UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Industrial Engineering

# Study of the potential for the implementation of photovoltaic systems on facades and roofs at the Universitat Politècnica de Valencia.

Master's Thesis

Master's Degree in Energy Technologies for Sustainable Development

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# RESUMEN

A lo largo de los años, y más expresamente en la actualidad, se está realizando la transición hacia el uso de energías renovables en sustitución de los combustibles fósiles. Los sistemas fotovoltaicos se incluyen dentro de los medios para obtener esta energía renovable.

El presente TFM incluye el diseño de un sistema fotovoltaico en todo el campus de Vera de la UPV con el que se intenta cubrir el mayor porcentaje posible de demanda energética. Para la implementación de los módulos se van a utilizar las cubiertas de los edificios permitiendo paneles fotovoltaicos con una inclinación determinada que optimice la generación de energía y, como complemento, se va a utilizar sistemas fotovoltaicos integrados en las fachadas este, oeste y sur de los edificios.

Se ha realizado una revisión del estado del arte mediante el cual se observa la tecnología disponible en la actualidad, y cuáles son los principales desafíos que los paneles fotovoltaicos integrados en fachadas presentan. Una vez terminado, se pasa a la parte de diseño y simulaciones donde se calcula y diseña todo lo relacionado con las características de los paneles: la orientación, el número, el modelo, el tamaño, disposición, inversor, entre otros. Por otro lado, se suprime el uso de las fachadas orientadas hacia el norte debido, como se ve en el trabajo, a que son las menos eficientes. Todas las simulaciones del sistema fotovoltaico se realizan mediante el uso del software “SAM”.

Se han desarrollado dos escenarios energéticos para el sistema, el primero consiste en simular el uso de cubiertas y fachadas con tres orientaciones diferentes, con una potencia instalada total de 15 MW, divididas entre 6.3 MW en las cubiertas, 2.58 MW en las fachadas este, 3.46 en las fachadas sur y 2.68 en las fachadas oeste. En este escenario, se ha llevado a cabo un estudio de sensibilidad económica, variando los precios de venta de energía del OMIP según la proyección futura. El modelo elegido como el más representativo propone una disminución en el precio de venta de energía según la tendencia del OMIP, pasando de los actuales 91.15 €/MWh a 42.95 €/MWh proyectado para 2032 y hasta 2047. En este contexto, la inversión inicial asciende a 13,101,523.32 €, con un período de retorno de 5.8 años y una tasa interna de retorno del 5.71%. El segundo escenario corresponde al modelo de tendencia económica obtenido previamente, simulando el sistema y excluyendo las fachadas Oeste debido a su baja eficiencia energética. En este caso, la inversión inicial se reduce a 10,801,691.15 €, con un período de retorno de 4.9 años y una tasa interna de retorno del 14.41%.

Finalmente, después de completar el modelo total en "SAM", se lleva a cabo un análisis del estudio de reducción de emisiones de CO2 en ambos escenarios, así como el presupuesto específico del sistema y de la investigación del trabajo.

**Palabras Clave:** Energías renovables; emisiones de CO2; fotovoltaica en fachada; ventilación natural; viabilidad económica; descarbonización.

# RESUM

Al llarg dels anys, i més expressament en l'actualitat, s'està realitzant la transició cap a l'ús d'energies renovables en substitució dels combustibles fòssils. Els sistemes fotovoltaics s'inclouen dins dels mitjans per a obtenir aquesta energia renovable.

El present TFM inclou el disseny d'un sistema fotovoltaic en tot el campus de Vera de la UPV amb el qual s'intenta cobrir el major percentatge possible de demanda energètica. Per a la implementació dels mòduls s'utilitzaran les cobertes dels edificis permetent panells fotovoltaics amb una inclinació determinada que optimitzi la generació d'energia i, com a complement, s'utilitzarà sistemes fotovoltaics integrats en les façanes aquest, oest i sud dels edificis.

S'ha realitzat un una revisió de l'estat de l'art mitjançant el qual s'observa la tecnologia disponible en l'actualitat, i quins són els principals desafiaments que els panells fotovoltaics integrats en façanes presenten. Una vegada acabat, es passa a la part de disseny i simulacions on es calcula i dissenya tot el relacionat amb les característiques dels panells: l'orientació, el número, el model, la grandària, disposició, inversor, entre altres. D'altra banda, se suprimeix l'ús de les façanes orientades cap al nord degut, com es veu en el treball, al fet que són les menys eficients. Totes les simulacions del sistema fotovoltaic es realitzen mitjançant l'ús del programari "SAM".

S'han desenvolupat dos escenaris energètics per al sistema, el primer consisteix a simular l'ús de cobertes i façanes amb tres orientacions diferents, amb una potència instal·lada total de 15 MW. En aquest escenari, s'ha dut a terme un estudi de sensibilitat econòmica, variant els preus de venda d'energia del OMIP segons la projecció futura. El model triat com el més representatiu proposa una disminució en el preu de venda d'energia del OMIP, passant dels actuals 91.15 €/MWh a 42.95 €/MWh projectat per a 2032 i fins a 2047. En aquest context, la inversió inicial ascendeix a 13,101,523.32 €, amb un període de retorn de 5.8 anys i una taxa interna de retorn del 5.71%. El segon escenari correspon al model de tendència econòmica obtingut prèviament, simulant el sistema i excloent les façanes Oest a causa de la seva baixa eficiència energètica. En aquest cas, la inversió inicial es redueix a 10,801,691.15 €, amb un període de retorn de 4.9 anys i una taxa interna de retorn del 14.41%.

Finalment, després de completar el model total en "SAM", es duu a terme una anàlisi de l'estudi de reducció d'emissions de $CO_2$ en tots dos escenaris, així com el pressupost específic del sistema i de la recerca del treball.

**Paraules clau:** Energies renovables; emissions de CO2; fotovoltaica en façana; ventilació natural; viabilitat econòmica; descarbonització.

# ABSTRACT

Over the years, and more specifically nowadays, the transition towards the use of renewable energies to replace fossil fuels is taking place. Photovoltaic systems are included among the means to obtain this renewable energy.

This TFM includes the design of a photovoltaic system throughout the Vera campus of the UPV with which it is intended to cover the highest possible percentage of energy demand. For the implementation of the modules, the roofs of the buildings will be used allowing photovoltaic panels with a certain inclination to optimize energy generation and, as a complement, integrated photovoltaic systems will be used on the east, west and south facades of the buildings.

A review of the state of the art has been carried out to see what technology is currently available, and what are the main challenges that facade-integrated photovoltaic panels present. Once finished, we move on to the design and simulations part where everything related to the characteristics of the panels is calculated and designed: orientation, number, model, size, layout, inverter, among others. On the other hand, the use of north-facing facades is eliminated because, as seen in the work, they are the least efficient. All simulations of the photovoltaic system are carried out using the "SAM" software.

Two energy scenarios have been developed for the system, the first one consists of simulating the use of roofs and facades with three different orientations, with a total installed power of 15 MW, divided between 6.3 MW on the roofs, 2.58 MW on the east facades, 3.46 on the south facades and 2.68 on the west facades. In this scenario, an economic sensitivity study has been carried out, varying the OMIP energy sales prices according to the future projection. The model chosen as the most representative one proposes a decrease in the energy selling price according to the OMIP trend, from the current 91.15 €/MWh to 42.95 €/MWh projected for 2032 and until 2047. In this context, the initial investment amounts to 13,101,523.32 €, with a payback period of 5.8 years and an internal rate of return of 5.71%. The second scenario corresponds to the economic trend model obtained previously, simulating the system and excluding the West facades due to their low energy efficiency. In this case, the initial investment is reduced to 10,801,691.15 €, with a payback period of 4.9 years and an internal rate of return of 14.41%.

Finally, after completing the total model in "SAM", an analysis of the $CO_2$ emission reduction study in both scenarios is carried out, as well as the specific budget of the system and the research work.

**Keywords:** Renewable energies; $CO_2$ emissions; façade photovoltaics; natural-air ventilation; economic feasibility; decarbonization.

