.

Criterion of the maximum admissible current

This criterion, also called thermal criterion, expresses that the connection cables must be sized to allow the circulation of a current at least 25% higher than the value of the maximum intensity that could circulate through the considered cabling section, according to the provisions of the "*Norma UNE-HD 60364-7-712*", dated 15th February 2017. Therefore, this intensity is expressed by:

$$I_C = 1{,}25 \cdot I_{SC\ mod} \leq I_{adm}$$

Equation 43. Condition of the criterion of the maximum admissible current for the cabling of the strings

Where:

- $\boldsymbol{I_C}$: Minimum current for which the connection cables between the strings and their corresponding junction boxes must be dimensioned, equal to the maximum current that may circulate through the cable (A)
- $\boldsymbol{I_{SC\ mod}}$: Short-circuit current of the photovoltaic panel, for cables in the rows of panels in series (strings) (A)
- $\boldsymbol{I_{adm}}$: Maximum admissible current of the cable (A) between the strings and their corresponding junction boxes

Since $I_{SC\ mod}$ =10,36 A, the value of the maximum current is $I_C = 12,95$ A.

In other words, this criterion seeks to size the conductor so that it does not exceed the maximum admissible temperature that its insulation can withstand in normal operation, being said temperature equal to 70°C in the case that the insulation is thermoplastic (PVC), or 90°C if it is thermosetting type (XLPE or EPR) (this last is the case in this thesis).

In the case of this type of cabling, first of all, it is necessary go to Table B.52-1 of the "*Norma UNE-HD 60364-5-52*" (which cancels UNE 20460-5-523: 2004) to know which the code corresponding to the reference installation method used in the project is. In this case, since as said before those cables that connect the strings and the junction boxes will run underground, the installation method is **D1**.

On the other hand, since there is a single conductor per cable but there is no column for that value, and XLPE insulation is used in these cables, the column corresponding to two conductors and with this type of insulation is taken. With this, and the installation method, the table and column of said table to which it is necessary to go to are known, depending on the section obtained with the previous criterion, check the maximum admissible current (to which it is subsequently necessary to apply the CF).

Therefore, the results are taken from Table C.52-2 bis, **column 5**.

Instalación de referencia		Tabla y columna – Intensidad admisible para los circuitos simples – Aislamiento PVC – Número de conductores 2	Aislamiento PVC – 3	Aislamiento XLPE o EPR – 2	Aislamiento XLPE o EPR – 3
Local – Conductores aislados en un conducto en una pared térmicamente aislante	A1	Tabla C.52-1 bis columna 4	Tabla C.52-1 bis columna 3	Tabla C.52-1 bis columna 7b	Tabla C.52-1 bis columna 6b
Local – Cable multiconductor en un conducto en una pared térmicamente aislante	A2	Tabla C.52-1 bis columna 3	Tabla C.52-1 bis columna 2	Tabla C.52-1 bis columna 6b	Tabla C.52-1 bis columna 5b
Conductores aislados en un conducto sobre una pared de madera o mampostería	B1	Tabla C.52-1 bis columna 6a	Tabla C.52-1 bis columna 5a	Tabla C.52-1 bis columna 10b	Tabla C.52-1 bis columna 8b
Cable multiconductor en un conducto sobre una pared de madera o mampostería	B2	Tabla C.52-1 bis columna 5a	Tabla C.52-1 bis columna 4	Tabla C.52-1 bis columna 8b	Tabla C.52-1 bis columna 7b
Cables unipolares o multipolares sobre una pared de madera o mampostería	C	Tabla C.52-1 bis columna 8a	Tabla C.52-1 bis columna 6a	Tabla C.52-1 bis columna 11	Tabla C.52-1 bis columna 9b
Cable multiconductor en conductos enterrados	D1	Tabla C.52-2 bis columna 3	Tabla C.52-2 bis columna 4	Tabla C.52-2 bis columna 5	Tabla C.52-2 bis columna 6
Cables con cubierta unipolares o multipolares directamente en el suelo	D2				
Cable multiconductor al aire libre. Distancia al muro no inferior a 0,3 veces el diámetro del cable	E	Tabla C.52-1 bis columna 9a	Tabla C.52-1 bis columna 7a	Tabla C.52-1 bis columna 12	Tabla C.52-1 bis columna 10b
Cables unipolares en contacto al aire libre. Distancia al muro no inferior al diámetro del cable	F	Tabla C.52-1 bis columna 10a	Tabla C.52-1 bis columna 8a	Tabla C.52-1 bis columna 13	Tabla C.52-1 bis columna 11
Cables unipolares espaciados al aire libre. Distancia entre ellos como mínimo el diámetro del cable	G	Ver UNE-HD 60364-5-52			

XLPE: Polietileno reticulado (90°C) **EPR**: Etileno-propileno (90°C) **PVC**: Policloruro de vinilo (70°C)

Cobre: ρ_{20} = 1/56 $\Omega mm^2/m$; Aluminio: ρ_{20} = 1/35 $\Omega mm^2/m$

$\rho = K_\theta \cdot \rho_{20}$ **Para el cobre y el aluminio: θ = 70ºC → K_θ = 1,20; θ = 90ºC → K_θ = 1,28**

POTENCIAS NORMALIZADAS DE TRANSFORMADORES (EN kVA):
5, 10, 15, 20, 30, 50, 75, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000

FACTORES DE MAYORACIÓN K_O: 1,25 para motores y 1,8 para lámparas de descarga

Figure 55. Table B.52-1 of the UNE-HD 60364-5-52 (2014). Reference installation methods

In this case, Table A.52-2 of the UNE 20460-5-523: 2004 standard is used (even though it is cancelled by the UNE-HD 60364-5-52 standard, there is no access to the equivalent updated table, the C.52-2 bis, so these values, which should be very close, are the ones used) to obtain the normalized sections. This is due to the D installation method is not found in the Table C.52-1 bis.

Método de instalación	Sección mm²	Número de conductores cargados y tipo de aislamiento – PVC2	PVC3	XLPE2	XLPE3
D	Cobre				
	1,5	20,5	17	24,5	21
	2,5	27,5	22,5	32,5	27,5
	4	36	29	42	35
	6	44	37	53	44
	10	59	49	70	58
	16	76	63	91	75
	25	98	81	116	96
	35	118	97	140	117
	50	140	115	166	138
	70	173	143	204	170
	95	205	170	241	202
	120	233	192	275	230
	150	264	218	311	260
	185	296	245	348	291
	240	342	282	402	336
	300	387	319	455	380

Figure 56. Table A.52-2 bis of the UNE 20460-5-523 (2004). Admissible currents for buried cables for a temperature of 25 ºC in the ground (A)

Although the values for the maximum admissible current are extracted from the previous table based on the standard sections of the cables installed on the surface obtained and shown in Table 47 (Sector 1) and Table 48 (Sector 2), this current carrying capacity will be diminished by the installation conditions, therefore, it must be corrected by two corresponding reduction factors. In this way, we have the following expression:

$$I_{adm} = CF_1 \cdot CF_2 \cdot I_0$$

Equation 44. Correction of the maximum admissible current for the cabling of the strings

Being:

- $\boldsymbol{CF_1}$: Correction factor corresponding to the bundling level of the cables. To determine the value of this factor, Table B.52.17 of the UNE HD 60364-5-52 standard is used, which includes the values that can be adopted according to the number of circuits or multipolar cables in the installation.

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

Figure 57. Table B.52.17 of the UNE-HD 60364-5-52 (2014). Correction factors according to the number of bundled cables

  The criterion is to consider that point of the installation where the grouping of cables is maximum. This point corresponds to the final section, that is, to the entrance of the junction boxes. In inverters 2, 3,4 and 5 of Sector 1, the number of cables that arrive at their respective junction boxes is 34 (2x17), and in the case of inverters 1 and 6 it is 10 (2x5). On the other hand, in inverters 1 and 2 of Sector 2, the number of cables that reach their respective junction boxes is 30 (2x15) and 8 (2x4) arrive to the junction box of inverters 3 and 4. Therefore, the CF1s are:
  - Junction boxes 2,3,4,5-1: 0,38
  - Junction box 1,6-1: 0,483 (linear interpolation between 0.50 and 0.45)
  - Junction boxes 1,2-2: 0,38
  - Junction boxes 3,4-2: 0,52
- $\boldsymbol{CF_2}$: Correction factor for operating temperature other than 60 °C. In this project a maximum operating temperature of 90 °C has been considered, so the value of this factor is, according to Table A.4 of UNE-EN 50618 standard, 0,75.

Temperatura ambiente °C	Factor de conversión
Hasta 60	1,00
70	0,92
80	0,84
90	0,75

Figure 58. Table A.4 of the UNE-EN 50618 (2015) standard. Correction factors for an operating temperature different to 60ºC

- $\boldsymbol{I_0}$: Maximum admissible current of the cable in permanent service at 60 °C of the individual conductor (A). It is the current obtained from Table A.52-2 above.

Therefore, the maximum admissible current based on the installation conditions, I_{adm}, will be:

Sector 1 (Canyoles I)

- Junction box 1-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}483 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 42{,}02\ A > I_C = 12{,}95\ A$$
- Junction box 2-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 35 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 140 \rightarrow I_{adm} = 39{,}9\ A > I_C = 12{,}95\ A$$
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 3-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 35 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 140 \rightarrow I_{adm} = 39{,}9\ A > I_C = 12{,}95\ A$$
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 4-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 5-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 35 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 140 \rightarrow I_{adm} = 39{,}9\ A > I_C = 12{,}95\ A$$
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 6-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}483 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 42{,}02\ A > I_C = 12{,}95\ A$$

Sector 2 (El Tollo)

- Junction box 1-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 2-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}38 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 33{,}06\ A > I_C = 12{,}95\ A$$
- Junction box 3-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}52 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 45{,}24\ A > I_C = 12{,}95\ A$$
- Junction box 4-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 25 mm^2:
$$I_{adm} = 0{,}52 \cdot 0{,}75 \cdot 116 \rightarrow I_{adm} = 45{,}24\ A > I_C = 12{,}95\ A$$

Therefore, with the sections previously obtained by the criterion of the maximum allowable voltage drop, the condition of maximum allowable intensity is also met. Therefore, there will be two types of cables for the strings, specifically 25 and 35 mm² in section, all of them being single-pole, made of copper, with XLPE insulation and PVC cover.

3.11.1.2 DC cabling between the junction boxes and the inverters

Criterion of the maximum admissible voltage drop

This formula is identical to that used in the DC cabling of the strings, with the difference that the number of parallel strings reaching these inverters must be taken into account. Therefore, in this case the following expression should be applied to obtain the minimum necessary cable section:

$$S_{vd\ DC\ inv} = \frac{2 \cdot L_{DC\ inv} \cdot N_P \cdot I_{mp}}{\sigma_{T^\circ C} \cdot \frac{e_{inv}}{100} \cdot N_S \cdot V_{M\ mod}} = \frac{2 \cdot L_{DC\ inv} \cdot N_P \cdot I_{mp}}{\sigma_{x^\circ C} \cdot \frac{e_{inv}}{100} \cdot V_{M\ string}}$$

Equation 45. Section of the cabling from the junction boxes to the inverters. Maximum voltage drop criterion

In which:

- $S_{vd\ DC\ inv}$: Section of the cable that goes from the junction box to its corresponding inverter according to the maximum admissible voltage drop criterion (mm^2)
- $L_{DC\ inv}$: Cable length that goes from the junction box to its corresponding inverter (m)
- e_{inv}: Maximum allowable voltage drop between the photovoltaic generator and the connection point to the Public Distribution Network or to the indoor installation. The ITC-BT-40 specifies that a value of 1,5% has to be adopted (V); thus, a value of 0,3% will be applied in case of the cables that connect the junction boxes and the inverters.

The protection boxes (junction boxes) will be installed, as they have an underground connection, in accordance with ITC-BT-13, in a niche in the wall, closed with a metal door, with protection degree IK 10 according to UNE-EN 50.102 protected against corrosion and raised at least 30 centimetres from the ground.

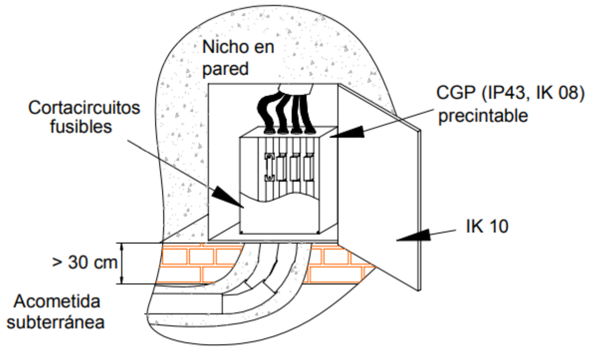


Figura A:. Ejemplo de caja general de protección (CGP) con acometida subterránea.

Producto		Norma de aplicación
CGP (Conjunto de aparamenta)		UNE-EN 60439-1
	Caja (para conjunto de aparamenta) de Clase II	UNE-EN 60439-1
	Cartuchos fusibles y bases abiertas	UNE-EN 60269 (serie)
	Bases cerradas (BUC) con contactos fusibles de cuchilla	UNE-EN 60269 (serie) UNE-EN 60947-3
Tubos	Rígido, hasta 2,5 m de altura, 4421 Rígido 4321	UNE-EN 50086-2-1
	Enterrado (Acometida subterránea)	UNE-EN 50086-2-4

Nota 1: Los diferentes componentes que conforman una CGP (caja y fusibles) deberán cumplir con su correspondiente norma de producto. Cuando se comercializan montados, todos estos elementos, constituyen el conjunto de aparamenta y deberán cumplir con las prescripciones de la norma (UNE-EN 60439-1).
Nota 2: El grado de protección IP43, el grado de protección contra los impactos mecánicos externos IK08 y el grado de inflamabilidad se verificarán de acuerdo a lo establecido en la norma UNE-EN 50298. El grado de inflamabilidad será:
- *(960 ± 10) ºC para las partes que soportan partes activas*
- *(650 ± 10) ºC para todas las demás partes*

Figure 59. Connection specifications and degree of protection of the protection boxes. Source: ITC-BT-13

As in the previous case, once the section of the cables is calculated, it must be normalized to the immediately higher value. Next, the new voltage drop is obtained.

Sector 1									
Cabling zone	$L_{DC\ inv}$ (m)	N_p	I_{mp} (A)	σ_T (m/Ω·mm²)	e_{inv} (%)	$V_{M\ string}$ (V)	$S_{vd\ DC\ inv}$ (mm²)	$S_{vd\ DC\ inv\ norm}$ (mm²)	e_{inv} (%) with S_{norm}
CC1-1-1	2,6842	5	9,6	45,49	0,3%	834	2,26	2,5	0,13%
CC2-2-1	2,6842	17	9,6	45,49	0,3%	834	7,70	10	0,11%
CC3-3-1	2,6842	17	9,6	45,49	0,3%	834	7,70	10	0,11%
CC4-4-1	2,6842	17	9,6	45,49	0,3%	834	7,70	10	0,11%
CC5-5-1	2,6842	17	9,6	45,49	0,3%	834	7,70	10	0,11%
CC6-6-1	2,6842	5	9,6	45,49	0,3%	834	2,26	2,5	0,13%

Table 49. Calculation of the section of the wiring between the junction boxes and the inverters of the PV installation corresponding to Sector 1. Criterion of the maximum allowable voltage drop

Sector 2									
Cabling zone	$L_{DC\ inv}$ (m)	N_p	I_{mp} (A)	σ_T (m/Ω·mm²)	e_{inv} (%)	$V_{M\ string}$ (V)	$S_{vd\ DC\ inv}$ (mm²)	$S_{vd\ DC\ inv\ norm}$ (mm²)	e_{inv} (%) with S_{norm}
CC1-1-2	2,6842	15	9,6	45,49	0,3%	834	6,79	10	0,10%
CC2-2-2	2,6842	15	9,6	45,49	0,3%	834	6,79	10	0,10%
CC3-3-2	2,6842	4	9,6	45,49	0,3%	834	1,81	2,5	0,11%
CC4-4-2	2,6842	4	9,6	45,49	0,3%	834	1,81	2,5	0,11%

Table 50. Calculation of the section of the wiring between the junction boxes and the inverters of the PV installation corresponding to Sector 2. Criterion of the maximum allowable voltage drop

According to this criterion, it would be necessary to install 6 cables of 10 mm² normalized section and 4 cables of 2,5 mm² normalized section.

However, it is by means of the criterion of the maximum admissible current that it is determined whether the previously obtained sections are adequate or whether, on the contrary, it is necessary to use larger sections.

Criterion of the maximum admissible current

The application of this criterion is analogous to that of the DC wiring of the strings but, as was the case with the previous criterion, on this occasion the number of branches in parallel that reach each inverter must be considered. Therefore, the following expression is defined:

$$I_{C\ jb-inv} = 1{,}25 \cdot N_P \cdot I_{SC\ mod} \leq I_{adm\ jb-inv}$$

Equation 46. Condition of the criterion of the maximum admissible current for the cabling from the junction boxes to the inverters

Being:

- $\boldsymbol{I_{C\ jb-inv}}$: Minimum current for which the connection cables between the junction boxes and their corresponding inverters must be dimensioned, equal to the maximum current that may circulate through the cable (A)
- $\boldsymbol{I_{adm\ jb-inv}}$: Maximum admissible current of the cable (A) between the junction boxes and their corresponding inverters

However, in this case, the corresponding installation **method** is **C**. This is because the cables would be installed on a wall, in vertical sections, and horizontally on the ceiling. Furthermore, since there is a single conductor per cable but there is no column for that value, and XLPE insulation is used in these cables, the column corresponding to two conductors and with this type of insulation is taken, being now **column 11**. With this, and the installation method, it is necessary to go the Table C.52-1 bis, column 11 and, depending on the section obtained with the previous criterion, obtain the maximum admissible current (to which it is subsequently necessary to apply the CF).

Intensidades admisibles en amperios   Temperatura ambiente 40 °C en el aire

Método de instalación de la tabla B.52-1	Número de conductores cargados y tipos de aislamiento																	
A1		PVC 3	PVC 2				XLPE 3		XLPE 2									
A2	PVC 3	PVC 2			XLPE 3		XLPE 2											
B1				PVC 3		PVC 2					XLPE 3				XLPE 2			
B2			PVC 3	PVC 2					XLPE 3		XLPE 2							
C						PVC 3				PVC 2			XLPE 3			XLPE 2		
E								PVC 3				PVC 2			XLPE 3		XLPE 2	
F										PVC 3				PVC 2		XLPE 3		XLPE 2
1	2	3	4	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	10a	10b	11	12	13
Sección mm² **Cobre**																		
1,5	11	11,5	12,5	13,5	14	14,5	15,5	16	16,5	17	17,5	19	20	20	20	21	23	–
2,5	15	15,5	17	18	19	20	20	21	22	23	24	26	27	26	28	30	32	–
4	20	20	22	24	25	26	28	29	30	31	32	34	36	36	38	40	44	–
6	25	26	29	31	32	34	36	37	39	40	41	44	46	46	49	52	57	–
10	33	36	40	43	45	46	49	52	54	54	57	60	63	65	68	72	78	–
16	45	48	53	59	61	63	66	69	72	73	77	81	85	87	91	97	104	–
25	59	63	69	77	80	82	86	87	91	95	100	103	108	110	115	122	135	146
35	–	–	–	95	100	101	106	109	114	119	124	127	133	137	143	153	168	182
50	–	–	–	116	121	122	128	133	139	145	151	155	162	167	174	188	204	220
70	–	–	–	148	155	155	162	170	178	185	193	199	208	214	223	243	262	282
95	–	–	–	180	188	187	196	207	216	224	234	241	252	259	271	298	320	343
120	–	–	–	207	217	216	226	240	251	260	272	280	293	301	314	350	373	397
150	–	–	–	–	–	247	259	276	289	299	313	322	337	343	359	401	430	458
185	–	–	–	–	–	281	294	314	329	341	356	368	385	391	409	460	493	523
240	–	–	–	–	–	330	345	368	385	401	419	435	455	468	489	545	583	617
Aluminio																		
2,5	11,5	12	13	14	15	16	16,5	17	17,5	18	19	20	20	20	21	23	25	–
4	15	16	17	19	20	21	22	22	23	24	25	26	28	27	29	31	34	–
6	20	20	22	24	25	27	29	28	30	31	32	33	35	36	38	40	44	–
10	26	27	31	33	35	38	40	40	41	42	44	46	49	50	52	56	60	–
16	35	37	41	46	48	50	52	53	55	57	60	63	66	66	70	76	82	–
25	46	49	54	60	63	63	66	67	70	72	75	78	81	84	88	91	98	110
35	–	–	–	74	78	78	81	83	87	89	93	97	101	104	109	114	122	136
50	–	–	–	90	94	95	100	101	106	108	113	118	123	127	132	140	149	167
70	–	–	–	115	121	121	127	130	136	139	145	151	158	162	170	180	192	215
95	–	–	–	140	146	147	154	159	166	169	177	183	192	197	206	219	233	262
120	–	–	–	161	169	171	179	184	192	196	205	213	222	228	239	254	273	306
150	–	–	–	–	–	196	205	213	222	227	237	246	257	264	276	294	314	353
185	–	–	–	–	–	222	232	243	254	259	271	281	293	301	315	337	361	406
240	–	–	–	–	–	261	273	287	300	306	320	332	347	355	372	399	427	482

Aislamientos termoestables (90°C)		*Aislamientos termoplásticos (70°C)*
XLPE: Polietileno reticulado	**EPR**: Etileno-propileno	**PVC**: Policloruro de vinilo

Figure 60. Table C.52-1 bis of the UNE-HD 60364-5-52 (2014). Admissible currents (A)

Carrying out the correction of the maximum admissible current obtained from Table A.3 using again the corresponding correction factors:

$$I_{adm\ jb-inv} = CF_1 \cdot CF_2 \cdot I_{0\ jb-inv}$$

Equation 47. Correction of the maximum admissible current for the cabling from the junction boxes to the inverters

Where:

- $\boldsymbol{I_{0\ jb-inv}}$: Maximum admissible current of the cable between the junction boxes and their corresponding inverters in permanent service at 60 °C of the individual conductor (A). It is the current obtained from Table C.52-1 bis.

Regarding to the values of both correction factors, they are in this case:

- CF_1= 1, since now there is no bundle of cables
- CF_2= 1, since Table C.52-1 bis is already tabulated for an operating temperature of 90 °C.

Thus, the following maximum admissible currents are obtained, using in first instance the normalized sections previously obtained with the maximum admissible voltage drop criterion:

Sector 1 (Canyoles I)

- Junction box 1-1 to inverter 1-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 2,5 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 30 \rightarrow I_{adm} = 30\ A < I_{C\ jb-inv} = 1{,}25 \cdot 5 \cdot 10{,}36 = 64{,}75\ A$$

- Junction box 2-1 to inverter 2-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 3-1 to inverter 3-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 4-1 to inverter 4-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 5-1 to inverter 5-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 6-1 to inverter 6-1
  - Cables with $S_{vd\ DC\ st\ norm}$ of 2,5 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 30 \rightarrow I_{adm\ jb-inv} = 30\ A < I_{C\ jb-inv} = 1{,}25 \cdot 5 \cdot 10{,}36 = 64{,}75\ A$$

Sector 2 (El Tollo)

- Junction box 1-2 to inverter 1-2
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 15 \cdot 10{,}36 = 194{,}25\ A$$

- Junction box 2-2 to inverter 2-2
  - Cables with $S_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A < I_{C\ jb-inv} = 1{,}25 \cdot 15 \cdot 10{,}36 = 194{,}25\ A$$

- Junction box 3-2 to inverter 3-2
  - Cables with $S_{vd\ DC\ st\ norm}$ of 2,5 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 30 \rightarrow I_{adm\ jb-inv} = 30\ A < I_{C\ jb-inv} = 1{,}25 \cdot 4 \cdot 10{,}36 = 51{,}8\ A$$

- Junction box 4-2 to inverter 4-2
  - Cables with $S_{vd\ DC\ st\ norm}$ of 2,5 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 30 \rightarrow I_{adm\ jb-inv} = 30\ A < I_{C\ jb-inv} = 1{,}25 \cdot 4 \cdot 10{,}36 = 51{,}8\ A$$

As can be seen, in this case the maximum admissible current criterion is not satisfied with the sections obtained previously with the maximum admissible voltage drop criterion. Thus, it is necessary to increase the section of the cables until the admissible current is higher than the maximum current.

Therefore, it is necessary to increase the section of the cables until the admissible current is sufficient. In this case, if the 70, 10 and 6 mm^2 sections are selected instead of 10, 2,5 (Canyoles) and 2,5 (El Tollo) mm^2 respectively, the previous condition is met:

Sector 1 (Canyoles I)

- Junction box 1-1 to inverter 1-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A > I_{C\ jb-inv} = 1{,}25 \cdot 5 \cdot 10{,}36 = 64{,}75\ A$$

- Junction box 2-1 to inverter 2-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 3-1 to inverter 3-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 4-1 to inverter 4-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 5-1 to inverter 5-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = 1{,}25 \cdot 17 \cdot 10{,}36 = 220{,}15\ A$$

- Junction box 6-1 to inverter 6-1
  - Cables with S $_{vd\ DC\ st\ norm}$ of 10 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 72 \rightarrow I_{adm\ jb-inv} = 72\ A > I_{C\ jb-inv} = 1{,}25 \cdot 5 \cdot 10{,}36 = 64{,}75\ A$$

Sector 2 (El Tollo)

- Junction box 1-2 to inverter 1-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = 1{,}25 \cdot 15 \cdot 10{,}36 = 194{,}25\ A$$

- Junction box 2-2 to inverter 2-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 70 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 243 \rightarrow I_{adm\ jb-inv} = 243\ A > I_{C\ jb-inv} = ,25 \cdot 15 \cdot 10{,}36 = 194{,}25\ A$$

- Junction box 3-2 to inverter 3-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 6 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 52 \rightarrow I_{adm\ jb-inv} = 52\ A > I_{C\ jb-inv} = 1{,}25 \cdot 4 \cdot 10{,}36 = 51{,}8\ A$$

- Junction box 3-2 to inverter 3-2
  - Cables with S $_{vd\ DC\ st\ norm}$ of 6 mm^2

$$I_{adm\ jb-inv} = 1 \cdot 1 \cdot 52 \rightarrow I_{adm\ jb-inv} = 52\ A > I_{C\ jb-inv} = 1{,}25 \cdot 4 \cdot 10{,}36 = 51{,}8\ A$$

In this wary, there are 16,11 m of 70 mm^2 section cable (six cables), 5,37 m of 10 mm^2 section cable (two cables) and 5,37 m of 6 mm^2 section cable (two cables).

Once the necessary sections of the DC cabling have been obtained, it is time to select a commercial model.

3.11.2 AC Cabling

This kind of cabling includes those sections that distribute the current from the output of each inverter to the corresponding AC measurement and protection panel, as well as the cables that connect said panels to the Low Voltage Panel (LVP), through which the current is alternating. Subsequently, the power line to the pumps goes from the LVP, at 400 V.

The protection and measurement box will be installed, as it has an underground connection, in accordance with the ITC-BT-13, in a niche in the wall, closed with a metal door, with IK 09 protection degree according to UNE-EN 50.102 protected against corrosion and with a height of the measuring equipment housed between 0.7 and 1.80 m.

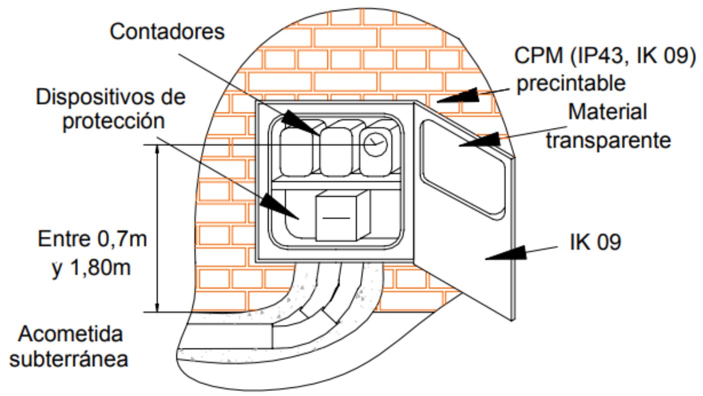


Figura B: Ejemplo de caja de protección y medida (CPM) con acometida subterránea.

Producto	Norma de aplicación
CPM (Conjunto de aparamenta)	UNE-EN 60439-1
Caja (para conjunto de aparamenta)	UNE-EN 60439-1
Bornes de conexión (domésticos o análogos)	UNE-EN 60998
Bornes de conexión (industriales)	UNE-EN 60947-7
Fusibles	UNE-EN 60269 (serie)
Contadores (electrónicos)	UNE-EN 61036
Contadores (inducción)	UNE-EN 60521

Figure 61. Connection specifications and degree of protection of the protection and measurement boxes. Source: ITC-BT-13

As said before, the calculation of the necessary section of the AC wiring follows some general lines common to the calculation of the DC wiring, but it has its peculiarities. The following is the procedure for calculating AC wiring sections using the two criteria already mentioned:

<u>Criterion of the maximum admissible voltage drop</u>

Taking into account that the current is triphasic, the formula to be used in this case is the following:

$$S_{vd\ AC\ triph} = \frac{\sqrt{3} \cdot L_{AC} \cdot I_{out\ inv\ AC} \cdot \cos \varphi}{\sigma_{T^{\circ}C} \cdot \frac{e_{AC}}{100} \cdot V_{net}}$$

Equation 48. Section of the cabling from the inverters to the AC m.a.p panels. Maximum voltage drop criterion

In which:

- $S_{vd\ AC\ triph}$: Section of the AC cable according to the maximum admissible voltage drop criterion (mm^2)
- L_{AC}: Length of the AC cable (m)
- $I_{out\ inv\ AC}$: Nominal current of the inverter in the alternating part (output) (A)
- $\cos\varphi$: Inverter power factor, which results from the quotient between active power (P) and apparent power (S). This parameter, according to the commercial catalogue of the inverter, is adjustable, so it has been assigned the ideal value, that is $\cos\varphi = 1$ ($\varphi = 0°$)
- e_{st}: Maximum allowable voltage drop between the photovoltaic generator and the connection point to the Public Distribution Network or to the indoor installation. The ITC-BT-40 and the IDAE specify that a value of 1,5% has to be adopted (V)
- V_{net}: Voltage between phases of the network to which the installation is connected (V). The value of this parameter is 400 V.

The obtained sections are shown below, as well as the normalized sections and the new voltage drops:

Sector 1									
Cabling zone	L_{AC} (m)	$I_{out\ inv\ AC}$ (A)	cos ϕ (°)	σ_T (m/Ω·mm²)	e_{AC} (%)	V_{net} (V)	$S_{vd\ AC\ triph}$ (mm²)	$S_{vd\ AC\ triph\ norm}$ (mm²)	e_{AC} (%) with S_{norm}
Inv 1-1	3,37	145	1	45,49	1,5%	400	3,10	4	1,16%
Inv 2-1	2,87	145	1	45,49	1,5%	400	2,64	4	0,99%
Inv 3-1	2,91	145	1	45,49	1,5%	400	2,68	4	1,00%
Inv 4-1	3,48	145	1	45,49	1,5%	400	3,20	4	1,20%
Inv 5-1	2,91	145	1	45,49	1,5%	400	2,68	4	1,00%
Inv 6-1	2,87	145	1	45,49	1,5%	400	2,64	4	0,99%

Table 51. Calculation of the section of the wiring between the inverters and the AC measurement and protection panel of the PV installation corresponding to Sector 1. Criterion of the maximum allowable voltage drop

Sector 1									
Cabling zone	L_{AC} (m)	$I_{out\ inv\ AC}$ (A)	cos ϕ (°)	σ_T (m/Ω·mm²)	e_{AC} (%)	V_{net} (V)	$S_{vd\ AC\ triph}$ (mm²)	$S_{vd\ AC\ triph\ norm}$ (mm²)	e_{AC} (%) with S_{norm}
Inv 1-2	2,98	145	1	45,49	1,5%	400	2,74	4	1,03%
Inv 2-2	3,56	145	1	45,49	1,5%	400	3,28	4	1,23%
Inv 3-2	3,51	145	1	45,49	1,5%	400	3,23	4	1,21%
Inv 4-2	2,93	145	1	45,49	1,5%	400	2,70	4	1,01%

Table 52. Calculation of the section of the wiring between the inverters and the AC measurement and protection panel of the PV installation corresponding to Sector 2. Criterion of the maximum allowable voltage drop

According to this criterion, it would be necessary to install 10 cables of 4 mm^2 normalized section.

<u>Criterion of the maximum admissible current</u>

Now, according to Table B.52-1 of the "*Norma UNE-HD 60364-5-52*", since these cables would be installed on a wall, in vertical sections, and horizontally on the ceiling, the installation **method** is **C**.

On the other hand, since there are 3 conductors per cable (this is the AC section, so current is triphasic and each phase runs through one conductor of the cable) and XLPE is the applied insulation, the column corresponding to three conductors and with this type of insulation is taken. With this, and the installation method, it is possible to obtain the results from Table C.52-1 bis, **column 9b**.

Again, the maximum current that may circulate through the cable is obtained by the expression shown below:

$$I_{C\ AC} = 1{,}25 \cdot I_{AC\ inv\ max} \leq I_{adm\ AC}$$

Equation 49. Condition of the criterion of the maximum admissible current for the cabling from the inverters to the AC m.a.p panels

Where:

- $\boldsymbol{I_{C\,AC}}$: Minimum current for which the AC connection cables must be dimensioned, equal to the maximum current that may circulate through them (A)
- $\boldsymbol{I_{AC\,inv\,max}}$: Maximum current value that will circulate from output of the inverter (A)
- $\boldsymbol{I_{adm\,AC}}$: Maximum admissible current of the AC cable (A)

So now, taking into account the following formula:

$$I_{adm\,AC} = CF_1 \cdot CF_2 \cdot I_{0\,AC}$$

Equation 50. Correction of the maximum admissible current for the cabling from the inverters to the AC m.a.p panels

Where:

- $\boldsymbol{I_{0\,AC}}$: Maximum admissible current of the AC cable (A). To check the maximum admissible current, once again it is necessary to refer to the Table C.52-1 bis of the "*Norma UNE-HD 60364-5-52*".

Regarding to the values of both correction factors, they are in this case:

- CF_1= 0,7 for the AC measurement and protection panels of inverters 1,2,3-1 and of inverters 4,5,6-1 (three bundled cables to each panel) and 0,8 for the AC measurement and protection panels of inverters 1,3-2 and 2,4-2 (two bundled cables to each panel).
- CF_2= 0,75 since in this project the maximum operating temperature has been considered of 90 °C

Now, the following maximum admissible currents are obtained, using in first instance the normalized sections previously obtained with the maximum admissible voltage drop criterion:

<u>Sector 1 (Canyoles I)</u>

- Inverters 1,2,3-1 to AC m.a.p panel 1,2,3-1
  - Cable with $S_{vd\,AC\,st\,norm}$ of 4 mm^2
    $I_{adm\,AC} = 0{,}70 \cdot 0{,}75 \cdot 36 \rightarrow I_{adm\,AC} = 18{,}9\,A < I_{C\,AC} = 1{,}25 \cdot 145 = 181{,}25A$

- Inverters 4,5,6-1 to AC m.a.p panel 4,5,6-1
  - Cable with $S_{vd\,AC\,st\,norm}$ of 4 mm^2
    $I_{adm\,AC} = 0{,}70 \cdot 0{,}75 \cdot 36 \rightarrow I_{adm\,AC} = 18{,}9\,A < I_{C\,AC} = 1{,}25 \cdot 145 = 181{,}25A$

<u>Sector 2 (El Tollo)</u>

- Inverters 1,3-2 to AC m.a.p panel 1,3-2
  - Cable with $S_{vd\,AC\,st\,norm}$ of 4 mm^2
    $I_{adm\,AC} = 0{,}80 \cdot 0{,}75 \cdot 36 \rightarrow I_{adm\,AC} = 21{,}6\,A < I_{C\,AC} = 1{,}25 \cdot 145 = 181{,}25A$

- Inverters 1,3-2 to AC m.a.p panel 1,3-2
  - Cable with $S_{vd\,AC\,st\,norm}$ of 4 mm^2
    $I_{adm\,AC} = 0{,}80 \cdot 0{,}75 \cdot 36 \rightarrow I_{adm\,AC} = 21{,}6\,A < I_{C\,AC} = 1{,}25 \cdot 145 = 181{,}25A$

As can be seen, in this case the maximum admissible current criterion is not satisfied with the sections obtained with the first one. Thus, it is necessary to increase the section of the cables until the admissible current is higher than the maximum current.

Therefore, it is necessary to increase the section of the cables until the admissible current is sufficient. In this case, if the 185 and 150 mm^2 sections are selected instead of 4 (Canyoles) and 4 (El Tollo) mm^2 respectively, the following maximum admissible currents are obtained and the previous condition is met:

Sector 1 (Canyoles I)

- Inverters 1,2,3-1 to AC m.a.p panel 1,2,3-1
  - Cable with $S_{vd\ AC\ st\ norm}$ of 185 mm^2

    $I_{adm\ AC} = 0{,}70 \cdot 0{,}75 \cdot 385 \rightarrow I_{adm\ AC} = 202{,}13\ A > I_{C\ AC} = 1{,}25 \cdot 145 = 181{,}25A$

- Inverters 4,5,6-1 to AC m.a.p panel 4,5,6-1
  - Cable with $S_{vd\ AC\ st\ norm}$ of 185 mm^2

    $I_{adm\ AC} = 0{,}70 \cdot 0{,}75 \cdot 385 \rightarrow I_{adm\ AC} = 202{,}13\ A > I_{C\ AC} = 1{,}25 \cdot 145 = 181{,}25A$

Sector 2 (El Tollo)

- Inverters 1,3-2 to AC m.a.p panel 1,3-2
  - Cable with $S_{vd\ AC\ st\ norm}$ of 150 mm^2

    $I_{adm\ AC} = 0{,}80 \cdot 0{,}75 \cdot 337 \rightarrow I_{adm\ AC} = 202{,}2\ A > I_{C\ AC} = 1{,}25 \cdot 145 = 181{,}25A$

- Inverters 1,3-2 to AC m.a.p panel 1,3-2
  - Cable with $S_{vd\ AC\ st\ norm}$ of 150 mm^2

    $I_{adm\ AC} = 0{,}80 \cdot 0{,}75 \cdot 337 \rightarrow I_{adm\ AC} = 202{,}2\ A > I_{C\ AC} = 1{,}25 \cdot 145 = 181{,}25A$

On the other hand, the dimensioning AC wiring section consists of three phase conductors and a neutral. The section of said neutral conductor is determined by means of Table 1 of ITC-BT-07. Although the table refers to the lines of underground low-voltage distribution facilities, these values have been assumed for the case of an AC line of a low-voltage generation facility as the values corresponding to this type of facility are not specified.

Conductores fase (mm^2)	Sección neutro (mm^2)
6 (Cu)	**6**
10 (Cu)	**10**
16 (Cu)	**10**
16 (Al)	**16**
25	**16**
35	**16**
50	**25**
70	**35**
95	**50**
120	**70**
150	**70**
185	**95**
240	**120**
300	**150**
400	**185**

Figure 62. Table 1 of the ITC-BT-07. Section of the neutral conductor as a function of the section of the phase conductors (mm^2)

Therefore, in conclusion, the AC section will need six triphasic lines of three conductors of 185 mm^2 and a neutral of 95 mm^2 each (Sector 1), and four triphasic lines of three conductors of 150 mm^2 and a neutral of 70 mm^2 each (Sector 2).

3.12 Protection tubes

Protection tubes are used to protect cables within building materials or the terrain they run through. Although it is true that, just as two types of cabling were distinguished, it is necessary to differentiate the protection tubes corresponding to DC cables and AC cables, in this case the procedure is identical for both types of protection tubes.

3.12.1.1 Protection tubes for DC cabling

First of all, the outer diameter of the protection tubes corresponding to the cabling that connects the end of the strings and the junction boxes must be obtained, for which, as indicated in the section corresponding to the calculation of the minimum necessary wiring sections circulates CC. Specifically, for the dimensioning of this element, Table 9 of the ITC-BT-21 (REBT) is used, since it corresponds to the tubes inside buried canalizations. This table is shown below:

Sección nominal de los conductores unipolares (mm^2)	Diámetro exterior de los tubos (mm)				
	Número de conductores				
	≤ 6	7	8	9	10
1,5	25	32	32	32	32
2,5	32	32	40	40	40
4	40	40	40	40	50
6	50	50	50	63	63
10	63	63	63	75	75
16	63	75	75	75	90
25	90	90	90	110	110
35	90	110	110	110	125
50	110	110	125	125	140
70	125	125	140	160	160
95	140	140	160	160	180
120	160	160	180	180	200
150	180	180	200	200	225
185	180	200	225	225	250
240	225	225	250	250	--

Figure 63. Table 9 of the ITC-BT-21. Minimum external diameters for buried cable protection tubes (mm)

In this way, taking into account the sections and number of the cables that come from the strings and arrive to the connection boxes, it is concluded that it would be necessary to acquire:

<u>Sector 1 (Canyoles I)</u>

- Junction box 1-1
  - 5 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm^2 → 90 mm external diameter tube
- Junction box 2-1
  - 16 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm^2 and 1 of 35 mm^2 → 110 mm (10) external diameter tube and 90 mm (6+1) external diameter tube
- Junction box 3-1
  - 3 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm^2 and 14 of 35 mm^2 → 110 mm (3+5) external diameter tube and 110 mm (9) external diameter tube
- Junction box 4-1

- 17 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 110 mm (9) external diameter tube and 90 mm (8) external diameter tube

- Junction box 5-1
  - 8 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² and 9 of 35 mm² → 90 mm (8) external diameter tube and 110 mm (9) external diameter tube
- Junction box 6-1
  - 5 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 90 mm external diameter tube

Sector 2 (El Tollo)

- Junction box 1-2
  - 15 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 90 mm external diameter tube (8) and 90 mm external diameter tube (7)

- Junction box 2-2
  - 15 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 90 mm external diameter tube (8) and 90 mm external diameter tube (7)

- Junction box 3-2
  - 4 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 90 mm external diameter tube

- Junction box 4-2
  - 4 Cables with $S_{vd\ DC\ st\ norm}$ of 25 mm² → 90 mm external diameter tube

In conclusion, 11 tubes of 90 mm external diameter (5592,38 m) and 5 tubes of 110 mm external diameter (2992,36 m) are needed. 5 tubes of 90 mm and other 5 of 110 mm will be in Sector 1, and the other 6 tubes of 90 mm will be in Sector 2. Finally, these amounts must be doubled, since there are two poles (positive and negative) and the previous results are obtained for each sense of the current (remember when the correction factor CF_1 was defined).

3.12.1.2 Protection tubes for AC cabling

On the other hand, for the dimensioning of the protective tube between the AC measurement and protection panel, the same table is used as in the previous case, since it also involves buried cables. Therefore, taking into account the diameter of these sections, it has been decided to use a tube with an external diameter of 225 mm, which will be able to accommodate the 3x185 mm² + 1x95 mm² and the 3x150 mm² + 1x70 mm². However, a **250 mm outer diameter** tube has finally been selected since the manufacturer has diameters of 200 and 250, but not 225 mm.

3.13 Protection devices specifications

In this section, the aim is to define the minimum necessary performance of the system protection elements required in the installation, both in the DC and in the AC part, as well as to select the commercial models that satisfy them at the lowest possible cost.

3.13.1 DC Protection devices

In this chapter, the protections corresponding to the part of the installation in which direct current circulates are dimensioned, and the corresponding commercial models are chosen.

3.13.1.1 Protection against overcurrents and short circuits

According to what is stated in the first chapter of this document, they must not only be capable of protecting against overcurrents, but also against short circuits, and must be dimensioned accordingly. For this, the ITC-BT-22 of the REBT is used, which establishes the following conditions to be met:

$$I_d \leq I_{nf} \leq I_{adm}$$

Equation 51. Condition I to be satisfied by the gPV fuses

$$I_{op\ g} \leq 1{,}45 \cdot \ I_{adm}$$

Equation 52. Condition II to be satisfied by the gPV fuses

Being:

- $\boldsymbol{I_d}$: Current for which the circuit or line has been designed. Since what reaches each of the fuses housed in each junction box is the set of modules connected in series that form the string they protect, said current is that corresponding to a photovoltaic module at its maximum power point ($I_{M\ mod}$) (A). Thus, the value of this parameter is 9,6 A.
- $\boldsymbol{I_{nf}}$: This is the rated current of the protection device; in this case, it is the nominal current of the fuse (A). It is the parameter to obtain.
- $\boldsymbol{I_{adm}}$: Maximum admissible current of the cable depending on the installation method used. Its value was obtained in the chapter corresponding to cabling sizing (A) of DC cabling of the strings.
  - For cables with $S_{vd\ DC\ st\ norm}$ of 25 mm^2:
    - If the number of cables that arrive at their respective junction boxes is 34 (2x17) or 30 (2x15), I_{adm} = 33,06 A
    - If the number of cables that arrive at their respective junction boxes is 10 (2x5), I_{adm} = 42,02 A
    - If the number of cables that arrive at their respective junction boxes is 8 (2x4), I_{adm} = 45,24 A
  - For cables with $S_{vd\ DC\ st\ norm}$ of 35 mm^2, since the number of cables that arrive at their respective junction boxes is 34 (2x17), I_{adm} = 39,90 A
- $\boldsymbol{I_{op\ g}}$: Current that ensures the effective operation of the protection device (fuse). According to the UNE-60269 standard, the value will be taken for the case of a gG type fuse since the standard does not specify values for gPV fuses. Therefore, the value of this parameter must be:
  - $$I_{op\ g} = \begin{cases} 1{,}6 \cdot I_{nf} & if\ I_{nf} \geq 16\ A \\ 1{,}9 \cdot I_{nf} & if 4\ A < I_{nf} < 16\ A \\ 2{,}1 \cdot I_{nf} & if I_{nf} \leq 4\ A \end{cases}$$

Equation 53. Current for the operation of the gPV fuses

Therefore, based on the values in this case, the previous expressions would be as follows:

- For cables with $S_{vd\ DC\ st\ norm}$ of 25 mm^2:
  - If the number of cables that arrive at their respective junction boxes is 34 (2x17) or 30 (2x15):
    - $9{,}6 \leq I_{nf} \leq 33{,}06\ A;\ 1{,}9 \cdot I_{nf}\ \leq 1{,}45 \cdot 33{,}06\ A \rightarrow I_{nf}\ \leq$25,23 A
  - If the number of cables that arrive at their respective junction boxes is 10 (2x5):
    - $9{,}6 \leq I_{nf} \leq 42{,}02\ A;\ 1{,}9 \cdot I_{nf}\ \leq 1{,}45 \cdot 42{,}02\ A \rightarrow I_{nf}\ \leq$32,07 A
  - If the number of cables that arrive at their respective junction boxes is 8 (2x4):
    - $9{,}6 \leq I_{nf} \leq 45{,}24\ A;\ 1{,}9 \cdot I_{nf}\ \leq 1{,}45 \cdot 45{,}24\ A \rightarrow I_{nf}\ \leq$34,53 A

- For cables with $S_{vd\ DC\ st\ norm}$ of 35 mm^2, since the number of cables that arrive at their respective junction boxes is 34 (2x17):
    - $9{,}6 \leq I_{nf} \leq 39{,}90\ A; 1{,}9 \cdot I_{nf} \leq 1{,}45 \cdot 39{,}90\ A \rightarrow I_{nf} \leq$30,45 A

Observing the values obtained, gPV-type fuses with a nominal intensity of 15 A, cutting power equal to or greater than 10 kA and a nominal voltage greater than 125% of the open circuit voltage of the photovoltaic field, which is will 996 V in each junction box since all of them receive strings of 20 modules with an open circuit voltage of 49,8 V (so with a nominal voltage greater than 1245 V) be installed on the DC side. Finally, it has been decided to select fuses of 1500 Vdc nominal voltage, 30 kA cutting power and nominal intensity of 15 A.

In addition, it can be observed that the two first conditions are met.

The above calculations determine the values that the chosen commercial fuses must achieve to satisfy the overcurrent protection conditions. However, as mentioned previously, these devices must also protect against short circuits. For this, and again in accordance with the provisions of ITC-BT-22, the following conditions must be met:

$$P_{f\ b} \geq I_{SC\ \max f}$$

Equation 54. Condition III to be satisfied by the gPV fuses

$$I_{SC\ adm\ cond} > I_{op\ f\ 5}$$

Equation 55. Condition IV to be satisfied by the gPV fuses

$$I_{SC\ \min f} > I_{op\ f\ 5}$$

Equation 56. Condition V to be satisfied by the gPV fuses

In which:

- $\boldsymbol{P_{f\ b}}$: Fuse breaking capacity (A)
- $\boldsymbol{I_{SC\ max\ f}}$: Maximum short-circuit current that can be generated downstream of the fuse (A)
- $\boldsymbol{I_{SC\ adm\ cond}}$: Admissible short-circuit current (A). Represents the maximum current that the cable can withstand for 5 seconds without deterioration. From the ITC-BT-22 the following expression is obtained, which allows to calculate this parameter:

$$I_{SC\ adm\ cond} = k \cdot \frac{S}{\sqrt{t}}$$

Equation 57. Admissible short-circuit current of the cable

Where, in turn:

- $\boldsymbol{k}$: Coefficient that depends on the material of which the conductor is made and the insulation it has. In case of using copper cable with XLPE insulation, its value is 143, according to the following table taken from the UNE 20460-4-43 standard:

	Aislamiento de los conductores							
	PVC 70°C ≤ 300 mm²	PVC 70°C > 300 mm²	PVC 90°C ≤ 300 mm²	PVC 90°C > 300 mm²	PR/EPR	Goma 60 °C	Mineral Con PVC	Mineral Desnudo
Temperatura inicial °C	70	70	90	90	90	60	70	105
Temperatura final °C	160	140	160	140	250	200	160	250
Material del conductor								
Cobre	115	103	100	86	143	141	115 *)	135
Aluminio	76	68	66	57	94	93	-	-
Conexiones soldadas con estaño para conductores de cobre	115	-	-	-	-	-	-	-

Figure 64. Values for k coefficient. Extracted from ITC-BT-22 (2005)

- $\boldsymbol{S}$: Cable section (mm^2)
- $\boldsymbol{t}$: Maximum duration of the short circuit, during which the equipment must guarantee the protection of the installation. It has been set at 5 s.

