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University Degree in Energy Engineering

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Bachelor Thesis

"Electric Vehicle charging through a photovoltaic car park connected to the grid."

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ABSTRACT

This project examines the possibility and potential efficacy of a photovoltaic car park, whose intentions include the charging of electric vehicles and partial supply of power to a supermarket. The project will provide an in-depth look at the overall plant design as well as an analysis of the electric material necessary for such an installation.

Once the project´s objectives are determined, introductions to the photovoltaic energy and electric vehicle markets are made, providing context of the current situation. The environmental and socioeconomical impact that the installation may imply is also covered within the project. Afterwards, the placement of the facility is decided by carefully comparing the characteristics of the supermarket´s nearby locations.

With the location settled, there will be two case studies, CASE 1 and 2, for the charging of electric vehicles: a photovoltaic plant connected to the grid in self-consumption mode without discharge to the distribution network, and a photovoltaic plant connected to the grid in self-consumption mode with a storage system and without discharge to the distribution network, respectively.

Many factors are taken into consideration for the development of the two cases, including the variety of potential equipment to be used, the structure used to hold the photovoltaic modules and the optimal conditions for the generation of PV energy. In order to achieve the most suitable elements for the installation, the optimal arrangement of the modules and inverters and the magnitudes of the electrical equipment and materials are calculated.

With the results obtained from the calculations and simulations of both CASE 1 and 2, the efficiency of both photovoltaic circuits is contrasted, and an economic analysis is completed.

Finally, a conclusion section will be included to gauge whether or not the project would be a successful undertaking. The main conclusion reached is that it is possible to use photovoltaic energy to support the general sources of high-capacity commercial buildings. This achieves future economic benefit through a sustainable project, since CO2 emissions and other harmful elements that negatively affect climate change are significantly reduced, and contributes to the goal of substantially increasing the share of renewable energy in the global energy matrix.

Keywords: *photovoltaic cells, solar energy, energy consumption, charging stations, electric vehicles.*

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Natalia Gutiérrez Tovar.

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NOMENCLATURE

LIST OF ABREVIATIONS

PDN: Public distribution network

BOE: Boletín OFICIAL DEL estado, Official State Gazette.

SCB: String Combiner Box

REBT: Reglamento Electrotécnico para baja tensión

LVER: Low Voltage Electrotechnical Regulation

EV: Electric vehicle

PV, pv: Photovoltaic

MPPT: Maximum power point tracking

SAVE: Sistema de alimentación específico para vehiculos electricos

ITC: in spanish, Instrucciones Técnicas Complementarias

BT: in spanish, Baja Tension (Low Voltage)

IDEA: Instituto para la Diversificación y Ahorro de la Energía

DPSC: Double Parking Solar Canopy

SPSC: Single Parking Solar Canopy

AC: Alternating Current

DC: Direct Current

SOC: State of charge

C.D.B: commercial distribution box

STC: Standard Test Conditions

LIST OF VARIABLES

P_{contr}	contracted power	$I_{\max inverter\,(fv)}$	Maximum input DC current of the inverter
A_{sup}	total supermarket's surface area.	$I_{mpp(string)}$	passing current per string
Cs	coefficient of simultaneity	$N_{strings}$	number of strings
P_{plant}	Power of the plant	W_{usef}	usable and available width of the canopy
$P_{station}$	Power supplied by each charging station	d_{rows}	vertical distance between panels
$N_{stations}$	Number of stations	L_{usef}	usable and available length of the canopy
S_{panel}	Module´s surface	L_{max}	maximum length of the canopy
H_{panel}	Height of the panel	d_{col}	distance between pv module columns
W_{panel}	Width of the panel	$nº_{columns}$	number of sets of 9 module columns
α	angle between the panel´s horizontal axis and the support´s horizontal axis	$A_{usef.max}$	the maximum usable space on the canopy for hosting panels
$P_{inverter}$	nominal power of the inverter	$N_{SCB,in}$	number of PV strings coming from the panels per inverter
$P_{pv.strings}$	total peak power obtained from the strings of panels	$C_{E.V\ battery}$	size of the vehicle´s battery.
$N_{inverters}$	number of inverters	H_{EV}	charging time in hours
T_{cell}	Cell Temperature	r	battery acceptance rate
T_{amb}	Ambient Temperature	$H_{EV.max}$	longest charging time
$NOCT$	Minimum Irradiance	r_{max}	maximum acceptance rate
G	Nominal Operating Cell Temperature	$E.cons_{full-charge}$	consumption that must be covered for full charge
$V_{OC,max}$	maximum voltage drop of the pv modules	$N_{E.V}$	number of EVs that can be charged
V_{OC}	Open Circuit Voltage	DOD	Depth of discharge
$Tª Coef$	Temperature coefficient of Voc	C_{nom}	nominal capacity of the battery at 10 hour discharge
$N_{max.series}$	maximum number of pv panels in series per entrance to the inverter	$N_{cell.series}$	number of OPzS cells in series

$V_{max,inv}$	maximum voltage output from the chosen inverter	k	safety coefficient for losses.
N_{series}	number of modules in series	$V_{bat.cell}$	Voltage of a OPzS cell
$N_{max.strings}$	maximum number of strings that the inverter is able to bear	$V_{min.inve.bat}$	minimum voltage range of the inverter for batteries
$I_{max,adm}$	maximum admissible current	$I_{mp,SCB}$	AC Nominal Current
$I_{max,adm.table}$	maximum admissible current from table C-52	$d_{inv-c.g.p}$	Distance between the inverter and C.D.B
$I_{max,adm.circuitpart}$	maximum admissible current calculated	S_p	Section of protection conductors
ΔV_{CC}	DC voltage drop	I_n	Assigned current of the device
ρ_{40}	resistivity from copper at 40ºC	I_b	Current for which the circuit has been designed according to the load forecast
ρ_{20}	resistivity from copper at 20ºC	I_z	Permissible cable current depending on the installation system used
I_{mp}	Nominal Current	I_2	current that ensures the performance of the protection device for a long time, tc.
F	temperature correction factor	I_f	I_2 but for fuses
$S_{min,CC}$	Minimum cable section	t	time that the conductor is able to bear the short-circuit current.
$\Delta V_{CC.máx}$	Maximum voltage drop	K	cable constant
L	Length of the circuit	Isc	short circuit current
V_{series}	Voltage of modules in series per string	$I_{sc,max}$	maximum short circuit current.
L_i	Unspecific length	P_{cut}	circuit breaker power cut
k_s	Cable safety coefficient	R_a	sum of the resistances of the grounding connection and the protection of the conductive masses.
D_i	Unspecific distance	I_a	current that ensures the automatic operation of the protection device

H_{can}	Height of the canopy	U	conventional limit contact voltage
S_i	Unspecific space	R_{vs}	Resistance vertical spike
d_2	Pitch distance	$N_{tot.panels}$	Total number of panels
${N_{tot.panels}}^{C1-3}$	total number of panels that the largest canopies	${N_{tot.panels}}^{C2-4}$	total number of panels that the smallest canopies
L_c	Normalized PV set losses	L_s	Normalized system losses
$EArrRef_{year}$	Energy reference energy of the set	$EArray_{year}$	Effective energy at the output of the array
E_Grid_{year}	Energy that would be injected into the grid	P_{nom}	Nominal power generated by the PV modules
$GlobInc$	Global incident irradiance	$Area$	Surface area occupied by PV modules
$EffArrR$	Efficiency energy output of the array	$EffSysR$	Efficiency energy output of the system
PR	Performance ratio	Y_f	AC energy produced
Y_r	DC energy generated by the panels		

1. OBJECT

The main objective of the proposed project is to study the feasibility of four solar photovoltaic canopies located in a parking lot beside a supermarket. The panels that will be supported by the canopies will be connected to the supermarket´s commercial distribution box, C.D.B, to which 4 fast-charging electric vehicle stations are connected. The power generated will be primarily used to supply these stations and the supermarket´s loads.

The aim is to create a facility that will provide income in the future, when the Electric Vehicle industry has settled, as well as to utilize as much of the energy generated by the photovoltaic plant as possible, minimizing waste of electricity.

The photovoltaic plant will work as the generator. This way, the power generated will be used as the main source of electricity for both the EV charging stations and supermarket itself.

1.1 Project´s Objectives

More specifically, the project will seek to achieve the following goals:

1. Use as much of the energy generated by the plant as possible to minimize waste.
2. Minimize the supermarket´s consumption of energy from the grid.
3. Create a fast-charging station that can provide multiple chargers simultaneously and whose main electricity supply is a renewable source, in addition to being available 24 hours a day.
4. Design and study a solar facility that follows the Spanish Low Voltage Electrotechnical Regulation. (LVER).
5. Prioritize generation above overall costs.
6. Offer more than one option to choose from.

1.2 Scope

This project seeks to find the optimal photovoltaic plant design to obtain the highest possible generation. For this, the parts of the photovoltaic circuit necessary to carry out the project are described, detailing and justifying their use. In addition, a scale design with real measurements will be made in AutoCAD to approximate the installation measurements as closely as possible, and the calculations will be made with the LVER taken into consideration.

As it is at the same time a self-consumption facility without surplus, the requirements and conditions on this type of facility as described in the Official State Gazette, BOE, will be met.

1.3 Motivation

This project came to mind for three main reasons:

1- The number of EV vehicles in the market is constantly rising, with a relatively low number of fast charging stations to accommodate them. The need for these fast-charging stations has become more obvious as more industries make the transition towards green energy.
2- The settlement of photovoltaic energy as a relevant source for electric power in the past two years, since the Spanish government repealed the "Transitory Charge for self-consumed energy", commonly known as "sun tax", in October, 2018. This has allowed the sector to experience rapid expansion, especially regarding self-consumption, as the consumed energy coming from renewable sources is exempt from any tolls. [1]
3- The desire of big companies to become "sustainable – green" examples. This allows them to take advantage of the associated benefits, such as green tags and government incentives. There is also the certainty that renewable energy will prove to be worthwhile investment in itself, and provide economic benefits in the long-term. [2]

This project would operate allowing for the replacement of traditional reliance on fossil fuels with a new, cleaner form of energy to power supermarkets, while at the same time providing much-needed charging stations for the growing number of electric vehicles. Moreover, with the active efforts being made in both photovoltaic and EV sector, together with the obvious prioritization of renewable energy and significant increase in energy capacity, the photovoltaic car park for EV charging presents an unique opportunity to contribute towards a transition to 100% electric transport and 100% renewable energy use.

1.4 Methodology

To achieve the goals of this project, the following topics have been studied:

- Optimal location of the facility, taking into account the factors described in the corresponding section.
- Analysis of the desired capacity for the project.
- Installation development, including the consideration of various designs.
- Generation simulation of both facility options.
- Generation comparison between the designs.
- Drawing conclusions based on the results of study and calculation.

2. INTRODUCTION

As mentioned before, the main objective of the project is to complete the necessary aspects for the creation of a photovoltaic generation plant that will serve as an additional parking lot and recharging station. The power generated will be used mainly for the fast charging of type N1 electric vehicles and, for one of the case studies which will be discussed further, the power generated will also supply the charging of solar batteries that will serve as back-up. In addition, the new facility is intended to be used as a self-consumption installation without surplus. This means that while there are no cars charging and the solar batteries are fully charged, the power will be consumed by the supermarket.

During the project, aspects related to the operation of the photovoltaic installation are covered along with the materials and equipment necessary to carry it out, in addition to a brief preliminary study to calculate as precisely as possible the power that the EV chargers will require.

Before starting the project, it is important to analyze the context of the topics to be discussed: photovoltaic energy, the charging of electric vehicles and the trend towards renewables by large companies.

2.1 Renewable Energy in Spain

In accordance with the growing need for an eco-friendlier system and self-sustainability, Spain has placed a strong focus on renewable energy over the last decade and the industry has consequentially experienced a steep rise. In 2020, 46.4GW (4.639 MW) of renewable energy capacity were added, and 71.8GW (7.177MW) the year before. Most of this came in the form of photovoltaic energy, as shown in the chart represented in Figure 1. This rise was very deliberate and is representative of the shift in focus within the Spanish government compared to the six years prior. [3]

Due to these efforts, in 2020, 43.6% of Spain’s electricity was produced using renewable energy technologies. The 109,269GWh that this percentage accounts for was a rise of 11.6% on the year before.

While wind farms were the greatest producers of renewable energy in 2020, the photovoltaic sector experienced the highest rate of expansion, with a raised output of 65.9% on the year before. This sets a precedent for growth, and if it continues in this manner, it will dramatically increase its share of the total energy output. By the end of 2020, this figure stood at 6.1%. [3]

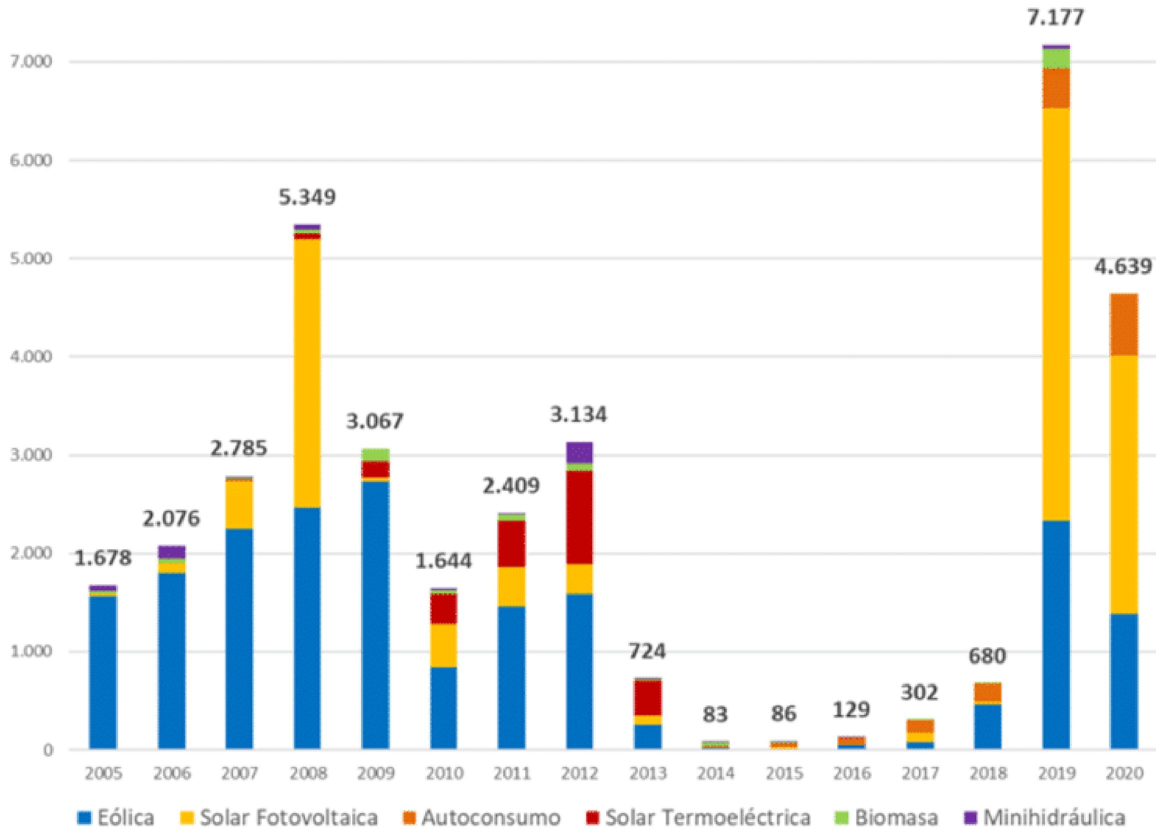


Figure 1. Megawatts of renewable energy in Spain among the recent decades [3]

2.2 Photovoltaic energy as a main renewable source.

As can be seen in Figure 1, Spain has focused on renewable energy in recent decades and, in particular, on photovoltaic solar energy during the last two years.

Energy forecasting predicts that photovoltaic energy will be the fastest growing renewable generation technology in the next decade. This prediction is based not only on the available statistics, but on clear statements from the National Energy and Climate Plan (NECP). The NECP intends for a 74% renewable electricity sector by 2030, and to have the sector powered totally by renewable energy by 2050. To reach this goal, it is expected that there will be 44MW of solar energy capacity by the time of its realization, 37MW of which will be photovoltaic. [4]

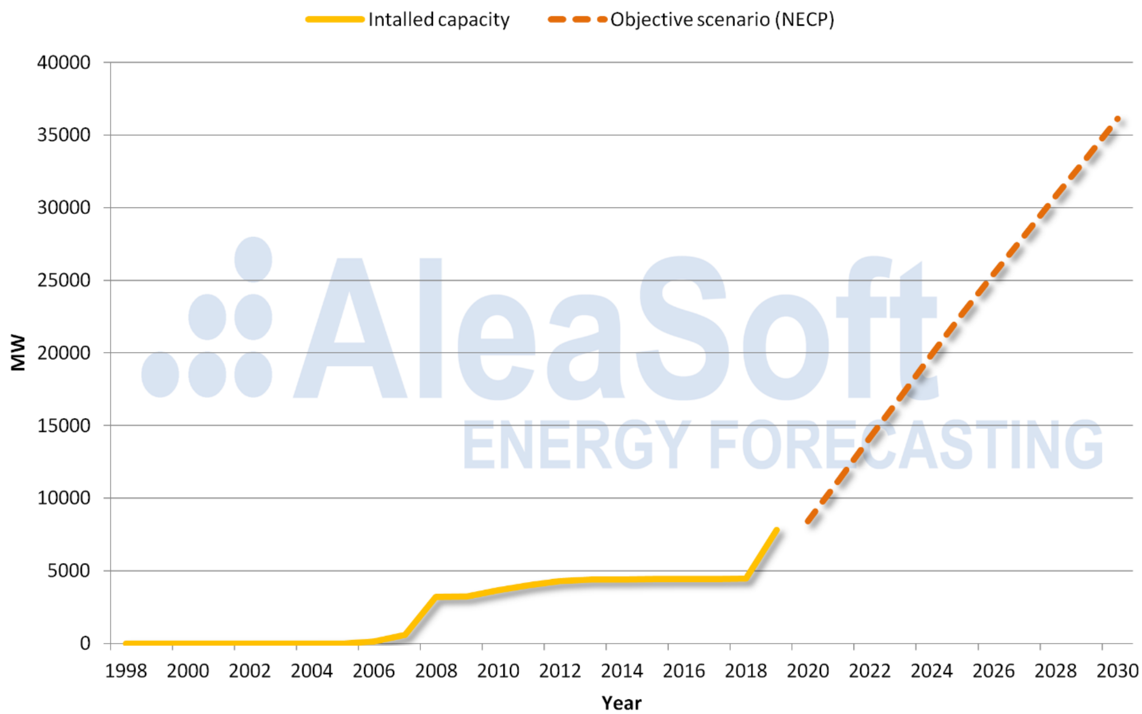


Figure 2. Photovoltaic installed power in mainland Spain [4]

This clear determination to make photovoltaic energy the main powerhouse of electricity in the country means that it will experience significant growth, even if it doesn't fully meet the expectations. For this reason, now is the perfect time to capitalize on the projected growth of photovoltaic energy.

Another advantage to using photovoltaic technology is that it is continuing to evolve. The conversion efficiency of the cell has risen by about 0.5% per year since 2010, which is both very consistent and a significant increase. The fact that the fuel used in this technology is free saves time and money, allowing specialists in the sector to focus these on advancing the hardware and optimizing functionality. Because of this, solar technology has seen many advancements over the past decade, including thinner cells through the introduction of the diamond wire saw, better conversion rates, PERC technology and bi-facial panels.

It may also be stated that solar technology requires truly little maintenance post-installation, due to the fact that the way in which they collect energy is quite passive, and physical intervention is rarely necessary. Many improvements have taken place in recent years to cut down the associated costs and improve the efficiency of this technology. [5]

2.3 The growing numbers of the Electric Vehicles market

The electric vehicle (EV) market in Spain has grown rapidly in recent years. In 2020, EV registrations were up by 64% compared to the previous year, and hybrid vehicle registrations were up by 213%. While this rise accurately depicts the success and popularity of the EV market in Spain, it also brings cause for concern. As can be seen below, projections for the future show steady growth, and as the number of electric vehicles increases, it is essential to be capable of facilitating so many with enough charging stations and energy capacity. [6][7]

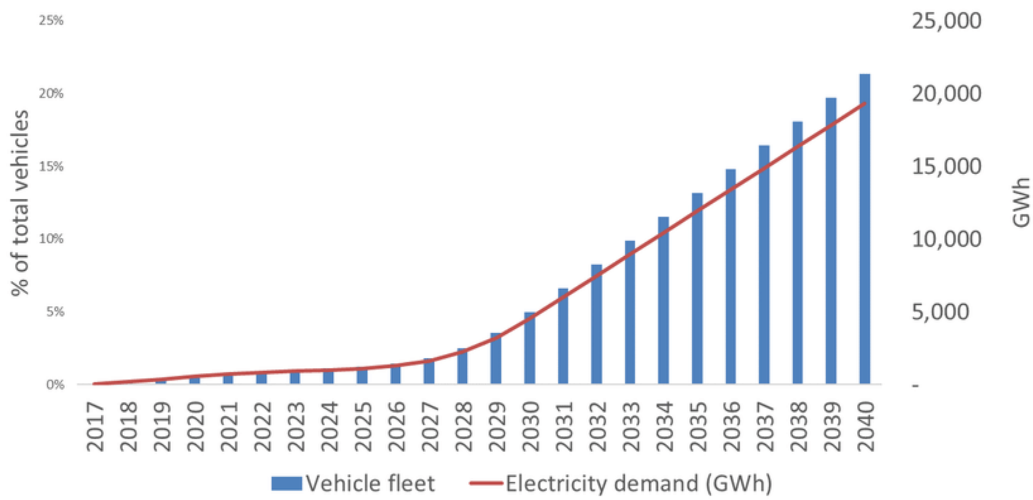


Figure 3. Increasing vehicle fleet and electricity demand [7]

According to the graph, both the demand for electricity and the percentage of vehicles which are electric will increase very consistently; however, from approximately 2028 onwards to 2040, it may prove challenging to accommodate such a high number of vehicles and high electricity demand without early preparation. Spain had approximately 26,000 electric vehicles by the end of 2019, working with a total of 8,000 charging points. To meet the projected market growth going forward, those numbers must increase drastically. [6]

In order to have 2.7 to 3.6 million electric vehicles by 2030, it is necessary to have 205,000 to 263,000 corresponding charging points to support them. Actions have already been taken to expand the infrastructure in this direction; Iberdrola recently signed a deal for approximately €60 million to build almost 2,500 additional charging stations on main roads across Spain. They also joined The Climate Group’s EV100 Initiative, a global effort to accelerate the transition to completely electric vehicles in order to reduce emissions and support a more sustainable, green system. [8][9][10]

2.4 Air Pollution and the impact of renewable energy and electric vehicles

Since 2018, Spain has experienced a steep rise in renewable energy capacity, in an effort to reduce the use of fossil fuels. This has contributed to a 55% reduction in the burning of coal for electricity and a 25% reduction in the consumption of natural gas. [11]

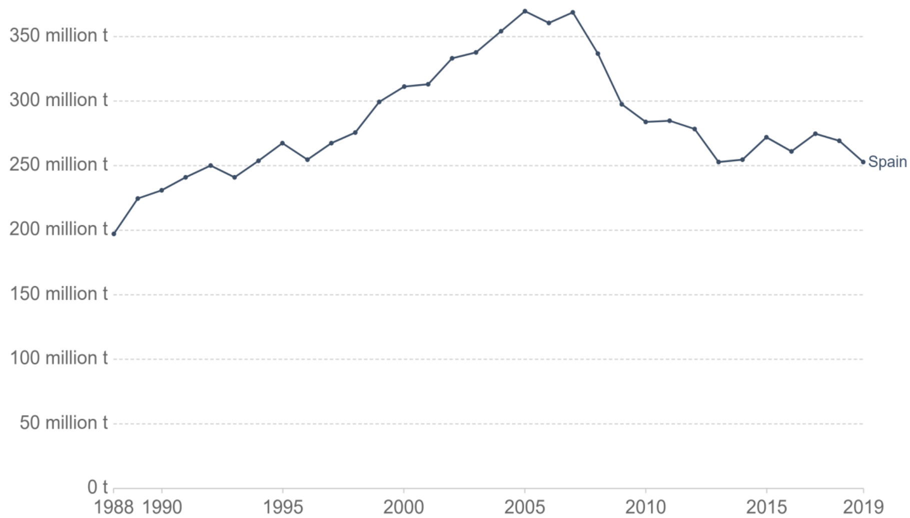


Figure 4. Carbon dioxide (CO2) emissions from the burning of fossil fuels for energy and cement production [12]

Also, since 2018, Spain has reduced its CO2 emissions by 22 million tons. Currently, the country is producing less CO2 than it was in the mid-1990s. This feat was achieved in part through a strong focus on the electric vehicle (EV) industry and the transition to renewable energy sources. In 2020, renewable energy accounted for 44% of the national total, with an increase in generation of almost 13% compared to 2019. These statistics led to the 'greenest' year in recorded Spanish history. [12][13]

Because of the dramatic increase in renewable energy capacity, the reduction in emissions from traffic and a generally smaller demand for electricity due to the pandemic, 2020 saw Spain's greenhouse gas emissions decrease by 27.8% from the year before. In February of 2021, 81.2% of electricity production came from technologies that do not emit CO2 equivalent. The generation of wind energy for the month was also 48.6% higher than the year before. [11][14]

2020 was a turning point for all of Europe as well, as renewable energy was responsible for 38% of overall electricity generation, one percent higher than fossil fuels. [15]

Though every form of renewable energy is being focused on more, the most rapidly increasing in Spain in 2020 was solar photovoltaic energy, which experienced a growth of 65% from 2019. Also, projections for the future by the National Energy and Climate Plan (NECP) show that solar photovoltaic energy will be prioritized. [13][4]

Spain has experienced significant air pollution in the last two decades. In 2017, a study conducted across the country discovered that 97% of the population was exposed to dangerous levels of pollution. The results of this study concluded that the highest contributor to the air pollution in urban areas was road traffic, due to emissions from the tailpipes of vehicles. One of the best solutions offered to this issue has been electric vehicles (EVs), which have been shown to significantly decrease the levels of CO2 emissions from road traffic. [16]

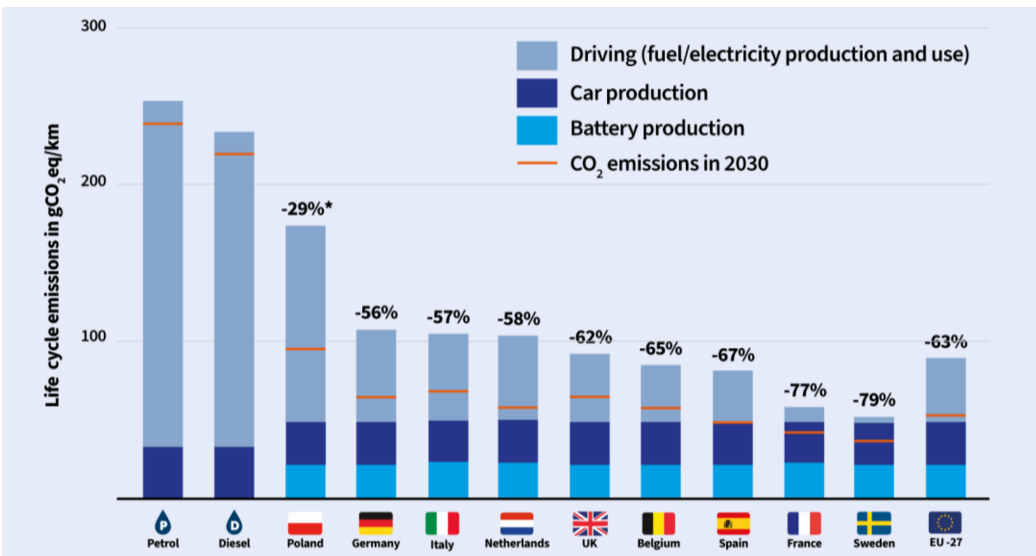


Figure 5. EV CO2 savings compared to the average of both diesel and petrol emissions [17]

As can be seen in the graph, electric vehicles offer a reduction in the amount of harmful CO2 emissions released. This is including all production processes involved in the batteries and vehicles, as electric vehicles do not emit any harmful gases from the tailpipe. This helps significantly to decrease air pollution in urban areas and allows for cleaner air and a healthier atmosphere. [17]

2.5 Renewable energy investments

Many companies around the world are investing in green energy and doing their part to contribute towards a more sustainable future. This was shown to a great extent in IRENA's White Papers, which document the efforts made by big companies such as Danfoss, Goess Brewery and Mars to transition to cleaner energy. Mars have even set a company-wide target of zero net emissions by 2040, and their company in Australia has already made the transition to 100% renewable power, indicating a clear shift of focus in the industrial world. [18][19]

This shift can be seen in projections for future investment in renewable energy, as displayed in the chart below (measured in billion USD):

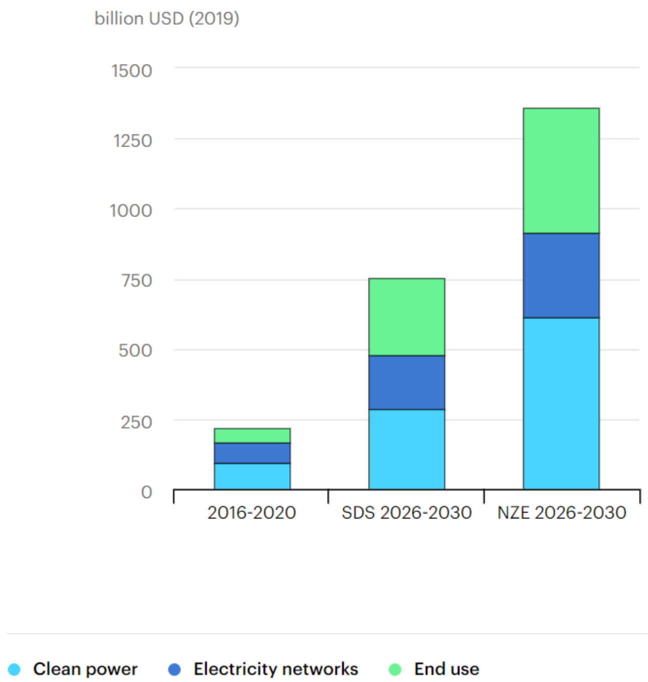


Figure 6. Average annual investment in clean enery, grid and power [20]

Setting a precedent for renewable energy in Spanish industries, and the consumer industry in particular, Carrefour recently made the decision to add wind energy to stores in three cities. Branches in Cordoba, Buenos Aires and Entre Rios will be powered using wind turbines. They will also implement LEDs and greener refrigeration equipment.

This is part of the overall effort being made by the Carrefour Group, which aims for a 55% reduction in carbon dioxide emissions by 2040. [21]

3. LOCATION OF THE INSTALLATION

When choosing the location of the photovoltaic installation, factors such as radiation, shading and ease of access had to be taken into consideration. Finally, a plot of land was chosen near the building of interest, which is a supermarket of the Spanish company Mercadona.

The terrain is located within 1 km of exit 5 of the A-42 motorway, and no more than 2 km from exit 27 of the M-40, one of the main motorways in Madrid. This means that the photovoltaic car park will not only be useful for locals, but also for anyone who wants to charge their EV while travelling. Additionally, the supermarket has more than one undeveloped terrain in its surroundings, offering several options for where to install the photovoltaic car park.

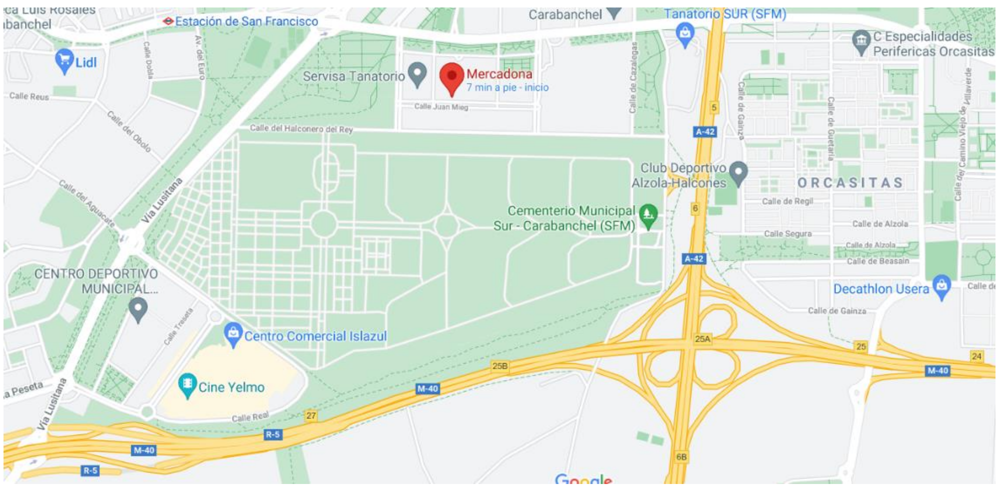


Figure 7. View of the main roads with quick access to the car park [22]

As can be seen in figure 7, the chosen location offers easy access for EV drivers to stop and recharge without straying too far from main roads.

The location of the supermarket in coordinates corresponds to:

40º 22’ 15.905’’N   3º 43’ 54.652’’W

Of the plots that surround the supermarket, the two closest to it are those which were considered as options for where to install the solar canopies that will form the car park.

The two options initially chosen were the terrain across from the supermarket and the terrain beside the supermarket.

In the first option, the land has a total area of 24064 m^2, which is plenty of space in which to choose the exact location for the canopies. One of the aims for the final location is to have the installation as close as possible to the building of interest. In this case, the closest distance from the supermarket to the plot is approximately 50 meters.

To connect all of the equipment involved in the photovoltaic installation with the C.D.B. of the building, it would be necessary to carry out work on the pavements. This would include the installation of conduits through which the cables would pass, either underground or aerial, crossing both roads and sidewalks. Figure 8 shows a graphic representation of this option.

On the other hand, there is the possibility of building the parking lot next to the Mercadona warehouse, approximately 20 meters away. The plots available would make up a total of 10482 m^2. Compared to the previous option, the size is much smaller, however, this area still offers more than enough space in which to install a generation plant with high capacity and plenty of parking spaces.

In this case, to connect all the equipment to Mercadona´s C.D.B, the conduits could be installed outdoors, and in avoidance of roads and pavements, which would be faster and more economical. The conduits would pass through a connecting door located at the barrier separating the building from the new car park. A representation of this option can be seen in figure 9.

Due to the proximity and canalization, option number two has been chosen as the final location where the works will be carried out.

To be able to accommodate the desired number of parking spaces and panels, three terrains will be used. These terrains are empty plots, with the following cadastral references: 8295108VK3689E0001XW, 8295107VK3689E0001DW and 8295111VK3689E0000ZQ, with areas of 2190 m^2, 2749 m^2 and 4473 m^2, respectively. [23]

Most of the canopies will be located in the first two plots, as they are the closest ones to the warehouse; only a segment of the third property will be used. Therefore, if necessary, the area can easily facilitate future expansion.