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# PORTADA DE LA MEMORIA

# CHAPTER 1. INTRODUCTION

## 1.1. OBJECTIVE

The objective of this project is to design an installation of photovoltaic using the rooftops and façades of the UPV's buildings, estimate the potential power available and analyze its economic viability. Therefore, a visual and analytic analyses are made in the façades to obtain the available surface to place modules that corresponds with its dimensions and are provided of enough sun radiation. For the case of the rooftops, the information is extracted from a previous UPV project [1] in which there is already a complex study of the PV viability on the rooftops at the UPV. Once the surface data is recollected, simulations using the software "System Advisor Model (SAM)" take place to obtain the plant's production. These simulations are conducted of the 3 most profitable façades, East, South and West, and the rooftops, not considering the North façades due to the lack profitability in terms of energy production/cost. Further on, energy and economic analysis are performed in which is observed the panels production, the daily profiles of electricity, the energy leveraged for the University demand and the amount of energy sold to the grid, the system profitability, the payback period using the current University electricity contract and some variability of how the profitability would change in case of new electricity prices.

This study aims for the installation of the PV plant at the University, facilitating the plans of the buildings installation and providing a complete budget including the modules, inverters, installation, mounting system, operation and maintenance, etc.

## 1.2. EL PLAN NACIONAL INTEGRADO DE ENERGÍA Y CLIMA 2021-2030 (PNIEC)

El Plan Nacional Integrado de Energía y Clima 2021-2030 (PNIEC), translated as the Integrated National Energy and Climate Plan 2021-2030, is a strategic framework developed by the Spanish government to address the challenges of climate change and transition towards a sustainable, low-carbon energy system. Here is an explanation and summary of some of its key aspects:

- **Objectives:**

The PNIEC outlines Spain's energy and climate objectives for the period 2021-2030, aligning with European Union targets and commitments under the Paris Agreement. The primary goals include reducing greenhouse gas emissions, increasing the share of renewable energy, enhancing energy efficiency, and promoting a just and inclusive energy transition.

- **Greenhouse Gas Emission Reduction:**

The plan sets ambitious targets for reducing greenhouse gas emissions. Spain aims to achieve a 20% reduction in emissions by 2030 compared to 1990 levels. This reduction is a crucial contribution to the overall EU objective of becoming climate-neutral by 2050.

- **Renewable Energy Targets:**

A significant focus of the PNIEC is the promotion of renewable energy sources. Spain aims to achieve a 42% share of renewable energy in its final energy consumption by 2030. This involves increasing the capacity of renewable energy installations, such as wind and solar power, and promoting energy self-consumption.

- **Energy Efficiency:**

The plan emphasizes the importance of energy efficiency measures across various sectors, including industry, transport, and buildings. Specific targets for improving energy efficiency are outlined, contributing to a more sustainable and resource-efficient economy.

- **Electrification of Economy:**

There is a strong focus on electrifying various sectors of the economy, such as transportation and heating, to reduce reliance on fossil fuels. This involves increasing the capacity of renewable electricity generation and expanding electric vehicle infrastructure.

This project aims for the sustainable transition of energy production, it is included inside the objective of 42% of renewable energy and

### 1.3. PRESENT SITUATION

The photovoltaic installations are a topic that is already present at the UPV. Although this project aims for the analysis of a PV plant that contains every building available in the University, there are some buildings that have already some small systems producing electricity. Those are [2]:

| Units: kW-h | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|
| **ETSID Plant 1** | 8,386.00 | 7,789.00 | 8,411.00 | 8,529.00 |
| **ETSID Plant 2** | 4,364.00 | 4,639.90 | 4,671.70 | 4,726.00 |
| **Nexus Plant (c-Si)** | 2,216.00 | 3,053.80 | 2,522.20 | 2,196.00 |
| **Nexus Plant (a-Si)** | 1,394.00 | 1,519.70 | 1,429.30 | 1,481.00 |
| **Nexus Plant 3** | 613.30 | 1,348.70 | 1,289.00 | 1,331.00 |
| **LabDER Plant** | 1,920.00 | 2,108.00 | 1,632.00 | 2,995.00 |
| **TOTAL** | **18,893.3** | **22,476.1** | **21,973.2** | **23,277** |

*Table 1. UPV's electricity production by PV Plants from 2016-2019* [3]

- Amporphous-Silica (A-Si) photovoltaic plant of 3.3 kW on the ETSID: Built in 2010, this installation contains 64 modules EPV52 connected to an inverter Danfoss ULX3600 HV, produce electricity that is introduced to the University grid.

- A 5 kWp installation formed by 1 kWp of Amorphous-Silica (A-Si) modules and 4 kWp of Amorphous crystalline connected to the University electric grid by one inverter GW3000D-NS of Goodwe, three inverters SB700, SB1200 and SB4000TL of SMA and microinverters of PowerOne.
- A small installation in the Rural Engineering laboratory department composed of modules of 45 W, a charge regulator PWM, 12 Volts batteries and an inverter of sinusoidal output. This plant supplies a submerged pump of 12 V/100 W.
- A 2.2 kWp plant installed in the LabDER laboratory belonging to the Energy Engineering Institute to supply the electricity demand of the laboratory and for research purposes.

In Table 1 it is shown the University photovoltaic production from 2016 to 2019. The year with the biggest production was the 2019 amounting of 23,277 kWh which represents a 0.05% of the total UPV's consumption, revealing the need for new photovoltaic installations.

## 1.4. JUSTIFICATION

The high electricity consumption of the UPV, added to the recent rises in the electricity prices and the reduction of the PV panels costs, have developed an optimal scenario for the installation of photovoltaics. Moreover, the challenge of transforming the World into a greener place where less $CO_2$ emissions are expelled to the atmosphere is something that must be in a high level of consideration thus, to create a culture of decarbonization in the population, the reference institutions need to give example and show the path to follow to other institutions to join the challenge. The UPV is one of the most honored Universities in Spain, accommodating approximately 28,000 students which a percentage of them, 12% comes from the Erasmus students exchange program, providing a remarkable opportunity to be a reference institution, not only in Spain but in Europe.

The implementation of the installation would provide as many benefits as in both the economic and energy sides, giving the University a higher level of self-sufficiency and independence from the grid as well as a reduction in the electricity cost, making the system profitable in just a few years after its installation. For this reason, it is important to establish the two systems, façades and rooftops, and its coordination, including the optimal surfaces where to introduce the panels, so in the future, in case the project is drove to reality the analysis would be already done.

## 1.5. ELECTRICITY DEMAND

To design the system, it is necessary to analyze the University demand and adjust the system parameters on duty of it. From the 2022 demand there is only data of the monthly consumption (Table 2), but there is not data of the hourly demand.

As can be seen in the Table 2 the months with higher demand are the central months, from May to September, when the hot temperatures of summer demand cooling inside the buildings. There is an exception in August which contrary to the trend, is the month with the lowest consumption, because the University closes and only few departments are still working. During the winter months, the electricity load decreases in comparison to the warm months due to the presence of a gas boiler that provides the heating demand for the University, not being reflected on the electricity demand.

| Month | Consumption (MWh) |
|---|---|
| January | 3,185.5 |
| February | 3,010.06 |
| March | 3,312.74 |
| April | 2,720.92 |
| May | 3,299.29 |
| June | 4,209.89 |
| July | 4,406.94 |
| August | 2,545.22 |
| September | 3,967.2 |
| October | 3,099.73 |
| November | 2,816.76 |
| December | 2,769.12 |
| Total | 39,343.36 |