- $\boldsymbol{I_{op\,f\,5}}$: Minimum current capable of making the fuse act in a time not exceeding 5s (A). It is therefore the fusing current in 5 seconds of the selected fuse.
- $\boldsymbol{I_{SC\,min\,f}}$: Minimum short-circuit current that can be generated downstream of the fuse (A). Its value is calculated using the simplified expression found in the "*Guía BT Anexo 3*":

$$I_{SC\,\min f} = \frac{0{,}8 \cdot U}{Z_L}$$

Equation 58. Minimum short-circuit current downstream the fuse

Being:

- $\boldsymbol{U}$: According to the "*Guía BT Anexo 3*", the phase-neutral supply voltage is taken, which is 230 V. This is because it is considered as the most unfavourable.
- $\boldsymbol{Z_L}$: Line impedance, which is calculated, again, under the most unfavourable conditions, which in this case correspond to those with the highest service temperature (Ω). The equation that allows obtaining its value is the following:

$$Z_L = \sqrt{{R_L}^2 + {X_L}^2}$$

Equation 59. Line impedance

Where, in turn:

- $\boldsymbol{R_L}$: Line resistance. It is obtained by means of the next formula (Ω)

$$R_L = \frac{L_L \cdot \rho_{90°C}}{S_L} = \frac{L_L}{\sigma_{90°C} \cdot S_L}$$

Equation 60. Line resistance

- $\boldsymbol{L_L}$: Length of the line (m). To calculate this parameter, the length of the longest string is taken, since this is the most unfavourable case, to ensure compliance with any of the other strings. In this case, it is 622,73 m.
- $\boldsymbol{\rho_{90°C}}$: Resistivity of the material that makes up the cable. At 90°C (highest service temperature) and for copper, its value is 0,02198 $(\Omega \cdot \mathrm{mm}^2/\mathrm{m})$
- $\boldsymbol{\sigma_{90°C}}$: Conductivity of the material that makes up the cable. At 90°C (highest service temperature) and for copper, its value is 45,49 $(\mathrm{m}/\Omega \cdot \mathrm{mm}^2)$

- $\boldsymbol{S_L}$: Section of the line conductor (mm^2). Equal to S.

▪ $\boldsymbol{X_L}$: Line inductive reactance (Ω). Its obtaining is carried out using the following equation:

$$X_L = L_L \cdot 2 \cdot \pi \cdot f \cdot L = L_L \cdot \omega \cdot L$$

Equation 61. Line reactance

- $\boldsymbol{f}$: Current frequency (Hz). In Europe, its value is 50 Hz.
- $\boldsymbol{L}$: Coil inductance (H). Its value is assumed in 0,5 μH.
- $\boldsymbol{\omega}$: Angular frequency (Rad)

For cables which section does not exceed 120 mm^2, the value of this parameter in the line can be considered negligible. The cables have a section that do not exceed 35 mm^2, so X_L ≅ 0 → Z_L = R_L.

Therefore, since the breaking capacity of the fuses selected in the first instance ($P_{f\ b}$ =30 kA) is far greater than the maximum short-circuit current that could occur not only in the string that each one protects (10,36 A) but also in the set of strings of the photovoltaic field that reach the DC junction box in which it is found in the worst case in which through said DC junction box all the current of the strings converges in a single branch (176,12 in the table that receives more branches in parallel, 17 in total), the first condition is fulfilled in all cases more than enough.

Regarding the second condition, there is:

$$I_{SC\ adm\ cond\ 25\ mm^2} = k \cdot \frac{S}{\sqrt{t}} = 143 \cdot \frac{25}{\sqrt{5}} = 1598{,}79\ A > I_{op\ f\ 5,\ \ 15\ \mathrm{A}} = 90\ A$$

$$I_{SC\ adm\ cond\ 35\ mm^2} = k \cdot \frac{S}{\sqrt{t}} = 143 \cdot \frac{35}{\sqrt{5}} = 2238{,}30\ A > I_{op\ f\ 5,\ \ 15\ \mathrm{A}} = 90\ A$$

So, it is also satisfied.

Finally, regarding the third condition:

$$I_{SC\ min\ f\ 25\ mm^2} = \frac{0{,}8 \cdot 230}{\frac{622{,}73}{45{,}39 \cdot 25}} = \frac{0{,}8 \cdot 230}{0{,}549} = 335{,}29\ A > I_{op\ f\ 5,\ \ 15\ \mathrm{A}} = 90\ A$$

$$I_{SC\ min\ f\ 35\ mm^2} = \frac{0{,}8 \cdot 230}{\frac{622{,}73}{45{,}39 \cdot 25}} = \frac{0{,}8 \cdot 230}{0{,}549} = 469{,}40\ A > I_{op\ f\ 5,\ \ 15\ \mathrm{A}} = 90\ A$$

So, as this condition is also met, the initial choice is corroborated, and the fuses selected in the first instance are the ones finally chosen.

3.13.1.2 Protection against overvoltages. Surge arresters

ITC-BT-23 establishes that the device in charge of this type of protection must reduce overvoltages (transient) to a value that is admissible and endurable by the equipment it protects downstream. Based on this, the DC junction box has to include Type 2 surge protection devices, characterized by the following properties:

- The nominal discharge current must be greater than 5 kA. The overvoltages protection element must be capable of grounding high currents characterized by an 8/20 µs curve, as established in UNE HD 60364-5-53 standard.
- Since of the four categories of overvoltages contemplated in this standard depending on the equipment it protects, in the case of the equipment of the installation that is the subject of this document, these can be included in Category III ("equipment and materials that are part of the electrical installation fixed and other equipment for which a high level of reliability is required ", such as elevators, switches, distribution cabinets, etc.), the associated protection level must be $U_p \leq 4$ kV. This value is taken from the next Table 1 extracted from the ITC-BT-23 standard:

TENSIÓN NOMINAL DE LA INSTALACIÓN		TENSIÓN SOPORTADA A IMPULSOS 1,2/50 (kV)			
SISTEMAS TRIFÁSICOS	SISTEMAS MONOFÁSICOS	CATEGORÍA IV	CATEGORÍA III	CATEGORÍA II	CATEGORÍA I
230/400	230	6	4	2,5	1,5
400/690 1000	-- --	8	6	4	2,5

Figure 65. Table 1 of the ITC-BT-23. Level of protection of the overvoltages protection devices

- They are the most widely used because they offer a level of protection compatible with most equipment that is connected to the power supply network.
- The connection between the protection element and its earth connection must be made by means of a copper conductor of at least 4 mm^2 section.
- The voltage applied to the protection device in permanent service U_c must be less than the maximum voltage supported by it continuously.

Following these conditions, it has been decided to install a Type 2 overvoltage protection device, with I_n=20 kA at 8/20 µs (current capable of bypassing the Type 2 protector at least 20 times), I_{max}=40 kA at 8/20 µs (maximum current capable of shifting to ground only once), $U_p \leq 4$ kV, nominal voltage U_c =1000 V and a maximum working voltage of 1170 V.

These devices are considered to comply with the prescriptions of devices with similar characteristics established in UNE-EN 61643-11: 2013 / A11: 2018.

3.13.1.3 Protection against direct and indirect contacts. DC side grounding

As established before, the pv generator will be grounded in floating mode. The UNE-HD 60364-4-41: 2018 standard sets out the minimum specifications that a system that uses the **IT** installation **scheme** must meet for grounding. First, it is established that all the masses of the pv installation must be grounded, either individually, in groups or together; in this case it has been decided to connect these masses in groups. In the DC section the frames of the modules will be connected to earth via copper rods. Their configuration must be round, highly resistant, ensuring maximum rigidity to facilitate their introduction into the ground and preventing them from bending due to the force of the hits.

An effort will be made to ensure that the grounding resistance of the set of 2 m long copper rods and the 35 mm^2 bare copper wiring that interconnects them is a maximum of 10 - 12 Ω. To do this, the calculus is done as it is shown in the following:

The resistance of each rod is given by:

$$R_{v\,g\,r} = \frac{\rho_t}{L_{v\,g\,r}}$$

Equation 62. Resistance of a vertical grounding rod

Being:

- $\boldsymbol{R_{v\,g\,r}}$: Resistance of a vertical grounding rod (Ω)
- $\boldsymbol{\rho_t}$: Resistivity of the terrain, with a value of 160 Ω·m. The following table shows the typical values of this parameter according to the characteristics of the terrain:

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

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

Table 53. Approximate average values of resistivity as a function of the terrain. Source: ITC-BT-18

- $\boldsymbol{L_{v\,g\,r}}$: Length of the vertical grounding rod (m), with a value of 2 m

For its part, the resistance of the bare copper conductor is obtained by means of the following formula:

$$R_{b\,c\,c} = \frac{2 \cdot \rho_t}{L_{b\,c\,c}}$$

Equation 63. Resistance of the bare copper conductor

In which:

- $\boldsymbol{R_{b\,c\,c}}$: Resistance of the bare copper conductor (Ω)
- $\boldsymbol{L_{b\,c\,c}}$: Length of the ring of bare copper cable (m)

In addition, it is necessary to know the total resistance of the set of rods:

$$R_{t\,v\,g\,r} = \frac{1}{n \cdot \frac{1}{R_{v\,g\,r}}}$$

Equation 64. Resistance of the set of vertical grounding rods

Where:

- $\boldsymbol{R_{t\,v\,g\,r}}$: Resistance of the set of vertical grounding rods (Ω)

- **n** : Number of grounding rods in the installation.

And together with the resistance offered by the bare copper conductor, there is:

$$R_{v\,g\,r\,n} = \frac{1}{\frac{1}{R_{t\,v\,g\,r}} \cdot \frac{1}{R_{b\,c\,c}}} \leq 10\ \Omega$$

Equation 65. Resistance of the network of vertical grounding rods and bare copper conductor

Being:

- $\boldsymbol{R_{v\,g\,r\,n}}$: Resistance of the network of vertical grounding rods and bare copper conductor (Ω)

Finally, substituting the known data, the minimum number of grounding rods necessary is determined:

$$\frac{1}{\frac{1}{\frac{1}{n \cdot \frac{1}{\frac{\rho_t}{L_{v\,g\,r}}}}} \cdot \frac{1}{\frac{2 \cdot \rho_t}{L_{b\,c\,c}}}} = \frac{1}{\frac{1}{\frac{1}{n \cdot \frac{1}{\frac{160}{2}}}} \cdot \frac{1}{\frac{2 \cdot 160}{20}}} \leq 10 \rightarrow n \geq 3$$

So, 3 grounding copper rods will be used, for every group of protected masses.

On the other hand, it is worth mentioning that the ITC-BT-18 establishes recommendations to set the minimum required section of the protection conductors (grounding) that connect the masses with the main grounding terminal, in such a way that protection and grounding is guaranteed, based on the cross-section of the phase conductors. These protective conductors are housed in the same conduit as the active conductors and are made of the same material. The following table, extracted from said ITC, reflects these values:

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

Figure 66. Relationship between the sections of the protective conductors and the phase conductors

Since the cables that connect the strings with the junction boxes have a section of 25 or 35 mm^2, according to the previously mentioned table, in any case, $S_p = 16\ mm^2$.

In view of the large number of strings that exist in the photovoltaic generator, as well as the limited space available for the correct arrangement of the different wiring, the following has been decided: a series of sets of strings have been established each one of which has its own grounding system consisting, as previously calculated, of 3 interconnected rods. In this way, the frames of the modules that make up each string will be connected to earth through the mentioned 16 mm^2 cable, to a system of 3 vertical rods of 2 m length interconnected with each other by about 20 m of bare copper cable with a section of 35 mm^2.

Only in the IT system a first insulation failure does not cause a system shutdown.

In addition, it is necessary to install an insulation controller, whose function is to warn of a first fault and allow disconnection to prevent a second fault from occurring that would already lead to dangerous fault voltages. This function is carried out by inverters.

Fourth, it is necessary to have devices that eliminate a second fault that could be due to short circuits. The installation also meets this condition, thanks to the systems incorporated by the selected commercial inverter and the DC connection box with the fuses.

Finally, as an additional measure to guarantee people's safety, all elements of the photovoltaic field (modules, cables, connection boxes ...) will be equipped with Class II insulation.

3.13.2 AC Protection devices

In this chapter, the protections corresponding to the part of the installation in which alternating current circulates are dimensioned, and the corresponding commercial models are chosen.

Said calculation, as can be seen later, is analogous to that developed in the direct current part of the installation, since the elements that carry out the protection of the AC part are also protected in indoor installations.

3.13.2.1 Protection against overcurrents and short circuits

A type C magnetothermal switch will be placed, as said in Chapter 1. Hence, the conditions to meet are:

$$I_{d\ AC} \leq I_{n\ ms} \leq I_{M\ adm\ cond\ AC}$$

Equation 66. Condition I to be satisfied by the magnetothermal switches

$$1{,}3 \cdot I_{n\ ms} \leq 1{,}45 \cdot I_{M\ adm\ cond\ AC}$$

Equation 67. Condition II to be satisfied by the magnetothermal switches

Being:

- $\boldsymbol{I_{d\ AC}}$: Line design current, equal to the inverter's maximum AC current (A). In this case, the value of tis parameter is 145 A.
- $\boldsymbol{I_{n\ ms}}$: This is the rated current of the protection device; in this case, it is the nominal current of the magnetothermal switch (A), which is necessary to determine.
- $\boldsymbol{I_{M\ adm\ cond\ AC}}$: Maximum admissible current of the cable depending on the installation method used. Its value was obtained in the chapter corresponding to the AC cabling sizing (A). It was of 202,13 A for the AC m.a.p panels of Sector 1, and 202,2 A for those of Sector 2.

Therefore, based on the values in this case, the previous expressions would be as follows:

Sector 1 (Canyoles I)

- AC m.a.p panel 1,2,3-1

$$145 \leq I_{n\ ms} \leq 202{,}13$$

$$1{,}3 \cdot I_{n\ ms} \leq 1{,}45 \cdot\ 202{,}13 \rightarrow I_{n\ ms} \leq 225{,}45\ A$$

- AC m.a.p panel 4,5,6-1

$$145 \leq I_{n\ ms} \leq 202{,}13$$

$$1{,}3 \cdot I_{n\ ms} \leq 1{,}45 \cdot\ 202{,}13 \rightarrow I_{n\ ms} \leq 225{,}45\ A$$

Sector 2 (El Tollo)

- AC m.a.p panel 1,3-2

$$145 \leq I_{n\,ms} \leq 202{,}2$$

$$1{,}3 \cdot I_{n\,ms} \leq 1{,}45 \cdot\ 202{,}2 \rightarrow I_{n\,ms} \leq 225{,}53\ A$$

- AC m.a.p panel 2,4-2

$$145 \leq I_{n\,ms} \leq 202{,}2$$

$$1{,}3 \cdot I_{n\,ms} \leq 1{,}45 \cdot\ 202{,}2 \rightarrow I_{n\,ms} \leq 225{,}53\ A$$

Thus, the two first conditions are met in any case.

The above calculations determine the values that the chosen commercial magnetothermal switch must achieve to satisfy the overcurrent protection conditions. However, as mentioned previously, these devices must also protect against short circuits. For this, and again in accordance with the provisions of ITC-BT-22, the following conditions must be met:

$$P_{ms\ b} \geq\ I_{SC\max ms}$$

Equation 68. Condition III to be satisfied by the magnetothermal switches

$$I_{SC\min ms} > I_{mt}$$

Equation 69. Condition IV to be satisfied by the magnetothermal switches

In which:

- $\boldsymbol{P_{ms\ b}}$: Magnetothermal switch breaking capacity (A)
- $\boldsymbol{I_{SC\,max\,ms}}$: Maximum short-circuit current that can occur at the point where the magnetothermal switch is located (A). The distribution company responsible for the area where the installation is located establishes the value of this parameter, since it is in the AC part. In the province of Valencia, the distribution company is IBERDROLA. The document MT 2.00.12 (13-09) of the company establishes a minimum value of 4500 A, as well as the ITC-BT-17, section 1.3, and the ITC-BT-22, section 1.1. In this case, a value of 12 kA is taken, to be more conservative.
- $\boldsymbol{I_{mt}}$: Magnetic tripping current of the protection device (A). From the ITC-BT-22 the following expression is obtained, which allows to calculate this parameter:

$$k^2 \cdot S^2 > {I_{mt}}^2 \cdot t$$

Equation 70. Magnetic tripping current of the magnetothermal switch

Where, in turn:

  - $\boldsymbol{k}$: Coefficient that depends on the material of which the conductor is made and the insulation it has. In case of using copper cable with XLPE insulation, its value is 143, according to the following table taken from the UNE 20460-4-43 standard:
  - $\boldsymbol{S}$: Cable section (mm^2)
  - $\boldsymbol{t}$: Maximum duration of the short circuit during which the equipment must guarantee the protection of the installation. It has been set at 0,1 s.

- $\boldsymbol{I_{SC\,min\,ms}}$: Minimum short-circuit current that can be generated downstream of the magnetothermal switch (A). Its value is calculated using the simplified expression found in the BT Guide Annex 3

$$I_{SC\,\min ms} = \frac{0{,}8 \cdot U}{Z_L + Z_N}$$

Equation 71. Minimum short-circuit current downstream the magnetothermal switch

Being:

- $\boldsymbol{U}$: Simple voltage, value 230 V. It is the phase-neutral supply voltage.
- $\boldsymbol{Z_N}$: Neutral impedance, which is calculated, again, under the most unfavourable conditions, which in this case correspond to those with the highest service temperature (Ω). The equation that allows obtaining its value is the following:

$$Z_N = \sqrt{{R_N}^2 + {X_N}^2}$$

Equation 72. Neutral impedance

Where, in turn:

- $\boldsymbol{R_N}$: Neutral resistance. It is obtained by means of the next formula (Ω)

$$R_N = \frac{L_L \cdot \rho_{90°C}}{S_N} = \frac{L_L}{\sigma_{90°C} \cdot S_N}$$

Equation 73. Neutral resistance

  - $\boldsymbol{S_N}$: Section of the neutral conductor (mm^2). Equal to S.

- $\boldsymbol{X_N}$: Neutral inductive reactance (Ω). Its obtaining is carried out using the following equation:

$$X_N = L_c \cdot 2 \cdot \pi \cdot f \cdot L = L_c \cdot \omega \cdot L$$

Equation 74. Neutral reactance

With all these formulas and the known data:

<u>Sector 1 (Canyoles I)</u>

- AC m.a.p panels 1,2,3-1 and 4,5,6-1
  - $R_L = \frac{L_L}{\sigma_{90°C} \cdot S_L} = \frac{3{,}48}{45{,}49 \cdot 185} \rightarrow R_L = 413{,}52 \cdot 10^{-6}\ \Omega$
  - $R_N = \frac{L_N}{\sigma_{90°C} \cdot S_N} = \frac{3{,}48}{45{,}49 \cdot 95} \rightarrow R_N = 805{,}27 \cdot 10^{-6}\ \Omega$
  - $X_L = L_L \cdot 2 \cdot \pi \cdot f \cdot L = 5 \cdot 10^{-5} \cdot \pi \cdot 3{,}48 \rightarrow X_L = 546{,}64 \cdot 10^{-6}\ \Omega$
  - $X_N = 0\ \Omega$ (Since the section is smaller than 120 mm²)
  - $Z_L = \sqrt{{R_L}^2 + {X_L}^2} = \sqrt{(413{,}52 \cdot 10^{-6})^2 + (546{,}64 \cdot 10^{-6})^2} \rightarrow Z_L = 685{,}43 \cdot 10^{-6}\ \Omega$
  - $Z_N = \sqrt{{R_N}^2 + {X_N}^2} = \sqrt{(805{,}27 \cdot 10^{-6})^2} \rightarrow Z_N = 805{,}27 \cdot 10^{-6}\ \Omega$
  - $I_{SC\,\min ms} = \frac{0{,}8 \cdot U}{Z_L + Z_N} = \frac{0{,}8 \cdot 230}{685{,}43 \cdot 10^{-6} + 805{,}27 \cdot 10^{-6}} \rightarrow I_{SC\,\min ms} = 123.426{,}19\ A$
  - $I_{mt} < 143 \cdot \frac{185}{\sqrt{0{,}1}} \rightarrow I_{mt} < 83.658{,}06\ A$

So, to summarize:

- $P_{ms\,b} \geq 12\ kA$
- $I_{SC\,min\,ms} = 123.426{,}19\ A\ > I_{mt} = 83.658{,}06\ A$

Sector 2 (El Tollo)

- AC m.a.p panels 1,3-2 and 2,4-2
  - $R_L = \frac{L_L}{\sigma_{90°C} \cdot S_L} = \frac{3{,}56}{45{,}49 \cdot 150} \rightarrow R_L = 521{,}73 \cdot 10^{-6}\ \Omega$
  - $R_N = \frac{L_N}{\sigma_{90°C} \cdot S_N} = \frac{3{,}56}{45{,}49 \cdot 70} \rightarrow R_N = 1{,}12 \cdot 10^{-3}\ \Omega$
  - $X_L = L_L \cdot 2 \cdot \pi \cdot f \cdot L = 5 \cdot 10^{-5} \cdot \pi \cdot 3{,}56 \rightarrow X_L = 559{,}20 \cdot 10^{-6}\ \Omega$
  - $X_N = 0\ \Omega$ (Since the section is smaller than 120 mm^2)
  - $Z_L = \sqrt{{R_L}^2 + {X_L}^2} = \sqrt{(521{,}73 \cdot 10^{-6})^2 + (559{,}20 \cdot 10^{-6})^2} \rightarrow Z_L = 764{,}79 \cdot 10^{-6}\ \Omega$
  - $Z_N = \sqrt{{R_N}^2 + {X_N}^2} = \sqrt{(1{,}12 \cdot 10^{-3})^2} \rightarrow Z_N = 1{,}12 \cdot 10^{-3}\ \Omega$
  - $I_{SC\,\min\,ms} = \frac{0{,}8 \cdot U}{Z_L + Z_N} = \frac{0{,}8 \cdot 230}{764{,}79 \cdot 10^{-6} + 1{,}12 \cdot 10^{-3}} \rightarrow I_{SC\,\min\,ms} = 97.722{,}30\ A$
  - $I_{mt} < 143 \cdot \frac{150}{\sqrt{0{,}1}} \rightarrow I_{mt} < 67.830{,}85\ A$

So, to summarize:

- $P_{ms\,b} \geq 12\ kA$
- $I_{SC\,min\,ms} = 97.722{,}30\ A\ > I_{mt} = 67.830{,}86\ A$

As these two conditions are also met, it will be sufficient to select a magnetothermal switch that has a breaking capacity of at least 12 kA and a nominal current of between 145 and 203 A. It has been selected a commercial model with $I_{n\,ms} = 160\ A$ and $P_{ms\,b} = 16\ kA$.

3.13.2.2 Protection against direct and indirect contacts

For this kind of protection, differential switches are the most widely used devices. Since the differential switch is sized basing on the characteristics of the chosen magnetothermal switch determined in the previous point, the selected commercial ID must comply with:

$$I_{n\,ds} \geq I_{n\,ms} = 160\ A$$

Equation 75. Condition I to be satisfied by the differential switches

$$P_{ds\,b} \geq P_{ms\,b} = 16\ kA$$

Equation 76. Condition II to be satisfied by the differential switches

In which:

- $\boldsymbol{I_{n\,ds}}$: This is the rated current of the protection device; in this case, it is the nominal current of the magnetothermal switch (A)
- $\boldsymbol{P_{ds\,b}}$: Differential switch breaking capacity (A)

As mentioned in the corresponding section of Document 2, the selected commercial model of magnetothermal switch also includes, according to the manufacturer Legrand, the differential protection function, so the above conditions are met.

On the other hand, another important parameter, and that is necessary to determine, is the sensitivity of the DS, since as seen in the next point the choice of this value will determine the value of the grounding resistance and with it the characteristics of electrode to use. A value of 300 mA is chosen, which implies that the DS allows the passage of fault currents of up to 0,3 A, which does not pose a risk to human health.

3.13.2.3 AC side grounding

In the AC section the inverters and the protection boxes will be connected to earth via copper rods, following a **TT scheme** in this case. The calculation of the grounding resistance of the AC masses according to the guide of the ITC-BT-18 of the REBT is developed below:

All the masses of the electrical equipment protected by the same protection device must be interconnected and connected by a protective conductor to the same earth connection in the installation.

The ground connection must meet the following condition:

$$R_{adm} \leq \frac{V_L}{I_{\Delta n}}$$

Equation 77. Total admissible resistance of the ground connection and protective ground conductors

Where:

- $\mathbf{R_{adm}}$: Sum of the resistances of the ground connection and of the protective ground conductors (Ω).
- $\mathbf{V_L}$: Conventional limit contact voltage (V). The value corresponding to the case of special or humid rooms is taken, this being 24 V.
- $\boldsymbol{I_{\Delta n}}$: Current that ensures the automatic operation of the protection device, being the residual current assigned in differential devices. In other words, this parameter represents the sensitivity of the differential switch, equal to 300 mA.

For the land where the grounding rods will be installed, a 160 Ω·m resistivity is taken. Therefore, the most unfavourable resistance may not exceed the value given by:

$$R_{adm} = \frac{24}{0{,}3} = 80\ \Omega$$

On the other hand, since the length of the grounding rods will be of 2 m, the resistance of one of these vertical grounding rod is solved by the equation:

$$R_{v\,g\,r} = \frac{\rho_t}{L_{v\,g\,r}}$$

Equation 78. Resistance of a vertical grounding rod

Being:

- $\boldsymbol{R_{v\,g\,r}}$: Resistance of a vertical grounding rod (Ω)
- $\boldsymbol{\rho_t}$: Resistivity of the terrain, with a value of 160 Ω·m
- $\boldsymbol{L_{v\,g\,r}}$: Length of the vertical grounding rod (m), with a value of 2 m

Thus, the resistance of a vertical grounding road is:

$$R_{v\ ground\ rod} = \frac{160}{2} = 80\ \Omega$$

As there will be N grounding rods in the installation, the following formula is applied:

$$R_{adm} \geq \frac{R_{v\ ground\ rod}}{n}$$

Equation 79. Number of required grounding rods

Where:

- **n** : Number of grounding rods in the installation.

Finally, the number of grounding roads will be the following, for each protected element:

$$n \geq \frac{80}{80} = 1$$

If, once the resistivity of the terrain has been verified, it is higher than the value considered, the number of grounding rods could be increased to ensure that the value established as the limit is not exceeded.

In a TT scheme, the neutral of the line must be grounded. Since the AC line is connected to the existing LV panel of the transformation centre and the transformer of said centre already has its neutral grounded, it is not necessary to ground this line. However, although not strictly necessary, this grounding could be reinforced by grounding the neutral of the AC line at an intermediate point between the inverter output and the C.T. This is done in the AC measurement and protection boxes.

3.14 Losses considered in the pv system. Performance Ratio

There are multiple causes that originate a reduction in the joint efficiency of the photovoltaic system, which results in a worse use of the incident solar energy. In this section the different losses that occur in the process of production, conversion and transport of electrical energy in a photovoltaic system will be defined and calculated (or at least estimated) to finally obtain the value of the performance ratio (PR).

This PR constitutes one of the fundamental parameters to evaluate the effectiveness of a photovoltaic installation, and expresses the relation of the real energy yield with respect to the theoretically possible energy yield.

The following illustration illustrates the main power losses from the maximum power of the generator to the power finally injected into the network or used to feed the loads of an industry or residential area.

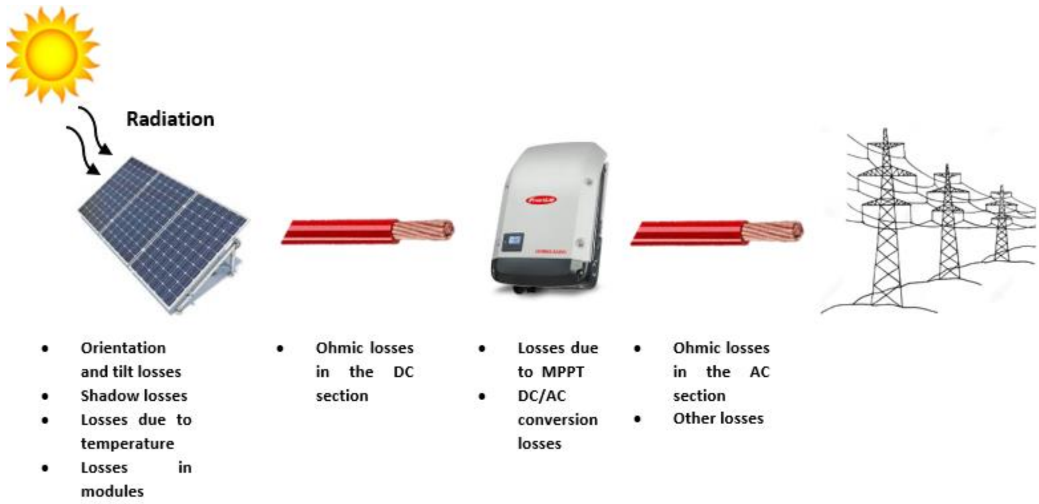


Figure 67. Energy losses in a photovoltaic installation. Source: Own

3.14.1 Orientation and tilt losses

As long as the collectors are not oriented and / or inclined optimally, there are energy losses due to orientation and / or inclination. In this sense, in the "*Pliego de Condiciones Técnicas de Instalaciones Aisladas de Red*", dated February 2009, and the "*Pliego de Condiciones Técnicas de Instalaciones Conectadas a Red*", dated July 2011, the limit values allowed for both this type of losses and those produced by shadows in isolated and grid-connected photovoltaic systems, respectively. These tables are shown below:

Generator radiation losses	Maximum allowed value (%)
Inclination and orientation	20
Shadows	10
Combination of both	20

Table 54. Maximum allowed values for OI, S and OI+S losses in off-grid installations. Source: IDAE

	Orientation and inclination (OI)	Shadows (S)	Total (OI+S)
General	10 %	10 %	15%
Overlap	20 %	15 %	30 %
Architectural integration	40 %	20 %	50 %

Table 55.Maximum allowed values for OI, S and OI+S losses in on-grid installations. Source: IDAE

The table for grid-connected installations can also be found on page 3 of the Section 5, "*Contribución fotovoltaica mínima de energía eléctrica*", of the "*Documento Básico HE Ahorro de Energía*", dated June 2017.

Figure 68. Panel layouts for losses estimation

According to the image above, the installation that this project deals with corresponds to a general case, making the limit of losses due to OI and S to be 10% each and 15% as a maximum together in the case of the on-grid installation. In the case of off-grid installation, as seen previously, these values would be somewhat more permissive (20, 10 and 20% respectively).

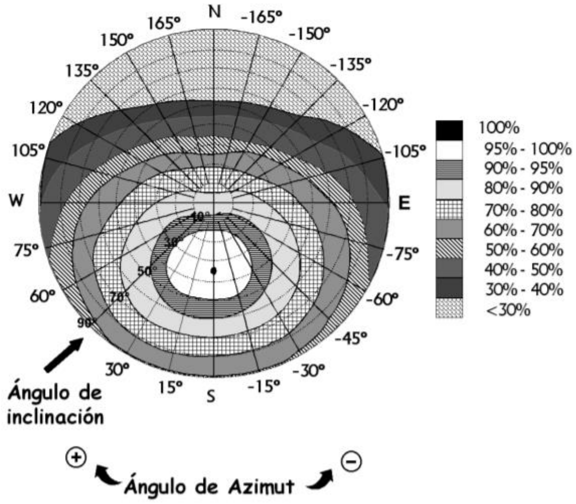
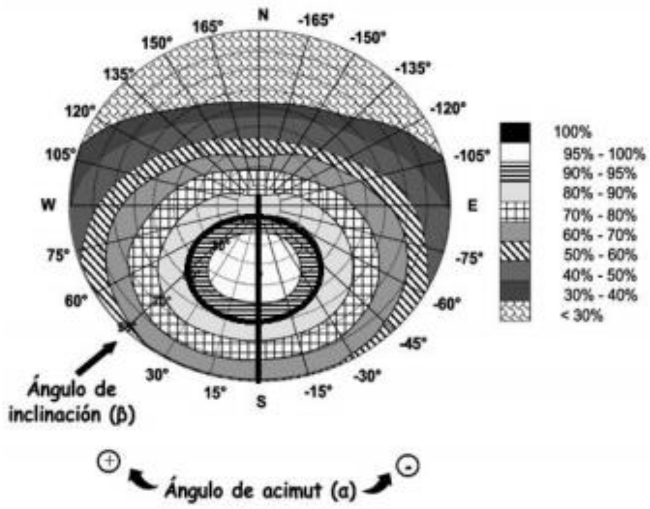


Figure 69. Graphical method for the obtention of the losses due to orientation and inclination, as well as shadows, for a latitude of Φ=41º. Source: IDAE

The calculation procedure for checking the values of these losses is as follows:

- On the graph (valid for latitude ϕ = 41°) the curve corresponding to the maximum allowed losses and the line of the installation azimuth angle are drawn. In this case, to see if the value is within the limits, the curve corresponding to the minimum utilization required is drawn on the graph (which, as the maximum losses allowed are 10%, corresponds to the curve of 90%) and the installation azimuth (α= 0 °). In the following illustration the curves drawn on the graph are represented:



- The points of intersection correspond to the maximum and minimum inclination for ϕ = 41°. If the cut-off points are observed, the following values are obtained: β_{max} (41°) ≈ 60°, β_{min} (41°) ≈ 2°.

- The inclination limits are corrected for the latitude of the installation. Since Vallada latitude is ϕ = 38,9°:

- $\beta_{max} = \beta_{max}(\Phi = 41°) - (41° - \Phi) = 60 - (41 - 38{,}9) \rightarrow \beta_{max}(\Phi = 38{,}9°) = 57{,}9°$
- $\beta_{min} = \beta_{min}(\Phi = 41°) - (41° - \Phi) = 2 - (41 - 38{,}9) \rightarrow \beta_{min}(\Phi = 38{,}9°) = -0{,}1°$

- It is checked whether the inclination of the generator is within the range indicated in the *PCT*. Therefore, as the angle of inclination established is within the limits indicated, the value of the losses will be less than 10%, fulfilling this requirement. These losses are finally estimated in a 2%.

3.14.2 Shadow losses

Next, the losses due to shadows in the photovoltaic installation are estimated. To do this, the following expression is used:

$$P_s = P_{MG} \cdot (1 - SF)$$

Equation 80. Power after discounting the shadow losses

In which:

- $\boldsymbol{P_s}$: Power after discounting losses due to the effect of obstacle shadows (W)
- $\boldsymbol{P_{MG}}$: Photovoltaic generator power at maximum power point (W)
- $\boldsymbol{SF}$: Incident radiation loss factor due to shadows on the generator (Shading Factor) (-)

In turn, it is necessary to know:

- Solar trajectories map, depending on the latitude (°N) of the site, and representation of the obstacle (or obstacles) on it as a function of the distance between the site and the obstacle, its height and orientation with respect to the south (azimuth). Degrees are sexagesimals.

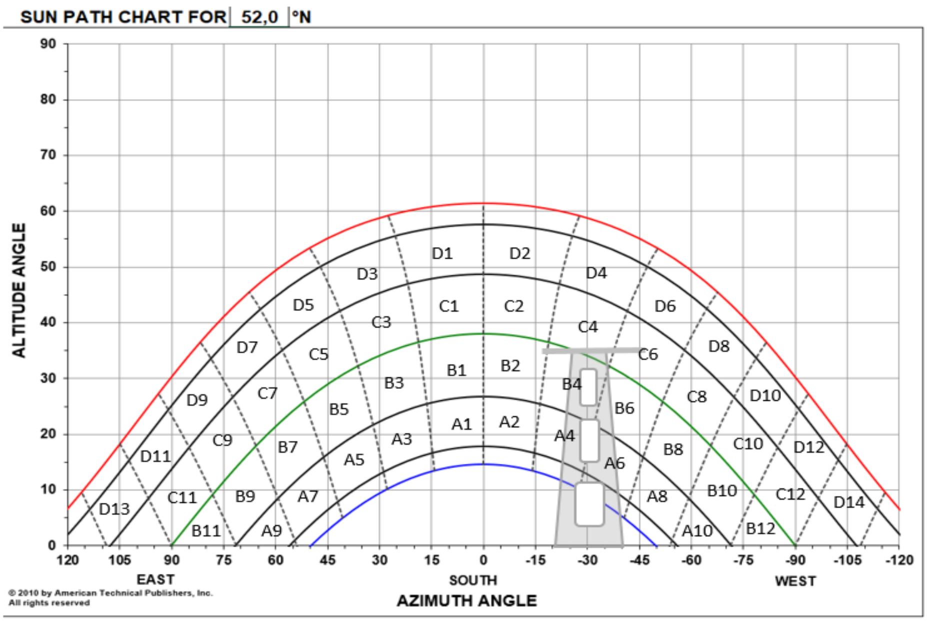


Figure 70. Example of sun path chart and representation of an obstacle on it. Source: Own

- Loss contribution tables in each zone for different orientation and inclination angles. The values corresponding to an inclination of 35° and azimuth 0° would be used, since they are the used ones in the photovoltaic installation, and due to their proximity, no interpolation would be carried out:

$\beta = 35°$ $\alpha = 0°$	A	B	C	D
13	0,00	0,00	0,00	0,03
11	0,00	0,01	0,12	0,44
9	0,13	0,41	0,62	1,49
7	1,00	0,95	1,27	2,76
5	1,84	1,50	1,83	3,87
3	2,70	1,88	2,21	4,67
1	3,15	2,12	2,43	5,04
2	3,17	2,12	2,33	4,99
4	2,70	1,89	2,01	4,46
6	1,79	1,51	1,65	3,63
8	0,98	0,99	1,08	2,55
10	0,11	0,42	0,52	1,33
12	0,00	0,02	0,10	0,40
14	0,00	0,00	0,00	0,02

Figure 71. Reference table for obtaining shadow losses if β=35° and α=0°. Source: Table C.1 of Appendix B of CTE-DB-HE 5

In this case, due to the dimensions of the photovoltaic park, the following has been done: the irradiance and temperature data have been obtained for the coordinates indicated in the section in which the location of the photovoltaic park and its limits have been indicated. These correspond to a position close to the geometric centre of the land it occupies. However, the northernmost panels are located a few tens of meters closer to the mountain, so the irradiance levels they receive may be lower than those that the southernmost panels receive. To correct this slight decrease in irradiance received by these rows of panels, despite the fact that there is no building or tree in the vicinity of the photovoltaic generator with sufficient height and / or proximity to produce any shade, it has finally been decided to account for the losses by shading by 5% in the whole photovoltaic generator.

3.14.3 Cell temperature losses

After knowing the shadow losses, it is necessary to estimate the temperature losses of the cells. To do this, it is necessary to obtain the hourly temperature from the PVGIS database. In addition, the hourly irradiance is determined in order to obtain the power losses due to temperature for those hours in which the average temperature exceeds 25°.

As described in Document 3, the temperature of the photovoltaic cell depending on the ambient temperature of the site and the irradiance received is obtained by means of the following formula:

$$T_{cel} = T_{loc} + \frac{NOCT - 20}{800} \cdot G_{loc}(\alpha, \beta)$$

Where, in turn:

- $\boldsymbol{T_{loc}}$: Ambient temperature of the location (°C).
- $\boldsymbol{NOCT}$: Nominal Operating Cell Temperature of photovoltaic cells= 45 °C. Conditions: Irradiance: 800 $\mathrm{W/m^2}$; AM 1.5 G spectral distribution; ambient temperature: 20 °C; wind speed: 1 m/s.
- $\boldsymbol{G_{loc}(\alpha, \beta)}$: Effective irradiance received by the solar collector surface according to its orientation and inclination (W/m^2).

To get the losses in each moment the following expression should be used as a function of the temperature coefficient of the cell power (g =-0,37%/°C):

$$L_t \begin{cases} -g \cdot (T_c - 25) & if\ T_c > 25°\mathrm{C} \\ 0 & if\ T_c < 25°\mathrm{C} \end{cases}$$

Therefore, the power of the photovoltaic generator after discounting these losses is given by the expression:

$$P_{GT} = P_S \cdot (1 - L_t)$$

Equation 81. Power after discounting the losses due to the cell temperature

Where:

- $\boldsymbol{P_{GT}}$: Power of the generator after discounting losses due to the cell temperature (W)

Since the effect of the temperature was already considered when the maximum power delivered by a module was estimated for each hour, these losses are not calculated and considered again at this point.

3.14.4 Losses in the modules

3.14.4.1 Losses due to mismatch effect

It can be thought that the power of the photovoltaic generator is the sum of the powers of each of the modules that make it up. However, this does not have to be like this. This becomes evident when the connection of different modules is carried out (whose nominal powers are not identical). In this way, when connecting modules in series with different currents, the branch current will be that corresponding to that of the module with less intensity; similarly, when connecting branches of photovoltaic panels in parallel, the resulting voltage is the lower of said branches, the voltage of each branch being in turn equal to the sum of the voltages generated by each module that integrates them. This is known as mismatch losses or connection losses between modules, in this way, the result is a photovoltaic generator power less than or equal to the sum of these powers. To reduce these losses, it is common to use what are known as "bypass" diodes, as well as ordering the photovoltaic panels with respect to their electrical characteristics.

In this case, the photovoltaic modules used in the installation are identical, ruling out the installation of different commercial modules, but these losses can also be caused by manufacturing defects in identical commercial modules that cause them to function differently, as well as by the deficient interconnection among them. Therefore, these losses will be finally estimated at 1,5%, close to the 2% adopted by PVsyst for the case in which the modules work in its MPP, as is the case with this project.

Thus, the expression that provides the power at this point is:

$$P_{G1} = P_{GT} \cdot (1 - L_{me})$$

Equation 82. Power after discounting the losses due to the mismatch effect

Being:

- $\boldsymbol{P_{G1}}$: Power after discounting losses due to the mismatch effect (W)
- $\boldsymbol{L_{me}}$: Losses factor due to the mismatch effect (-)

3.14.4.2 Losses due to dust

These are losses in the electrical power generation capacity of the modules as a consequence of the deposition of dust and dirt on their surface. This parameter depends on various factors.

Thus, these losses depend on the climatology of the place, being lower in areas with rainy climates and with regular winds.

On the other hand, not all types of dirt affect equally, since for example the presence of bird droppings is more harmful than a light film of fine dust.

In addition, this parameter also depends on the inclination of the photovoltaic modules, so that the greater this inclination, the more difficult will be the accumulation of this dirt and therefore the lower the losses. To reduce these losses, it is advisable to have a cleaning plan for the photovoltaic panels. These losses will be finally considered equal to 1 %.

The power at this point is given by:

$$P_{G2} = P_{G1} \cdot (1 - L_d)$$

Equation 83. Power after discounting the losses due to dust

In which:

- $\boldsymbol{P_{G2}}$: Power after discounting losses due to dust (W)
- $\boldsymbol{L_d}$: Losses factor due to dust (-)

3.14.4.3 Angular and spectral losses

The angular losses are due to the reduction in the irradiance levels that reach the cells of the photovoltaic module compared to the irradiance that would be received if the incident radiation were not affected by the reflections induced by the glass that protects the module. This is known as the Fresnel effect.

On the other hand, photovoltaic modules are spectrally selective, which means that the current generated is different for each wavelength of the solar spectrum. The variation of the solar spectrum at each moment can affect the response of the photovoltaic cells, leading to energy gains or losses. These losses will be estimated at 1,5%.

So, the resulting power after discounting these losses is calculated by the following expression:

$$P_{G3} = P_{G2} \cdot (1 - L_{a-e})$$

Equation 84. Power after discounting the angular and spectral losses

Where:

- $\boldsymbol{P_{G3}}$: Power after discounting angular and spectral losses (W)
- $\boldsymbol{L_{a-e}}$: Losses factor due to angular and spectral losses (-)

3.14.4.4 Losses due to non-compliance with nominal power

Manufacturers provide in their commercial catalogues the nominal powers of the photovoltaic modules they manufacture. However, its nominal power referred to the standard test conditions (STC) presents a certain dispersion. In this way, the real power may be slightly below or above its nominal value, although the former is generally the case. In this sense, it is estimated that in this project the power value is reduced by 5%, since it is a common value.

Therefore, finally, the power obtained at the output of the photovoltaic generator after subtracting the previous losses is:

$$P_G = P_{G3} \cdot \left(1 - L_{ncnp}\right)$$

Equation 85. Power after discounting the losses due to non-compliance with nominal power

In which:

- $\boldsymbol{P_G}$: Power after discounting losses due to non-compliance with nominal power (W)
- $\boldsymbol{L_{ncnp}}$: Losses factor due to non-compliance with nominal power (-)

3.14.5 Ohmic losses in the DC section

These are the losses that occur as result of the voltage drops produced by the circulation of a direct current through a series of conductors made of a specific material and with a certain section. To minimize the impact of these losses, the section of the conductors must be properly dimensioned.

The lost power is given in this case by the expression:

$$P_{ohm,DC} = \sum \frac{2 \cdot L}{\sigma \cdot S} {I_{DC}}^2$$

So, the percentage of losses is:

$$L_{ohm,DC} = \frac{P_{ohm,DC}}{P_G} \cdot 100$$

And the resulting power from subtracting these losses, which is the power at the input of the inverter, turns out to be:

$$P_{DC} = P_G \cdot (1 - L_{ohm,DC})$$

Equation 86. Power after discounting the losses in the DC section

Where:

- $\boldsymbol{L}$: Length of the wire (m)
- $\boldsymbol{I_{DC}}$: Current of the DC zone (A)
- $\boldsymbol{\sigma}$: Conductivity of the material $(\mathrm{m}/\Omega \cdot \mathrm{mm}^2)$
- $\boldsymbol{S}$: Section of the wire (mm^2)
- $\boldsymbol{P_{ohm,DC}}$: Losses due to ohmic effect (W)
- $\boldsymbol{L_{ohm,DC}}$: Losses factor due to DC flow through wiring (-)
- $\boldsymbol{P_{DC}}$: Power after discounting losses in the DC section (W)

3.14.6 Losses in the MPPT system

These are the losses that occur due to the inaccuracy of the maximum power point tracking algorithms of the devices responsible for carrying out said solar tracking. These algorithms try to adjust the curve of the modules in an optimal way so that they work continuously in their MPP, so that their efficiency is at the same time as high as possible. In this case, it is estimated that for the chosen commercial investor the yield of said MPPT algorithm is 98.5%, this is a percentage of losses of 1,5%.

The expression that calculates the power at the input of the DC/AC converter is:

$$P_{DC,MPPT} = P_{DC} \cdot \eta_{MPPT} = P_{DC} \cdot (1 - L_{MPPT})$$

Equation 87. Power after discounting the losses in the MPPT system

Being:

- $\boldsymbol{\eta_{MPPT}}$: Efficiency of the MPPT system (-)

- $\boldsymbol{L_{MPPT}}$: Losses factor due to MPPT´s efficiency (-)
- $\boldsymbol{P_{DC,MPPT}}$: Power after discounting losses due to the inaccuracy of the MPPT system (W)

3.14.7 Losses in the DC / AC converter

These energy losses take place in the process of converting direct current into alternating current by the inverter. It is therefore important to select a high-performance inverter in nominal operating conditions and with adequate power based on the power of the photovoltaic generator that it supports. Therefore, the following expression gives the power at the output of the inverter:

$$P_{AC1} = P_{DC,MPPT} \cdot \eta_{inv} = P_{DC} \cdot (1 - L_{inv})$$

Equation 88. Power after discounting the losses in the inverter

Being:

- $\boldsymbol{\eta_{inv}}$: Efficiency of the inverter (-)
- $\boldsymbol{L_{inv}}$: Losses due to inverter´s efficiency (-)
- $\boldsymbol{P_{AC1}}$: Power after discounting losses due to the efficiency of the inverter (W)

Since this efficiency was already considered when the power required at the entrance of the inverters was calculated, these losses are not taken into account again now.

3.14.8 Ohmic losses in the AC section

This kind of losses is equivalent to those ones of the 3.14.5 section, but in this case with alternating current circulation.

Since in this case the losses due to the circulation of an electric current are being calculated, the process is equivalent to that one of the DC. In this case, the lost power is given by the expression:

$$P_{ohm,AC} = \sum \frac{2 \cdot L}{\sigma \cdot S} {I_{AC}}^2$$

So, the percentage of losses is:

$$L_{ohm,AC} = \frac{P_{ohm,AC}}{P_{AC1}} \cdot 100$$

And the resulting power from subtracting these losses, which is the power at the input of the inverter, turns out to be:

$$P_{AC2} = P_{AC1} \cdot (1 - L_{ohm,AC})$$

Equation 89. Power after discounting the losses in the AC section

In which:

- $\boldsymbol{L}$: Length of the wire (m)
- $\boldsymbol{I_{AC}}$: Current of the AC zone (A)
- $\boldsymbol{\sigma}$: Conductivity of the material $(\mathrm{m}/\Omega \cdot \mathrm{mm}^2)$
- $\boldsymbol{S}$: Section of the wire (mm^2)
- $\boldsymbol{L_{ohm,AC}}$: Losses factor due to AC flow through wiring (-)
- $\boldsymbol{P_{AC2}}$: Power after discounting losses in the AC section (W)

3.14.9 Other losses

In this last point, other losses that occur in the photovoltaic installation as a whole are jointly estimated, such as those that occur in the transformer of the transformation centre, due to operation and maintenance, or those due to the reduction of the efficiency of the photovoltaic modules as a consequence of the degradation of their materials over the years. A percentage of 2,5% is established in this section.

Therefore, finally, the value of the available power obtained at the output of the photovoltaic system and that finally reaches the loads or the electrical network is given by the following expression:

$$P_{av} = P_{AC2} \cdot (1 - L_{other})$$

Equation 90. Power after discounting other losses

Where:

- $\boldsymbol{L_{other}}$: Losses factor due to other causes not contemplated in the previous sections (-).
- $\boldsymbol{P_{av}}$: Finally, available power (W).

So finally, the PR obtained is $(1 - L_{or\,\&\,tilt}) \cdot (1 - SF) \cdot (1 - L_{me}) \cdot (1 - L_d) \cdot (1 - L_{a-e}) \cdot \big(1 - L_{ncnp}\big) \cdot \big(1 - L_{ohm,DC}\big) \cdot (1 - L_{MPPT}) \cdot \big(1 - L_{ohm,AC}\big) \cdot (1 - L_{other}) = (1 - 0{,}020) \cdot (1 - 0{,}050) \cdot (1 - 0{,}015) \cdot (1 - 0{,}010) \cdot (1 - 0{,}015) \cdot (1 - 0{,}050) \cdot (1 - 0{,}010) \cdot (1 - 0{,}015) \cdot (1 - 0{,}010) \cdot (1 - 0{,}025) \rightarrow PR = 0{,}7996 = 79{,}96\% \approx 80\%$

Again, it is noted that this is a PR in which the losses in the inverter and those due to temperature have already been discounted.

3.15 Maintenance of the hydraulic-photovoltaic installation

In all types of facilities, both industrial and domestic and on a small or large scale, it is necessary to carry out a minimum periodic maintenance, not only because of the benefits that this entails, but also because of the existence of laws that oblige it.