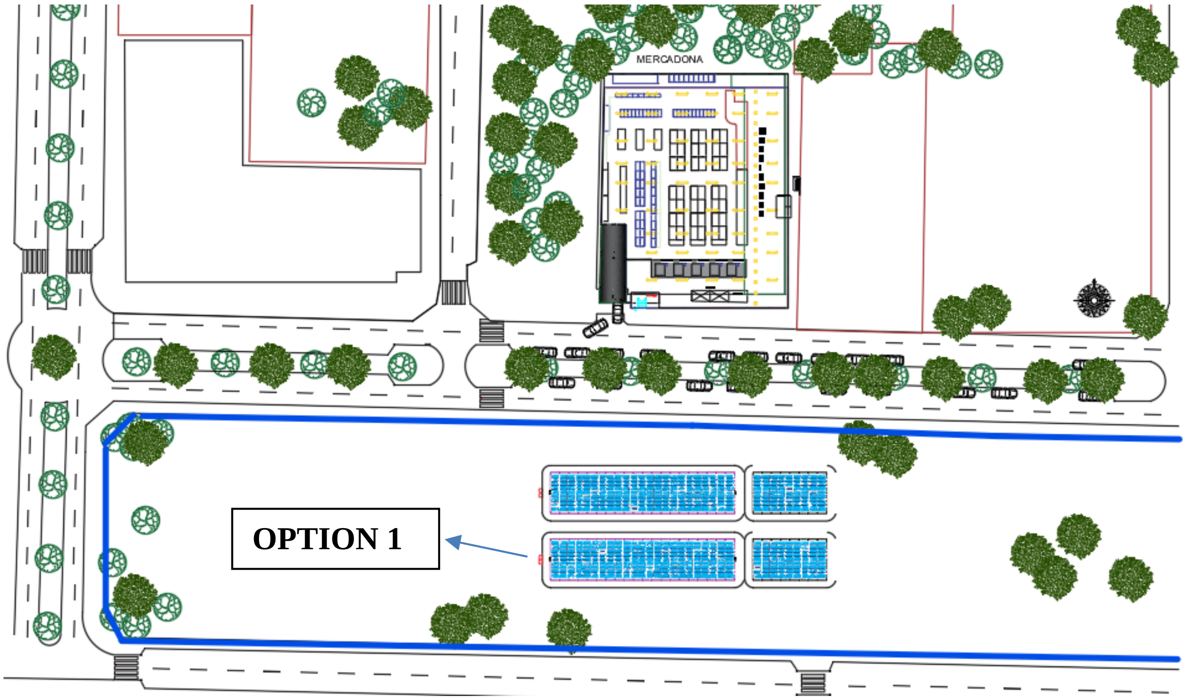


Figure 8. Location option 1

Figure 9. Location option 2

3.1 Impact of the solar facility

Solar facilities, similarly to other renewable energies, have an impact on their location and surroundings. However, compared to other non-renewable energy sources, they are much less damaging to the environment. This is because they avoid direct generation effects, such as atmospheric pollution and waste production, as well as effects derived from generation.

Some of the effects caused by photovoltaic solar energy facilities are:

- Geological: as will be explained in section 7.2 of the project, solar panels are built from silicon, an abundant element obtained from sand. Although only a small amount of this element is consumed for the creation of solar modules, it is necessary to obtain it. However, there is no need to perform lithological, topographic or structural alterations of the terrain for its obtainment.
- Ground: although the panels themselves do not have a direct effect on the ground, the structures to be installed do alter the environment slightly. For installation, although it is not necessary, it is advisable to build a foundation over the ground. [24]
- Scenery: one of the advantages of solar panels is their design. This makes it easier to integrate than other devices, minimizing the visual impact.

By not using power lines, using a silent generation system and not dumping CO2 into the atmosphere or waste to the ground during generation, the impact on flora, fauna, water and climate is practically non-existent. At the same time, the area in which the photovoltaic plant is situated has already experienced urban development, which minimizes its impact on the social environment. [24]

3.2 Radiation

One of the fundamental aspects of choosing the placement for a new solar installation is to know the average values for magnitudes and meteorological data.

It was necessary to obtain the average values for horizontal global irradiation, ambient temperature, incident global irradiation in collector plane and effective global incident energy after all optical losses, such as shadings and soiling.

In table one, the data described above is represented for each month of the year.

TABLE 1. Meteorological and incident energy data

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²
January	62.0	5.19	70.0	63.1
February	82.2	6.71	89.8	82.3
March	133.8	10.31	142.2	130.4
April	166.7	12.18	171.9	159.8
May	196.2	16.99	198.7	185.3
June	219.7	22.87	221.1	208.0
July	237.4	25.69	240.0	225.3
August	207.3	24.93	212.9	198.9
September	152.6	19.98	160.5	148.0
October	102.3	14.77	109.5	100.3
November	68.6	8.53	75.5	69.0
December	52.5	5.49	58.9	53.4
Year	1681.3	14.52	1751.0	1623.6

The Global Horizontal Irradiance (GHI) can be described as the total incident radiation obtained from the Direct Normal Irradiance (DNI), the Diffuse Horizontal Irradiance (DHI) and the radiation reflected from the ground. In Spain, this value is higher in southern regions, reaching between 1826 and 1972 kWh/m2 annually, and lower in northern regions. Madrid is in the center, reaching a yearly average of 1681 kWh/m2.[25][26]

3.3 Shadow analysis

Another relevant and more specific factor to analyze is the fact that objects near the modules might produce shadows, and disrupt the sunlight at certain times of the day or year. These shadows fall into either of the following categories:

- Temporary shadows, which are produced by meteorological or circumstantial elements, such as dust, tree leaves, snow, dirt, etc. They reduce the performance of the panels, so to minimize this loss, periodic cleaning and maintenance must be carried out. Others, such as clouds, do not have a quick fix.
- Shadow by situation or fixed shadow, when the origin of the shade is not a temporary object, but fixed elements around the solar modules, such as trees, antennas, buildings or billboards.

For this project, temporary shadows such as those mentioned were considered, as well as shadows cast by the supermarket, surrounding trees and the photovoltaic canopies themselves.

The general shadow analysis will be analyzed with the Iso-shading diagram obtained from the shading analysis made with PVSyst. The diagram can be seen below, in figure 10:

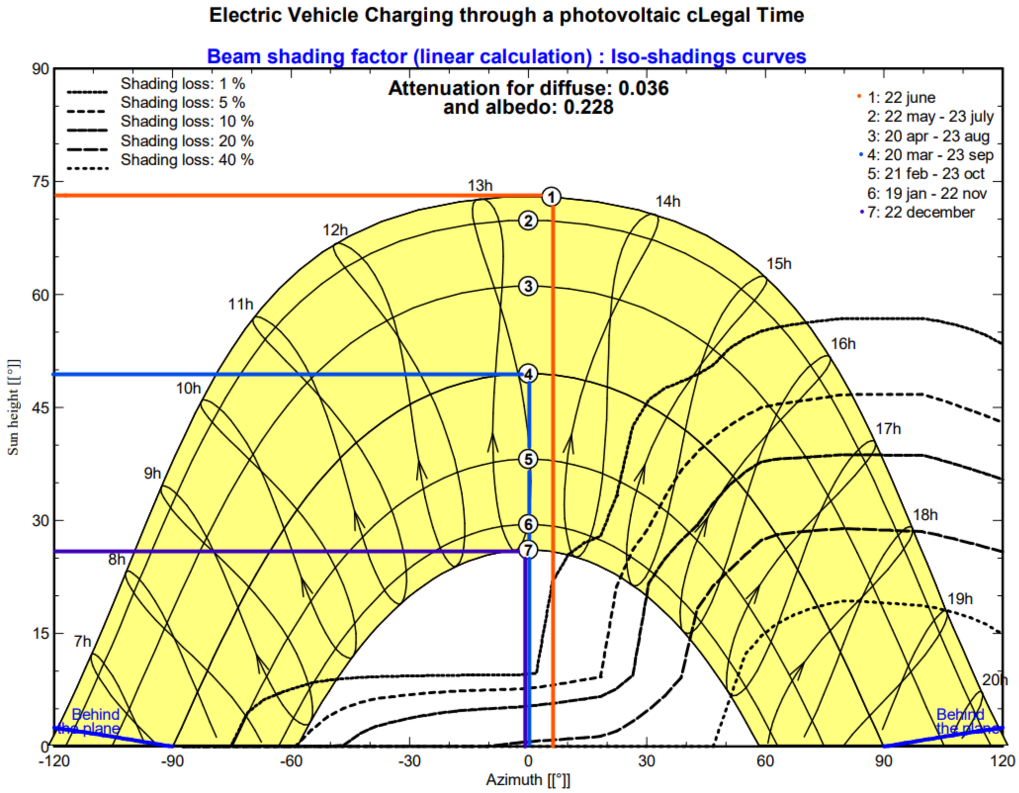


Figure 10. Iso-shadings diagram of the photovoltaic plant

In figure 10, the different points, represented by the numbers 1 to 7, represent the maximum elevation of the sun on the most remarkable days of the year, such as solstices and equinoxes.

To better understand the diagram, the equinoxes and solstices will be discussed from the point of view of the Northern hemisphere:

Equinox: There are two equinoxes per year. During those days, both hemispheres reach an equal amount of heat due to the solar rays reaching the intertropical zone with a higher intensity, which translates into 12 hours of daylight. The equinoxes also coincide with the day of the year in which the sun is closest to the Equator line. The two equinoxes are:[27]

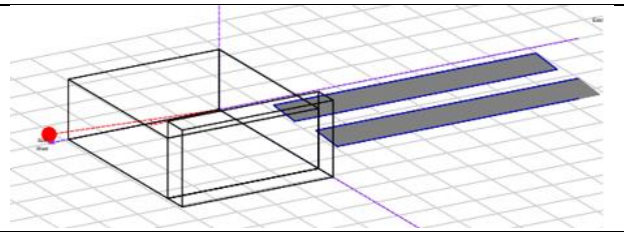
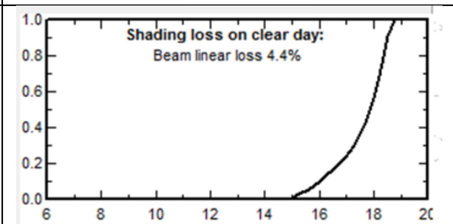
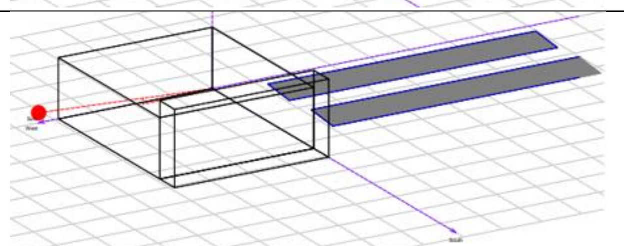
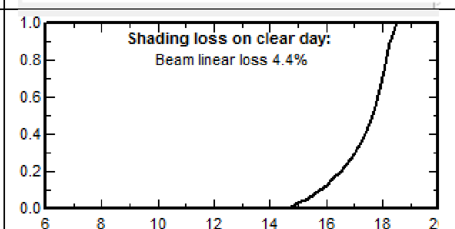
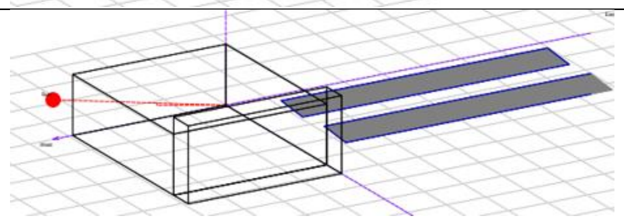
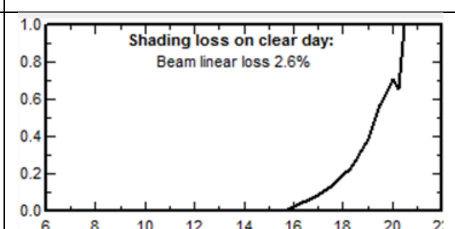
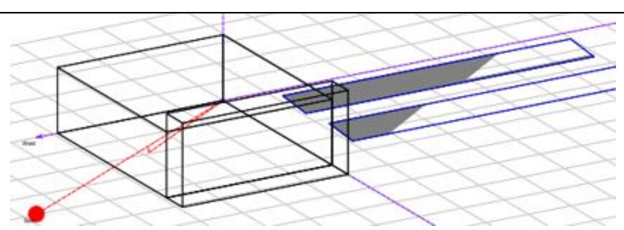
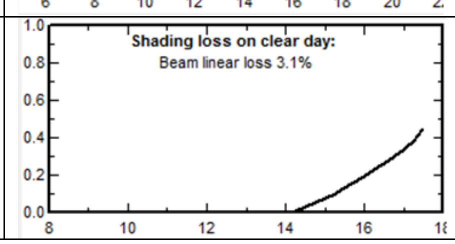
- Spring equinox: 20/03/2021 and Autumnal equinox: 23/09/2021. They both correspond to point 4 in the diagram. In these days, the sun reaches a maximum height of 49º at around 13.15 hours.

Solstice: During the two solstices, the sun is at its furthest from the equator line. Moreover, one hemisphere receives more daylight than the other, and this causes the longest and shortest day of the year. There are two solstices: [27]

- Summer Solstice: coincides with the longest day of the year, 21/06/2021. In the diagram, the summer solstice is represented by point 1, with the sun´s maximum height of the year, 73º at 13.20 hours. In comparison with the other 6 points, the azimuth angle is not 0º, but 3º.
- Winter Solstice: coincides with the shortest day of the year, 21/12/2021. Lastly, point 7, with the sun at a height of 26º, represents the winter solstice.

Additionally, the shadow analysis results obtained from the shading animations in PVSyst can be seen in the following table:

TABLE 2. Shading analysis

DATE	REPRESENTATION	RESULT
20.03.2021		
22.09.2021		
21.06.2021		
21.12.2021		

The square in the pictures represents the supermarket´s building, whereas the two horizontal rectangles beside it represent the solar modules. Both figures use real measurements to be able to obtain results as realistic as possible. The building´s height is approximately 13,50 meters, except for a raised section of 6,5 meters at the front end, which stands at 18,25 meters.

As we can see in the table, the shading losses reach their minimum and maximum during summer and winter solstice, respectively. However, the only day out of the four where the building does not create shade on the panels is the 21st of December.

4. DESCRIPTION OF A PHOTOVOLTAIC PLANT

A PV plant aims to generate electricity through solar energy. This generation begins with solar modules, which, thanks to the photovoltaic effect that occurs in their solar cells, make it possible to transform the energy received by the sun into electricity. This electricity is in direct current, and must be converted to alternating current to be able to pass into the electrical distribution network. This is done using inverters, which change the DC to AC. There are mainly two types of generation plants:

- Isolated from the grid: these plants tend to be of a smaller size and most of them use batteries for energy storage. Also, there is no connection between the facility's electrical circuit and the public distribution network, PDN.
- Connected to the grid: the two main installations to use this model are solar farms and roof installations. Inside this model, there exists the option for self-consumption, with or without surpluses. According to ITC-BT-40, generating facilities can be connected in parallel to the PDN, in the case of interconnected generating facilities, or not in parallel to the PDN, in the case of assisted generating facilities. [28][29]

In the case of this project, the solar circuit will be connected to the grid, but it may also have battery storage, as a back-up system. Because of this, the equipment will include solar batteries, and they will be part of the project analysis.

The main components are solar modules, inverters, batteries, solar cables for both DC and AC currents and structures to support the modules. [28]

To analyze the photovoltaic plant, we will assume the use of solar batteries while using Ingecon Sun Training. The results obtained from the study of the operating mode used for the project are given in table 3. An operational grid status was assumed for the entire simulation, and the battery-backup function was studied when the PV energy balance was higher and lower than the loads, as well as how the battery's state of charge affects the installation's functionality.

Figure 11 shows a representation of the elements to be used. The icon at the top represents the solar panels; the icon in the middle represents the inverter; the icon on the left represents the solar batteries; the drawing of a house on the right represents the loads connected to the supermarket's C.D.B, such as the EV stations and appliances; and finally, at the bottom of the picture is the grid.

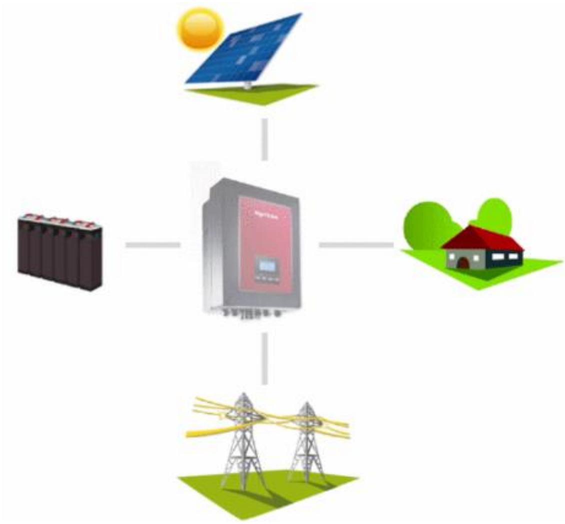


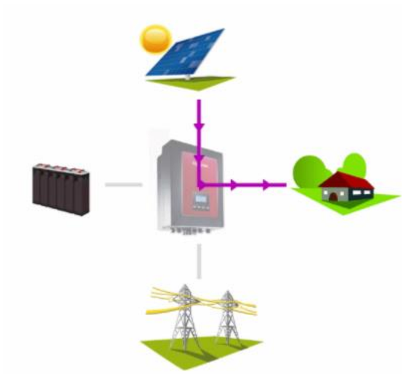
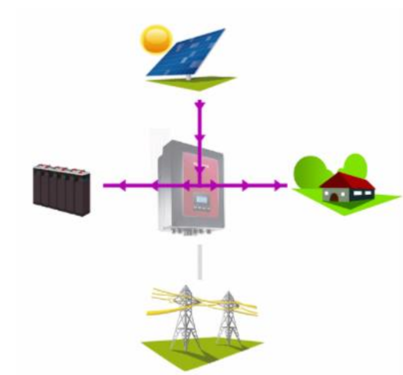
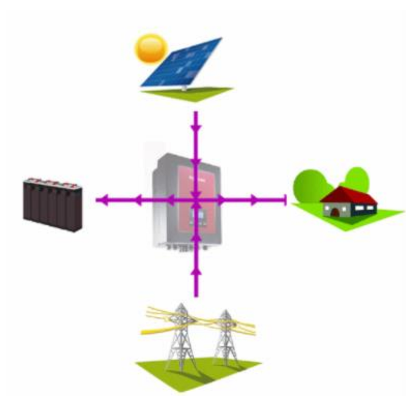
Figure 11. Self-consumption management [30]

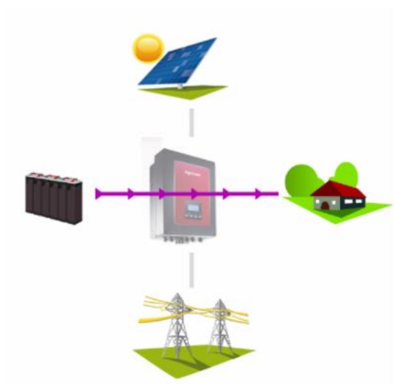
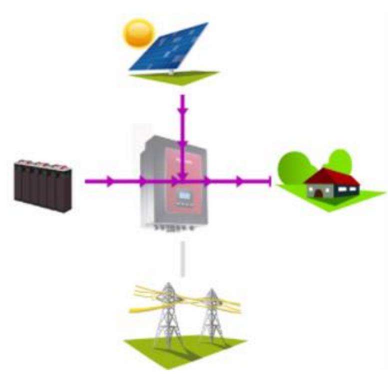
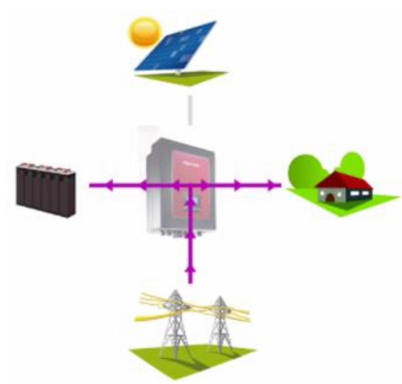
The different levels for the battery's state of charge in the table below correspond to:

- A: 100% > SOC > SOChyst, where SOChyst is the optimal state of charge for the batteries to be in. SOchyst corresponds to values from 50% to 70% stored energy.
- B1: SOChyst > SOC > SOCmin. The energy stored has values between 30% and 50%. When referring to this level, one refers to discharge.
- B2: SOChyst > SOC > SOCmin. This level has the same range than B1, however, in this case, it refers to battery charging.
- C: SOCmin > SOC > SOCrecx. From this level on, the batteries activate the backup function. The energy stored in this level goes from 20% to 30%, for both charge and discharge.
- D1: SOCrecx > SOC > SOCdescx. For the proper care of the batteries, levels D1 and D2 should not be reached, since from the SOCrecx point, there are many possibilities of damaging the battery if it is allowed to discharge more. D1 corresponds to values between 10% and 20%, and it is referred to as battery discharging.
- D2: SOCrecx > SOC > SOCdescx. The only difference between D2 and D1 is that the former is referred to as battery charging.

In addition to the six distinctions for the state of charge of the batteries, it is also necessary to analyze for SOC= 100% and SOC= SOCdescx. [30]

TABLE 3. Ingecon sun training operation mode simulation results [30]

Visual representation	Scenario	Energy balance and battery SOC
	In this case, the power generated by the modules will go directly to supplying the loads, as the batteries are fully charged.	PV > LOAD and SOC=100%
	In this case, as the batteries are not fully charged, the power generated will be supplied to both the loads and solar batteries.	PV > LOAD and A PV > LOAD and B1
	This scenario will be the most common. As the batteries are not charged, the PV energy may not be enough to supply all the demand. In this case, the distribution network to which the building is connected will also oversee supplying the supermarket's loads.	PV > LOAD and B2 PV > LOAD and C PV > LOAD and D1 and D2 PV > LOAD and SOC = SOCdescx PV < LOAD and B2 PV < LOAD and C PV < LOAD and D1 and D2 PV < LOAD and SOC = SOCdescx

	This situation will happen at night time, on cloudy days, or at any other moment when PV generation is not possible. In this case, the charged batteries will supply the electricity demanded for as long as possible.	PV = 0 and SOC = 100% PV = 0 and A PV = 0 and B1
	There will be occasions when the PV plant is generating less than usual, and so both the solar modules and batteries will provide the electricity needed.	PV < LOAD and SOC = 100% PV < LOAD and A PV < LOAD and B1
	In this last scenario, there is no PV generation, and the batteries are nearly empty and in need of charging. In this scenario only, the PDN will be in charge of supplying all the electricity.	PV = 0 and B2 PV = 0 and C PV = 0 and D1 and D2 PV = 0 and SOC = SOCdescx

With the explanation of the photovoltaic plant´s operation, it is feasible to begin detailing the necessary elements for the realization of a PV generating parking lot, connected to the network for charging electric vehicles.

Firstly, an estimation of the desired capacity must be undertaken, which will determine the size of the plant. Next, issues related to the new PV facility will be designed and analyzed, followed finally by the development of the elements of the EV charging stations.

5. PROJECT DIMENSIONING

Before deciding on the necessary equipment, all of the factors that will define the size of the facility must be considered. The first of these is the estimated contracted power of the supermarket. To do this, the indications of chapter five of the ITC-BT-10 must be followed, whereby the forecast of loads for commercial premises corresponds to 100W per square meter and a coefficient of simultaneity, Cs, equal to 1.

$$P_{contr} = 100\,W \times A_{sup} \times C_s \quad (1)$$

Where:

- P_{contr} is the contracted power.
- A_{sup} is the supermarket's total area.

Therefore, the estimated contracted power of the commercial building is 280 kW.

As the objective is not to completely cover Mercadona's consumption, but to supply EV chargers, power was set at the level required for fast and semi-fast charging at 50 kW per station. The desired number of charging stations is 4. Each station will have two connectors, making it possible to charge two vehicles simultaneously.

To calculate the power of the plant, the following equation must be used:

$$P_{plant} = P_{station} \times N_{stations} \quad (2)$$

Therefore, a plant will be designed with a power equal to 200 kWac and a capacity of charge for 8 vehicles.

When there are no electric vehicles or batteries charging, all generation will be used to partially cover the supermarket's consumption.

6. REGULATORY FRAMEWORK

During the project, the regulations and standards specified in the 2020 edition of the Electrotechnical Regulation for Low Voltage, LVER, will be followed. These include the complementary technical instructions, ITC, and guides for the application of the LVER in accordance with the royal decree of RD 842/2002, updated according to RD 560/2010, RD 1053/2014, RD 244/2019 and the delegated regulation 2016/64. [29]

The chapters which include the complementary technical instructions, ITC, that must be taken into consideration for the photovoltaic facility are:

- Chapter II. Documentation and inspections.
- Chapter III. Distribution networks: ITC-BT-06.
- Chapter V. Forecasting of loads and link facilities: ITC-BT-10.
- Chapter VI. Indoor or receiving facilities: ITC-BT-18 and ITC-BT-19.
- Chapter VII. Protections: ITC-BT-22 and ITC-BT-24.
- Chapter IX. Installations in special premises: ITC-BT-30.
- Chapter X. Special purpose facilities: ITC-BT-40.

Finally, the new ITC-BT-52 for electric vehicles will also be taken into consideration for this project. [29]

7. PV PLANT DESIGN AND ANALYSIS

The project will consider two design possibilities: CASE 1 and CASE 2. The first will consist of supplying the C.D.B with all the power generated by the plant, and from there supplying the building's loads and the car park's charging points. In the second case, the storage capacity will be added as backup, to dispense with the building's distribution network as much as possible.

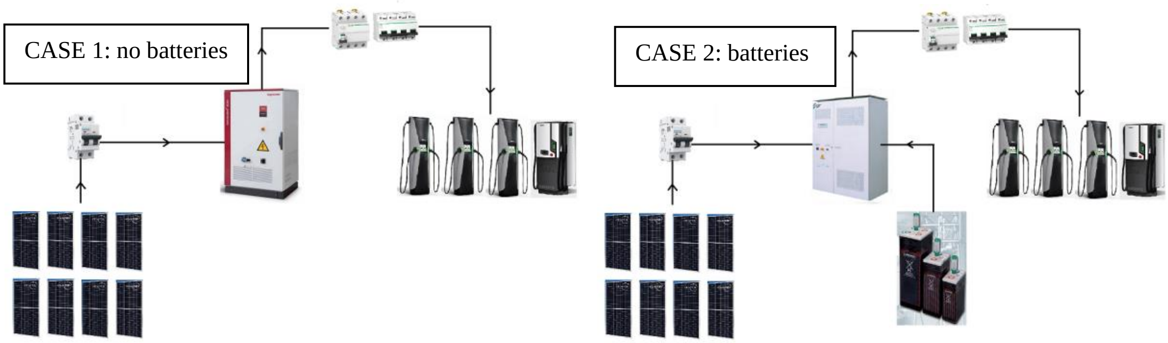


Figure 12. Design possibilities for the project

As can be seen in figure 12, the main alterations in design will be the inverter and batteries, maintaining the same structure for the rest of the equipment and materials. A more detailed representation can be seen in Annex C. Plans.

To calculate the number of panels, it is necessary to examine a specific solar module and the structure in which the modules will be installed.

7.1 Procedure for the PV plant design

Once the power that must be generated has been determined, the first step is to choose the photovoltaic module and inverter that will be used in the project. Afterwards, the maximum number of strings and maximum number of panels in series will be calculated.

With these calculations, an analysis will be carried out in PVSyst to find the best possible arrangement. Finally, with the number of panels obtained from the simulation, the design configuration will be obtained and the most suitable supporting structure for the panels and their distribution on the terrain will be applied.

7.2 Solar modules

A photovoltaic module is the smallest planar assembly of solar cells and other ancillary parts whose purpose is to generate DC power through sunlight. [31]

Currently, there are three main types of PV panels available: polycrystalline, monocrystalline and thin film. When deciding which type of panel is the most suitable for the project, the characteristics of each must be examined.

In the case of polycrystalline and monocrystalline solar modules, the PV cells are made with just one material, silicon, whereas the thin-film modules use more materials. Thin-film solar panels are the slimmest technology out of the three. They are flexible and portable, which can be beneficial in certain cases, such as on vehicles or mobile homes. They are also generally the cheapest option available; however, the cells tend to have efficiency levels of lower than 11%. [32]

Due to this low efficiency, these panels will not be considered as an option for the PV generation plant.

Polycrystalline solar panels are made up of solar cells which are built from many silicon fragments melted together. This can be noticed in the color of the panel, with distinctively bluish cells. These panels are less expensive than monocrystalline panels, as their efficiency tends to be lower at around 15% to 17%. Monocrystalline panels can reach a high efficiency of over 20%.

Monocrystalline panels are the most efficient and expensive kind of solar panel available. This is because their manufacturing process results in a single silicon crystal, from which the panel is made. With the many crystals in polycrystalline cells, electrons have less space to move and thus work less efficiently. Monocrystalline panels can be recognized by their black hue, which is due to the reaction of sunlight with pure silicon crystal. [32] [33]

After considering both technologies, the GCL-M8/72H monocrystalline module has been chosen. While this option is more expensive, the high efficiency is essential in maximizing the energy output of the photovoltaic car park for both the electric charging stations and the supermarket.

GCL Systems are a well-known manufacturer, and their panels are included in the TIER 1 list. The decision for this panel was supported by the DNVGL results, in which the panels positively passed tests for thermal cycles, operation in humid climates, mechanical loads and force degradation. [34]

This model has 144 (6 x 24) cells and a maximum power output of 465W at STC; however, the chosen maximum peak power for the modules will be 440 Wp. This panel also has a yield of 17,23 %. During the first year, the power loss will be less than 2,5 % and its power efficiency will be no less than 97.5%. During the remaining years, this loss will not surpass

0.7% per year, reaching a total power loss of less than 19.3% at the end of a 25-year period. The power of the panels at the end of the first 25 years will stand at a minimum of 80.7%, according to the indications of manufacturers' warranties.

As the desired capacity is 200 nominal kW, a total peak power of between 230 kWp and 270 kWp is expected depending on the inverter and PV modules´ characteristics, since the nominal power relationship between modules and inverters is from 1.15 to 1.35, respectively.

The main technical characteristics of the modules are shown on the following table:

TABLE 4. Solar Module Technical Characterisitics

Parameter	Value
Measurements (mm,mm,mm)	2108 x 1048 x 35 mm
Maximum Power at STC (W)	440 Wp
Open Circuit Voltage (V)	49.25 V
Max Power Point Voltage (V)	41.4 V
Short-circuit Current (A)	11.28 A
Max Power Point Current (A)	10.63 A
Performance (%)	19.9%
Temperature Coefficient of Isc (%/ºC)	+0,06 %
Temperature Coefficient of Voc (%/ºC)	-0,30 %
Temperature Coefficient of Pmax (%/ºC)	-0,39 %

The measurements are taken under STC conditions, of 1000 W/m^2, cell temperature of 25ºC and air mass of 1,5.

The rest of the characteristics can be seen in the manufacturer's data sheet, located in Annex A: Equipment´s technical data.

ORIENTATION AND INCLINATION

When calculating how the panels should be placed and the angles necessary to get the most sunlight, it is essential to understand the movement of the sun, as well as to calculate the optimal degree of inclination and the optimal east-west orientation (azimuth angle).

The project is located in the Northern hemisphere, at a latitude of approximately 40°. For solar modules in the Northern hemisphere within the latitudes of 23º and 90º, the sun is always in the South, and at solar noon (0°), it is always directly to the South.

If the azimuth angle were negative 90°, the panels would face due east, and at positive 90°, they would face due west. If the arrangement faces either East or West, it will only see half the achievable generation; facing South allows the panels to capture the maximum amount of energy throughout the year. Therefore, the optimal azimuth angle for this project is 0° South.

The optimal inclination degree is approximately 30°, coinciding with ten degrees lower than the latitude. However, after considering the wind force, the weight of the panels and the shading, given that the canopies must provide adequate shade to the electric vehicles, the final tilt angle of the solar canopies is 5°. The panels are installed coplanar and at a 0° angle, so with the tilt of the canopies taken into consideration, the final tilt is 5°. [35][36]

Also, as all the panels have the same orientation, it is not necessary to use inverters with more than 1 MPPT.

7.2.1 PV modules calculation procedure

It is important to know the surface area that a module will occupy, to limit the size of the support later. To do this, the width (W_{panel}) and height (H_{panel}) of the panel will be multiplied and this, by the cosine of the angle, α, of inclination between the panel and the support.

$$S_{panel} = H_{panel} \times W_{panel} \times \cos\alpha \qquad (3)$$

Where:

- S_{panel} is the module´s surface.
- α is the angle between the panel´s horizontal axis and the support´s horizontal axis.

7.3 Inverter

The purpose of the inverter is to change the output of a solar panel from DC to AC, which is the more commonly used form of energy in electrical appliances. It also contributes to the network's safety, as it monitors the overall process and can switch off if it detects any faults or major changes in current. [41]

There are two main types of inverters to choose from: standard and hybrid. Standard solar inverters perform the basic function of converting DC to AC for use. This AC is fed directly into the grid or used to power household appliances. While hybrid inverters also perform this function, they allow for battery storage as well. Hybrid inverters send excess power to the battery to be stored. This allows for back-up power in case of emergency, or to be used as needed. [42]

Solar inverters also come in varying levels of power. The power necessary for an inverter depends on many factors, such as geographical location, terrain and how much power the site is generating. For the project's size and purpose, an inverter capable of 50 kW of power is necessary. There are options for this in both standard and hybrid inverters. [43]

The chosen devices for the project come from the well renowned companies Ingeteam and Zigor.

- CASE 1: The Incegon Sun 50 offers a power of 50 kW, and it is a very efficient model, with a maximum efficiency level of 96.3%. It has one MPPT and it can handle 130 A of DC energy. This is a standard inverter, and thus would not allow for any back-up battery storage. To allow battery storage in the future, one would have to install either a hybrid inverter or a charging-converter-regulator alongside the Incegon Sun 50 feeding directly to the batteries. [44]
- CASE 2: The ZGR HITC 50 also has a power of 50 kW. The transformers inside operate at an efficiency level of greater than 96%, meaning it will work just as well as the Incegon Sun 50. This inverter also has one MPPT and can handle 125 A of DC energy. While very similar statistically to the inverter previously discussed, the ZGR HITC 50 is a hybrid inverter, and so it also offers the ability to feed AC or DC into the batteries for later use or conversion. This would allow back-up storage without the need to purchase more equipment. [45]

Both of the above options also offer the monitoring and recording of all inverter data, and protection against any potential faults in the network.

For more information about the devices, fundamental parameters can be found in Annex A. Equipment´s technical data.

7.3.1 Inverter´s calculation procedure

For the calculation of the number of inverters and the power capacity, in both CASE 1 and CASE 2, the software PVSyst was used. The aim was to leave a nominal relationship of approximately 1.25 between the nominal power of the inverter and total peak power obtained from the strings of the panels, thus:

$$Pn = \frac{Pinverter}{P_{pv.strings}} \tag{4}$$

The number of inverters will be calculated following the equation 5:

$$N_{inverters} = \frac{P_{plant}}{P_{inverter}} \tag{5}$$

Where:

- $N_{inverters}$ is the number of inverters.
- P_{plant} = 200 kW
- $P_{inverter} = 50\ kW$

With the chosen inverter, it is now possible to focus on calculating the arrangement of the modules. Before using the PVSyst software, it is necessary to calculate the maximum number of strings and modules in series and in parallel.

1. Number of panels per string – Series arrangement

For this, the following equations must be used in this exact order:

$$T_{cell} = T_{amb} + (NOCT - 20) \cdot \frac{G}{800} \tag{6}$$

Where:

- Tcell = Cell Temperature (ºC)

- Tamb = Ambient Temperature (ºC)
- G = Minimum Irradiance (W/m2)
- NOCT= Nominal Operating Cell Temperature (ºC)

With this data, the maximum voltage drop of the modules is now calculable:

$$V_{OC,max} = V_{OC} + \left(1 - Tª Coef \times (25 - T_{cell})\right) \quad (7)$$

Where:

- V_{OC} = Open Circuit Voltage
- $TªCoef$ = Temperature coefficient of Voc

Finally, with $V_{max,inv}$ and $V_{OC,max}$, the maximum number of panels in series can be obtained.

$$N_{max.series} = \frac{V_{max,inv}}{V_{OC,max}} \quad (8)$$

Where:

- $N_{max.series}$= maximum number of photovoltaic panels in series per entrance to the inverter.
- $V_{max,inv}$ = maximum voltage output from the chosen inverter.