*Table 2. UPV's 2022 monthly electricity consumption (MWh)*

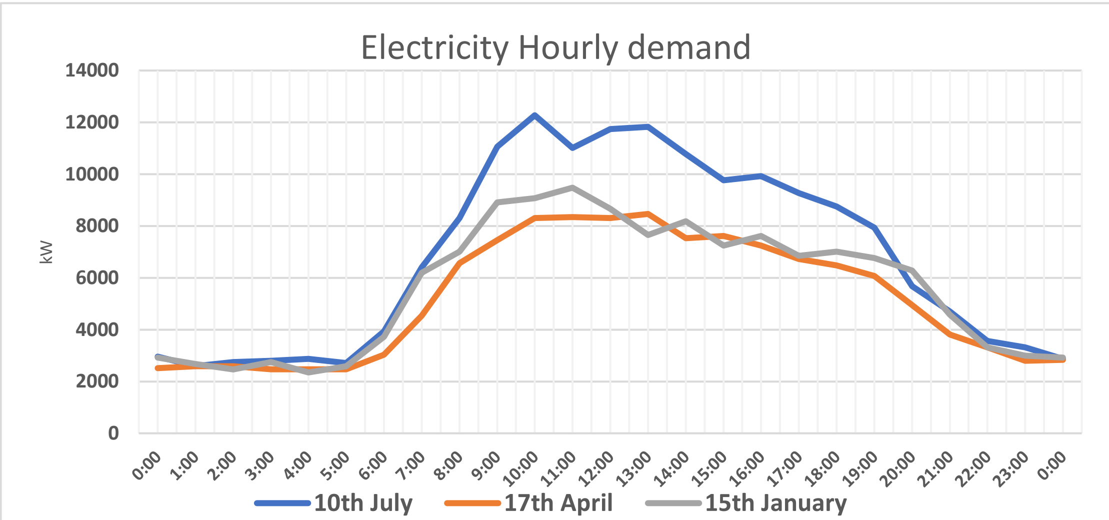



*Figure 1. July 10th, April 17th and January 15th electricity hourly demand*

There is hourly data from previous years but for 2021 and 2020 are considered not significant due to the COVID-19 pandemic and the consequences that supposed to the electricity demand as the university was closed and classes were mostly online. The 2019 hourly demand is taken as base for this project although the data is actualized with the 2022 total demand. The daily demand profiles have been obtained from multiplying the 2019 hourly data times 1.0296, coming from the division of the 2022's total demand by the 2019's total demand. Finally, the daily demand present an identical drawing as the 2019's hourly data while being actualized with the 2022 consumption.

The Figure 1 shows the hourly demand for three significant days distributed all around the year. The form of the three curves is the same and it can be appreciated the following trends:

- At night when the University is closed, the power demand is around 2,500 kW powering devices and systems that need continuous supply.
- The University opens around 05:00-05:30 AM with the first increases in the demand until reaching the peak before noon, from 11:00 to 12:00.
- After the midday, the consumption starts to lower while maintaining high, until 19:00-20:00 hours.
- Finally, at 19:00-20:00 hours, the University and its faculties start to close, producing a pronounced decrease until reaching the 2,500 kW around 22:00 hours.

The divergences between the peak loads come from, as mentioned above, the cooling systems, or from other systems or buildings that require higher amounts of energy, but overall, the demand follows the same trend around the year.

### 1.6. DOCUMENT STRUCTURE

The present project is form by four documents: the report, the budget, the plans and the annexes. The report the is divided by the following chapters:

- Introduction
- Regulation
- Surfaces description
- Programs used
- Methodology
- Tecno-economic analysis of the results
- Conclusions
- Bibliography

### 1.7. LEGISLATION

The plant, as it is shown later in the document, contains 15 MWp as peak power to install, the Spanish regulation stablish differences in normative of the electricity generation plants, relating its installed power. The normative regulating these installations is expressed in different decrees:

- **Real Decreto 413/2014:** One of the fundamental principles assumed by this regulation is that the articulation of the remuneration systems must allow this type of facility to cover the costs necessary to compete in the market on an equal footing with other technologies and to obtain a reasonable return on the project as a whole.
- **Real Decreto 23/2020**: The Government is authorized to establish another remuneration framework as an alternative to the specific remuneration regime. The aforementioned

remuneration framework will be granted through a competitive mechanism in which the variable on which the offer will be based will be the energy remuneration price. The procedures must be oriented towards cost efficiency and may distinguish between different generation technologies based on their technical characteristics, size, manageability levels, location criteria and technological maturity, among others.

- **Real Decreto 1183/2020:** A new, simpler and more transparent framework for access and connection to electricity grids, in a scenario where there is a growing demand for access to electricity grids for generating facilities.
- **Circular 1/2021:** Establishes the methodology and conditions for access and connection to the transmission and distribution networks of electricity production facilities.

## 1.8. DESCRIPTION OF THE CAMPUS

The UPV Campus is located in Valencia, Spain with Geo referential coordinates of latitude and longitude at: +39° 28' 56.53", -0° 20' 36.88" / 39.482369, -0.343578.
The Campus contains 98 buildings distributed in Departments, institutes and research centers, besides sports centers, including gyms, one pavilion and other centers of maintenance. Almost every building have flat rooftop, opening an opportunity to place PV panels in the optimal orientation and with the most profitable slope angle.


*Figure 2. 2D scheme of the UPV's Vera campus.*

In case of the façades, the Campus presents zones where there is low space between buildings, especially in the same Institutes, not letting to place as many façade panels as possible for the total surface of the UPV.

In Figure 3 it is shown the rooftop of buildings 5B, 5F, 5H, 5J, 3D, 3H, 2J and 3K among others. This is the most typical rooftop configuration of the UPV's buildings making it ideal for placing panels optimizing its efficiency.

*Figure 3. UPV's buildings most common rooftops.*

The facades of the buildings contain in most of the cases windows, doors and other elements where panels cannot be placed. Figure 4 contains the facade representation of the buildings 3C and 3B, differentiating various high levels with rows of windows for each one and free surfaces available for modules between.

*Figure 4. Facades representation of buildings 3C and 3B.*

Another example, in Figure 5 representing building 7F, it can be seen the same pattern of windows for each high level, while there is more surface available in this case as the windows are smaller. Here can be seen also, that in the East facade there are some platforms as terraces where impossibilities the modules.

*Figure 5. Facades representation of buildings 7F.*

### 1.9. CAMPUS BUILDINGS ORIENTATION

The Campus buildings are not perfectly oriented with the Cardinal Points, every building present a positive rotation of 20°, that means the North, East, South and West façades are orientated to 20°, 110°, 200° and 290° respectively. The effect of this rotation is shown later in the results analysis but primarily produces the disparity of Sun hours between the East and South façades and the non-optimal orientation for the South façade, reducing the electricity generation on the façades system. The Rooftops panels are affected by this rotation, as in order to maximize the number of panels its orientation must match the orientation of the building and are also oriented facing 200° South-West. In Figure 2 it is shown the Campus scheme with a compass on the left high side of the image, representing visually this disparity between buildings and the cardinal orientations.

# CHAPTER 2. FAÇADES PHOTOVOLTAIC TECHNOLOGIES

## 2.1. ¿WHY USING FAÇADES FOR PV PANELS?

As numerous studies have indicated, optimal energy production from photovoltaic (PV) panels is achieved through specific panel orientations, depending on the hemisphere, and adjusting the tilt angle to modulate the amount of solar radiation reaching the modules. Conventionally, it is acknowledged that the ideal tilt angle approximates the latitude of the installation site, thereby necessitating different tilt angles for various geographic locations [4].

However, notwithstanding the aforementioned considerations, there exist compelling advantages that justify the utilization of PV modules on building façades, including spatial constraints, reduced maintenance requirements, and mitigated losses due to soiling. Notably, the allocation of space for PV panels within buildings is often restricted, with rooftops frequently lacking the sufficient area to meet a substantial portion of the electricity demand. Façades, conversely, offer larger surface areas for solar panel deployment in comparison to roofs. Moreover, taller buildings present even greater façade surfaces for potential PV integration [5]

The study conducted in [6], simulations were conducted with horizontal axis tracking for every façade orientation. The highest recorded renewable energy production was 417.68 kWh/m2, achieved when employing windows and surfaces on the East façade. Additionally, noteworthy results were obtained with 388.4 kWh/m2 of energy generation when utilizing windows and surfaces on both the East and South façades.

In [7] LiDAR data was employed to assess the PV potential of two cases in Lisbon. The results indicated that hourly electricity demand could only be fully met during winter mid-days, considering both façade and rooftop solar potential. However, on an annual basis, PV systems were found to contribute significantly, covering 50-75% of the total electricity demand.