The installation of this project is not an exception. Therefore, it is necessary to define a series of periodic maintenance guidelines, both corrective and preventive:

- **Corrective maintenance**: Consists of using the device in question until failure, after which it must be repaired or, if necessary, replaced. It requires no planning or inspection and the investment is minimal, but it offers little security. This includes the periodically necessary changes of the various components of the installation. Based on this, it is estimated that every 5 years it will be necessary to replace between 5 and 7% of the solar panels, and a further 350 € amount per year is reserved for other types of minor repairs or replacements such as some sections of cabling or protection elements that have become unusable after having acted.
- **Preventive maintenance**: It consists of carrying out a planning of the necessary inspections and interventions of the installation in order to avoid important damages that result in a significant reduction in the activity of the plant or pose a danger to its integrity. To select the actuation times, it is possible to resort to the data of the manufacturers, with which the statistical laws of failure (MTBF and probability density function) can be determined. In this sense, during the first ten years of the project's useful life, a complete review of the state of the projected photovoltaic installation will be carried out every two years. Said review will be carried out annually in subsequent years. The estimated annual cost is € 400. On the other hand, frequent cleaning of the panels will also be carried out to mitigate losses due to dust and dirt as well as their scratch. Its annual cost will be estimated at € 1000.

To efficiently manage maintenance tasks based on the elements to be maintained, the operations carried out, their useful lifetime and other necessary parameters, the option of using a CMMS is interesting, although it is left to the customer's discretion if it should finally be use this methodology.

Considering these and other expenses, it is decided to allocate an annual amount of 4000 € to maintenance and replacements. However, the possible effect of inflation (sustained and generalized increase in the level of prices and services) must be taken into account, for which the CPI ("Consumer Price Index") is taken as a reference. It is taken as 2,2% per year until the end of the project's life period. It does not only affect the expenses due to maintenance, replacements and insurance, but also the selling price and the purchase price (for these two last prices a 2% is considered).

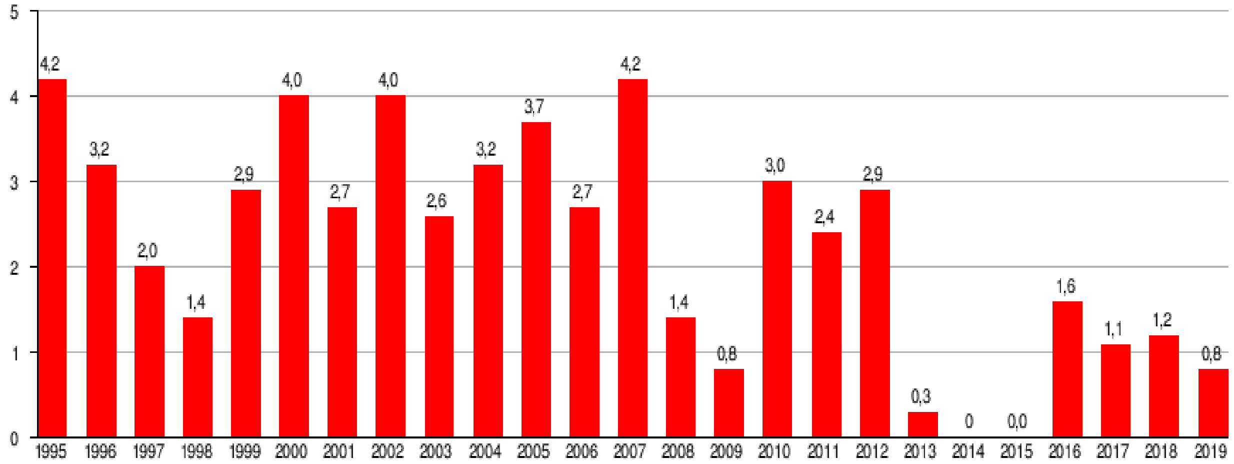


Figure 72. Spanish CPI evolution for the last 25 years. Source: Masdeu Asesoria

Although it would also affect electricity prices, both the electricity tariff and the surplus sale price, specific variations have been considered for these.

3.16 Conclusions

Photovoltaic energy has gained great weight in recent years, and its growth is expected to continue at a high rate, becoming the main (or second) renewable energy worldwide in the coming decades. Its applications are numerous, as already mentioned above.

In the project that illustrates this master's thesis, the aim was to achieve the highest level of self-consumption by installing a photovoltaic generator that would supply the energy demand of two pumping groups. Finally, due to the available space and establishing a reasonable budget, it was decided to install a total of 2320 panels, which with a peak power in STC of 400 Wp gives rise to a photovoltaic installation of 928 kWp, so it is of a considerable size. This means that in the first year almost 90% of self-sufficiency is reached, which is progressively decreasing due to the loss of efficiency of the panels due to their degradation. At the same time, this quantity of panels means that great benefits are obtained, not only due to the savings in the purchase of energy from the network, but also due to the sale of surpluses in those moments when it is not necessary to pump water (or a part of the energy can be injected into the network). However, due to the large outlay that must be made in year 0, the benefits, although important, are not reached until the last five years of the installation's useful life. Based on the last mentioned, it is necessary to take into account several assumptions that have been considered (although trying to be as strict and objective as possible) in this project:

- The water and energy needs have been assumed to be constant throughout the useful life of the projected installation. In the future, the needs may increase, due to greater cultivation area or due to the substitution of rainfed crops for irrigated crops, they may be reduced or they may be practically the same.

- The irradiance levels used for the calculations of the power deliverable by the panels have also been considered constant. This is also perfectly variable in successive years, not only due to the weather itself but also due to the evolution of solar activity.

- A multitude of parameters have been assumed in this project, such as the percentages of industrial profit and general expenses, the discount rate, the interest rate of the bank loan, the own funds that can be counted on to make the investment, the prices of purchase and sale of energy or the evolution of both the associated emissions of various pollutants when consuming energy from the network and the CPI of energy. On the other hand, to say that it has been tried to choose conservative values in many cases to obtain fewer misleading results.

It would be interesting to study other alternatives in which the percentage of self-consumption is lower, or also the possibility of increasing the capacity of the reservoirs to allow a greater volume of water to be stored and, perhaps with this, to be able to allocate a greater percentage of photovoltaic energy its sale in the electrical network.

On the other hand, although it is true that, in principle, the profitability of the project would be assured and that the reduction in pollutant emissions in successive years is undeniable (although it would be necessary to analyse the emissions during the life cycle of the components used), Threats that may arise in the field of energy generation must also be taken into account. For example, it could be the case that the price of energy in the network is reduced, or increased less than expected, reducing savings, due to the improvement of the efficiency in the production of existing technologies or even the penetration of new energy sources, such as nuclear fusion, which could make the facility's profitability lower than expected.

Document 4.

Economic analysis

4.1 Introduction

This document presents two economic studies related to the project described.

First, a project budget is drawn up, detailing the different costs of both the materials and components to be installed and the work force and machinery that must be used for the development of the works.

Second, an economic viability analysis is carried out, which reflects the expected evolution of the cash flows based on the benefits obtained both from the saving of energy consumed from the network and from the sale of surplus energy, in the event of exist, so that the suitability of the execution of said project can be analysed intuitively based on the expected benefits.

In this way, the Promoter could decide, based on fairly solid results, if the effort made to disburse the necessary investment in year 0 is compensated in an appropriate period and proportion.

4.2 Installation budget

The budget prepared consists of three perfectly differentiated sections or tables:

- **Table of unit prices** (*V Presupuesto: Cuadro de precios nº 1*): It contains, in figure and letter, the total prices (without decomposition) of each work unit.
- **Table of decomposed prices** (*V Presupuesto: Cuadro de precios nº 2*): Contains the decomposition of each of the prices indicated in the table of unit prices. It has no legal character.
- **Table of measurements and budget** (*V–Presupuesto*): It includes all the information about the concepts of each work unit, the unit in which said work unit is measured and its unit price (already indicated in the Unit Price Table) as well as its quantity and its total amount, in figures.

On the other hand, the sum of the costs indicated in the measurement and budget table reflects the Material Execution Budget (PEM in spanish), which must be provided in capital letters and figures. In this budget, the I.V.A. is not taken into account, since it is applied afterwards (in the PEM attached in this document it has been considered, so in the economic analysis it was discounted). Next, a certain percentage of General Expenses and Construction Management and another of Industrial Profit must be applied (13% and 6% have been taken respectively, since they are very common values) to, added to the previous budget, obtain the Budget Execution by Contract (PEC in spanish). Finally, adding 21% of I.V.A., the Tender Base Budget (PBL in Spanish) is calculated, which again must be provided both in figures and in capital letters.

To avoid an excessive length of the document, only tables 2 and 3 will be presented. These tables are shown in the following pages.

V Presupuesto: Cuadro de precios nº 2

DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADA CULTIVATION AREA (VALENCIA, SPAIN)

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADA ...
Promotor: Sociedad Riego Canyoles
Situación: Vallada

Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto: Cuadro de precios nº 2**

1	01.01.01	h	Terrain study	
			Sin descomposición	60,00 €
			3 % Costes indirectos	1,80 €
			Total por h............:	**61,80 €**
			Son SESENTA Y UN EUROS CON OCHENTA CÉNTIMOS por h	
2	01.02.01.	U	Previous signalling works and others	
			Mano de obra	54,00 €
			Materiales	240,00 €
			3 % Costes indirectos	8,82 €
			Total por U............:	**302,82 €**
			Son TRESCIENTOS DOS EUROS CON OCHENTA Y DOS CÉNTIMOS por U	
3	01.03.01	m2	Suitability of the land	
			Mano de obra	0,15 €
			Maquinaria	0,10 €
			3 % Costes indirectos	0,01 €
			Total por m2............:	**0,26 €**
			Son VEINTISEIS CÉNTIMOS por m2	
4	02.01.01	m3	Placing of footings on the ground	
			Mano de obra	10,00 €
			Maquinaria	5,00 €
			Materiales	50,00 €
			3 % Costes indirectos	1,95 €
			Total por m3............:	**66,95 €**
			Son SESENTA Y SEIS EUROS CON NOVENTA Y CINCO CÉNTIMOS por m3	
5	02.02.01	U	Assembly of panel structures	
			Mano de obra	35,00 €
			Maquinaria	16,33 €
			Materiales	1.046,86 €
			3 % Costes indirectos	32,95 €
			Total por U............:	**1.131,14 €**
			Son MIL CIENTO TREINTA Y UN EUROS CON CATORCE CÉNTIMOS por U	
6	02.03.01	U	Placing of the panels	
			Mano de obra	2,50 €
			Materiales	135,65 €
			3 % Costes indirectos	4,14 €
			Total por U............:	**142,29 €**
			Son CIENTO CUARENTA Y DOS EUROS CON VEINTINUEVE CÉNTIMOS por U	
7	02.04.01	U	Connection of the modules	
			Mano de obra	2,50 €
			Materiales	0,50 €
			3 % Costes indirectos	0,09 €

			Total por U............:	**3,09 €**
			Son TRES EUROS CON NUEVE CÉNTIMOS por U	
8	03.01.01	U	DC Junction box type I (17 strings)	
			Mano de obra	100,00 €
			Materiales	2.328,60 €
			3 % Costes indirectos	72,86 €
			Total por U............:	**2.501,46 €**
			Son DOS MIL QUINIENTOS UN EUROS CON CUARENTA Y SEIS CÉNTIMOS por U	
9	03.01.02	U	DC Junction box type II (15 strings)	
			Mano de obra	100,00 €
			Materiales	2.156,94 €
			3 % Costes indirectos	67,71 €
			Total por U............:	**2.324,65 €**
			Son DOS MIL TRESCIENTOS VEINTICUATRO EUROS CON SESENTA Y CINCO CÉNTIMOS por U	
10	03.01.03	U	DC Junction box type III (5 strings)	
			Mano de obra	100,00 €
			Materiales	1.298,64 €
			3 % Costes indirectos	41,96 €
			Total por U............:	**1.440,60 €**
			Son MIL CUATROCIENTOS CUARENTA EUROS CON SESENTA CÉNTIMOS por U	
11	03.01.04	U	DC Junction box type IV (4 strings)	
			Mano de obra	100,00 €
			Materiales	1.212,81 €
			3 % Costes indirectos	39,38 €
			Total por U............:	**1.352,19 €**
			Son MIL TRESCIENTOS CINCUENTA Y DOS EUROS CON DIECINUEVE CÉNTIMOS por U	
12	03.02.01	U	Mounting of the inverters	
			Mano de obra	15,00 €
			Materiales	9.144,99 €
			3 % Costes indirectos	274,80 €
			Total por U............:	**9.434,79 €**
			Son NUEVE MIL CUATROCIENTOS TREINTA Y CUATRO EUROS CON SETENTA Y NUEVE CÉNTIMOS por U	
13	03.03.01	U	Mounting of the AC m.a.p. panels	
			Mano de obra	25,00 €
			Materiales	3.927,34 €
			3 % Costes indirectos	118,57 €
			Total por U............:	**4.070,91 €**
			Son CUATRO MIL SETENTA EUROS CON NOVENTA Y UN CÉNTIMOS por U	
14	03.04.01	U	Mounting of the monitoring equipment	

			Mano de obra	25,00 €
			Materiales	585,30 €
			3 % Costes indirectos	18,31 €
			Total por U............:	**628,61 €**
			Son SEISCIENTOS VEINTIOCHO EUROS CON SESENTA Y UN CÉNTIMOS por U	
15	04.01.01	m3	Excavation of the trenches	
			Mano de obra	0,50 €
			Maquinaria	2,50 €
			3 % Costes indirectos	0,09 €
			Total por m3............:	**3,09 €**
			Son TRES EUROS CON NUEVE CÉNTIMOS por m3	
16	04.02.01	m	Laying of the cabling in the trenches	
			Mano de obra	9.336,93 €
			3 % Costes indirectos	280,11 €
			Total por m............:	**9.617,04 €**
			Son NUEVE MIL SEISCIENTOS DIECISIETE EUROS CON CUATRO CÉNTIMOS por m	
17	04.03.01	m3	Burial of the trenches	
			Mano de obra	0,50 €
			Maquinaria	2,50 €
			3 % Costes indirectos	0,09 €
			Total por m3............:	**3,09 €**
			Son TRES EUROS CON NUEVE CÉNTIMOS por m3	
18	05.01.01	Lm	Protection tubes type I (90 mm ext.diam)	
			Mano de obra	4,00 €
			Materiales	5,98 €
			3 % Costes indirectos	0,30 €
			Total por Lm............:	**10,28 €**
			Son DIEZ EUROS CON VEINTIOCHO CÉNTIMOS por Lm	
19	05.01.02	Lm	Protection tubes type II (110 mm ext.diam)	
			Mano de obra	4,00 €
			Materiales	6,95 €
			3 % Costes indirectos	0,33 €
			Total por Lm............:	**11,28 €**
			Son ONCE EUROS CON VEINTIOCHO CÉNTIMOS por Lm	
20	05.01.03	Lm	Protection tubes type III (250 mm ext.diam)	
			Mano de obra	4,00 €
			Materiales	19,75 €
			3 % Costes indirectos	0,71 €
			Total por Lm............:	**24,46 €**
			Son VEINTICUATRO EUROS CON CUARENTA Y SEIS CÉNTIMOS por Lm	

21	05.02.01	Lm	DC cable of 25 mm2	
			Materiales	3,88 €
			3 % Costes indirectos	0,12 €
			Total por Lm............:	**4,00 €**
			Son CUATRO EUROS por Lm	
22	05.02.02	Lm	DC cable of 35 mm2	
			Materiales	4,78 €
			3 % Costes indirectos	0,14 €
			Total por Lm............:	**4,92 €**
			Son CUATRO EUROS CON NOVENTA Y DOS CÉNTIMOS por Lm	
23	05.03.01	Lm	DC cable of 6 mm2	
			Mano de obra	0,38 €
			Materiales	0,60 €
			3 % Costes indirectos	0,03 €
			Total por Lm............:	**1,01 €**
			Son UN EURO CON UN CÉNTIMO por Lm	
24	05.03.02	Lm	DC cable of 10 mm2	
			Mano de obra	0,38 €
			Materiales	0,93 €
			3 % Costes indirectos	0,04 €
			Total por Lm............:	**1,35 €**
			Son UN EURO CON TREINTA Y CINCO CÉNTIMOS por Lm	
25	05.03.03	Lm	DC cable of 70 mm2	
			Mano de obra	0,38 €
			Materiales	13,75 €
			3 % Costes indirectos	0,42 €
			Total por Lm............:	**14,55 €**
			Son CATORCE EUROS CON CINCUENTA Y CINCO CÉNTIMOS por Lm	
26	05.04.01	Lm	AC cable of 150 mm2+70 mm2	
			Mano de obra	0,38 €
			Materiales	25,24 €
			3 % Costes indirectos	0,77 €
			Total por Lm............:	**26,39 €**
			Son VEINTISEIS EUROS CON TREINTA Y NUEVE CÉNTIMOS por Lm	
27	05.04.02	Lm	AC cable of 185 mm2+95 mm2	
			Mano de obra	0,38 €
			Materiales	37,48 €
			3 % Costes indirectos	1,14 €
			Total por Lm............:	**39,00 €**
			Son TREINTA Y NUEVE EUROS por Lm	

28	05.05.01	Lm	AC cable of 150 mm2+70 mm2	
			Mano de obra	0,38 €
			Materiales	25,24 €
			3 % Costes indirectos	0,77 €
			Total por Lm............:	**26,39 €**
			Son VEINTISEIS EUROS CON TREINTA Y NUEVE CÉNTIMOS por Lm	
29	05.05.02	Lm	AC cable of 185 mm2+95 mm2	
			Mano de obra	0,38 €
			Materiales	37,48 €
			3 % Costes indirectos	1,14 €
			Total por Lm............:	**39,00 €**
			Son TREINTA Y NUEVE EUROS por Lm	
30	06.01.01	U	SDX 1,8-4 (Sector 1)	
			Mano de obra	650,00 €
			Maquinaria	500,00 €
			Materiales	24.574,00 €
			3 % Costes indirectos	771,72 €
			Total por U............:	**26.495,72 €**
			Son VEINTISEIS MIL CUATROCIENTOS NOVENTA Y CINCO EUROS CON SETENTA Y DOS CÉNTIMOS por U	
31	06.01.02	U	SDX 1,8-2 (Sector 2)	
			Mano de obra	650,00 €
			Maquinaria	500,00 €
			Materiales	17.022,00 €
			3 % Costes indirectos	545,16 €
			Total por U............:	**18.717,16 €**
			Son DIECIOCHO MIL SETECIENTOS DIECISIETE EUROS CON DIECISEIS CÉNTIMOS por U	
32	07.01.01	U	Installation of grounding rods	
			Mano de obra	9,35 €
			Maquinaria	0,11 €
			Materiales	35,00 €
			3 % Costes indirectos	1,33 €
			Total por U............:	**45,79 €**
			Son CUARENTA Y CINCO EUROS CON SETENTA Y NUEVE CÉNTIMOS por U	
33	07.02.01	U	Placement of other protective elements	
			Mano de obra	50,00 €
			Materiales	450,00 €
			3 % Costes indirectos	15,00 €
			Total por U............:	**515,00 €**
			Son QUINIENTOS QUINCE EUROS por U	
34	07.03.01	h	General check of the connections	
			Sin descomposición	400,00 €
			3 % Costes indirectos	12,00 €

			Total por h............:	**412,00 €**
			Son CUATROCIENTOS DOCE EUROS por h	
35	08.01.01	U	Purchase and installation of cable glands, flat strips of steel clamps, etc	
			Mano de obra	500,00 €
			Materiales	2.000,00 €
			3 % Costes indirectos	75,00 €
			Total por U............:	**2.575,00 €**
			Son DOS MIL QUINIENTOS SETENTA Y CINCO EUROS por U	
36	09.01.01	h	Checking of the status of all components and their operation condition	
			Sin descomposición	800,00 €
			3 % Costes indirectos	24,00 €
			Total por h............:	**824,00 €**
			Son OCHOCIENTOS VEINTICUATRO EUROS por h	
37	09.02.01	h	Visit to the work of the interested parties for their approval	
			Sin descomposición	200,00 €
			3 % Costes indirectos	6,00 €
			Total por h............:	**206,00 €**
			Son DOSCIENTOS SEIS EUROS por h	
38	10.01.01..	h	Obtention of the prior administrative authorizations and construction licenses	
			Sin descomposición	3.000,00 €
			3 % Costes indirectos	90,00 €
			Total por h............:	**3.090,00 €**
			Son TRES MIL NOVENTA EUROS por h	
39	10.02.01	U	Health and Safety Study	
			Mano de obra	1.000,00 €
			Materiales	3.000,00 €
			3 % Costes indirectos	120,00 €
			Total por U............:	**4.120,00 €**
			Son CUATRO MIL CIENTO VEINTE EUROS por U	
40	10.03.01	h	Environmental Analysis of the project	
			Sin descomposición	1.000,00 €
			3 % Costes indirectos	30,00 €
			Total por h............:	**1.030,00 €**
			Son MIL TREINTA EUROS por h	

V - Presupuesto

DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADA CULTIVATION AREA (VALENCIA, SPAIN)

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
Promotor: Sociedad Riego Canyoles
Situación: Vallada

Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto**

Capítulo Nº 1 CHAPTER 1. LAND MOVEMENT AND GROUND PREPARATIONS

Nº	Ud	Descripción	Medición	Precio	Importe
1.1.- Terrain study					
1.1.1	**H**	Study to know the state of the land, solidity, erosivity, firmness, etc. and the presence of pipes and plants.			
		Total h :	1,000	61,80	**61,80**
		Total subcapítulo 1.1.- Terrain study:			**61,80**
1.2.- Previous signalling works and others					
1.2.1	**U**	Signposting and limitation of the work area. Establishment of areas for the collection of materials and deposition of residues or waste.			
		Total U :	1,000	302,82	**302,82**
		Total subcapítulo 1.2.- Previous signalling works and others:			**302,82**
1.3.- Suitability of the land					
1.3.1	**M2**	Clearing and cleaning of the terrain of the pv panels and nearby roads, removal of plants, shrubs, stones and crops by mechanical means and excavation. Adequacy of the entrance area. Transport of lands (if necessary).			
		Total m2 :	20.000,000	0,26	**5.200,00**
		Total subcapítulo 1.3.- Suitability of the land:			**5.200,00**
		Parcial Nº 1 CHAPTER 1. LAND MOVEMENT AND GROUND PREPARATIONS :			**5.564,62**

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
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Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto**

Capítulo Nº 2 CHAPTER 2. INSTALLATION OF THE PHOTOVOLTAIC GENERATOR

Nº	Ud	Descripción	Medición	Precio	Importe
2.1.- Placing of footings on the ground					
2.1.1	**M3**	Placement of footings for the structure of the photovoltaic modules. Includes purchase and pouring of concrete and creation of the footing.			
		Total m3 :	155,000	66,95	**10.377,25**
		Total subcapítulo 2.1.- Placing of footings on the ground:			**10.377,25**
2.2.- Assembly of panel structures					
2.2.1	**U**	Purchase and installation of module structures and wire mesh cable trays.			
		Total U :	116,000	1.131,14	**131.212,24**
		Total subcapítulo 2.2.- Assembly of panel structures:			**131.212,24**
2.3.- Placing of the panels					
2.3.1	**U**	Purchase and installation of solar modules with a nominal power of 400 Wp. 20.17% efficiency in STC. 10-year product warranty. Maintenance guarantee of 90% of nominal power for 10 years and 80% for the next 15 years.			
		Total U :	2.320,000	142,29	**330.112,80**
		Total subcapítulo 2.3.- Placing of the panels:			**330.112,80**
2.4.- Connection of the modules					
2.4.1	**U**	Serial connection of modules (cables on tray) and wiring fastening.			
		Total U :	2.320,000	3,09	**7.168,80**
		Total subcapítulo 2.4.- Connection of the modules:			**7.168,80**
		Parcial Nº 2 CHAPTER 2. INSTALLATION OF THE PHOTOVOLTAIC GENERATOR :			**478.871,09**

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
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Capítulo Nº 3 CHAPTER 3. INSTALLATION OF THE DC JUNCTION BOXES, INVERTERS, ...

Nº	Ud	Descripción	Medición	Precio	Importe
3.1.- Mounting of the DC Junction boxes					
3.1.1	**U**	DC Junction box type I (17 strings). Purchase and installation of photovoltaic series protection panels (DC Junction boxes). Indicative price (special order). Including the protections it contains and their connection.			
		Total U :	4,000	2.501,46	**10.005,84**
3.1.2	**U**	DC Junction box type II (15 strings). Purchase and installation of photovoltaic series protection panels (DC Junction boxes). Indicative price (special order). Including the protections it contains and their connection.			
		Total U :	2,000	2.324,65	**4.649,30**
3.1.3	**U**	DC Junction box type III (5 strings). Purchase and installation of photovoltaic series protection panels (DC Junction boxes). Indicative price (special order). Including the protections it contains and their connection.			
		Total U :	2,000	1.440,60	**2.881,20**
3.1.4	**U**	DC Junction box type IV (4 strings). Purchase and installation of photovoltaic series protection panels (DC Junction boxes). Indicative price (special order). Including the protections it contains and their connection.			
		Total U :	2,000	1.352,19	**2.704,38**
		Total subcapítulo 3.1.- Mounting of the DC Junction boxes:			**20.240,72**
3.2.- Mounting of the inverters					
3.2.1	**U**	Purchase and installation of inverters. Ingeteam brand, INGECON Sun 3Play 100TL model with high efficiency (up to 99.1%). Output power of up to 110 kW in case of connecting to a 440 Vac network (in this case it is 400 Vac so its output power is 100 kW).			
		Total U :	10,000	9.434,79	**94.347,90**
		Total subcapítulo 3.2.- Mounting of the inverters:			**94.347,90**
3.3.- Mounting of the AC m.a.p. panels					
3.3.1	**U**	Purchase and installation of AC junction boxes. Including purchase and installation in them of the required protection and manoeuvring elements.			
		Total U :	4,000	4.070,91	**16.283,64**
		Total subcapítulo 3.3.- Mounting of the AC m.a.p. panels:			**16.283,64**
3.4.- Mounting of the monitoring equipment					
3.4.1	**U**	Purchase and installation of monitoring equipment. Triphasic wattmeters for uni and bi-directional measurement of the energy flows between the photovoltaic installation, the grid and the loads (consumptions). Carlo Gavazzi model EM24. Including purchase and installation of the communications cards in the inverters, model INGECON SUN EMS Board.			
		Total U :	10,000	628,61	**6.286,10**
		Total subcapítulo 3.4.- Mounting of the monitoring equipment:			**6.286,10**
Parcial Nº 3 CHAPTER 3. INSTALLATION OF THE DC JUNCTION BOXES, INVERTERS, ...					**137.158,36**

Capítulo Nº 4 CHAPTER 4. MAKING OF THE TRENCHES

Nº	Ud	Descripción	Medición	Precio	Importe
4.1.- Excavation of the trenches					
4.1.1	**M3**	Mechanical excavation of trenches, following the layout and with the indicated section. Medium-low consistency soil. There is no land transport.			
		Total m3 :	6.600,000	3,09	**20.394,00**
		Total subcapítulo 4.1.- Excavation of the trenches:			**20.394,00**
4.2.- Laying of the cabling in the trenches					
4.2.1	**M**	Laying the underground wiring that joins the strings with the DC junction boxes in the trenches.			
		Total m :	1,000	9.617,04	**9.617,04**
		Total subcapítulo 4.2.- Laying of the cabling in the trenches:			**9.617,04**
4.3.- Burial of the trenches					
4.3.1	**M3**	Buried of the trenches by mechanical means and terrain compaction. Use of previously extracted land.			
		Total m3 :	6.600,000	3,09	**20.394,00**
		Total subcapítulo 4.3.- Burial of the trenches:			**20.394,00**
		Parcial Nº 4 CHAPTER 4. MAKING OF THE TRENCHES :			**50.405,04**

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
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Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto**

Capítulo Nº 5 CHAPTER 5. ELECTRICAL ELEMENTS CONNECTION

Nº	Ud	Descripción		Medición	Precio	Importe

5.1.- Underground electrical pipeline

Nº	Ud	Descripción		Medición	Precio	Importe
5.1.1	Lm	Protection tubes type I (90 mm ext.diam). Acquisition of protection tubes. Double-walled tubes with ringed outer part and smooth inner part. Made of halogen-free high-density polyethylene (HDPE). Wide range of service temperatures (-25 to 100 °C). Supplied in rolls. Including sleeves and accessories. Red colour (and others). 450 N resistance to crushing. Normal impact resistance. Laying of the wiring inside. IBK Cables.				
			Total Lm :	11.184,760	10,28	**114.979,33**
5.1.2	Lm	Protection tubes type II (110 mm ext.diam). Acquisition of protection tubes. Double-walled tubes with ringed outer part and smooth inner part. Made of halogen-free high-density polyethylene (HDPE). Wide range of service temperatures (-25 to 100 °C). Supplied in rolls. Including sleeves and accessories. Red colour (and others). 450 N resistance to crushing. Normal impact resistance. Laying of the wiring inside. IBK Cables.				
			Total Lm :	5.984,000	11,28	**67.499,52**
5.1.3	Lm	Protection tubes type III (250 mm ext.diam). Acquisition of protection tubes. Double-walled tubes with ringed outer part and smooth inner part. Made of halogen-free high-density polyethylene (HDPE). Wide range of service temperatures (-25 to 100 °C). Supplied in rolls. Including sleeves and accessories. Red colour (and others). 450 N resistance to crushing. Normal impact resistance. Laying of the wiring inside. IBK Cables.				
			Total Lm :	64,980	24,46	**1.589,41**

Total subcapítulo 5.1.- Underground electrical pipeline: 184.068,26

5.2.- Cabling between the strings and the DC junction boxes

Nº	Ud	Descripción		Medición	Precio	Importe
5.2.1	Lm	DC cable of 25 mm2. Purchase and connection of the wiring for the interconnection of the strings with the DC junction boxes. Cable Exzhellent Solar XZ1FA3Z-K (AS) 1,8 kV DC. Made of copper Class 5. Special conductor for photovoltaic applications. XLPE isolation.				
			Total Lm :	47.695,000	4,00	**190.780,00**
5.2.2	Lm	DC cable of 35 mm2. Purchase and connection of the wiring for the interconnection of the strings with the DC junction boxes. Cable Exzhellent Solar XZ1FA3Z-K (AS) 1,8 kV DC. Made of copper Class 5. Special conductor for photovoltaic applications. XLPE isolation.				
			Total Lm :	14.550,000	4,92	**71.586,00**

Total subcapítulo 5.2.- Cabling between the strings and the DC junction boxes: 262.366,00

5.3.- Cabling between the DC junction boxes and the inverters

Nº	Ud	Descripción		Medición	Precio	Importe
5.3.1	Lm	DC cable of 6 mm2. Purchase and connection of the cabling that goes from the DC junction boxes to the inverters. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.				
			Total Lm :	5,370	1,01	**5,42**
5.3.2	Lm	DC cable of 10 mm2. Purchase and connection of the cabling that goes from the DC junction boxes to the inverters. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.				
			Total Lm :	5,370	1,35	**7,25**
5.3.3	Lm	DC cable of 70 mm2. Purchase and connection of the cabling that goes from the DC junction boxes to the inverters. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.				
			Total Lm :	16,110	14,55	**234,40**

Total subcapítulo 5.3.- Cabling between the DC junction boxes and the inverters: 247,07

Capítulo Nº 5 CHAPTER 5. ELECTRICAL ELEMENTS CONNECTION

Nº	Ud	Descripción	Medición	Precio	Importe
5.4.- Cabling between the inverters and the AC m.a.p. panels					
5.4.1	**Lm**	AC cable of 150 mm2+70 mm2. Purchase and connection of the cabling for the interconnection of the inverters to the m.a.p. panels. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.			
		Total Lm :	12,980	26,39	**342,54**
5.4.2	**Lm**	AC cable of 185 mm2+95 mm2. Purchase and connection of the cabling for the interconnection of the inverters to the m.a.p. panels. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.			
		Total Lm :	18,410	39,00	**717,99**
		Total subcapítulo 5.4.- Cabling between the inverters and the AC m.a.p. panels:			**1.060,53**
5.5.- Cabling between the AC m.a.p. panels and the monitoring equipment					
5.5.1	**Lm**	AC cable of 150 mm2+70 mm2. Purchase and connection of the cable that goes from the m.a.p panels to the monitoring equipment. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.			
		Total Lm :	167,460	26,39	**4.419,27**
5.5.2	**Lm**	AC cable of 185 mm2+95 mm2. Purchase and connection of the cable that goes from the m.a.p panels to the monitoring equipment. Cable ENERGY RV-K FOC. Made of copper, XLPE isolation, flexible PVC external cover.			
		Total Lm :	27,480	39,00	**1.071,72**
		Total subcapítulo 5.5.- Cabling between the AC m.a.p. panels and the monitoring equipm...			**5.490,99**
		Parcial Nº 5 CHAPTER 5. ELECTRICAL ELEMENTS CONNECTION :			**453.232,85**

Capítulo Nº 6 CHAPTER 6. INSTALLATION OF THE PUMPING GROUPS

Nº	Ud	Descripción	Medición	Precio	Importe
6.1.- Mounting of the pumps of both sectors					
6.1.1	**U**	Installation of 2 pumps in parallel in Sector 1 (brand IDEAL, model SDX 1.8-4). It includes the hydraulic bodies, triphasic motors, electroweldable adaptation pipes, welding, meters/flow meters and others.			
		Total U :	1,000	26.495,72	**26.495,72**
6.1.2	**U**	Installation of 2 pumps in parallel in Sector 2 (brand IDEAL, model SDX 1.8-2). It includes the hydraulic bodies, triphasic motors, electroweldable adaptation pipes, welding, meters/flow meters and others.			
		Total U :	1,000	18.717,16	**18.717,16**
		Total subcapítulo 6.1.- Mounting of the pumps of both sectors:			**45.212,88**
		Parcial Nº 6 CHAPTER 6. INSTALLATION OF THE PUMPING GROUPS :			**45.212,88**

Capítulo Nº 7 CHAPTER 7. INSTALLATION OF OTHER ELEMENTS OF THE PROJECTED S...

Nº	Ud	Descripción	Medición	Precio	Importe
7.1.- Installation of grounding rods					
7.1.1	**U**	Purchase and installation of copper-plated steel grounding rods, 2 m long and 18.2 mm in diameter. Sofamel brand. It includes the grounding electrode, 35 mm2 bare copper conductor, clamp for connection of the rod and a bag of mineral salts to improve the conductivity of earthing.			
		Total U :	50,000	45,79	**2.289,50**
		Total subcapítulo 7.1.- Installation of grounding rods:			**2.289,50**
7.2.- Placement of other protective elements					
7.2.1	**U**	Placement of protective elements such as fire extinguisher and first aid boxes.			
		Total U :	1,000	515,00	**515,00**
		Total subcapítulo 7.2.- Placement of other protective elements:			**515,00**
7.3.- General check of the connections					
7.3.1	**H**	Checking the connections between components.			
		Total h :	1,000	412,00	**412,00**
		Total subcapítulo 7.3.- General check of the connections:			**412,00**
Parcial Nº 7 CHAPTER 7. INSTALLATION OF OTHER ELEMENTS OF THE PROJECTED S...					**3.216,50**

Capítulo Nº 8 CHAPTER 8. MINOR MATERIAL

Nº	Ud	Descripción	Medición	Precio	Importe
8.1.- Other minor equipment and materials					
8.1.1	**U**	Purchase and installation of cable glands, flat strips of steel clamps, etc			
		Total U :	1,000	2.575,00	**2.575,00**
		Total subcapítulo 8.1.- Other minor equipment and materials:			**2.575,00**
		Parcial Nº 8 CHAPTER 8. MINOR MATERIAL :			**2.575,00**

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
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Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto**

Capítulo Nº 9 CHAPTER 9. COMISSIONING

Nº	Ud	Descripción	Medición	Precio	Importe
9.1.- Checking of the status of all components and their operation condition					
9.1.1	**H**	Visit of the Technical Directorate together with the Construction Company for the final verification of the status of the components, their connections, distribution and ultimately compliance with the technical specifications of the project.			
		Total h :	1,000	824,00	**824,00**
Total subcapítulo 9.1.- Checking of the status of all components and their operation condi...					**824,00**
9.2.- Visit to the work of the interested parties for their approval					
9.2.1	**H**	Meeting of the representatives of the interested parties of the project (Promoter, Technical Directorate and Contractor) for the joint visit to the facilities for their approval and signing of the Final Acceptance Certificate.			
		Total h :	1,000	206,00	**206,00**
Total subcapítulo 9.2.- Visit to the work of the interested parties for their approval:					**206,00**
Parcial Nº 9 CHAPTER 9. COMISSIONING :					**1.030,00**

Capítulo Nº 10 CHAPTER 10. OTHER STUDIES AND PROCEDURES

Nº	Ud	Descripción	Medición	Precio	Importe
10.1.- Obtention of the prior administrative authorizations and construction licenses					
10.1.1	**H**	Obtention of the prior administrative authorizations and construction licenses. Registration of the photovoltaic installation.			
		Total h :	1,000	3.090,00	**3.090,00**
Total subcapítulo 10.1.- Obtention of the prior administrative authorizations and constructi...					**3.090,00**
10.2.- Health and Safety Study					
10.2.1	**U**	Preparation of the Health and Safety Study. Purchase of materials.			
		Total U :	1,000	4.120,00	**4.120,00**
Total subcapítulo 10.2.- Health and Safety Study:					**4.120,00**
10.3.- Environmental Analysis of the project					
10.3.1	**H**	Preparation of the Environmental Analysis of the project.			
		Total h :	1,000	1.030,00	**1.030,00**
Total subcapítulo 10.3.- Environmental Analysis of the project:					**1.030,00**
Parcial Nº 10 CHAPTER 10. OTHER STUDIES AND PROCEDURES :					**8.240,00**

Proyecto: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLAD...
Promotor: Sociedad Riego Canyoles
Situación: Vallada

Ing. Industrial (Gen. Energía): Víctor Felip Plaza **V Presupuesto**

Presupuesto de ejecución material

1 CHAPTER 1. LAND MOVEMENT AND GROUND PREPARATIONS	**5.564,62**
1.1.- Terrain study	61,80
1.2.- Previous signalling works and others	302,82
1.3.- Suitability of the land	5.200,00
2 CHAPTER 2. INSTALLATION OF THE PHOTOVOLTAIC GENERATOR	**478.871,09**
2.1.- Placing of footings on the ground	10.377,25
2.2.- Assembly of panel structures	131.212,24
2.3.- Placing of the panels	330.112,80
2.4.- Connection of the modules	7.168,80
3 CHAPTER 3. INSTALLATION OF THE DC JUNCTION BOXES, INVERTERS, AC ...	**137.158,36**
3.1.- Mounting of the DC Junction boxes	20.240,72
3.2.- Mounting of the inverters	94.347,90
3.3.- Mounting of the AC m.a.p. panels	16.283,64
3.4.- Mounting of the monitoring equipment	6.286,10
4 CHAPTER 4. MAKING OF THE TRENCHES	**50.405,04**
4.1.- Excavation of the trenches	20.394,00
4.2.- Laying of the cabling in the trenches	9.617,04
4.3.- Burial of the trenches	20.394,00
5 CHAPTER 5. ELECTRICAL ELEMENTS CONNECTION	**453.232,85**
5.1.- Underground electrical pipeline	184.068,26
5.2.- Cabling between the strings and the DC junction boxes	262.366,00
5.3.- Cabling between the DC junction boxes and the inverters	247,07
5.4.- Cabling between the inverters and the AC m.a.p. panels	1.060,53
5.5.- Cabling between the AC m.a.p. panels and the monitoring equipment	5.490,99
6 CHAPTER 6. INSTALLATION OF THE PUMPING GROUPS	**45.212,88**
6.1.- Mounting of the pumps of both sectors	45.212,88
7 CHAPTER 7. INSTALLATION OF OTHER ELEMENTS OF THE PROJECTED SYSTEM	**3.216,50**
7.1.- Installation of grounding rods	2.289,50
7.2.- Placement of other protective elements	515,00
7.3.- General check of the connections	412,00
8 CHAPTER 8. MINOR MATERIAL	**2.575,00**
8.1.- Other minor equipment and materials	2.575,00
9 CHAPTER 9. COMISSIONING	**1.030,00**
9.1.- Checking of the status of all components and their operation condition	824,00
9.2.- Visit to the work of the interested parties for their approval	206,00
10 CHAPTER 10. OTHER STUDIES AND PROCEDURES	**8.240,00**
10.1.- Obtention of the prior administrative authorizations and construction lic...	3.090,00
10.2.- Health and Safety Study	4.120,00
10.3.- Environmental Analysis of the project	1.030,00
Total ....:	**1.185.506,34**

The Material Execution Budget material execution budget amounts to the expressed amount of ONE MILLION ONE HUNDRED EIGHTY-FIVE THOUSAND FIVE HUNDRED SIX EUROS AND THIRTY-FOUR CENTS.

Discounting the I.V.A, it amounts to NINE HUNDRED SEVENTY-NINE THOUSAND SEVEN HUNDRED FIFTY-SEVEN EUROS AND THIRTY-ONE CENTS.

MATERIAL EXECUTION BUDGET	**979.757,31 €**
General Expenses (13%)	**127.368,45 €**
Industrial Benefit (6%)	**58.785,44 €**
EXECUTION BUDGET BY CONTRACT	**1.165.911,20 €**
I.V.A (21%)	**244.841,35 €**
TENDER BASE BUDGET	**1.410.752,56 €**

The projected budget amounts to the expressed amount of:

ONE MILLION FOUR HUNDRED TEN THOUSAND SEVEN HUNDRED FIFTY-TWO EUROS AND FIFTY-SIX CENTS.

4.3 Financial indicators used in the calculation of economic viability

As in any project, in this case it is necessary to apply certain financial indicators that allow us to know if the execution of the project would be profitable and, therefore, if it is convenient to carry it out or not, as well as, if it is profitable, how long it would take to obtain economic benefits that allow not only to recover the initial investment but to generate additional income. These indicators take into account the different costs present in the execution of a project (investment expenses, fixed and variable operating expenses), the income obtained and some of them also the evolution of the price of money.

On the other hand, these indicators are applied in order to optimize the project not only from the economic point of view, looking for the most advantageous technical solution in economic terms (minimum cost), but also trying to maximize the production and the profit obtained throughout the useful life of the works executed.

In this sense, there are three chosen financial indicators, widely used in the financial analysis of a multitude of projects of different nature. These indicators are included within the group of those known as dynamic methods which, unlike static methods, do take into account the influence of time on the evolution of the value of money.

Net Present Value (NPV)

This first indicator is one of the most widely used in the economic evaluation and profitability analysis of projects of various kinds. The reason for its popularity lies in that it allows, in a simple way, to determine with certainty whether a project is going to be profitable or not. The NPV indicates the added value that the project in question brings to the company, since it allows the initial investment cost to be discounted from the annual cash flows, which are in turn the result of subtracting the operating costs from the income, those that apply a discount rate that represents the present value of money obtained in the future. This indicator is based on 3 main assumptions:

- Cash flows are established as expected and known average values at the time of approaching the financial analysis.
- The selected discount rate or update rate is assumed to be known and constant.
- The market prices are established based on the costs of the first year of operation of the project.

The equation that represents NPV is:

$$VAN = -I + \frac{F_1}{(1+k)^1} + \cdots + \frac{F_n}{(1+k)^n}$$

Being:

- $\boldsymbol{I}$: Initial investment
- $\boldsymbol{F_i}$: Cash flow for year i
- $\boldsymbol{k}$: Discount or update rate
- $\boldsymbol{n}$: Number of established periods

Once the value of the NPV of the project is known, the decisional criterion is as follows:

- If the NPV> 0, the project is profitable and must be accepted, as it will generate income higher than the required profitability.
- If the NPV= 0, this indicator does not provide any conclusive results, so it is necessary to use another methodology that clarifies the convenience of executing the project. On the other hand, some authors indicate that if the NPV is equal to zero, the project can be accepted, since said project returns the initial investment as well as the money generated at the established opportunity cost (discount rate)
- Finally, if the NPV< 0, the project must be rejected.

Internal Rate of Return (IRR)

For its part, the IRR is a financial indicator, also widely used in the literature on the economic evaluation of projects, which allows in a simple and intuitive way to know the convenience of a project based on obtaining that interest or discount rate that makes that the NPV is 0, that is, the discount rate that implies the updated benefits generated by the project in its useful life are equal to the expenses in each period, also expressed in the current monetary value. In this way, it can be defined as the discount rate that implies that the cash flows generated during the useful life of the project are equal to the initial investment, and that therefore implies the highest value of interest than whoever is going to make the investment can assume so as not to risk losing money. Therefore, its expression turns out to be simply:

$$VAN = -I + \frac{F_1}{(1+k)^1} + \cdots + \frac{F_n}{(1+k)^n} = 0$$

Regarding the decisional criterion, in this case it is similar to what happened with NPV:

- If the IRR> k, it must be accepted.
- If the IRR= k is equal to the discount rate, it must be accepted.
- If the IRR< k is less than the discount rate, it must be rejected.

The IRR can be used to accept or reject alternatives, but not to select them. Thus, while in the case of NPV the best alternative is always the one that presents a higher value, in the case of IRR this is not necessarily the case, and among projects that present an IRR greater than (or equal to) the value of the interest rate chosen, the one with the highest NPV must be chosen, regardless of the IRR value.

This indicator gives a percentage value, which is used more in the markets than the absolute value that, for example, the NPV, but it can have multiple solutions and in the case of exclusive projects it is less precise and reliable than the NPV. The higher the IRR, the higher the profitability.

The discount rate k allows considering the depreciation of money over time. The IRR can be compared with a cut or discount rate that must be exceeded to accept the project, or with the Equivalent Annual Rate (EAR, *TAE* in Spanish) in case a bank loan is needed to make the investment, so that the IRR must exceed the APR to accept the investment.

Amortization period or Payback

Lastly, the payback period indicates the years needed to recover the investment needed to start the project and, therefore, the period of time needed for the project to start generating net benefits. This is a very simple criterion, which focuses only on the period of time necessary to recover the initial investment, so it should be applied with caution.

For example, if there is project A that required 10,000 euros of initial investment and they were recovered the following year (payback of 1 year) but only generated 20,000 euros of benefit in the following 3 years, and a project B that needed 2 years to recover the investment (payback of 2 years) but generate 30,000 euros in the following 3 years, although the payback of project A is better than that of project B, probably project B would be chosen for generating greater benefits.

4.4 Economic feasibility analysis

The production of electrical energy through the photovoltaic generator is associated with savings. In certain periods the energy production will be enough to cover the demand and the surplus will be poured into the grid, obtaining profits from its sale, and in other periods, even if the energy consumption exceeds the photovoltaic production, there will be savings due to the reduction of energy consumed from the grid .

On the other hand, the main stumbling block when it comes to guaranteeing the final profitability of any project is the initial investment involved in the construction and start-up of the facility.

First of all, the following table shows the monthly and annual consumptions of the two sectors of the irrigation area for which the photovoltaic installation has been designed. As it is not an industrial building, these consumptions are not distributed in a practically uniform way in the different months of the year, but there are very noticeable variations in those months in which said consumptions rise as a consequence of the greater irrigation needs.

Month	Sector 1 (kWh)	Sector 2 (kWh)
January	11358,54	8731,71
February	9555,60	8018,92
March	11178,25	7484,32
April	11900,01	14523,15
May	19652,08	15859,63
June	29748,57	29669,99
July	38582,99	40450,97
August	45614,47	45173,22
September	35878,58	29313,59
October	23618,56	21294,68
November	15865,90	12028,37
December	12800,90	14255,85
Annual	265754,45	246804,40
Total	**512558,85**	

Table 56. Monthly and annual consumptions (kWh) of the pumping systems of Sector 1, 2 and total

Similarly, energy production by the photovoltaic system will not be constant throughout the year, reaching higher production in the months closer to the summer period, where solar radiation is considerably higher (the increase in power generated as a consequence the increase in irradiance received more than compensates for the reduction in said power due to the higher temperatures reached in the cells of the photovoltaic modules).

It should be emphasized that, when determining the benefits, a distinction is made, on the one hand, that is indirectly due to the annual economic savings associated with the reduction in consumption of electrical energy from the network and, on the other hand, that due to the sale of the energy surpluses in the electricity market in those moments in which photovoltaic generation exceeds the consumption of the pumping groups. The corresponding expressions of these benefits are the following:

- Benefit associated to the reduction in the consumption of electrical energy from the network:

$$Saving_{month\ i}(€) = \begin{cases} E_{prod\ month\ i}(kWh)\ \cdot price_{purchase}\ (\frac{€}{kWh}) & if\ E_{prod\ month\ i} < E_{cons\ month\ i} \\ E_{cons\ month\ i}(kWh)\ \cdot price_{purchase}\ (\frac{€}{kWh}) & if\ E_{prod\ month\ i} > E_{cons\ month\ i} \end{cases}$$

  Here, the annual savings due to the use of the energy recovered by the PATs (around 4500 €/year) has been taken into account.

- Benefit associated to the sale of surpluses:

$$Benefits_{month\ i}(€) = \left(E_{prod\ month\ i}(kWh) - E_{cons\ month\ i}(kWh)\right) \cdot price_{sale}\ (\frac{€}{kWh})$$

The sale price of the energy considered is, as indicated in the previous document, 0,05 €/kWh initially, with an annual increase of 2%, close to the considered CPI (2,2%). This difference is considered in order to have into account the impact that the entrance of new energies could have in the sale price of the energy; however, it must be said that it is a conservative value (most of the sources consulted apply a CPI of 3% to energy, what would result in higher benefits). Regarding the purchase price of energy from the grid, it is taken equal to 0,0934 €/kWh; this is an average price based on the various types of rates that exist and the powers contracted, to which the 2% annual increase is also applied due to the IPC expected evolution.

The following table lists the values used for the various variables that need to be taken into account to carry out the economic analysis of the project:

Parameter	Unit	Value
Investment (TBB)	€	1.410.752,56
Maintenance, replacements and insurance	€	4000
Useful life	Years	25
Production (first year)	kWh	1.385.509,74
Consumption	kWh	512.558,85
Consumption from pv energy	kWh	459.062,91
Surplus energy	kWh	926.446,84
CPI (for maintenance and insurance)	%	2,2
CPI (for sale and purchase price)	%	2
k	%	2,5
Annual power loss (%) first 10 years	%	1
Annual power loss (%) last 15 years	%	0,67
Cost of representation	€/kWh	0,00082
Generation access toll	€/kWh	0,0005
Sale price of energy (first year)	€/kWh	0,05
Purchase price of energy (first year)	€/kWh	0,0934

Table 57. Considerations for the cash flows and economic indicators (NPV, IRR and PP)

On the other hand, two relevant aspects are assumed: firstly, it is assumed that the hourly irradiance levels with which it has been worked will be relatively constant in future years, and that the solar irradiance will remain at a similar intensity (for example, currently the sun is in a period of low activity); secondly, that the water needs, and therefore energy needs, will be the same in the years for which the useful life of the installation has been projected.

The following graphs illustrate the energy flows in the hydraulic-photovoltaic installation, the savings and benefits obtained in the first year, the cash flows and the updated accumulated cash flows in the case of installing the designed photovoltaic system (≈70% of required modules).