The number of panels connected in series cannot surpass the value determined by $N_{max.series}$.

$$N_{series} \leq N_{max.series} \quad (9)$$

Where:

- N_{series}= number of modules in series chosen.

2. Number of strings – parallel arrangement

The maximum number of branches to be connected in parallel is given by the quotient between maximum DC input current of the inverter and the maximum peak power current of the series.

$$N_{max.strings} = \frac{I_{\max inverter\,(fv)}}{I_{mpp(string)}} \quad (10)$$

Where:

- $N_{max.strings}$= the maximum number of strings that the inverter is able to bear.
- $I_{\max inverter\,(fv)}$= Maximum input DC current of the inverter
- $I_{mpp(string)}$= the passing current per string.

Thus, the final number of strings in the design can not surpass the value of $N_{max.strings}$.

$$N_{strings} \leq N_{max.strings} \quad (11)$$

Where:

- $N_{strings}$= number of strings chosen.

With the data obtained from the equations above, it is finally possible to make a design in PVSyst with which to finish the design of the PV plant. The results obtained from the calculations and simulation are explained in point 9.2 and the simulation results can be seen in Annex B. PVSyst.

It was decided to divide the car park into two equal subsystems, each with a nominal power of 100 kW. For this, 2 inverters of 50 kW and 288 panels are used.

- Subsystem 1: it consists of canopies 1 and 2 and inverters 1 and 2.
- Subsystem 2: it consists of canopies 3 and 4 and inverters 3 and 4.

The following two tables show the final design and arrangement of the panels and inverters used in the installation:

TABLE 5. Configuration of canopies 1 and 2

	INVERTER	50 kWn	String	Panels per string	String Power
SUB. 1	**1**	MPPT1	1	16	7.040 kWp
			2	16	7.040 kWp
			3	16	7.040 kWp
			4	16	7.040 kWp
			5	16	7.040 kWp
			6	16	7.040 kWp
			7	16	7.040 kWp
			8	16	7.040 kWp
			9	16	7.040 kWp
	TOTAL INVERTER 1			**144 panels**	**63.36 kWp**
	2	MPPT1	1	16	7.040 kWp
			2	16	7.040 kWp
			3	16	7.040 kWp
			4	16	7.040 kWp
			5	16	7.040 kWp
			6	16	7.040 kWp
			7	16	7.040 kWp
			8	16	7.040 kWp
			9	16	7.040 kWp
	TOTAL INVERTER 2			**144 panels**	**63.36 kWp**
	TOTAL NOMINAL POWER			**288 panels**	**126.72 kWp**

TABLE 6. Configuration of canopies 3 and 4

	INVERTER	50 kWn	String	Panels per string	String Power
SUB. 2	**3**	MPPT1	1	16	7.040 kWp
			2	16	7.040 kWp
			3	16	7.040 kWp
			4	16	7.040 kWp
			5	16	7.040 kWp
			6	16	7.040 kWp
			7	16	7.040 kWp
			8	16	7.040 kWp
			9	16	7.040 kWp
	TOTAL INVERTER 1			**144 panels**	**63.36 kWp**
	4	MPPT1	1	16	7.040 kWp
			2	16	7.040 kWp
			3	16	7.040 kWp
			4	16	7.040 kWp
			5	16	7.040 kWp
			6	16	7.040 kWp
			7	16	7.040 kWp
			8	16	7.040 kWp
			9	16	7.040 kWp
	TOTAL INVERTER 2			**144 panels**	**63.36 kWp**
	TOTAL NOMINAL POWER			**288 panels**	**126.72 kWp**

7.4 Structures of Solar Canopies

As mentioned above, the project to be developed consists of a parking lot for photovoltaic generation and electric vehicle charging, also known as a solar carport. Therefore, the structures that will support all the solar panels will be solar canopies. The objective of these canopies is to offer shelter to the cars that park in the enclosure, and, at the same time, to arrange the panels as discreetly as possible. Consequently, the visual impact will be less than that of other photovoltaic plants.

Various types of canopies have been considered:

- Single Solar Panel Canopy: The single canopies consist of individual parking spaces, with a tilted roof available for solar modules coupling in south and north orientation. This option was quickly dismissed as there was enough space for double solar canopies, which are more economical and take less space than two single canopies together.

- Double Solar Panel Canopy: The DSPC is used for double row parking spaces. This structure allows more panels on its rooftop, and the space necessary to support it is similar to that of the SSPC. [40]

Thus, the DSPCs will be the chosen. Based on the canopy´s rooftop design, there are two main types inside this group:

- Monotpitch: Monopitch canopies have one inclination across the entire rooftop, meaning that the panels face the same direction.
- V-shaped: this type of canopy has each side tilted and facing towards the other. In this design, the solar panels face each other and there are two separate inclinations.

In order to choose between these two, a study undertaken by Farhana Umer was taken into consideration, as the situation studied has similarities to our own project. (There exists shading from the building and trees). In this study, it was concluded that by using monopitch canopies, a higher power generation could be achieved. [40]

The monopitch canopies come with two options for module fixing systems:

- Direct module fixing with G3 profile: this system includes some bars as the support for the panels, leaving the bottom part of the panels visible. This is a more flexible option that allows bigger panels.

Figure 13. Direct module fixing with G3 profile [66]

- Microrail 06H: This aluminum support screwed to the microrail allows the panels to be installed coplanar. The compatible pressors that this metal cover includes are S06, S10 and S11.

Figure 14. Microrrail 06H

This option covers the bottom part of the panels, however, the maximum size that the panels can have is of 2000 x 1000 mm, and in the case of the GCL panels, this size is exceeded.

For this reason, the direct fixing system will be used in the monopitch canopies.

The chosen canopies for the project are the SUNFER PR3, a double-parking canopy.

Figure 15. Monopitch Double Solar Panel Canopy [66]

As shown in the picture, the roof is 11.20 meters wide and has a free height of 2.20 meters. This structure has a 5º tilt, which makes it more robust against winds of up to 100km/h, snow, leaves and general debris. The tilt also guarantees shading for the vehicles parked underneath the structure. It is available in lengths of 5 up to 50 meters, with pillars located every 5 meters to support the roof. The range of available sizes corresponds to 4 up to 40 parking spaces, each of which shares the following dimensions:

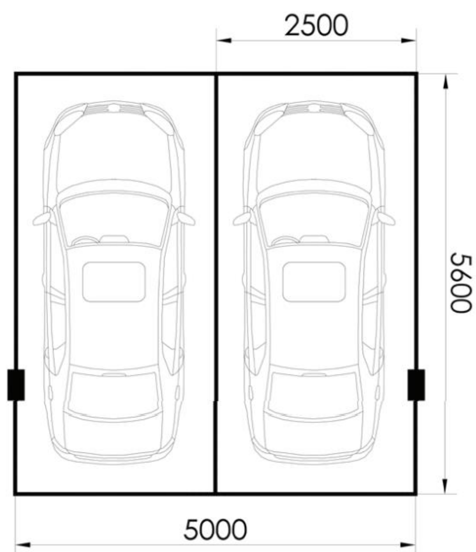


Figure 16. Parking space dimentions [66]

7.4.1 Calculation procedure and dimensioning of the canopies

To decide how the 576 pv modules are displayed, the solar canopy´s limitations in dimensions must be considered. According to the company´s datasheet, the monopitch DSPC has an estimated width of 11.20 maximum meters, and a maximum length of 50 meters. However, due to the panel's dimensions, only 9 panels can fit in one column of the canopy. This is:

$$W_{usef} = W_{panel} + d_{rows} \times 9 \tag{12}$$

If,

- W_{usef}= useful and available width of the canopy.
- W_{panel}= width of the panel.
- d_{rows}= vertical distance between panels = 0.030 m.

Also, the total length of the longest canopy is 50, but not all of this can be used. The number of panels will be determined with the help of AutoCAD:

$$L_{usef} = L_{max} - \{(nº_{columns} - 1) \times d_{col}\} \tag{13}$$

If,

- L_{usef}= useful and available length of the canopy.
- L_{max}= maximum length of the canopy = 50 m.
- d_{col}= distance between pv module columns = 0.040 m.
- $nº_{columns}$= number of sets of 9 module columns.

With the new measurements, it is possible to estimate the number of panels that the largest canopy can host:

$$A_{usef.max} = W_{usef} \times L_{usef} \tag{14}$$

Where:

- $A_{usef.max}$= the maximum usaful space on the canopy for hosting panels.

With this estimation, the total number of panels that fits in the estimated space available is studied using AutoCAD, and the results are shown in the section 9.3.

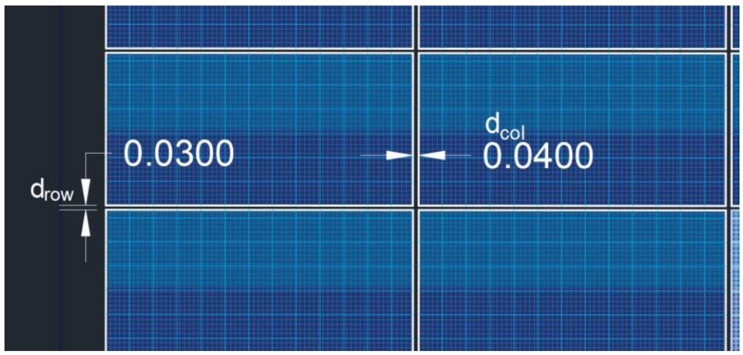


Figure 17. Distance between modules

With the help of these calculations, and after considering several designs in AutoCAD, it has been decided that the two subsystems will be distributed between 4 solar canopies. Canopies 1 and 3 will reach the maximum length allowed by the manufacturer, 50 meters, and the remaining canopies will be located next to them, leaving enough space in-between for the free circulation of vehicles. The length of canopies 2 and 4 will be 20 meters.

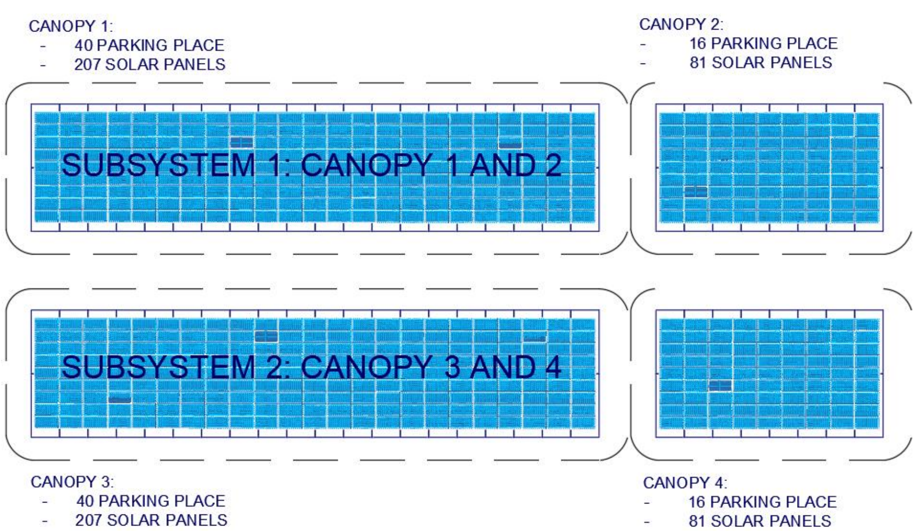


Figure 18. Subsystem 1 and 2 layout

7.5 String combiner box, SCB.

As the inverters only allow one entrance, an SCB or junction box is used. As its name indicates, the PV junction box is in charge of joining the strings of the photovoltaic modules and interconnecting them. This enclosure may also include protections, such as fuses. [31]

The SCBs will include as many fuses as $N_{SCB,in}$ determines, a voltage discharger and a disconnect switch.

7.5.1 SCB calculation procedure

Once the results have been obtained from the PVSyst simulation with both inverters, the number of PV strings that must be connected to the inverter will be known. However, as is indicated by their datasheets on figures A.4 and A.6 of Annex A, the inverters to be used in this project only have one entrance. Therefore, the number of entries for the SCB, $N_{SCB,in}$, will coincide with the number of PV strings coming from the panels per inverter, and the number of outputs of the SCB will be the same as the number of entries of the inverter.

$$N_{SCB,in} = N_{strings} \times 2 \quad (15)$$

The strings consist of a positive and a negative connection.

7.6 Batteries

A battery is formed by two or more electrochemical cells, the simplest operating unit, interconnected in parallel or series arrangements to be used as a storage system. [31]

Solar batteries store solar energy, and discharge power as needed. There are a few different kinds available on the market, but the two main ones are lead-acid batteries and lithium batteries, which come in either a flat-plate or tubular-plate form. [46]

While lithium tends to offer a boost in performance and requires less maintenance, it is also less cost-effective. This is mostly because lithium batteries are usually 95% efficient in terms of how much power is available after charging and discharging, whereas lead-acid are about 80-85% depending on the model. [47]

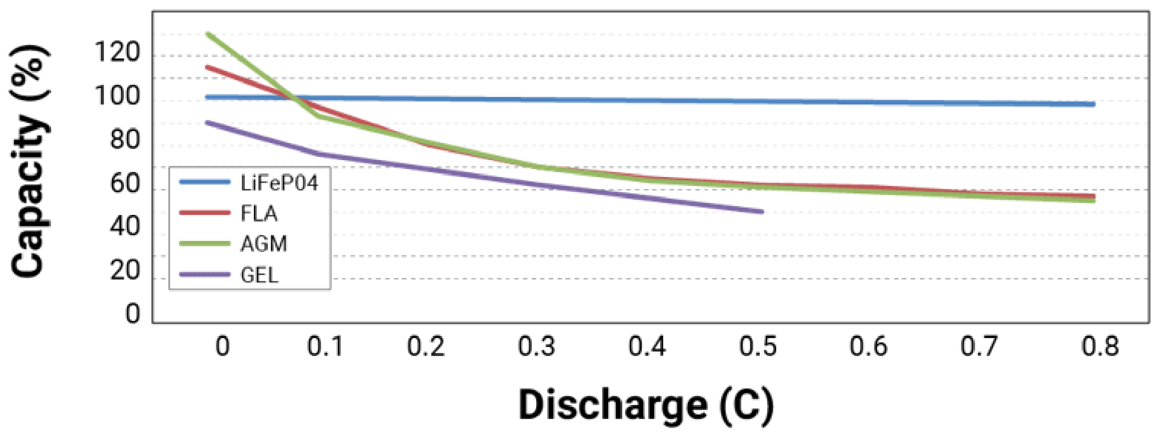


Figure 19. Capacity of LiFePO4 vs Lead Acid at various currents of discharge[47]

As shown in the graph, lithium batteries will maintain their capacity as the discharge rate increases whereas various kinds of traditional lead-acid batteries will not. Lithium batteries also tend to recharge faster than lead-acid; when compared to sealed lead-acid batteries, lithium batteries will charge at four times the speed. What´s more, lithium batteries are 55% lighter than sealed lead-acid batteries, on average. This extra weight associated with lead-acid batteries contributes to a more challenging installation. Lithium batteries also tend to be more energy-dense and can therefore handle more power in a smaller amount of space. [47][48]

Another important consideration was the maintenance required for each kind of battery. Generally, lithium and sealed lead-acid batteries require little to no maintenance, whereas the flooded lead-acid options should be checked and refilled every 1-3 months. The OPzS lead-acid battery utilizes an advanced recombination system that reduces gas and aerosol emissions, as well as the frequency with which it may require maintenance, making it a considerable choice for storage. The OPzS model uses a tubular plate design, which contributes to the stability of its cycle. It also has improved short-circuit safety, even during the installation, thanks to its high-quality system connectors.

Once the typical characteristics of each type of battery were analyzed, it was decided to opt for lithium batteries. Unfortunately, due to the fact that several chosen options did not manage the sufficient voltage that our inverters require, by not providing the serial connection options, the OPzS battery banks were chosen. These batteries allowed connection of the 2 V cells in both series and parallel, as well as offering several more advantages.

The HOPPECKE OPzS lead-acid batteries are a good fit for photovoltaic facilities with large generation, due to their service life, long cycle stability and compatibility. [48][49]

7.6.1 Battery calculation procedure

To achieve a correct approximation for the number of batteries required in this project, it is necessary to analyze the consumption that needs to be provided in case of peak hours. For easier dimensioning, the assumption is made that the minimum consumption needed is for a car to be fully charged by the batteries alone at semi-fast speed.

The power of this charge is 22 kW. However, nowadays, electric vehicles can only charge at a speed that the vehicle´s battery accepts. For the calculations, the longest loading time out of the models in table 5 is used as a reference. The estimated charging time was calculated following the equation:

$$H_{EV} = \frac{C_{E.V\ battery}}{r} \tag{16}$$

Where:

- H_{EV} (h) = charging time in hours.
- $C_{E.V\ battery}$(kWh) = size of the vehicle´s battery.
- r (kW) = battery acceptance rate.

TABLE 7. Capacity and battery acceptance rates of some EV models [50]

Vehicle	Acceptance Rate (kW)	Battery Size (kWh)	Estimated charging time (h)
BMW ActiveE	7	32	4.571
BMW i3 2014-2016	7.4	23	3.108
BMW i3 2017 (60 Ah battery)	7.4	23	3.108
BMW i3 2017 (90 Ah battery)	7.4	32	4.324
Coda	6.6	31	4.697
Fiat 500E	6.6	24	3.636
Ford Focus EV	6.6	23	3.485
Ford Focus EV 2017	6.6	33.5	5.076
Honda Clarity EV	6.6	25.5	3.864
Hyundai Ioniq	6.6	28	4.242
Kia Soul	6.6	27	4.091
Mercedes B Class B250e	9.6	28	2.917
Mitsubishi i-MiEV	3.3	16	4.848
Nissan Leaf S 2016	6.6	30	4.545
Nissan Leaf 2017	6.6	30	4.545
Nissan Leaf 2018	6.6	40	6.061
Smart Car	3.3	17.6	5.333
Smart Fortwo ED 2017	7.2	17.6	2.444
Tesla Model S 100D & P100D	17.2	100	5.814
Tesla Model X 60 Single	11.5	60	5.217
Tesla Model X 60 Dual	17.2	60	3.488
Tesla Model X 75 Dual	17.2	75	4.360
Tesla Model X 90 Dual	17.2	90	5.233
Tesla Model X 100D & P100D	17.2	100	5.814
Tesla Roadster	17.2	56	3.256
Toyota Rav4	9.6	41.8	4.354
VW e-Golf	7.2	24	3.333
VW e-Golf 2017	7.2	35.8	4.972

The maximum acceptance rate, r_{max}, is 17.2 kW, and the longest charging time, $H_{EV.max}$, is approximately 6 hours.

With the maximum estimated charging time, the capacitance that the solar batteries will need can be estimated (in this case, the OPzS cells).

The process consists of calculating the nominal capacitance. It is necessary to know the consumption that is required for the EV with the longest estimated charging time, which can be obtained by multiplying the time in hours by the maximum acceptance rate of all the EVs in table 5.:

$$E.cons_{full-charge} = r_{max} \times H_{EV.max} \times N_{E.V} \tag{17}$$

Where:

- $E.cons_{full-charge}$= consumption that needs to be covered for full charge
- r_{max}= highest rate of acceptance
- $H_{EV.max}$= longest estimated charging time
- $N_{E.V}$= number of electric vehicles that can be charged.

By knowing the consumption to supply, the capacitance of the batteries and the number of batteries to be connected in parallel can finally be obtained:

$$C_{nom} = \frac{E.cons_{full-charge} \times k}{DOD \times V_{bat.cell} \times N_{cell.series}} \tag{18}$$

And,

$$N_{batteries} = \frac{C_{nom}}{C_{bat}} \tag{19}$$

Where:

- $E.cons_{full-charge}$= consumption that needs to be covered for full charge.
- k= safety coefficient for losses.
- C_{nom}= nominal capacity of the battery at 10 hour discharge – DIN 40736-1.
- DOD = Depth of discharge.
- $V_{bat.cell}$= Voltage of an OPzS cell.
- $N_{cell.series}$= number of OPzS cells in series.

Another important point that it is necessary to consider when choosing the battery capacitance is the current at which the cells can work for a certain numbers of hours.

In the case of ZGR SOLAR HITC 50, the maximum current that can pass to the battery while charging is 50A. However, for discharge, the maximum current is more than triple the previous value at 173 A. As the goal is for the batteries to be able to reach this latter value, the chosen OPzS must be the type 14 OPzS, as:

$$C_{nom} = 1750\ Ah = 175\ A\ \times 10\ hours \quad (20)$$

7.7 Wiring

A wire is a conductor through which electricity is transmitted. The cables are in charge of connecting the whole circuit and make it possible for the power to reach its destination.[31]

These cables have a certain section which allows a maximum voltage and current to pass. To carry out the project, it is necessary to calculate these sections of the circuit wiring. For this, it must be made sure that the sections comply with the regulations described in LVER.

Some of these regulations include:

- The voltage drop from the generator to the distribution network must never surpass 1.5%.
- The connection cables will be dimensioned for an intensity no less than 125% of the maximum intensity of the generator, in this case, the solar panels.
- The wiring is outdoors, exposed to the sun, so according to Table A.1 from the guide ITC-BT-19, the temperature correction factor for unburied cables, F, is equal to 1.
- The minimum section for copper conductors is of 2.5 mm^2 as, according to the recommendations given by the IDEA, the minimum section should be 2,5 mm2 from the generator to inverter/regulator and 4 mm2 from the inverter/regulator/charger to the batteries. [29]

In this project, three different types of wiring will be used, DC wiring, AC wiring and cable for grounding connection.

WIRING SECTION CALCULATION

Before calculating the section of the DC and AC cables, it is necessary to make sure that the chosen wiring complies with thermal and maximum voltage drop criteria.

1. <u>Criteria 1 or Thermal norm</u>: The current flowing withing the cable must never surpass the maximum admissible current, so that the insulator does not reach temperatures that could cause faster deterioration.

   The maximum admissible current, $I_{max,adm}$, is determined by the LVER. The conductor must be able to bear this current.

$$I_{max,adm.table} > I_{max,adm.circuitpart} \tag{21}$$

2. Criteria 2 or Maximum voltage drop norm: the voltage drop must not surpass the value of 1.5% within the whole installation. Moreover, the smaller this voltage drop is, the better the functionality of further away instruments. [51]

$$\Delta V_{CC} < 1.5\ \% \quad (22)$$

To calculate the DC and AC cable sections certain assumptions have been made:

- The temperature for the whole calculation is assumed to be 40ºC.
- Therefore, the resistivity from copper used will be at 40ºC:

$$\rho_{40} = \rho_{20} \times \left(1 + T_{coef} \times (40 - 20)\right) = 0.0185\ {ohm * mm^2}/{m} \quad (23)$$

Where:

- T_{coef}= Temperature coefficient: 0,00393 $ºC^{-1}$
- ρ_{20} = 0.0172 ${ohm\ mm^2}/{m}$

The previous values were taken from the LVER book. [29]

- The wires will not be buried, and the chosen conductor type for the wiring will be cross-linked polyethylene, XLPE.
- For the DC circuits, the method of installation will correspond to method E, and will be unipolar cables.

For the estimation of maximum admissible current and section, table C-52-1 bis – UNE-HD 60.364-5-52, maximum admissible current for non-buried cables at 40ºC will be used. This table is represented in table 8.

TABLE 8. table C- 52-1 bis – UNE-HD 60.364-5-52, maximum admissible current for non-buried cables at 40ºC [29]

A1			PVC3 (70 °C)	PVC2 (70 °C)				XLPE3 (90 °C)		XLPE2 (90 °C)									
A2		PVC3 (70 °C)	PVC2 (70 °C)			XLPE3 (90 °C)		XLPE2 (90 °C)											
B1					PVC3 (70 °C)		PVC2 (70 °C)					XLPE3 (90 °C)				XLPE2 (90 °C)			
B2				PVC3 (70 °C)	PVC2 (70 °C)					XLPE3 (90 °C)		PVC2 (90 °C)							
C							PVC3 (70 °C)				PVC2 (70 °C)			XLPE3 (90 °C)			XLPE2 (90 °C)		
E									PVC3 (70 °C)				PVC2 (70 °C)			XLPE3 (90 °C)		XLPE2 (90 °C)	
F											PVC3 (70 °C)				PVC2 (70 °C)		XLPE3 (90 °C)		XLPE2 (90 °C)
	1 (1)	2 (2)	3 (3)	4 (4)	5a (5)	5b (5)	6a (6)	6b (6)	7a (7)	7b (7)	8a (8)	8b (8)	9a (9)	9b (9)	10a (10)	10b (10)	11 (11)	12 (12)	13 (13)
	mm²																		
	1,5	11	11,5	12,5 (+0,5)	13,5	14 (-0,5)	14,5 (+0,5)	15,5 (-0,5)	16	16,5 (-0,5)	17 (-0,5)	17,5 (-1)	19	20 (-1)	20	20	21	23 (+1)	
	2,5	15	15,5 (+0,5)	17 (+0,5)	18 (+0,5)	19 (-0,5)	20 (+1)	20 (+1)	21 (+1)	22	23	24 (-1)	26	27 (-1)	27 (-0,5)	28 (-1,5)	30 (-1)	32 (+1)	
	4	20	20 (+1)	22 (+1)	24	25 (-1)	26 (+1)	27 (-1)	29 (+1)	30	31	32 (-1)	34	36 (-2)	36	38 (-2)	40 (-2)	44 (+1)	
	6	25	26 (+1)	29 (+1)	31 (+1)	32	34 (+2)	36	37	39 (-2)	40	41 (-1)	44	46 (-2)	46	49 (-3)	52 (-3)	57	
	10	33 (+1)	36 (+1)	40	43 (+1)	45 (-1)	46 (+4)	49 (+1)	52	54 (-2)	54	57 (-3)	60	63 (-3)	65	68 (-3)	72 (-4)	78 (-2)	
	16	45	48 (+1)	53 (+1)	59	61 (-2)	63 (+3)	66	69 (+1)	72 (-2)	73	77 (-4)	81	85 (-4)	87	91 (-4)	97 (-6)	104 (+1)	
Cobre	25	59	63 (+1)	69 (+1)	77	80 (-3)	82 (+2)	86 (-2)	87 (+1)	91 (-3)	95	100 (-5)	103	108 (-5)	110	115 (-5)	122 (-6)	135 (-12)	146 (-6)
	35				95 (+1)	100 (-4)	101 (+3)	106 (-2)	109 (+1)	114 (-4)	119	124 (-5)	127	133 (-6)	137	143 (-6)	153 (-9)	168 (-14)	182 (-8)
	50				116 (+1)	121 (-4)	122 (+3)	128 (-3)	133	139 (-6)	145	151 (-6)	155	162 (-7)	167	174 (-7)	188 (-13)	204 (-16)	220 (-10)
	70				148 (+1)	155 (-6)	155 (+5)	162 (-2)	170 (+1)	178 (-7)	185	193 (-8)	199	208 (-9)	214	223 (-9)	243 (-19)	262 (-18)	282 (-13)
	95				180	188 (-8)	187 (+7)	198 (-4)	207	216 (-9)	224	234 (-10)	241	252 (-11)	259	271 (-12)	298 (-27)	320 (-24)	343 (-16)
	120				207 (+1)	217 (-9)	216 (+9)	226 (-1)	240	251 (-11)	260	272 (-12)	280	293 (-13)	301	314 (-13)	346 (-36)	373 (-25)	397 (-17)
	150						247 (+13)	259 (+1)	276 (+2)	287 (-9)	299	313 (-14)	322	337 (-15)	343	359 (-16)	401 (-38)	430 (-26)	458 (-20)
	185						281 (+16)	294 (+3)	314 (+3)	329 (-12)	341	356 (-15)	368	385 (-17)	391	409 (-18)	460 (-45)	493(-29)	523 (-23)
	240						330 (+20)	345 (+5)	368 (+6)	385 (-11)	401	419 (-18)	435	455 (-20)	468	489 (-21)	545 (-55)	583 (-31)	617 (-27)

7.7.1 DC wiring

This type of wiring covers the following parts of the photovoltaic circuit:

- Solar modules to String Combiner Box
- String Combiner Box to Inverter

For CASE 2, where batteries are part of the circuit, the part connecting the batteries to the inverter will also be using DC wiring.

To calculate the cable section for the DC circuits, the maximum admissible current and voltage drop need to be calculated. For this, equation 24 will be used. Once the minimum cable section is calculated, the normalized section with the closest value from table 8 is taken. Afterwards, that section, S, is used in equation 26 to check if the voltage drop is lower than the specified by the LVER. [29]

To apply the above-mentioned procedure, the following equations will be used in the displayed order:

$$I_{max,adm} = \frac{1.25 \times I_{mp}}{F} \quad (24)$$

$$S_{min,CC} = \frac{2 \cdot \rho_{40} \cdot L \cdot I_{mp}}{V_{series} \cdot \Delta V_{CC.máx}} \quad (25)$$

$$\Delta V_{CC} = \frac{2 \cdot \rho_{40} \cdot L \cdot I_{mp}}{V_{series} \cdot S} \quad (26)$$

Where:

- L = length of the circuit (m)
- F = temperature correction factor.
- I_{mp} = Nominal Current (A)
- $I_{max,adm}$= Maximum admissible current through the cable (A)
- $S_{min,CC}$= minimum cable section (mm^2)
- S = cable´s section (mm^2)
- $\Delta V_{CC.máx}$= maximum voltage drop according to the LVER.
- V_{series}= Voltage of modules in series per string (V)
- ΔV_{CC} = DC voltage drop

The length of the cables will be determined in more detail in the results section. To estimate the length, the following formulas have been used:

- From PV modules to SCB:

$$\sum_{i=1}^{i=4} L_i \times k_s \quad (27)$$

Where the lengths correspond to:

- L_1= upper half module to upper corner of the canopy.
- L_2= upper corner of the canopy to upper part of the pillar.
- L_3= lower half module to upper corner of the canopy.
- L_4 = lower corner of the canopy to upper part of the pillar.
- k_{s1}= safety coefficient one.

- From the SCBs to the inverter:

$$\sum_{i=1}^{i=2}(D_i + H_{can}) \times k_{s2} \quad (28)$$

Where,

- D_1= distance from SCB1 to inverter 1, and SCB3 to inverter 2
- D_2= distance from SCB2 to inverter 1, and SCB4 to inverter 2
- H_{can}= height of the canopy.
- k_{s2}= safety coefficient two.

- From the batteries to the inverter:

$$\sum_{i=1}^{i=3} S_i \times k_{s2} \quad (29)$$

Where:

- S_1= space between the battery housing and the door connecting the plots.
- S_2= distance between the door and the point parallel to the inverter´s housing in the wall, p_2.
- S_3= distance between the inverter and p_2.

7.7.2 AC wiring

This type of wiring covers from the inverter´s output to the supermarket´s fuse box (C.D.B).

The criteria used for the calculations is the same as for the DC wiring. However, the formulas differ slightly.

$$I_{max,adm} = \frac{1.25 \times I_{mp,SCB}}{F} \tag{30}$$

$$S_{min,CC} = \frac{\sqrt{3} \cdot \rho_{40} \cdot L \cdot I_{mp}}{V_{series} \cdot \Delta V_{CC.máx}} \tag{31}$$

$$\Delta V_{CC} = \frac{\sqrt{3} \cdot \rho_{40} \cdot L \cdot I_{mp}}{V_{series} \cdot S} \tag{32}$$

To calculate the first equation of the section, it is necessary to calculate the nominal current that will pass through the wire. This can be obtained with the following equation:

$$I_{mp,SCB} = N_{strings} \times I_{mppt,pv} \tag{33}$$

As in the DC wiring, the chosen $I_{max,adm.table}$ from the table must be higher than the value obtained from eq. 30.

$$I_{max,adm} < I_{max,adm.table} \tag{34}$$

In this case, the length of the table is also estimated with AutoCAD, but assuming the C.B.B is in the warehouse. Therefore, a distance of $d_{inv-c.g.p} = 45$ m is assumed.

7.7.3 Grounding section

For the appropriate minimum section of the grounding conductors, table two of ITC-BT-18 is taken as a reference. This table is valid because the phase material coincides with the protection conductor’s material (ITC-BT-18, chapter 3.4) and it complies with norm UNE-HD 60.364-5-54. [29]

TABLE 9. Relationship between section of the conductor´s protection and phase conductors. [29]

Phase conductors’ section of the installation	Minimum section of protection conductors
$S\ (mm^2)$	$S_p\ (mm^2)$
$S \leq 16$	$S_p = S$
$16 < S \leq 35$	$S_p = 16$
$S > 35$	$S_p = S/2$

7.8 Protections

This chapter will cover the protection against direct and indirect contact, for the safety of all against electric shock. According to the new norm UNE-HD 60364-4-41, these protections are denominated primary protection and protection in case of defect, respectively. [29]

To avoid direct contact with part of the installation with high voltage levels, the following measures will be taken:

- Protection of active circuit parts by isolations.
- Protection through barriers and electric enclosures.
- Protection through obstacles.
- Protection by maintaining distance and keeping potential danger out of reach.
- Protections against inverse connection and DC overvoltages, included in the inverter.

The other protections are meant to protect people from indirect contact. For this, switches such as super immunized differential with a sensitivity of 30 mA will be used in the circuits of alternating current. Some of the protections are:

- Protection against an automatic power cut.
- Double isolation boxes.
- Grounding.

These rules will be followed as indicated in ITC-BT-24. [29]

7.8.1 DC protections:

For security and functionality purposes, it is mandatory to use the appropriate protections for the different circuits of the installation.

Overload protection: according to the guide in ITC-BT-22, the following conditions need to be satisfied:

1. $I_b \leq I_n \leq I_z$ (35)
2. $I_2 \leq 1{,}45 I_z$ (36)

Where:

- I_b = Current for which the circuit has been designed according to the load forecast.
- I_n = Assigned current of the device.
- I_z = Permissible cable current depending on the installation system used. (ITC-BT-19 and UNE-HD 60.364-5-52).
- I_2 = current that ensures the performance of the protection device for a long time, tc. In the cases of fuses, it is also known as I_f. [29]

PANEL TO INVERTER CIRCUIT:

There will be two safety equipments for this part of the circuit:

- Fuses inside the String Combiner Box
- Circuit Breaker between the SCB and the inverter

In the case of fuses of type gG, I_f takes the following values:

$$I_f = 1{,}6 I_n \quad if \quad I_n \geq 16\ A \tag{37}$$

$$I_f = 1{,}9 I_n \quad if \quad 4\ A < I_n < 16\ A \tag{38}$$

$$I_f = 2{,}1 I_n \quad if \quad I_n \leq 4\ A \tag{39}$$

For the circuit breaker, the following formula must be satisfied:

$$t \geq \frac{K^2 s^2}{Isc^2} \quad (40)$$

Where:

- t= time for which the conductor is able to bear the short-circuit current.
- K= cable constant.
- Isc= short circuit current.
- s= section of the wire.

As well as the following condition to ensure surge protection:

- Condition 1:

$$I_{sc,max} \leq P_{cut} \quad (41)$$

Where:

- P_{cut}= circuit breaker power cut.
- $I_{sc,max}$= maximum short circuit current.

BATTERIES TO HYBRID INVERTER

In this case, the procedure explained in point 7.7 is followed, and the equations 24, 25 and 26 to calculate the maximum admissible current are used.

7.8.2 AC protections

Unlike direct current, alternating current has a sinusoidal nature. Therefore, the protections are intended to mitigate when this current is at one of the low points of its energy. The protections are then different. [37]

The cables will be unipolar and made of copper, and their isolation protection will be 0,6/1 kV.