In [8] reported average daily insolation potential in Burgos, Spain, as follows: 2.99 kWh/m2 for South façades, 2.54 kWh/m2 for East façades, 2.39 kWh/m2 for West façades, and 1.23 kWh/m2 for North façades. Cumulatively, the energy collected from all four façades nearly doubled that of a horizontal surface. Moreover, during winter, the south façade received a greater amount of solar energy than the horizontal surface.

[9] demonstrated that natural ventilation for a 7.4 kWp PV façade system in Izmir, Turkey, could increase electricity generation by 2% to 4%. In cases of forced ventilation, electricity gains reached as high as 5.7% with a ventilation rate of 460 l/s.

The software SAM (System Advisor Model) is employed in [10] to evaluate the potential of a vertical photovoltaic façade system on a high-rise building in Malaysia using HIT-Si module with

15.6% of nominal efficiency. The results revealed an energy production between 400-700 MWh from façades system with a payback period of 12 years.

Finally, [11] conducted an analysis of a PV system on a university building in Karachi, Pakistan, exclusively using rooftops. Annually, this system had the potential to generate 5389.2 MWh/year. When considering electricity pricing at 0.05 USD/kWh, a levelized cost of electricity, and a discounted payback period of 11.17 years were determined.

There are two mainly classifications for the PV technologies: building-integrated photovoltaics (BIPV) and building-attached photovoltaics (BAPV).

**BIPV**

BIPV (Building integrated PV) consists of integrating PV technology in the buildings envelope being part of the sloped roofs, flat, roofs, façades and solar shading systems, replacing conventional building materials. BIPV has structural functions and can be considered as an integral part of the energy system of the building [12]. As the BIPV are replacing the building envelope there are specific mechanical and thermal requirements that must achieve.

The efficiency of the solar modules is extremely sensitive with the panel temperature. While the temperature increases, the module efficiency decreases that is why is important to introduce refrigeration methods in the panels. In Figure 6 is presented the scheme of a BIPV system with natural ventilation.

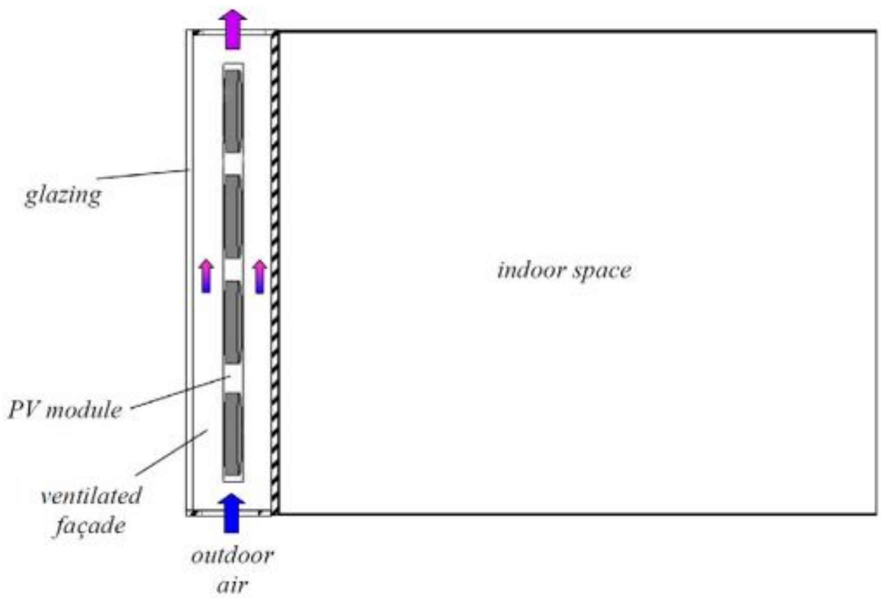



*Figure 6. Scheme of BIPV with natural ventilation.* [13]

**BIPVT**

High temperatures reduce the performance of the modules for producing electricity, thus refrigeration is needed to increase the efficiency and lifetime [13]. In the same process of absorbing heat from the panels, that heat can be used inside the building energy systems to reduce the heating load in winter [16]. The Figure 7 a scheme of how a BIPVT is and works. The benefits of using thermal recovery are:

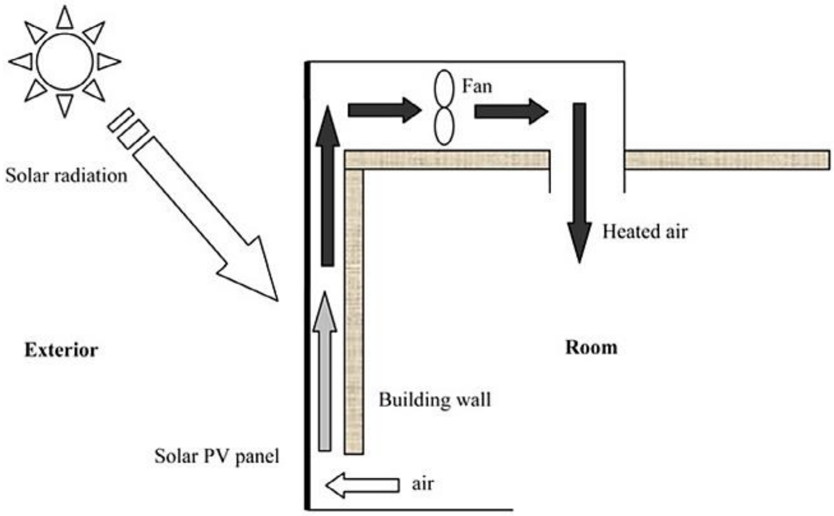



*Figure 7. Scheme of a BIPVT with forced ventilation.* [14]

*Figure 8. Façade of a BIPV installation.* [15]

- As light and thermal energy from the Sun light spectrum use different wavelengths, there are low interferences between the applications that leads in a more profitable use of the solar rays.
- The cost of applying both technologies in one system is lower than if both applications were installed in two different systems.
- As both technologies are applied together, it requires less space than if the systems would be separated.

**BAPV**

BAPV, different from BIPV, the panels are added to the existing building envelope. No wall or component is replaced in the installation hence it is not related with the structure [12]. The main objective of BAPV is to produce electricity and no structural purpose is presented [17].

For the rooftops applications two types of categories can be differenced: Standoff and rack mounted arrays. Standoff arrays adjust to the surface form and inclination, parallel to the envelope, this are common in façades or in tilt rooftops where not additional elements can be placed. Rack mounted arrays are installed in flat roofs and are designed with the optimum orientation and tilt for the application to maximize the energy production [18].

*Figure 9. BAPV façade configuration.* [19]

*Figure 10. Rooftop BAPV* [20]

## 2.2. FAÇADE PHOTOVOLTAICS CHARACTERISTICS

### 2.2.1. OPTIMIZATION OF THE GENERATION – CONSUMPTION

One of the main problems of the PV panels placed on the building's rooftops, as the most common way, is the lack synchronization between the electricity generated by the panel and the consumption that the residential buildings have. Normally, at noon is the moment of the day when buildings have the lowest consumption due to the working activities the families does, this coincides with the maximum production of electricity by the PV panels placed on the rooftops, leading to non-optimized systems as significant amount of electricity generated is not leveraged at the same moment of the production. This problem can be reduced by adding batteries to the system so the energy can be used in the moments of high demand, but the high prices of these elements mean that in most cases a system with batteries is not profitable[21].