Regarding the results of the NPV, IRR and PP, they are shown in the following table:

NPV (€)	**267.747,46 €**
IRR (%)	**4,0207%**
PP	**20,309**

Table 58. Results of the financial indicators of the economic analysis

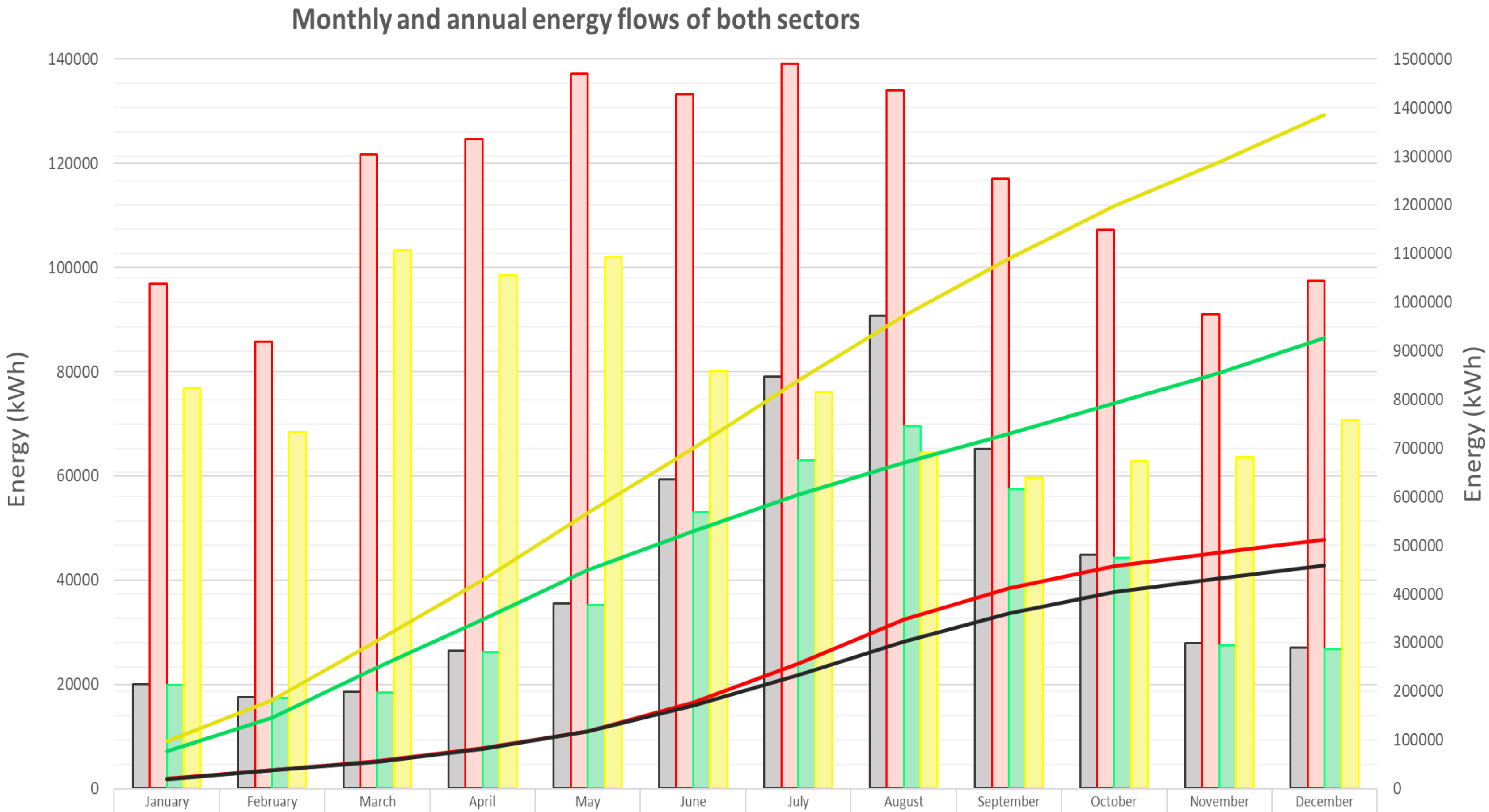
As can be seen, the NPV of the project is 267.747,46 €, so it is positive and produces benefits within the 25-year term considered. In turn, the IRR is 4,021%, so it is higher than both the discount rate k (2,5%) and the Equivalent Annual Rate (2%) in case of requesting a bank loan for this type of investment (see attached table below), so it would be feasible to finance the investment through said loan.

With these parameters it is possible, in principle, to guarantee that the project is profitable, and that therefore it is advisable to carry out its execution and start-up. Specifically, according to the PP, this project will report benefits from the year 20; this result is the least promising, since a return on investment ends very far from year 0, and it is desirable and usual for benefits to be reported between the eighth and the twelfth year of operation.

On the other hand, it should be noted what has already been said above, and that is that the energy and water needs of the analyzed system and the irradiance levels received have been considered constant, and the evolution of the prices of sale and purchase of energy, as well as the discount rate and interest rate of the bank loan (*TAE*) applied, have been taken basing on a personal criterion, although as objective and well-founded as possible, which variation would have a direct and notable influence on the financial indicators obtained, which could result in both an unprofitable project and a project with higher profits than expected.

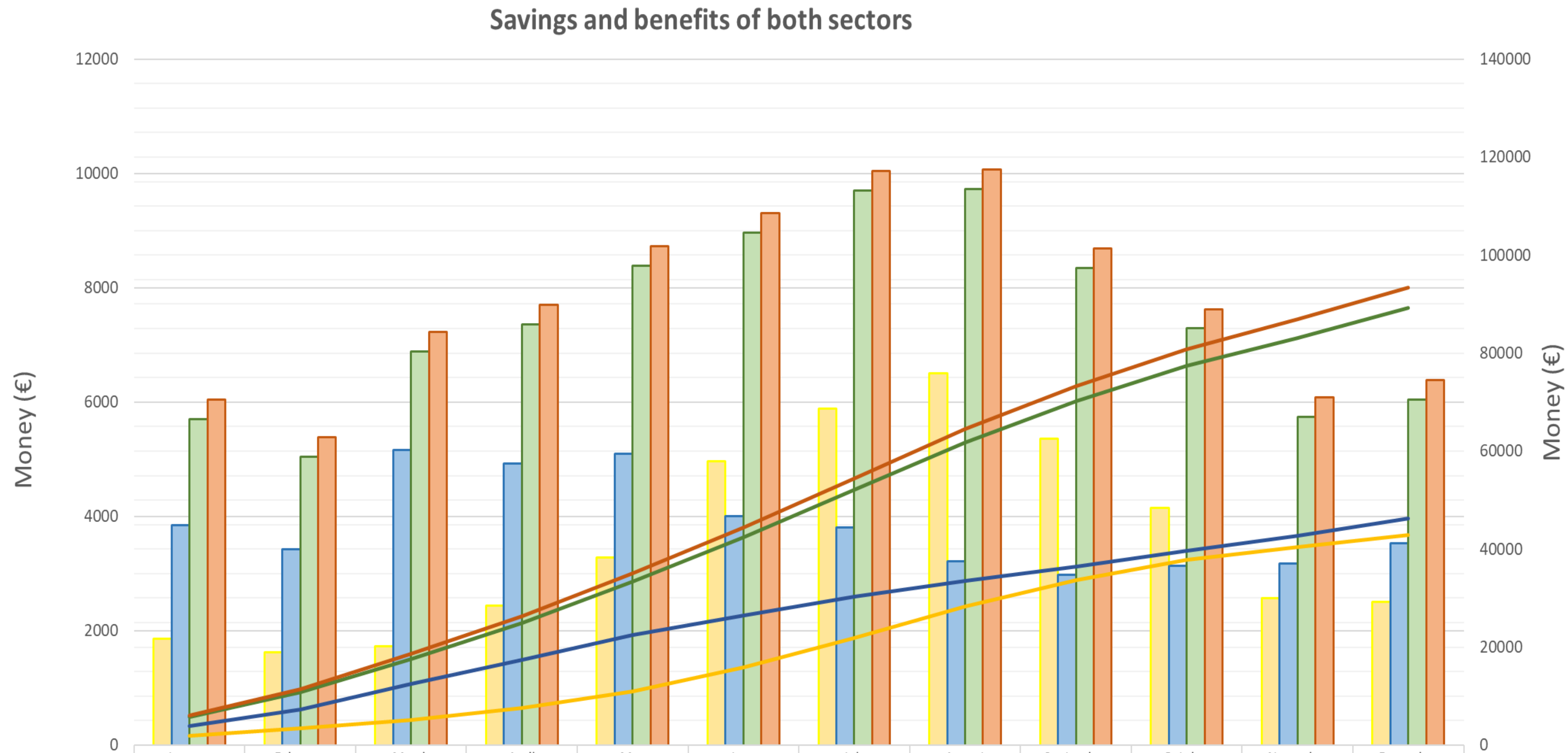
	TAE					
	Hogares e ISFLSH			Sociedades no financieras		
	Vivienda	Consumo (c)	Otros Fines	Otros créditos hasta 250 mil euros	Otros créditos entre 250 mil y 1 millón de euros	Otros créditos de más de 1 millón de euros
	1	2	3	4	5	6
16	2,18	8,05	4,27	3,28	1,91	1,63
17	2,05	8,27	4,01	2,93	1,80	1,56
18	2,24	8,31	3,72	2,67	1,70	1,59
19	1,93	7,91	3,47	2,58	1,55	1,26
20	1,67	7,57	3,12	2,55	1,66	1,43
19 *Nov*	2,02	7,56	4,23	2,70	1,60	1,50
Dic	1,93	7,91	3,47	2,58	1,55	1,26
20 *Ene*	2,02	8,41	4,47	3,50	1,84	1,42
Feb	2,06	8,04	4,04	2,59	1,65	1,52
Mar	2,01	7,93	3,37	2,44	1,57	1,29
Abr	1,89	7,41	2,75	2,22	1,74	1,58
May	1,91	7,44	3,06	2,27	1,81	1,76
Jun	1,92	7,64	3,10	2,37	1,76	1,58
Jul	1,92	8,01	3,67	3,02	1,81	1,79
Ago	1,98	8,20	3,71	2,70	1,65	1,52
Sep	1,91	7,78	3,46	2,73	1,62	1,40
Oct	1,91	7,52	3,94	3,11	1,69	1,44
Nov	1,82	6,98	3,74	2,74	1,66	1,32
Dic	1,67	7,57	3,12	2,55	1,66	1,43
21 *Ene* P	1,74	7,52	4,32	3,48	1,78	1,16

Figure 73. Evolution of the last 5 years of the EAR interest rates for new operations. Loans and credits to households and NPISHs and non-financial corporations. Credit institutions and EFC. Source: Banco de España



	January	February	March	April	May	June	July	August	September	October	November	December
Monthly consumptions S1+S2 (kWh)	20090,25	17574,52	18662,57	26423,16	35511,72	59418,56	79033,96	90787,69	65192,17	44913,24	27894,28	27056,75
Monthly production S1+S2 (kWh)	96843,28	85845,86	121777,38	124603,95	137202,24	133248,55	139147,91	134040,73	117044,78	107213,34	91021,42	97520,30
Monthly consumptions from pv E S1+S2 (kWh)	19903,15	17418,79	18482,83	26137,09	35185,80	53138,84	63045,95	69633,87	57428,30	44372,00	27489,36	26826,92
Monthly surplus (+) or lack (-) S1+S2 (kWh)	76940,13	68427,07	103294,55	98466,86	102016,44	80109,71	76101,96	64406,85	59616,47	62841,34	63532,05	70693,38
Monthly and annual consumptions S1+S2 accumulated (kWh)	20090,25	37664,77	56327,34	82750,49	118262,21	177680,77	256714,73	347502,43	412694,59	457607,83	485502,10	512558,85
Monthly and annual production S1+S2 accumulated (kWh)	96843,28	182689,15	304466,53	429070,48	566272,72	699521,28	838669,19	972709,91	1089754,69	1196968,03	1287989,45	1385509,74
Monthly and annual consumptions from pv E S1+S2 accumulated (kWh)	19903,15	37321,94	55804,77	81941,86	117127,67	170266,51	233312,46	302946,33	360374,63	404746,63	432235,99	459062,91
Monthly and annual surplus (+) or lack (-) S1+S2 accumulated (kWh)	76940,13	145367,20	248661,75	347128,62	449145,06	529254,77	605356,73	669763,59	729380,06	792221,40	855753,46	926446,84

Figure 74. Energy flows of both sectors

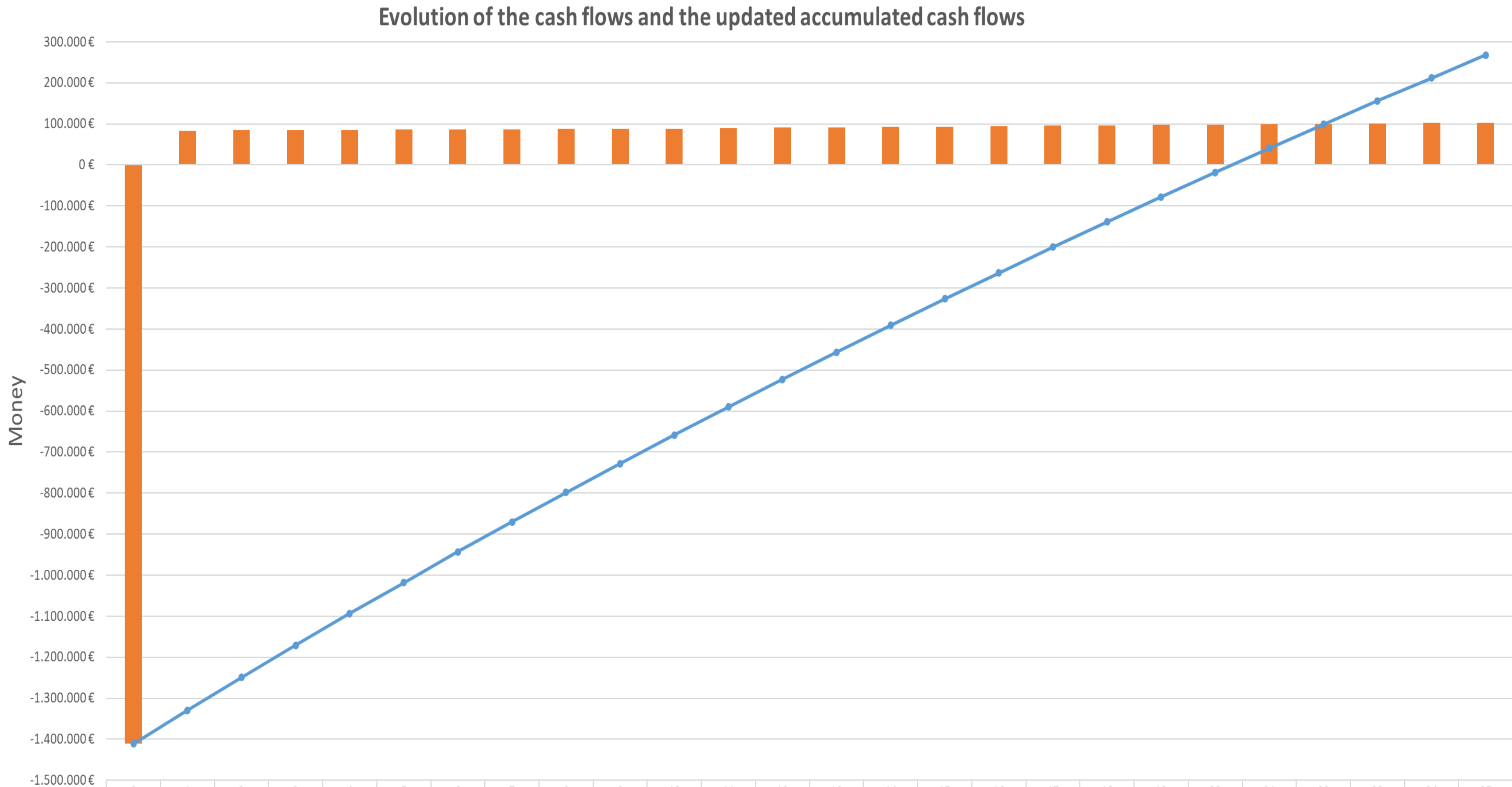


	January	February	March	April	May	June	July	August	September	October	November	December
Savings S1+S2	1858,95	1626,92	1726,30	2441,20	3286,35	4963,17	5888,49	6503,80	5363,80	4144,34	2567,51	2505,63
Benefits from sales S1+S2	3847,01	3421,35	5164,73	4923,34	5100,82	4005,49	3805,10	3220,34	2980,82	3142,07	3176,60	3534,67
Total benefits S1+S2	5705,96	5048,27	6891,02	7364,55	8387,18	8968,65	9693,59	9724,15	8344,63	7286,41	5744,11	6040,30
Total benefits S1+S2 with PATs	6047,65	5389,96	7232,72	7706,24	8728,87	9310,35	10035,28	10065,84	8686,32	7628,10	6085,80	6381,99
Savings accumulated S1+S2	1858,95	3485,87	5212,17	7653,37	10939,72	15902,89	21791,38	28295,19	33658,99	37803,34	40370,84	42876,48
Benefits from sales accumulated S1+S2	3847,01	7268,36	12433,09	17356,43	22457,25	26462,74	30267,84	33488,18	36469,00	39611,07	42787,67	46322,34
Total benefits accumulated S1+S2	5705,96	10754,23	17645,25	25009,80	33396,98	42365,63	52059,22	61783,37	70127,99	77414,41	83158,51	89198,82
Total benefits accumulated S1+S2 with PATs	6047,65	11437,61	18670,33	26376,57	35105,44	44415,78	54451,06	64516,90	73203,22	80831,32	86917,12	93299,12

Figure 75. Expected savings and benefits of both sectors in the first year

Year (y)	Incomes from the sale of surpluses and the save of cons. from grid (€)	Expenses per purchase of energy (€)	Expenses per maintenance (€)	Cash flow F (€)	Updated F (€)	Updated accumulated F (€)
0				-1.410.752,56 €		-1410752,56
1	92.407,13 €	-5.046,49 €	-4.000,00 €	83.360,64 €	81.327,46 €	-1.329.425,10 €
2	93.263,44 €	-5.198,38 €	-4.080,00 €	83.985,06 €	79.938,19 €	-1.249.486,91 €
3	94.118,68 €	-5.354,33 €	-4.161,60 €	84.602,74 €	78.562,06 €	-1.170.924,85 €
4	94.972,46 €	-5.514,44 €	-4.244,83 €	85.213,18 €	77.198,94 €	-1.093.725,91 €
5	95.824,39 €	-5.678,82 €	-4.329,73 €	85.815,84 €	75.848,70 €	-1.017.877,21 €
6	96.674,04 €	-5.847,56 €	-4.416,32 €	86.410,16 €	74.511,21 €	-943.366,00 €
7	97.520,99 €	-6.020,78 €	-4.504,65 €	86.995,56 €	73.186,34 €	-870.179,66 €
8	98.364,79 €	-6.198,59 €	-4.594,74 €	87.571,46 €	71.873,98 €	-798.305,68 €
9	99.204,97 €	-6.381,10 €	-4.686,64 €	88.137,24 €	70.573,98 €	-727.731,70 €
10	100.041,06 €	-6.568,44 €	-4.780,37 €	88.692,25 €	69.286,25 €	-658.445,45 €
11	101.234,99 €	-6.740,41 €	-4.875,98 €	89.618,60 €	68.302,35 €	-590.143,10 €
12	102.438,30 €	-6.916,63 €	-4.973,50 €	90.548,17 €	67.327,62 €	-522.815,48 €
13	103.650,89 €	-7.097,21 €	-5.072,97 €	91.480,71 €	66.361,97 €	-456.453,51 €
14	104.872,65 €	-7.282,25 €	-5.174,43 €	92.415,97 €	65.405,30 €	-391.048,21 €
15	106.103,45 €	-7.471,84 €	-5.277,92 €	93.353,69 €	64.457,51 €	-326.590,70 €
16	107.343,18 €	-7.666,11 €	-5.383,47 €	94.293,60 €	63.518,52 €	-263.072,18 €
17	108.591,70 €	-7.865,16 €	-5.491,14 €	95.235,40 €	62.588,23 €	-200.483,95 €
18	109.848,86 €	-8.069,11 €	-5.600,97 €	96.178,79 €	61.666,56 €	-138.817,39 €
19	111.114,52 €	-8.278,06 €	-5.712,98 €	97.123,47 €	60.753,42 €	-78.063,97 €
20	112.388,50 €	-8.492,15 €	-5.827,24 €	98.069,10 €	59.848,72 €	-18.215,25 €
21	113.670,63 €	-8.711,49 €	-5.943,79 €	99.015,35 €	58.952,38 €	40.737,13 €
22	114.960,73 €	-8.936,21 €	-6.062,67 €	99.961,85 €	58.064,31 €	98.801,44 €
23	116.258,61 €	-9.166,43 €	-6.183,92 €	100.908,26 €	57.184,43 €	155.985,87 €
24	117.564,06 €	-9.402,29 €	-6.307,60 €	101.854,17 €	56.312,66 €	212.298,54 €
25	118.876,86 €	-9.643,91 €	-6.433,75 €	102.799,20 €	55.448,92 €	267.747,46 €

Table 59. Results of income, expenses and evolution of annual updated accumulated cash flows



	0	1	2	3	4	5	6	7	8	9	10	11	12
Cash flow F (€)	-1410752	83360,64	83985,06	84602,74	85213,18	85815,84	86410,16	86995,56	87571,46	88137,24	88692,25	89618,60	90548,17
Updated accumulated F (€)	-1410752	-1329425	-1249486	-1170924	-1093725	-1017877	-943366,	-870179,	-798305,	-727731,	-658445,	-590143,	-522815,

	13	14	15	16	17	18	19	20	21	22	23	24	25
Cash flow F (€)	91480,71	92415,97	93353,69	94293,60	95235,40	96178,79	97123,47	98069,10	99015,35	99961,85	100908,2	101854,1	102799,2
Updated accumulated F (€)	-456453,	-391048,	-326590,	-263072,	-200483,	-138817,	-78063,9	-18215,2	40737,13	98801,44	155985,8	212298,5	267747,4

Figure 76. Cash flows and updated accumulated cash flows

On the other hand, the following conclusions can be drawn from the three previous graphs:

- In the first of them, it is observed how in every month the energy produced by the photovoltaic installation is higher than the consumption needs, which means that in all of them there is a surplus of energy that can be sold in the network and, therefore, from which benefits can be obtained. In turn, it is observed how in the months in which the water and energy needs are higher (June-October), despite the fact that the energy production of the installation is notably higher, as the energy needs increase to a much greater extent, the energy surpluses are lower. On the contrary, in those months in which less radiation is received, but the needs of the irrigation sectors are much lower (November-May), despite the fact that energy production is lower, greater surpluses of energy are obtained that can be sold In the net. The self-consumption level is, in the first year,:

$$S.C_{level} = \frac{Annual\ consumptions\ from\ pv\ E}{Annual\ consumption\ needs} = \frac{459.062{,}91}{512.558{,}85} \rightarrow S.C_{level} \approx 0{,}8956 = 89{,}56\%$$

Equation 91. Self-consumption level (in the first year)

- The second graph is closely related to the first, since it reflects, in monetary terms, the different energy flows existing in the installation. In this way, it can be seen how in the months that were previously indicated as having higher energy production, but even higher energy demand (June-October), the benefits from savings are higher than the benefits from the sale of surplus energy, while that in the other months (November-May) a higher profit is obtained from the sale of surpluses than from savings due to the decrease in energy demand from the network.

- Finally, the last graph reflects two facts: the first, that the cash flows are somewhat higher each year, going from about 83.360 € to 102.799 €, since although an annual power loss of the photovoltaic generator has been considered, and therefore a decrease in the energy that is obtained both for self-consumption and for sale and an increase in the demand for energy from the network, the established CPI allows the benefits to increase slightly each year (about 800 € per year); the second, that the cumulative updated cash flow becomes positive at the beginning of year 20, as previously indicated by the PP.

As a last conclusion in the economic aspect, to emphasize that the financial parameters obtained would change taking into account the annual interest derived from the bank loan required for the partial or total financing of the investment (it should be remembered that the budget is closely of a million and a half euros, and that the Promoter is an irrigation society with about 20-25 members). In addition, accounting for the investment at once in year 0 instead of the annual payment corresponding to the entity that lends the money distorts the results obtained to some extent. Therefore, just as an example, and without going into greater detail, two possible scenarios are proposed:

Case 1 (Pessimistic): Financing of 100% of the initial investment through a bank loan,, with an annual interest of 2,5% and a repayment term of 18 years.

Initial capital C (€)	1.410.752,56
Annual interest i (%)	2,5
Years of payment t (y)	18
Periods per year (-)	1
Number of payments (-)	18
Payment per period (€)	98.287,24
Annual payment (€)	98.287,24
Payment of interests (€)	358.417,84
Total payment (€)	1.769.170,39

Table 60. Financial parameters considered (Case 1)

Period	Inicial balance	Share	Interests	Amortization	Final balance
1	1.410.752,56 €	98.287,24 €	35.268,81 €	63.018,43 €	1.347.734,12 €
2	1.347.734,12 €	98.287,24 €	33.693,35 €	64.593,89 €	1.283.140,23 €
3	1.283.140,23 €	98.287,24 €	32.078,51 €	66.208,74 €	1.216.931,50 €
4	1.216.931,50 €	98.287,24 €	30.423,29 €	67.863,96 €	1.149.067,54 €
5	1.149.067,54 €	98.287,24 €	28.726,69 €	69.560,56 €	1.079.506,98 €
6	1.079.506,98 €	98.287,24 €	26.987,67 €	71.299,57 €	1.008.207,41 €
7	1.008.207,41 €	98.287,24 €	25.205,19 €	73.082,06 €	935.125,35 €
8	935.125,35 €	98.287,24 €	23.378,13 €	74.909,11 €	860.216,24 €
9	860.216,24 €	98.287,24 €	21.505,41 €	76.781,84 €	783.434,41 €
10	783.434,41 €	98.287,24 €	19.585,86 €	78.701,38 €	704.733,02 €
11	704.733,02 €	98.287,24 €	17.618,33 €	80.668,92 €	624.064,10 €
12	624.064,10 €	98.287,24 €	15.601,60 €	82.685,64 €	541.378,46 €
13	541.378,46 €	98.287,24 €	13.534,46 €	84.752,78 €	456.625,68 €
14	456.625,68 €	98.287,24 €	11.415,64 €	86.871,60 €	369.754,08 €
15	369.754,08 €	98.287,24 €	9.243,85 €	89.043,39 €	280.710,69 €
16	280.710,69 €	98.287,24 €	7.017,77 €	91.269,48 €	189.441,21 €
17	189.441,21 €	98.287,24 €	4.736,03 €	93.551,21 €	95.889,99 €
18	95.889,99 €	98.287,24 €	2.397,25 €	95.889,99 €	0,00 €

Table 61. Annual payment of the loan amortization and the interests generated (Case 1)

NPV (€)	**-36.339,98 €**
IRR (%)	**2,3020%**
PP	**>25**

Table 62. Results of the financial indicators of the economic analysis (Case 1)

Therefore, in this case, the project would not be profitable (although narrowly), since the NPV is negative, the IRR is lower than both the discount rate k and the interest on the bank loan (EAR) and the PP is longer than the estimated duration of the installation (25 years).

Year (y)	Incomes from the sale of surpluses and the save of cons. from grid (€)	Exenses due to the payment of the interests(€)	Expenses per purchase of energy (€)	Expenses per maintenance (€)	Cash flow F (€)	Updated F (€)	Updated accumulated F (€)
0					-1.410.752,56 €		-1.410.752,56 €
1	92.407,13 €	-35.268,81 €	-5.046,49 €	-4.000,00 €	48.091,83 €	46.918,86 €	-1.363.833,70 €
2	93.263,44 €	-33.693,35 €	-5.198,38 €	-4.080,00 €	50.291,70 €	47.868,37 €	-1.315.965,33 €
3	94.118,68 €	-32.078,51 €	-5.354,33 €	-4.161,60 €	52.524,24 €	48.773,98 €	-1.267.191,35 €
4	94.972,46 €	-30.423,29 €	-5.514,44 €	-4.244,83 €	54.789,90 €	49.636,94 €	-1.217.554,41 €
5	95.824,39 €	-28.726,69 €	-5.678,82 €	-4.329,73 €	57.089,15 €	50.458,49 €	-1.167.095,92 €
6	96.674,04 €	-26.987,67 €	-5.847,56 €	-4.416,32 €	59.422,49 €	51.239,82 €	-1.115.856,09 €
7	97.520,99 €	-25.205,19 €	-6.020,78 €	-4.504,65 €	61.790,38 €	51.982,10 €	-1.063.874,00 €
8	98.364,79 €	-23.378,13 €	-6.198,59 €	-4.594,74 €	64.193,33 €	52.686,45 €	-1.011.187,54 €
9	99.204,97 €	-21.505,41 €	-6.381,10 €	-4.686,64 €	66.631,83 €	53.354,00 €	-957.833,55 €
10	100.041,06 €	-19.585,86 €	-6.568,44 €	-4.780,37 €	69.106,39 €	53.985,80 €	-903.847,74 €
11	101.234,99 €	-17.618,33 €	-6.740,41 €	-4.875,98 €	72.000,28 €	54.874,64 €	-848.973,11 €
12	102.438,30 €	-15.601,60 €	-6.916,63 €	-4.973,50 €	74.946,57 €	55.726,96 €	-793.246,15 €
13	103.650,89 €	-13.534,46 €	-7.097,21 €	-5.072,97 €	77.946,25 €	56.543,80 €	-736.702,35 €
14	104.872,65 €	-11.415,64 €	-7.282,25 €	-5.174,43 €	81.000,33 €	57.326,14 €	-679.376,21 €
15	106.103,45 €	-9.243,85 €	-7.471,84 €	-5.277,92 €	84.109,84 €	58.074,95 €	-621.301,27 €
16	107.343,18 €	-7.017,77 €	-7.666,11 €	-5.383,47 €	87.275,83 €	58.791,18 €	-562.510,09 €
17	108.591,70 €	-4.736,03 €	-7.865,16 €	-5.491,14 €	90.499,37 €	59.475,74 €	-503.034,35 €
18	109.848,86 €	-2.397,25 €	-8.069,11 €	-5.600,97 €	93.781,54 €	60.129,53 €	-442.904,83 €
19	111.114,52 €		-8.278,06 €	-5.712,98 €	97.123,47 €	60.753,42 €	-382.151,41 €
20	112.388,50 €		-8.492,15 €	-5.827,24 €	98.069,10 €	59.848,72 €	-322.302,68 €
21	113.670,63 €		-8.711,49 €	-5.943,79 €	99.015,35 €	58.952,38 €	-263.350,31 €
22	114.960,73 €		-8.936,21 €	-6.062,67 €	99.961,85 €	58.064,31 €	-205.286,00 €
23	116.258,61 €		-9.166,43 €	-6.183,92 €	100.908,26 €	57.184,43 €	-148.101,57 €
24	117.564,06 €		-9.402,29 €	-6.307,60 €	101.854,17 €	56.312,66 €	-91.788,90 €
25	118.876,86 €		-9.643,91 €	-6.433,75 €	102.799,20 €	55.448,92 €	-36.339,98 €

Table 63. Results of income, expenses and evolution of annual updated accumulated cash flows (Case 1)

<u>Case 2 (Optimistic)</u>: Financing of ≈92% of the initial investment through a bank loan, with an annual interest of 2% and a repayment term of 8 years.

In this case, 115.000€ will be directly paid by the Sociedad de Riego as part of the initial investment of year 0.

Initial capital C (€)	1.295.752,56
Annual interest i (%)	2
Years of payment t (y)	8
Periods per year (-)	1
Number of payments (-)	8
Payment per period (€)	176.882,92
Annual payment (€)	176.882,92
Payment of interests (€)	119.310,81
Total payment (€)	1.415.063,37

Table 64. Financial parameters considered (Case 2)

Period	Inicial balance	Share	Interests	Amortization	Final balance
1	1.295.752,56 €	176.882,92 €	25.915,05 €	150.967,87 €	1.144.784,69 €
2	1.144.784,69 €	176.882,92 €	22.895,69 €	153.987,23 €	990.797,46 €
3	990.797,46 €	176.882,92 €	19.815,95 €	157.066,97 €	833.730,49 €
4	833.730,49 €	176.882,92 €	16.674,61 €	160.208,31 €	673.522,17 €
5	673.522,17 €	176.882,92 €	13.470,44 €	163.412,48 €	510.109,70 €
6	510.109,70 €	176.882,92 €	10.202,19 €	166.680,73 €	343.428,97 €
7	343.428,97 €	176.882,92 €	6.868,58 €	170.014,34 €	173.414,63 €
8	173.414,63 €	176.882,92 €	3.468,29 €	173.414,63 €	0,00 €

Table 65. Annual payment of the loan amortization and the interest generated (Case 2)

NPV (€)	**272.836,46 €**
IRR (%)	**4,0885%**
PP	**20,223**

Table 66. Results of the financial indicators of the economic analysis (Case 2)

Since there are now more favourable conditions, with a smaller bank interest and a shorter loan repayment period, as well as a smaller loan considering that a small part of the initial investment can be made with own funds, all indicators are favourable for the execution of the project, being even slightly better than those obtained initially, when the annual expenses derived from the repayment of the loan were not considered.

Year (y)	Incomes from the sale of surpluses and the save of cons. from grid (€)	Exenses due to the payment of the interests(€)	Expenses per purchase of energy (€)	Expenses per maintenance (€)	Cash flow F (€)	Updated F (€)	Updated accumulated F (€)
0					-1.295.752,56 €		-1.295.752,56 €
1	92.407,13 €	-25.915,05 €	-5.046,49 €	-4.000,00 €	57.445,59 €	56.044,48 €	-1.239.708,08 €
2	93.263,44 €	-22.895,69 €	-5.198,38 €	-4.080,00 €	61.089,36 €	58.145,74 €	-1.181.562,34 €
3	94.118,68 €	-19.815,95 €	-5.354,33 €	-4.161,60 €	64.786,80 €	60.160,98 €	-1.121.401,36 €
4	94.972,46 €	-16.674,61 €	-5.514,44 €	-4.244,83 €	68.538,58 €	62.092,57 €	-1.059.308,79 €
5	95.824,39 €	-13.470,44 €	-5.678,82 €	-4.329,73 €	72.345,40 €	63.942,79 €	-995.366,00 €
6	96.674,04 €	-10.202,19 €	-5.847,56 €	-4.416,32 €	76.207,97 €	65.713,89 €	-929.652,11 €
7	97.520,99 €	-6.868,58 €	-6.020,78 €	-4.504,65 €	80.126,99 €	67.408,05 €	-862.244,06 €
8	98.364,79 €	-3.468,29 €	-6.198,59 €	-4.594,74 €	84.103,17 €	69.027,39 €	-793.216,68 €
9	99.204,97 €		-6.381,10 €	-4.686,64 €	88.137,24 €	70.573,98 €	-722.642,69 €
10	100.041,06 €		-6.568,44 €	-4.780,37 €	88.692,25 €	69.286,25 €	-653.356,45 €
11	101.234,99 €		-6.740,41 €	-4.875,98 €	89.618,60 €	68.302,35 €	-585.054,10 €
12	102.438,30 €		-6.916,63 €	-4.973,50 €	90.548,17 €	67.327,62 €	-517.726,47 €
13	103.650,89 €		-7.097,21 €	-5.072,97 €	91.480,71 €	66.361,97 €	-451.364,50 €
14	104.872,65 €		-7.282,25 €	-5.174,43 €	92.415,97 €	65.405,30 €	-385.959,21 €
15	106.103,45 €		-7.471,84 €	-5.277,92 €	93.353,69 €	64.457,51 €	-321.501,70 €
16	107.343,18 €		-7.666,11 €	-5.383,47 €	94.293,60 €	63.518,52 €	-257.983,18 €
17	108.591,70 €		-7.865,16 €	-5.491,14 €	95.235,40 €	62.588,23 €	-195.394,94 €
18	109.848,86 €		-8.069,11 €	-5.600,97 €	96.178,79 €	61.666,56 €	-133.728,38 €
19	111.114,52 €		-8.278,06 €	-5.712,98 €	97.123,47 €	60.753,42 €	-72.974,96 €
20	112.388,50 €		-8.492,15 €	-5.827,24 €	98.069,10 €	59.848,72 €	-13.126,24 €
21	113.670,63 €		-8.711,49 €	-5.943,79 €	99.015,35 €	58.952,38 €	45.826,14 €
22	114.960,73 €		-8.936,21 €	-6.062,67 €	99.961,85 €	58.064,31 €	103.890,45 €
23	116.258,61 €		-9.166,43 €	-6.183,92 €	100.908,26 €	57.184,43 €	161.074,88 €
24	117.564,06 €		-9.402,29 €	-6.307,60 €	101.854,17 €	56.312,66 €	217.387,54 €
25	118.876,86 €		-9.643,91 €	-6.433,75 €	102.799,20 €	55.448,92 €	272.836,46 €

Table 67. Results of income, expenses and evolution of annual updated accumulated cash flows (Case 2)

Document 5.

Plans

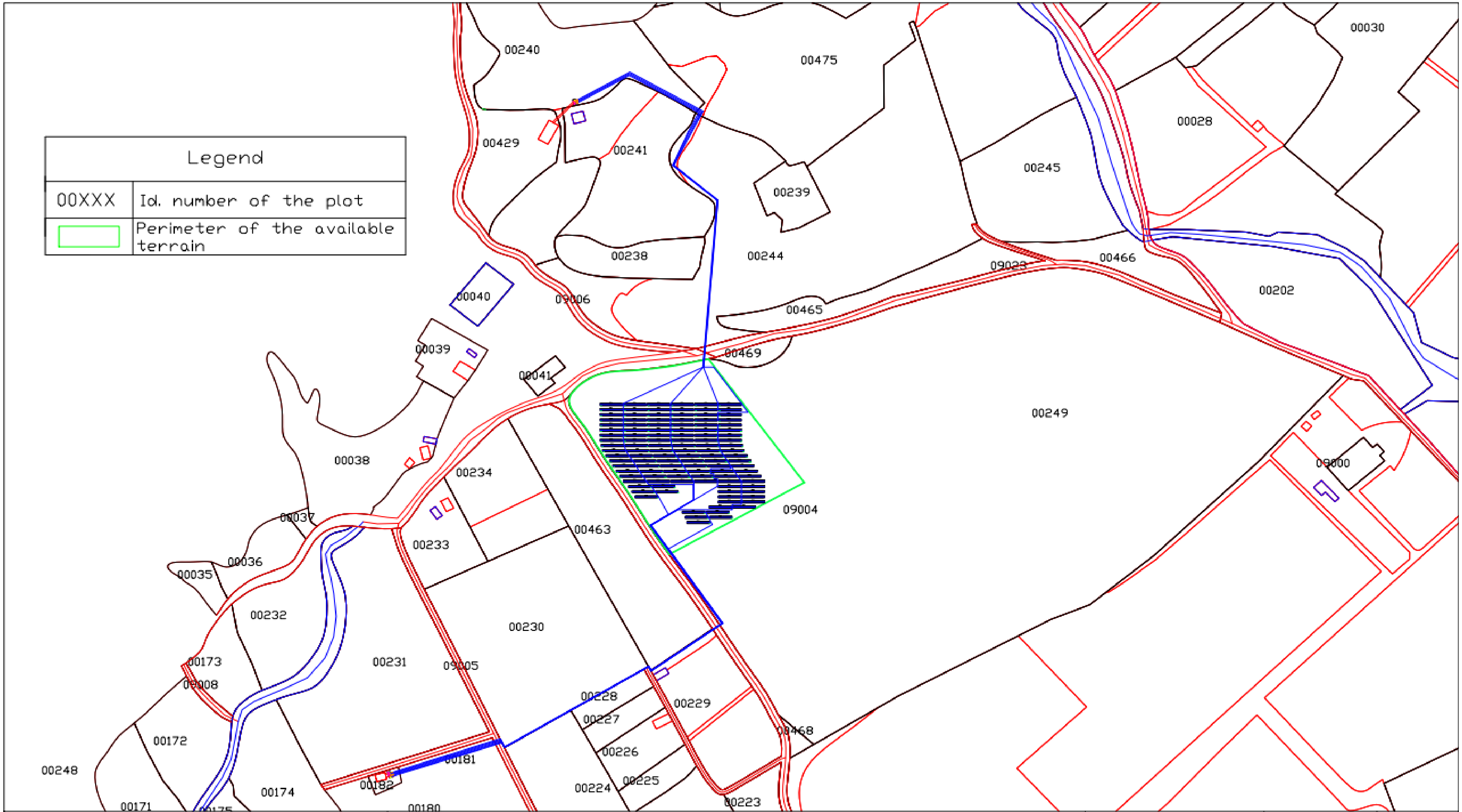
Scale 1:2.500.000

Scale 1:36.000

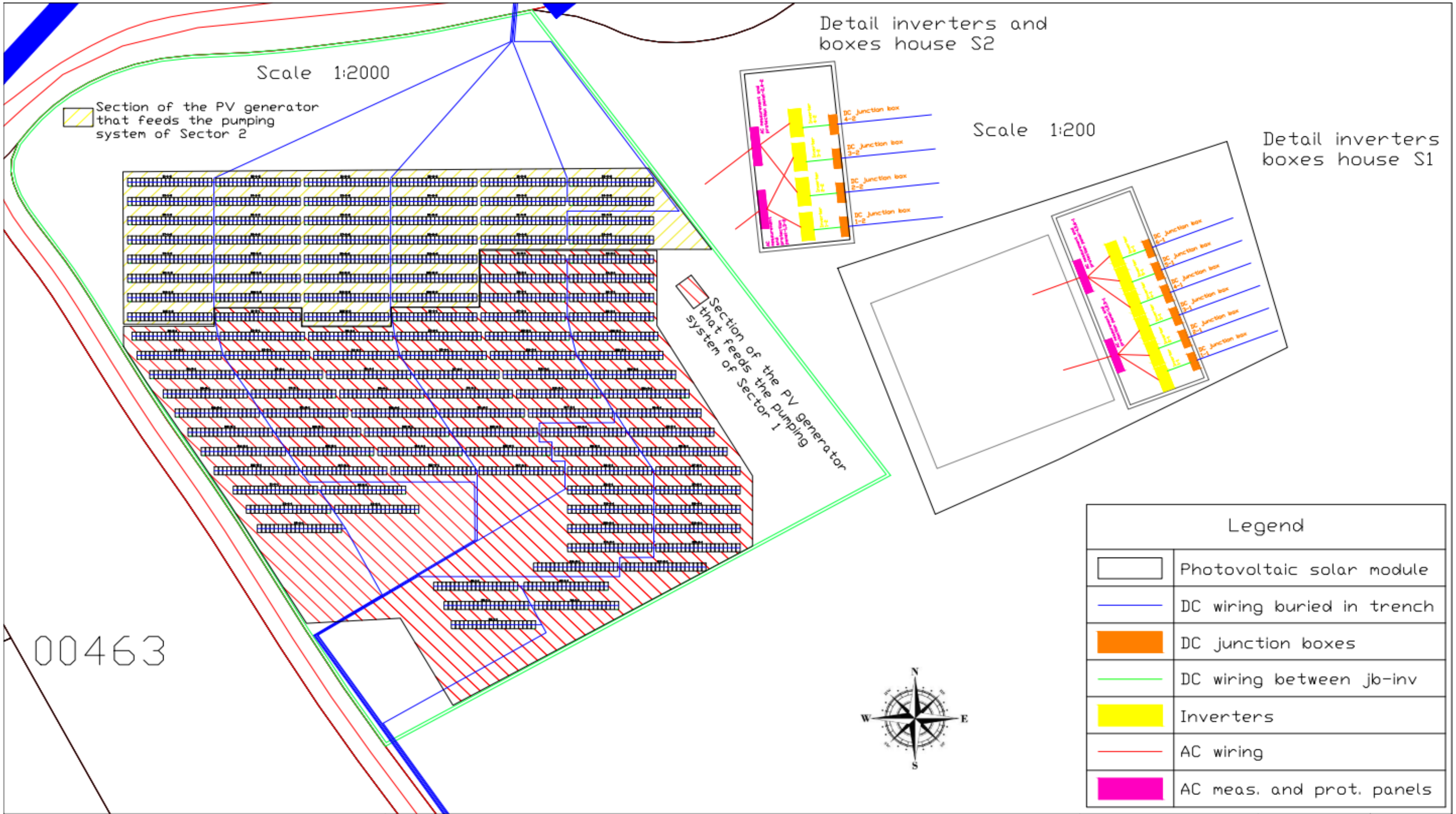
Scale 1:110.000

Legend	
	Railroad network
	Railroad network
	Dual carriageway A-35
	Autonomous road of Com. Val CV-649

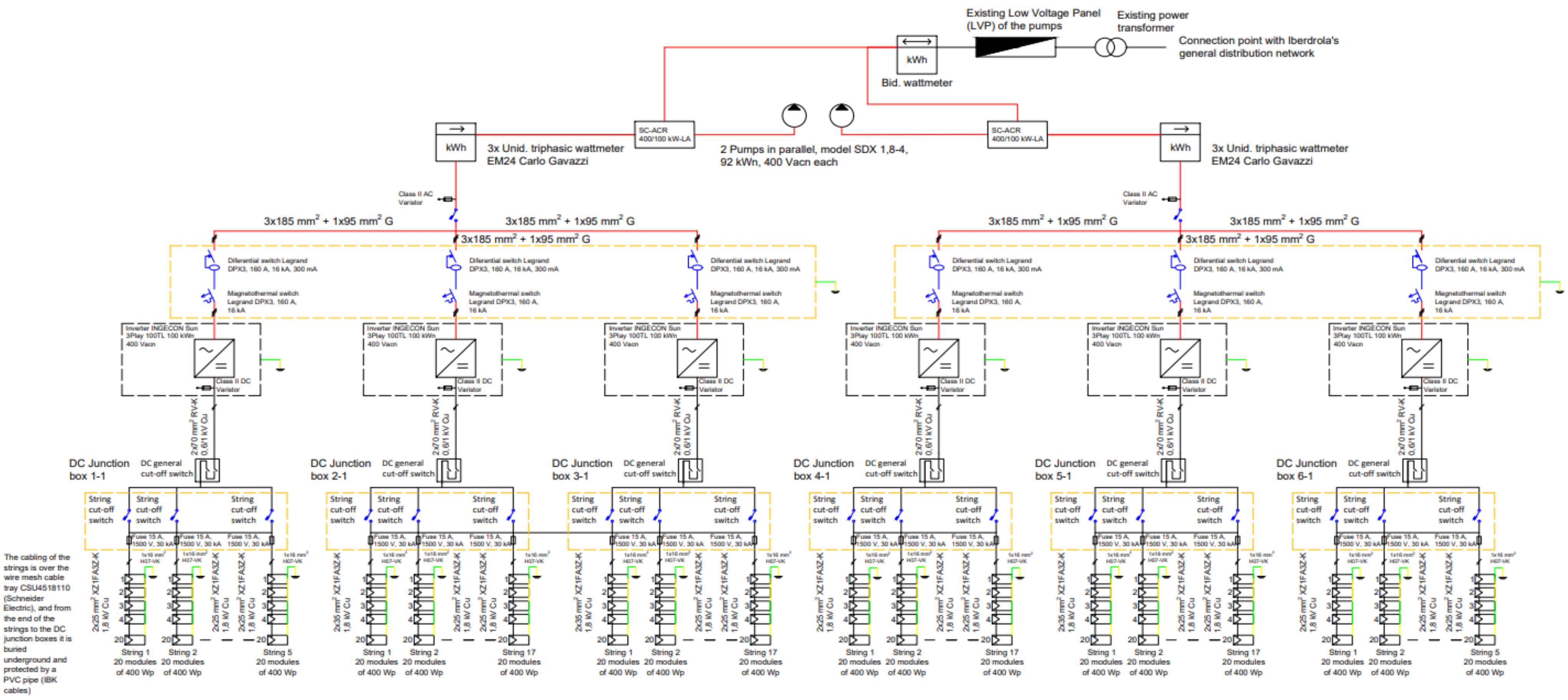
MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA) Plan: Situation and location	Author: Víctor Felip Plaza Signature:	Date: March 2021 Scale: Several	Plane nº: 1



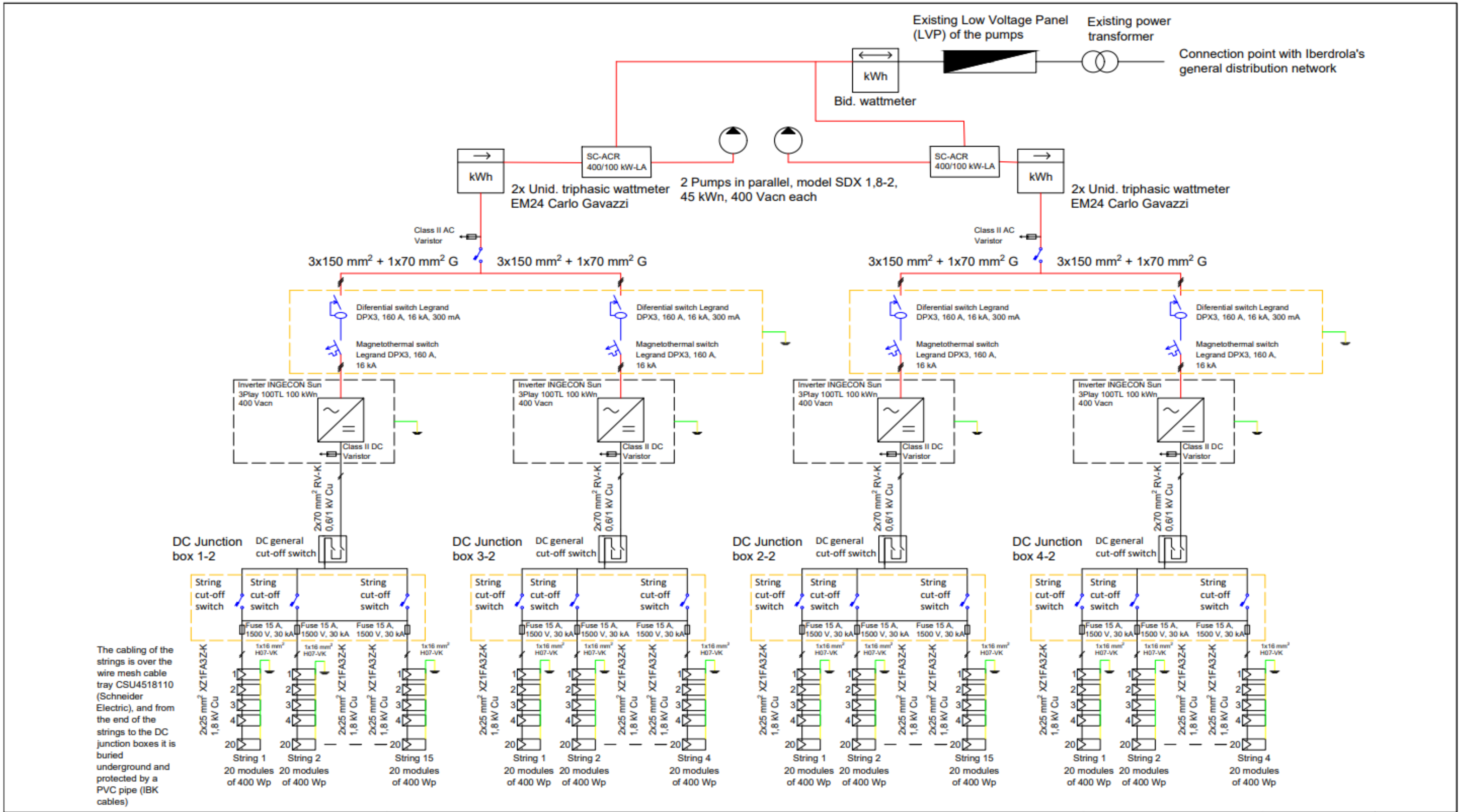
MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA) Plan: Site plan of the photovoltaic generator	Author: Víctor Felip Plaza Signature:	Date: March 2021 Scale: 1:10000	Plane nº: 2



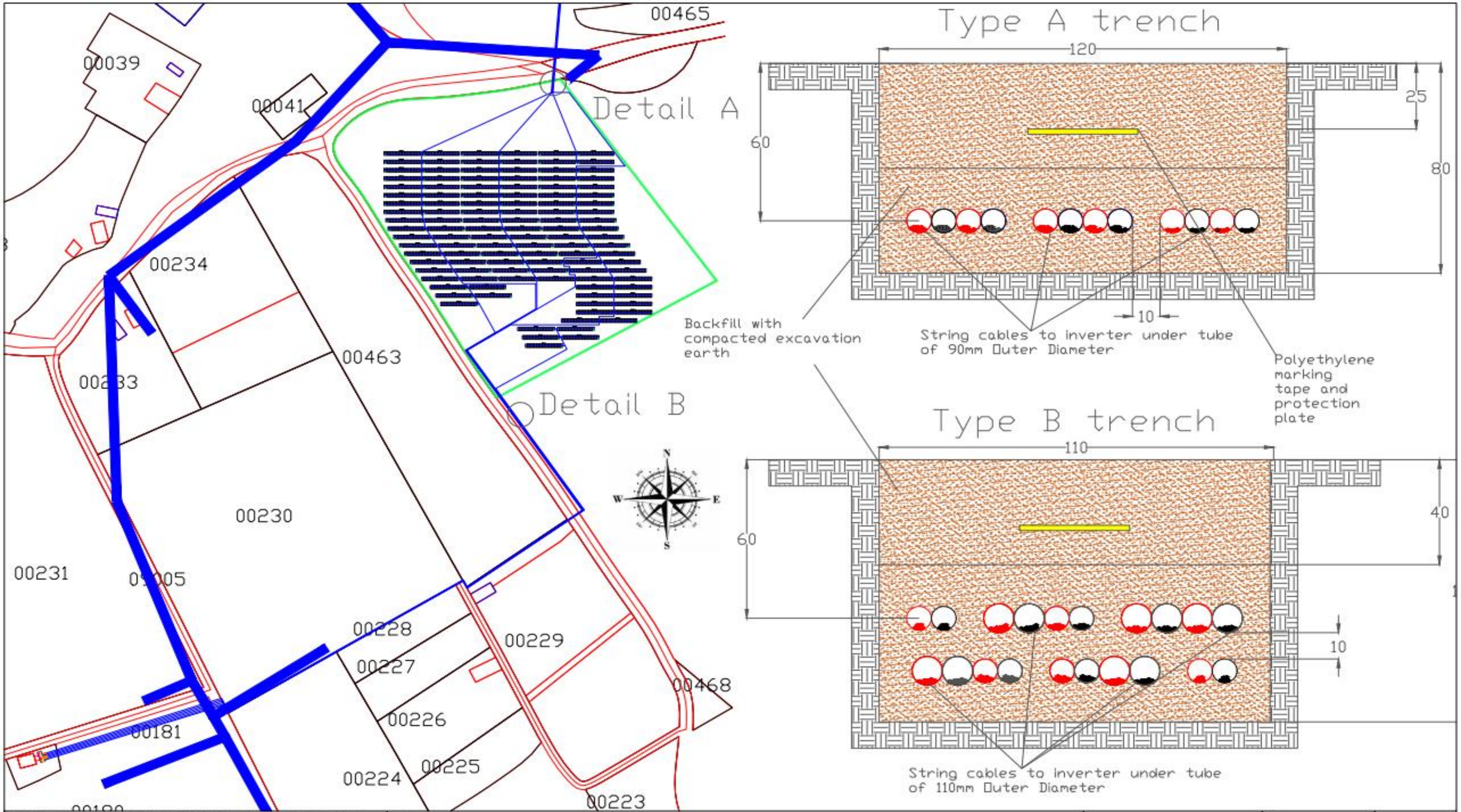
MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA) Plan: Site plan of the pv generator, detail of inverter housing and connection panels	Author: Víctor Felip Plaza Signature:	Date: March 2021 Scale: Several Plane nº: 3



MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA) Plan: Single-line diagram of the installation of Sector 2	Author: Víctor Felip Plaza Signature:	Date: March 2021 Scale: N/S	Plane nº: 4



MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA) Plan: Single-line diagram of the installation of Sector 2	Author: Víctor Felip Plaza Signature:	Date: March 2021 Scale: N/S	Plane nº: 5



MASTER'S FINAL PROJECT IN INDUSTRIAL ENGINEERING. SPECIALIZATION IN ENERGY GENERATION UNIVERSITAT POLITÈCNICA DE VALÈNCIA · ESCUELA TÉCNICA SUPERIOR INGENIEROS INDUSTRIALES VALENCIA · TÉCNICO LISBOA	Project: DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADACULTIVATION AREA (VALENCIA)	Author: Víctor Felip Plaza	Date: March 2021	Plane nº: 6
	Plan: Detail plan of the trenches	Signature:	Scale: N/S	

Document 6.