Despite this, to calculate the protections, previous equations (35, 36, 40 and 41) must be used, as well as a new similar one:

1. $$I_2 = 1{,}25 I_n \tag{42}$$

The difference from the DC section is that I_2 is multiplied by a safety coefficient of 1.25, as is stated in point 5, ITC-BT-40. [29]

7.9 Grounding and Equipotential Connection

Grounding consists of the direct connection between a particular conductive part of the circuit through a ground connection with one or more electrodes, buried in the ground.

According to Chapter VI from ITC-BT.18, the grounding is established mainly to limit the voltage of the metallic masses, reduce the risk that a breakdown in the electrical materials would cause and ensure the proper functioning of the circuit protections.

For this project, a grounding network is not created, as the facility can be connected to the building. Still, an electrode will be installed between the panels and the inverter.

The photovoltaic generation will be arranged in a “floating scheme”, that is, the direct current network of the PV generator is isolated on the ground and there is a protective ground to which the metallic masses of the system will be attached, such as surge protection devices.

Thereby, there will be an equipotential connection to earth will be provided to which all the metallic masses of the solar facility will be joined. This grounding network will have two main objectives:

- Protection of people against indirect contacts, by preventing the masses from acquiring high potential values in the occurrence of insulation defects.
- Allow the correct operation of current and overvoltage limiters of the internal protection.

For the project, the contemplated option is a 2m vertical spike as grounding device and IT distribution scheme, with active conductors isolated from ground. [29]

Also, according to Chapter IV from ITC-BT-24, protection against indirect contact shall be achieved by an automatic power cut-off. This measure is used to prevent, after the occurrence of a fault, a contact voltage of sufficient value from being maintained for such a time as to result in a risk. The conventional limit voltage is equal to 50 V, the effective value in alternating current, under normal conditions and to 24 V in humid environments.

All masses of electrical equipment protected by the same protection device must be interconnected and joined by a protective conductor to the same grounding connection. The neutral point of each generator must be grounded. [29]

7.9.1 Grounding resistivity calculations.

To analyze whether the chosen grounding complies with the regulation, the following condition has to comply:

$$R_a \times I_a \leq U \quad (43)$$

Where:

- U is the conventional limit contact voltage.
- I_a is the current that ensures the automatic operation of the protection device.
- R_a is the sum of the resistances of the grounding connection and the protection of the conductive masses.

The nature of the soil where the spike is will be installed sis assumed to be clay sand, with an approximate resistivity of 150 Ωm following table 3, chapter VIII. To find the grounding resistance adopted according to the terrain and electrode, the formula given in table 5, chapter VIII is used. [29]

TABLE 10. Formulas for estimating grounding resistance as a function of soil resistivity and electrode characteristics.[29]

Electrode	**Grounding resistance in ohms (Ω)**
Buried plate	R_{plate}= 0,8 Ρ / P
Vertical spike	R_{vs}= Ρ / L
Horizontally buried conductor	R_{cond}= 2 Ρ / L
▪ Ρ, resistivity of the terrain (Ωm) ▪ P, perimeter of the plate (m) ▪ L, length of the spike or conductor (m)	

TABLE 11. Guidance values of resisitivity depending on the terrain[29]

Nature of the terrain	**Resistivity in Ωm**
Marshlands	From units until 30
Silt	20 to 100
Humus	10 to 150
Wet peat	5 to 100
Plastic clay	50
Compact loaves and clays	100-200
Jurassic margins	30 to 40
Clay sand	50 to 500
Siliceous sand	200 to 3000

The equation to calculate the vertical spike resistance can be seen on table 5:

$$R_{vs} = \frac{\rho}{L} \quad (44)$$

This resistance needs to be lower than the admissible resistance in the low voltage circuit for 24 V of contact voltage (chapter IX, ITC-BT-18) and the differential switch´s sensitivity.

$$R = \frac{V}{I_a} \quad (45)$$

To conclude, the electrode for grounding of the metallic elements of the installation will be independent from the neutral electrode of the supermarket´s distribution network. (according to article 15 of RC 1.699/2011 and ITC-BT-40. [29]

The protection conductors will run through the same direct and alternating current conduits from the canopy’s facility.

7.10 Network measurement equipment

A wattmeter system with 0 injection equipment will be installed in the facility to measure the customer's consumption and the production of the photovoltaic plants and – in the event of surplus production, a situation that would hardly occur – the output power of the inverters automatically, so that the evacuation of energy to the PDN can be avoided.

For the consumption and production of the building, the wattmeter will be connected to the low voltage box or C.D.B.

This equipment will therefore be installed in approved cabinets that comply with the specifications included in the instructions ITC-BT13 and ITC-BT16, of the current LVER. [29]

8. EV CHARGING POINTS

8.1 Electric Vehicles

An electric vehicle is denoted by the fact that all or part of its propulsion energy comes from its battery's electricity. To charge these batteries, there are many suitable options available in today's market. [38]

The following is a brief summary of the various chargers that were considered for this project.

8.1.1 Chargers for electric vehicles

To accurately understand and compare the electric vehicle chargers available, it is necessary to consider the various physical connectors as well as the actual mode of charging. Firstly, there are many different connectors to choose from.

- **Schuko connector and 3-pin plug or Cetac**

This connector is also the conventional household plug, thereby allowing for the charging of an EV more or less anywhere. It is the most commonly used connector in Europe, and allows one to charge their EV just as they would another household appliance.

However, the charging time associated with this connector is very high, as it allows a limited maximum current of 16 A, and maximum power of 3.7 kW for single phase operation. The Schuko connector can only operate for single-phase power whereas the Cetac can operate both three-phase and single-phase.

- **Type 1 connector or Yazaki**

This connector is called the pioneer, because it was the first type of connector used for the specific purpose of EV charging. It is more frequently used in America and Asia than in Europe, as it was first introduced in Japan.

This is an AC connector that provides a slow charge using single-phase. The maximum current is double that of the Schuko connector at 32 A, and the maximum power is 7.4 kW. This connector can also be locked while charging to prevent it from disconnecting.

As can be seen in the third picture from table 10, it offers five points of contact.

- **Type 2 connector or Mennekes**

This connector is generally accepted as the standard in Europe for electric vehicles. It is an AC connector used to charge many different kinds of electric vehicles. It allows for seven points of contact between the electric vehicle and the charger, as shown in table XX. ,which is an advantage over the Type 1 connector.

These extra points of contact in the Mennekes connector, allow for three-phase power with a maximum current of 63 A, as well as a maximum power of 43 kW. In the case for single-phase power, the maximum voltage will be of 250 V and 70 A. It is capable of facilitating both slow and fast charging, depending on the power.[52]

The seven pins are divided as followed: The bigger circles at the bottom of the connector, surrounding the centre, are the phases L1, L2, L3 and Neutral. For slower power, only L1 and N will be connected, whereas for faster, the three phases will connect. At the centre of the connector, the grounding pin is found, necessary for security reasons as before the charging starts, the charging point will check for an adequate grounding. The last two pins at the tope of the connector are PP and CP, pilot and proximity point respectively.[39]

In the case of type 4 connectors, there are two main models in the market – CHAdeMO and CCS. These allow for DC charging:

- **CHAdeMO connector**

This was the first DC connector to be introduced and is widely used in Japanese and American electric vehicles for its rapid rate of charge. It is also commonly seen in the United Kingdom.

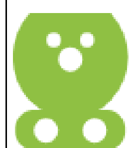
The CHAdeMO connector has a maximum current of 125 A, and a maximum power of 50kW, allowing for a superior rate of charge to that of the connectors previously discussed.

- **Combined Charging System (CCS) connector**

The CCS connector is potentially much faster than the CHAdeMO connector and allows for both AC and DC charging using a single port. As seen in table 10, the round shape of the top of the connecter facilitates altern current, whereas the bottom two points of contact allow for high-power DC.

This connector has a high maximum current of 200 A, and a maximum power of 350 kW. This can facilitate a rapid charge rate compared to that of other available connectors, including the CHAdeMO. However, CCS connectors are not yet as commonly used, likely due to their comparatively high price.[52][53]

TABLE 12. Type of connectors for EV charging [52]

TYPE/ MODEL	**SCHUKO**	**CETAC**	**TYPE 1 or YAKAZI**	**TYPE 2 or MENNEKES**	**TYPE 4 CHAdeMO**	**TYPE 4 CCS**
WORKING CURRENT AND VOLTAGE	AC Single-phase	AC Single-phase Three-phase	AC Single-phase	AC Single-phase Three-phase	DC	DC
PICTURE						

8.1.2 Electric vehicles charging modes

There are currently 4 different modes in existence for electric vehicle charging. Modes 1 and 2 do not have a specific connector for EV and the type of charge they offer is slow AC charge, whereas mode 3 and 4 do have a specific type of connector.[38] The four output modes are detailed in more depth below:

MODE 1

Mode 1 involves the connection of the electric vehicle to the AC supply network using the Schuko connector. The maximum current associated with Mode 1 is 16 A, and the maximum charging power achievable is 3.7 kW. [38]

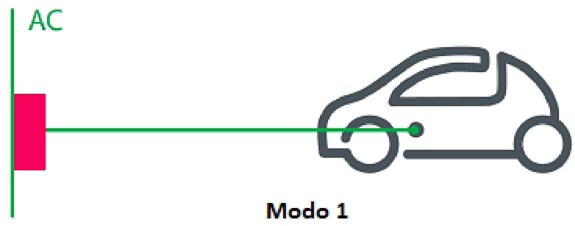


Figure 20. Output Mode 1[54]

MODE 2

This mode allows for the connection of the electric vehicle to the AC power supply network without exceeding 250 V for single-phase, and 480 V for three-phase. Its maximum power is also 3.7 kW.

Mode 2 works very similarly to mode 1, as it too uses a Schuko connector. However, this mode incorporates a differential current device, located between the electric vehicle and the charging point. This means that there is some communication between the charging point and the vehicle, and as a safety feature, will disconnect the charge if the connection experiences any problems.

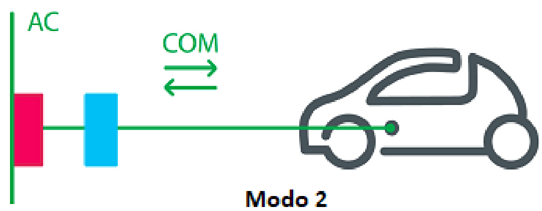


Figure 21.Output Mode 2. [54]

MODE 3

This mode consists of a direct connection between the power supply and the vehicle, through a SAVE (specific power supply system for the electric vehicle). Because of this, the amount of communication between the charging point and vehicle is very high with this mode, and the pilot control function will be amplified. It offers a much more secure connection than previously discussed modes and it offers the option for both slow and semi-fast AC charging.

The maximum current associated with mode 3 is 32 A for single-phase power, and 63 A for three-phase. In addition, the maximum power achievable is 43 kW. This mode is commonly known as Wallbox, and it is used in in destination recharges, such as community garages, workplace, shopping centres and similar establishments.

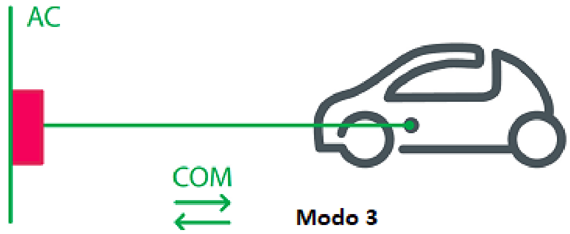


Figure 22.Output Mode 3. [54]

MODE 4

This mode incorporates DC power, allowing for a much faster rate of charge. This is by far the most efficient option in terms of charging speed, because it utilizes the CCS and CHAdeMO connectors. It is commonly known as emergency charge, as the price for its use is significantly more expensive than the modes mentioned before.

This mode offers a potential maximum power of 350 kW, which allows for rapid charging. It also provides optimum communication between the vehicle and the charging point.

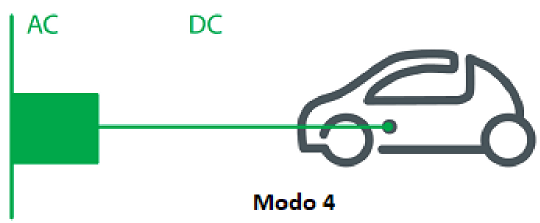


Figure 23. Output Mode 4. [54]

8.2 Charging stations

For this project, only mode 3 and 4 will be used, as they allow fast charging. The type of vehicle that will be suited for charging belongs to category N1 – electric vehicles whose mass does not surpass 3.5 tons.[38]

Also, as mentioned in section 5, there will be 4 charging stations, and they will be located in the parking spaces at the ends of canopies 1 and 3.

The charging stations from EVBox have been the chosen, due to their recognition and efficiency during the past few years. The models are:

8.2.1 EVBox Iqon

This charging station can charge up to 22 kW AC, and it has dual cables to facilitate the charging of two electric vehicles at once.

The Iqon provides very accessible charging; it comes with a unique, auto retractable 5.5m cable that never has to touch the ground, a multi-language LCD touchscreen and wheelchair access. It also has a load balancing feature, by which it can link up with other stations and distribute power more efficiently between the electric vehicles. This kind of controlled distribution allows for more security, as it actively manages how much energy is being used.

Figure 24. EVBox Iqon. [55]

The Iqon can be used to charge any electric vehicle with a Type 2 connector.[55]

8.2.2 EVBox Troniq 50

This charging station can potentially charge at twice the power than that previously discussed. The Troniq 50 is a fast-charging solution, capable of charging one vehicle with DC and another with AC simultaneously. It charges at 22 kW, but if only one vehicle is being charged, the DC cable can charge at 50 kW.

This model includes an advanced cooling and heating system, auto-retractable cables and easy installation. It also offers additional battery storage. In the case of this project, the batteries will not be necessary; however, when the EV industry evolves and charging stations require more electricity, this feature could be very useful.

Figure 25. EVBox Troniq 50. [56]

The Troniq 50 also has universally compatible connectors, including CHAdeMO, CCS2, Type 2 and a Type E/F socket. [56]

9. CALCULATION RESULTS

In this section the results from the calculations and simulations are found.

9.1 PV modules calculations

The modules will be installed coplanar, so this angle α is 0. This explanation can be seen in the picture below.

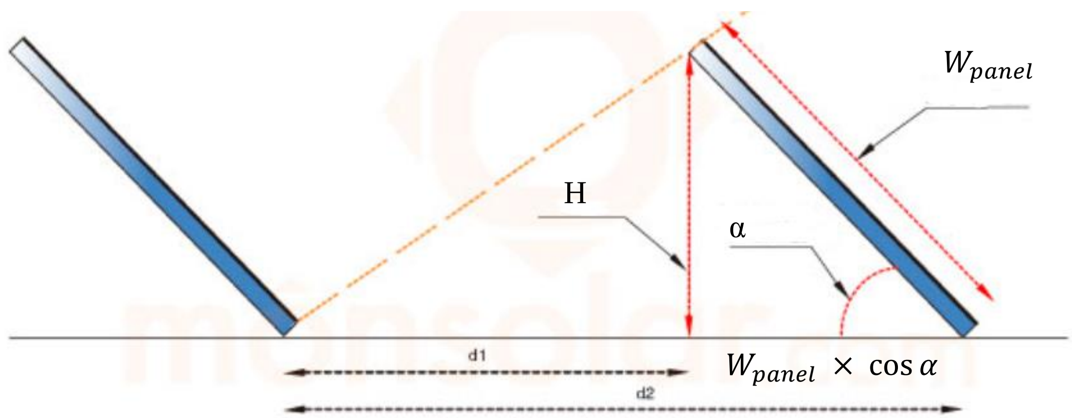


Figure 26. Angle alpha [62]

As the angle equals to zero, the distance between panels (d_1) and the highest point the panel will reach (H) will be approximately 0. However, in the case of d1, a small distance will be left for the pressors that will be located between panels. Distance d_2, also known as pitch, will be determined as follows:

$$d_2 = W_{panel} + d_{row} \tag{46}$$

Therefore, using the values from table 4 and equation 3, the obtained result is $S_{panel} = 2.209\ m^2$.

9.2 Inverter calculation

By applying equation 4, a total of 4 inverters of 50 kW will be part of the project´s facility.

Also, it is possible to determine the maximum number of panels in series and strings. For this, the following values have been calculated using equations 5, 6 and 7, and the values from the module´s technical paper:

The values used are:

- $NOCT = 44 \pm 2ºC$
- $Tamb = 20ºC$
- $V_{OC} = 49.25\ V$
- $TªCoef = -0{,}30\%/ºC = -0{,}1477\ V/ºC$

And the results are:

$$T_{cell} = -2\ ºC$$

$$V_{OC,max} = 54{,}23\ V$$

Moreover, from the datasheet of the chosen inverter, the maximum input voltage of the inverter, that must never be surpassed, can be found.

- CASE 1: $V_{max,inv}$= 900 V.
- CASE 2: $V_{max,inv}$= 880 V

Thanks to this data, it is determined the maximum number of panels that can be connected in series:

$$N_{max.series.CASE1} = 16.59 \rightarrow 16 \text{ panels}$$

$$N_{max.series.CASE2} = 16.22 \rightarrow 16 \text{ panels}$$

Finally, the total number of strings for both CASE 1 and 2 will be calculated using equation 9 and the maximum current of the inverter for DC, which can be found on the inverter's datasheet in Annex A.

$$N_{max.strings}^{CASE1} = 13{,}45 \rightarrow 13 \text{ strings}$$

$$N_{max.strings}^{CASE2} = 11{,}75 \rightarrow 11 \text{ strings}$$

With this information, a PVSyst simulation is made for both CASE 1 and 2. The results can be seen in figures B.1 and B.6 from Annex B. Thanks to this simulation, the final arrangement of the modules and inverters, and the total number of panels that is needed to use to generate as much as P_{plant} is known.

As seen in tables 5 and 6, the total number of strings per inverter´s entrance is 9 and the number of panels in series per string is 16. These numbers are less than the maximum calculated above, therefore equations 8 and 10 are satisfied:

$$N_{strings} = 9 < N_{max.strings}^{CASE1} \,\&\, N_{max.strings}^{CASE2}$$

$$N_{series} \leq N_{max.series.CASE1} \,\&\, N_{max.series.CASE2}$$

9.3 Occupancy calculations – structures

Following the procedure explained previously in point 7.4.1, using the data from table 4, and obtaining a design with 23 columns in AutoCAD, the equations 12, 13 and 14 get the following results:

$$W_{usef} = 9{,}702\ m$$

$$L_{usef} = 49{,}12\ m$$

$$A_{usef.max} = 476{,}56\ m^2$$

The surface area occupied by the 207 solar panels should not surpass the previous value, $A_{usef.max}$. To calculate the total area that the modules take up, the surface of the panel is multiplied by the total number of panels that the largest canopies can support, ${N_{tot.panels}}^{C1-3}$.

$$S_{panel} \times {N_{tot.panels}}^{C1-3} = 457{,}26\ m^2 \qquad (47)$$

Where,

- ${N_{tot.panels}}^{C1-3}$= 207 panels

As this value is smaller than $A_{usef.max}$, it is confirmed that canopies 1 and 3 will support 207 panels each, leaving the rest of the panels for canopies 2 and 4:

$${N_{tot.panels}}^{C2-4} = \frac{N_{tot.panels} - {N_{tot.panels}}^{C1-3}}{2} = \frac{576-(2\times 207)}{2} = 81\ panels \qquad (48)$$

Where,

- ${N_{tot.panels}}^{C2-4}$= total number of panels that canopies 2 and 4 can each support.
- $N_{tot.panels}$= total number of panels of the whole facility.

9.4 SCB calculations

The number of strings coming into the junction box are 18, 9 positive inputs and 9 negatives.

9.5 Battery calculations

With equation 16 and the values from table 7, we get a total consumption of 103,2 kWh for one car. Therefore, the nominal capacitance is:

$$C_{nom.1EV} = 533{,}23\ Ah$$

As the depth of discharge of the batteries equals 0.8, $N_{cell.series} = 168$, k= 1.25 and $V_{bat.cell} = 1.8\ V$.

This capacity is less than the nominal capacity of the chosen OPzS, $C_{bat,10} = 1750\ Ah$. This means, that multiple cars will be able to charge just from the battery's generation:

$$N_{E.V} = \frac{C_{bat,10}}{C_{nom}} = 3{,}28\ EV \quad (49)$$

Therefore, the $E.cons_{full-charge}$ will be 309.6 kWh, which will allow for 3 vehicles to charge completely from the batteries, and the nominal capacitance will be:

$$C_{nom.3EV} = 1599\ Ah$$

NOTE:

$N_{cell.series}$ is estimated taking into consideration two values: $V_{bat.cell}$, given by the batteries and the minimum voltage range of the inverter, $V_{min.inve.bat} = 300\ V$, which can be also found in the inverter´s datasheet. The condition that needs to be satisfied is that:

$$V_{bat.cell} \times N_{cell.series} > V_{min.inve.bat} \tag{50}$$

Thus,

$$302{,}4\ V > 300\ V$$

Also, equation 18 is equal to 1. Therefore, none of the cells will be connected in parallel.

The 168 lead-acid cells can charge an EV from 0% up to its maximum charge. However, the EV´s batteries are not usually completely empty. Usually, a car will arrive to a charging station half charged at around 40%, which is an acceptable discharge percentage. As the batteries fully charge up till 80%, for a good use, this will save half time compared to the previous calculation and half of batteries capacitance needed. This means that instead of charging 3 cars it has the capacity to charge six cars whose batteries are half empty.

9.6 Wiring section calculation

9.6.1 DC wiring

Before calculating the section needed for the cables, we need to estimate the distances that separate the equipment from each other.

From equation 27, 20 meters is obtained for the first string. From then on, each row will add 3 meters consecutively to the cable length until it reaches the limit of canopies 1 and 3.

This picture shows where L2 and L3 come from:

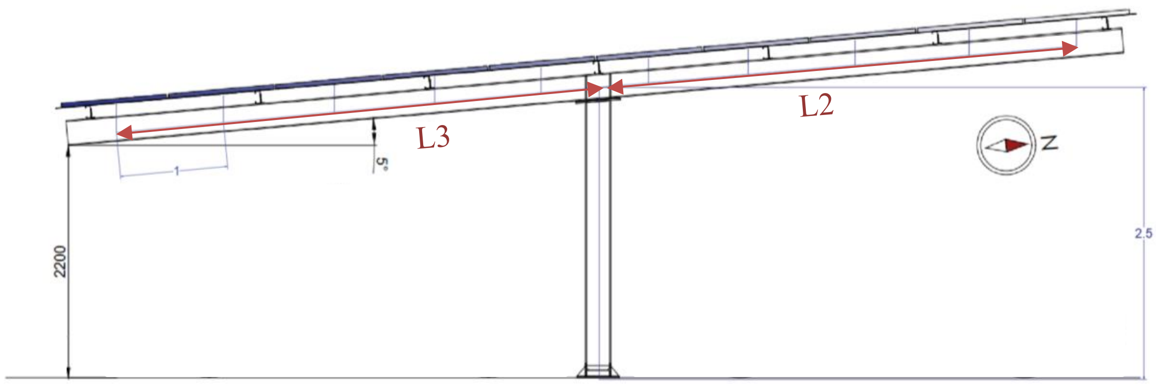


Figure 27. Canopy´s profile measurements

And in the following one, distances L1 and L4 are shown to be 1 meter each, as the distance corresponds to half the width of the panel:

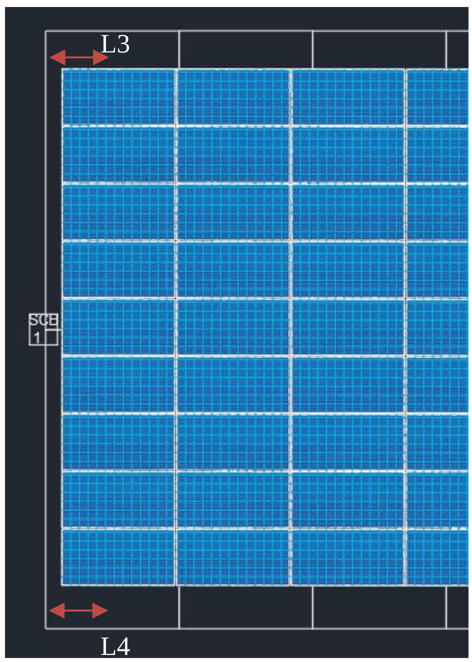


Figure 28. Upper view canopy and SCB

The estimated cable length from the SCB´s to the inverter is 57.5 meters in the case of distance 1, and 10 meters for Distance 2. This calculation has been done using the measurements taken from AutoCAD and the equation 28, where $k_{s2} = 2$. In Annex C, this distance can be seen more clearly.

Finally, from equation 29 the length of the wires from the batteries to the inverters is 41 meters.

Since the length variables have already been calculated, it is possible to proceed with the results for the DC wiring section:

In table 13, the cable sections of the 36 strings are shown, as well as the minimum section of the cable and the chosen section of the cable that will be used. Also, the voltage drop is calculated following the equations 23, 24 and 25, as well as table 8.

For the first equation, the value of the nominal current, I_{mppc}, can be found in table 4. Also, the temperature correction factor is equal to 1, as indicated in table 7 from chapter III, ITC-BT-06. [38]

Similarly, tables 14 and 15 are calculated. In the case of the SCB section to the inverter, the current is the short current from the module multiplied by the number of strings:

$$I_{sc,pv} \times N_{strings} = 101{,}52 \text{ A} \quad (51)$$

However, the current passing through the DC wiring from the batteries to the inverter is of 175 A, as explained before in section 7.6.1.

With the chosen wire sections, both criteria 1 and 2 are met:

TABLE 13. Section and voltage drop results from PV modules to SCB

String (SUB.Inv.Series)	**Panels (Ud)**	**Pot Panel (W)**	**Pot total (W)**	**Voltage (V)**	**Current (A)**	**L (m)**	**Voltage drop (%)**	**Smin,cc**	**Section (mm²)**
SUB. 1.1.1	16	440	7040	662.4	11.28	23	0.29	0.966	**2.5**
SUB. 1.1.2	16	440	7040	662.4	11.28	29	0.37	1.218	**2.5**
SUB. 1.1.3	16	440	7040	662.4	11.28	35	0.44	1.470	**2.5**
SUB. 1.1.4	16	440	7040	662.4	11.28	41	0.52	1.722	**2.5**
SUB. 1.1.5	16	440	7040	662.4	11.28	44	0.55	1.848	**2.5**
SUB. 1.1.6	16	440	7040	662.4	11.28	50	0.63	2.100	**2.5**
SUB. 1.1.7	16	440	7040	662.4	11.28	56	0.71	2.352	**2.5**
SUB. 1.1.8	16	440	7040	662.4	11.28	62	0.49	2.604	**4**
SUB. 1.1.9	16	440	7040	662.4	11.28	65	0.51	2.730	**4**
SUB. 1.2.1	16	440	7040	662.4	11.28	38	0.48	1.596	**2.5**
SUB. 1.2.2	16	440	7040	662.4	11.28	35	0.44	1.470	**2.5**
SUB. 1.2.3	16	440	7040	662.4	11.28	29	0.37	1.218	**2.5**
SUB. 1.2.4	16	440	7040	662.4	11.28	40	0.50	1.680	**2.5**
SUB. 1.2.5	16	440	7040	662.4	11.28	43	0.54	1.806	**2.5**
SUB. 1.2.6	16	440	7040	662.4	11.28	49	0.62	2.058	**2.5**
SUB. 1.2.7	16	440	7040	662.4	11.28	55	0.69	2.310	**2.5**
SUB. 1.2.8	16	440	7040	662.4	11.28	61	0.48	2.562	**4**
SUB. 1.2.9	16	440	7040	662.4	11.28	64	0.50	2.688	**4**
SUB. 2.3.1	16	440	7040	662.4	11.28	23	0.29	0.966	**2.5**
SUB. 2.3.2	16	440	7040	662.4	11.28	35	0.44	1.470	**2.5**
SUB. 2.3.3	16	440	7040	662.4	11.28	35	0.44	1.470	**2.5**
SUB. 2.3.4	16	440	7040	662.4	11.28	41	0.52	1.722	**2.5**
SUB. 2.3.5	16	440	7040	662.4	11.28	44	0.55	1.848	**2.5**
SUB. 2.3.6	16	440	7040	662.4	11.28	50	0.63	2.100	**2.5**
SUB. 2.3.7	16	440	7040	662.4	11.28	56	0.71	2.352	**2.5**
SUB. 2.3.8	16	440	7040	662.4	11.28	62	0.49	2.604	**4**
SUB. 2.3.9	16	440	7040	662.4	11.28	65	0.51	2.730	**4**
SUB. 2.4.1	16	440	7040	662.4	11.28	38	0.48	1.596	**2.5**
SUB. 2.4.2	16	440	7040	662.4	11.28	35	0.44	1.470	**2.5**
SUB. 2.4.3	16	440	7040	662.4	11.28	29	0.37	1.218	**2.5**
SUB. 2.4.4	16	440	7040	662.4	11.28	40	0.50	1.680	**2.5**
SUB. 2.4.5	16	440	7040	662.4	11.28	43	0.54	1.806	**2.5**
SUB. 2.4.6	16	440	7040	662.4	11.28	49	0.62	2.058	**2.5**
SUB. 2.4.7	16	440	7040	662.4	11.28	55	0.69	2.310	**2.5**
SUB. 2.4.8	16	440	7040	662.4	11.28	61	0.48	2.562	**4**
SUB. 2.4.9	16	440	7040	662.4	11.28	64	0.50	2.688	**4**

TABLE 14. Section and voltage drop results from SCB to inverter

String Combiner Box	Voltage (V)	Current (A)	L(m)	Voltage Drop (%)	Smin,cc	S(mm2)
SCB.1	662.40	101.52	10.00	0.11	3.780	**25**
SCB.2	662.40	101.52	57.50	0.65	21.738	**25**
SCB.3	662.40	101.52	10.00	0.11	3.780	**25**
SCB.4	662.40	101.52	57.50	0.65	21.738	**25**

TABLE 15. Section and voltage drop results from battery bank to inverter

Nº Units/ bank	Voltage/ unit (V)	Nº Banks	Voltage (V)	Total Voltage (V)	Current (A)	Length (m)	Section (mm²)	Voltage Drop (%)
24	2	7	48	336	175	41	50	1.098

Finally, the chosen cable is the EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC, of sections 2.5 mm^2, 4 mm^2, 25 mm^2 and 50 mm^2. The cable and its characteristics are shown in the following picture:

Sección (mm²)	Diámetro nominal exterior (mm)	Peso nominal (kg/km)	Radio mínimo de curvatura (mm)	Intensidad máx. admisible al aire 60 °C * (A)	Caída de tensión DC system (V/A.km)
1x2,5	4,8	45	20	41	22,9
1x4	6,0	65	25	55	14,2
1x6	6,6	85	25	70	9,45
1x10	8,0	135	35	96	5,43
1x16	8,5	195	35	132	3,46
1x25	10,2	290	45	176	2,22
1x35	11,5	390	50	218	1,57
1x50	13,7	550	55	267	1,10
1x70	15,2	750	65	332	0,772
1x95	17,1	970	70	397	0,585
1x120	19,1	1.215	80	471	0,457
1x150	21,2	1.525	85	541	0,368
1x185	23,1	1.830	95	615	0,301
1x240	26,7	2.415	135	745	0,228
1x300	29,8	3.045	150	857	0,182

Figure 29. DC cable

9.6.2 AC wiring results

Similarly to DC wiring calculations, the thermal and voltage drop criteria mentioned in section 7.7.2 need to be met. For this, the estimated length is given by the variable $d_{inv-c.g.p}$. Regarding the Ingecon Sun 50, the inverter´s nominal current is 93A, whereas for the hybrid inverter, the current is 76 A. With this data and table 8, the maximum admissible current for this section is obtained following equation 33 and a nominal current equal to:

$$I_{mp,SCB} = 119{,}59\ A$$

Therefore, $I_{max.adm}$ is also $119.59\ A$, and the condition 34 is satisfied.

$$I_{max,adm} < I_{max,adm.table} = 125A$$

In the results of the following tables, we can find the final section and voltage drop < 1.25%:

TABLE 16. Sections and voltage drop for CASE 1

Subsystem. Inverter	Series (Ud)	Total Power (Wdc)	Pot Inverter (Wac)	Voltage (V)	Current (A)	Length (m)	Section (mm²)	Voltage Drop (%)
SUB.1.1	1	63360	50000	400	93	45	25	1.076
SUB.1.2	1	63360	50000	400	93	45	25	1.076
SUB.2.3	1	63360	50000	400	93	45	25	1.076
SUB.2.4	1	63360	50000	400	93	45	25	1.076

TABLE 17. Sections and voltage drop for CASE 2

Subsystem. Inverter	Series (Ud)	Total Power (Wdc)	Pot Inverter (Wac)	Voltage (V)	Current (A)	Length (m)	Section (mm²)	Voltage Drop (%)
SUB.1.1	1	63360	50000	400	76	45	16	1.374
SUB.1.2	1	63360	50000	400	76	45	16	1.374
SUB.2.3	1	63360	50000	400	76	45	16	1.374
SUB.2.4	1	63360	50000	400	76	45	16	1.374

As we can see on the tables above, in the event that CASE 1 is chosen, a bigger section will be necessary for the AC circuit. With the Ingecon Sun 50, the section could not be 16 mm^2, as the voltage drop would be of 1.68% if we kept that section.

Finally, the chosen wire will be EXZHELLENT XXI RZ1-K Cu (AS) 0,6/1kV 4G16mm2. This cable includes optional wiring for grounding and neutral. Some of its characteristics can be seen in the picture below. The chosen sections would be 16 mm^2 for CASE 2, where batteries are used for the project, or 25 mm^2 for CASE 1, where no batteries are used.

EXZHELLENT XXI RZ1-K

Calibre mm²	Diámetro exterior aprox. mm	Peso total aprox. kg/km	Radio de curvatura mm	Capacidad de corriente A Ducto enterrado (1)	Capacidad de corriente A Aire libre (2)
2,5	5,6	54	25	36	29
4	6,1	69	30	46	38
6	6,8	89	30	58	49
10	7,5	132	35	77	68
16	8,8	192	40	100	91
25	10,6	283	45	128	116
35	11,7	374	50	154	144
50	14,6	544	55	183	175
70	15,9	738	60	224	224
95	17,7	917	70	265	271
120	19,6	1.169	80	302	314
150	21,5	1.473	90	342	363
185	23,9	1.744	95	383	415
240	26,6	2.370	135	442	490

Figure 30. AC wiring [57]

9.6.3 Grounding section

The section where the grounding will be connected is from the PV modules to the inverter. Due to this, the conductor´s section will correspond to the 25 mm^2 from the SCB section, thus, according to table 7, the protective conductors shall be of section 16.

The protective conductors shall be on the same type and model as those employed in their respective sections, described in the previous section of the project. Finally, the chosen wiring will be:

- EXZHELLENT-XXI H07Z1-K (AS) 1x16 yellow/green.
- Bare copper wire of 4 mm^2, of the concentric type (2).