The daily load profile for the university shows that the peak power consumption happens approximately at middle morning before noon. At that time rooftops panels have not already reached their maximum production, which coincides between the hours 13:00 and 14:00 of the noon however, East side façade modules are oriented towards the sun at its first hours in the day reaching their maximum production currently coinciding with the maximum load. As the load maintains high until the University starts to close the buildings, happening at around 20:00 hours, the resting façade orientations are the ones responsible for the electricity generation with the South façade reaching its maximum during noon, at the same time as the rooftops panels because those are facing South, and the West façade modules which maximum is reached after noon, later in the afternoon. [21]

In Figure 11 is represented the power generation of two systems, including both North, East, South and West façade panels and rooftops modules. On the one hand, for the winter day the highest production of façades is achieved by the South one in both systems, while for the East and West modules the generation level is lower. On the other hand, at the summer day the trend is reversed, West and East systems produces the majority of the electricity coming from the façades, increasing the generation in comparison to the winter profile, while for the South modules, the peak generation does not align with the rest of façades and in summer decreases its generation. The case of the North façade panels in both days, generate an amount of electricity not even significative in comparison to the rest of façades.

The Figure 11 shows, in the black line how the façades production curve is flatter than the rooftops one, as the peak production of every system is obtained at different moments of the day. For the rooftop modules, the peak generation occurs at noon when the Solar radiation is absorbed more perpendicular in relationship with the tilt angle of the panels.

As it has been seen before, the UPV's demand reaches its peak in the morning, around 11:00 PM and it starts faintly decreasing until close. The combination of both systems, façades and rooftops, would lead to a more aligned consumption-production curve while at the same time, leverage the production of the rooftop plants.

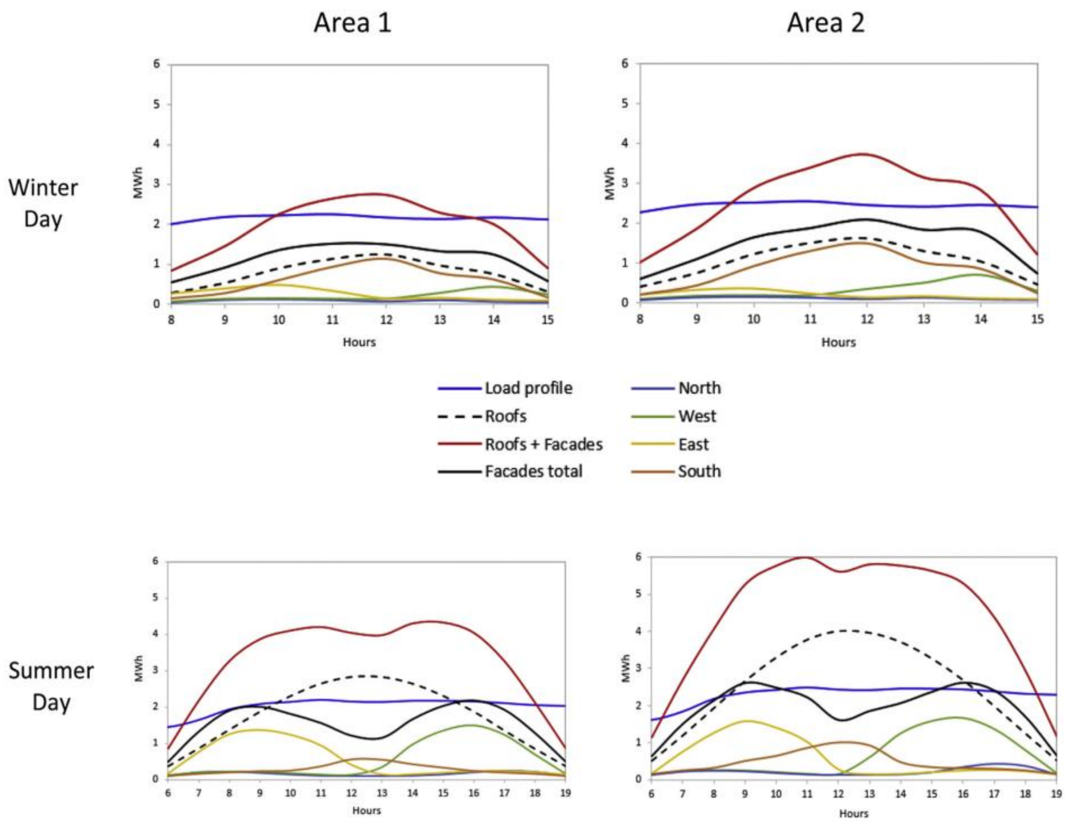



*Figure 11. North, East, South, West façades and rooftops profiles production of two systems for a day in winter and other in summer* [22]

## 2.2.2.BUILDING SURFACE

The use of rooftops of buildings for placing PV panels generate electricity with the most efficient way possible and with the best kWh/m$^2$ ratio within the PV panels technology, as the panels are installed with the optimal angle for maximizing the electricity generation all around the year. However, the capacity installed on the rooftops is often not enough to satisfy the demand of the building and placing more panels could cause structure damage due to the weight including mounting structures, inverters, etc.[23]. Moreover, over dimensioning the installation would generate shadows between modules, reducing the amount of solar radiation received and in consequence the electric production. Commonly for buildings of a considerable height, more than three floors, the surface available for placing PV panels is several times higher in façades rather than in rooftop, this appears as an alternative for increasing the installed power in a building without the need of buying additional area [23]. Even though placing modules in façades means that those are place in vertical position far from the slope optimal angle, thus obtaining less electricity, this lack of production can be compensated with the available surface. As the number of panels placed in façades can be higher, the amount of electricity can be similar to rooftops, however it affects to the efficiency as more panels are needed for obtaining the same production [21].

### 2.2.3.SHADOWS

One of the problems with the sloping PV panels is the interferences produced by the modules in form of shadows. For this reason, prudential separation must be calculated between each panel reducing the number of them that can be placed in a surface. Façade PV panels systems do not generate this disadvantage as the distribution is vertical adjusted to the wall form and do not interfere with the panels in the same plane, allowing a greater number of modules in the same surface [24].

The inconvenient in urban environments of implementing PV, especially in façades is the shadowing produced by all the objects surrounding the building, which can be: other building, trees, billboards, bridges, etc. These interferences reduce the radiation absorbed and the generation, creating the need to develop a shadowing study in the places where the installation is made [24].

In [25] is made an analysis of how panels could be connected to maximize the energy output. The paper studied four panels in different places interconnected in diverse variants. Four interconnections were examined:

a) All PV cells in series.
b) All PV cells in parallel.
c) Two series connected cells (cell 1 & 2 and cell 3 & 4) in parallel.
d) Two series connected cells (cell 1 & 4 and cell 2 & 3) in parallel.

The results showed that the variant of all cells in parallel produced the most amount of energy with 25.6 Wh while for the a), c) and d) systems energy obtained was 20.9 Wh, 24.6 Wh and 23.6 Wh, respectively.

### 2.2.4.AIR GAP AND FLOW RATE

In [26] the experimental analysis of a system with induced ventilation, using minimal fan energy and varying the mass flow rates in the range of 0.03-0.05 kg/s $m^2$ the electrical PV efficiencies went in the range between 10.6% to 12.2%. This paper clearly shows the direct relation between the air mass flow rate for panels ventilation and the efficiencies in the photovoltaic plants, however this also includes an increase in the fan consumption, making necessary to stablish the optimal one for each application.

Valencia presents a high percentage of annual percentage humidity which accentuate the risk of condensation in both the natural ventilated and non-ventilated string [27].

### 2.2.5.FIRE SAFETY

The increase of the number of PV panels used on the rooftops and in the façades of the buildings are related with problems with safety conditions in case of fire. PV panels contain numerous heavy metals in their composition, including silicon, cadmium, and other toxic substances. PV panels are flammable and increase the risk of fire in buildings, moreover, their toxic materials in case of burning can cause more damage to people. For the rooftop installations in case of fire, the toxic gases go directly to the atmosphere and have a low impact on the building windows, nevertheless, façades panels can produce a more significant effect on people installations, as these are being closer to the windows, the toxic gases enter inside the building envelope affecting the air. It is important that the panels used in the façade ensure safety conditions for the people inside and reduce the impact of other problems such as; propagation of the fire to the same and nearby buildings; difficult the firefighters labor causing possible electric discharges; less efficient mitigation of the fire due to the toxic smoke and temperatures [28].