Environmental analysis of the project

6.1 Introduction

This chapter aims to collect the impacts, both positive and negative, that the execution of the installation projected in this document could have on the natural environment in which it is developed, as well as the possible measures to be adopted to mitigate, at least partially, the consequences of said effects if they were harmful.

In this way it is intended, on the other hand, to show the compliance of this project with Law 21/2013, dated on December 9th, of Environmental Assessment, which "establishes the bases that must govern the Environmental Assessment of plans, programs and projects that may have significant effects on the environment, guaranteeing a high level of environmental protection throughout the State territory, in order to promote sustainable development ".

6.2 Project peculiarities

In accordance with the provisions of Article 5 of Title I, the Environmental Assessment, in the case of a project, is understood as an Environmental Impact Assessment. In turn, it concludes:

- Through the "Environmental Impact Statement", with respect to those submitted to the Ordinary Environmental Impact Assessment procedure, in accordance with the provisions of Section 1 of Chapter II of Title II.
- Through the "Environmental Impact Report", with respect to those submitted to the Simplified Environmental Impact Assessment procedure, in accordance with the provisions of Section 2 of Chapter II of Title II.

At the same time, it is convenient to indicate that those projects that are in Annex I of this Law are adapted to the provisions of Section 1, while those numbered in the Annex II do so to the provisions of Section 2.

This project is not included in the group of projects included in Annex I (see Group 3. Energy industry, and Group 9. Other projects), nor in that of Annex II (see Group 4. Energy industry and Group 9 . Other projects). For this reason, it should not be submitted to either the Ordinary or the Simplified Environmental Impact Assessment, respectively.

The reason for this is that, in this case, a modification of a pre-existing project takes place. If carried out from 0, this project would be included in "Group 8. Hydraulic engineering and water management projects", specifically section a) **Extraction of groundwater** or recharge of aquifers (not included in Annex I) when the **annual volume of water extracted** or supplied is **greater than 1 cubic hectometre and less than 10 cubic hectometres per year** "of Annex II, so a Simplified Environmental Impact Assessment would be necessary. This is because the extraction of the 1.57 hectometres cubic meters (1,570,661.28 m^3) would be projected from 0, and not only, as is done in this thesis, the photovoltaic part that must, at least to a large extent, supply the energy needs for said extraction.

6.3 Actions carried out in the natural environment

The most relevant actions carried out in the natural environment as a result of the development of the works to build the designed project are those mentioned below:

- Emission of polluting gases due to the circulation of the vehicles in charge of transporting the materials and removing the waste.
- Alteration of the terrain due to land movement and excavation of trenches.
- Removal of a certain cultivation area, as well as other plants that may exist in the area finally destined for the installation of the components of the photovoltaic installation.

- Laying of cabling in the subsoil.
- Noise generation.
- Residues generation.

6.4 Impacts on the environment

The aforementioned actions can produce a series of potential impacts in the area where they take place. Some of the most notable are the following:

- **Impacts on fauna**: In the project development zone there is no evidence of the existence of nests of protected bird species, since it is land destined to the cultivation of fruits and vegetables. On the other hand, there is no evidence of the existence of burrows of moles or rabbits in the vicinity. These works could only affect insects and minor animals, such as ants or worms.
- **Impacts on the flora**: There are also no species of protected trees affected, since the land destined for the photovoltaic installation corresponds to a plot previously destined for cultivation, and the occupied area is of a few thousand m^2.
- **Impacts on the ground**: The earthworks carried out for the excavation of trenches and the installation of the photovoltaic panels is of little relevance, since they are not large earthworks nor at great depth. The erosivity of the land could increase a little but it would not be relevant because it would not be used again for the cultivation or growth of any plant species. Nor would there be contamination of the water, since these works, in addition to being small, are located far from the extraction point of the same in the two existing wells.
- **Impacts on people or populations**: There is no negative impact on people or nearby populations.
- **Impacts on existing infrastructures**: There is no infrastructure that could be negatively affected in the vicinity of the land on which the executed project would be located, be it industrial, road, energy generation or historical heritage.

6.5 Environmental benefits

Therefore, the execution of this project would not only entail a reduced environmental impact, but also the environmental benefits that this would entail due to the reduction of polluting emissions associated with the generation of part of the electrical energy supplied by the network, and that of another form would be the only source of energy supply of the pumping groups, would be appreciable throughout the useful life of the project.

However, for its optimization, it is necessary to try to generate the least amount of waste possible, both in the construction stage and throughout the useful life of the project, carrying out a correct maintenance of the components to avoid their unnecessary substitution and a later end of life suitable for them, since solar panels have components that are harmful to the environment.

In this sense, it is possible to carry out an estimation of the amount of annual and total emissions and waste in the useful life of the project, which has been set at 25 years (hence the feasibility analyses have been carried out with this time horizon), that can be avoided by installing the photovoltaic plant designed in this document. For this, the following table, extracted from the latest report developed by the "*Observatorio de la Electricidad*", published in 2016, and which relates the electricity consumption of the network with the corresponding generation of different pollutants, is used.

On the other hand, it is relevant to indicate that the value of each of the indices that relate the electricity consumption from the network with the emission of a specific pollutant has been reduced by 1% from the second year to the last. This has been done because, in anticipation that renewable energies continue to gain weight in the generation and injection of current in the network and that traditional energies will be able to slightly reduce the emissions associated with their electricity production, the energy consumption from the network will be associated with decreasing levels of polluting emissions.

At the same time, a relevant assumption has been taken into account: the water needs are assumed to be constant, that is, the variation in the environmental impact of electricity consumption is not being analysed if it varies for any reason, such as higher irrigation needs either by increasing the cultivated area or by substituting part of the area devoted to rainfed crops by crops that require greater water needs.

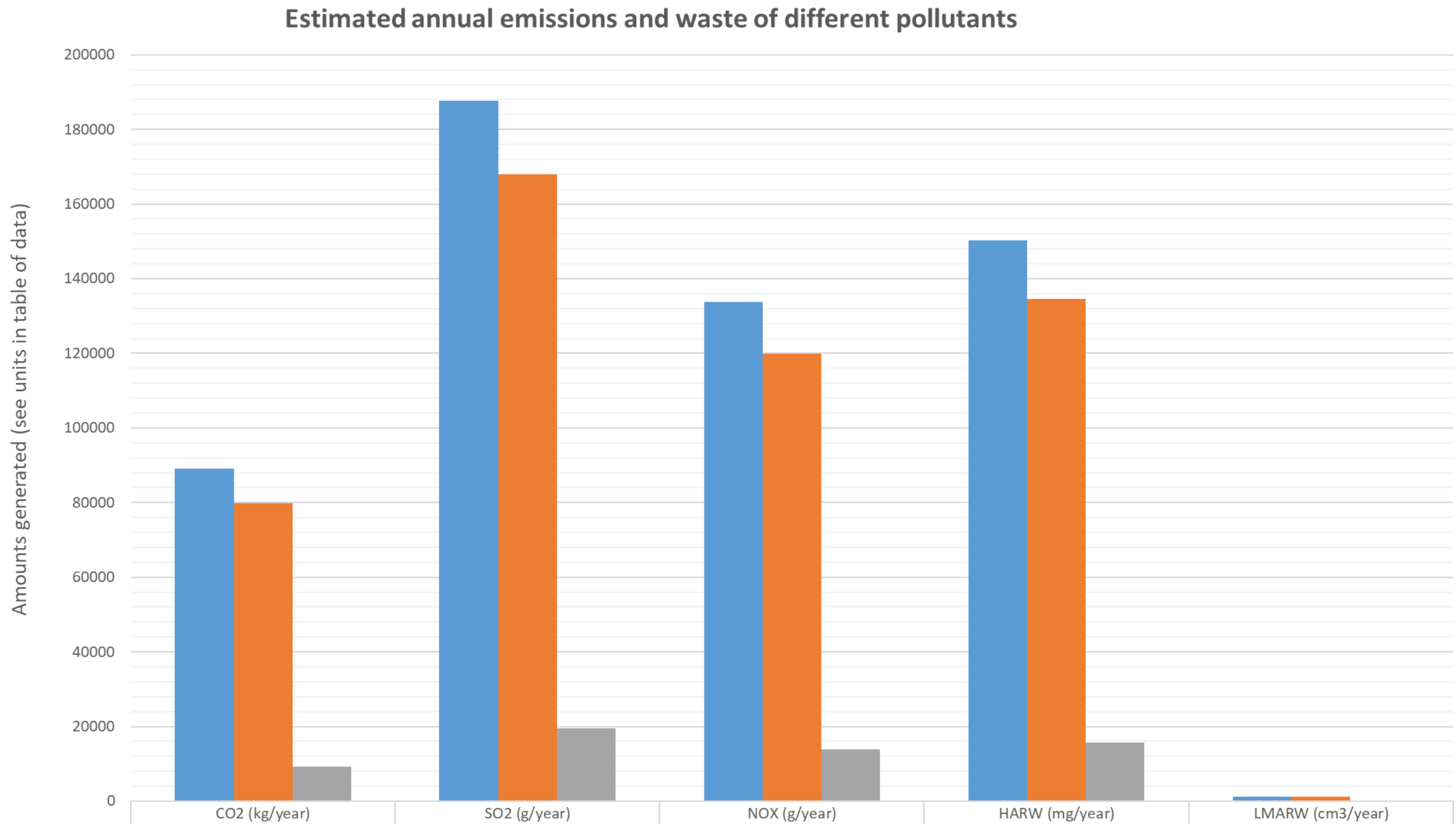
__ kWh	x 0,174=	________	kg CO2
__ kWh	x 0,366 =	________	gramos SO2
__ kWh	x 0,261 =	________	gramos NOx
__ kWh	x 0,293 =	________	mg RAA
__ kWh	x 0,00240 =	________	cm3 RBMA

Table 68. Environmental impact of the electricity consumption. Source: Observatorio de la Electricidad

Where:

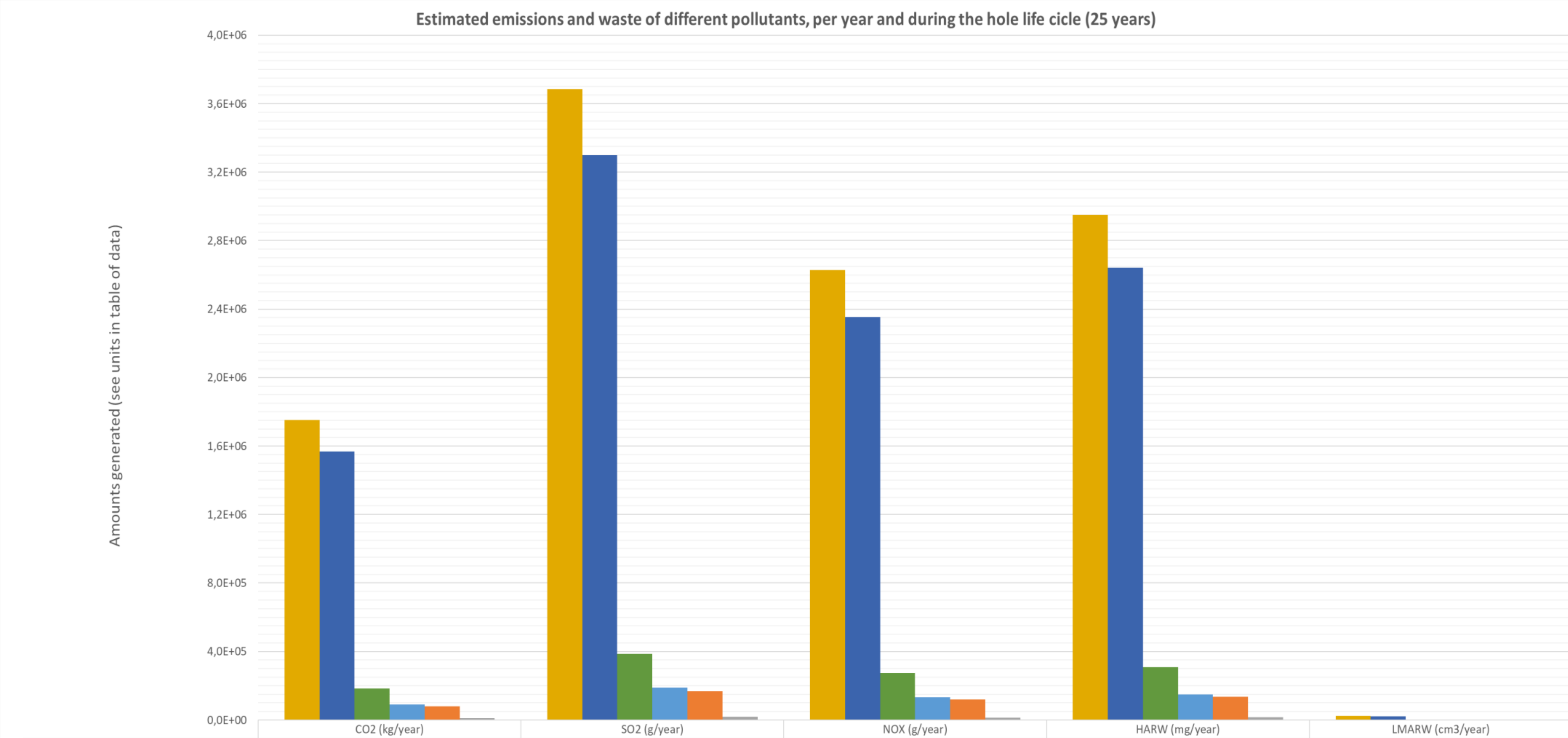
- CO_2: Carbon dioxide.
- SO_2: Sulphur dioxide.
- NO_x: Nitrogen oxides.
- HARW: High Activity Radioactive Waste.
- LMARW: Low and Medium Activity Radioactive Waste.

Therefore, knowing the electricity consumption that theoretically it is possible to save annually through electricity generation through the photovoltaic installation and with the above factors, the following results are obtained:



	CO2 (kg/year)	SO2 (g/year)	NOX (g/year)	HARW (mg/year)	LMARW (cm3/year)
Annual generation (net only)	89185,240	187596,540	133777,861	150179,744	1230,141
Annual savings (from pv production)	79876,946	168017,024	119815,419	134505,432	1101,751
Annual generation (to fill demand)	9308,295	19579,516	13962,442	15674,312	128,390

Figure 77. Estimated annual emissions of different pollutants, without and with the pv installation



	CO2 (kg/year)	SO2 (g/year)	NOX (g/year)	HARW (mg/year)	LMARW (cm3/year)
Generation n 25 years (net only)	1,752E+06	3,685E+06	2,628E+06	2,950E+06	2,416E+04
Generation in 25 years (from pv production)	1,569E+06	3,300E+06	2,353E+06	2,642E+06	2,164E+04
Generation in 25 years (to fill demand)	1,828E+05	3,846E+05	2,742E+05	3,079E+05	2,522E+03
Annual generation (net only)	89185,240	187596,540	133777,861	150179,744	1230,141
Annual savings (from pv production)	79876,946	168017,024	119815,419	134505,432	1101,751
Annual generation (to fill demand)	9308,295	19579,516	13962,442	15674,312	128,390

Figure 78. Estimated emissions of different pollutants during the next 25 years, without and with the pv installation

Document 7.

Study of the health and safety conditions

7.1 Introduction

This chapter establishes the causes and factors for which the Health and Safety Study is developed. Said document establishes a set of premises that allow guaranteeing optimal working conditions for workers with its application, reducing the dangers that may compromise their health and physical integrity. The parties participating in the preparation and / or execution of the project may use this study as a basis for preparing their own Health and Safety Plan before the start of the works.

7.2 Motivation and justification of the Study

In "*Artículo 4: Obligatoriedad del estudio de seguridad y salud o del estudio básico de seguridad y salud en las obras*" of "*Real Decreto 1627/1997"*, dated October 24 and which subsequent modifications have been included in "*Real Decreto 604/2006"* , on May 19 in the first place and "*Real Decreto 337/2010"*, on March 19 in second place, it is established that:

- The promoter shall be obliged to prepare a health and safety study in the project drafting phase for works projects in which any of the following cases occur:
    - That the Execution Budget by Contract included in the project is equal to or greater than 75 million pesetas (450.759,08 €). In this case, this budget amounts to 1.165.911,20 € (I.V.A. not included).
    - That the estimated duration is greater than 30 working days, employing at some point more than 20 workers simultaneously. In this project, the estimated duration of the works is of 45 working days.
    - That the volume of labour estimated, understanding by such the sum of the working days of the total of workers on the construction site, exceeds 500.
    - The works of tunnels, galleries, underground pipes and dams.
- In works projects not included in any of the cases provided for in the previous section, the promoter will be obliged to prepare a basic health and safety study during the drafting phase of the project.

Therefore, as the works of this project comply with at least one of the previous points, it would be necessary to prepare a Health and Safety Study instead of being limited to a Basic Health and Safety Study. However, due to the scope of the present work, this Study is not developed in its fullness, but rather the most relevant points have been written trying not to incur excessive and too detailed writing.

7.3 General characteristics of the work

7.3.1 General data

7.3.1.1 Title of the project

DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION FOR THE IRRIGATION OF THE VALLADA CULTIVATION AREA (VALENCIA).

7.3.1.2 Author of the Project and the Health and Safety Study.

Mr. VÍCTOR FELIP PLAZA.

7.3.1.3 Project Director

Mr. VÍCTOR FELIP PLAZA.

7.3.1.4 Promoter

COMUNIDAD DE REGANTES DE CAÑOLES 1, in VALLADA (VALENCIA).

7.3.1.5 Place and date of writing of the Study

LISBON (PORTUGAL), MARCH 2021.

7.3.2 Location and conditions of the zone

The works referred to in this Health and Safety Study are located in the parcel 09004 owned by the *Comunidad de Regantes de Cañoles I,* in the vicinity of Vallada. This parcel can be accessed by means of existing dirt roads, both by vehicle (not large) and on foot.

It is a terrain that, although it is not very rugged because it is terrain that has been modified for cultivation, it has a certain slope, since it is located near the side of a mountain. It should be ensured that the slope does not exceed 15% in the case of making an access ramp to the land and 5% for joining the roads.

It is a mainly agricultural environment, with some small construction (stall) to store the farmers' tools but that in no case would be affected.

7.3.3 Current situation and general description of the work

7.3.3.1 Current situation

As described in chapter 2, up to now the cultivation plots owned by the *Comunidad de Regantes de Cañoles I* are supplied by means of the water stored in two water tanks, which in turn are filled by means of their respective pumping groups. These groups are fed through the AC of the electrical network.

7.3.3.2 Object and description of the Project

The present project aims to take advantage of the solar energy available in the area throughout the year to, through the projected photovoltaic installation, achieve a renewable energy generation system that satisfies the highest possible percentage of the energy needs of the pumping groups, being necessary on the other hand in those moments in which solar energy is not available or it is insufficient to use the energy of the network. In this way, despite requiring a strong initial investment, in successive years not only an appreciable saving in electricity bills is achieved, but also the emission of large amounts of greenhouse gases is avoided.

7.3.4 Estimated execution time

The estimated duration of the works is of 45 working days, from Monday 4th October 2020 to Thursday 9th December 2020.

7.3.5 Number of workers

The number of workers working simultaneously could vary from around 8 and 20.

7.3.6 Budget

The Material Execution Budget of the work amounts to 979.757,31 €

The budget for the material execution of the work for the Health and Safety Study amounts to 1000 €.

7.4 Legislation in force applicable to the work

The execution of the work that is the object of this Health and Safety Study will be regulated by the Mandatory Regulations that are cited below, being mandatory for the parties involved:

- RD 327/2009, of March 13, which modifies R.D. 1109/2007, of August 24, which develops Ley 32/2006, of October 18, which regulates subcontracting in the construction sector.

- R.D 171/2004, of January 30, which develops article 24 of Ley 31/1995, on the "*Prevención de Riesgos Laborales*" in matters of coordination of business activities.

- R.D 2177/2004, of November 12, which modifies R.D 1215/1997, which establishes minimum health and safety conditions for the use by workers of work equipment, in terms of temporary work at height.

- Ley 54/2003, on the reform of the regulatory framework for the prevention of occupational risks.

- R.D. 842/2002, of August 2, which approves the "*Reglamento Electrotécnico de Baja Tensión e ITCs*: ITC BT 01 a 51".

- R.D. 614/2001, of June 8, on minimum provisions for the protection of the health and safety of workers against electrical risks (BOE 21-06-01)

- R.D. 374/2001, of April 6, on the protection of the health and safety of workers against the risks related to chemical agents during work.

- "*Guía Técnica para la evaluación y prevención de los riesgos relativos a la Manipulación manual de cargas*".

- "*Guía Técnica para la evaluación y prevención de los riesgos relativos a la Utilización de los Equipos de trabajo*".

- "*Guía Técnica para la evaluación y prevención de los riesgos relativos a las obras de construcción*".

- R.D. 1627/1997, of October 24, which establishes minimum health and safety provisions in construction sites.

- R.D. 1215/1997, of July 18, which establishes the minimum health and safety provisions for the use of work equipment by workers.

- R.D. 773/1997, of 30 May, on the minimum health and safety provisions relating to the use by workers of personal protective equipment.

- R.D. 665/1997, on the protection of workers against the risks related to exposure to carcinogens at work.

- R.D. 485/1997, of April 14, on minimum provisions on health and safety signs at work.

- R.D. 486/1997, of April 14, which establishes the minimum health and safety provisions in the workplace.

- R.D. 487/1997, of April 14, on minimum health and safety provisions related to the handling of loads that involve risks, in particular back-lumbar, for workers.

- R.D. 314/2006, of March 17, which approves the "*Código Técnico de la Edificación*" and its "*Instrucciones Técnicas Complementarias* (ITCs)".

- R.D. 604/2006, of May 19, which modifies the R.D 39/1997, of January 17, which aproves the "*Reglamento de los Servicios de Prevención*", and the R.D 1627/1997, of October 24, which stablishes the minimum health and safety provisions in construction sites.

- R.D. 105/2008, of February 1, which regulates the production and management of construction and demolition waste.

- R.D. 223/2008, of February 15, which approves the "*Reglamento de Líneas eléctricas de Alta tensión y sus ITCs*".

- R.D 337/2014, of May 9, which approves the "*Reglamento sobre condiciones técnicas y garantías de seguridad en instalaciones eléctricas de Alta Tensión y sus Instrucciones Técnicas Complementarias ITC-RAT 01 a 23*".

7.5 List of planned activities

- Previous work
    - Delimitation and marking of the work area
    - Study of the terrain
- Earthworks
    - Clearing and clearing
    - Open pit excavations
    - Land or rock fillings
- Installation and connection of elements
    - Panels
    - Investors
    - Connection of protection and measurement and protection boxes
    - Protections
- Removal of waste and debris

7.6 Work equipment, machinery, tools and auxiliary means

- Machines
    - Backhoe
    - Compact
    - Trucks for the transport of components
    - Pneumatic perforator
    - Forklifts in case the trucks do not have a lifting platform
- Manual machinery
    - Radial
    - Drill
    - Pneumatic hammer
    - Compressor
    - Electric and oxyfuel welding equipment
- Hand tools
    - Hammers
    - Screwdrivers
    - Tongs

- Pliers
- Limes

7.7 General risks

- Accidents by vehicles (run over)
- Collisions and rollovers of vehicles
- Visual and/or respiratory damage due to the presence of dust.
- Overexertion of the workers
- Excessive noises
- Bruises
- Falling objects
- Projection of particles
- Damage to the eyes, by welding or glare
- Burns
- Falls at level and at different levels (into the ditches)
- Puncture wounds
- Detachments
- Fires
- Risks produced by atmospheric agents (strong winds, lightnings, etc.)
- Thermal contacts
- Chemical contacts
- Electrical contacts
- Traffic (off-site)
- Explosions
- Aggressions of animals
- Overexertions

The probability and the consequences of the previous risks are shown in the following table:

Risk	Probability			Consequences			Risk magnitude
	High	Medium	Low	Serious	Moderate	Mild	
Accidents by vehicles			x		x		Tolerable
Collisions and rollovers of vehicles		x			x		Tolerable
Visual and/or respiratory damage due to the presence of dust			x		x		Tolerable
Overexertion of the workers			x		x		Tolerable
Excessive noises			x		x		Tolerable
Bruises			x			x	Low
Falling objects			x			x	Low
Projection of particles		x				x	Tolerable
Damage to the eyes, by welding or glare			x	x			Important
Burns			x		x		Tolerable
Falls at level and at different levels (into the ditches)		x			x		Tolerable
Puncture wounds		x				x	Tolerable
Detachments		x			x		Tolerable
Fires			x		x		Tolerable

Risks produced by atmospheric agents (strong winds, lightnings, etc.)		x			x		Tolerable
Thermal contacts			x		x		Tolerable
Chemical contacts			x			x	Low
Electrical contacts		x		x			Important
Traffic (off-site)			x		x		Tolerable
Explosions			x		x		Tolerable
Aggressions of animals			x			x	Low
Overexertions		x			x		Tolerable

Table 69 Probability and consequences of the detected risks

7.8 Individual protections and tools

- Safety helmet against shocks and impacts
- Protective glasses against projection of particles
- Protective masks for dusty environments
- Work gloves
- Tool bag
- Dust masks
- Filters for masks
- Footwear with protection against electric shock
- Rubber gloves for working with concrete
- Dielectric gloves
- Reflective vest for signalmen and strobers
- Safety boots with toe cap and reinforced steel insole
- Hearing protections for personnel whose exposure to noise exceeds the levels allowed
- Lumbar protection belt
- Protective clothing for bad weather

7.9 Security considerations and measures

It must be met:

- Comfortable and safe accesses will be established, both for people and for vehicles and machinery.
- Passage areas must be permanently free of stockpiles and obstacles.
- All personnel passage areas will have sufficient lighting.
- The electrical cables and hoses must not be affected by the passage of vehicles, if necessary going to the buried canalization or by means of a protection of planks at the same level.
- In the work, the maximum speed allowed will be limited to 30 km/h, and must be reduced whenever the visibility of the workers is disturbed.
- Workers who move on foot must always be protected by vests and other reflective elements.
- Proper preventive maintenance of installation components must be carried out.

On the other hand, in anticipation that the works may be visited by people related to the property, it is established that:

- No person who does not participate in the works should be allowed to go inside the work if they are not accompanied by the responsible personnel designated for this function.
- The use of PPEs is mandatory for everyone who visits the works.

- Once the working day is over, access to the interior of the works site must be prevented.

The marking of at least the following points must be placed in a visible place:

- Mandatory use of PPEs on the site of the work.
- Prohibition of entry to unauthorized persons and vehicles.
- Risk signalling plate.
- Work poster.
- It will be controlled that the stockpiles are always carried out inside the affected plots, avoiding the placement of materials, machinery and other elements in the vicinity of the work site.

7.10 Measures to preserve health

All workers must have basic first aid knowledge, and those who do not have it must be trained before working on the construction site.

On the other hand, a first aid kit with gauze, bandages, scissors, alcohol and antiseptics must always be available to treat relatively minor wounds and bruises.

If the first aid kit is not enough, an action protocol must be in place to transfer the affected person to a suitable hospital. For this, it is necessary to know the nearest centres and the services available, as well as have a vehicle in the work area that can be used in turn to transfer the affected person to said centre if necessary.

7.11 Some illustrative images of signalling elements and personal protective equipment

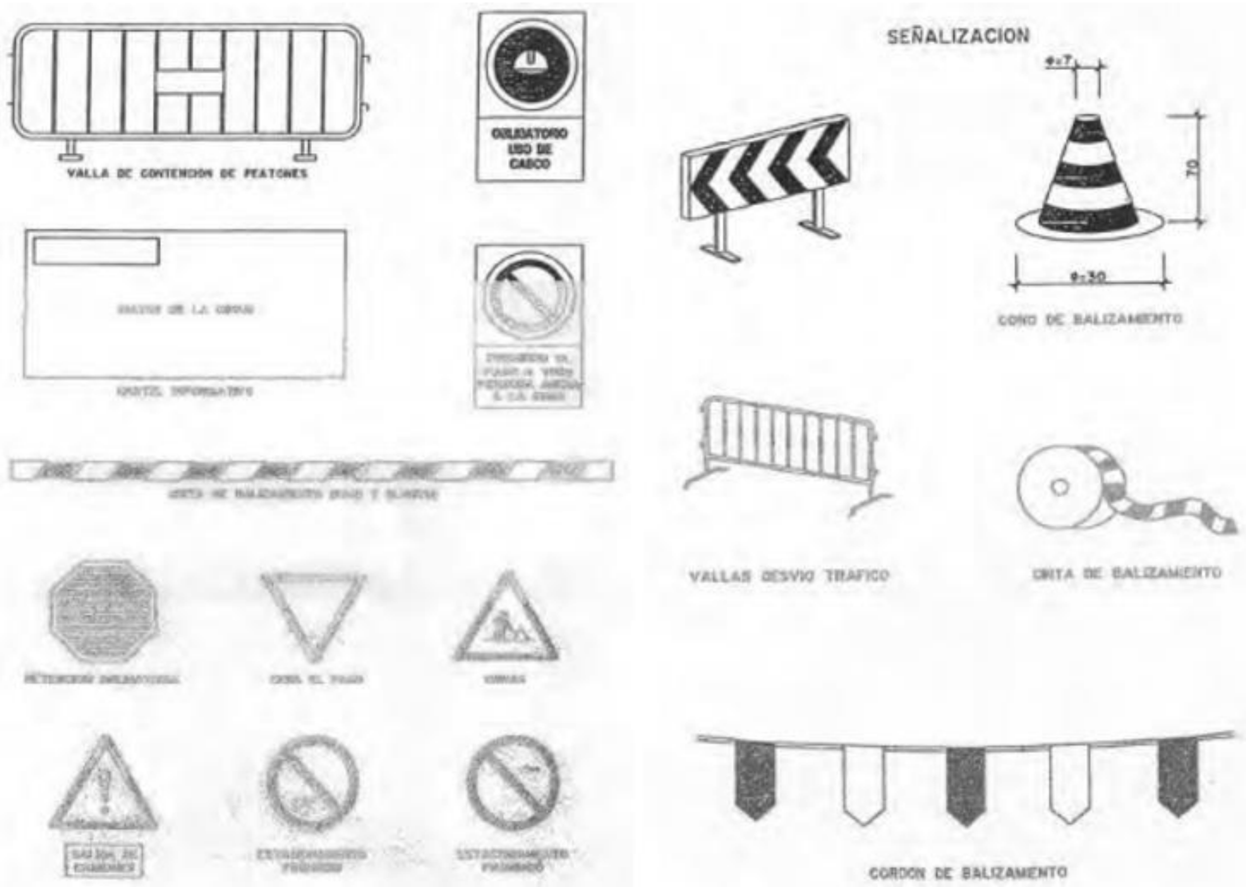


Figure 79. Illustrative images of signalling elements and p.p.e. (I)

Figure 80. Illustrative images of signalling elements and p.p.e. (II)

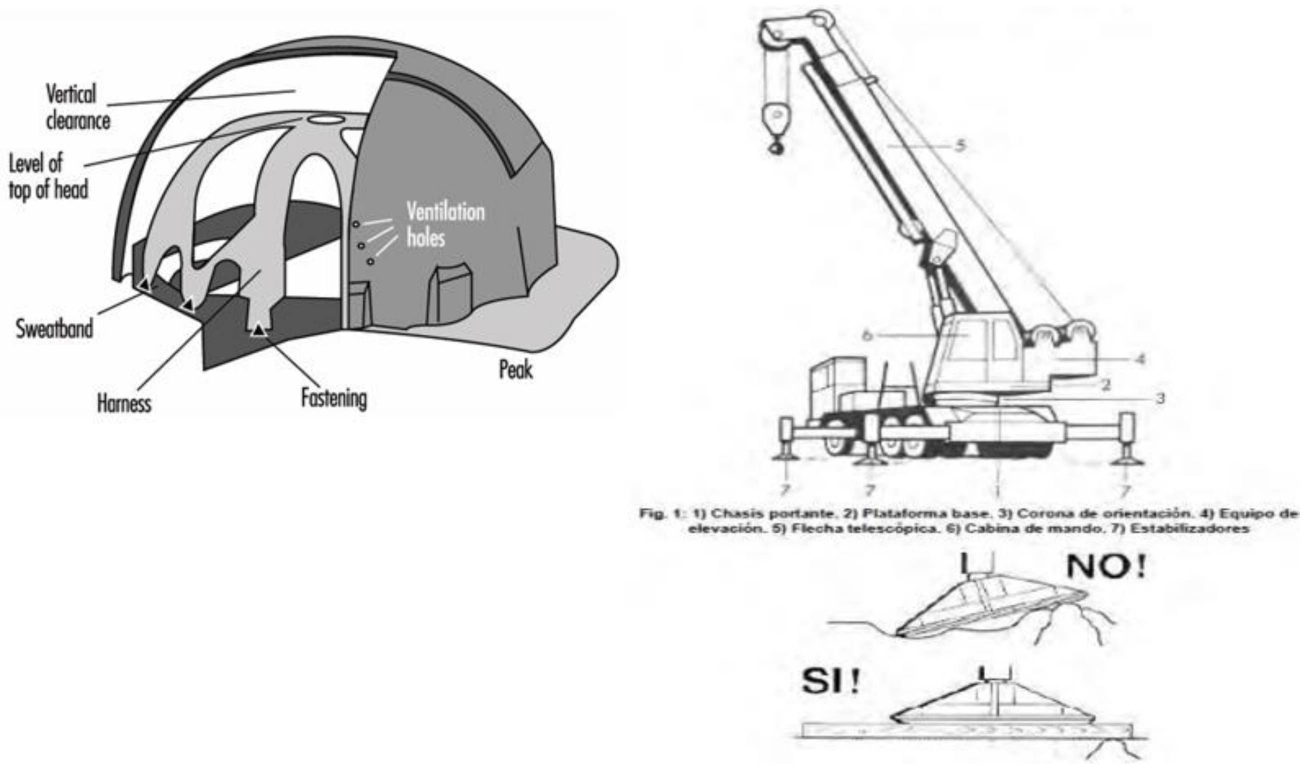


Figure 81. Illustrative images of signalling elements and p.p.e. (III)

Document 8.

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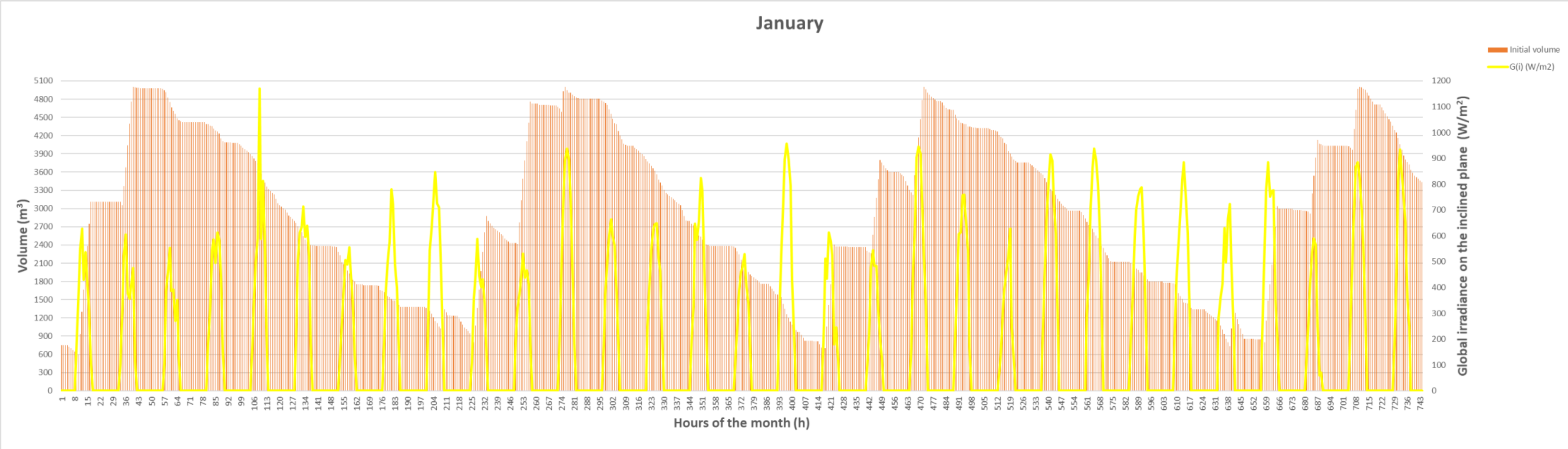
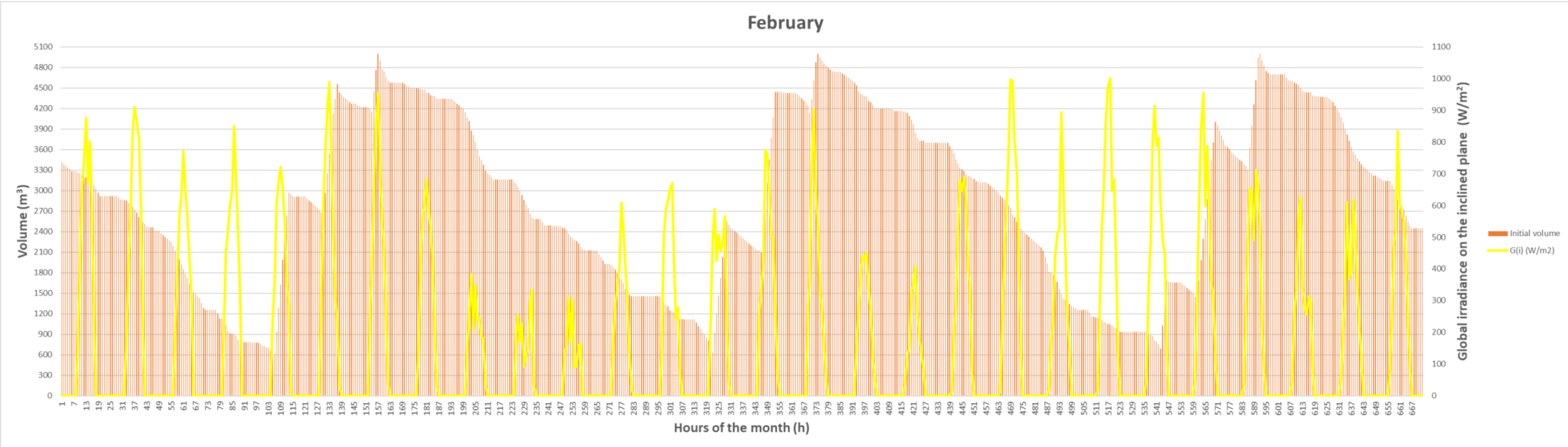
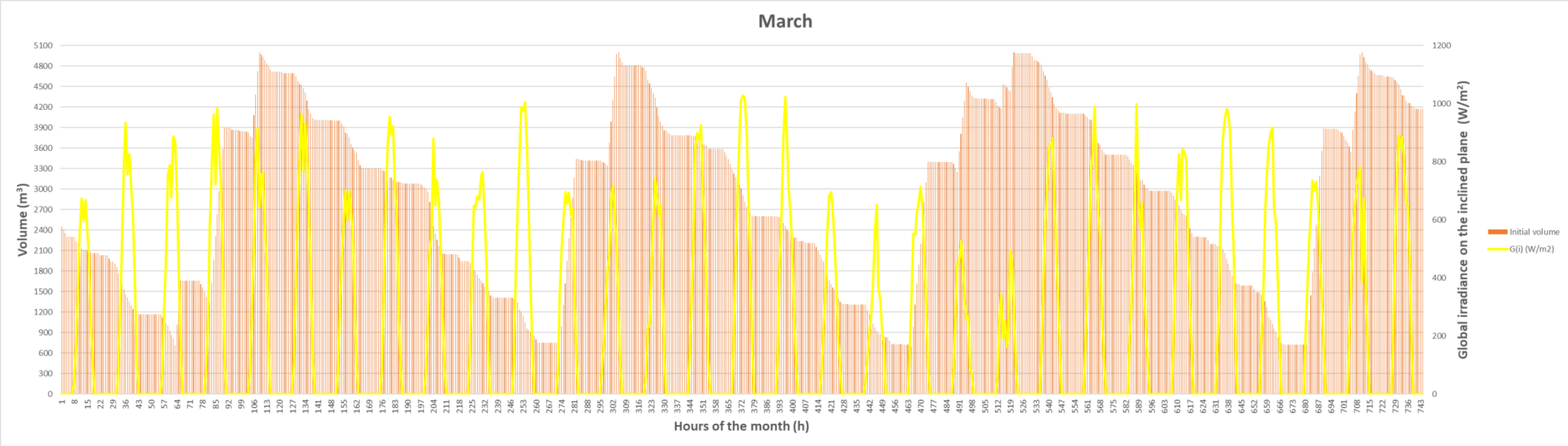
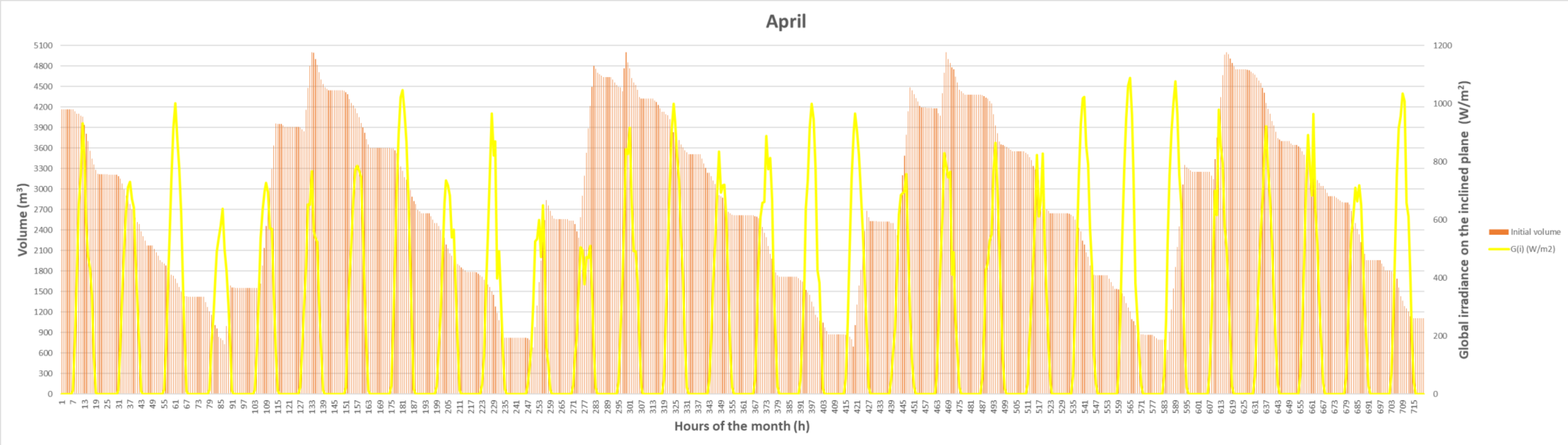
Annex I.