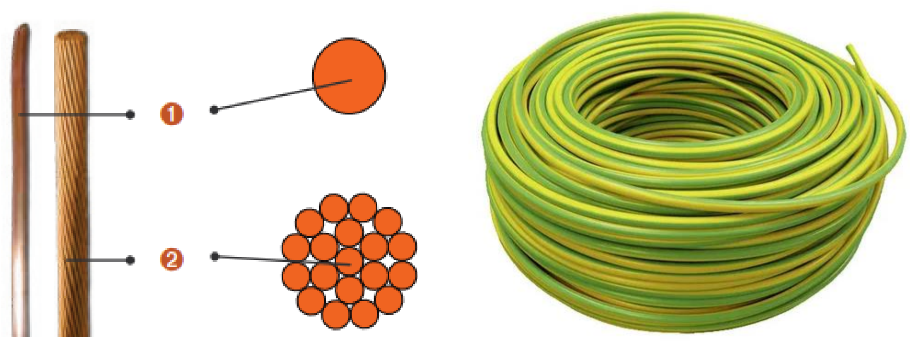


Figure 31. Grounding wiring [64][65]

9.7 Protection calculations

9.7.1 DC protection results

Inside the panel to inverter circuit, at the string combiner box, a 20 A fuse will be installed per string. Taking into consideration conditions 1 and 2 from section 7.8.1, and equation 36, and estimating I_n to be 20A, we obtain:

TABLE 18. Panel to inverter fuses

PARAMETER	VALUE
I_b	11.28 A
I_n	20 A
I_z	32 A

1. $11,28 \le 20 \le 32$
2. $I_f = 1,6 \times 20 = 32\ A \quad as \quad I_n \ge 16\ A$
3. $I_2 = I_f = 32\ A < 1,45 \times 32 = 46,4\ A$

Also, for installations with a voltage higher than 48V, where currents reach dangerous values, it is advisable to install a circuit breaker. Therefore, assuming I_n to be 125 A, and considering the equations 34 and 35, together with 42, we obtain:

TABLE 19. Panel to inverter circuit breaker

PARAMETER	VALUE
I_b	11.28 x 9 = 101.52 A
I_n	125 A
I_z	135 A

1. $101.52 \le 125 \le 135$
2. $I_2 = 1,25 \times 125 = 156.25\ A$
3. $I_2 = 156.25\ A < 1,45 \times 135 = 195.75\ A$

The wiring from the pv panels are made of copper and have a XLPE isolation, so the cable constant is equal to 135 and the section for the calculation will be 4 mm^2. Moreover, the UNE 20460-4-43 guarantees $t \geq 0.1\ s$.[29]

So, the Isc is equal to 1707 A, which is lower than 10000A, therefore condition 2 from section 7.8.1, eq 41, is met. Then, the circuit breaker will be a two-pole switch of 125 A.

Figure 32. DC Circuit breaker[58]

Similarly, between the batteries and the hybrid inverter, fuses of 200 A will be installed:

TABLE 20. Batteries to hybrid inverter fuses

PARAMETER	VALUE
I_b	173 A
I_n	180 A
I_z	262 A

Where,

1. $173 \leq 200 \leq 262$
2. $I_f = 1,6 \times 200 = 320\ A \quad as \quad I_n \geq 16\ A$
3. $I_2 = I_f = 320\ A < 1,45 \times 262 = 379,9\ A$

9.7.2 AC protections results.

The equations that will be used to calculate the current values of the protection devices for the AC circuit, will be the ones mentioned in section 7.8.2. First, the circuit breaker must be calculated and afterwards, the differential switch. Both will have 4 poles, as we are working in a three-phase system of phases R,S,T and N.

CIRCUIT BREAKER:

The same procedure is used here as in the DC calculations.

TABLE 21. AC Circuit breaker

PARAMETER	VALUE
I_b	76 A
I_n	80 A
I_z	97 A

1. $76 \leq 80 \ \leq 97$
2. $I_2 = 1{,}25 \times 80 = 100\ A$
3. $I_2 = 100\ A\ < 1{,}45 \times 97 = 140.65\ A$

Moreover, the cable is made of copper and has a XLPE isolation, so the cable constant is equal to 135 and the section for the calculation will be 16 mm^2. In addition, the UNE 20460-4-43 guarantees $t \geq 0.1\ s$.[29]

So, Isc will be 6830.52 A. To see if this option is valid, it must be checked that the condition 2 is satisfied:

$$6830.52 \ \leq \ 10000$$

The condition is satisfied, therefore, the circuit breaker that will be used is a MGNC120n-4P-80A, shown in figure 32.

More technical information can be found in the datasheet located in Annex A.

DIFFERENTIAL SWITCH

Similarly to the circuit breaker, the gauge of the switch and the estimated model must be calculated using equations 35, 36, 40 and 41.

From these equations, it can be concluded that the switch will have a gauge of 80 A and a sensitivity of 300 mA. This sensitivity is chosen due to the large capacity of the facility. However, the supermarket must have secondary fuse boxes in which the sensitivity should be 30 mA.

Figure 33. AC Circuit breaker [59]

Figure 34. AC Differential switch [60]

From the previous calculations, the electric configurations needed to comply with the regulations and guarantee good functionality and coupling between generator and inverter have been obtained.

9.8 Grounding and Equipotential connection results

From section 7.9.1, the following results have been obtained:

Equation 45 is used to find a resistance for the vertical spike of 75 and from equation 44 we get the maximum admissible resistance of 80, as Ia of the differential switch is 300mA:

$$75\ ohm\ < 80\ ohm$$

As the vertical spike resistance of the installation is lower than that allowed by the regulation LVER, its compliance can be verified with the normative. Also, the first condition is satisfied by applying equation 43:

$$75\ \times 0.3 = 22{,}5\,V\ < 24\,V = U$$

10. SIMULATION RESULTS

The simulation results will be divided into three sections: Produced energy, Production per installed kWp and Performance Ratio:

1. Produced energy.

The energy produced annually is considered to coincide with the energy that would be injected into the grid, E_Grid_{year}, which would be the output energy of the inverter minus the AC losses. In the project's case, as the facility consists of self-consumption with an output power of over 100 kW, there is not injection of power into the grid.

In CASE 1, using the standard inverter Ingecon Sun 50, the following results are obtained:

TABLE 22. Balances and main results CASE 1, Ingecon Sun 50

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	62.0	5.19	70.0	63.1	16.06	15.13	18.03	16.97
February	82.2	6.71	89.8	82.3	20.76	19.70	18.17	17.25
March	133.8	10.31	142.2	130.4	32.20	30.59	17.80	16.91
April	166.7	12.18	171.9	159.8	38.74	36.76	17.72	16.81
May	196.2	16.99	198.7	185.3	44.21	42.01	17.49	16.61
June	219.7	22.87	221.1	208.0	48.05	45.61	17.08	16.21
July	237.4	25.69	240.0	225.3	51.47	48.89	16.86	16.01
August	207.3	24.93	212.9	198.9	45.91	43.62	16.95	16.10
September	152.6	19.98	160.5	148.0	35.07	33.32	17.17	16.31
October	102.3	14.77	109.5	100.3	24.49	23.23	17.57	16.66
November	68.6	8.53	75.5	69.0	17.32	16.33	18.02	16.99
December	52.5	5.49	58.9	53.4	13.59	12.76	18.12	17.02
Year	1681.3	14.52	1751.0	1623.6	387.88	367.94	17.41	16.51

The annual produced energy or $E\_Grid_{year}{}^{CASE\ 1}$, equals 367.94 MWh. The highest values correspond to the summer months of June, July and August, when the global incident irradiation is at its highest, reaching values between 43 and 49 MWh.

In the second case studied, CASE 2, where the ZGR HITC 50 hybrid inverter and storage system is considered, the results achieved are slightly higher than those in case 1, as represented in table 23. In this case, $E\_Grid_{year}{}^{CASE\ 2}$ is equal to 383.04 MWh, and the months which experienced the greatest energy production were also the summer months.[61]

TABLE 23. Balances and main results CASE 2, ZGR HITC 50

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	62.0	5.19	70.0	65.8	16.75	15.91	18.79	17.86
February	82.2	6.71	89.8	85.4	21.55	20.54	18.86	17.98
March	133.8	10.31	142.2	136.4	33.67	32.11	18.61	17.75
April	166.7	12.18	171.9	165.9	40.15	38.28	18.36	17.50
May	196.2	16.99	198.7	191.6	45.68	43.55	18.07	17.23
June	219.7	22.87	221.1	214.0	49.33	47.03	17.54	16.72
July	237.4	25.69	240.0	232.7	53.11	50.62	17.39	16.58
August	207.3	24.93	212.9	206.0	47.48	45.29	17.53	16.72
September	152.6	19.98	160.5	154.6	36.62	34.92	17.93	17.10
October	102.3	14.77	109.5	104.7	25.55	24.36	18.33	17.47
November	68.6	8.53	75.5	71.5	17.95	17.06	18.68	17.76
December	52.5	5.49	58.9	55.3	14.07	13.36	18.77	17.81
Year	1681.3	14.52	1751.0	1683.9	401.90	383.04	18.04	17.19

It is important to keep in mind that in case 2, the battery storage will increase the energy production of the plant.

2. Production per installed kWp.

The energy produced consists of the relationship between the generation of the plant in kWh and the peak installed power. This parameter is observed in two ways, normalized monthly in kWh/kWp/day; and in a specific annual index, measured in kWh/kWp/year.

There are two main losses which have a direct effect on the energy production of the plant. The first are photovoltaic set losses, which can be caused by shading, high temperatures, irradiance levels, ohmic losses of the DC wiring or modules' mismatch losses. The second are the system losses, which also decrease PV production. This kind of loss pertains to the alternating current section of the circuit. Some examples are AC wiring losses and the losses caused by the inverter´s efficiency. These losses are represented in the Sankey chart, located in figures B.5 and B.9 [61]

The normalized production and loss factors are calculated using the formulas:

$$L_c = \frac{EArrRef_{year} - EArray_{year}}{P_{nom} \times 365} \quad (52)$$

$$L_s = \frac{EArray_{year} - E\_Grid_{year}}{P_{nom} \times 365} \quad (53)$$

As:

$$EArrRef_{year} = GlobInc \times Area \ \times EffArrR \tag{54}$$

$$EArrNom_{year} = GlobEff \times Area \ \times EffSysR \tag{55}$$

Where,

- L_c= Normalized PV set losses.
- L_s= Normalized system losses.
- $EArrRef_{year}$= Energy reference of the set.
- $EArray_{year}$= Effective energy at the output of the array.
- E_Grid_{year}= Energy that would be injected into the grid.
- P_{nom}= Nominal power generated by the pv modules.
- $GlobInc$= Global incident irradiance.
- $Area$= Surface area occupied by photovoltaic modules.
- $EffArrR$= Efficiency energy output of the array.
- $EffSysR$= Efficiency energy output of the system.

For case 1, the specific production is 1452 kWh/kWp/year whereas for CASE 2, this value is 1511 kWh/kWp/year. Also, using equations 48, 49, 50 and 51, and the data from tables 22 and 23, the losses represented in figures 35 and 36 are:

- CASE 1:

$$L_{c1} = 0.45 \; kWh/kWp \cdot day$$
$$L_{s1} = 0.68 \; kWh/kWp \cdot day$$

- CASE 2:

$$L_{c2} = 0.46 \; kWh/kWp \cdot day$$
$$L_{s2} = 0.58 \; kWh/kWp \cdot day$$

3. Performance Ratio

The final relevant factor in a photovoltaic plant is its performance ratio, PR. The performance ratio relates the output useful energy generated with the energy produced by the system in STC conditions.

The PR is calculated by dividing the AC energy produced, Y_f, by the DC energy generated by the panels, Y_r. The higher this index is, the better the performance of the plant will be. [61]

The following figures show the PR values of CASE 1 and 2 throughout the year.

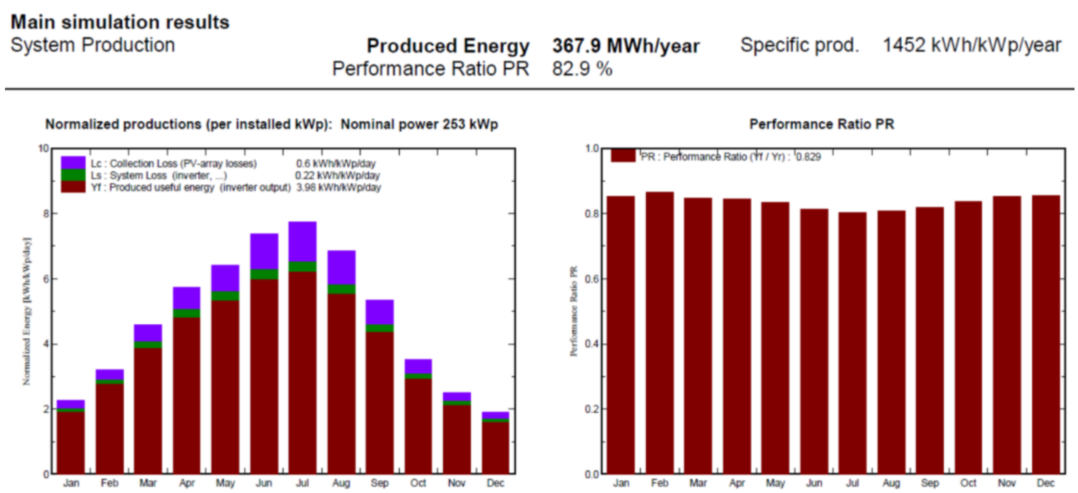


Figure 35. Normalized production and plant performance ratio, CASE 1

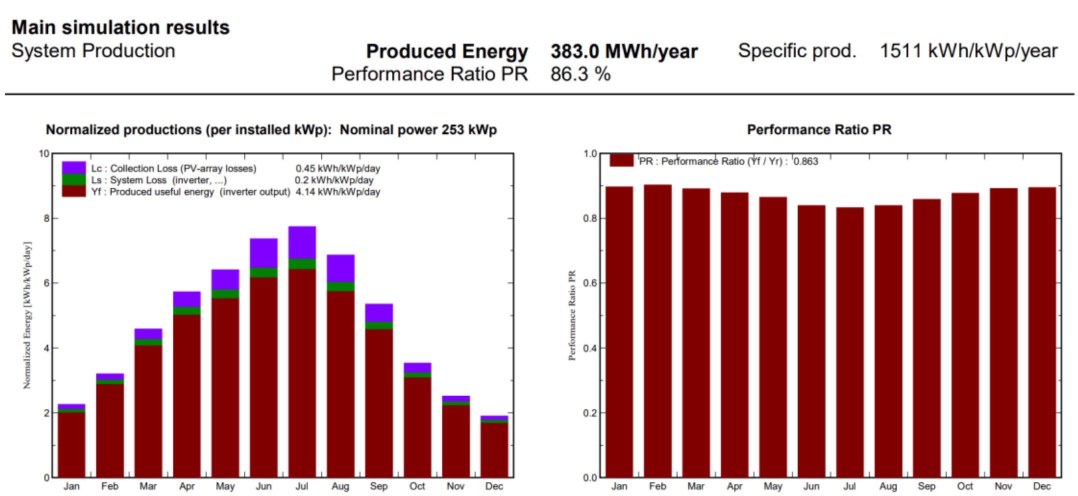


Figure 36.Normalized production and plant performance ratio, CASE 2

11.BUDGET

TABLE 24. Budget for CASE 1

EQUIPMENT	DESCRIPTION	UNITS	PRICE/UNIT	TOTAL
GCL- M8/72H	Photovoltaic panel	576	159.00 €	91,584.00 €
Ingecon SUN 50	Standard inverter	1	21,997.00 €	21,997.00 €
PR3-D40 SUNFIELD	Solar canopies 50 meters, ref 10 m	2	29,566.07 €	59,132.14 €
PR3-D16 SUNFIELD	Solar canopies 20 meters	2	13,148. 67 €	26,297.34 €
Hyundai HGD2P125C	Circuit breaker	1	19.80 €	19.80 €
NH1-20A	DC Fuse	72	4.83 €	347.76 €
C120N-4P-80 Schneider Electric	Circuit breaker	1	229.29 €	229.29 €
Differential 4P 80A 300mA Schneider Electric	Differential switch	1	134.18€	134.18 €
Sofamel Vertical spike	2 meter vertical spike	1	11.00 €	11.00 €
EVBox Iqonic	AC charging station	3	2,500.00 €	7,500.00 €
EVBox Troniq 50	DC and AC charging station	1	22,710.00 €	22,710.00 €
				229,962.51 €

CABLE	DESCRIPTION	METERS	PRICE/UNIT	TOTAL
EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC	PV-MODULE STRINGS TO SCB	1644	1.65	2,712.60 €
EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC	SCB- INVERTER	135	1.65	222.75 €
EXZHELLENT XXI RZ1-K Cu (AS) 0,6/1kV 4G16mm2	INVERTER - AC PROTECTION	180	265.84	265.84 €
EXZHELLENT-XXI H07Z1-K (AS) 1x16 yellow/green.	GROUND	50	132.025	132.03 €
TOTAL				**3,333.22 €**

TABLE 25. Budget for CASE 2

EQUIPMENT	DESCRIPTION	UNITS	PRICE/UNIT	TOTAL
GCL- M8/72H	Photovoltaic panel	576	159.00 €	91,584.00 €
ZGR HITC 50	Hybrid inverter	4	3,880.00 €	15,520.00 €
OPZS- HOPEKKE	Battery banks of 48 V	7	7,500.00 €	52,500.00 €
PR3-D40 SUNFIELD	Solar canopies 50 meters, ref 10 m	2	29,566.07 €	59,132.14 €
PR3-D16 SUNFIELD	Solar canopies 20 meters	2	13,148. 67 €	26,297.34 €
HYUNDAI	Circuit breaker	1	19.80 €	19.80 €
NH1-20 - 200A	DC Fuse	74	4.83 €	357.42 €
C120N-4P-80 SCHNEIDER ELECTRIC	Circuit breaker	1	229.29 €	229.29 €
DIFFERENTIAL 4P 80A 300MA SCHNEIDER ELECTRIC	Differential switch	1	134.18€	134.18 €
SOFAMEL VERTICAL SPIKE	2 meter vertical spike	1	11.00 €	11.00 €
EVBOX IQONIC	AC charging station	3	2,500.00 €	7,500.00 €
EVBOX TRONIQ 50	DC and AC charging station	1	22,710.00 €	22,710.00 €
TOTAL				**275,995.17 €**

CABLE	DESCRIPTION	METERS	PRICE/UNIT	TOTAL
EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC	PV-MODULE STRINGS TO SCB	1644	1.65	2,712.60 €
EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC	SCB- INVERTER	135	1.65	222.75 €
EXZHELLENT XXI RZ1-K Cu (AS) 0,6/1kV 4G16mm2	INVERTER - AC PROTECTION	180	1.32	265.84 €
EXZHELLENT-XXI H07Z1-K (AS) 1x16 yellow/green.	GROUND	50	2.64	132.03 €
EXZHELLENT SOLAR CABLE ZZ-F 1.8 kV DC - 0,6/1 kV AC	BATTERY-INVERTER	41	1.65	67.65 €
TOTAL				**3,400.87 €**

From tables 24 and 24, it is seen that the difference in material with respect to both design possibilities is approximately 42,700 euros.

Apart from the materialistic costs, there are additional expenses to be taken into consideration, leaving the total budget of the photovoltaic car park:

TABLE 26. Total budget

EXPENSES	**CASE 1 TOTAL**	**CASE 2 TOTAL**
ELECTRIC MATERIAL	233,295.73 €	275,995.17 €
LABOUR	100,000.00 €	100,000.00 €
MAINTENANCE	5,000.00 €	5,000.00 €
MISCELLANEOUS	50,000.00 €	50,000.00 €
TOTAL	**388,295.73 €**	**430,995.17 €**

The costs of labour include, the workers needed to install the modules, inverters, pavement works, structure stand up, and wiring; apart from the equipment and machinery needed to perform it and the transport.

In the section "miscellaneous", the back-up elements in case of equipment failure, licenses and permits and the legalization process are included. The latter is especially relevant for self-consumption projects over 100 kW, which typically require periodic revisions for reassurance of good practices, increasing the overall price.

The maintenance expenses do not vary between CASE 1 and 2, as the chosen model of lead-acid batteries employ an advance recombination system that reduces the need for regular maintenance to little-to-none.

Overall, the difference in price is significant, being almost 25% extra for storage.

12.RATE ESTIMATION FOR SEMI-FAST AND FAST CHARGING

The price of electricity varies due to many factors, such as the contracted distribution company, the time at which the consumption occurs, the contracted rate, and in this specific case, the place wherein the electricity is consumed.

The average prices for public charging stations range between 0.22 and 0.40 €/ kWh for semi-fast and fast charging. The chosen prices for the estimations are 0.38 €/kWh for the DC charging point, and 0.25€/kWh for the remaining charging stations. [63]

With these values, an approximation of revenue per day has been calculated for two cases:

- Best case scenario: This situation represents the ideal state for the electric vehicle charging stations, whereby they would supply electricity to the EV batteries all day long every day of the year.
- Estimated scenario: In this case, the number of vehicles per day would be 48: 6 per connector or 12 per charging station every day of the year.

With both cases taken into consideration, the following revenue calculations were made:

TABLE 27. Daily amortization from best case scenario

BEST CASE SCENARIO					
NUMBER OF CONNECTORS	**50 KW CHARGE**	**AVG CHARGING TIME (H)**	**OPEN HOURS/ DAY**	**Nº CARS IN A DAY PER CONNECTOR**	**TOTAL € PER DAY**
1	15.25	0.80	24	29.90	456 €
connectors	€	hours	hours	cars/day	
NUMBER OF CONNECTORS	**20 KW CHARGE**	**AVG CHARGING TIME (H)**		**Nº CARS IN A DAY PER CONNECTOR**	
7	10.03	1.82	24	13.16	924 €
connectors	€	hours	hours	cars/day	
					1380 €

As shown in table 24, the number of cars to charge their battery in one day would be 122, and earnings would reach 1380 €. These values are very far from the expected daily revenue seen in table 25.

TABLE 28. Daily amortization from expected scenario

ESTIMATED SCENARIO				
NUMBER OF CONNECTORS	**50 KW CHARGE**	**AVG CHARGING TIME (H)**	**Nº CARS IN A DAY PER CONNECTOR**	**TOTAL € PER DAY**
1	15.25	0.80	6	91.50 €
connectors	€	hours	cars/day	
NUMBER OF CONNECTORS	**20 KW CHARGE**	**AVG CHARGING TIME (H)**	**Nº CARS IN A DAY PER CONNECTOR**	
7	10.03	1.82	6	421.43 €
connectors	€	hours	cars/day	
				512.93 €

The payback period for the investment required for the project is calculated following the discounted payback period formula represented below:

$$Payback = -Budget + Profit_{year.1} + \cdots + Profit_{year.n}$$

Therefore, for the first scenario, every year the car park would bring an income from the charging fees of:

TABLE 29. Payback perdiod for best case scenario

BEST CASE SCENARIO				
year	1	2	3	4
daily income	1,380.00 €	1,380.00 €	1,380.00 €	1,380.00 €
days/year	365	365	365	365
CASE 1				
	503,700.00 €	503,700.00 €	503,700.00 €	503,700.00 €
- 388,295.73 €	115,404.27 €	619,104.27 €	1,122,804.27 €	1,626,504.27 €
CASE2				
	503,700.00 €	503,700.00 €	503,700.00 €	503,700.00 €
- 430,995.17 €	72,704.83 €	576,404.83 €	1,080,104.83 €	1,583,804.83 €

In this case, the amount invested in the project will be paid back within the first year.

TABLE 30. Payback period for the estimated scenario

ESTIMATED SCENARIO				
year	1	2	3	4
daily income	512.93 €	512.93 €	512.93 €	512.93 €
days/year	365	365	365	365
CASE 1				
- 388,295.73 €	187,219.45 €	187,219.45 €	187,219.45 €	187,219.45 €
	- 201,076.28 €	- 13,856.83 €	173,362.62 €	360,582.07 €
CASE2				
- 430,995.17 €	187,219.45 €	187,219.45 €	187,219.45 €	187,219.45 €
	- 243,775.72 €	- 56,556.27 €	130,663.18 €	317,882.63 €

However, in this case it will take 3 years for the installation to become profitable. It is important to mention that the amount of money saved by not consuming as much energy from the grid is not included in this calculation, meaning additional profit.

13.CONCLUSION

Overall, the project provided an extensive look at the best possible scenarios for a photovoltaic car park to charge electric vehicles. There were many factors necessary to consider, and several options to choose between, each of which affected the project’s outcome to some degree.

In the following points, the objectives achieved during the project will be highlighted:

1. Use as much of the energy generated by the plant as possible to minimize waste.

This first objective has been successfully achieved. By connecting the photovoltaic installation as one more load in the supermarket's C.D.B, the electricity coming from it directly accesses the supermarket, where together with the building's distribution network, it distributes electricity to all connected loads according to demand. This design ensures that all the energy generated is distributed, giving priority to photovoltaic generation over electricity from the grid.

Moreover, the inverter is configured in such a way that the priority is to power the building panel. In CASE 2, the electricity produced would prioritize the solar batteries if they were low on charge.

2. Minimize the supermarket´s consumption of energy from the grid.

The dimensioning of the photovoltaic car park was devised with the necessity to supply the 4 charging stations for electric cars taken into consideration. The final power of the plant is 200 kW, enough power to charge 8 vehicles simultaneously. However, the situation where 8 EVs are recharging at the same time would be rare. Therefore, excluding such a situation, a portion of the 200 kW of power will be supplied to the supermarket's consumption. Also, in the event that there are no electric vehicles at the connection points, the nominal power of 200 kW will be supplied to the supermarket, constituting 71.42% of its contracted power.

Therefore, this second goal has been also covered.

3. Create a fast-charging station that can provide multiple chargers simultaneously and whose main electricity supply is a renewable source, in addition to being available 24 hours a day.

When deciding on the number of charging stations, this third goal was also kept in mind. The four charging stations, three for semi-fast charging and one for fast charging (through one of its connectors), offer the possibility of charging 8 vehicles simultaneously. In addition, by being connected to the building's network, we ensure the operation of the charging points throughout the day, since in the case of no photovoltaic generation, the building's distribution network is in charge of supplying the charging points with power. As this could be a problem, the best solution is offered in CASE 2. CASE 2 is supported by solar batteries, which would be in charge of supplying some of the charging points with power in the event of no photovoltaic generation.

The most common cases in which the distribution network would be relied upon are at night and in adverse weather conditions. At night, electricity rates are at their most economical point, during valley hours. This is why, although the cost of consumption must be paid to the distribution company, the fee to use the charging points would cover this expense as a minimum and turn a profit. Even so, it is preferable not to depend on the distribution network since it is designed to supply only supermarket consumption, and although it costs less at night than during the day, it would not be the ideal situation.

4. Design and study a solar facility that follows the Spanish Low Voltage Electrotechnical Regulation. (LVER).

The procedure followed for the calculations of this project was done so in accordance with the LVER guidelines. In addition, all the equipment and materials described in this work comply with the regulations stipulated by official entities.

5. Prioritize generation above overall costs.

At the time of the calculation and design of this project, the main objective was to obtain the highest possible efficiency for the installation, putting the costs that this entailed in the background. That is why the prices of the equipment are not the cheapest currently offered in the market, as priority was given to reputation and quality. Even so, the budget obtained for both CASE 1 and CASE 2 is consistent with facilities of this size.

6. Offer more than one option to choose from.

During the project, two possibilities for the location of the installation were discussed, as well as two possibilities within the design of the entire installation (CASE 1 and CASE 2). What’s more, a study and sizing of lithium battery storage was carried out in comparison with lead-acid battery storage; the former was ruled out despite being the preferred choice, due to issues with connecting the batteries in series.

These variety of options has made it possible to obtain the most efficient version of the electric vehicle charging station through a photovoltaic car park connected to the grid.

To conclude, the project would be a successful undertaking, both as a supporting resource for high-capacity commercial buildings and an eco-friendly, economic venture in itself. With that said, it might not be the best option to have this non-reliable source of energy as the sole power supply for this type of building, as it would be in an isolated installation.

There is a high likelihood that projects similar to this one will be implemented in the future, as the associated technologies are constantly improving in efficiency and capacity, making this type of facility increasingly desirable and feasible.

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ANNEX A. EQUIPMENT´S TECHNICAL DATA

The technical information of the materials and equipment used during this project can be found in this section.

The equipment will follow the order:

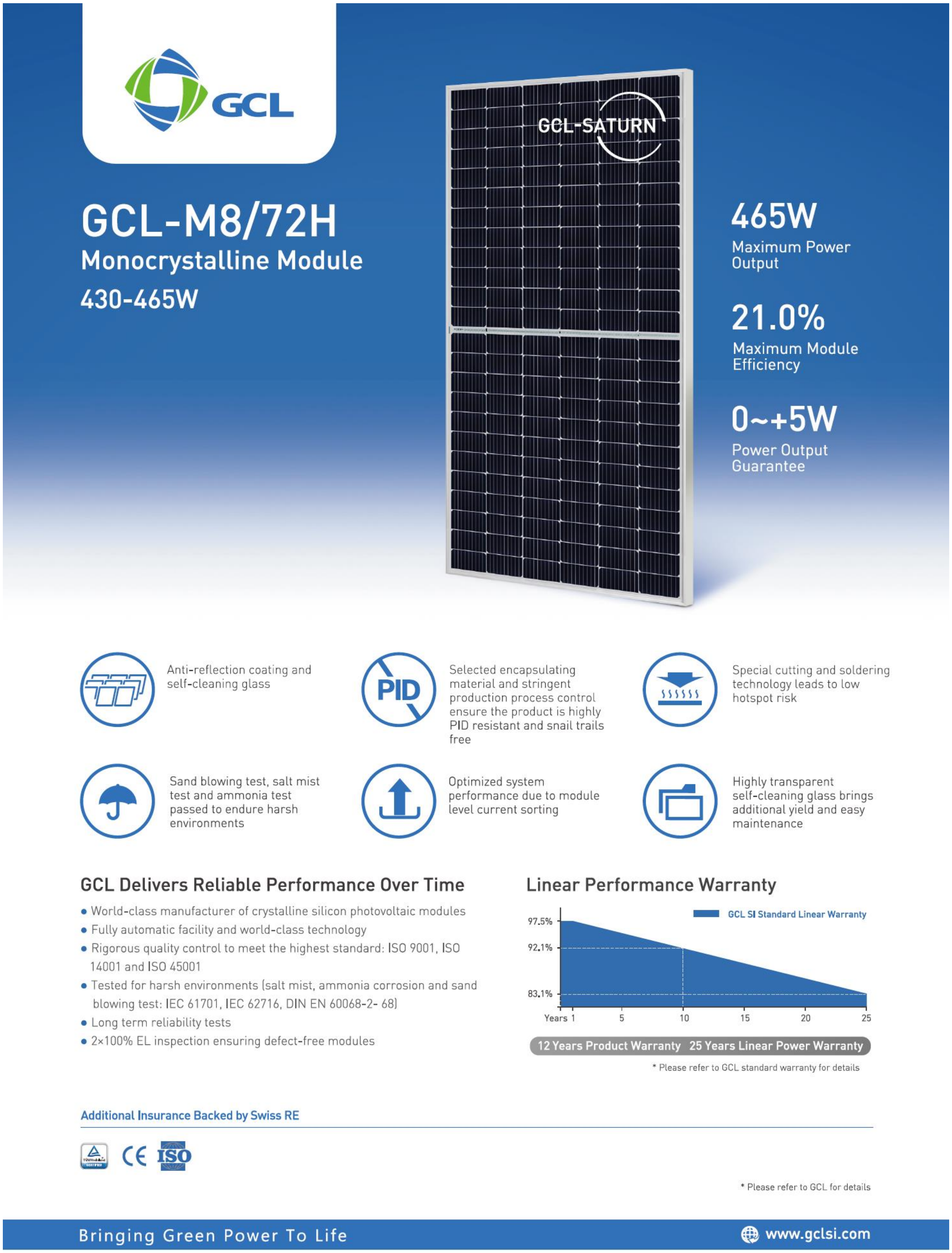


Figure A.1. Solar Module, page 1[38]

GCL-M8/72H

Monocrystalline Module | 430-465W

Electrical Specification (STC*)

Maximum Power	Pmax(W)	430	435	440	445	450	455	460	465
Maximum Power Voltage	Vmp(V)	40.72	41.08	41.40	41.75	42.10	42.41	42.76	43.10
Maximum Power Current	Imp(A)	10.56	10.59	10.63	10.66	10.69	10.73	10.76	10.79
Open Circuit Voltage	Voc(V)	48.69	48.99	49.25	49.55	49.84	50.10	50.39	50.68
Short Circuit Current	Isc(A)	11.22	11.25	11.28	11.31	11.34	11.37	11.40	11.43
Module Efficiency	(%)	19.5	19.7	19.9	20.1	20.4	20.6	20.8	21.0
Power Output Tolerance	(W)	0~+5							

* Irradiance 1000W/m², Module Temperature 25°C, Air Mass 1.5

Electrical Specification (NOCT*)

Maximum Power	Pmax (W)	313.58	317.30	321.03	324.79	328.57	332.36	336.18	340.02
Maximum Power Voltage	Vmp (V)	37.26	37.55	37.84	38.13	38.42	38.71	39.00	39.29
Maximum Power Current	Imp (A)	8.42	8.45	8.48	8.52	8.55	8.59	8.62	8.65
Open Circuit Voltage	Voc(V)	45.04	45.30	45.56	45.82	46.08	46.34	46.60	46.86
Short Circuit Current	Isc (A)	9.06	9.09	9.12	9.14	9.17	9.19	9.22	9.25

* Irradiance 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s

Mechanical Data

Number of Cells	144 Cells (6×24)
Dimensions of Module L*W*H (mm)	2108×1048×35 mm (82.99×41.26×1.38 inches)
Weight (kg)	25.1 kg
Glass	High transparency solar glass 3.2mm (0.13 inches)
Backsheet	White
Frame	Silver, anodized aluminium alloy
J-Box	IP68 Rated
Cable	4.0mm² (0.006 inches²), Portrait: 300/300mm (11.81inches)
Number of diodes	3
Wind/ Snow Load	2400Pa/ 5400Pa*
Connector	MC Compatible

* For more details please check the installation manual of GCLSI

Temperature Ratings

Nominal Operating Cell Temperature (NOCT)	44±2°C
Temperature Coefficient of Isc	+0.06%/°C
Temperature Coefficient of Voc	-0.30%/°C
Temperature Coefficient of PMAX	-0.39%/°C

Maximum Ratings

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

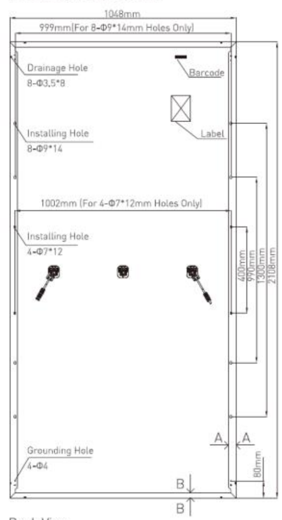
Packaging Configuration

Module per box	30 pieces
Module per 40' container	600 pieces

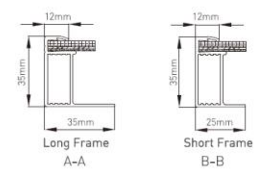
Optional

Connector:	☐ Original MC4

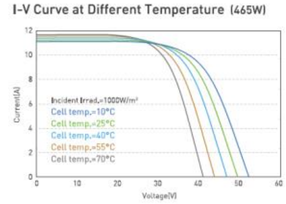
Module Dimension



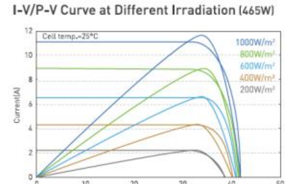
Back View



I-V Curve at Different Temperature (465W)



I-V/P-V Curve at Different Irradiation (465W)



CAUTION: READ INSTALLATION MANUAL BEFORE USING THE PRODUCT

GCL

Contact Us for More Information

website: www.gclsi.com email: gclsisales@gclsi.com

Bringing Green Power To Life

GCL/XXJC/2-MKT-123-D0

Figure A.2. Solar Module, page 2[38]

Ingecon®Sun Power

50 / 60 / 70 / 80 / 90 / 100

Su diseño orientado a facilitar el mantenimiento, su alta eficiencia a temperaturas elevadas, así como su completo equipamiento de protecciones eléctricas incluidas de serie, hacen que esta familia de inversores sea una de las más demandadas de la gama de inversores **Ingecon®Sun**. Estos inversores **Ingecon®Sun Power** están diseñados tanto para instalaciones en cubierta de medianas y grandes potencias como para instalaciones multimegavatio en suelo.