# CHAPTER 3. TOOLS

## 3.1. GOOGLE EARTH

The software application "Google Earth" is a free application that permits to visualize almost every retreat of the World by and image in 3D allowing the rotation, zoom or displacement of the images. The software contains numerous tools for measuring 2D planes, 3D figures, polygons, 3D polygons, etc. The "3D polygon" tool was employed to determine the available surface area on the building façades. Within the 3D representation of UPV, it became feasible to discern areas suitable for photovoltaic (PV) installations while excluding those subjects to shading or possessing unsuitable forms or materials. The "3D polygon" tool facilitated the computation of surface areas on the map by factoring in the dimensions of the buildings, including their length, width, and height. Figure 12 provides a visual depiction of this methodology, which is explained in the next chapter.


*Figure 12. Surface calculation method in Google Earth.*

While it is acknowledged that this method may not be the most precise, and there are inherent uncertainties due to the need for high sensitivity in accurately delineating exact surfaces within the program, it is important to note that the potential gains in precision would not have significantly justified the implementation of a more exhaustive calculation.

### 3.2. SAM

The System Advisor Model (SAM) is a comprehensive, cost-effective software tool designed to support decision-making processes within the renewable energy sector. SAM possesses the capability to model a diverse array of renewable energy systems, including but not limited to:

- Photovoltaic systems, spanning from small-scale residential rooftop installations to large-scale utility-grade systems.
- Battery storage solutions featuring various technologies such as Lithium-ion, lead acid, or flow batteries, suitable for both front-of-meter and behind-the-meter applications.
- Concentrating Solar Power systems intended for electricity generation, encompassing parabolic trough, power tower, and linear Fresnel configurations.
- Industrial process heat generation using parabolic trough and linear Fresnel systems.
- Wind power applications, covering individual turbines and expansive wind farms.
- Marine energy systems utilizing wave and tidal energy sources.
- Solar water heating solutions.
- Fuel cell technology.
- Geothermal power generation systems.
- Biomass combustion for electricity production.
- High concentration photovoltaic systems.

In addition to its system modeling capabilities, SAM offers a range of detailed options for conducting economic analyses. These options encompass factors such as net metering bills, financial rates, inflation rates, index rates, and various electricity contracts with different durations and associated fees, among other parameters. The Figure 13. SAM's chart of the Annual AC energy in year 1 by hours is a chart proportioned by SAM after the simulation, showing the heat map of the energy generation annually.

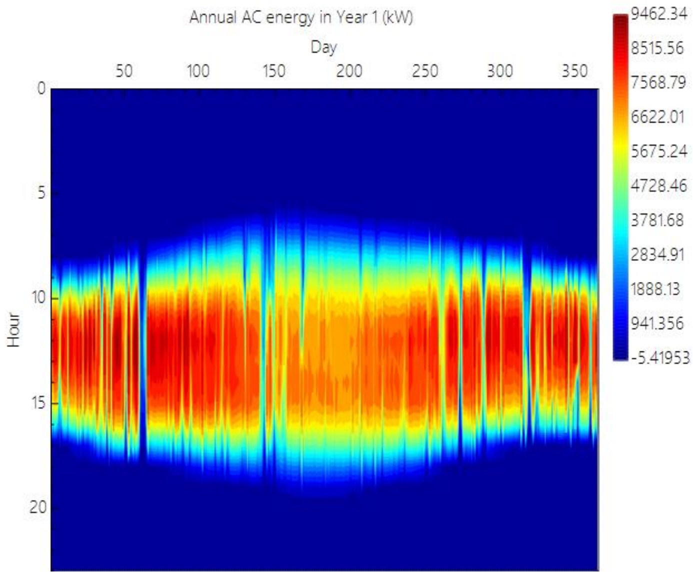



*Figure 13. SAM's chart of the Annual AC energy in year 1 by hours*

Moreover, for this project SAM is used for a shadowing analysis on the facades, to determine the minimum distance between facades and objects that do not affect the energy production (Figure 14).

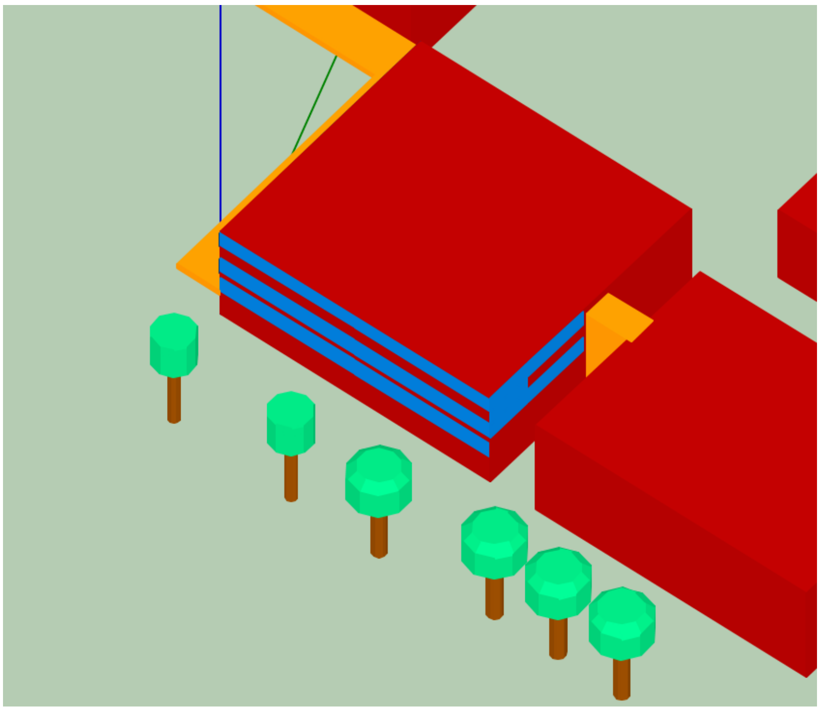


*Figure 14. Shadowing facades analysis in SAM of the 5C building.*

### 3.3. EXCEL

In scientific research, Excel's scientific mode proves essential for data organization, validation, and statistical analysis. Researchers use Excel to efficiently manage data, ensuring accuracy through validation rules. Built-in functions facilitate complex calculations and statistical analyses, aiding in hypothesis testing and trend analysis. The software's graphical visualization features enable researchers to create informative charts and graphs, enhancing data representation. Filtering and sorting functions assist in identifying patterns and outliers crucial for scientific interpretation. Excel also supports collaborative work, allowing multiple researchers to edit and analyze data concurrently. Integration with other scientific tools enhances its versatility, making it a valuable asset in scientific research and data analysis.

Excel has used in this project as a tool for compilating, calculating, organizing and analyzing every part of the study including, the surfaces available, the number of panels, the power installed in each building, the energy results… Every data obtained has been processed through Excel.

# CHAPTER 4. METHODOLOGY

The primary aim of this section is to describe the methodology and steps undertaken in the project to yield the results of the rooftop and façade photovoltaic installation in UPV's Vera Campus, represented schematically in Figure 15.