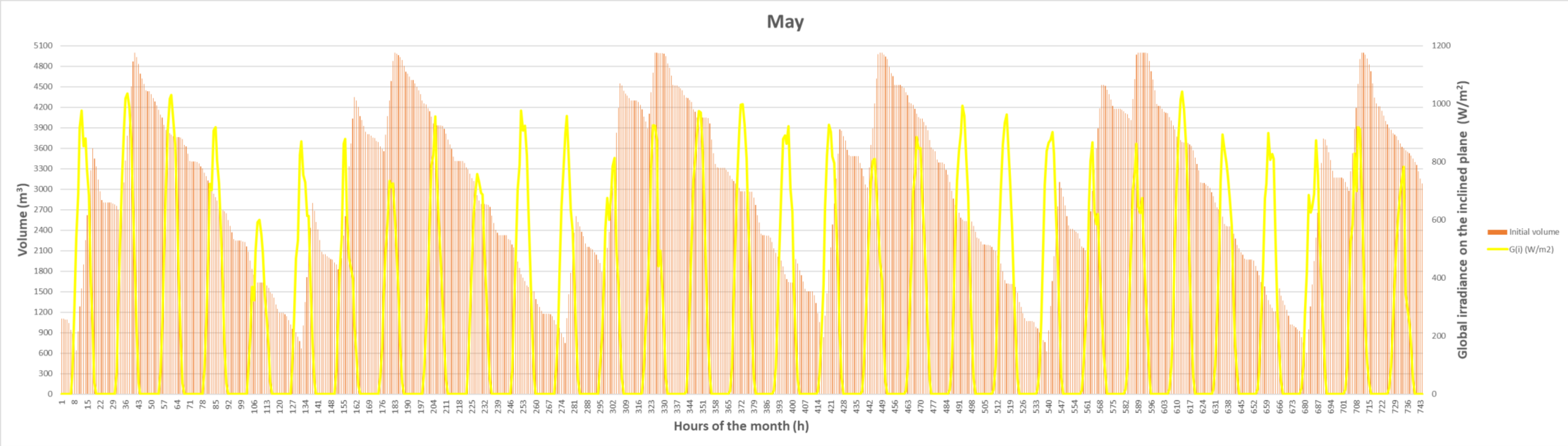
Graphs of time evolution of consumption, irradiance and regulation of water tanks

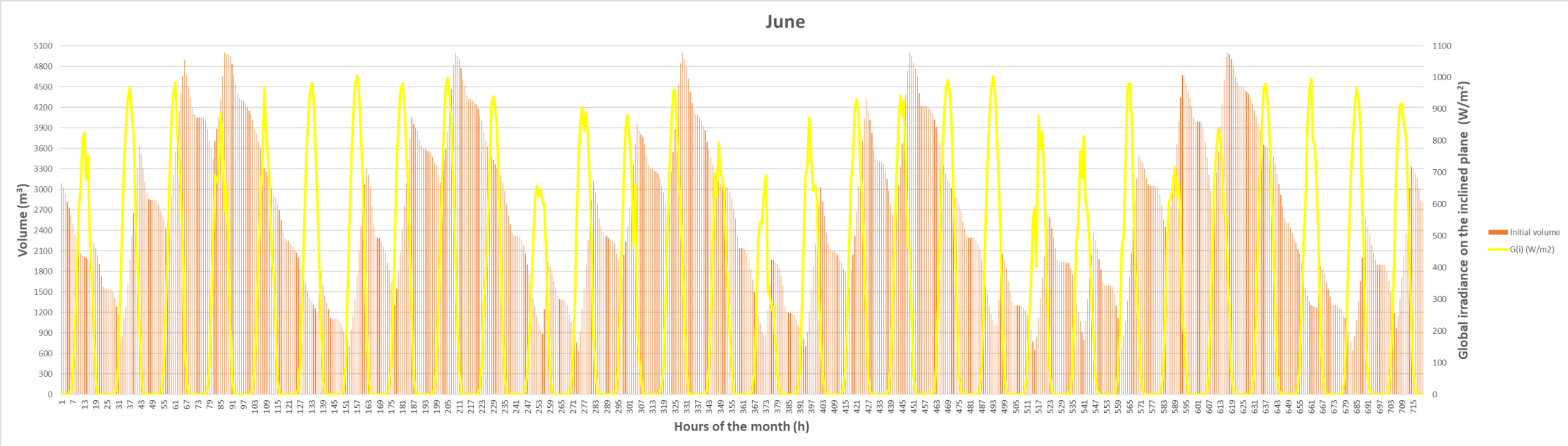

January
Initial volume
G(i) (W/m2)
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)

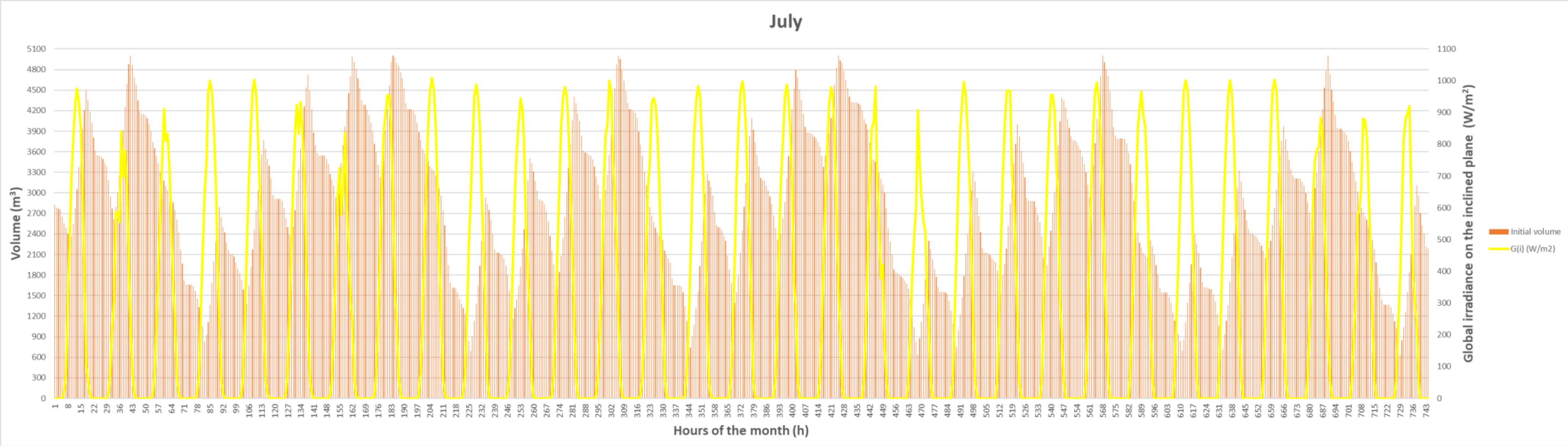

February
Initial volume
G(i) (W/m2)
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)

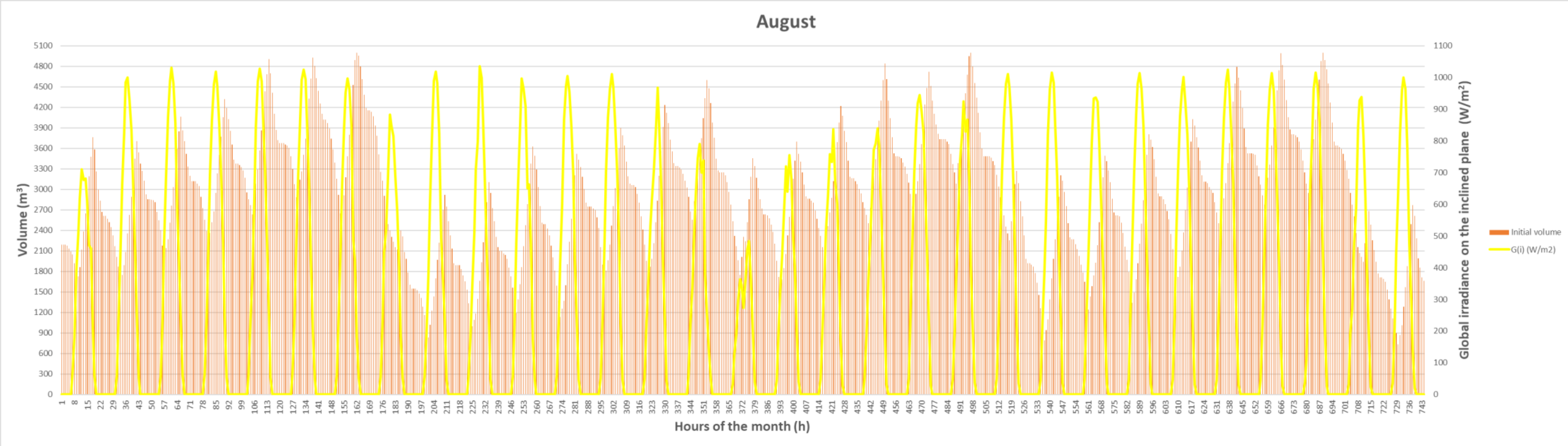

March
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

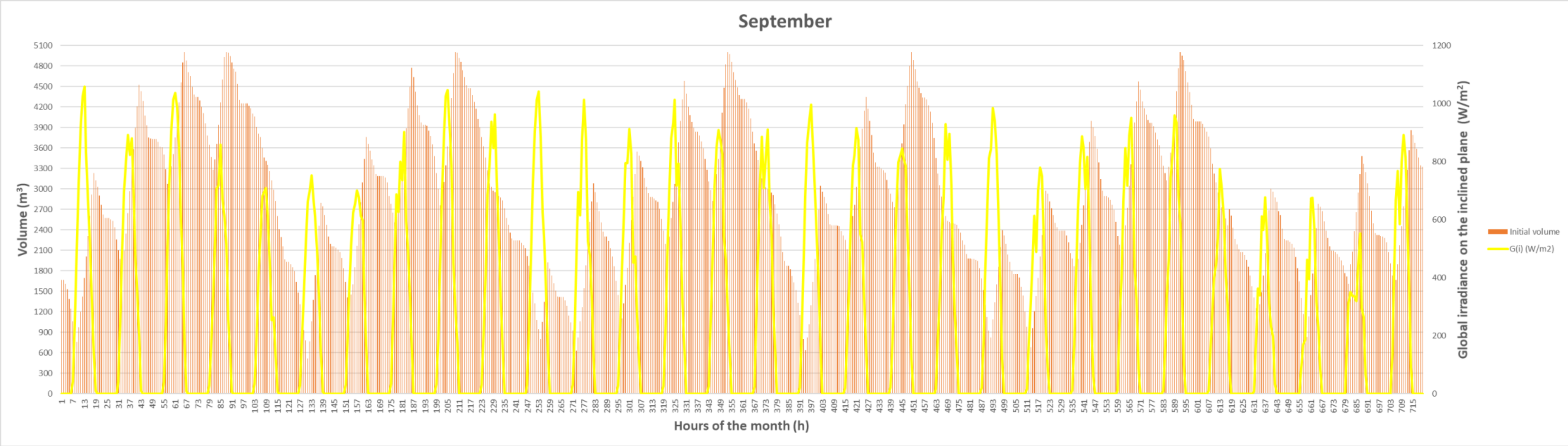

April
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

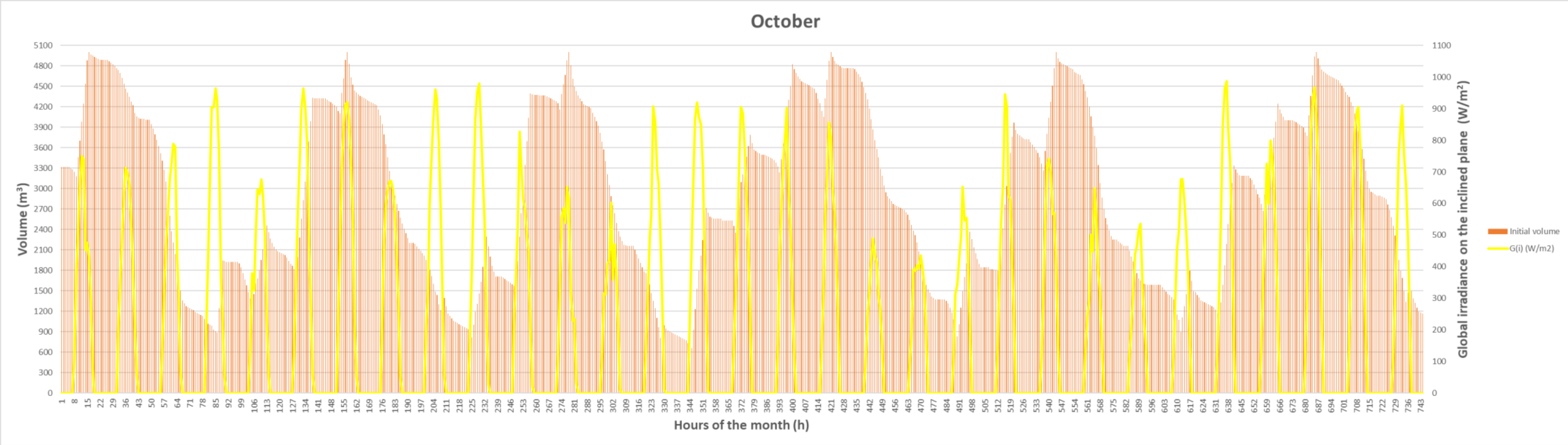

May
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

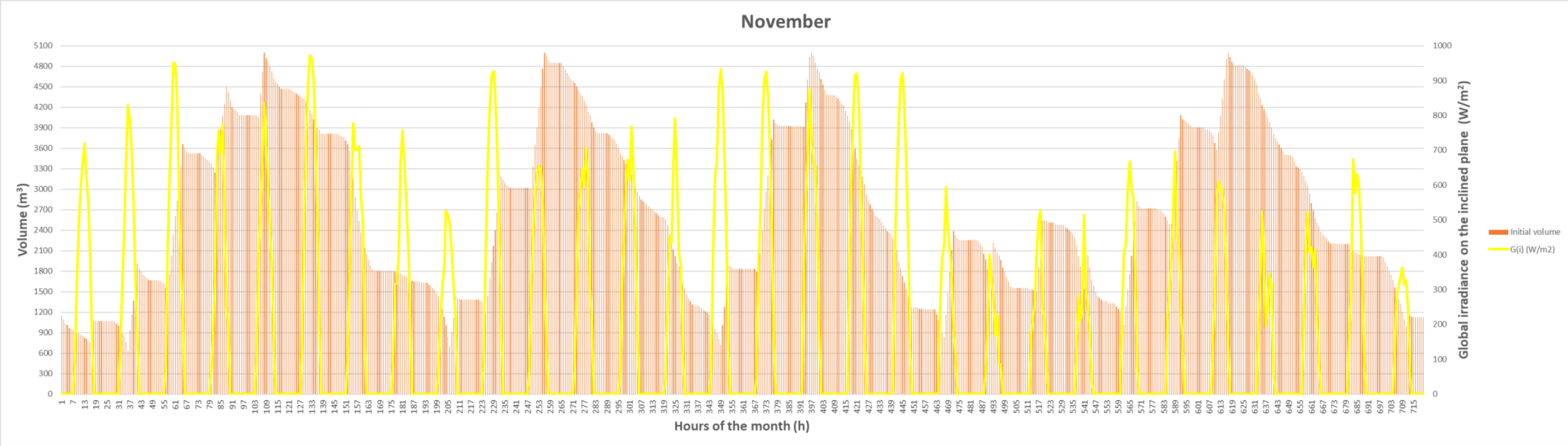

June
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

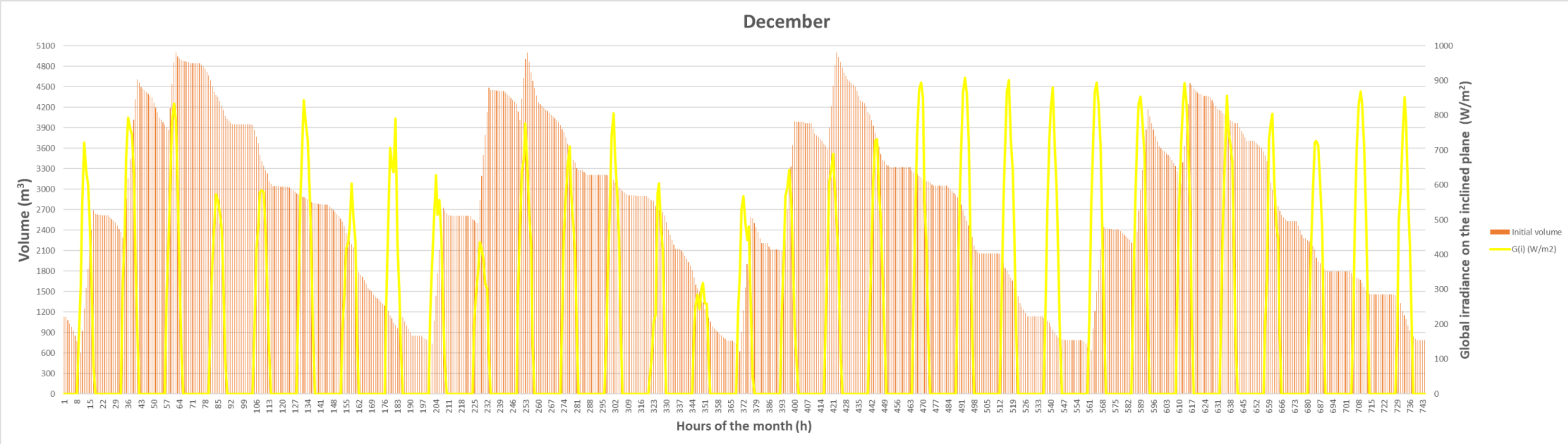

July
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

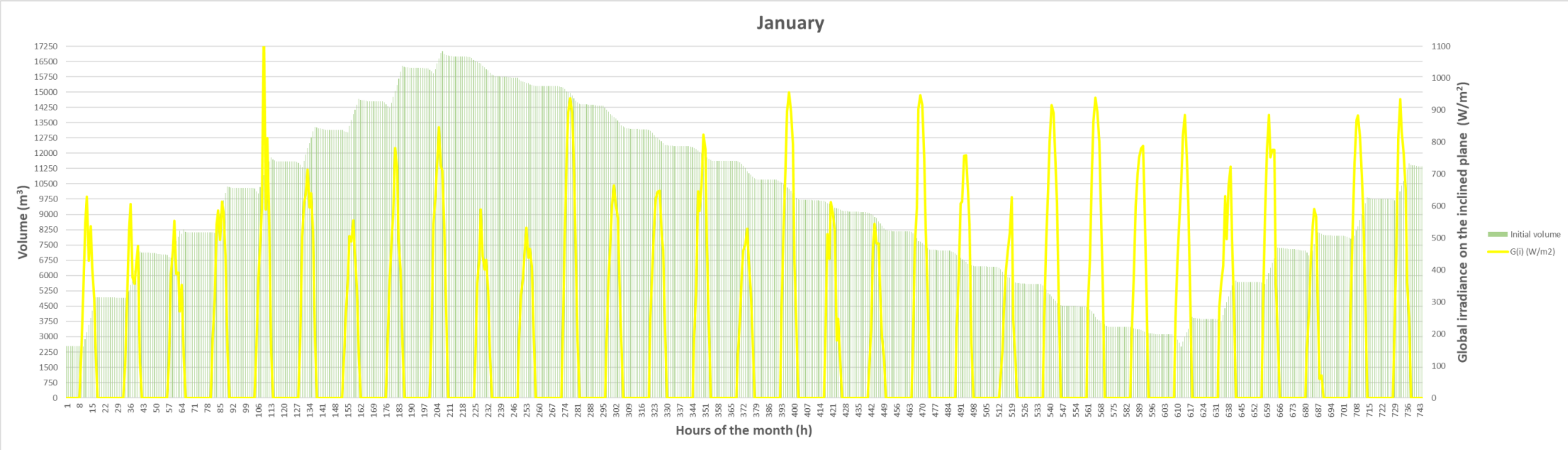

August
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

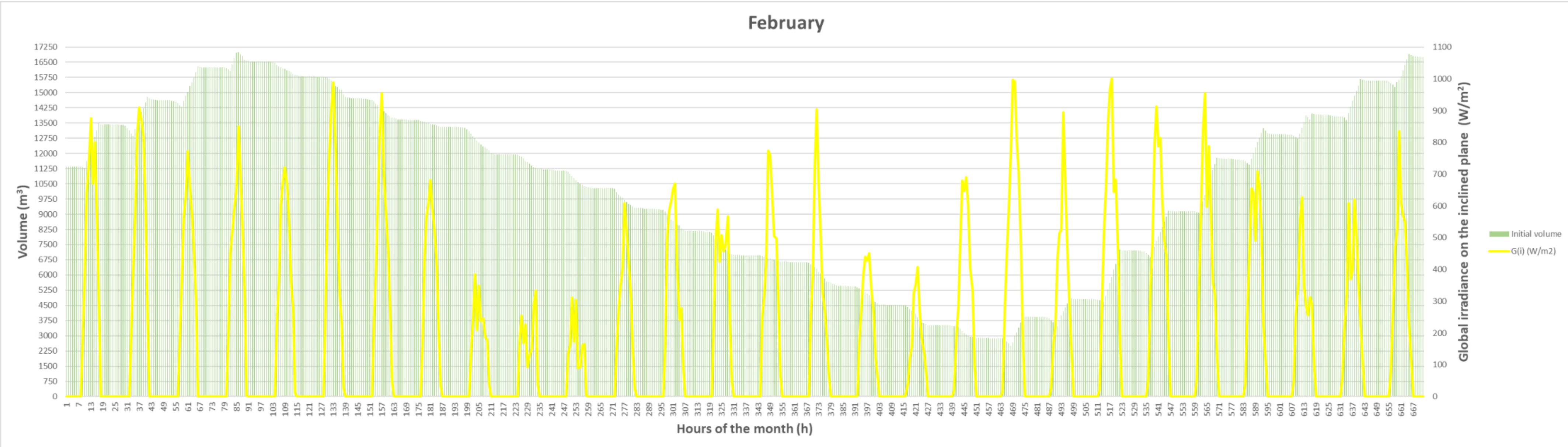

September
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

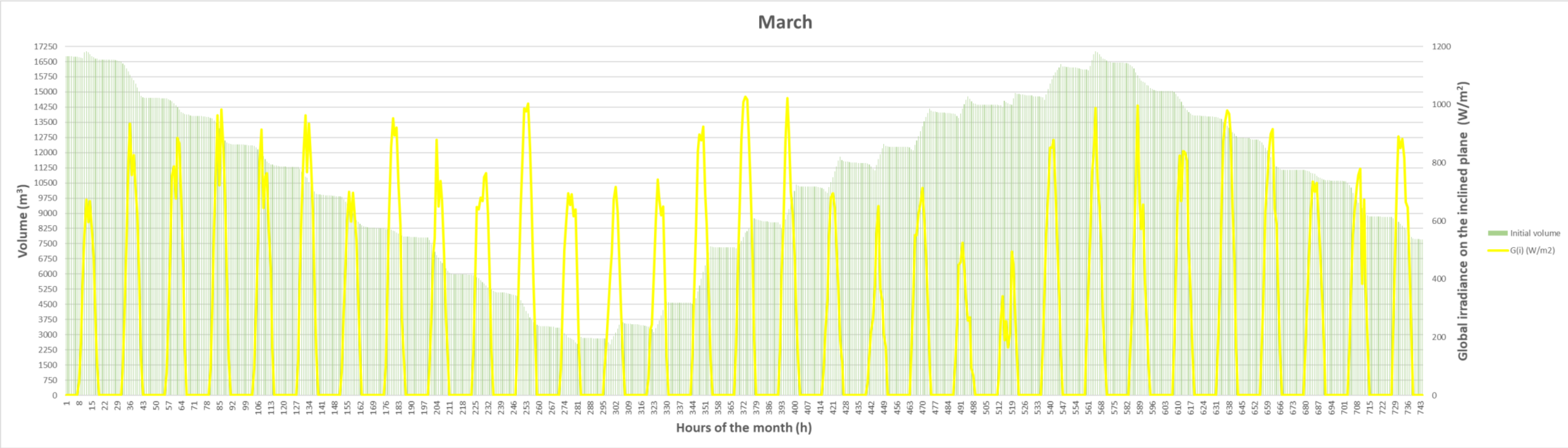

October
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

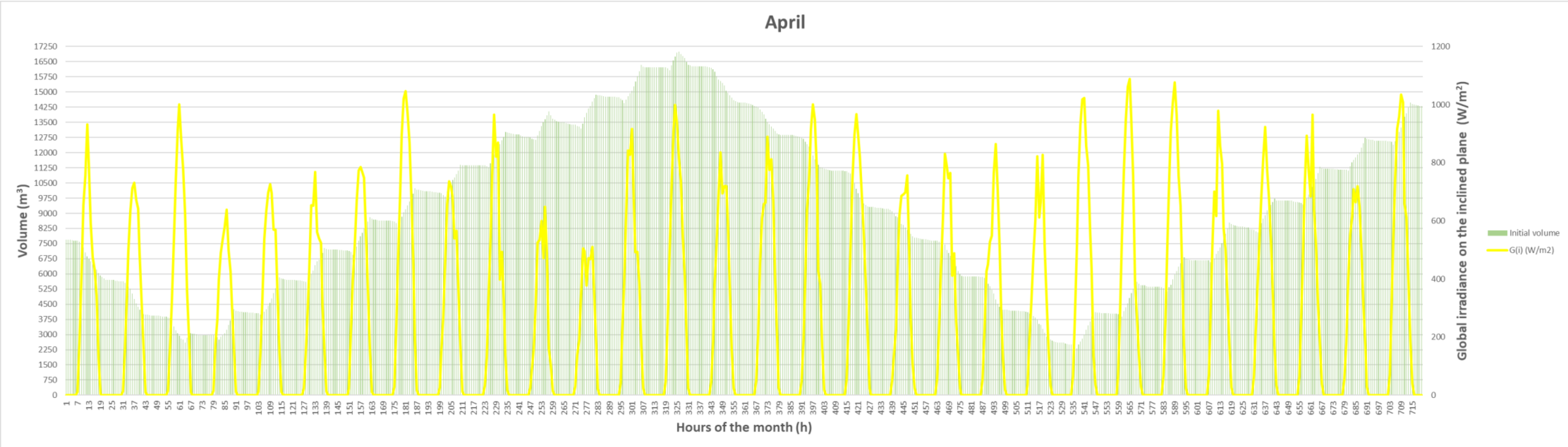

November
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

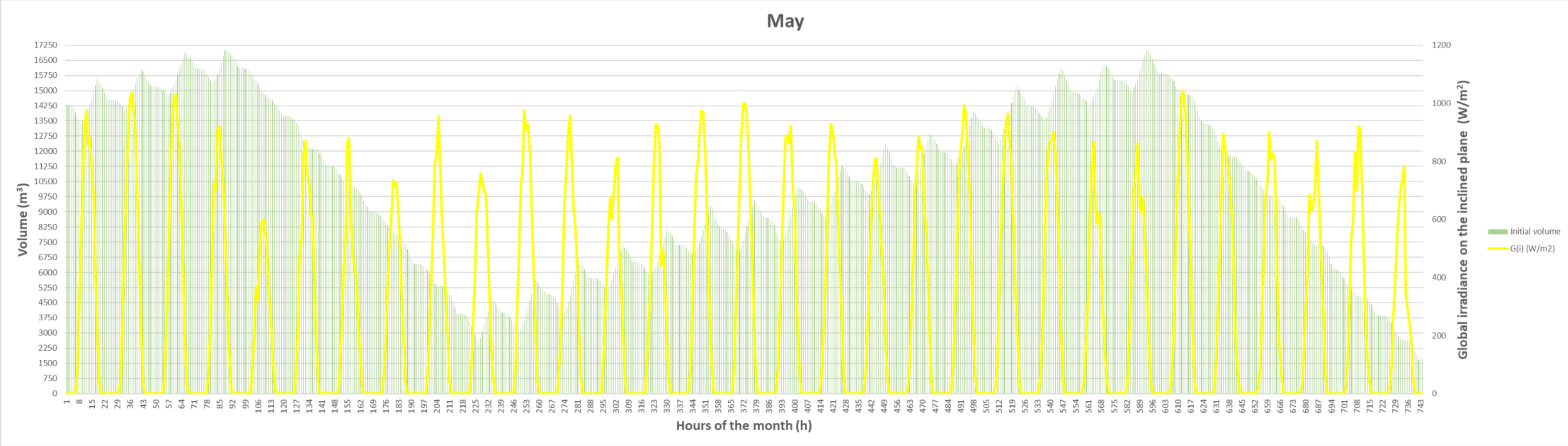

December
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

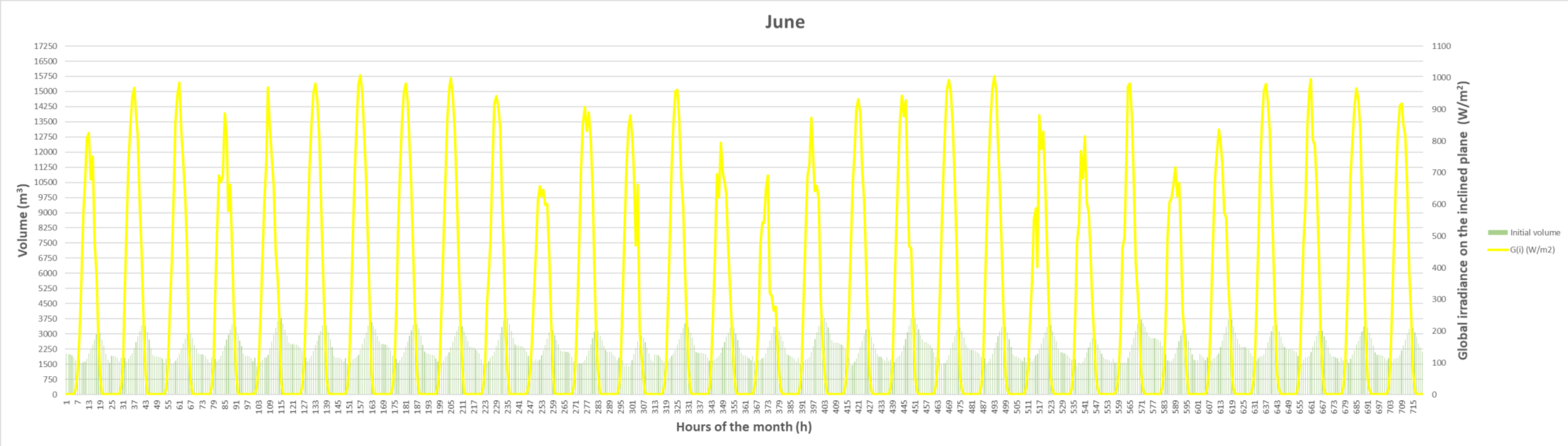

January
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

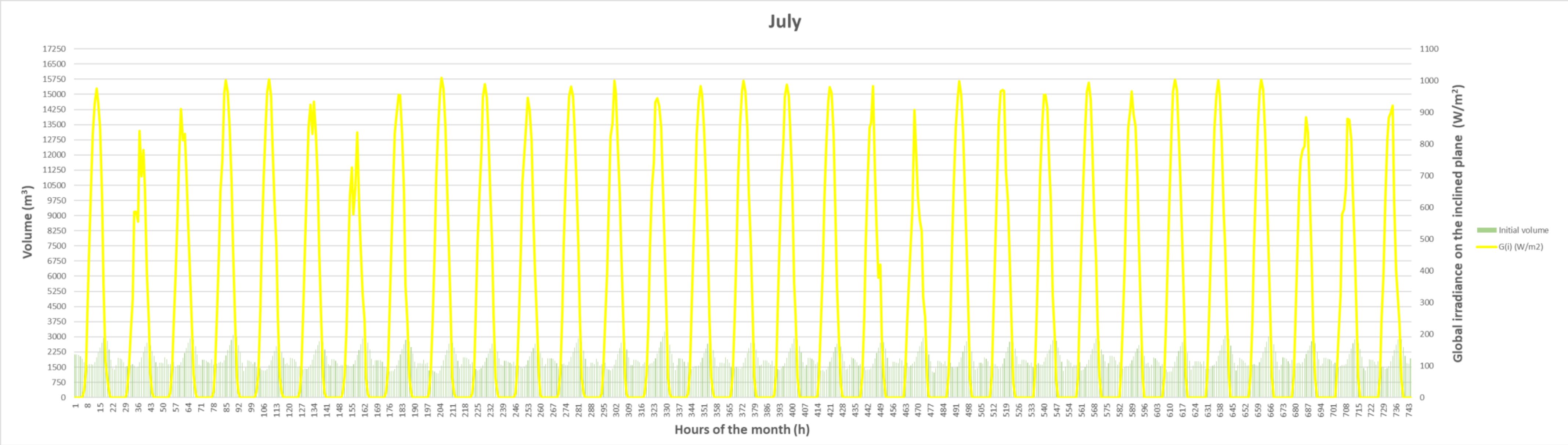

February
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

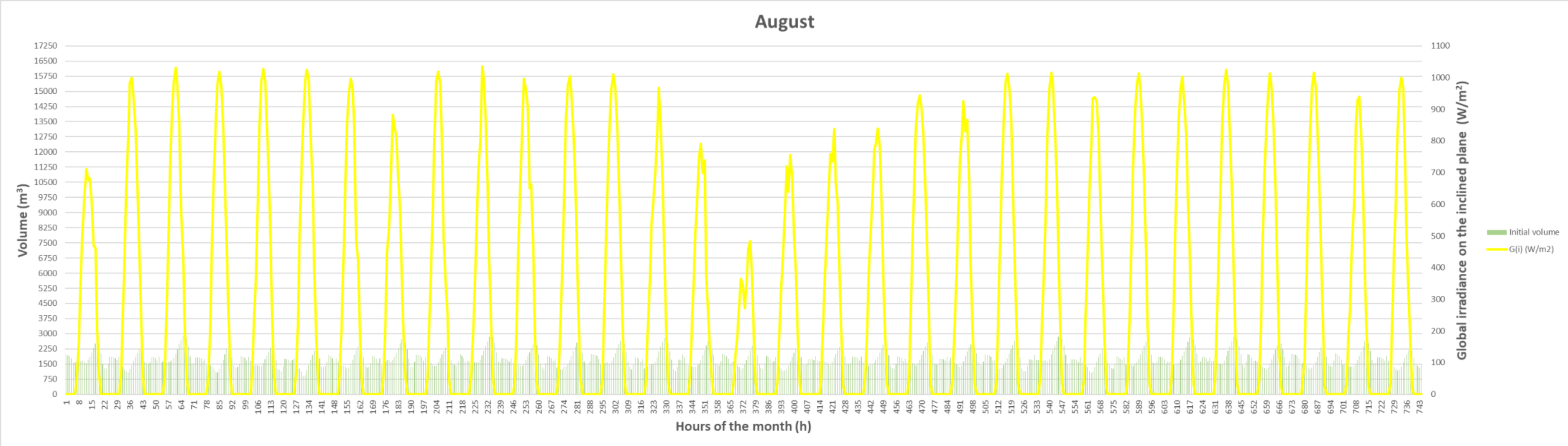

March
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

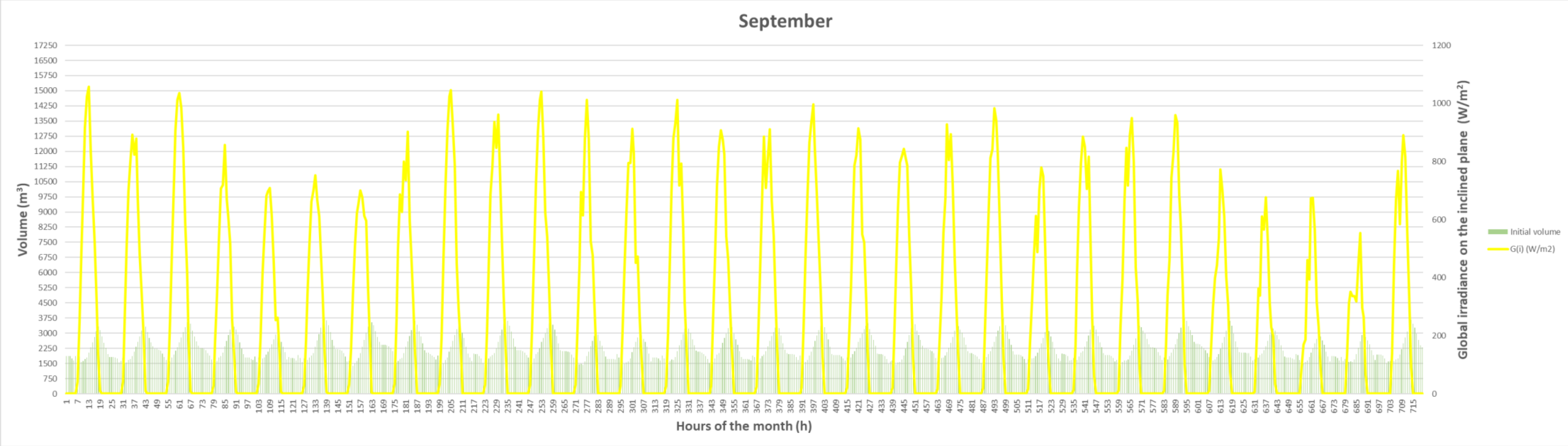

April
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

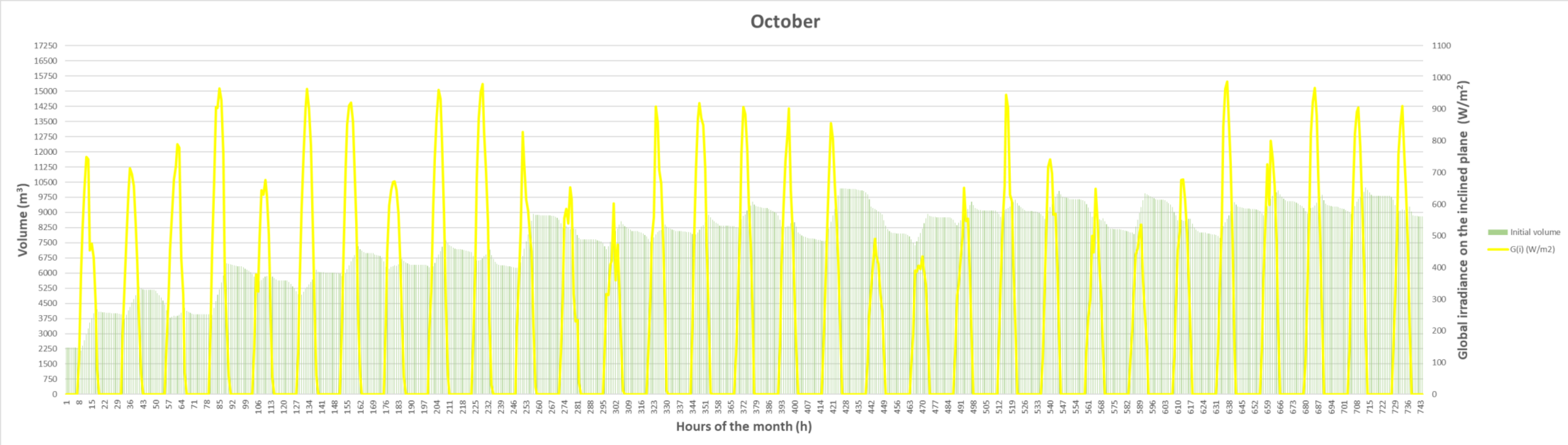

May
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

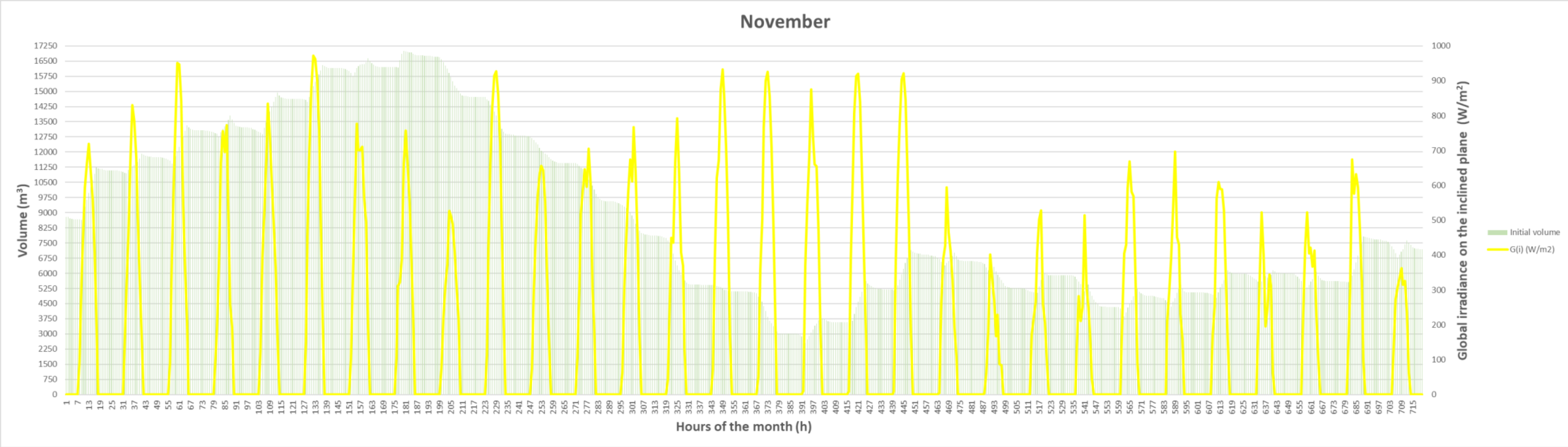

June
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

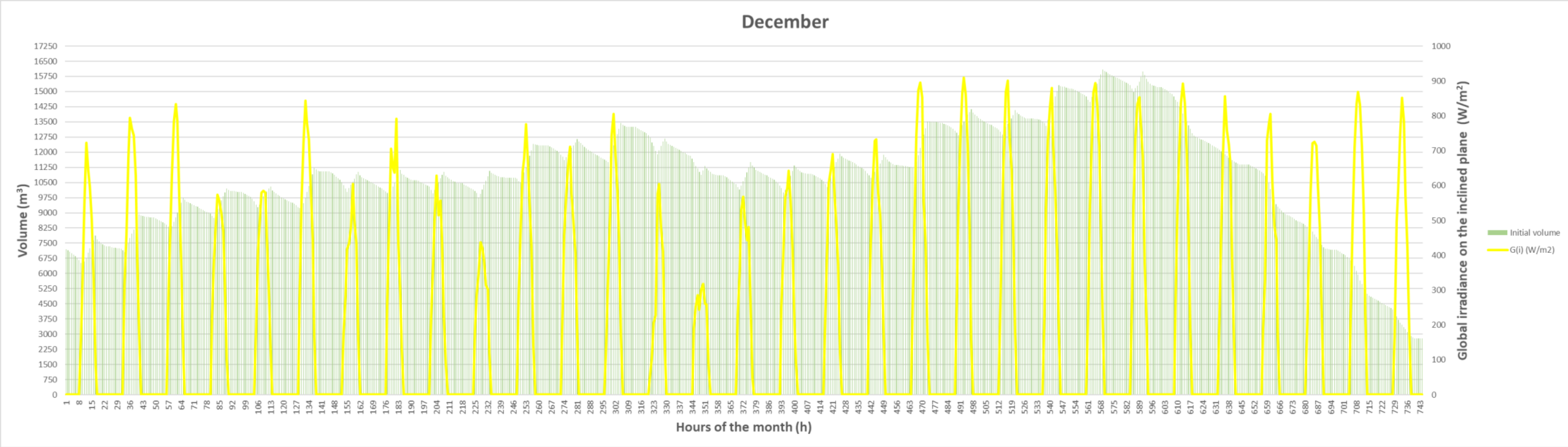

July
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)


August
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)


September
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)


October
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)


November
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)


December
Volume (m³)
Global irradiance on the inclined plane (W/m²)
Hours of the month (h)
Initial volume
G(i) (W/m2)

Annex II.

Planning of the temporal evolution of the execution of the works

II.1 Introduction

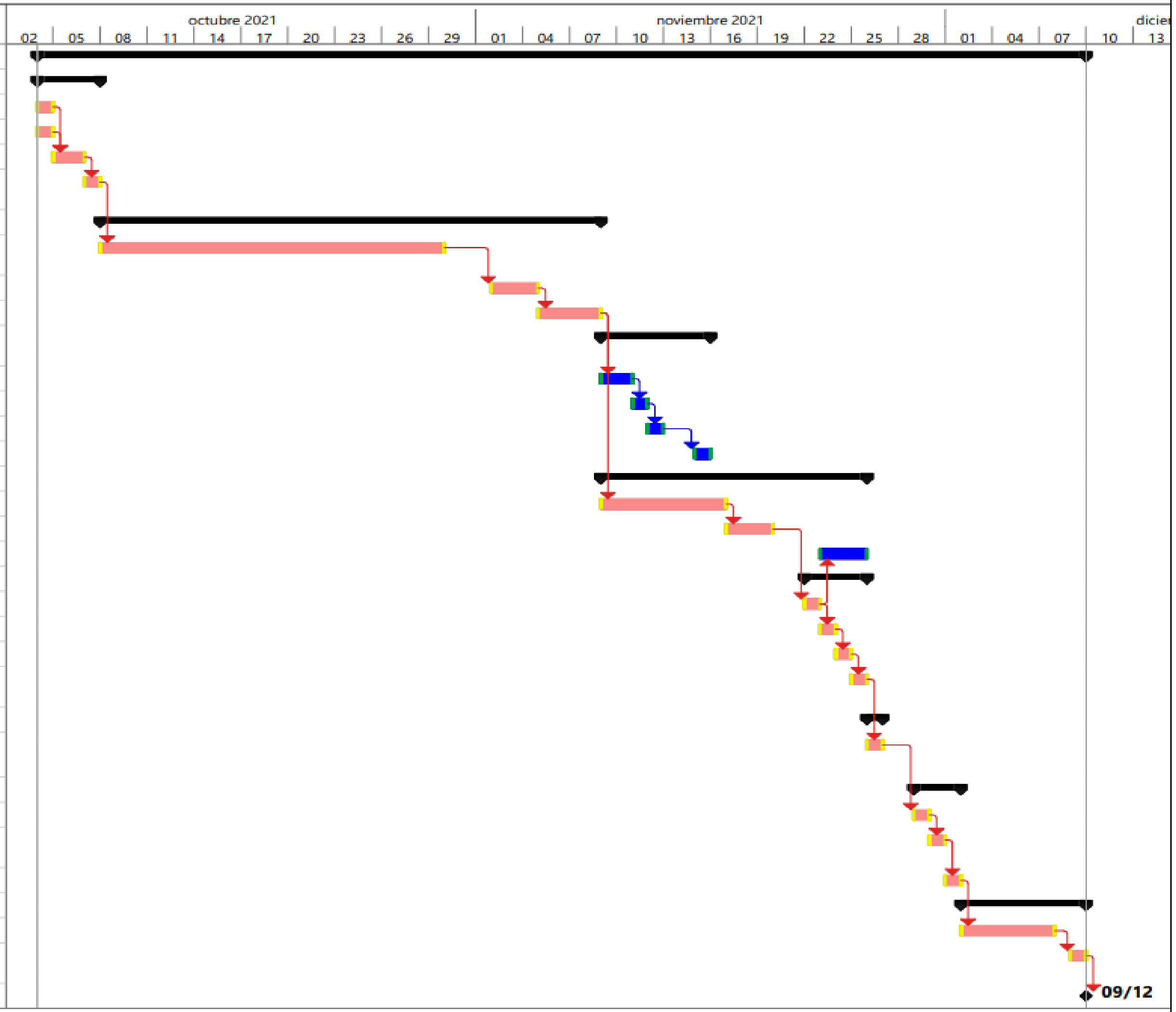
This Annex presents the result of the execution schedule obtained with the MS Project software. In this way, by configuring the achievement and estimated duration of the tasks involved in the works of this electricity supply project by means of this software, it is possible to know the evolution of their development, the critical path of the project and the estimated final duration of its execution in a fast and intuitive way. In this sense, the so-called Gantt Chart has been used for its representation.

The start day of the work is taken into account once the necessary administrative authorizations and prior building licenses have been obtained. Therefore, the entire duration of the project could be one or several weeks longer, if the period of time necessary to obtain said authorizations and licenses were taken into account.

II.2 Gantt Chart

Gantt of the temporalevolution of the execution of the works

Id	Name of the task	Duration	Predecessors
1	**Execution of the works of the PV Installation**	**45 días**	
2	**Preparation of the works area**	**4 días**	
3	Terrain survey	1 día	
4	Signage of the works area	1 día	
5	Adequacy of the works area	2 días	4;3
6	Fixing a parking area for vehicles, disposal of components of the installation and waste	1 día	5
7	**Installation of the photovoltaic generator**	**20 días**	
8	Mounting of the modules (footings, strucrture and placement of modules)	15 días	6
9	Connection of the modules	3 días	8
10	Cabling bracket	2 días	9
11	**Installation of the DC junction boxes, inverters, AC m.a.p. panels and monitoring equipment**	**5 días**	
12	Mounting of the DC junction boxes	2 días	10
13	Mounting of the inverters	1 día	12
14	Mounting of the AC m.a.p. panels	1 día	13
15	Mounting of the monitoring equipment	1 día	14
16	**Making of the trenches**	**13 días**	
17	Excavation of the trenches	6 días	10
18	Laying of the cabling in the trenches	3 días	17
19	Burial of the trenches	3 días	21
20	**Electrical elements connection**	**4 días**	
21	Connection of the strings to the DC junction boxes	1 día	18
22	Connection of the DC junction boxes to the inverters	1 día	21
23	Connection of the inverters to the AC m.a.p. panels	1 día	22
24	Connection of the AC m.a.p. panels to the monitoring equipment	1 día	23
25	**Installation of the pumping groups**	**1 día**	
26	Mounting of the pumping groups (lowering the pump to the well)	1 día	24
27	**Installation of other elements of the installation**	**3 días**	
28	Installation of grounding rods	1 día	26
29	Placement of protective elements such as fire extinguishers and first aid box	1 día	28
30	General check of connections	1 día	29
31	**Commissioning**	**4 días**	
32	Checking the status of components and their operation	3 días	30
33	Visit to the work of the interested parties for their approval	1 día	32
34	Commissioning of the installation	0 días	33



Fecha comienzo prevista: lun 04/10/21
Fecha fin prevista: jue 09/12/21

Annex III.

Technical documentation – Catalogues

III.1 Submersible well pumps

bombas IDEAL

Electrobomba sumergida
Electric submersible pumps
Electropompe immerge

SD-SDX

Descripción
Electrobombas sumergidas multicelulares con turbinas radiales o semiaxiales en hierro fundido GG-25 o bronce, cuerpos de bomba en hierro fundido GG-25 o bronce, eje en acero inoxidable guiado por cojinetes de goma. Acoplamiento bomba a motor según norma NEMA. Disponible versión SDX completamente en acero inoxidable, con diseño y espesores optimizados.

Description
Electro submersible multistage borehole pumps, with radial or semi-axial in cast iron or bronze impellers. Pump casings in cast iron or bronze, shaft in Stainless Steel with rubber bearings. Sumersible motors are according to Nema standards. Available SDX range fully in St.St. with improved design and optimized thickness.

Denomination
Eletropompes immergées multicellulaires avec roues radiales ou semi-axiales en fonte GG-25, ou bronze , corps de pompe en fonte GG-25, arbre en acier inoxydable avec des coussinets en caoutchouc. L'accouplement pompe-moteur conforme à la norme NEMA. Version SDX disponible entièrement en acier inoxydable avec le concept et l'épaisseur optimisée.

SD

SDX

bombas IDEAL

SDX 1,8 10"Ø MIN.

BOMBA TIPO: SEMIAXIAL
TEMP. MAX. LIQUIDO: 25º
MAX. ARENA: 160 gr/m³
SENTIDO ROT.: ANTIHORARIO
VALV. RET.: BAJO PEDIDO

PUMP TYPE: MIXED FLOW
MAXI. TEMP. LIQUID: 25º
SAND MAX.: 160 gr/m³
ROTATION: C.C.W.
CHECK VAL.: ON REQUEST

POMPE TYPE: SEMIAXIAL
TEMP. MAX. LIQUIDE: 25º
MAX. SABLE: 160 gr/m³
SENS. ROT.: ANTIHORAIRE
CLAPET RET.: SUR DEMENDE

Tablas de selección / Selection charts / Tables de selection

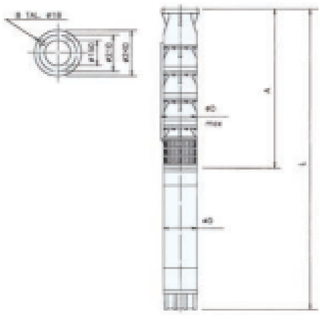
Tipo Type	Motor - Moteur			Caudal - Capacity - Debit					
	KW	HP	l/min.	0	1750	2250	2750	3250	3750
			m³/h	0	105	135	165	195	225
SDX 1,8-1F1	18	25	m.c.a.	40	35	33	30	23	10
SDX 1,8-1	22	30		46	40	38	35	32	23
SDX 1,8-2F2	37	50		80	70	65	60	46	20
SDX 1,8-2	44	60		92	80	76	70	64	46
SDX 1,8-3F3	55	75		120	105	98	90	69	30
SDX 1,8-3F2	59	80		126	110	103	95	78	43
SDX 1,8-3	66	90		138	120	114	105	96	69
SDX 1,8-4F4	74	100		160	140	130	120	92	40
SDX 1,8-4	92	125		184	160	152	140	128	92
SDX 1,8-5	110	150		230	200	190	175	160	115
SDX 1,8-6F2	129	175		264	230	217	200	174	112
SDX 1,8-7F2	147	200		310	270	255	235	206	135
SDX 1,8-7	166	225		322	280	266	245	224	161
SDX 1,8-8	184	250		368	320	304	280	256	184
SDX 1,8-9	221	300		414	360	342	315	288	207

Dimensiones / Dimensions / Dimensions

Materiales tipo E
Impulsor: AISI 316
Cuerpo: AISI 316
Eje: Acero inox.