Esta familia de inversores está equipada con un avanzado sistema de seguimiento del punto de máxima potencia (MPPT) para extraer la máxima energía del campo fotovoltaico.

No necesitan elementos adicionales y permiten su desconexión manual de la red. Cada inversor lleva incorporado un datalogger interno para almacenamiento de datos hasta 3 meses al que se puede acceder desde un PC remoto y también in situ desde el frontal del inversor a través de un teclado. Asimismo este frontal dispone de LEDs indicadores de estado y alarmas y pantalla LCD.

Los **Ingecon®Sun Power** han sido diseñados con componentes que ofrecen una vida útil de más de 20 años. Tienen una garantía estándar de 5 años, ampliable hasta 25 años.

Protecciones

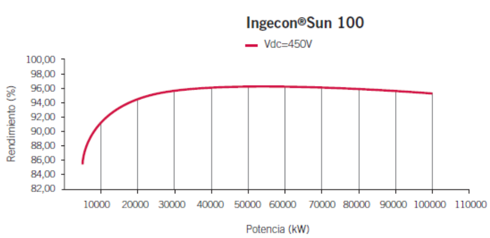
Los inversores **Ingecon®Sun Power** llevan integradas las siguientes protecciones eléctricas:

- Aislamiento galvánico entre la parte de DC y AC.
- Polarizaciones inversas.
- Cortocircuitos y sobrecargas en la salida.
- Fallos de aislamiento.
- Anti-isla con desconexión automática.
- Seccionador en carga DC.
- Fusibles DC.
- Seccionador- magnetotérmico AC.
- Descargadores de sobretensiones DC.
- Descargadores de sobretensiones AC.

Accesorios opcionales

- Comunicación entre inversores mediante RS-485, fibra óptica, inalámbrica o Ethernet.
- Comunicación remota GSM/GPRS mediante módem.
- Software **Ingecon®Sun Manager** para visualización de parámetros y registro de datos.
- Visualización de datos a través de Internet. **IngeRAS™ PV**.
- Tarjeta de entradas analógicas para la medición de variables meteorológicas.
- Monitorización de las corrientes de string del campo fotovoltaico. **Ingecon®Sun String Control**.
- Kit de puesta a tierra para los módulos FV que lo requieran.

Rendimiento



Dimensiones y peso

(mm)

Ingecon®Sun 50/60: 900 kg.
Ingecon®Sun 70/80: 1.026 kg.
Ingecon®Sun 90/100: 1.162 kg.

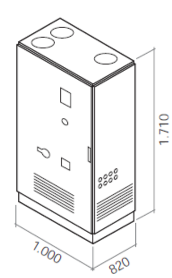


Figure A.3. inverter for CASE 1, page 1[44]

Características técnicas

Modelo	Ingecon®Sun 50	Ingecon®Sun 60	Ingecon®Sun 70	Ingecon®Sun 80	Ingecon®Sun 90	Ingecon®Sun 100
Valores de Entrada (DC)						
Rango pot. campo FV recomendado[1]	57 - 65 kWp	69 - 78 kWp	80 - 91 kWp	92 - 104 kWp	103 - 117 kWp	115 - 130 kWp
Rango de tensión MPP	405 - 750 V	405 - 750 V	405 - 750 V	405 - 750 V	405 - 750 V	405 - 750 V
Tensión máxima DC[2]	900 V	900 V	900 V	900 V	900 V	900 V
Corriente máxima DC	143 A	172 A	200 A	229 A	257 A	286 A
Nº entradas DC	4	4	4	4	4	4
MPPT	1	1	1	1	1	1
Valores de Salida (AC)						
Potencia nominal AC modo HT[3]	50 kW	60 kW	70 kW	80 kW	90 kW	100 kW
Potencia nominal AC modo HP[4]	55 kW	66 kW	77 kW	88 kW	99 kW	110 kW
Corriente máxima AC	93 A	118 A	131 A	156 A	161 A	161 A
Tensión nominal AC	400 V	400 V	400 V	400 V	400 V	400 V
Frecuencia nominal AC	50 / 60 Hz	50 / 60 Hz	50 / 60 Hz	50 / 60 Hz	50 / 60 Hz	50 / 60 Hz
Coseno Phi[5]	1	1	1	1	1	1
THD[5]	< 3%	< 3%	< 3%	< 3%	< 3%	< 3%
Rendimiento						
Eficiencia máxima	96,3%	96,40%	97,20%	97,50%	96,90%	96,80%
Euroeficiencia	94,30%	94,70%	96,10%	96,20%	95,80%	95,70%
Datos Generales						
Consumo energía standby	30 W	30 W	30 W	30 W	30 W	30 W
Consumo energía nocturno	1 W	1 W	1 W	1 W	1 W	1 W
Temperatura funcionamiento	-10ºC a +65ºC	-10ºC a +65ºC	-10ºC a +65ºC	-10ºC a +65ºC	-10ºC a +65ºC	-10ºC a +65ºC
Humedad relativa	0 - 95%	0 - 95%	0 - 95%	0 - 95%	0 - 95%	0 - 95%
Grado de protección	IP 20	IP 20	IP 20	IP 20	IP 20	IP 20
Referencias normativas	RD 661/2007, EN 50178, Reglamento VDEW BT					
	RTC alle rete BT di Enel Distribuzione					
	CEI 11-20					
	CEI 11-20 V1					
	CEI 0-16					
	Marcado CE					

Modo HT (high temperature) - Potencias nominales a 45ºC
Modo HP (high power) - Potencias nominales a 40ºC

Notas: [1] Dependiendo del tipo de instalación y de la ubicación geográfica [2] No superar en ningún caso. Considerar el aumento de tensión de los paneles 'Voc' a bajas temperaturas [3] Hasta 45ºC ambiente, Pmax=110% Pnom para transitorios no permanentes [4] Hasta 40ºC ambiente, Pmax = Pnom [5] Para PAC > 25% de la potencia nominal

Ingecon®Sun Power

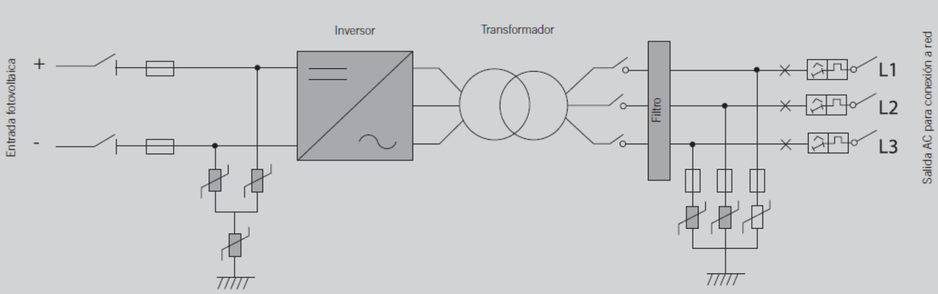


Figure A.4. inverter for CASE 1, page 2[44]

ZGR SOLAR HITC
INVERSORES CENTRALES HÍBRIDOS TRIFÁSICOS

always ON

Los inversores solares ZGR SOLAR HITC son la solución ideal para aplicaciones off-grid.

La gama de inversores solares híbridos ZGR SOLAR HITC están diseñados para cubrir las necesidades energéticas donde no llega la red eléctrica, para electrificación rural y/o electrificación de zonas remotas.

La característica principal de los inversores híbridos ZGR SOLAR HITC, es ser capaz de generar electricidad a partir de distintos recursos: Fotovoltaica, Baterías, Red o Grupo Electrógeno.

Los inversores híbridos trifásicos de ZGR SOLAR HITC pueden agregar las energías provenientes de diferentes fuentes y controlar al mismo tiempo todas las contribuciones de energía de un solo sistema.

APLICACIONES

REDES AISLADAS

CARACTERÍSTICAS

» Amplio rango de tensión de entrada (350-700 Vdc) para paneles solares
» Muy baja distorsión armónica THD< 3%
» Entrada Red o Grupos Electrógenos
» Entrada de Campo fotovoltaico a través de regulador interno
» Batería de respaldo
» Grado de protección IP21
» Aislamiento galvánico a través de transformador
» Protección contra
- Polarización inversa
- Cortocircuito
- Sobretensiones
- Fallo de aislamiento
» Monitorización del equipo mediante LCD
» Acceso Web para monitorización remota

CONECTIVIDAD Y MONITORIZACIÓN

WEB SERVER INTEGRADO

Pasarela de comunicaciones integrada para proporcionar acceso completo vía Web Server. Este servidor web permite al usuario acceder a los datos del inversor en diferentes idiomas y grabar los siguientes datos: estado, parámetros, eventos, registro de eventos, funcionamiento.

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Figure A.5. inverter for CASE 2, page 1[45]

ESPECIFICACIONES GENERALES					
Modelo	ZGR HITC 30	ZGR HITC 50	ZGR HITC 100	ZGR HITC 100+	ZGR HITC 150
CARACTERÍSTICAS ELÉCTRICAS DE SALIDA AC					
Potencia Activa nominal	30 kW	50 kW	100 kW	100 kW	150 kW
Tensión nominal de salida	208 / 220 / 240 ó 380 / 400 / 440 Vac (3F + N)				380 / 400 / 440 V
Frecuencia de operación	50 – 60 Hz				
Corriente máxima por fase	83 A / 46 A	139 A / 76 A	278 / 152 A	278 A / 152 A	228 A
Protección sobretensiones AC	Sí				
Protección cortocircuito	Sí				
CARACTERÍSTICAS ELÉCTRICAS DE ENTRADA FV					
Potencia recomendada de campo FV	32 kWp	52 kWp	105 kWp	105 kWp	157 kWp
Máxima corriente de entrada	76 A	125 A	250 A	250 A	375 A
Número de entradas	1				
Rango tensión FV	350~700 Vdc				
Rango tensión FV óptima generación	420~470 Vdc				
Tensión máxima en circuito abierto OC	880 Vdc (1)				
Protección sobretensiones DC	Sí				
Protección conexión inversa	Sí				
CARACTERÍSTICAS ELÉCTRICAS DE ENTRADA GRUPO / RED					
Potencia nominal	≥ 70 kVA	≥ 95 kVA	≥ 180 kVA	≥ 280 kVA	≥ 340 kVA
Tensión nominal de entrada	208 / 220 / 240 ó 380 / 400 / 440 Vac (3F + N)				
Frecuencia de operación	50 / 60 ± 5 Hz				
Corriente máxima por fase	139 A / 76 A	194 A / 106 A	389 A / 213 A	595 / 345 A	725 A / 420 A
Control arranque grupo	Contacto libre de potencial (230 Vac/4 A máx.)				
Protección cortocircuito	Sí				
BATERÍA					
Tensión nominal	340 Vdc				
Rango de tensión	300~420 Vdc				
Máxima corriente de carga	50 A	50 A	100 A	300 A	300 A
Máxima corriente de descarga	105 A	173 A	350 A	350 A	510 A
Protección cortocircuito	Sí				
Protección conexión inversa	Sí				
Protección sobre-descarga	Sí				
Control de carga	Sí				
OTROS					
Eficiencia	>96 % Incluido el transformador, entre recurso renovable y salida AC.				
Panel de control	Display 2 líneas, teclado y 3 leds de señalización				
Monitorización	Autochecking / Registro de datos y eventos / Interfaz web				
Comunicaciones	Ethernet - Web Server, SNMP				
Seccionadores AC y DC	Integrados en el sistema				
Transformador de aislamiento	Integrado en el sistema				
Refrigeración	Ventilación forzada				
Temperatura ambiente de funcionamiento	-10~50 °C				
Grado de protección del armario	IP21				
Altitud de funcionamiento	<1000 m sin pérdida de potencia				
Humedad relativa	0 ~ 95 % sin condensación				
Dimensiones (AnxAlxF) (mm)	1950 x 1200 x 730		2150 x 1600 x 630	2150 x 2400 x 630	
Peso aproximado	850 kg	850 kg	1320 kg	1420 kg	1480 kg
NORMATIVAS					
Marcado	CE				
Directivas generales	2006/95/CEE-93/68/CEE, 2004/108/CEE				
Normativas	IEC 62909-1, IEC 62109-1, IEC 62109-2, IEC 61000-6-4, IEC 61000-6-2, UNE 217002, UNE 206007-1 IN				

(1) Este valor de tensión no debe ser superado bajo ningún concepto.
** Las especificaciones técnicas podrán modificarse sin previo aviso.*
** Para cualquier otra necesidad técnica o modificación de las existentes, consultar a ZIGOR.*

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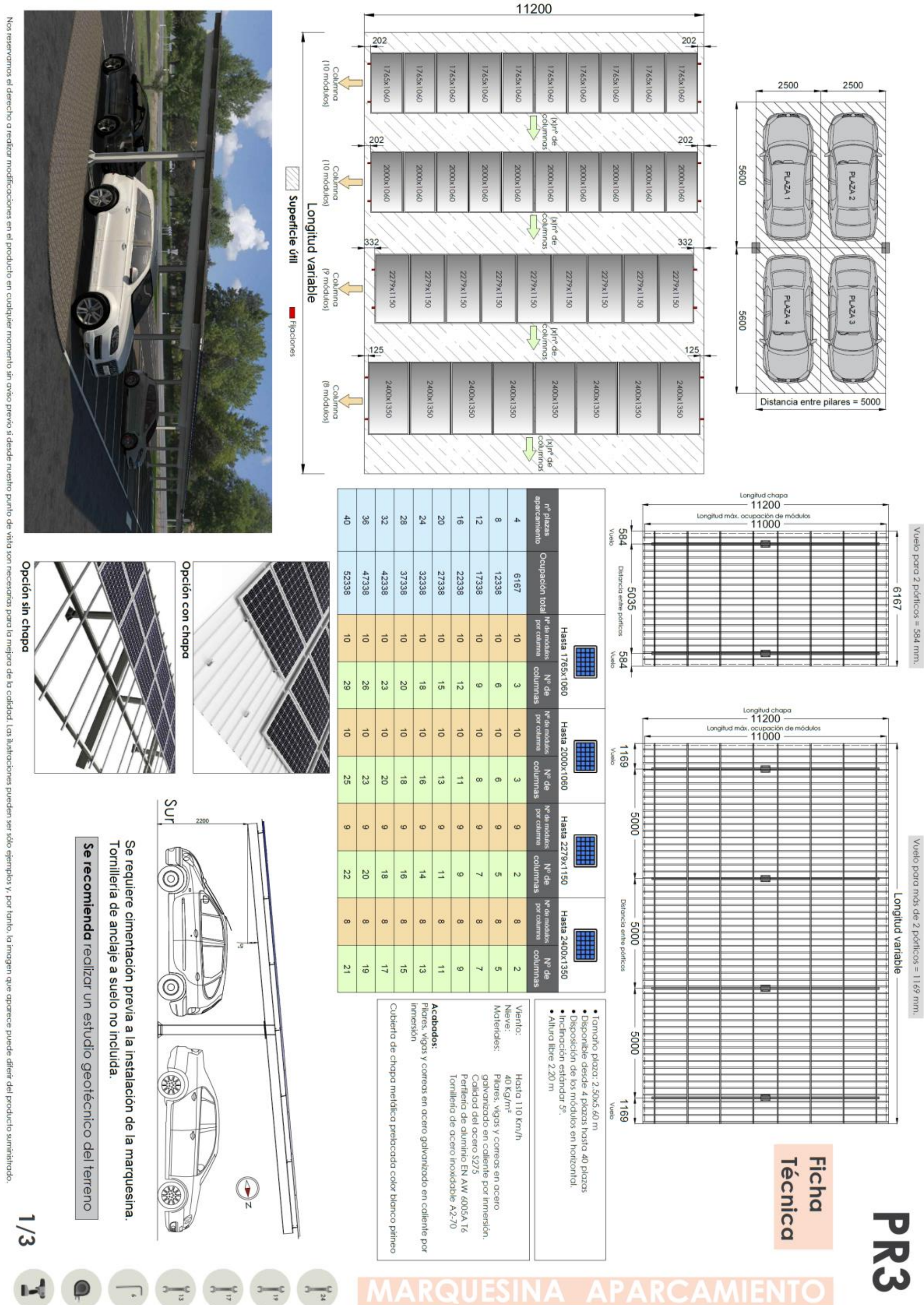
Figure A.6. inverter for CASE 2, page 2[45]



nº plazas aparcamiento	Ocupación total	Hasta 1765x1060: Nº de módulos por columna	Hasta 1765x1060: Nº de columnas	Hasta 2000x1060: Nº de módulos por columna	Hasta 2000x1060: Nº de columnas	Hasta 2279x1150: Nº de módulos por columna	Hasta 2279x1150: Nº de columnas	Hasta 2400x1350: Nº de módulos por columna	Hasta 2400x1350: Nº de columnas
4	6167	10	3	10	3	9	2	8	2
8	12338	10	6	10	6	9	5	8	5
12	17338	10	9	10	8	9	7	8	7
16	22338	10	12	10	11	9	9	8	9
20	27338	10	15	10	13	9	11	8	11
24	32338	10	18	10	16	9	14	8	13
28	37338	10	20	10	18	9	16	8	15
32	42338	10	23	10	20	9	18	8	17
36	47338	10	26	10	23	9	20	8	19
40	52338	10	29	10	25	9	22	8	21

- Tamaño plaza: 2.50x5.60 m
- Disponible desde 4 plazas hasta 40 plazas
- Disposición de los módulos en horizontal.
- Inclinación estándar 5º.
- Altura libre 2.20 m

Viento: Hasta 110 Km/h
Nieve: 40 Kg/m²
Materiales: Pilares, vigas y correas en acero galvanizado en caliente por inmersión. Calidad del acero S275. Perfilería de aluminio EN AW 6005A T6. Tornillería de acero inoxidable A2-70

Acabados:
Pilares, vigas y correas en acero galvanizado en caliente por inmersión
Cubierta de chapa metálica prelacada color blanco pirineo

Se requiere cimentación previa a la instalación de la marquesina.
Tornillería de anclaje a suelo no incluida.

Se recomienda realizar un estudio geotécnico del terreno

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.

Figure A.7. monopitch canopy [66]


OPzS
Vented lead-acid battery

Motive Power Systems
Reserve Power Systems
Special Power Systems
Service

Your benefits with HOPPECKE OPzS

- **Very high expected service life** - due to optimized low-antimony selenium alloy
- **Excellent cycle stability** - due to tubular plate design
- **Maximum compatibility** - design according to DIN 40736-1
- **Higher short-circuit safety even during the installation** - based on HOPPECKE system connectors
- **Extremely extended water refill intervals up to maintenance-free** - optional use of AquaGen® recombination system minimizes emission of gas and aerosols[1]

Typical applications of HOPPECKE OPzS

- **Telecommunications**
  Mobile phone stations
  BTS-stations
  Off-grid/on-grid solutions
- **Power Supply**
- **Security lighting**

HOPPECKE
POWER FROM INNOVATION

Figure A.8. Lead-acid battery cells, page 1[49]

HOPPECKE
POWER FROM INNOVATION

OPzS

Type Overview

Capacities, dimensions and weights

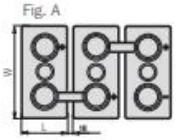
Type	C_{nom}/1.80 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah	C_3/1.75 V Ah	C_1/1.67 V Ah	max.* Weight kg	Weight electrolyte kg (1.24 kg/l)	max.* Length L mm	max.* Widht W mm	max.* Height H mm	Fig.
4 OPzS 200	200	213	182	161	118	17.3	4.5	105	208	420	A
5 OPzS 250	250	266	227	201	147	21.0	5.6	126	208	420	A
6 OPzS 300	300	320	273	241	177	24.9	6.7	147	208	420	A
5 OPzS 350	350	390	345	303	217	29.3	8.5	126	208	535	A
6 OPzS 420	420	468	414	363	261	34.4	10.1	147	208	535	A
7 OPzS 490	490	546	483	426	304	39.5	11.7	168	208	535	A
6 OPzS 600	600	686	590	510	353	46.1	13.3	147	208	710	A
7 OPzS 700	700	801	691	596	411	59.1	16.7	215	193	710	B
8 OPzS 800	800	915	790	681	470	63.1	17.3	215	193	710	B
9 OPzS 900	900	1026	887	767	529	72.4	20.5	215	235	710	B
10 OPzS 1000	1000	1140	985	852	588	76.4	21.1	215	235	710	B
11 OPzS 1100	1100	1256	1086	938	647	86.6	25.2	215	277	710	B
12 OPzS 1200	1200	1370	1185	1023	706	90.6	25.8	215	277	710	B
12 OPzS 1500	1500	1610	1400	1197	784	110.4	32.7	215	277	855	B
14 OPzS 1750	1750	1881	1632	1397	914	142.3	46.2	215	400	815	C
15 OPzS 1875	1875	2016	1748	1496	980	146.6	46.7	215	400	815	C
16 OPzS 2000	2000	2150	1865	1596	1045	150.9	45.9	215	400	815	C
18 OPzS 2250	2250	2412	2097	1796	1176	179.1	56.4	215	490	815	D
19 OPzS 2375	2375	2546	2213	1895	1242	182.9	55.6	215	490	815	D
20 OPzS 2500	2500	2680	2330	1995	1307	187.3	55.7	215	490	815	D
22 OPzS 2750	2750	2952	2562	2195	1437	212.5	67.0	215	580	815	D
23 OPzS 2875	2875	3086	2678	2294	1503	216.8	65.9	215	580	815	D
24 OPzS 3000	3000	3220	2795	2394	1568	221.2	66.4	215	580	815	D
26 OPzS 3250	3250	3488	3028	2594	1699	229.6	65.4	215	580	815	D

C_{nom} = nominal capacity at 10 h discharge according to DIN 40736-1

C_{10}, C_5, C_3 and C_1 = Capacity at 10 h, 5 h, 3 h and 1 h discharge

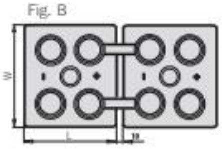
* according to DIN 40736-1 data to be understood as maximum values

Fig. A



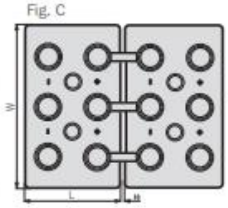
4 OPzS 200 -
6 OPzS 600

Fig. B



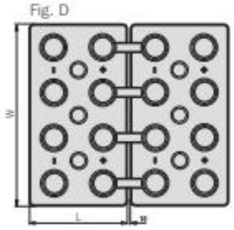
7 OPzS 700 -
12 OPzS 1500

Fig. C



14 OPzS 1750 -
16 OPzS 2000

Fig. D



18 OPzS 2250 -
26 OPzS 3250

Design life: up to 20 years

Optimal environmental compatibility - closed loop for recovery of materials in an accredited recycling system

¹ Similar to sealed lead-acid batteries

HOPPECKE
POWER FROM INNOVATION

HOPPECKE Batterien GmbH & Co. KG
P.O. Box 1140 · D-59914 Brilon · Germany
Bontkirchener Straße 1 · D-59929 Brilon-Hoppecke
Phone +49(0)2963 61-374
Fax +49(0)2963 61-270
Email info@hoppecke.com
www.hoppecke.com

Figure A.9. Lead-acid battery cells, page 2[49]

EXZHELLENT® SOLAR

ZZ-F - Libre de halógenos
1.8 kV DC - 0,6/1 kV AC

NORMAS:

CONSTRUCCIÓN	REACCIÓN AL FUEGO	
TÜV 2Pfg 1169	IEC 60332-1-2	IEC 61034-2
EN 50618	EN 60332-1-2	EN 61034-2
	IEC 60754-1	
	EN 60754-1	

CONSTRUCCIÓN:

1. **CONDUCTOR**
Cobre, clase 5 según IEC 60228.

2. **AISLAMIENTO**
Compuesto de EVA reticulado.
Color natural.

3. **CUBIERTA EXTERIOR**
Compuesto de EVA reticulado.
Colores rojo o negro.

APLICACIONES:

Pensados para la interconexión de paneles en instalaciones fotovoltaicas y para la conexión de estos con las cajas de conexión y los inversores, tanto en interiores, exteriores e instalaciones fijas o móviles (seguidores solares), como en tierra, tejados o integrados en edificios. No recomendado para instalación subterránea, ya sea bajo tubo o directamente enterrado.
Estos cables no están diseñados para ser sumergidos.

Temperatura máxima del conductor: +90 ºC (120 ºC durante 20.000 horas)
Temperatura mínima de trabajo: -40 ºC.

CERTIFICACIONES:

• BAUART GEPRÜFT
• TYPE APPROVED

LCIE se aplica a secciones desde 4 mm² hasta 25 mm² inclusive.
TÜV no se aplica a la sección 300 mm².

General Cable

Figure A.10. DC wire, page 1[67]

CARACTERÍSTICAS FÍSICAS Y ELÉCTRICAS:

Código de General Cable	Sección (mm²)	Diámetro nominal exterior (mm)	Peso nominal (kg/km)	Radio mínimo de curvatura (mm)	Intensidad máx. admisible al aire 60 °C * (A)	Caída de tensión DC system (V/A.km)
1614107	1x2,5	4,8	45	20	41	22,9
1619108	1x4	6,0	65	25	55	14,2
1619109	1x6	6,6	85	25	70	9,45
1619110	1x10	8,0	135	35	96	5,43
1614111	1x16	8,5	195	35	132	3,46
1614112	1x25	10,2	290	45	176	2,22
1614113	1x35	11,5	390	50	218	1,57
1614114	1x50	13,7	550	55	267	1,10
1614115	1x70	15,2	750	65	332	0,772
1614116	1x95	17,1	970	70	397	0,585
1614117	1x120	19,1	1.215	80	471	0,457
1614118	1x150	21,2	1.525	85	541	0,368
1614119	1x185	23,1	1.830	95	615	0,301
1614120	1x240	26,7	2.415	135	745	0,228
1614121	1x300	29,8	3.045	150	857	0,182

* Temperatura máxima del conductor de 120 °C, según TÜV 2Pfg 1169:2007.

Valores nominales sujetos a variación en función de la tolerancia de fabricación.

Figure A.11. DC wire, page 2[67]

EXZHELLENT XXI 1000V
RZ1-K (AS)
TENSIÓN: 0.6/1 kV

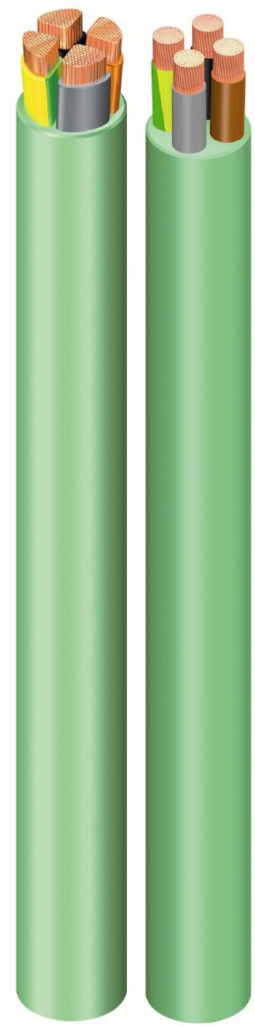
General Cable

NORMAS

UNE 21123-4 - Norma constructiva

IEC 60502-1 - Norma constructiva

UNE-EN 60332-1-2 - No propagador de la llama
UNE-EN 60332-3-24 ó 25 - No propagador del incendio
UNE-EN 60754 - Baja acidez y corrosividad de los gases
UNE-EN 61034 - Baja opacidad de los humos emitidos
IEC 60332-1-2 - No propagador de la llama
IEC 60332-3-24 ó 25 - No propagador del incendio
IEC 60754 - Baja acidez y corrosividad de los gases
IEC 61034 - Baja opacidad de los humos emitidos



CONSTRUCCIÓN

CONDUCTOR:
Cobre, flexible clase 5

AISLAMIENTO:
Polietileno reticulado (XLPE)

CUBIERTA EXTERIOR:
Poliolefina termoplástica libre de halógenos

APLICACIONES Y CARACTERÍSTICAS PRINCIPALES

La serie de cables EXZHELLENT XXI está constituida por cables flexibles unipolares y multipolares de 600/1000V. Su designación técnica es RZ1-K. La temperatura máxima de servicio del cable es de 90ºC, siendo capaz de trabajar a muy baja temperatura (-40ºC)

A partir de la sección de 50 mm2 inclusive se ofrece la configuración SECTORFLEX con conductor sectorial 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.

Los cables de Alta Seguridad (AS) son No Propagadores de la Llama, No Propagadores del Incendio (categoria C para diámetros superiores a 12 mm y categoria D para diámetros inferiores a 12 mm), de reducidad opacidad de los humos emitidos, libres de halógenos y de reducida acidez y corrosividad de los gases emitidos durante la combustión.

Son cables especialmente indicados para ser instalados en viviendas (línea general de alimentación y derivaciones individuales) según indica el Reglamento de Baja Tensión en las correspondientes ITC-BT-14 y 15, en los locales de pública concurrencia según ITC-BT-28, así como en aquellos lugares donde se pretenda elevar el grado de seguridad.

Figure A.12. AC wire, page 1[68]

EXZHELLENT XXI 1000V
RZ1-K (AS)

TENSIÓN: 0.6/1 kV

General Cable

	mm2	mm	kg/km	mm	40°C A	25°C A	cosφ=0.8 V/A.km	cosφ=1 V/A.km
1992106	1x1.5	5,7	45	25	21	25	23,65	29,37
1992107	1x2.5	6,1	60	25	30	33	14,24	17,62
1992108	1x4	6,7	75	30	40	43	8,873	10,93
1992109	1x6	7,2	95	30	52	54	5,95	7,288
1992110	1x10	8,2	140	35	72	71	3,484	4,218
1992111	1x16	9,2	195	40	97	93	2,24	2,672
1992112	1x25	10,8	285	45	122	118	1,476	1,723
1992113	1x35	11,9	380	50	153	143	1,073	1,224
1992114	1x50	13,5	520	55	188	170	0,773	0,852
1992115	1x70	15,6	715	65	243	209	0,568	0,601
1992116	1x95	17,4	925	70	298	248	0,449	0,455
1992117	1x120	19,4	1165	80	350	283	0,368	0,356
1992118	1x150	21,4	1445	90	401	319	0,311	0,285
1992119	1x185	23,3	1745	95	460	358	0,27	0,234
1992120	1x240	26,6	2295	135	545	413	0,223	0,177
1992121	1x300	30,2	2895	155	638	466	0,193	0,142
1992122	1x400	34,8	3930	175	770	544	0,164	0,107
1992123	1x500	39,5	5055	200	889	614	0,146	0,085
1992206	2x1.5	8,6	100	35	23	30	23,61	29,37
1992207	2x2.5	9,4	130	40	32	39	14,2	17,62
1992208	2x4	10,5	170	45	44	52	8,839	10,93
1992209	2x6	11,6	220	50	57	66	5,919	7,288
1992210	2x10	13,5	330	55	78	75	3,458	4,218
1992211	2x16	15,5	455	65	104	112	2,218	2,672
1992212	2x25	18,8	700	75	135	142	1,458	1,723
1992213	2x35	21,8	985	90	168	171	1,057	1,224
1998214	2x50	21,3	1150	85	204	203	0,759	0,852
1998215	2x70	24,7	1590	100	262	250	0,556	0,601
1998216	2x95	27,7	2060	140	320	297	0,438	0,455
1998217	2x120	31,3	2630	160	373	338	0,358	0,356
1998218	2x150	34,5	3245	175	430	382	0,302	0,285
1998219	2x185	37,8	3935	190	493	427	0,262	0,234
1998220	2x240	43,3	5200	220	583	493	0,215	0,177
1992306	3G1.5	9,0	115	40	23	30	23,61	29,37
1992307	3G2.5	9,9	155	40	32	39	14,2	17,62
1992308	3G4	11,1	205	45	44	52	8,839	10,93
1992309	3G6	12,3	275	50	57	66	5,919	7,288
1992310	3G10	14,3	415	60	78	85	3,458	4,218
1992311	3G16	16,5	600	70	104	112	2,218	2,672
1992311	3x16	16,5	600	70	91	93	2,218	2,672
1992312	3x25	20,0	900	80	115	118	1,458	1,723
1992313	3x35	23,3	1270	95	143	143	1,057	1,224
1998314	3x50	24,9	1550	100	174	170	0,759	0,852
1998315	3x70	29,2	2160	150	223	209	0,556	0,601
1998316	3x95	32,5	2790	165	271	248	0,438	0,455
1998317	3x120	36,7	3555	185	314	283	0,358	0,356
1998318	3x150	40,6	4405	205	359	319	0,302	0,285
1998319	3x185	44,3	5330	225	409	358	0,262	0,234
1998320	3x240	50,8	7035	305	489	413	0,215	0,177
1992406	4G1.5	9,9	140	40	20	25	23,61	29,37
1992407	4G2.5	10,9	185	45	28	33	14,2	17,62

Figure A.13. AC wire, page 2[68]

EXZHELLENT XXI 1000V
RZ1-K (AS)

TENSIÓN: 0.6/1 kV

General Cable

	mm2	mm	kg/km	mm	40ºC A	25ºC A	cosφ=0.8 V/A.km	cosφ=1 V/A.km
1992408	4G4	12,2	255	50	38	43	8,839	10,93
1992409	4G6	13,5	340	55	49	54	5,919	7,288
1992410	4G10	15,8	525	65	68	71	3,458	4,218
1992411	4G16	18,3	760	75	91	93	2,218	2,672
1992411	4x16	18,3	760	75	91	93	2,218	2,672
1992412	4x25	22,4	1150	90	115	118	1,458	1,723
1992413	4x35	25,6	1600	130	143	413	1,057	1,224
1998414	4x50	27,5	2065	140	174	170	0,759	0,852
1998415	4x70	32,3	2885	165	223	209	0,556	0,601
1998416	4x95	35,9	3735	180	271	248	0,438	0,455
1998417	4x120	40,7	4780	205	314	283	0,358	0,356
1998418	4x150	44,9	5900	225	359	319	0,302	0,285
1998419	4x185	49,4	7195	250	409	358	0,262	0,234
1998420	4x240	56,6	9500	340	489	413	0,215	0,177
1992506	5G1.5	10,8	170	45	20	25	23,61	29,37
1992507	5G2.5	11,9	225	50	28	33	14,2	17,62
1992508	5G4	13,4	310	55	38	43	8,839	10,93
1992509	5G6	14,9	420	60	49	54	5,919	7,288
1992510	5G10	17,5	645	70	68	71	3,458	4,218
1992511	5G16	20,2	925	85	91	93	2,218	2,672
1992512	5G25	24,8	1410	100	115	118	1,458	1,723
1992513	5G35	28,4	1955	145	143	143	1,057	1,224
1992514	5G50	33,1	2730	170	174	170	0,759	0,852
1992515	5G70	39,0	3870	195	223	209	0,556	0,601
1992516	5G95	43,4	4985	220	271	248	0,438	0,455
1992517	5G120	49,4	6375	250	314	283	0,358	0,356
1992518	5G150	54,7	8000	330	359	319	0,302	0,285

Figure A.14. AC wire, page 3[68]

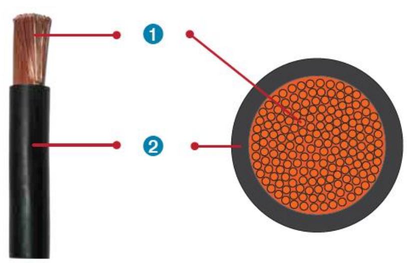
Baja Tensión - Cables para la construcción

EXZHELLENT XXI® - H07Z1-K (AS)

Monoconductor de cobre extraflexible con cubierta libre de halógenos. 450/750 V

AHORRO DE TIEMPO **SUPER DESLIZANTE** FACILIDAD DE INSTALACIÓN

indice



1 CONDUCTOR: cobre blando extraflexible, clase 5.

2 AISLACIÓN: cubierta de poliolefina termoplástica, ignífuga, libre de halógenos. Disponible en varios colores: negro, rojo, azul, blanco, verde y otros.