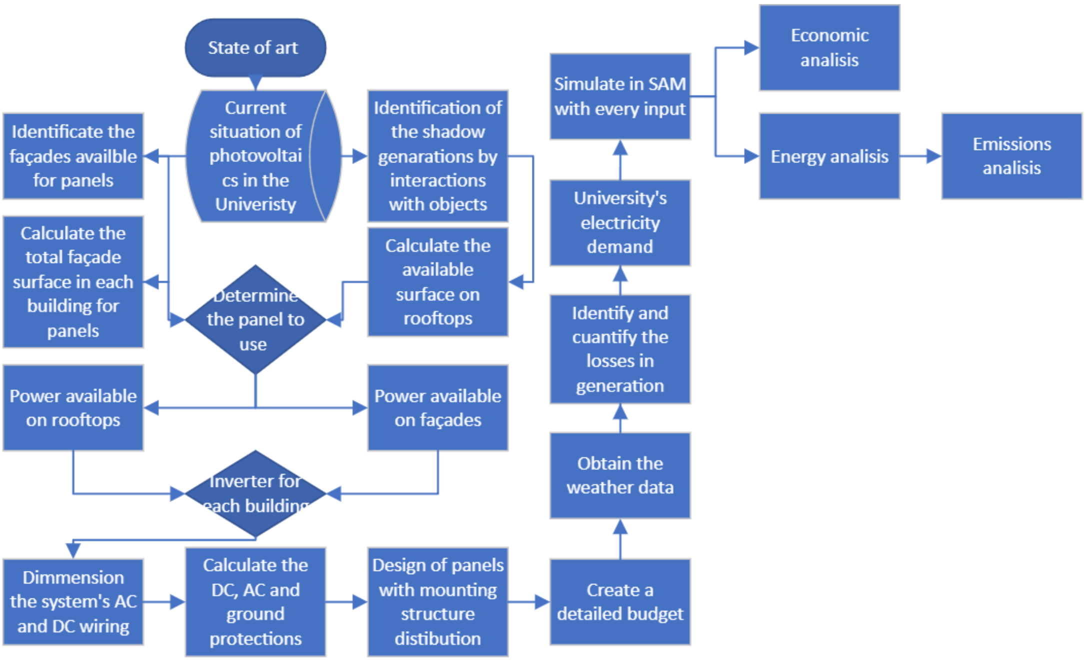



*Figure 15. Flux diagram of the methodology followed in the project.*

First of all, given that north-facing façades, in the northern hemisphere, exhibit lower efficiency compared to other orientations and rooftops, a deliberate decision was made to exclude them from the simulation. Instead, the analysis focused on the East, South, and West façades, along with rooftops.

Initially, the surface area available on the building's façades was computed using Google Earth. This entailed utilizing the 3D map of the University to identify shadow-free surfaces on each building. Portions susceptible to interference from other elements such as neighboring buildings, trees, and fences, leading to shadow casting, were excluded. Additionally, façades with unsuitable shapes or construction materials for PV panel installation were also eliminated from consideration.

For the rooftop PV area, data from a reliable source, specifically [1] was employed, as the calculation process was deemed accurate, and the surface area data remained consistent over the last two years within the University.

Subsequently, a PV module was selected for both façade and rooftop systems. Leveraging knowledge of the panel's area and the available building area, the number of panels required was calculated by dividing these two values.

The subsequent step involved simulating the system using SAM (System Advisor Model), the details of which are elucidated in subsequent sections. Two distinct cases, varying the installed power, were conducted to broaden the project's scope, involving modifications to electricity rates to account for an unusually high electricity contract for the year 2023. The scenarios considered encompassed:

- CASE 1 (PV system leveraging East, South, West façades and rooftops)
    - System with surplus energy under the 2023 energy contract with OMIP price of 91.15€/MWh.
    - System with surplus energy under the 2023 energy contract with OMIP price of 55.8€/MWh.
    - System with surplus energy under an energy contract following market trends until 2032.
- CASE 2 (PV system leveraging East, South façades and rooftops)
    - System with surplus energy under an energy contract following market trends until 2032.

A good number of calculations are required for the correct dimensioning of the installation. In order to stablish a well-rounded, reliable and as much as real as possible budget and viability of the studio, Chapters 5 and 6 are presented. In chapter 5 there is every calculation needed to design the electrical installation dimensioning it for each inverter, starting from the numbers of panels per MPPT, continuing with the distribution of panels per MPPT in every building and finishing with the wiring AC and DC cable section selection and the protections needed with the ground connections. Moreover, in the Chapter 5, there is also the analysis of the weigh loads of the photovoltaic rooftop structures for guaranteeing that the building's rooftops support the weight loads, and the wind loads the plant would apply to them. Leveraging the information obtained from the project so far, there is Chapter 6 where there is the representation of every device selected. Firstly, there is a comparison between four different panel models and the explanation of which panel has been selected, continuing to the inverters selection which each building would require one of a specific capacity. Completing the PV installation there is also, explained the panels structures selection for both facades and rooftops and finally using the calculations of Chapter 5, the models of every electrical device needed is showed.

Finally, a comprehensive analysis encompassing economic and energy aspects was conducted for each scenario in Chapters 7 and 8. Emphasis was placed on evaluating the discounted payback period (in years), return on investment (ROI in percentage), and the percentage of energy utilization which provide the viability of the installation. Moreover, a detailed $CO_2$ emissions study was included to establish the environmental gains.

### 4.1. WEATHER DATA

Valencia, located in the Mediterranean region of eastern Spain at geographic coordinates 39°28′12″N 0°22′35″W, is characterized by a Mediterranean climate. This climate type is known for mild winters and hot summers, typically featuring a limited number of rainy days annually and a significant summer drought. However, precipitation can be intense, particularly during cold fronts in autumn or winter [29].

In SAM, weather data was incorporated using the "ESP_Valencia.082840_IWEC.epw" file from "EnergyPlus" [30]. Table 3 numerically represents the monthly beam irradiance throughout the year. The data shows Max Beam irradiance values ranging between 550-660 DNI (Direct Normal Irradiance) in watts per square meter (W/m2) from October to April, and between 630-800 DNI (W/m2) from May to September. This data supports the assertion that Valencia is an ideal location for photovoltaic (PV) systems, given the ample solar radiation levels.

| Weather Valencia | Max Beam irradiance - DNI (W/m2) | Max Diffuse irradiance - DHI (W/m2) | Max Global irradiance - GHI (W/m2) | Dry bulb temp (°C) | Snow depth (cm) |
|---|---|---|---|---|---|
| **Jan** | 607.07 | 162.00 | 407.32 | 10.30 | 0 |
| **Feb** | 569.90 | 213.90 | 462.10 | 11.30 | 0 |
| **Mar** | 558.32 | 248.13 | 616.03 | 12.81 | 0 |
| **Apr** | 667.74 | 297.81 | 776.48 | 14.92 | 0 |
| **May** | 598.29 | 301.26 | 751.06 | 18.01 | 0 |
| **Jun** | 675.39 | 312.71 | 850.19 | 21.70 | 0 |
| **Jul** | 798.52 | 267.87 | 905.42 | 25.51 | 0 |
| **Aug** | 775.13 | 238.74 | 832.84 | 25.63 | 0 |
| **Sep** | 633.26 | 251.07 | 678.45 | 23.18 | 0 |
| **Oct** | 554.77 | 222.84 | 536.55 | 18.89 | 0 |
| **Nov** | 586.80 | 173.52 | 424.61 | 14.24 | 0 |
| **Dec** | 566.52 | 151.32 | 363.68 | 10.69 | 0 |
| **Total** | 626.72 | 236.82 | 634.53 | 17.30 | 0 |

*Table 3. Monthly mean values of weather data of Valencia.*

### 4.2. SYSTEM AVAILABLE SURFACES CALCULATION

The measurement of the available surface in both systems, façades and rooftop, is key for knowing with precision the full PV potential of the UPV. An especial analysis has been made for each system, explained below:

#### 4.2.1. FAÇADES

Firstly, façade photovoltaics are an alternative for energy production for those cases where there is not or there is not more available surface in rooftops, leveraging areas of the buildings included in the façades that do not have any use without the need of buying new land areas to place sloped panels. However, as was exposed before, apart from producing less energy per kilowatt installed, this production is highly dependent of the façade orientation and research in previous façade photovoltaics installations carried on in the northern hemisphere exposes that the North orientation presents less Sun hours and thereby, less energy production. Because of that factor it was decided to extract the North façades from the project with the objective of improve the economic expectations.

To determine the available surface on the façades for this project, it was used a previous study [31] conducted at UPV regarding the potential of integrating PV panels into the university's façades. However, for this project, an updated and refined calculation of the façade surfaces was conducted. The initial calculation from [31] was meticulously reviewed, corrected, and updated to account for new university buildings and additional surfaces that were not considered in the previous study.


*Figure 16. Façades Surface measurement for building 3N*

The method employed for this revised calculation, as mentioned earlier, involved utilizing the 3D polygon calculator tool in Google Earth. This approach is depicted in Figure 16. It entailed outlining a polygon on the façade, delineating the areas deemed optimal for electricity production, and using this data to determine the available surface for PV panel integration.