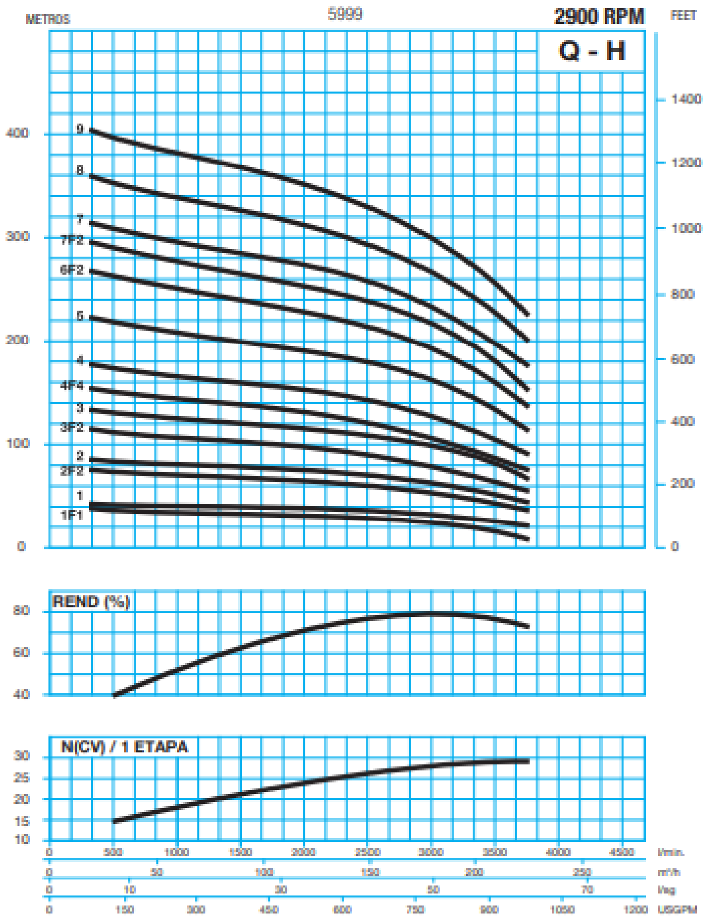
Material type E
Impeller: AISI 316
Bowl: AISI 316
Shaft: St. steel

Materiaux type E
Roue: AISI 316
Corps: AISI 316
Arbre: Acier inox.



50Hz

Tipo Type	Motor - Moteur		D máx.	D Motor-M	A mm	L mm	Peso Weight Poids (kg)
	KW	HP					
SDX 1,8-1F1	18	25	250	140	710	1572	127
SDX 1,8-1	22	30	250	140	710	1766	134
SDX 1,8-2F2	37	50	254	140	895	2242	252
SDX 1,8-2	44	60	254	140	895	2170	266
SDX 1,8-3F3	55	75	254	192	1080	2400	313
SDX 1,8-3F2	59	80	254	192	1080	2450	320
SDX 1,8-3	66	90	254	192	1080	2540	335
SDX 1,8-4F4	74	100	254	192	1265	2815	376
SDX 1,8-4	92	125	260	192	1265	2801	490
SDX 1,8-5	110	150	260	192	1450	3294	550
SDX 1,8-6F2	129	175	260	236	1635	3245	625
SDX 1,8-7F2	147	200	260	236	1820	3560	690
SDX 1,8-7	166	225	276	236	1820	3742	771
SDX 1,8-8	184	250	276	236	2005	3927	796
SDX 1,8-9	221	300	276	236	2190	4230	881



Motores trifásicos en baño de agua - Rebobinables 8" **CORMOTOR AQUA**
8" three-phase motors in water bath-rewindable **CORMOTOR WATER**
Moteurs triphasés dans bain d'eau rebobinables 8" **CORMOTOR AQUA**

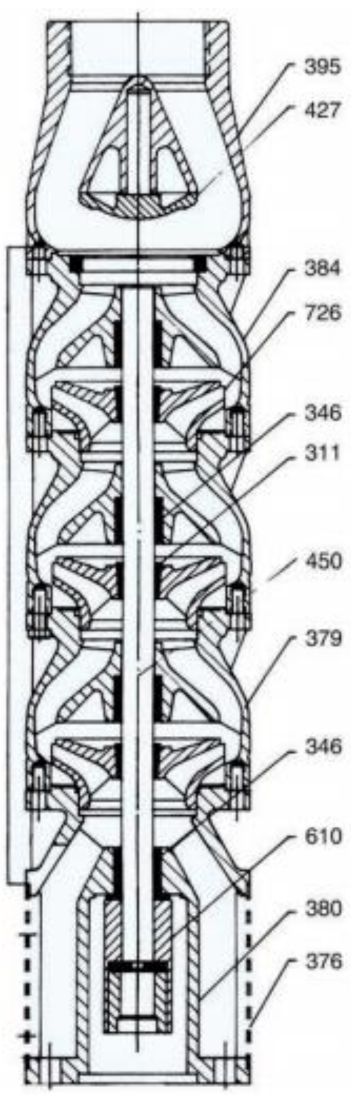
Hz	Motor	Motor P2		Tensión	I_N	Rend.	Cos. φ	RPM	$I_{arr.}$	Carga	Peso	Long.
	Tipo	kW	HP	(V)	(A)	%			A	axial (KN)	Kg	(mm)
50 Hz	CORMOTOR AQUA 8" 40	30	40	380	61,7	83	0,89	2850	238,5	45	127	1056
		30	40	400	59,3	84	0,87	2865	229	45	127	1056
		30	40	415	57,8	84	0,86	2875	223,3	45	127	1056
60 Hz	CORMOTOR AQUA 8" 40	30	40	460	51	82	0,90	3450	258	45	127	1056
50 Hz	CORMOTOR AQUA 8" 50	37	50	380	74,3	85	0,89	2860	287,2	45	133	1116
		37	50	400	71,4	86	0,87	2875	275,9	45	133	1116
		37	50	415	69,6	86	0,86	2885	269	45	133	1116
60 Hz	CORMOTOR AQUA 8" 50	37	50	460	61	84	0,90	3460	308	45	133	1116
50 Hz	CORMOTOR AQUA 8" 60	45	60	380	90,4	85	0,89	2860	349,3	45	140	1201
		45	60	400	86,8	86	0,87	2875	335,5	45	140	1201
		45	60	415	84,6	86	0,86	2885	327,2	45	140	1201
60 Hz	CORMOTOR AQUA 8" 60	45	60	460	75	84	0,90	3460	382	45	140	1201
50 Hz	CORMOTOR AQUA 8" 70	52	70	380	103,3	85	0,90	2850	399,2	45	146	1286
		52	70	400	99,2	86	0,88	2865	383,3	45	146	1286
		52	70	415	96,7	86	0,87	2875	373,7	45	146	1286
60 Hz	CORMOTOR AQUA 8" 70	52	70	460	85	84	0,91	3450	431	45	146	1286
50 Hz	CORMOTOR AQUA 8" 75	55	75	380	110,5	84	0,90	2850	427,2	45	152	1286
		55	75	400	107,4	84	0,88	2864	415,1	45	152	1286
		55	75	415	103,5	85	0,87	2876	399,9	45	152	1286
60 Hz	CORMOTOR AQUA 8" 75	55	75	460	90	84	0,91	3450	458	45	152	1286
50 Hz	CORMOTOR AQUA 8" 80	59	80	380	119,1	86	0,89	2850	460,3	45	160	1341
		59	80	400	115,7	86	0,87	2865	447,4	45	160	1341
		59	80	415	112,9	86	0,86	2875	436,2	45	160	1341
60 Hz	CORMOTOR AQUA 8" 80	59	80	460	100	84	0,90	3450	509	45	160	1341
50 Hz	CORMOTOR AQUA 8" 90	67	90	380	134,6	85	0,89	2850	520,1	45	169	1366
		67	90	400	129,3	86	0,87	2865	499,6	45	169	1366
		67	90	415	126	86	0,86	2875	487,1	45	169	1366
60 Hz	CORMOTOR AQUA 8" 90	67	90	460	111	84	0,90	3450	563	45	169	1366
50 Hz	CORMOTOR AQUA 8" 100	75	100	380	150,7	84	0,90	2850	582,6	45	190	1391
		75	100	400	144,7	85	0,88	2865	559,4	45	190	1391
		75	100	415	141,1	85	0,87	2875	545,3	45	190	1391
60 Hz	CORMOTOR AQUA 8" 100	75	100	460	123	84	0,91	3450	625	45	190	1391
50 Hz	CORMOTOR AQUA 8" 110	81	110	380	162,7	85	0,89	2855	628,8	55	197	1471
		81	110	400	156,3	86	0,87	2860	603,9	55	197	1471
		81	110	415	152,4	86	0,86	2865	588,9	55	197	1471
60 Hz	CORMOTOR AQUA 8" 110	81	110	460	134	84	0,90	3430	681	55	197	1471
50 Hz	CORMOTOR AQUA 8" 125	92	125	380	184,8	85	0,89	2820	714,1	55	208	1536
		92	125	400	177,5	86	0,87	2835	686	55	208	1536
		92	125	415	173,1	86	0,86	2850	668,9	55	208	1536
60 Hz	CORMOTOR AQUA 8" 125	92	125	460	153	84	0,90	3430	770	55	208	1536
50 Hz	CORMOTOR AQUA 8" 150	110	150	380	216	85,9	0,87	2852	835	45	295	1844
		110	150	400	209,7	86	0,87	2852	809	45	295	1844
		110	150	415	205	86	0,87	2852	791	45	295	1844
60 Hz	CORMOTOR AQUA 8" 150	110	150	460	185,1	89,2	0,82	3506	910	45	295	1844

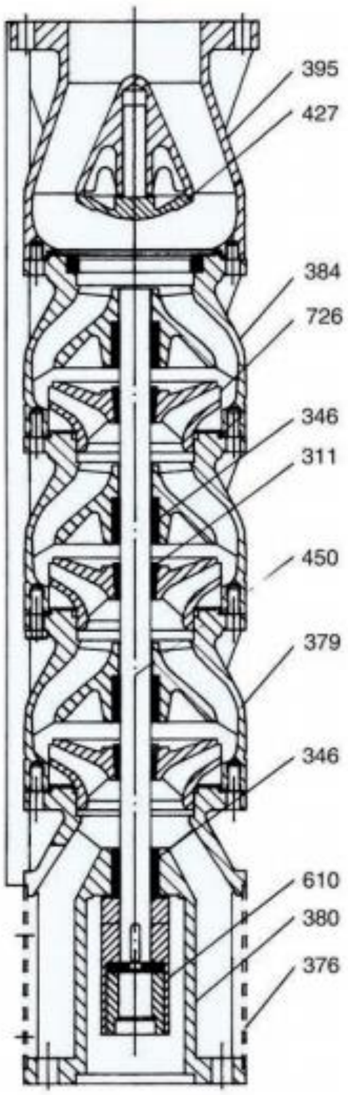
bombas IDEAL

BOMBA SEMIAXIAL
MIXED FLOW PUMP
POMPE DEMI AXIALE

SD 0,30
SD 0,36
SD 0,42
SD 0,46

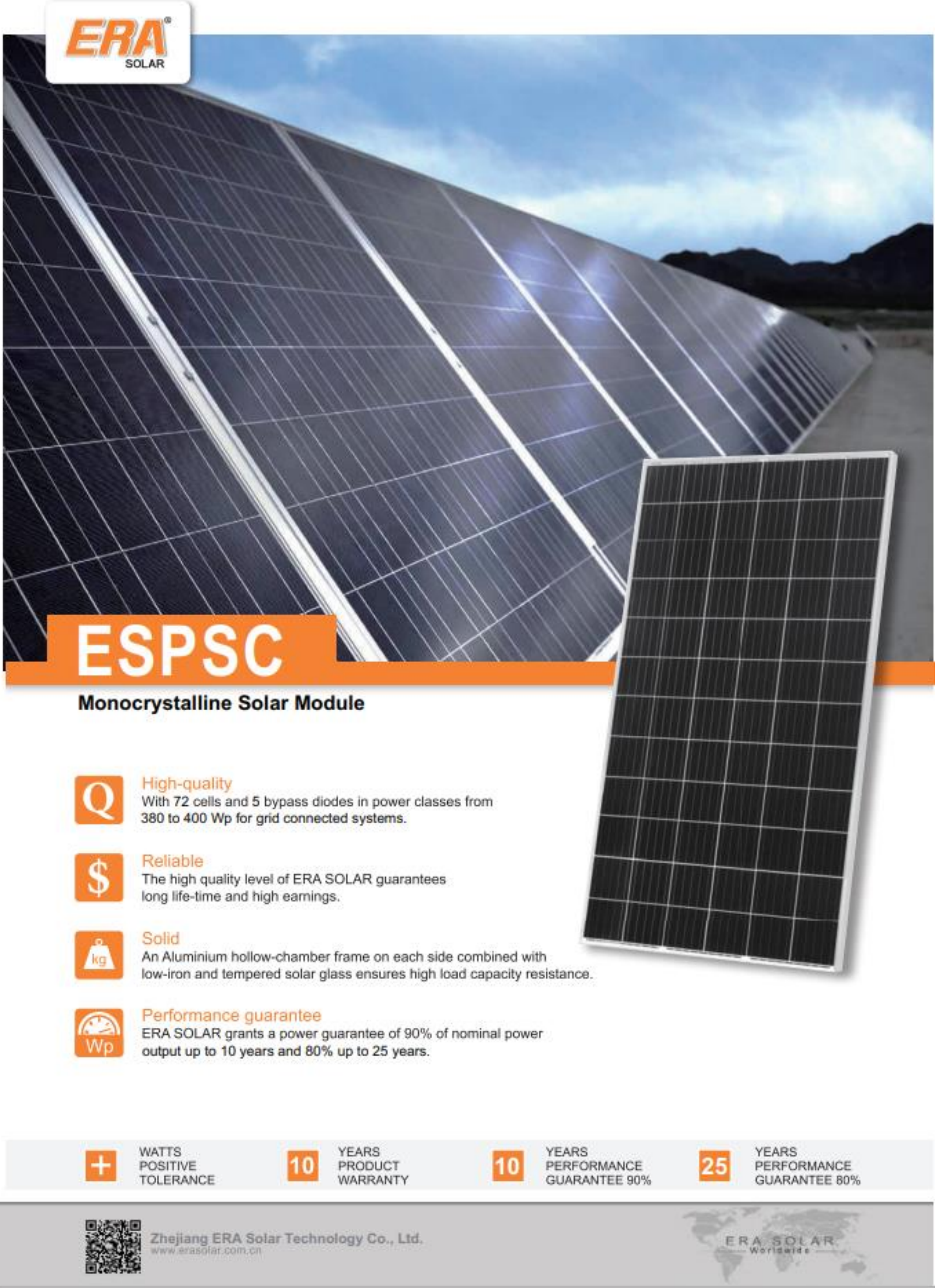
SD 0,62
SD 0,76
SD 0,82
SD 0,88
SD 1,8 SDX 1,8
SD 2,5 SDX 2,5
SD 2,6 SDX 2,6





CÓDIGO / CODE	DESIGNACIÓN / DESIGNATION
311	BUJE RODETE CONIC BUSHING DOUILLE
346	COJINETE BEARING COUSSINET
376	COLADOR STRAINER CREPINE
379	DIFUSOR DIFFUSER DIFFUSEUR
380	CUERPO DE ASPIRACIÓN SUCTION CASING CORPS ASPIRATION
384	CUERPO BOMBA SUP. UPPER DIFFUSER DIFFUSEUR SUP.
395	CUERPO IMPULSIÓN DELIVERY CASING CORPS REFOULEMENT
427	VÁLVULA VALVE SOUPAPE
450	EJE BOMBA SHAFT ARBRE
485	JUNTA TÓRICA O'RING JOINT TORIQUE
610	MANGUITO COUPLING ACCOUPLEMENT
726	RODETE IMPELLER TURBINE

III.2 Panel



ERA SOLAR

ESPSC

Monocrystalline Solar Module

High-quality
With 72 cells and 5 bypass diodes in power classes from 380 to 400 Wp for grid connected systems.

Reliable
The high quality level of ERA SOLAR guarantees long life-time and high earnings.

Solid
An Aluminium hollow-chamber frame on each side combined with low-iron and tempered solar glass ensures high load capacity resistance.

Performance guarantee
ERA SOLAR grants a power guarantee of 90% of nominal power output up to 10 years and 80% up to 25 years.

+ WATTS POSITIVE TOLERANCE
10 YEARS PRODUCT WARRANTY
10 YEARS PERFORMANCE GUARANTEE 90%
25 YEARS PERFORMANCE GUARANTEE 80%

Zhejiang ERA Solar Technology Co., Ltd.
www.erasolar.com.cn

ERA SOLAR Worldwide

ESPSC

Monocrystalline Solar Module

SPECIFICATIONS

Dimensions	1979 x 1002 x 40mm
Weight	22.5 kg
Frame	Aluminium hollow-chamber frame on each side
Glass	Low-iron and tempered glass 3.2 mm
Cells	72 pcs Mono PERC (158.75 x158.75 mm)
Cell Embedding	EVA
Back-Foil	FEVE / PET / FEVE
Junction Box	TÜV certified
Cable	4 mm² solar cable 2 x 900 mm or Customized Length
Temperature Range	-40°C ... +85°C
Load Capacity	5400 Pa(IEC 61215),40mm
Application class	Class A
Electrical protection class	Class II
Fire safety class	Class C
Product warranty	10 years
Power Guarantee	10 years 90% 25 years 80%

Packaging Configuration

(Two pallets = One stack)

27pcs/pallet, 54pcs/stack, 594pcs/40'HQ Container

CHARACTERISTICS

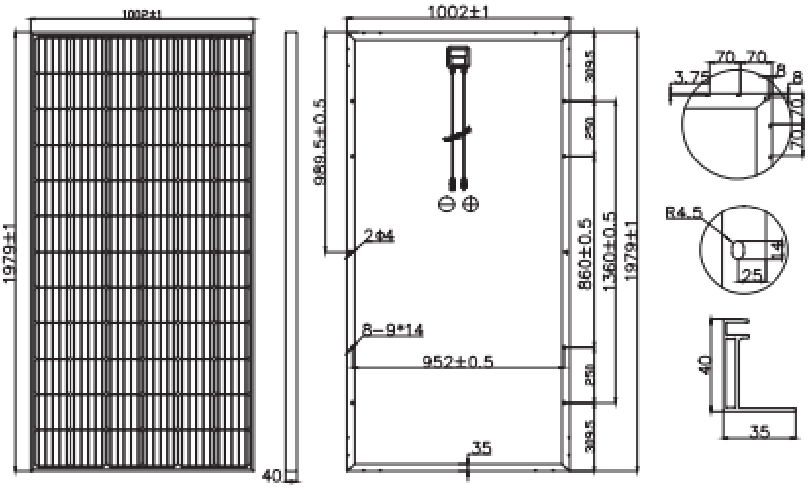
Max. System Voltage	1000V/DC
Temperature-Coefficient I_{sc}	+0.02973%/°K
Temperature-Coefficient V_{oc}	-0.38038%/°K
Temperature-Coefficient P_{mpp}	-0.57402%/°K
NOCT***	45°C

CERTIFICATES

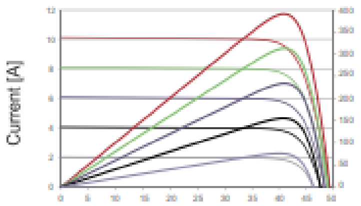
IEC 61215 edition 2 (TÜV Nord)
(TÜV Rheinland)
IEC 61730 MCS INMETRO
CE CEC SALT-MIST
UL1703 CSA
PID Resisitant

INSURANCE

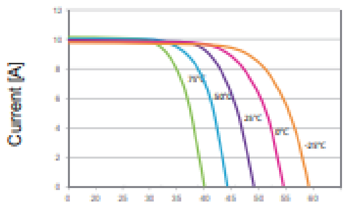
Chubb



CURRENT-VOLTAGE CURVES



Voltage [V]
Module characteristics at constant module temperatures of 25°C and variable levels of irradiance



Voltage [V]
Module characteristics at variable module temperatures and constant module irradiance of 1.000 W/m²

ESPSC TYPE	380M	385M	390M	395M	400M
Power Class	380Wp	385Wp	390Wp	395Wp	400Wp
Max. Power Voltage (V_{mpp})* at STC**	40.5V	40.8V	41.1V	41.4V	41.7V
Max. Power Current (I_{mpp}) at STC	9.39A	9.44A	9.49A	9.55A	9.60A
Open Circuit Voltage (V_{OC}) at STC	48.9V	49.1V	49.3V	49.5V	49.8V
Short Circuit Current (I_{SC}) at STC	9.75A	9.92A	10.12A	10.23A	10.36A
Module Efficiency	19.16%	19.42%	19.67%	19.92%	20.17%

* MPP: Maximum Power Point
** STC (Standard Test Conditions): 1000W/m², 25°C, AM 1.5
*** Normal Operating Cell Temperature

III.3 Inverter

INGECON SUN 3Play Serie TL

100TL

INVERSOR DE STRING TRIFÁSICO SIN TRANSFORMADOR Y CON LA MÁXIMA DENSIDAD DE POTENCIA

Familia de inversores trifásicos para plantas fotovoltaicas comerciales, industriales y de gran escala.

Mayor competitividad
Gracias a su mayor potencia de salida (hasta 110 kW si el equipo se conecta a una red de 440 Vac), el nuevo INGECON® SUN 100TL permite una drástica reducción del número de inversores requeridos para el diseño de una planta fotovoltaica. Así, minimiza el gasto en mano de obra y cableado total. Es más, gracias a este equipo se puede ahorrar hasta un 20% en cableado AC, ya que no requiere cable de neutro.

Además, este inversor no necesita cajas de conexiones ni en DC ni en AC. Todo ello garantiza los menores gastos de capital o CAPEX (Capital Expenditures).

Menores costes operacionales
Gracias a la red de comunicación inalámbrica que se puede establecer con el INGECON® SUN 100TL, la planta FV puede ser puesta en marcha, monitorizada y controlada sin cables. Además, su filosofía de inversor de string permite una fácil y rápida sustitución que no precisa de técnicos cualificados.

Mayor flexibilidad y densidad de potencia
La mayor flexibilidad es posible gracias a sus elevados índices de tensión DC máxima (1.100 V) y a su amplio rango de tensión MPP (570-850 V). Gran densidad de potencia, con hasta 105 kW en un inversor de tan sólo 75 kg.

Diseño duradero y robusto
Envolvente de aluminio, especialmente concebida para instalaciones de interior y exterior (IP65). El diseño de la familia INGECON® SUN 3Play garantiza la máxima durabilidad en el tiempo y las mejores prestaciones, incluso ante temperaturas extremas.

Ethernet y Wi-Fi de serie
Este inversor FV presenta comunicaciones Ethernet y Wi-Fi de serie. Estas comunicaciones, junto con el webserver que integra el equipo, permiten una rápida y fiable puesta en marcha usando un teléfono móvil, una Tablet o un PC portátil. Además, es compatible con Cloud Connect externo.

Garantía estándar de 5 años, ampliable hasta 25 años

www.ingeteam.com
solar.energy@ingeteam.com

Ingeteam

100TL

Diferentes versiones para elegir
Ingeteam ha creado dos versiones distintas para poder satisfacer todas las necesidades de sus clientes:

- Versión STD
- Versión PRO

Versiones disponibles	Versión STD	Versión PRO
Bornas DC	✓	
Conectores fotovoltaicos[1]		✓
Seccionador DC	✓	✓
Descargadores DC, tipo 2	✓	✓
Descargadores AC, tipo 2	✓	✓
Fusibles DC		✓ [2]
Kit de medida de corrientes		✓

Notas: [1] No necesita herramientas de crimpado [2] Fusibles de 1.500 V, sólo para el polo positivo.

PRINCIPALES CARACTERÍSTICAS

- Capacidad para soportar huecos de tensión.
- Capacidad para inyectar potencia reactiva.
- Compatible con Cloud Connect externo.
- Eficiencia máxima del 99,1%.
- Comunicaciones Ethernet y Wi-Fi de serie.
- Webserver integrado.
- Software de monitorización INGECON® SUN Monitor.
- Apto para instalaciones de interior y exterior (IP65).
- Alto rendimiento a altas temperaturas.
- Distintas versiones para ajustarse a todo tipo de proyectos.
- Compatible fuentes de alimentación nocturna.
- 4 entradas digitales y 2 salidas digitales.
- Apto para DRM0 (para mercado australiano).

PROTECCIONES

- Polaridad inversa.
- Cortocircuitos y sobrecargas en la salida.
- Anti-isla con desconexión automática.
- Fallo de aislamiento.
- Sobretensiones AC con descargadores tipo 2.
- Sobretensiones DC con descargadores tipo 2.

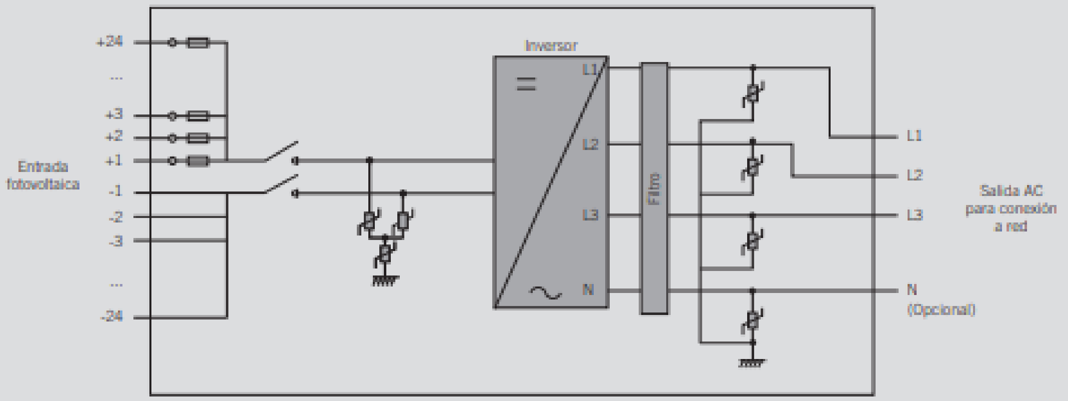
ACCESORIOS OPCIONALES

- Kit de autoconsumo.
- Comunicación RS-485.
- Fusibles DC para el polo negativo.

BENEFICIOS

- Mayor densidad de potencia.
- Mayor competitividad gracias a la reducción del gasto en cableado.
- Alta disponibilidad comparada con inversores centrales.
- Elevados índices de eficiencia.
- Fácil mantenimiento.

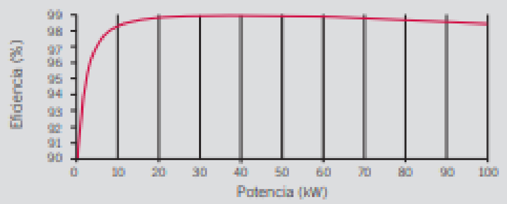
3Play TL versión PRO



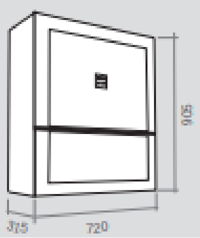
	100TL					
Valores de Entrada (DC)						
Rango pot. campo FV recomendado	56 - 80,2 kWp	91,1 - 130,5 kWp	96,2 - 137,8 kWp	101,2 - 145 kWp	106,3 - 152,3 kWp	111,3 - 159,5 kWp
Rango de tensión MPP[1]	513 - 850 V	513 - 850 V	541,5 - 850 V	570 - 850 V	598,5 - 850 V	627 - 850 V
Tensión máxima[2]	1.100 V					
Corriente máxima[3]	185 A					
Corriente de cortocircuito	240 A					
Entradas (STD / PRO)	1 / 24					
MPPT	1					
Valores de Salida (AC)						
Potencia nominal	55,3 kW	90 kW	95 kW	100 kW	105 kW	110 kW
Máx. temperatura a potencia nominal[4]	50 °C					
Corriente máxima	145 A					
Tensión nominal	220 V	360 V	380 V	400 V	420 V	440 V
Frecuencia nominal	50 / 60 Hz					
Tipo de red[5]	TT / TN					
Factor de Potencia	1					
Factor de Potencia ajustable[6]	Sí. Smáx=55,3 kVA Qmáx=33,2 kVAR	Sí. Smáx=90 kVA Qmáx=54 kVAR	Sí. Smáx=95 kVA Qmáx=57 kVAR	Sí. Smáx=100 kVA Qmáx=60 kVAR	Sí. Smáx=105 kVA Qmáx=63 kVAR	Sí. Smáx=110 kVA Qmáx=66 kVAR
THD	<3%					
Rendimiento						
Eficiencia máxima	99,1%					
Euroeficiencia	98,5%					
Datos Generales						
Sistema de refrigeración	Ventilación forzada					
Caudal de aire	570 m³/h					
Consumo en stand-by	20 W					
Consumo nocturno	1 W					
Temperatura de funcionamiento	-25 °C a 60 °C					
Humedad relativa (sin condensación)	0 - 100%					
Grado de protección	IP65 / NEMA 4					
Interruptor diferencial	1.000 mA					
Altitud máxima[7]	3.000 m					
Conexión	AC: Máxima sección: 240 mm² (un cable) Conexión DC (STD): Máxima sección: 300 mm² (un cable) Conexión DC (PRO): 6 mm2 (24 pares de conectores PV-Stick) Permitido el cableado en cobre y aluminio, tanto en DC como en AC					
Marcado	CE					
Normativa EMC y de seguridad	IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3, IEC 61000-6-4, IEC 61000-3-11, IEC 62109-1, IEC 62109-2, IEC 62103, IEC 61000-3-12, EN50178, FCC Part 15, IEC 60068-2-1, IEC 60068-2-2, IEC 60068-2-14, IEC 60068-2-30, IEC 60068-2-68, IEC 60529					
Normativa de conexión a red	DIN V VDE V 0126-1-1, Arrêté du 23 avril 2008, EN 50438, EN 50439, EN 50549, CEI 0-21, CEI 0-16 VDE-AR-N 4105:2011-08, G59/3, P.O.12.3, AS4777.2, BDEW, IEC 62116, IEC 61727, UNE 206007-1, ABNT NBR 16149, ABNT NBR 16150, Brazilian Grid Code, South African Grid Code, Chilean Grid Code, DEWA 2.0, Jordanian Grid Code, Thailand MEA & PEA requirements					

Notas: [1] $V_{mpp,min}$ es para condiciones nominales (V_{ac}=1 p.u. y Factor de potencia=1). $V_{mpp,min}$ dependerá de la tensión de red (V_{ac}), de acuerdo con esta relación: $V_{mpp,min}=1.425 \cdot V_{ac}$ [2] El inversor no entra en funcionamiento hasta que Vdc <1.000 V. Si se han instalado los fusibles de DC para el polo negativo, la tensión máxima DC es de 1.000 V [3] La corriente máxima por conector FV es 11 A para la versión PRO [4] Por cada °C de aumento, la potencia de salida se reducirá un 2,3% [5] Estas unidades deberán conectarse a una red trifásica en estrella con neutro aterrado. No pueden ser conectadas a redes IT o redes delta aterradas en una de sus líneas [6] Q=0 fuera del rango de tensión MPP [7] Por encima de 1.000 m, la temperatura máxima para entregar potencia nominal se reduce a razón de 5,5°C por cada 1.000 m adicionales.

Rendimiento INGECON® SUN 100TL Vdc = 570 V



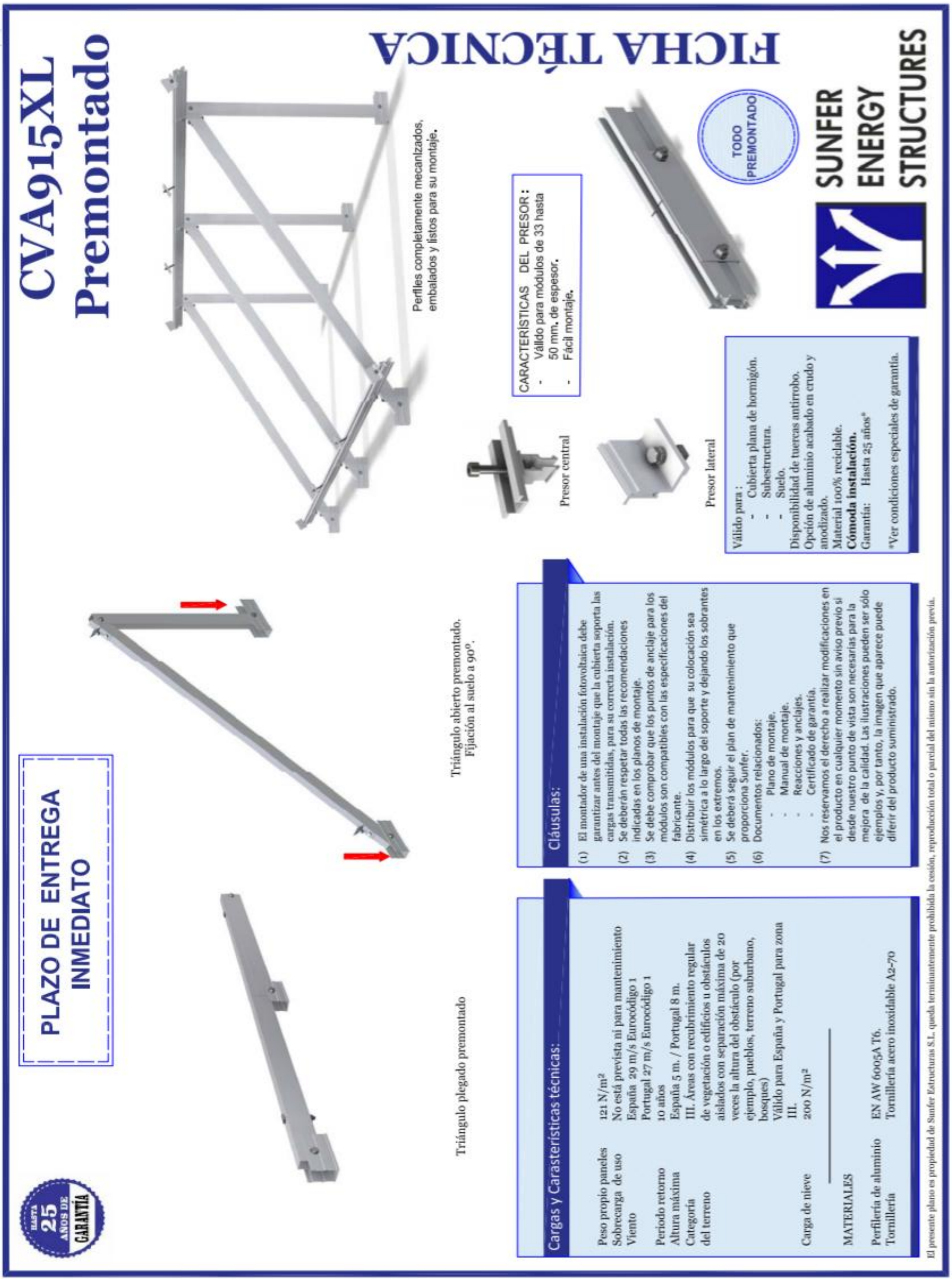
Dimensiones y peso (mm)



100TL STD
75 kg.

100TL PRO
78 kg.

III.4 Panel structure



HASTA 25 AÑOS DE GARANTÍA

PLAZO DE ENTREGA INMEDIATO

CVA915XL Premontado

FICHA TÉCNICA

Triángulo plegado premontado

Triángulo abierto premontado. Fijación al suelo a 90º.

Perfiles completamente mecanizados, embalados y listos para su montaje.

Presor central

Presor lateral

CARACTERÍSTICAS DEL PRESOR:
- Válido para módulos de 33 hasta 50 mm. de espesor.
- Fácil montaje.

TODO PREMONTADO

Cargas y Carasterísticas técnicas:

Peso propio paneles	121 N/m²
Sobrecarga de uso	No está prevista ni para mantenimiento
Viento	España 29 m/s Eurocódigo 1 Portugal 27 m/s Eurocódigo 1
Periodo retorno	10 años
Altura máxima	España 5 m. / Portugal 8 m.
Categoría del terreno	III. Áreas con recubrimiento regular de vegetación o edificios u obstáculos aislados con separación máxima de 20 veces la altura del obstáculo (por ejemplo, pueblos, terreno suburbano, bosques) Válido para España y Portugal para zona III.
Carga de nieve	200 N/m²

MATERIALES

Perfilería de aluminio	EN AW 6005A T6.
Tornillería	Tornillería acero inoxidable A2-70

Cláusulas:

(1) El montador de una instalación fotovoltaica debe garantizar antes del montaje que la cubierta soporta las cargas transmitidas, para su correcta instalación.
(2) Se deberán respetar todas las recomendaciones indicadas en los planos de montaje.
(3) Se debe comprobar que los puntos de anclaje para los módulos son compatibles con las especificaciones del fabricante.
(4) Distribuir los módulos para que su colocación sea simétrica a lo largo del soporte y dejando los sobrantes en los extremos.
(5) Se deberá seguir el plan de mantenimiento que proporciona Sunfer.
(6) Documentos relacionados:
- Plano de montaje.
- Manual de montaje.
- Reacciones y anclajes.
- Certificado de garantía.

(7) Nos reservamos el derecho a realizar modificaciones en el producto en cualquier momento sin aviso previo si desde nuestro punto de vista son necesarias para la mejora de la calidad. Las ilustraciones pueden ser sólo ejemplos y, por tanto, la imagen que aparece puede diferir del producto suministrado.

Válido para:
- Cubierta plana de hormigón.
- Subestructura.
- Suelo.

Disponibilidad de tuercas antirrobo.
Opción de aluminio acabado en crudo y anodizado.
Material 100% reciclable.
Cómoda instalación.
Garantía: Hasta 25 años*

*Ver condiciones especiales de garantía.

SUNFER ENERGY STRUCTURES

El presente plano es propiedad de Sunfer Estructuras S.L. queda terminantemente prohibida la cesión, reproducción total o parcial del mismo sin la autorización previa.

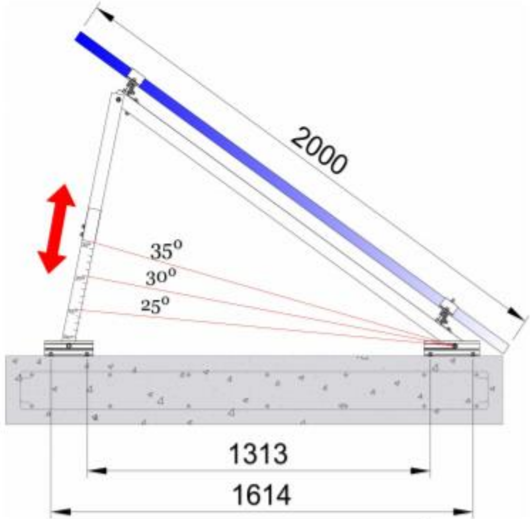
12V

Soporte inclinado abierto regulable para cubierta plana, vertical

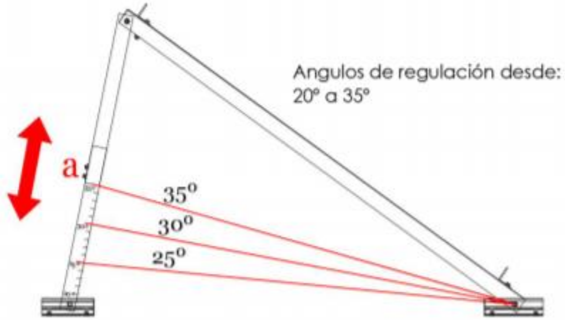
Válido para:
- Cubierta plana de hormigón, subestructura.
- Soporte premontado.
- Anclaje a hormigón.
- Regulable de 20° a 35°

- Tornillería de anclaje NO incluida

Disponibilidad de tuercas antirrobo.
Material 100% reciclable.
Cómoda instalación.



Distancia máxima entre pórticos: ≤1850 mm.

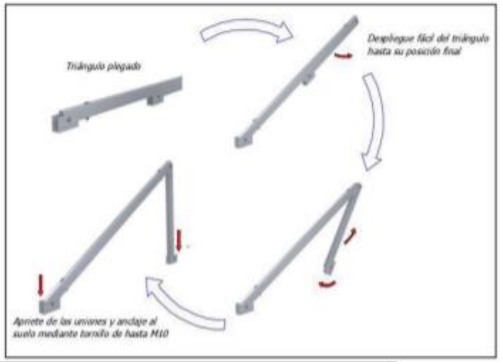


El kit incluye:

Triángulos 12V
Perfiles G1
Uniones UG1
Presores laterales
Presores centrales
Arriostramientos

Número de paneles
- Vertical: de 1 a 6 módulos
- Inclinaciones: Regulable de 20° a 35°

Para módulos de 60 y 72 células (1650/2000x1000) de 33 a 50 mm de espesor.



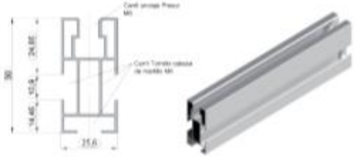
- Comprobar el buen estado de la cubierta y la capacidad portante de la misma.
- Comprobar la impermeabilidad de la fijación una vez colocada
- Distribuir los módulos para que su colocación sea simétrica a lo largo del soporte y dejando los sobrantes en los extremos.
- Los presores no se deben apretar con máquinas de impacto.
- Para el montaje de los arriostramientos consultar detalle de montaje en menú "Detalles y Accesorios"

Par de apriete:	
Tornillo Presor	7 Nm
Tornillo M8 Hexagonal	20 Nm
Tornillo M10 Hexagonal	40 Nm
Tornillo M6.3 Hexagonal	10 Nm

Viento	150 Km/h
MATERIALES	Perfilería de aluminio EN AW 6005A T6
TORNILLERÍA	Tornillería acero inoxidable A2-70

-Comprobar el buen estado de la cubierta y la capacidad portante de la misma.
-Comprobar la impermeabilidad de la fijación una vez colocada

Para más información consultar

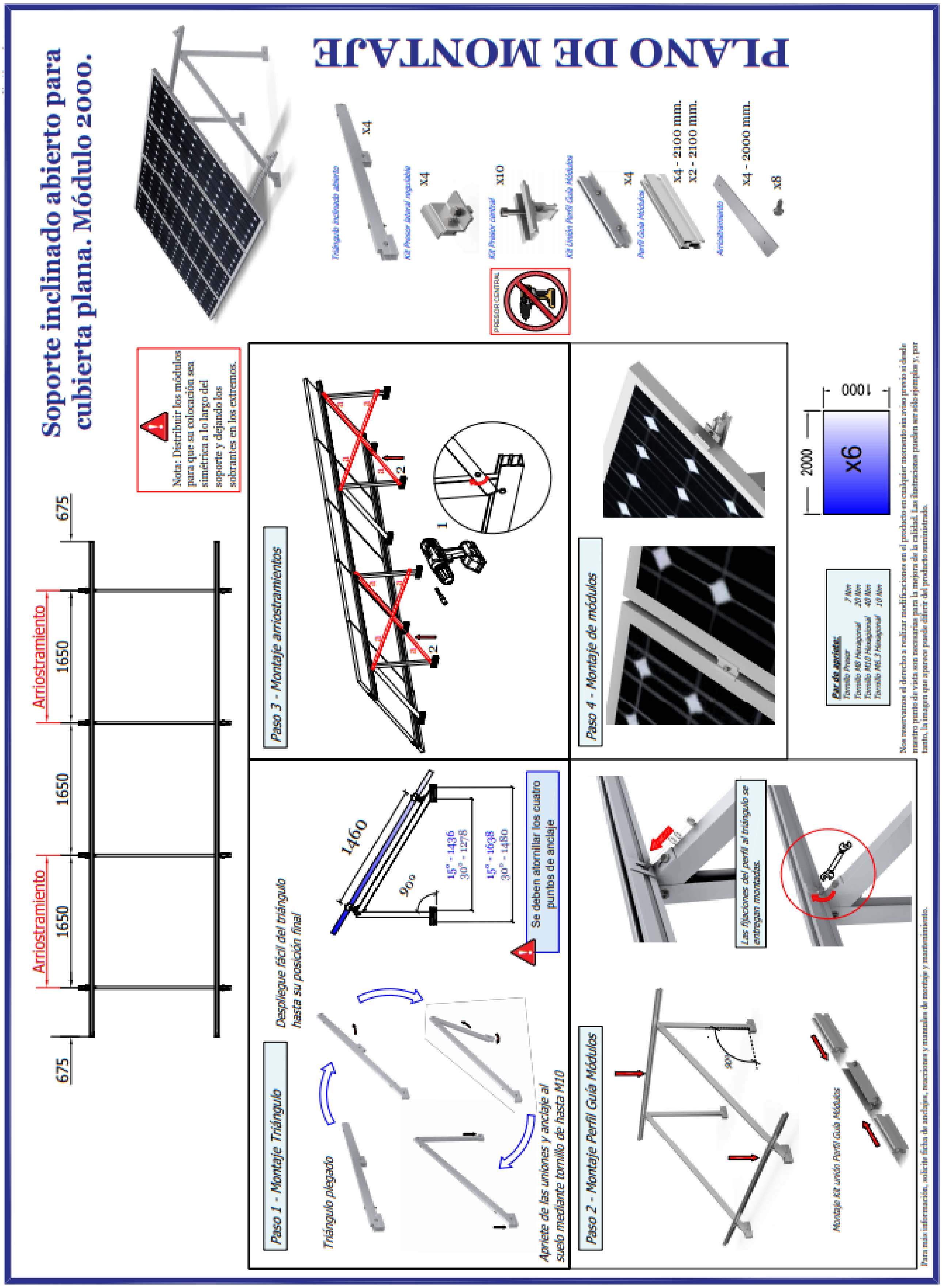


Perfil compatible: G1

Herramientas necesarias:

Seguridad:

Reservado el derecho a efectuar modificaciones · Las ilustraciones de productos son a modo de ejemplo y pueden diferir del original

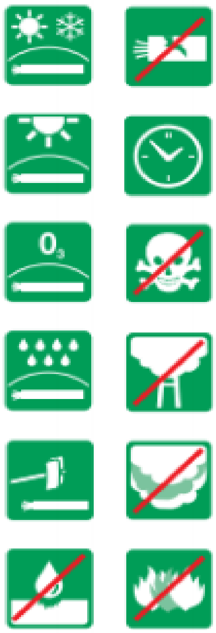

Soporte inclinado abierto para cubierta plana. Módulo 2000.
PLANO DE MONTAJE
675
1650
1650
1650
675
Arriostramiento
Arriostramiento
Nota: Distribuir los módulos para que su colocación sea simétrica a lo largo del soporte y dejando los sobrantes en los extremos.
X4
X4
X10
X4
X4 - 2100 mm.
X2 - 2100 mm.
X4 - 2000 mm.
X8
Paso 1 - Montaje Triángulo
Triángulo plegado
Despliegue fácil del triángulo hasta su posición final
Apriete de las uniones y anclaje al suelo mediante tornillo de hasta M10
1460
90°
Se deben atornillar los cuatro puntos de anclaje
Paso 2 - Montaje Perfil Guía Módulos
Las fijaciones del perfil al triángulo se entregan montadas.
Montaje Kit unión Perfil Guía Módulos
Paso 3 - Montaje arriostramientos
Paso 4 - Montaje de módulos
2000
1000
x6

III.5 DC Cabling between strings and junction boxes

exZhellent SOLAR XZ1FA3Z-K (AS) 1,8 kV DC - 0,6/1 kV AC

HUERTAS SOLARES **SERVICIO FIJO**

TENSIÓN 1,8 kV DC - 0,6 / 1 kV AC

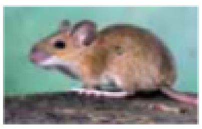


LA MEJOR PROTECCIÓN MECÁNICA DURANTE EL TENDIDO, LA INSTALACIÓN Y EL SERVICIO

EXZHELLENT SOLAR XZ1FA3Z-K (AS) 1,8 kV DC-0,6/1 kV AC

Conductor:	Cobre Clase 5 para servicio fijo (-k)
Aislamiento:	Polietilenio Reticulado XLPE (X)
Asiento de Armadura:	Poliolefina libre de halógenos (Z1)
Armadura:	Fleje corrugado de AL (FA3)
Cubierta:	Elastómero termoestable libre de halógenos (Z). Color Negro
Norma:	AENOR EA 0038

Ecológico



Resistente a la acción de los roedores

Código	Sección	Diámetro exterior	Peso	Radio Mín. Curvatura	Intensidad al Aire (1)	Intensidad Enterrado (2)	Caída tensión en DC
	mm²	mm²	kg/km	mm²	A	A	V/A.km
1618110	1x10	12,0	230	120	80	77	4,87
1618111	1x16	13,0	290	130	107	100	3,09
1618112	1x25	14,8	405	150	140	128	1,99
1618113	1x35	15,9	510	160	174	154	1,41
1618114	1x50	17,5	665	175	210	183	0,984
1618115	1x70	19,8	895	200	269	224	0,694
1618116	1x95	21,6	1.125	220	327	265	0,525
1618117	1x120	23,6	1.390	240	380	302	0,411
1618118	1x150	25,6	1.695	260	438	342	0,329
1618119	1x185	27,5	2.010	275	500	383	0,270
1618120	1x240	30,8	2.615	310	590	442	0,204
1618121	1x300	34,4	3.245	345	659	500	0,163

(1) Al aire a 40°C según UNE 20460-5-523 Tabla A.52-1 bis Método F, 2 conductores cargados
(2) Enterrado, 25°C, 0,7 m de profundidad, 1,5 K m/W según UNE 20460-5-523 Tabla A.52-2 bis Método D

III.6 Wire mesh cable tray (connection of modules in series)

Surface treatments for all environments

Codifications

EZ = Electro-Zinc
HDG = Hot-Dip Galvanized
ZA, ZM = Performa Zinc+
SS = Stainless Steel
PG = Pre-Galvanized
LZ = Lamellar Zinc

	Electro-zinc EZ	Hot-dip galvanized HDG	Performa Zinc+ ZA, ZM	Stainless steel SS
Indoor installations, not aggressive atmosphere (office building, commercial malls)				
Indoor installations, aggressive atmosphere, tunnels, underground				
Outdoor installation, urban location				
Chemical industries, acid and alkaline atmosphere				
Harbours, marines, water treatment				
Food industry				
Atmosphere with halogen				

Recommended

Possible to a certain extent. In case of doubt, please contact Schneider Electric.