LEYENDA SOBRE LA CUBIERTA: GENERAL CABLE 1 H07Z1-K TYPE 2 (AS) AENOR <HAR> [calibre] mm² 450/750V

APLICACIONES Y USOS

Se utiliza en circuitos y derivaciones de baja tensión, tanto para instalaciones comerciales y domiciliarias interiores como lugares de pública concurrencia.

Por las propiedades del conductor (EXTRAFLEXIBLE) y de proceso de fabricación de la aislación (que la convierte en SUPERDESLIZANTE) este cable entrega las siguientes ventajas:

- Simplificación en el montaje al requerirse menor tensión de tendido y esfuerzo al tirar del cable.
- Disminución del riesgo de daño físico del conductor durante la instalación.
- Menor tiempo de instalación y montaje con el consiguiente beneficio de un ahorro en los costos del proceso de cableado y montaje.

CERTIFICACIONES, PRUEBAS Y NORMAS

La fabricación, métodos y frecuencias de prueba de estos cables están basados en las normas UNE 211002.

Las características especiales de los cables EXZHELLENT XXI H07Z1-K en condiciones de incendio son controladas de acuerdo a las siguientes normas y métodos:

- Retardancia a la llama: IEC 60332-1-2
- No propagación incendio: IEC 60332-3 24
- Emisión de humos: IEC 61034-2
- Contenido halógeno y corrosividad de los gasess: IEC 60754

Figure A.15. Grounding wire, page 1[69]

CARACTERÍSTICAS DE OPERACIÓN

Voltajes máximos: 450 V entre fase y tierra. 750 V entre fases.

La temperatura máxima del conductor en servicio permanente es de 70 °C y la de operación previa al cortocircuito es de 160 °C.

Flexibilidad: Cable de clase 5.

La aislación, en caso de incendio, es retardante a la llama, no propaga el incendio, emite poco humo, siendo este –además– libre de halógenos y no tóxico ni corrosivo.

EMBALAJE

En cajas y carretes.

CONDICIONES DE INSTALACIÓN

En ambientes secos, en tuberías, bandejas, y canaletas fijas.

INFORMACIÓN TÉCNICA ADICIONAL

EXZHELLENT XXI H07Z1-K

Calibre mm²	Diámetro exterior aprox. mm	Peso total aprox. kg/km	Radio de curvatura mm	Resistencia máx. a 20 °C CC Ω/km	Capacidad de corriente al aire libre (1) A
1,5	2,9	20	20	13,3	13
2,5	3,5	35	25	7,98	18
4	4,1	45	25	4,95	23
6	4,6	65	30	3,30	30
10	6,0	110	40	1,91	40
16	7,0	165	45	1,21	54
25	8,6	250	53	0,780	70
35	9,7	340	60	0,554	86
50	11,5	480	70	0,386	103
70	13,4	670	80	0,272	160
95	15,4	885	95	0,206	194
120	17,2	1.120	105	0,161	225
150	19,0	1.390	115	0,129	260
185	20,9	1.680	125	0,106	297
240	24,2	2.245	145	0,0801	350

(1) Según UN_E 20640-5-523, tabla A.52-1 bis. Para secciones hasta 50 mm² y método de instalación B1 para secciones iguales o superiores a 70 mm²-Temperatura ambiente a 40 °C.

Los valores aquí indicados son aproximados y están sujetos a tolerancias de fabricación.

CAMINO A MELIPILLA 6307, CASILLA 100, CERRILLOS, SANTIAGO, CHILE
SERVICIO AL CLIENTE: (56) 22 422 2200 • servicio.cliente@generalcable.cl
MESA CENTRAL: (56) 22 422 2000

General Cable cocesa

Figure A.16. Grounding wire, page 2[69]

Características técnicas HGD PRO

HGD (Gama Pro)

Modelo	HGD63N, 63 AF, 6 kA	HGD63H, 63 AF, 10 kA	HGD125, 125 AF, 10 kA
			
Norma de referencia	IEC/EN 60898-1	IEC/EN 60898-1 ; IEC/EN 60947-2	IEC/EN 60947-2
Núm. de polos	1P, 2P, 3P, 3P + N, 4P	1P, 2P, 3P, 4P	1P,, 2P, 3P, 4P
Intensidad nominal (In)	0.5, 1, 2, 3, 4, 5, 6, 10, 16, 20, 25, 32, 40, 50, 63 A	0.5, 1, 2, 3 4, 5, 6, 10, 16, 20, 25, 32, 40, 50, 63 A	80 A, 100 A, 125 A
Tensión de empleo máx. (Ue)	AC 240/415 V	AC 240/415 V	AC 240/415 V
Frecuencia (F)	50/60 Hz	50/60 Hz	50/60 Hz
Poder de corte (Inc)	6 kA (Ics=100 % Icn)	10 kA (Ics=100 % Icn)	10 kA (Ics=75 % Icn)
Característica de disparo (curva)	(3-5) In - Curva B (5-10) In - Curva C (10-20) In - Curva D	(3-5) In - Curva B (5-10) In - Curva C (10-20) In - Curva D	(3-5) In - Curva B (5-10) In - Curva C (10-20) In - Curva D
Tensión asignada de aislamiento (Ui)	500 V	500 V	690 V
Tensión nominal de resistencia a los impulsos (Uimp)	4 kV	4 kV	4 kV
Resistencia dieléctrica	2.5 kV	2.5 kV	2.5 kV
Endurancia Eléctrica / Mecánica (núm. de maniobras)	10,000/20,000	10,000/20,000	10,000/20,000
Temperatura de funcionamiento	-5 °C a + 55 °C	-5 °C a + 55 °C	-5 °C a + 55 °C
Humedad	95 % RH	95 % RH	95 % RH
Clase de limitación de energía	3	3	3
Tamaño del terminal (máx)	35 mm^2	35 mm^2	50 mm^2
Par de apriete máximo	2 N·m	2 N·m	2.5 N·m
Vibración	3 g	3 g	3 g
Grado de protección IP	IP20	IP20	IP20
Indicacior visual de posición de contacto	Rojo-ON, Verde-OFF	Rojo-ON, Verde-OFF	Rojo-ON, Verde-OFF
Peso neto por polo	0.125 kg	0.125 kg	0.150 kg
Dimensiones (Alto x Profundo x Ancho) por polo	87.5 x 71.7 x 17.7 mm	87.5 x 71.7 x 17.7 mm	81 x 74.5 x 26.5 mm
Montaje	Clip 35 mm x 7.5 mm carril DIN	Clip 35 mm x 7.5 mm carril DIN	Clip 35 mm x 7.5 mm carril DIN
Posición de instalación	Vertical/Horizontal	Vertical/Horizontal	Vertical/Horizontal
Carcasa y cubierta	Material termoplástico moldeado, ignífugo	Material termoplástico moldeado, ignífugo	Material termoplástico moldeado, ignífugo
Tipo conexión peine lado superior/inferior	Tipo Pin/Horquilla (Inferior)	Tipo Pin/Horquilla (Inferior)	-
AUX/ALT/SHT/UVT/OVT	Sí	Sí	No

* HGD63N y HGD63H Son igual en apariencia

Figure A.17. Circuit breaker for the DC circuit, page 1[58]

Hoja de características del producto
Características

A9N18372

Magnetotérmico, Acti9 C120N, 4P, 80 A, C curva, 10000 A (IEC 60898-1), 10 kA (IEC 60947-2)

Principal

Gama de producto	Dardo Plus
Gama	Acti 9
Nombre del producto	C120
Tipo de producto o componente	Interruptor automático en miniatura
Nombre corto del dispositivo	C120N
Aplicación del dispositivo	Distribución
Número de polos	4P
Número de polos protegidos	4
[In] Corriente nominal	80 A en 30 °C
Tipo de red	CA
Tecnología de unidad de disparo	Térmico-magnético
Código de curva	C
Capacidad de corte	10000 A Icn en 230...400 V CA 50/60 Hz acorde a EN/IEC 60898-1 6 kA Icu en 440 V CA 50/60 Hz acorde a EN/IEC 60947-2 20 kA Icu en 220...240 V CA 50/60 Hz acorde a EN/IEC 60947-2 10 kA Icu en 380...415 V CA 50/60 Hz acorde a EN/IEC 60947-2 10 kA Icu en <= 500 V CC acorde a EN/IEC 60947-2
Poder de seccionamiento	Sí acorde a IEC 60947-2

Complementario

Frecuencia de red	50/60 Hz
[Ue] Tensión nominal de empleo	380...415 V AC 50/60 Hz <= 500 V CC 220...240 V AC 50/60 Hz 440 V CA 50/60 Hz 230...400 V CA 50/60 Hz
Límite de enlace magnético	5...10 x In
[Ics] poder de corte en servicio	7500 A 75 % acorde a EN/IEC 60898-1 - 230...400 V CA 50/60 Hz 4,5 kA 75 % acorde a EN/IEC 60947-2 - 440 V CA 50/60 Hz

Figure A.18. AC circuit breaker, page 1 [59]

	7,5 kA 75 % acorde a EN/IEC 60947-2 - 380...415 V CA 50/60 Hz 15 kA 75 % acorde a EN/IEC 60947-2 - 220...240 V CA 50/60 Hz 10 kA 100 % acorde a EN/IEC 60947-2 - <= 500 V CC
Clase de limitación	3 acorde a EN/IEC 60947-2
[Ui] Tensión nominal de aislamiento	500 V CA 50/60 Hz acorde a EN/IEC 60947-2
[Uimp] Resistencia a picos de tensión	6 kV acorde a EN/IEC 60947-2
Indicador de posición del contacto	Sí
Tipo de control	Maneta
Señalizaciones en local	Indicación de encendido/apagado
Tipo de montaje	Ajustable en clip
Soporte de montaje	Carril DIN simétrico de 35 mm
Compatibilidad de bloque de distribución y embarrado tipo peine	SÍ
Pasos de 9 mm	12
Altura	81 mm
Anchura	108 mm
Profundidad	73 mm
Peso del producto	0,82 kg
Color	White
Durabilidad mecánica	20000 ciclos
Durabilidad eléctrica	5000 ciclos acorde a IEC 60947-2
Conexiones - terminales	Terminales de tipo túnel1…50 mm² rígido Terminales de tipo túnel1,5…35 mm² Flexible
Longitud de cable pelado para conectar bornas	15 mm
Par de apriete	3,5 N.m
Protección contra fugas a tierra	Bloque independiente

Entorno

Normas	EN/IEC 60898-1 EN/IEC 60947-2
Certificaciones de producto	EAC
Grado de protección IP	IP20 acorde a IEC 60529
Grado de contaminación	3 conforming to IEC 60947-2
Categoría de sobretensión	IV
Tropicalización	2 acorde a IEC 60068-1
Humedad relativa	95 % en 55 °C
Altitud máxima de funcionamiento	2000 m
Temperatura ambiente de funcionamiento	-25…70 °C
Temperatura ambiente de almacenamiento	-40…85 °C

Figure A.19. AC circuit breaker, page 2[59]

Hoja de características del producto
Características

A9R14480
iID 4P 80A 300mA AC

Principal

Gama	Acti 9
Nombre del producto	Acti 9 iID
Tipo de producto o componente	Interruptor diferencial (RCCB)
Nombre corto del dispositivo	IID
Número de polos	4P
Posición de neutro	Izquierda
[In] Corriente nominal	80 A
Tipo de red	CA
Sensibilidad de fuga a tierra	300 mA
Retardo de la protección contra fugas a tierra	Instantáneo
Clase de protección contra fugas a tierra	Tipo AC

Complementario

Ubicación del dispositivo en el sistema	Salida
Frecuencia de red	50/60 Hz
[Ue] Tensión nominal de empleo	380...415 V AC 50/60 Hz
Tecnologia de disparo corriente residual	Independiente de la tensión
Poder de conexión y de corte	Idm 1500 A Im 1500 A
Corriente condicional de cortocircuito	10 kA
[Ui] Tensión nominal de aislamiento	500 V CA 50/60 Hz
[Uimp] Resistencia a picos de tensión	6 kV
Indicador de posición del contacto	Sí
Tipo de control	Maneta
Tipo de montaje	Ajustable en clip
Soporte de montaje	Carril DIN

Figure A.20. AC differential switch, page 1[60]

Pasos de 9 mm	8
Altura	91 mm
Anchura	72 mm
Profundidad	73,5 mm
Peso del producto	0,37 kg
Color	White
Durabilidad mecánica	20000 ciclos
Durabilidad eléctrica	AC-1, estado 1 10000 ciclos
Descripción de las opciones de bloqueo	Dispositivo de cierre con candado
Conexiones - terminales	Terminal simple arriba o abajo1…35 mm² rígido Terminal simple arriba o abajo1…25 mm² Flexible Terminal simple arriba o abajo1…25 mm² flexible con terminal
Longitud de cable pelado para conectar bornas	14 mm for top or bottom connection
Par de apriete	3,5 N.m arriba o abajo

Entorno

Normas	EN/IEC 61008-1
Certificaciones de producto	SNI
Grado de protección IP	IP20 conforming to IEC 60529 IP40 (modular enclosure) conforming to IEC 60529
Grado de contaminación	3
Compatibilidad electromagnética	Resistencia a impulsos 8/20 µs, 250 A acorde a EN/IEC 61008-1
Temperatura ambiente de funcionamiento	-5…60 °C
Temperatura ambiente de almacenamiento	-40…85 °C

Figure A.21. AC differential switch, page 2 [60]

EVBox Iqon

EVBox Iqon is the award-winning 22 kW AC charging station that provides reliable and accessible charging for all commercial locations.

reddot award 2019

iF DESIGN AWARD 2019

CES INNOVATION AWARDS 2019 HONOREE

EVBOX

22 kW AC
charging station

Figure A.22. AC fast charging station, page 1[55]

Technical
specifications

ELECTRICAL OUTPUT	
Max. charging capacity	Up to 22 kW per cable
Charge mode	Mode 3 (IEC 61851) / Level 2 (UL2594)
Output power (dual 32 A input)	2x 22 kW (3-phase, 400 V AC, 32 A per cable)

PHYSICAL PROPERTIES	
Dimensions, mm (W x H x D)	415 x 1894 x 275 mm with 50 mm removable base extension
Weight	85 kg (excluding packaging)
Mounting	Ground mount (free standing, wall-supported or back-to-back)
Housing	Stainless steel, polycarbonate
Plastic materials	ISO 3795 passed, DIN 53438 F1/K1

INTERFACES	
Connectors	2x Type 2 (IEC 62196-2) cables
Charging cable length	5.5 m with smart cable management system
Plug holders	With docking sensor and locking mechanism
Display	8" (20 cm) LCD IPS full color screen (768 x 1024 px) with capacitive touch, sunlight readable
Display languages	English, Spanish, French, German,
System lighting	Day/night mode, auto-adjustable light intensity, automatic system wake-up
Session activation	RFID / QR code

SAFETY AND CONNECTIVITY	
Electrical safety	Integrated RCBO 40 A / 30 mA AC leakage detection per outlet / CCID 6 mA DC leakage detection per outlet
Station surge protection	4 kV
Maximum cluster size	10 dual chargers (20 connectors)
Mobile connectivity - Hub	4G LTE-FDD CAT1 (B1/3/7/8/20) / 3G WCDMA (Band 1/8) / GSM (900/1800 Mhz)
Connectivity - Hub	Dual band Wi-Fi 2.4/5 GHz, Bluetooth 4.0 for configuration with the EVBox Connect app, GPS
Time synchronization - Hub	GPS / Wi-Fi
Communication protocol - Hub	OCPP 1.5 S / 1.6 S / 1.6 J
Enclosure rating	IEC 60529 / IP55 / IK10
Collision detection	Tilt sensor
Operating temperature	-30°C to +50°C
Operating humidity	85% @ 50°C (non-condensing)
Storage temperature	-40°C to +60°C
Storage humidity	95% @ 50°C (non-condensing)
Safety and compliance	IEC 61851-1 (2017), IEC 61851-21-2 (2018), IEC 61000-3-2 (2014), IEC 61000-3-3 (2013), EN 301 489-1 V2.2.0, EN 301 489-3 V2.1.1, EN 301 489-17 V3.2.0, EN 301 489-52 V1.1.0, EN 301 908-1 V11.1.1, EN 301 511 V12.5.1, EN 300 330 V2.1.1, EN 300 328 V2.1.1, EN 301 893 V2.1.1, EN 300 220-1 V3.1.1, EN 300 220-2 V3.1.1, CE conformity, RoHS, REACH
Metering	S-Bus MID certified class B
Smart energy management	Adjusting max. current, charging profiles, dynamic load balancing (via MAX protocol)

Figure A.23. AC fast charging station, page 2[55]

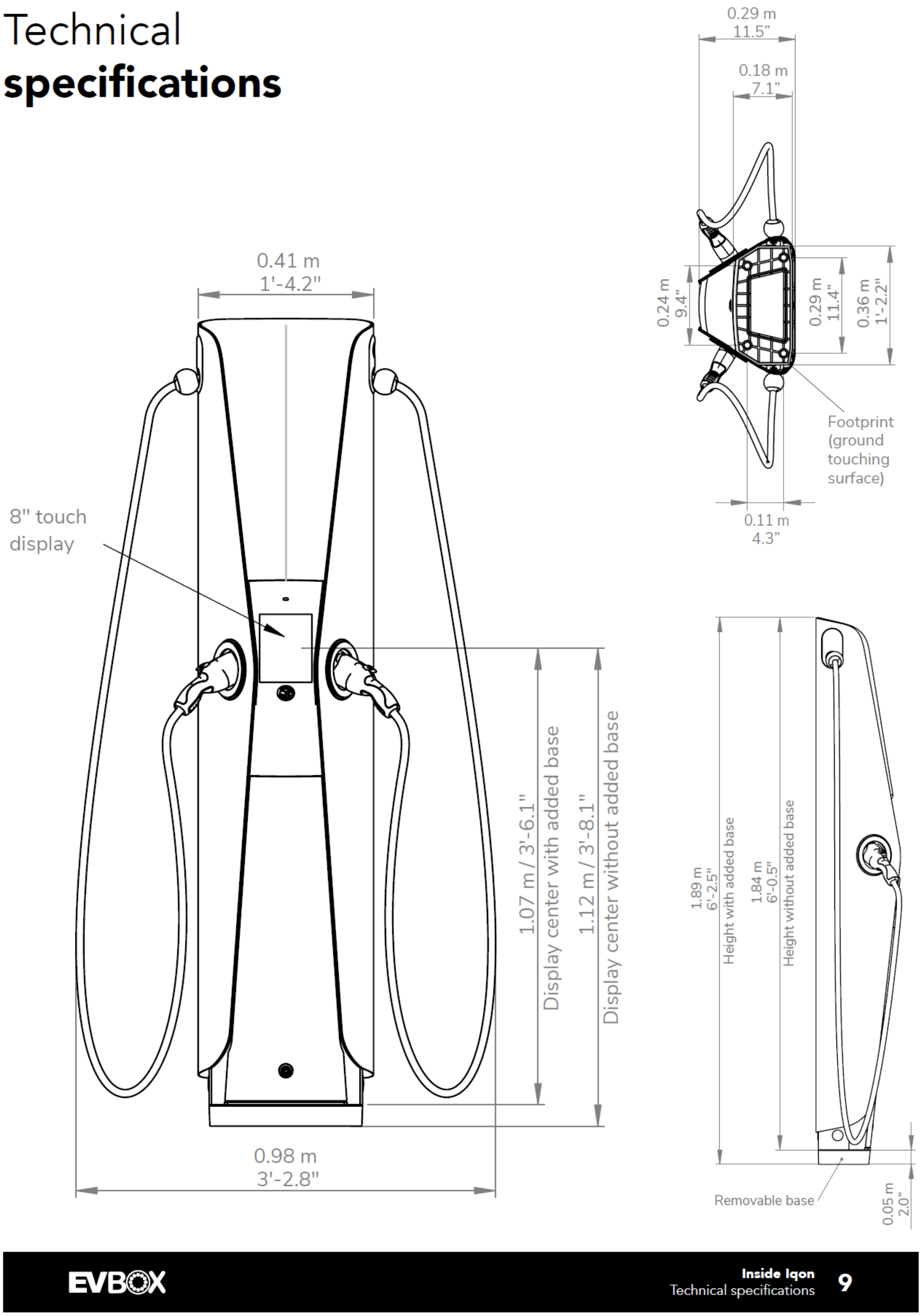


Figure A.24. AC fast charging station, page 3[55]

EVBox Troniq 50

EVBOX

fast charging solution

50 kW
Charges up to 125 km in just 30 minutes
Flexible architecture and universally compatible in every space and use case
Made to last with auto-retractable cables, high quality power electronic components, and more
Consumes power efficiently with smart queuing and battery storage options

- 50 kW fast charging capacity
- Flexible architecture
- Tariff settings
- Universally compatible
- Roaming
- Utility power cabinet
- Auto-retractable cables
- Easy transportation, installation and maintenance
- Advanced cooling and heating system
- Remote maintenance
- 3-year warranty
- Smart queuing
- Color touchscreen with 4 languages
- Optional battery storage

evbox.com

Figure A.25. DC/AC fast charging station, page 1[56]

General **specifications**

Charging modes	
Mode 4 (DC charging)	CHAdeMO up to 500 V / 120 A; CCS2 up to 500 V / 125 A
Mode 3 (AC charging)	Up to 43 kW / 63 A or limited up to 22 kW / 32 A
Mode 2 (AC charging)	Up to 2.3 kW / 10 A
Connector type	
Mode 4	JEVS G105 (CHAdeMO), CCS2
Mode 3	Type 2 attached cable (43 kW), Type 2 socket (22 kW)
Mode 2	Type E/F socket
Cable length	
Mode 4	3.95 m with auto-retractable cable
Mode 3	3.95 m with auto-retractable cable
Mode 2	--
Structure and physical properties	
Enclosure material	Galvanized steel (structure), aluminum (casing), stainless steel (feet)
Enclosure ratings	IP54 / IK10
Operating temperature	-30°C to +50°C
Storage temperature	-40°C to +70°C
Operating humidity	5% to 95% non-condensing
Enclosure fire ratings	M3 (NF P 92-501)
Cooling	Forced ventilation
Mounting method	Floor / Ground (recommended with the optional clamping-sealing kit)
Maximum installation height	< 2000 m
Dimension (W x H x D) and weight*	
EVBox Troniq 50	765 x 1920 x 465 mm / 340 kg (Mono-standard) 820 x 1920 x 465 mm / 345 kg (Bi-standard) 920 x 1920 x 465 mm / 350 kg (Tri-standard)
EVBox Troniq User Unit 125 A	331 x 1895 x 467 mm / 85 kg (Mono-standard) 421 x 1895 x 467 mm / 90 kg (Bi-standard) 513 x 1895 x 467 mm / 95 kg (Tri-standard)
Connectivity	
Authorization	RFID/NFC (ISO 14443, ISO 18092, ISO 15693, ISO 18000-3, Calypso, Mifare Ultralight C, -Classic, -Desfire)
Status indication / HMI	2 beacon RGB LED Indicators / 7" anti-vandalism LCD touch screen
Communication standard	GPRS/3G modem and Ethernet
Communication protocol	OCPP 1.5 S and 1.6 J
Positioning	GPS
Certifications	CE, EMC Directive 2014/30/EU, Low Voltage Directive 2014/35/EU, EN/IEC 61851-1, EN/IEC 61851-21-2, EN/IEC 61851-22, EN/IEC 61851-23, DIN 70121, ISO15118, CHAdeMO, EV/ZE-Ready

Figure A.26. DC/AC fast charging station, page 2[56]

Electrical **properties**

EVBox Troniq 50

EVBOX

AC input

Voltage range	400 VAC +/- 10%
Number of phases	3 P + N + PE
Frequency	50 Hz
Input rating	54 kVA (36 kVA with battery storage)
Nominal input current	77 A (52 A with battery storage)
Maximal input current	87 A (60 A with battery storage)
Power factor	> 0.99
Efficiency	95%
Grounding system	IT, TT or TN-S
AC MID Meter	Yes (except with User Unit option)
Stand-by power consumption	100 W

DC output

Output power	50 kW
Output voltage range	50 VDC – 500 VDC
Output current range	1 A – 125 A

AC output (mode 3)

Output power	43 kW with attached cable / 22 kW with socket outlet
Output voltage range	400 VAC +/- 10%
Maximum output current	63 A with attached cable / 32 A with socket outlet

AC output (mode 2)

Output power	2.3 kW
Output voltage range	230 VAC +/- 10%
Maximum output current	10 A

Electrical protections

Internal electrical protections	RCBO 30 mA Type A, RCD 30 mA Type A + 6 mA detection, MCB curve C/D
Required circuit breaker upstream	MCBB Curve D, 120 A & RCD 300 mA, Type A, HI, (S)

Models	CHA	CCS	CCS + CHA	CCS + CHA + T2 CABLE	CCS + CHA + T2 SOCKET
Required power supply capacity	54 kVA	54 kVA	54 kVA	54 kVA	54 kVA
Nominal AC input current	77 A	77 A	77 A	77 A	77 A
Maximum output power	DC: 50 kW	DC: 50 kW	DC: 50 kW	DC: 50 kW AC: 43 kW	DC: 50 kW AC: 22 kW
Maximum output current	DC: 120 A	DC: 125 A	DC: 120 A	DC: 120 A AC: 63 A	DC: 120 A AC: 32 A
Output voltage range	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V	DC: 50 - 500 V
Number of plugs	1	1	2	3	3
Connections	JEVS G105	CCS2	CCS2 - JEVS G105	CCS2 - JEVS G105 Type 2 cable	CCS2 - JEVS G105 Type 2 socket
EVBox Troniq 50	✓	✓	✓	✓	✓
EVBox Troniq 50 + 1 x UU	✓	✓	✓	✓	✓

EVBox Manufacturing B.V.
Fred. Roeskestraat 115
1076 EE Amsterdam
The Netherlands
evbox.com/support

Figure A.27. DC/AC fast charging station, page 3 [56]

ANNEX B. PVSyst SIMULATION RESULTS

In the following pages we will be able to see the simulations done with the PVSyst software for cases 1 and 2.

CASE 1, will use the Ingecon Sun 50 while CASE 2 uses ZIGOR Sunzet 50, an inverter from the same brand with very similar characteristics as the hybrid device chosen for the project.

The simulations will be shown in the following pictures:

ELECTRIC VEHICLE CHARGING THROUGH A PHOTOVOLTAIC CAR PARK CONNECTED TO THE GRID
200 KW SOLAR CANOPIES REPORT

Grid-Connected System: Simulation parameters

Project : **Electric Vehicle Charging through a photovoltaic car park co**

Geographical Site	**Madrid**		Country	**Spain**
Situation	Latitude	40.5°N	Longitude	3.5°W
Time defined as	Legal Time	Time zone UT+1	Altitude	585 m
	Albedo	0.20		
Meteo data:	**Madrid**	MeteoNorm 7.1 station - Synthetic		

Simulation variant : **200KW SOLAR CANOPIES**

Simulation date 09/05/21 20h24

Simulation parameters

Collector Plane Orientation	Tilt	5°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			

PV Arrays Characteristics (2 kinds of array defined)

PV module Si-mono	Model	**GCL-M8/72H-440**		
Custom parameters definition	Manufacturer	GCL		
Sub-array "Sub-generador #1"				
Number of PV modules	In series	16 modules	In parallel	18 strings
Total number of PV modules	Nb. modules	288	Unit Nom. Power	440 Wp
Array global power	Nominal (STC)	**127 kWp**	At operating cond.	116 kWp (50°C)
Array operating characteristics (50°C)	U mpp	593 V	I mpp	195 A
Sub-array "Sub-generador #2"				
Number of PV modules	In series	16 modules	In parallel	18 strings
Total number of PV modules	Nb. modules	288	Unit Nom. Power	440 Wp
Array global power	Nominal (STC)	**127 kWp**	At operating cond.	116 kWp (50°C)
Array operating characteristics (50°C)	U mpp	593 V	I mpp	195 A
Total Arrays global power	Nominal (STC)	**253 kWp**	Total	576 modules
	Module area	**1272 m²**	Cell area	1137 m²

Inverter	Model	**Ingecon Sun 50**		
Original PVsyst database	Manufacturer	Ingeteam		
Characteristics	Operating Voltage	405-750 V	Unit Nom. Power	50 kWac
Sub-array "Sub-generador #1"	Nb. of inverters	2 units	Total Power	100 kWac
Sub-array "Sub-generador #2"	Nb. of inverters	2 units	Total Power	100 kWac
Total	Nb. of inverters	4	Total Power	200 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	51 mOhm	Loss Fraction	1.5 % at STC
	Array#2	51 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Figure B.1. PVSyst simulation case 1, page 1

ELECTRIC VEHICLE CHARGING THROUGH A PHOTOVOLTAIC CAR PARK CONNECTED TO THE GRID
200 KW SOLAR CANOPIES REPORT

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Figure B.2. PVSyst simulation case 1, page 2

ELECTRIC VEHICLE CHARGING THROUGH A PHOTOVOLTAIC CAR PARK CONNECTED TO THE GRID
200 KW SOLAR CANOPIES REPORT

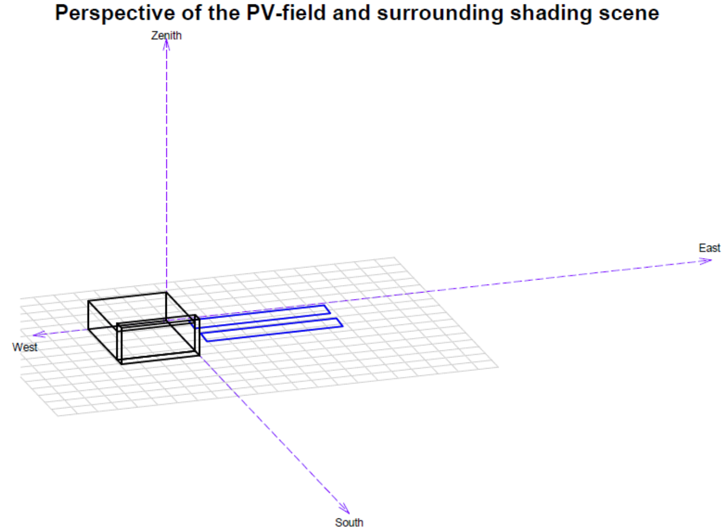
Grid-Connected System: Near shading definition

Project : **Electric Vehicle Charging through a photovoltaic car park co**

Simulation variant : **200KW SOLAR CANOPIES**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	5°	azimuth	0°
PV modules	Model	GCL-M8/72H-440	Pnom	440 Wp
PV Array	Nb. of modules	576	Pnom total	**253 kWp**
Inverter	Model	Ingecon Sun 50	Pnom	50.0 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**200 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

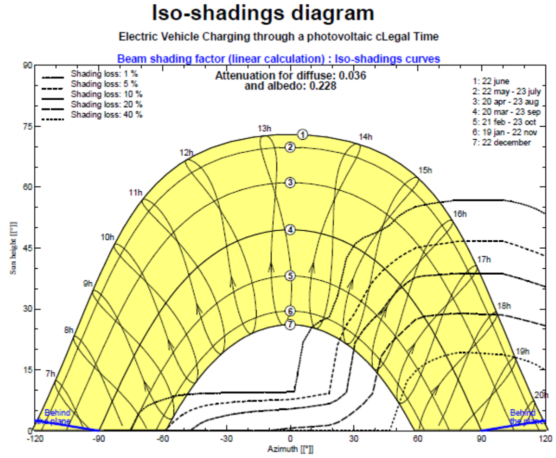


Figure B.3. PVSyst simulation case 1, page 3

ELECTRIC VEHICLE CHARGING THROUGH A PHOTOVOLTAIC CAR PARK CONNECTED TO THE GRID
200 KW SOLAR CANOPIES REPORT

Grid-Connected System: Main results

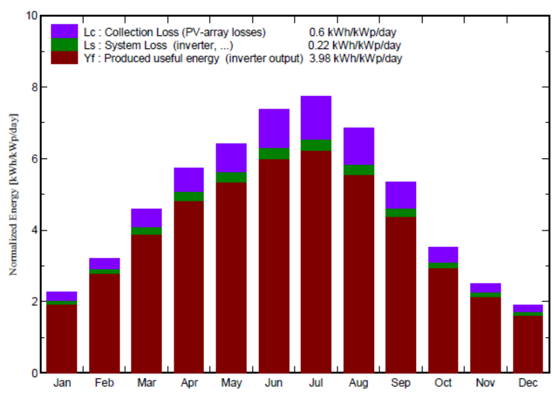
Project : **Electric Vehicle Charging through a photovoltaic car park co**

Simulation variant : **200KW SOLAR CANOPIES**

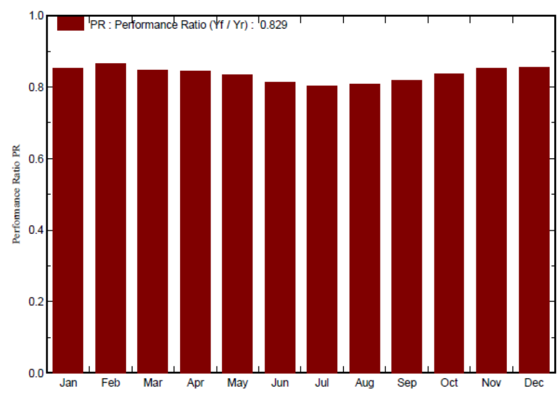
Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	5°	azimuth	0°
PV modules	Model	GCL-M8/72H-440	Pnom	440 Wp
PV Array	Nb. of modules	576	Pnom total	**253 kWp**
Inverter	Model	Ingecon Sun 50	Pnom	50.0 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**200 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**367.9 MWh/year**	Specific prod.	1452 kWh/kWp/year
	Performance Ratio PR	82.9 %		

Normalized productions (per installed kWp): Nominal power 253 kWp



Performance Ratio PR



200KW SOLAR CANOPIES

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	62.0	5.19	70.0	63.1	16.06	15.13	18.03	16.97
February	82.2	6.71	89.8	82.3	20.76	19.70	18.17	17.25
March	133.8	10.31	142.2	130.4	32.20	30.59	17.80	16.91
April	166.7	12.18	171.9	159.8	38.74	36.76	17.72	16.81
May	196.2	16.99	198.7	185.3	44.21	42.01	17.49	16.61
June	219.7	22.87	221.1	208.0	48.05	45.61	17.08	16.21
July	237.4	25.69	240.0	225.3	51.47	48.89	16.86	16.01
August	207.3	24.93	212.9	198.9	45.91	43.62	16.95	16.10
September	152.6	19.98	160.5	148.0	35.07	33.32	17.17	16.31
October	102.3	14.77	109.5	100.3	24.49	23.23	17.57	16.66
November	68.6	8.53	75.5	69.0	17.32	16.33	18.02	16.99
December	52.5	5.49	58.9	53.4	13.59	12.76	18.12	17.02
Year	1681.3	14.52	1751.0	1623.6	387.88	367.94	17.41	16.51

Legends:			
GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Figure B.4. PVSyst simulation case 1, page 4

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ELECTRIC VEHICLE CHARGING THROUGH A PHOTOVOLTAIC CAR PARK CONNECTED TO THE GRID
200 KW SOLAR CANOPIES REPORT