EZ: Electro-Zinc (according to EN 12329-1) is a process that deposits a thin layer of zinc over the steel through an electro-chemical process, with an additional passivation that gives a typical shiny grey colour. The benefits of this process are control over zinc thickness and smoother surfaces.

HDG: Hot-Dip Galvanized (EN ISO 1461) is the process of coating steel with a zinc layer, by passing the steel through a molten bath of zinc at a temperature of more than 400 °C. The result is a surface treatment that protects the steel from environmental elements.

ZA: Performa Zinc+ surface treatment for mesh trays (EN 10244/2) with corrosion resistance exceeding that of HDG surface treatment. Excellent surface finish with self-repairing protection (galvanic protection).

ZM: Performa Zinc+ surface treatment for support and accessory system (EN 10346) with corrosion resistance exceeding that of HDG surface treatment. Excellent surface finish with self-repairing protection (galvanic protection).

SS: Stainless Steel AISI 304 (EN 10088-2) offers a high resistance to aggressive atmospheres. The pickling and passivation processes taking place after manufacturing improve the degree of protection of the steel.

PG: Pre-Galvanized steel (EN 10346) is carbon steel that has gone through a zinc bath just after rolling. Good protection against oxidation and rust.

LZ: Lamellar Zinc is a zinc and aluminium coating with a degree of resistance to severe atmosphere comparable to that of hot-dip galvanised steel. It is used for small items to achieve a smooth surface.

Product data sheet
Characteristics

CSU4518110
Performa - mesh tray - ZnAl (Zinc-Aluminium) - 35 mm x 100 mm x 3000 mm

Main

Range of product	Performa
Product or component type	Mesh tray
Quantity per set	24 m

Complementary

Shape	U-shape
Material	Steel (zinc+)
Atmospheric-corrosivity category	C3/C4
Longitudinal wire diameter	3.9 mm
Transversal wire diameter	3.9 mm
Cable cross section	2688 mm²
Standards	IEC 60068-2-75 EN 50102 DIN 4102-12 EN 10244-2 EN/ISO 9227 IEC 61537
Length	3 m
Height	40 mm
Width	100 mm
Height compatibility	35 mm
Width compatibility	100 mm
Surface treatment compatibility	Zinc+

Environment

Ambient air temperature for operation	-40…120 °C
IK degree of protection	IK10

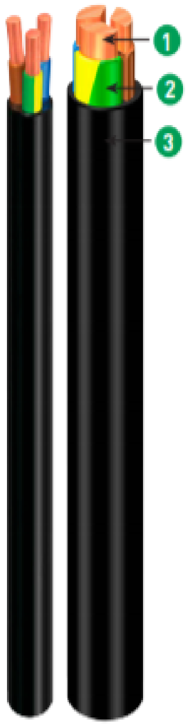
Packing Units

Package 1 Weight	917.000 g
Package 1 Height	35.000 mm
Package 1 width	100.000 mm
Package 1 Length	1000.000 mm

III.7 DC Cabling between junction boxes and inverters, and AC cabling

General Cable

Cable de Baja Tensión ENERGY RV-K FOC, Cobre, 0.6/1 kV, XLPE, Cubierta de PVC Flexible



Descripción

1. Conductor: Cobre, flexible clase 5.
2. Aislamiento: Polietileno reticulado (XLPE).
3. Cubierta Exterior: Policloruro de vinilo acrílico (PVC flexible).

Aplicaciones

• Los cables ENERGY RV-K FOC son cables flexibles para la utilización en la distribución de energía en baja tensión en instalaciones fijas de interior y exterior. Se distinguen por su flexibilidad y manejabilidad, que facilitan y ahorran tiempo en la instalación.

Características

• Cumplen en toda su gama con la No Propagación de la Llama según norma **UNE-EN 60332-1-2** (correspondiente a la norma internacional **IEC 60332-1-2**). La variante UNFIRE cumple además la No Propagación del Incendio según norma **UNE-EN 60332-3** (correspondiente norma internacional **IEC 60332-3**).

• A partir de la sección de 50 mm2 inclusive se ofrece la configuración SECTORFLEX con conductor sectoral flexible que, manteniendo idénticas prestaciones eléctricas y los mismos terminales y accesorios convencionales que el cable circular, consigue un menor diámetro y peso del cable, incrementando significativamente su manejabilidad y facilidad de instalación.

• Cables certificados con la marca AENOR.

• Temperatura máxima del conductor en servicio permanente 90ºC.

• Intensidades máximas admisibles en instalación al aire a 40 ºC conforme a **IEC 60364-5-52**, tabla A.52-12, tres conductores cargados, método de instalación F para cables unipolares y método de instalación E para cables multiconductores.

• Intensidades máximas admisibles para cables directamente enterrados a 25 ºC, 0,7 m profundidad y 1,5 K•m/W de conductividad térmica del terreno conforme a **IEC 60364-5-52**, tabla B.52-2.

Especificaciones de Referencia

UNE 21123-2 - Norma constructiva y de ensayos
IEC 60502-1 - Norma constructiva y de ensayos
UNE-EN 60332-1-2 - No propagador de la llama
IEC 60332-1-2 - No propagador de la llama

Información Técnica

Número de Parte	Calibre	Diámetro sobre el aislamiento	Peso total aprox.	Radio de curvatura	*Ampacidad 40°	*Ampacidad 25°	Caída de Tensión V↓ cosφ=0.8	Caída de Tensión V↓ cosφ=1
	mm^2	mm	kg/km	mm	A	A	V/A.km	V/A.km
1994106	1x1.5	5.7	45	25	19	25	23.65	29.37
1994107	1x2.5	6.1	60	25	27	33	14.24	17.62
1994108	1x4	6.7	75	30	37	43	8.873	10.93
1994109	1x6	7.2	95	30	48	54	5.95	7.288
1994110	1x10	8.2	140	35	67	71	3.484	4.218
1994111	1x16	9.2	195	40	91	93	2.24	2.672
1994112	1x25	10.8	285	45	122	118	1.476	1.723
1994113	1x35	11.9	375	50	153	143	1.073	1.224
1994114	1x50	13.5	515	55	188	170	0.773	0.852
1994115	1x70	15.6	710	65	243	209	0.568	0.601
1994116	1x95	17.4	920	70	298	248	0.449	0.455
1994117	1x120	19.4	1160	80	348	283	0.368	0.356
1994118	1x150	21.4	1435	90	404	319	0.311	0.285
1994119	1x185	23.3	1735	95	464	358	0.27	0.234
1994120	1x240	26.6	2290	135	552	413	0.223	0.177
1994121	1x300	30.2	2885	155	639	466	0.193	0.142
1994122	1x400	34.8	3920	175	748	544	0.164	0.107
1994123	1x500	39.1	5015	200	860	614	0.146	0.085
1994124	1x630	43.7	6585	220	990	693	0.128	0.063
1994206	2x1.5	8.6	100	35	23	30	23.61	29.37
1994207	2x2.5	9.4	130	40	32	39	14.2	17.62
1994208	2x4	10.5	170	45	44	52	8.839	10.93
1994209	2x6	11.6	220	50	57	66	5.919	7.288
1994210	2x10	13.5	330	55	78	85	3.458	4.218
1994211	2x16	15.5	465	65	104	112	2.218	2.672
1994212	2x25	18.8	700	75	135	142	1.458	1.723
1994213	2x35	21.2	940	85	168	171	1.057	1.224
1999214	2x50	21.3	1160	85	204	203	0.759	0.852
1999215	2x70	24.7	1600	100	262	250	0.556	0.601
1999216	2x95	27.7	2075	140	320	297	0.438	0.455
1999217	2x120	31.3	2640	160	373	338	0.358	0.356
1999218	2x150	34.5	3255	175	430	382	0.302	0.285
1999219	2x185	37.8	3950	190	493	427	0.262	0.234
1999220	2x240	43.3	5220	220	583	493	0.215	0.177
1994306	3G1.5	9.0	115	40	23	30	23.61	29.37
1994307	3G2.5	9.9	155	40	32	39	14.2	17.62
1994308	3G4	11.1	205	45	44	52	8.839	10.93
1994309	3G6	12.3	275	50	57	66	5.919	7.288
1994310	3G10	14.3	415	60	78	85	3.458	4.218
1994311	3G16	16.5	600	70	104	112	2.218	2.672
1994311	3x16	16.5	600	70	91	93	2.218	2.672

Nota: * Variable de acuerdo a tipo y lugar de instalación.

Número de Parte	Calibre	Diámetro sobre el aislamiento	Peso total aprox.	Radio de curvatura	*Ampacidad 40°	*Ampacidad 25°	Caída de Tensión V↓ cosφ=0.8	Caída de Tensión V↓ cosφ=1
	mm^2	mm	kg/km	mm	A	A	V/A.km	V/A.km
1994312	3x25	20.0	900	80	115	118	1.458	1.723
1994313	3x35	22.7	1225	95	143	143	1.057	1.224
1999314	3x50	24.9	1555	100	174	170	0.759	0.852
1999315	3x70	29.2	2170	150	223	209	0.556	0.601
1999316	3x95	32.5	2805	165	271	248	0.438	0.455
1999317	3x120	36.7	3560	185	314	283	0.358	0.356
1999318	3x150	40.6	4415	205	363	319	0.302	0.285
1999319	3x185	44.3	5340	225	414	358	0.262	0.234
1999320	3x240	50.8	7050	305	489	413	0.215	0.177
1994321	3x300	64.1	10705	385	565	413	0.186	0.142
1994406	4G1.5	9.9	140	40	20	25	23.61	29.37
1994407	4G2.5	10.9	185	45	29	33	14.2	17.62
1994408	4G4	12.2	255	50	38	43	8.839	10.93
1994409	4G6	13.5	340	55	49	54	5.919	7.288
1994410	4G10	15.8	525	65	68	71	3.458	4.218
1994411	4x16	18.3	760	75	91	93	2.218	2.672
1994411	4G16	18.3	760	75	91	93	2.218	2.672
1994412	4x25	22.4	1155	90	115	118	1.458	1.723
1994413	4x35	25.1	1560	125	143	143	1.057	1.224
1999414	4x50	27.5	2075	140	174	170	0.759	0.852
1999415	4x70	32.3	2900	165	223	209	0.556	0.601
1999416	4x95	35.6	3735	180	271	248	0.438	0.455
1999417	4x120	40.5	4770	205	314	283	0.358	0.356
1999418	4x150	44.6	5895	225	363	319	0.302	0.285
1999419	4x185	49.2	7190	250	414	358	0.262	0.234
1999420	4x240	56.4	9495	340	489	413	0.215	0.177
1994506	5G1.5	10.8	170	45	20	25	23.61	29.37
1994507	5G2.5	11.9	225	50	29	33	14.2	17.62
1994508	5G4	13.4	310	55	38	43	8.839	10.93
1994509	5G6	14.9	420	60	49	54	5.919	7.288
1994510	5G10	17.5	645	70	68	71	3.458	4.218
1994511	5G16	20.2	925	85	91	93	2.218	2.672
1994512	5G25	24.8	1410	100	115	118	1.458	1.723
1994513	5G35	27.8	1905	140	143	143	1.057	1.224
1994514	5G50	32.5	2670	165	174	170	0.759	0.852
1994515	5G70	39.6	4075	200	223	209	0.556	0.601
1994516	5G95	44.6	5320	225	271	248	0.438	0.455
1994517	5G120	50.4	6765	305	314	283	0.358	0.356
1994518	5G150	55.7	8360	335	363	319	0.302	0.285

Nota: * Variable de acuerdo a tipo y lugar de instalación.

III.8 Protection tubes for underground electrical conduits

IBK cables

Canalizaciones eléctricas subterráneas

Especificaciones

Tubería para protección de conducciones eléctricas, telecomunicaciones, de teledistribución, gas, agua, etc... Se trata de tubos de estructura celular, fabricados en polietileno cuya unión se realiza mediante manguitos. Los tubos deben su rigidez a la parte externa anillada que aumenta el momento de inercia de la pared del tubo. La pared interior lisa facilita el paso de los cables, fácil manipulación y fuerte resistencia al punzonamiento.

Datos Técnicos

- Temperatura de servicio: -25ºC a +100ºC.
- Material: Polietileno PEAD libre halógenos.
- Resistencia al aplastamiento: 250N ó 450N.
- Norma: UNE EN 61386.2.4.
- Suministro: en rollos (con guía) o barras de 6 mts.
- Accesorios: Manguitos, tapones y separadores.
- Color: rojo (otros colores, consultar).

Referencias

Imagen	Descripción	Referencia	Diám. Ext. (mm)	Diám. Int.Min (mm)	Diám. Int. (mm)	Resistencia al impacto ligero "L"	Resistencia al impacto normal "N"	Rollo (m.)
	Tubo Can. Sub. Rojo Ø 40 mm.	MOTD40L	40	30	31	3 J.	15 J.	50
	Tubo Can. Sub. Rojo Ø 50 mm.	MOTD50L	50	37	40	3 J.	15 J.	50
	Tubo Can. Sub. Rojo Ø 63 mm.	MOTD63L	63	47	50	6 J.	20 J.	50
	Tubo Can. Sub. Rojo Ø 75 mm.	MOTD75L	75	56	61	6 J.	20 J.	50
	Tubo Can. Sub. Rojo Ø 90 mm.	MOTD90L	90	67	75	6 J.	20 J.	50
	Tubo Can. Sub. Rojo Ø 110 mm.	MOTD110L	110	80	92	12 J.	28 J.	50
	Tubo Can. Sub. Rojo Ø 125 mm.	MOTD125L	125	94	107	12 J.	28 J.	50
	Tubo Can. Sub. Rojo Ø 160 mm.	MOTD160L	160	120	135	15 J.	40 J.	50
	Tubo Can. Sub. Rojo Ø 200 mm.	MOTD200L	200	150	170	15 J.	40 J.	25/50
	Tubo Can. Sub. Rojo Ø 250 mm.	MOTD250L	250	188	220	15 J.	40 J.	--
	Tubo Can. Sub. Rojo Ø 315 mm.	MOTD315L	315	237	276	15 J.	40 J.	--

Aplicaciones

Tubo protector de cables en instalaciones subterráneas eléctricas, de telecomunicación, teledistribución, agua, gas, señalización de vías férreas..., donde se requiera alta resistencia a las cargas estáticas y móviles.

III.9 Fuses and fuse holders

DF Electric

FOTOVOLTAICOS

FUSIBLES & BASES PORTAFUSIBLES PARA APLICACIONES FOTOVOLTAICAS

CIL gPV CILINDRICOS fusibles

Los fusibles cilíndricos 10x38 y 14x51 gPV DF Electric han sido desarrollados para ofrecer una solución de protección compacta, segura y económica de los módulos fotovoltaicos en tensiones hasta 1.000/1.100V DC.

Proporcionan protección contra sobrecargas y cortocircuitos (clase gPV de acuerdo a la Norma IEC 60269-6 y UL248-19).

Están construidos con tubo cerámico de alta resistencia a la presión interna y a los choques térmicos lo que permite un alto poder de corte en un reducido espacio. Los contactos están realizados en cobre plateado y los elementos de fusión son de plata, lo que evita el envejecimiento y mantiene inalterables las características.

Para la instalación de estos fusibles se recomienda la utilización de las bases modulares PMX.

10x38

U: 1000V DC
PODER DE CORTE: 30kA
NORMAS: UL

In (A)	REFERENCIA	EMBALAJE Uni /CAJA
1	491601	10/100
2	491602 UL	10/100
3	491604 UL	10/100
4	491605 UL	10/100
5	491606 UL	10/100
6	491610 UL	10/100
8	491615 UL	10/100
10	491620 UL	10/100
12	491625 UL	10/100
15	491629 UL	10/100
16	491630 UL	10/100
20	491635 UL	10/100
NEUTRO	431000	10/100

491635

14x51

In (A)	REFERENCIA	EMBALAJE Uni /CAJA
U: 1100V DC; PODER DE CORTE: 10kA		
15	491647	10/50
20	491648	10/50
U: 1000V DC; PODER DE CORTE: 30kA		
25	491650	10/50
32	491655	10/50
NEUTRO	432000	10/50

491655

df Electric

FOTOVOLTAICOS

FUSIBLES & BASES PORTAFUSIBLES PARA APLICACIONES FOTOVOLTAICAS

CIL gPV CILINDRICOS fusibles

Los fusibles cilíndricos gPV 10x85 y 10/14x85 DF Electric han sido desarrollados para ofrecer una solución de protección compacta, segura y económica de los módulos fotovoltaicos en tensiones hasta 1.200/1.500V DC.

Proporcionan protección contra sobrecargas y cortocircuitos (clase gPV de acuerdo a la Norma IEC 60269-6 y UL248-19). Están construidos con tubo cerámico de alta resistencia a la presión interna y a los choques térmicos. Los contactos están realizados en cobre plateado y los elementos de fusión son de plata, lo que evita el envejecimiento y mantiene inalterables las características.

Para estos fusibles recomendamos la utilización de bases portafusibles PML.

10x85

U 1500V DC
PODER DE CORTE 30kA
NORMAS UL

In (A)	REFERENCIA	EMBALAJE Uni /CAJA
2	492202 UL	10/50/1000
4	492205 UL	10/50/1000
6	492210 UL	10/50/1000
8	492215 UL	10/50/1000
10	492220 UL	10/50/1000
12	492225 UL	10/50/1000
15	492229 UL	10/50/1000
16	492230 UL	10/50/1000

U 1200V DC
PODER DE CORTE 10kA

In (A)	REFERENCIA	EMBALAJE Uni /CAJA
20	492235	10/50/1000
25	492240	10/50/1000
NEUTRO	431010	10/50/1000

492240

10/14x85

U 1500V DC
PODER DE CORTE 10kA

In (A)	REFERENCIA	EMBALAJE Uni /CAJA
20	492250	10/480
25	492255	10/480
30	492260	10/480
32	492262	10/480

492262

22x65

U 1500V DC
PODER DE CORTE 30kA

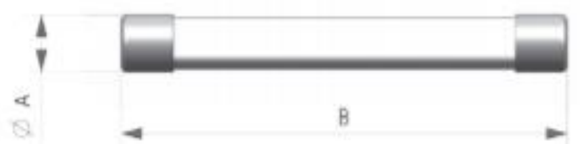
In (A)	REFERENCIA	EMBALAJE Uni /CAJA
40	492270	10/260
50	492275	10/260

492275

CIL 10x85 **gPV** CILINDRICOS fusibles

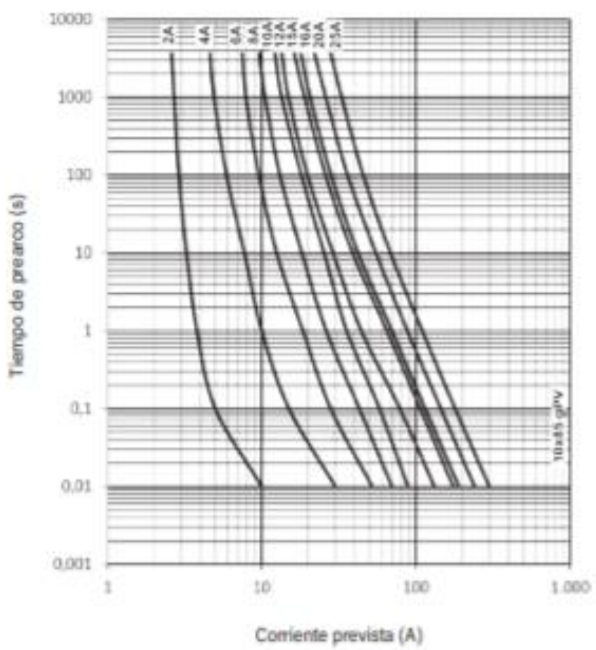
TENSION ASIGNADA	CORRIENTE ASIGNADA	PODER DE CORTE
1500V DC	2A..16A	30kA
1200V DC	20A I 25A	10kA

DIMENSIONES



A	B
10,3	85

CARACTERISTICAS t-I



POTENCIAS DISIPADAS

U	CORRIENTE ASIGNADA (A)	REFERENCIA	POTENCIAS DISIPADAS (W @ 0,7 In)	POTENCIAS DISIPADAS (W @ In)	I^2t PREARCO (A^2s)	I^2t TOTAL (A^2s)
1500V DC	2	**492202**	1,28	3,2	0,8	1,1
	4	**492205**	1,16	2,9	13	17
	6	**492210**	1,04	2,6	65	84
	8	**492215**	1,13	2,8	175	225
	10	**492220**	1,36	3,4	44	72
	12	**492225**	1,56	3,9	78	129
	15	**492229**	1,79	4,5	121	201
	16	**492230**	1,92	4,8	175	290
1200V DC	20	**492235**	2,04	5,1	242	478
	25	**492240**	2,20	5,5	545	1075

FOTOVOLTAICOS

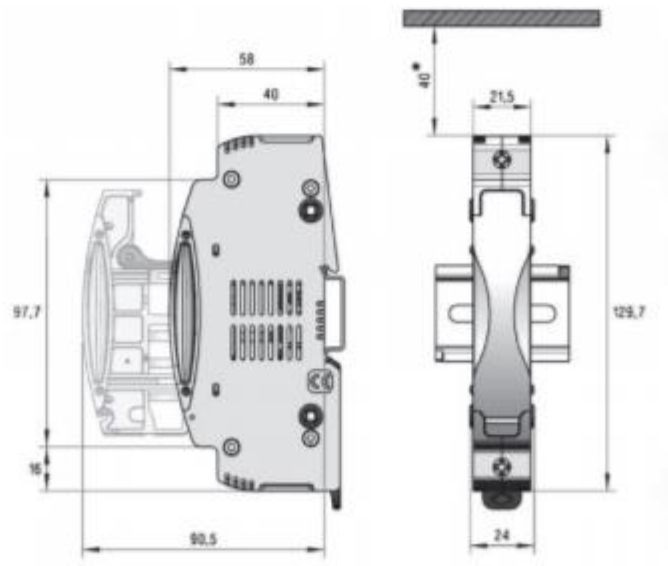
FUSIBLES & BASES PORTAFUSIBLES PARA APLICACIONES FOTOVOLTAICAS

PML 10x85 10/14x85

PML CILINDRICOS portafusibles

TENSION ASIGNADA	CORRIENTE ASIGNADA	INDICE PROTECCION
1000V DC	32A	IP20
1500V DC		

DIMENSIONES



* Espacio de montaje libre recomendado

posición **10x85**

posición **10/14x85**

ACCESORIOS

REFERENCIA	DESCRIPCION	EMBALAJE Un/CAJA
480005	PINZA PARA UNION MULTIPOLAR	12
485050	PASADOR PARA UNION MULTIPOLAR	12
485051	ACCESORIO DE BLOQUEO	5
485052	ACCESORIO PROTECCIÓN ESPECIAL IP20	24
485053	ACCESORIO SEPARADOR FASES	12
485656	ACCESORIO PROTECCION TORNILLOS	20

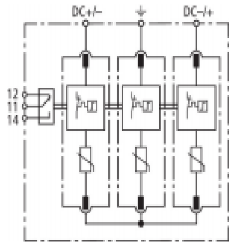
III.10 Surge arresters

Product Data Sheet: DEHNguard modular YPV ... FM

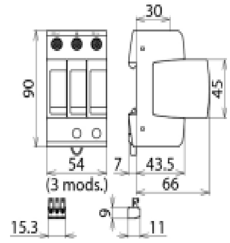
DG M YPV 1200 FM (952 565)

- Modular prewired complete unit for use in photovoltaic systems consisting of a base part and plug-in protection modules
- High reliability due to "Thermo Dynamic Control" SPD monitoring device
- Tried and tested fault-resistant Y circuit

Figure without obligation



Basic circuit diagram DG M YPV 1200 FM



Dimension drawing DG M YPV 1200 FM

Multipole modular surge arrester for use in PV systems; with remote signalling contact for monitoring unit (floating changeover contact).

Type **Part No.**	**DG M YPV 1200 FM** **952 565**
SPD according to EN 50539-11	type 2
Energy coordination with terminal equipment (≤ 10 m)	type 2 + type 3
Max. PV voltage (U_{CPV})	1170 V
Short-circuit current rating (I_{SCPV})	10 kA
Total discharge current (8/20 µs) (I_{total})	40 kA
Nominal discharge current (8/20 µs) [(DC+/DC-) --> PE] (I_n)	20 kA
Max. discharge current (8/20 µs) [(DC+/DC-) --> PE] (I_{max})	40 kA
Voltage protection level (U_P)	≤ 4 kV
Response time (t_A)	≤ 25 ns
Operating temperature range (T_U)	-40 °C ... +80 °C
Operating state / fault indication	green / red
Number of ports	1
Cross-sectional area (min.)	1.5 mm^2 solid / flexible
Cross-sectional area (max.)	35 mm^2 stranded / 25 mm^2 flexible
For mounting on	35 mm DIN rails acc. to EN 60715
Enclosure material	thermoplastic, red, UL 94 V-0
Place of installation	indoor installation
Degree of protection	IP 20
Capacity	3 module(s), DIN 43880
Approvals	UL, KEMA
Type of remote signalling contact	changeover contact
Switching capacity (a.c.)	250 V / 0.5 A
Switching capacity (d.c.)	250 V / 0.1 A; 125 V / 0.2 A; 75 V / 0.5 A
Cross-sectional area for remote signalling terminals	max. 1.5 mm^2 solid / flexible
Extended technical data:	--------------------------------
– Use in DC battery storage systems up to I_{SCCR}	≤ 50 kA (t ≤ 4 ms)
– Backup fuse for DC battery storage systems up to I_{SCCR}	Bussman HLS 2000Vdc / 200 A 2+/A173 DST aR, manufacturer's Part. No.: 170M2040
Weight	300 g
Customs tariff number (Comb. Nomenclature EU)	85363030
GTIN	4013364327719
PU	1 pc(s)

III.11 Cable glands

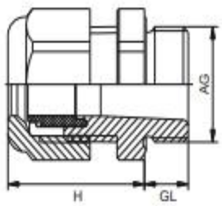
PRENSAESTOPAS DE PLÁSTICO

HSK-K | **Metr.-rosca larga**

Material	Poliamida V0 según UL 94
Junta	NBR
Protección	IP 68 – 10 bar / IP 69K con junta tórica adicional
Temperatura de trabajo	-40 °C – 100 °C
Colores	gris (RAL 7035), negro (RAL 9005), azul (RAL 5012) para seguridad intrínseca de rango "i"

ULfi En color negro

// Junta tórica adicional, consultar
// Por favor, localize la junta tórica adecuada en la página 88
// Otros materiales para juntas, por ejemplo Silicona, consultar
// Otros colores, consultar



AG	Ø mm	GL mm	H mm	mm	Referencia gris	Referencia negro	Referencia azul
M 12 x 1,5	3–6,5	15	21	15	1.209.1200.30	1.209.1201.30	1.209.1202.30
M 12 x 1,5	2–5	15	21	15	1.209.1200.31	1.209.1201.31	1.209.1202.31
M 16 x 1,5	4–8	15	22	19	1.209.1600.30	1.209.1601.30	1.209.1602.30
M 16 x 1,5	2–6	15	22	19	1.209.1600.31	1.209.1601.31	1.209.1602.31
M 16 x 1,5	5–10	15	25	22	1.219.1600.30	1.219.1601.30	1.219.1602.30
M 20 x 1,5	6–12	15	27	24	1.209.2000.30	1.209.2001.30	1.209.2002.30
M 20 x 1,5	5–9	15	27	24	1.209.2000.31	1.209.2001.31	1.209.2002.31
M 20 x 1,5	10–14	15	28	27	1.219.2000.30	1.219.2001.30	1.219.2002.30
M 25 x 1,5	13–18	15	31	33	1.209.2500.30	1.209.2501.30	1.209.2502.30
M 25 x 1,5	9–16	15	31	33	1.209.2500.31	1.209.2501.31	1.209.2502.31
M 32 x 1,5	18–25	15	39	42	1.209.3200.30	1.209.3201.30	1.209.3202.30
M 32 x 1,5	13–20	15	39	42	1.209.3200.31	1.209.3201.31	1.209.3202.31
M 40 x 1,5	22–32	18	48	53	1.209.4000.30	1.209.4001.30	1.209.4002.30
M 40 x 1,5	20–26	18	48	53	1.209.4000.31	1.209.4001.31	1.209.4002.31
M 50 x 1,5	32–38	18	49	60	1.209.5000.30	1.209.5001.30	1.209.5002.30
M 50 x 1,5	25–31	18	49	60	1.209.5000.31	1.209.5001.31	1.209.5002.31
M 63 x 1,5	37–44	18	49	65 / 68	1.209.6300.30	1.209.6301.30	1.209.6302.30
M 63 x 1,5	29–35	18	49	65 / 68	1.209.6300.31	1.209.6301.31	1.209.6302.31

III.12 Grounding spike

Picas y Accesorios de Puesta a Tierra
Conexiones

TARIFA ENERO 2019

CE

Picas de puesta a tierra
Picas 100 o 300 micras

Las picas de puesta a tierra están fabricadas con acero calibrado con un tratamiento superficial de cobreado electrolítico de 100 o 300 micras. Las picas de 100µ con diámetro 14,2 cumplen con la Norma UNE 202006 y poseen la certificación de AENOR.

Picas de puesta a tierra 100µ - Ø 14,2 mm

Código	Ref.	Dimensiones L	Dimensiones D	Bolsa	Caja	Palet	€
T101415	Picas tierra 100µ - Ø 14,2 Long 1,5 m	1,5 m	14,2 mm	10	100	400	18,86
T101420	Picas tierra 100µ - Ø 14,2 Long 2,0 m	2,0 m	14,2 mm	10	100	400	25,42

Picas de puesta a tierra 100µ - Ø 18,2 mm

Código	Ref.	Dimensiones L	Dimensiones D	Bolsa	Caja	Palet	€
T101820	Picas tierra 100µ - Ø 18,2 Long 2,0 m	2,0 m	18,2 mm	5	100	400	30,75

Picas de puesta a tierra 300µ - Ø 14,6 mm

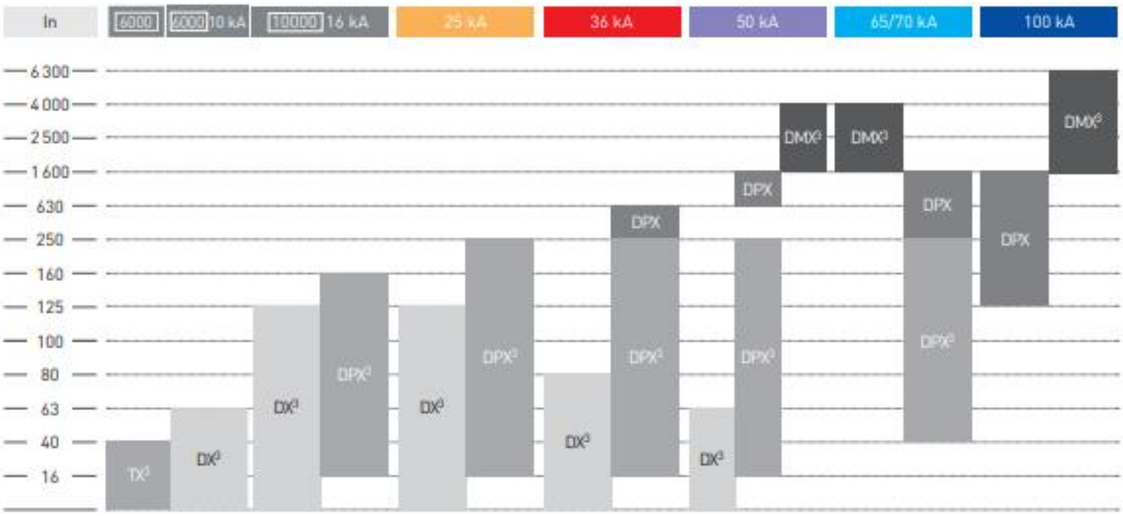
Código	Ref.	Dimensiones L	Dimensiones D	Bolsa	Caja	Palet	€
T301420	Picas tierra 300µ - Ø 14,6 Long 2,0 m	2,0 m	14,6 mm	10	100	400	30,75

III.13 Magnetothermic and differential switch

legrand

Una solución de potencia para cada poder de corte

El complemento perfecto para sus cuadros de hasta 6.300 A y 100 kA de poder de corte.



WWW.LEGRAND.ES

TX³/DX³ | LA NUEVA PROTECCIÓN MODULAR | 3

III.14 Triphasic wattmeter

EM24

CARLO GAVAZZI

Energy analyzer for three-phase systems

Benefits

- **Time saving set-up**, by frontal joystick and selector.
- **Error-proof installation,** by self-power supply and phase sequence detection.
- **Easy variable scrolling,** by means of the front joystick.
- **Wide interfacing capability,** choosing among 2 pulse outputs, the RS485, the M-Bus, Dupline or the Ethernet communication port.
- **Extended energy measurements,** using total/partial or total/multi-tariff metering.
- **Flexible installation,** by means of the direct connection up to 65 A or the connection of 5 A current transformers.
- **Extended alarm control** on any available variable by means of up to two digital outputs.
- **Legal metrology,** guaranteed by the MID approval

Description

Three-phase energy analyzer for DIN-rail mounting with configuration joystick, frontal selector and LCD display. Direct connection up to 65A or via current and voltage transformers. It can be equipped with 2 digital outputs (pulse transmission or alarm function). In alternative the Modbus RTU or Dupline communication port and 3 digital inputs, the M-Bus communication, or the Modbus TCP/IP Ethernet ports are available.

Applications

EM24 is perfect solution in any application, specially in building and industrial automation, for cost allocation, and for energy efficiency monitoring, legal submetering in commercial and residential installations, and wherever energy and main electrical variables monitoring is required.
EM24 is particularly suited for:
• energy efficiency monitoring
• cost allocation
• fiscal/legal sub-billing

Main functions

- Measurement of energy consumption and main electrical variables of single-phase, two-phase or three-phase loads.
- Display of single phase measurements and total measurements.
- Transmission of data via serial communication (Modbus RTU, M-Bus or Dupline) or Ethernet (Modbus TCP/IP).
- Transmission of power consumption via pulse output (optional).
- Easy connection function

EM24

CARLO GAVAZZI

Main features

- Energy measurements: total and partial kWh and kvarh or based on 4 different tariffs; single phase measurements
- Gas, cold water, hot water, kWh remote heating measurements
- TRMS measurements of distorted sine waves (voltages/currents)

Structure

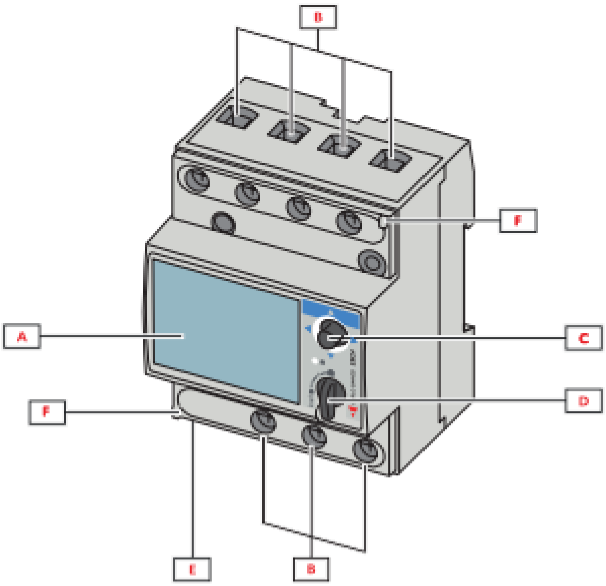


Fig. 1 *Direct connection*

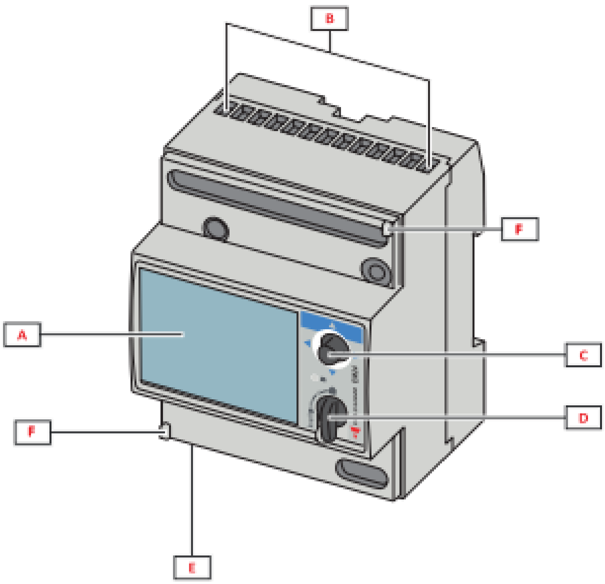


Fig. 2 *CT connection*

Area	Description
A	LCD display
B	Voltage/current connections
C	Joystick
D	Selector with pin for MID seal (programming block)
E	Inputs/outputs or communication port
F	Pins for MID seal (protection covers included)

Input and output insulation

Type	Measuring inputs	Relay outputs	Open collector outputs	Communication port and digital inputs	Dupline	Ethernet port	Self power supply	Auxiliary power supply
Measuring inputs	-	4 kV	4 kV	4 kV	4 kV	4 kV	0 kV	4 kV
Relay outputs	4 kV	-	-	-	-	-	4 kV	4 kV
Open collector outputs	4 kV	-	-	-	-	-	4 kV	4 kV
Communication port and digital inputs	4 kV	-	-	-	-	-	4 kV	4 kV
Dupline	4 kV	-	-	-	-	-	4 kV	4 kV
Ethernet port	4 kV	-	-	-	-	-	4 kV	-
Self power supply	0 kV	4 kV	4 kV	4 kV	4 kV	4 kV	-	-
Auxiliary power supply	4 kV	4 kV	4 kV	4 kV	4 kV	-	-	-

Compatibility and conformity

Directives	2011/65/EU (RoHs)
Standards	Electromagnetic compatibility (EMC) - emissions and immunity: EN 62052-11 Electrical safety: EN 61010-1, EN 50470-1 (MID) Accuracy: EN 62053-21, EN 62053-23, EN 50470-3 (MID) Pulse outputs: IEC 62053-31, DIN 43864
Approvals	CE c UL us LISTED (AV5, AV6 only, except M2) **MID** (PF only)

Electrical specifications

Voltage - MID models				
Voltage inputs	AV2	AV9	AV5	AV6
Voltage connection	Direct			
Rated voltage L-N (from Un min to Un max)	133 to 230 V	230 V	230 V	57.7 to 120 V
Rated voltage L-L (from Un min to Un max)	230 to 400 V	400 V	400 V	100 to 208 V
Voltage tolerance (*)	-20%, +15%			
Overload (**)	Continuous: 1.15 Un max			
Input impedance	Refer to "Power supply"			
Frequency	50 Hz			

III.15 Communications card

INGECON SUN EMS Board

LA GESTIÓN ENERGÉTICA MÁS EFICIENTE PARA EL AUTOCONSUMO

Los gestores energéticos INGECON® SUN EMS de Ingeteam (EMS: Energy Management System) están destinados a optimizar el consumo de energía en instalaciones de ámbito doméstico, comercial e industrial. Su objetivo es aumentar en todo momento la tasa de generación de energía desde fuentes renovables, en función de las necesidades de consumo de la instalación.

Gestor energético inteligente
La tarjeta de control INGECON® SUN EMS Board gestiona los flujos de energía de la instalación a partir de la lectura de un vatímetro colocado en el punto de conexión, enviando consignas de funcionamiento a los diferentes inversores. Este dispositivo de control y comunicación se coloca en el interior del inversor, simplificando y abaratando el conjunto de la instalación.

Conectividad avanzada
El INGECON® SUN EMS Board se conecta a los equipos de la instalación mediante su interfaz Ethernet o Wi-Fi (integrados de serie) y puede ser monitorizado con el software INGECON® SUN EMS Tools. Dicho software se utiliza también para configurar la estrategia de control del gestor EMS Board. Adicionalmente, este dispositivo cuenta con un puerto RS-485 para la comunicación con el vatímetro externo.

Máximo control de la energía consumida
El gestor energético de la instalación lleva un control exhaustivo de la cantidad de energía intercambiada con la red pública. Esta información es transferida en tiempo real desde el vatímetro al INGECON SUN® EMS Board, y estaría disponible para su visualización a través del software INGECON SUN® EMS Tools. Además, en el caso de una caída de red, la instalación puede operar en modo aislado si hay un sistema de almacenamiento acoplado a la instalación.

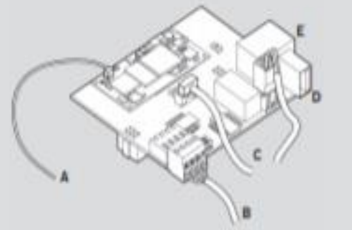
Múltiples instalaciones
Hay diversos tipos de sistemas que pueden ser controlados por un INGECON® SUN EMS Board:

- Autoconsumo con generación fotovoltaica.
- Autoconsumo con almacenamiento.
- Hibridación diésel-generación fotovoltaica.
- Hibridación red pública-diésel-generación fotovoltaica.
- Monitorización.

Garantía estándar de 3 años

	EMS Board
Suministro de potencia	
Tensión de entrada	100 - 240 Vac
Frecuencia nominal	50 / 60 Hz
Consumo de potencia	5 - 8 W
Posibilidad de alimentación AC externa	+5 Vdc
Conectividad	
Wi-Fi	✓
Ethernet	1
RS-485	1
Actualización de FW desde la nube	✓
Estrategias EMS avanzadas	✓
Compatible con IS Board Interface	✓
Compatible con IS Monitor	✓
Interfaz de comunicación con otros equipos	
Inversores Ingeteam	RS-485, Ethernet, Wi-Fi
Sistemas de monitorización	Ethernet, Wi-Fi, 3G(*)
Vatímetro	RS-485

(*) Se puede conectar un módem 3G externo usando la conexión Ethernet o Wi-Fi del dispositivo IS EMS Board.



A Antena Wi-Fi
B RS-485
C Fuente de alimentación externa +5 Vdc
D USB
E Ethernet

III.16 AC Control relay

SEMICODE ELECTRONICA

SC-ACRLA_I

SC-ACR-LA SERIES

THREE PHASE SCR AC REGULATORS

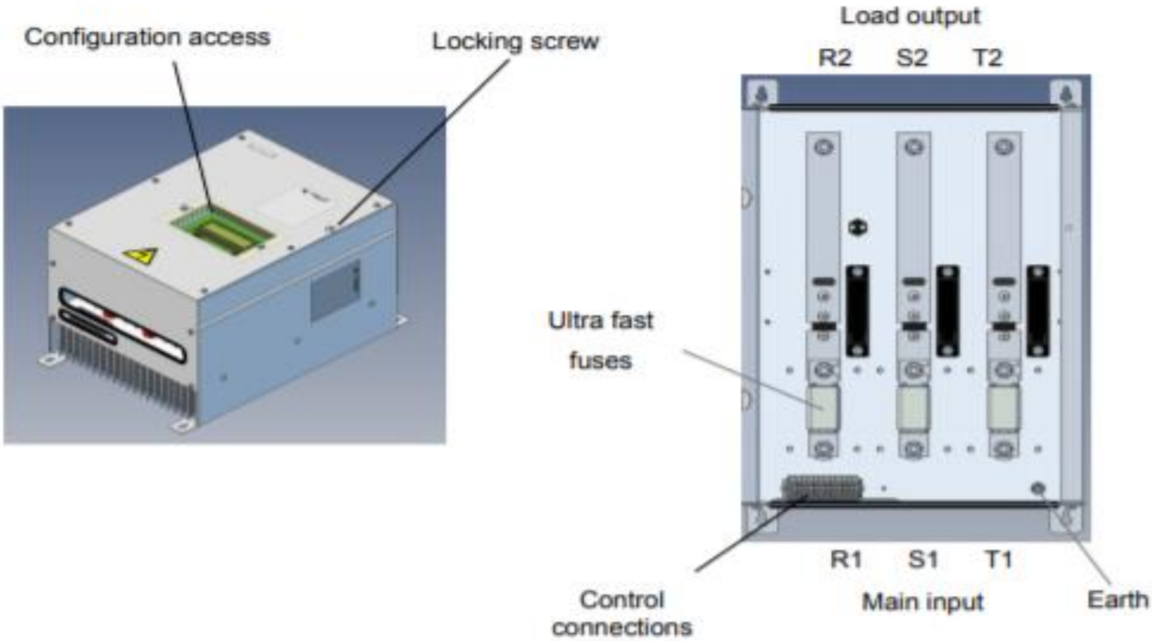
PRELIMINARY TECHNICAL INFORMATION

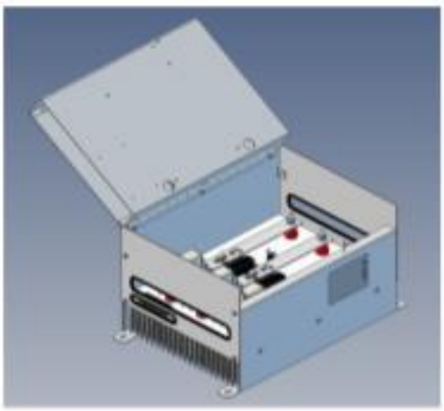
HIGLIGHTS

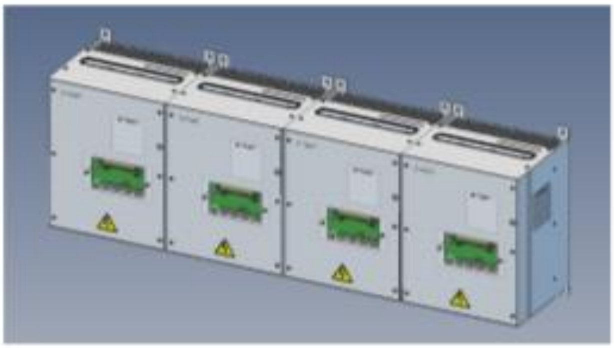
- Main power 230/400/480 V_{AC} / 50-60 Hz
- Ultra fast protection fuses included
- Multiple operating modes
- Multiple input levels
- Phase rotation protection
- LCD configuration / status indication
- LED indications of status
- Thermal protection with thermal switch
- Fault contact NC / NO

Non contractual image

GENERAL DESCRIPTION







®SEMICODE
ELECTRONICA
SC-ACRLA_i

RANGE AND CHARACTERISTICS

Reference	Cooling	I_{OUT} Nom (A_{AC})	Power (kW) 230V_{AC} 50/60Hz	400V_{AC} 50/60Hz	480V_{AC} 50/60Hz
SC-ACR400/025kW-LA	Natural	40	15 kW	25 kW	30 kW
SC-ACR400/050kW-LA	Natural	75	30 kW	50 kW	60 kW
SC-ACR400/075kW-LA	Natural	110	40 kW	75 kW	90 kW
SC-ACR400/100kW-LA	Natural	150	60 kW	100 kW	120 kW
SC-ACR400/125kW-LA	Natural	180	70 kW	125 kW	150 kW
SC-ACR400/180kW-LA	Forced	260	100 kW	185 kW	215 kW
SC-ACR400/250kW-LA	Forced	362	140 kW	250 kW	300 kW

Characteristics at T_A = 40ºC, 1000 m.a.s.l., full angle, working factor 100%

TERMINAL CONNECTIONS

Power terminal	Type	Conditions
Inputs R1, S1 y T1	M8	Torque: 10 Nm.
Outputs R2, S2 y T2		
Input fuses (1)		
Earth connection	M6	Torque: 4 Nm.

(1) The function of the included fuses is the protection of the semiconductor against short circuits, the installation must provide the adequate protection of cables via line fuses and / or magnetothermic. In case of replacement, fuses of the same type as the one supplied must be used and the replace the 3 of them.

Control terminal	Function	Conditions
1	Thermal protection jumper (NC contact) Option to connect external protections (external NC contacts) in series.	Snap in connection (without screws) Wire: 0.25-1 mm^2
2		
3	Common/GND for external potentiometer / control signal (1) (2)	
4	Input external potentiometer / control signal input (1) (2)	
5	Positive output for external potentiometer (1)	
6	Control power (230 V_{AC} to 480 V_{AC}; 50/60 Hz)	
7		
8	NC fault signal output	
9	Common/GND fault signal output	
10	NO fault signal output	
11	External inhibition input (3) NO contact (normally open)	
12		

Reserves the right to change limits, test conditions and dimensions given in this data sheet at any time without previous notice.

13 (4)	Neutral point of fan power
14 (4)	L1 phase fan power
15 (4)	L2 phase fan power
16 (4)	L3 phase fan power

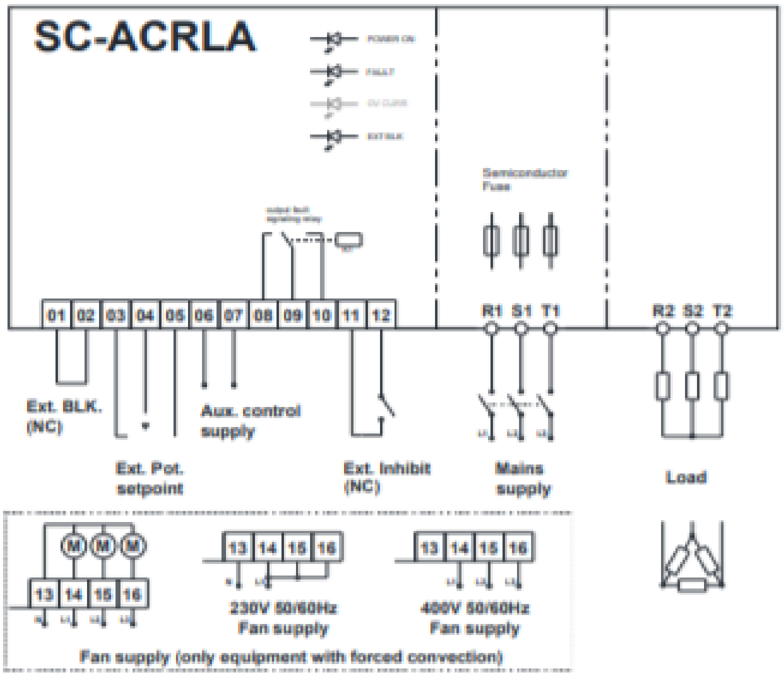
(1) Regulation with potentiometer: Any type of 4k7 linear type potentiometer can be used.
(2) Contol signal: 0-5 V / 0-10 V / 0-20 mA configurable by DIP-switch; 4-20 mA configurable through LCD.
(3) Signal of inhibition by external contact (by default NO, can be configured as NC).
(4) Only on equipment with forced convection.

MOUNTING

- Mount the equipment in its location using 4 M5 screws.
- Several equipment can be mounted together laterally.
- You should leave a minimum ventilation space at the bottom and top 100 mm.

CONNECTION

- Open the top cover of the control to access the power section (by loosening the locking screw).
- Make the earth connection (M6 threaded stud).
- Connect the control cables, the included terminals work with pressure terminal (without screws).
- Connect the power inputs and outputs to ensure proper tightening.
- Close the top cover using the locking screw.



The default configuration of the device is as follows:

- Phase angle control (PSA, see "OPERATING MODES)
- 0-5 V reference signal / External potentiometer (4k7)
- Inhibit contact NC (normally closed)