Grid-Connected System: Loss diagram

Project : **Electric Vehicle Charging through a photovoltaic car park co**

Simulation variant : **200KW SOLAR CANOPIES**

Main system parameters	System type	**Grid-Connected**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	5°	azimuth	0°
PV modules	Model	GCL-M8/72H-440	Pnom	440 Wp
PV Array	Nb. of modules	576	Pnom total	**253 kWp**
Inverter	Model	Ingecon Sun 50	Pnom	50.0 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**200 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

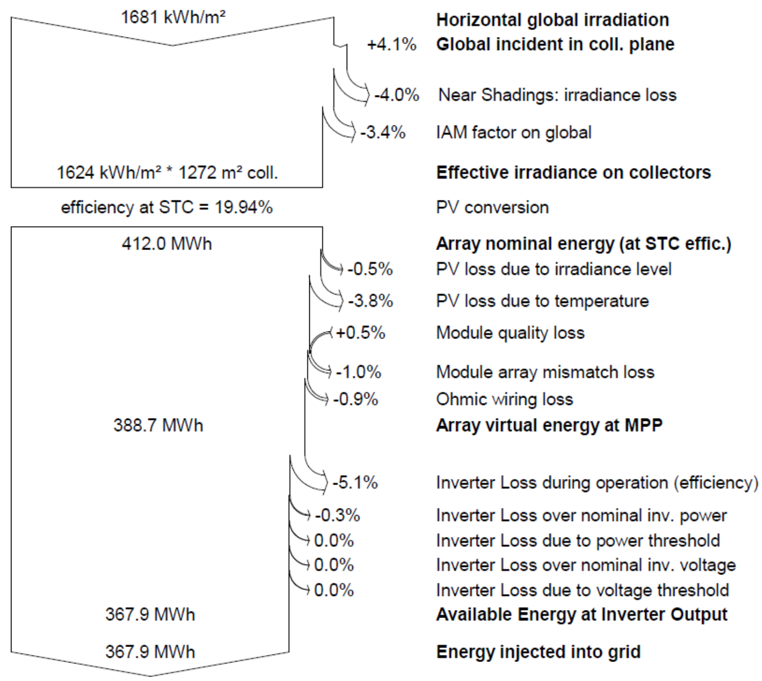


Figure B.5. PVSyst simulation case 1, page 5

Electric Vehicle Charging through a photovoltaic car park connected to the grid
200 KW SOLAR CANOPIES

Grid-Connected System: Simulation parameters

Project : **Electric Vehicle Charging through a photovoltaic car park co**

Geographical Site	**Madrid**		Country	**Spain**
Situation	Latitude	40.5°N	Longitude	3.5°W
Time defined as	Legal Time	Time zone UT+1	Altitude	585 m
	Albedo	0.20		
Meteo data:	**Madrid**	MeteoNorm 7.1 station - Synthetic		

Simulation variant : **200KW SOLAR CANOPIES**

Simulation date 21/05/21 12h55

Simulation parameters

Collector Plane Orientation	Tilt	5°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Arrays Characteristics (2 kinds of array defined)

PV module Si-mono	Model	**GCL-M8/72H-440**		
Custom parameters definition	Manufacturer	GCL		
Sub-array "Sub-generador #1"				
Number of PV modules	In series	16 modules	In parallel	18 strings
Total number of PV modules	Nb. modules	288	Unit Nom. Power	440 Wp
Array global power	Nominal (STC)	**127 kWp**	At operating cond.	116 kWp (50°C)
Array operating characteristics (50°C)	U mpp	593 V	I mpp	195 A
Sub-array "Sub-generador #2"				
Number of PV modules	In series	16 modules	In parallel	18 strings
Total number of PV modules	Nb. modules	288	Unit Nom. Power	440 Wp
Array global power	Nominal (STC)	**127 kWp**	At operating cond.	116 kWp (50°C)
Array operating characteristics (50°C)	U mpp	593 V	I mpp	195 A
Total Arrays global power	Nominal (STC)	**253 kWp**	Total	576 modules
	Module area	**1272 m²**	Cell area	1137 m²

Inverter	Model	**Sunzet 50KVA T**		
Original PVsyst database	Manufacturer	Zigor		
Characteristics	Operating Voltage	350-700 V	Unit Nom. Power	50 kWac
Sub-array "Sub-generador #1"	Nb. of inverters	2 units	Total Power	100 kWac
Sub-array "Sub-generador #2"	Nb. of inverters	2 units	Total Power	100 kWac
Total	Nb. of inverters	4	Total Power	200 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	51 mOhm	Loss Fraction	1.5 % at STC
	Array#2	51 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Figure B.6. PVSyst simulation case 2, page 1

Electric Vehicle Charging through a photovoltaic car park connected to the grid
200 KW SOLAR CANOPIES

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Figure B.7. PVSyst simulation case 2, page 2

Electric Vehicle Charging through a photovoltaic car park connected to the grid
200 KW SOLAR CANOPIES

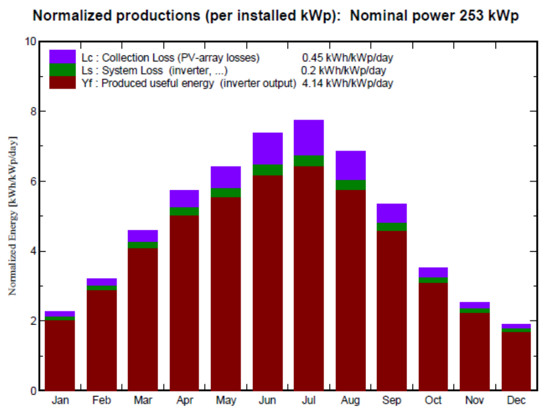
Grid-Connected System: Main results

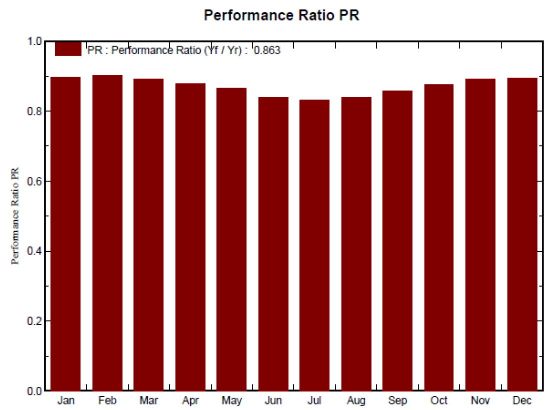
Project : **Electric Vehicle Charging through a photovoltaic car park co**

Simulation variant : **200KW SOLAR CANOPIES**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	5°	azimuth	0°
PV modules	Model	GCL-M8/72H-440	Pnom	440 Wp
PV Array	Nb. of modules	576	Pnom total	**253 kWp**
Inverter	Model	Sunzet 50KVA T	Pnom	50.0 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**200 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**383.0 MWh/year**	Specific prod.	1511 kWh/kWp/year
	Performance Ratio PR	86.3 %		





200KW SOLAR CANOPIES
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	62.0	5.19	70.0	65.8	16.75	15.91	18.79	17.86
February	82.2	6.71	89.8	85.4	21.55	20.54	18.86	17.98
March	133.8	10.31	142.2	136.4	33.67	32.11	18.61	17.75
April	166.7	12.18	171.9	165.9	40.15	38.28	18.36	17.50
May	196.2	16.99	198.7	191.6	45.68	43.55	18.07	17.23
June	219.7	22.87	221.1	214.0	49.33	47.03	17.54	16.72
July	237.4	25.69	240.0	232.7	53.11	50.62	17.39	16.58
August	207.3	24.93	212.9	206.0	47.48	45.29	17.53	16.72
September	152.6	19.98	160.5	154.6	36.62	34.92	17.93	17.10
October	102.3	14.77	109.5	104.7	25.55	24.36	18.33	17.47
November	68.6	8.53	75.5	71.5	17.95	17.06	18.68	17.76
December	52.5	5.49	58.9	55.3	14.07	13.36	18.77	17.81
Year	1681.3	14.52	1751.0	1683.9	401.90	383.04	18.04	17.19

Legends:			
GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Figure B.8. PVSyst simulation case 2, page 3

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Electric Vehicle Charging through a photovoltaic car park connected to the grid
200 KW SOLAR CANOPIES

Grid-Connected System: Loss diagram

Project : **Electric Vehicle Charging through a photovoltaic car park co**

Simulation variant : **200KW SOLAR CANOPIES**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	5°	azimuth	0°
PV modules	Model	GCL-M8/72H-440	Pnom	440 Wp
PV Array	Nb. of modules	576	Pnom total	**253 kWp**
Inverter	Model	Sunzet 50KVA T	Pnom	50.0 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**200 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

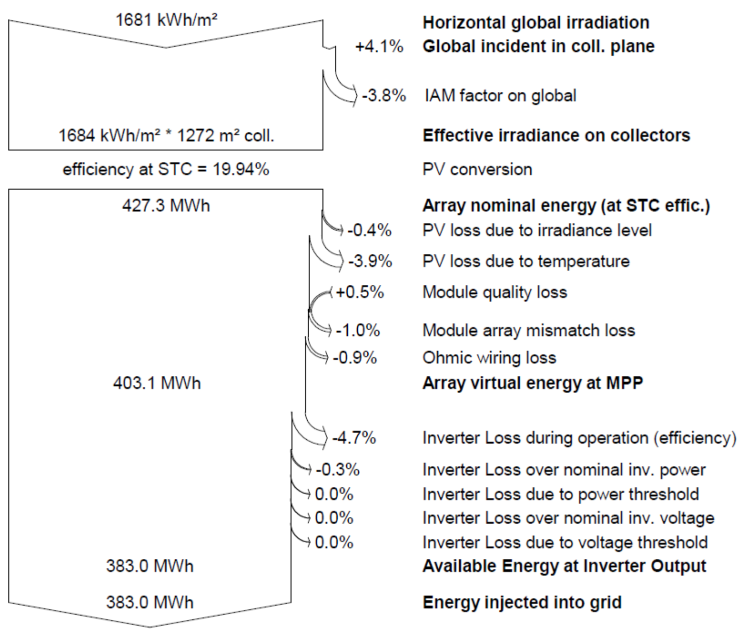


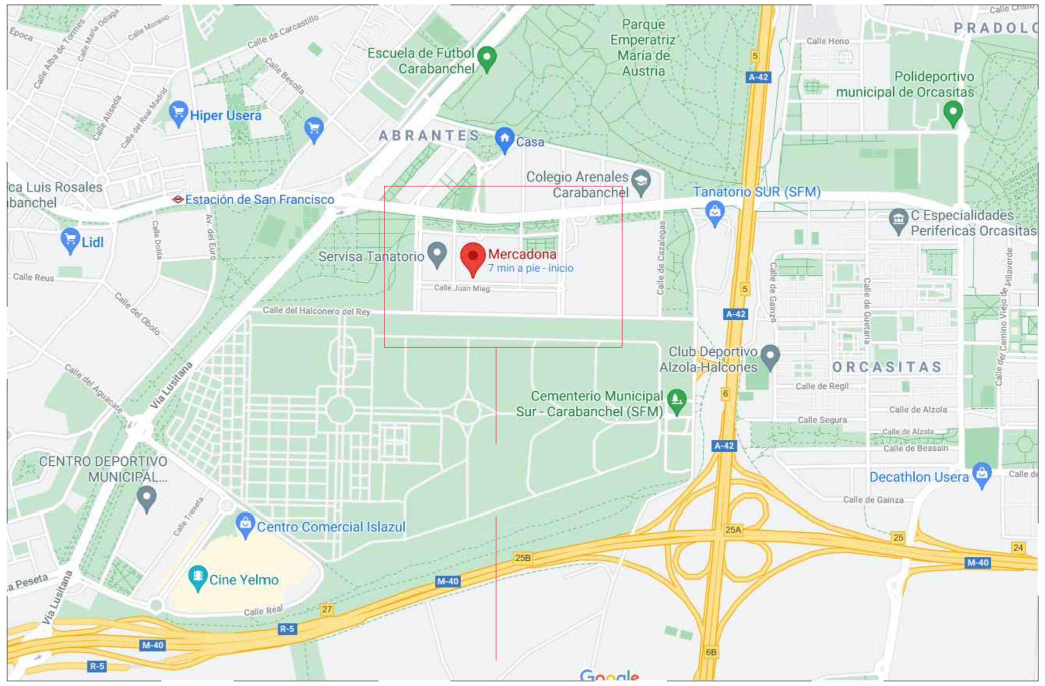
Figure B.9. PVSyst simulation case 2, page 4

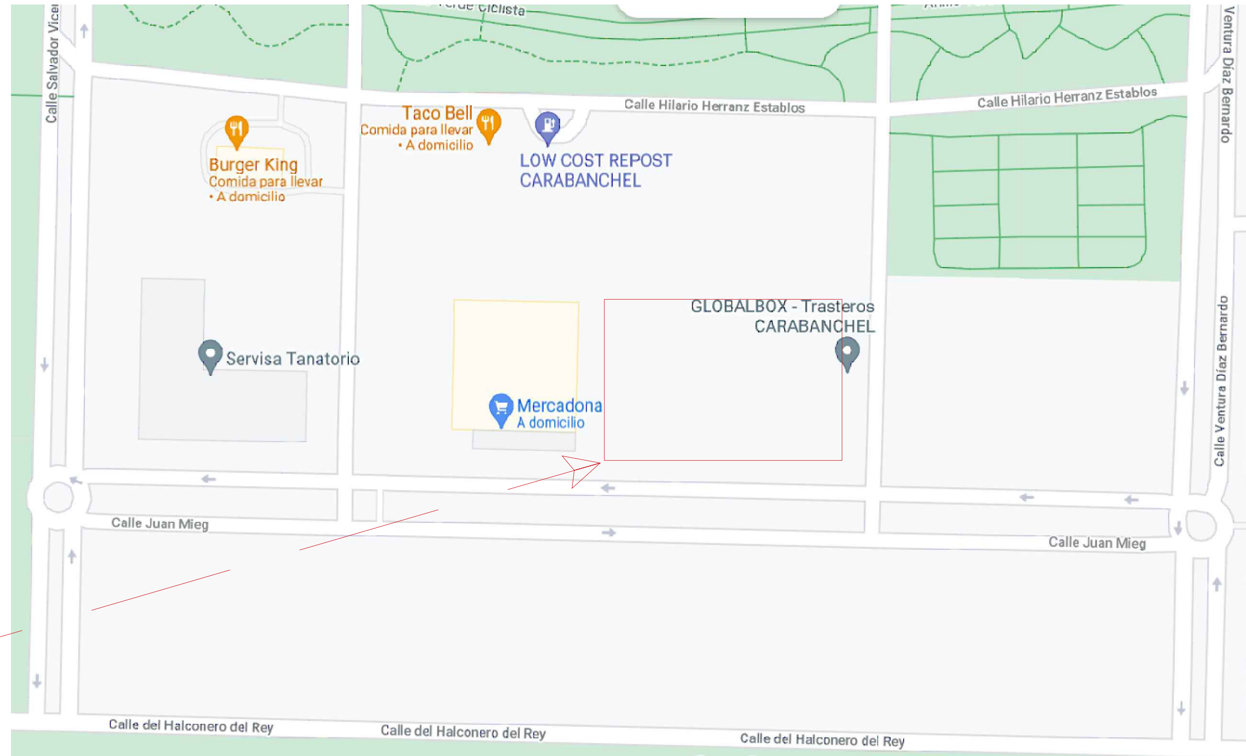
ANNEX C. PLANS

This annex shows the location of the installation, the layout, the distribution of the solar panels on the canopies and the single-line diagrams of the installation.

The plans will follow the following order:

1. LOCATION: general view of the chosen placement
2. LAYOUT: the layout of the chosen installation.
3. PANEL DISPLAY AND STRING ARRANGEMENT: the panels and four canopies are displayed. The distribution of the modules is explained in the drawing, and the number of strings is represented in colours. Each color represents a string of 16 panels:
    - Colours blue, yellow and red correspond to the different strings that inverters 1 and 3 will be connected to.
    - Colours grey, dark blue and black correspond to the strings that inverters 2 and 4 will be connected to.
4. SINGLE LINE DIAGRAM FOR CASE 1
5. SINGLE LINE DIAGRAM FOR CASE 2
6. SINGLE LINE DIAGRAM FROM PANELS TO INVERTER.





REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT: Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION: LOCALIZATION OF THE EV CHARGING STATION

NUMBER OF DRAWING: 1

	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE: S/E

OF01

A3
420 mm x 297 mm

REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT

Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION

LAYOUT OF THE FACILITY

NUMBER OF DRAWING

1

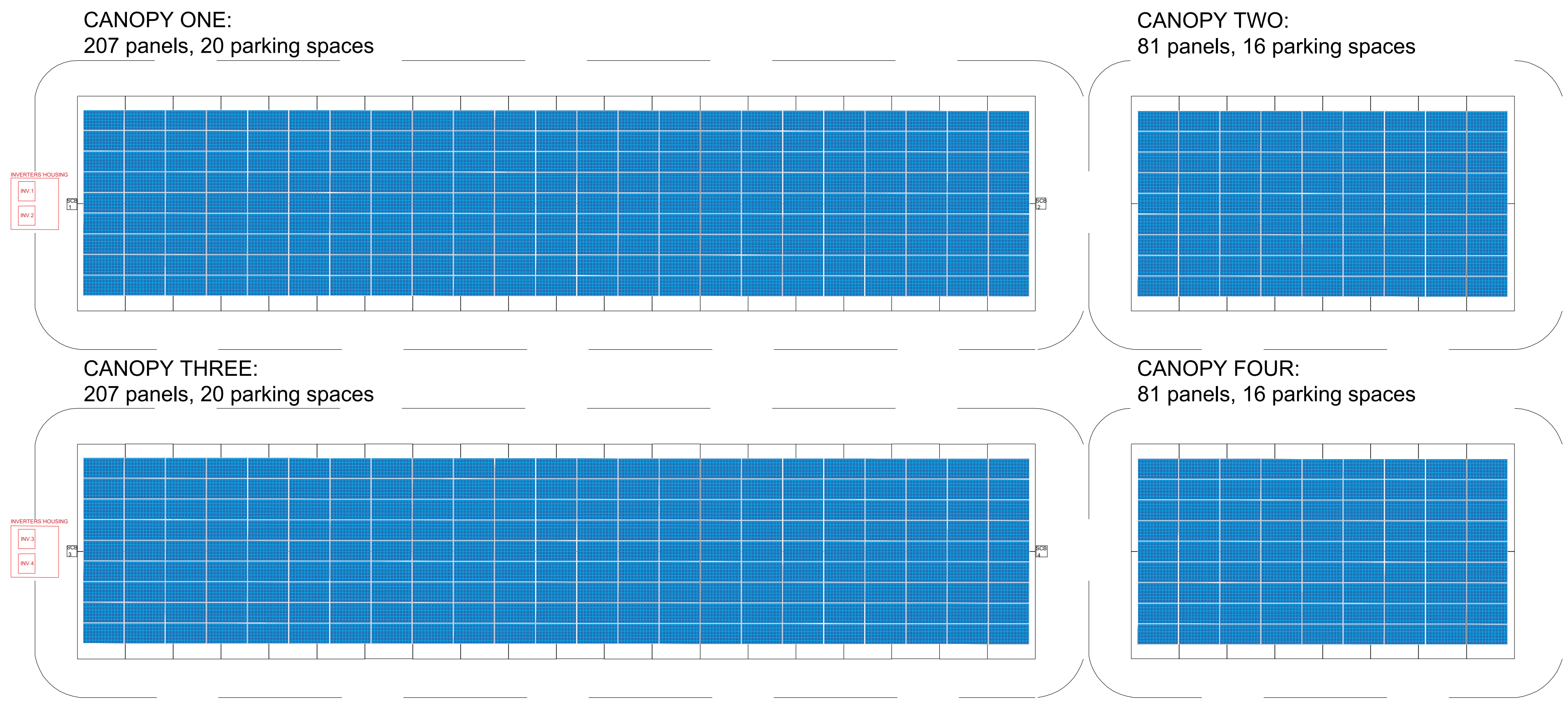
	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE: S/E

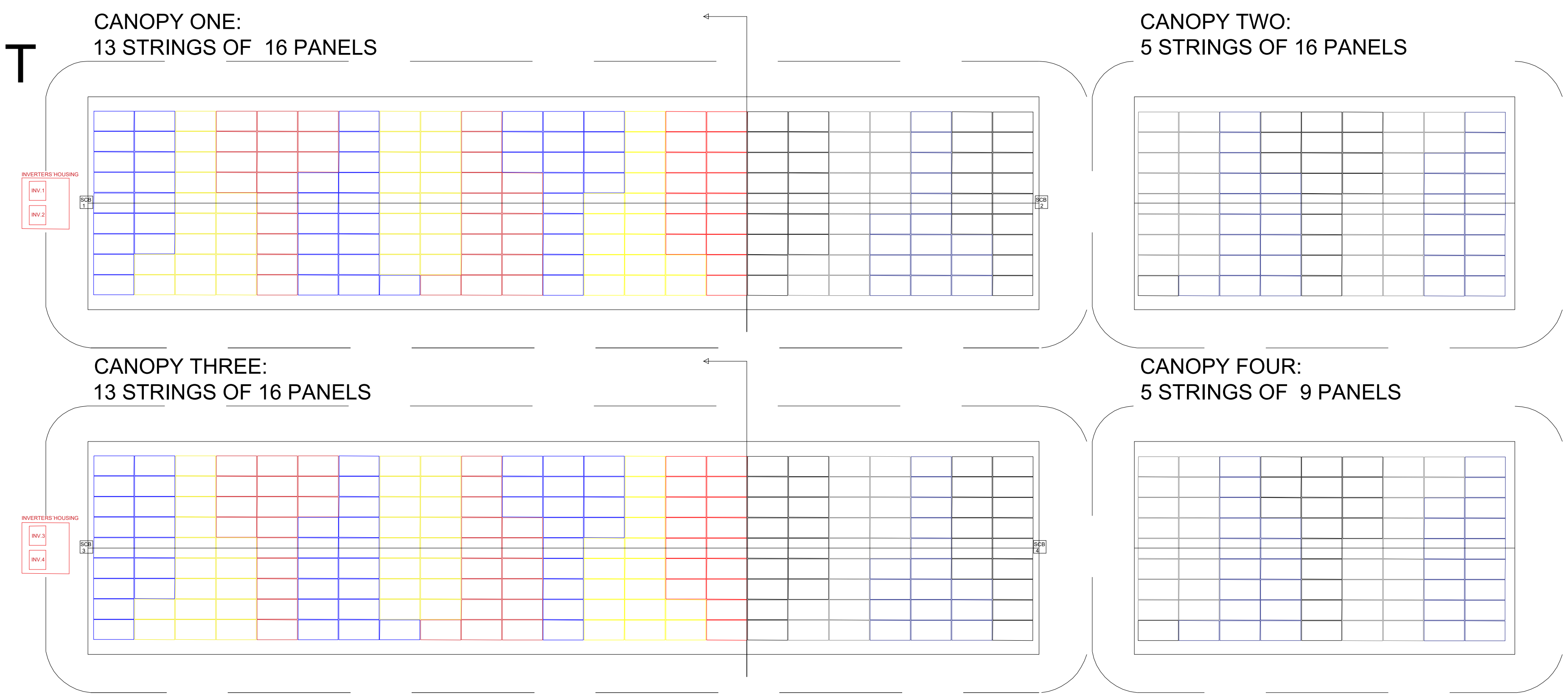
OF01

A3
420 mm x 297 mm

PANEL DISPLAY



STRING ARRANGEMENT



REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT: Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION: PANEL DISPLAY AND STRING ARRANGEMENT

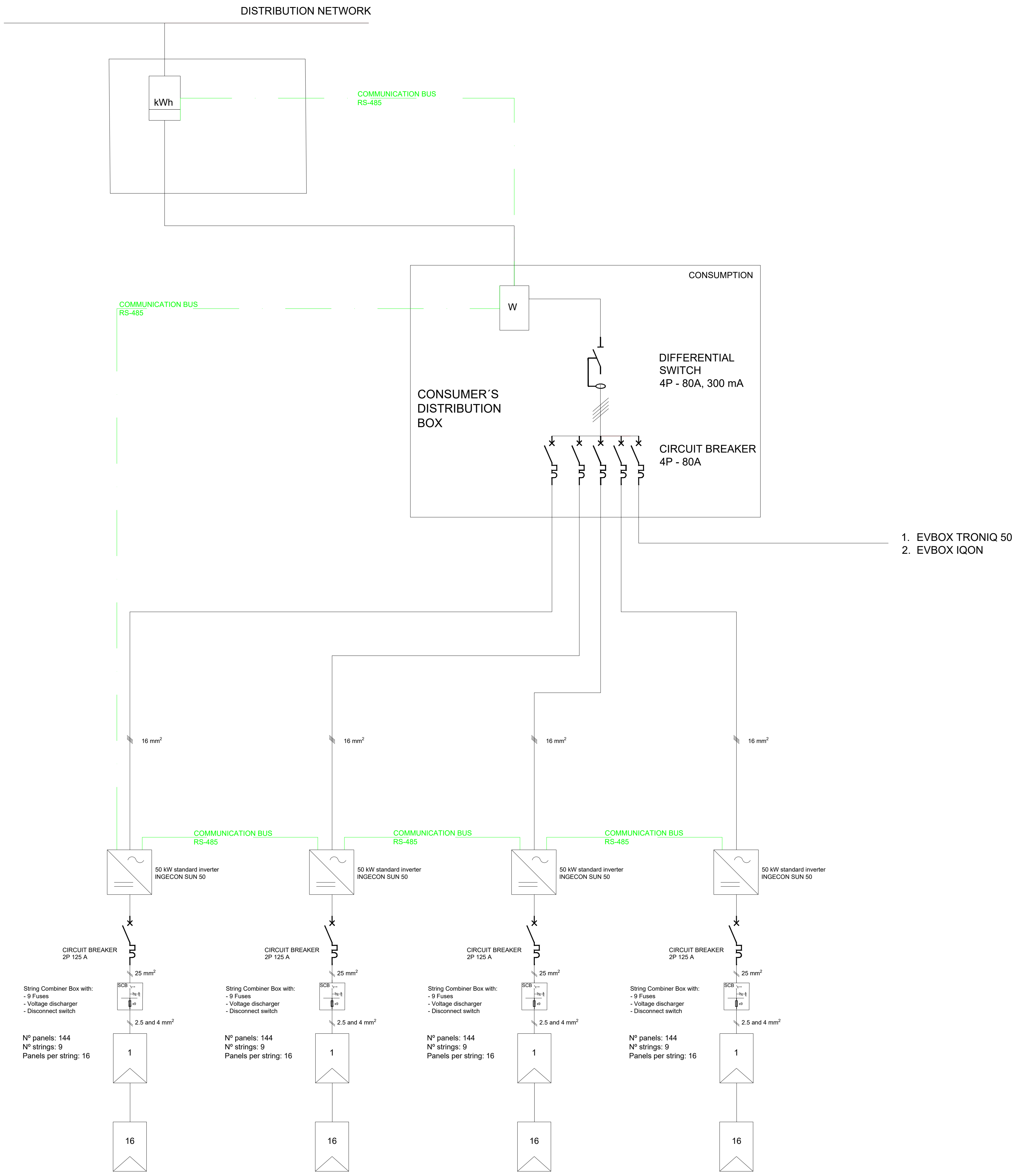
NUMBER OF DRAWING: 3

	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE: S/E

OF01

A3
420 mm x 297 mm



REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT: Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION: UNIFILAR SCHEME CASE 1

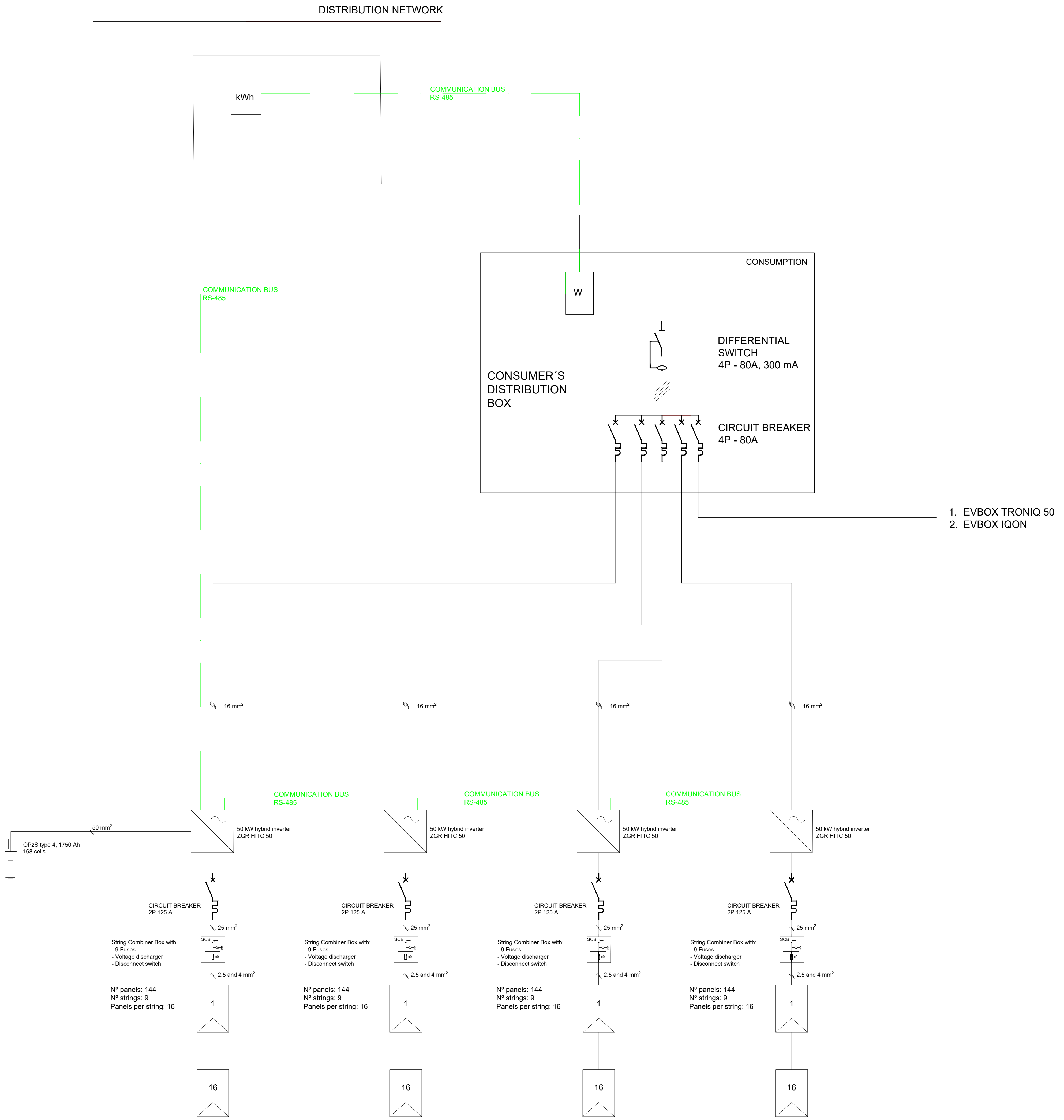
NUMBER OF DRAWING: 4

	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE: S/E

OF01

A3
420 mm x 297 mm



REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT
Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION
UNIFILAR SCHEME - CASE 2

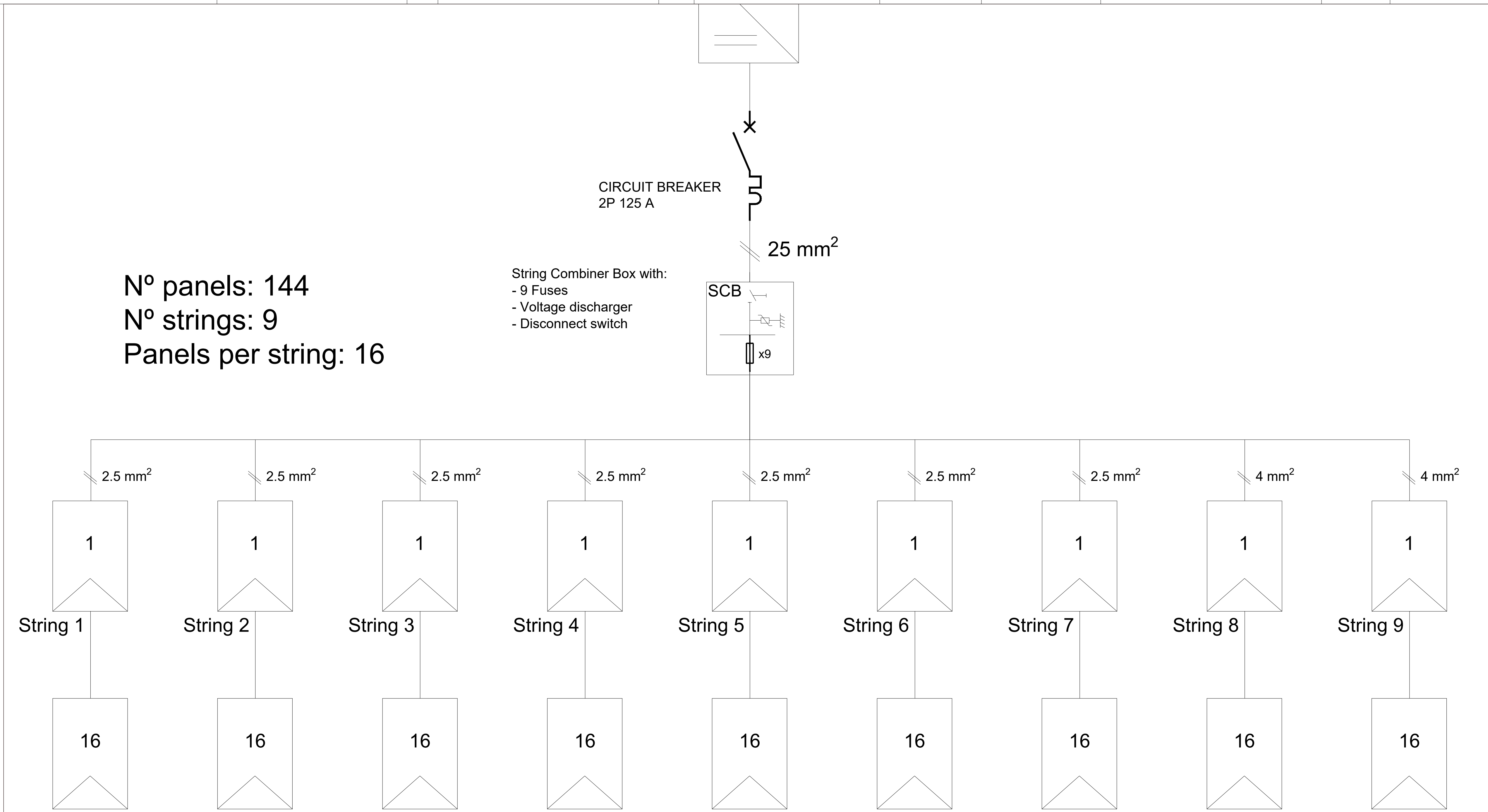
NUMBER OF DRAWING
5

	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE:
S/E

OF01

A3
420 mm x 297 mm



REV.	NUMBER OF DRAWING	DRAWING

COMPANY:

CLIENT:

PROJECT
Electric Vehicle Charging through a photovoltaic car park connected to the grid

DESIGNATION
UNIFILAR SCHEME - MODULE ARRANGEMENT

NUMBER OF DRAWING
6

	DRAWING	REVISADO	ACCEPTED	CUSTOMER ACCEPTANCE
DATE	21/04/2021	07/05/2021		
NAME	Natalia Gutiérrez	Natalia Gutiérrez		

SCALE: S/E

OF01

A3
420 mm x 297 mm