It is crucial to emphasize that only surfaces unaffected by shadows have been considered for this project. Several factors were considered in the exclusion of certain surfaces, including:

- **Ground floor level façades:** These were excluded due to potential interferences caused by pedestrian and vehicular traffic.
- **Façades with proximity to trees:** Façades close to trees, related to this fact it is challenging to stablish a detailed criteria by Google Earth, but façades nearer than 10 meters to a tree including the crown could cast shadows and were excluded.
- **Façades with shadows from nearby buildings:** Surfaces with shadows caused by neighboring buildings were also excluded from consideration.
- **Façades unsuitable for installation due to construction materials:** Façades where installation of panels was not feasible due to construction materials, as the façades of the prefabricated building 8H mostly made by insulation materials as mineral wood insulation and building 4P presenting a façade design unable adjunct the panels structure.
- **Windows:** Areas designated as windows were excluded from the calculation.

By excluding these specific areas based on the mentioned criteria, the calculation focused on feasible and optimal surfaces unaffected by shadows for the integration of PV panels.

The process of determining the surface in façades comes in the following steps:

- Identify the free-windows surface and with proper construction materials.
- Measure that in the surface selected, there is space for the panels in vertical or horizontal.
- Extract the surfaces affected by shadows and the ones on ground floor level.

In Figure 17 is shown right side of the South facade of the building 5E obtained from Google Earth with the area in red indicates the surface determined to be placed panels. On the left side of the building 5E, Figure 18, it can be seen that because of the shadows caused by the trees, less surface is considered.

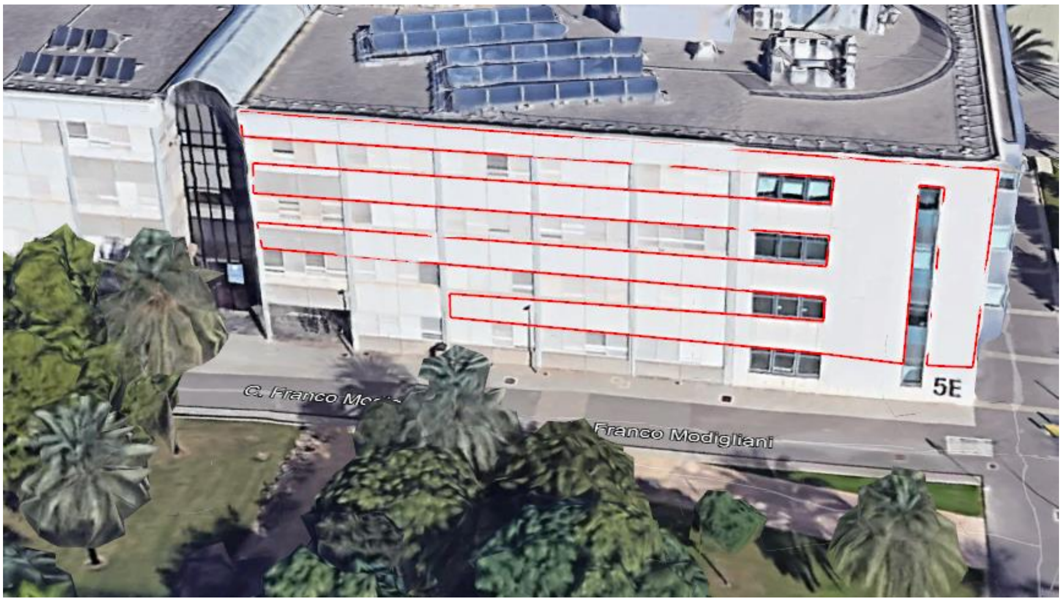



*Figure 17. Building 5E, right side, South facade surface consideration.*

*Figure 18. Building 5E, left side, South facade surface consideration.*

The Figure 19 represents the South facade of the building 4P as one that does not allow to place modules. The combination of the big presence of windows and the lack of a rigid and uniform wall impossibilities the facade structure to support panels. However, this building in its two left orientations have available surface for panels as Figure 20 and Figure 21 show, in this case using only the highest part of the facade considering the nearby buildings causing shadows.

*Figure 19. South facade of the building 4P.*

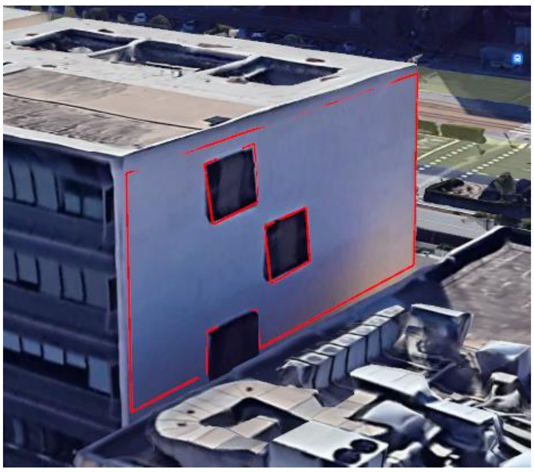


*Figure 20. Building 4P West facade surface consideration.*

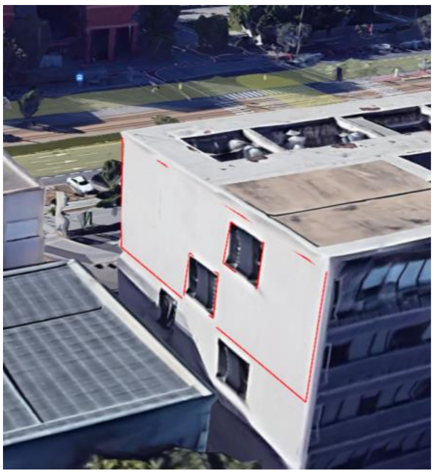


*Figure 21. Building 4P East facade surface consideration*

### 4.2.2. ROOFTOPS

The surface area available on the rooftops of the buildings has been obtained as a reference from [1], a project conducted at UPV that involved a comprehensive analysis of the rooftop photovoltaic potential. This analysis included detailed assessments such as shadow analysis produced by objects, in function of its height and the distance between the object and the panels and optimization of module space. Given the rigorous analysis conducted in [1] for each rooftop also including the optimal slope angle of the panels, this source has been regarded as highly reliable for extracting information regarding the rooftop potential for photovoltaic installations.

## 4.3. ECONOMIC FEASIBILITY AND FINANCIAL PARAMETERS

The inflation rate and market discount rate are crucial parameters influencing financial decision-making. The inflation rate impacts the real value of money over time, while the market discount rate serves as a key determinant in assessing the present value of future cash flows, guiding investment and valuation strategies. Understanding these rates is essential for effective financial planning and risk management.

### 4.3.1. INFLATION RATE

A reliable and stable electricity inflation rate plays a pivotal role in the economic analysis of any region or industry. It serves as a fundamental indicator that influences economic decisions, impacting both businesses and consumers. In this context, electricity cost and its rate of inflation are of paramount significance for various reasons. A low and predictable electricity inflation rate is essential for economic planning, cost estimations, and sustainable growth.


*Figure 22. Spanish electricity inflation rate January 2019-June 2023* [32].

For this case, the inflation has been examined for the past 8 years since January of 2015 to October of 2023 [32], represented in Figure 22. In order to introduce a representative value of the recent years and future trend, assuming the most recent values are exceptional, it has been decided to obtain the mean inflation between January 2019 to the actuality, amounting to 3.07%.

Future inflations for the Spanish electricity market are not precisely expressed, however as the prices would be influenced in any case by the inflation rate of the country, this inflation rate is extrapolated to the electricity field.

### 4.3.2. MARKET DISCOUNT RATE

The market discount rate, often referred to as the "discount factor," is a critical component in economic analysis. It wields immense influence over investment decisions, project evaluations, and fiscal policies. A well-defined and appropriate market discount rate is indispensable for comprehensive economic analyses, and its importance cannot be overstated.

Following the data proportioned by [33] the market interest rate for Spain since 01/06/2023 amounts to 3.64%, however in the past years this value was near 0% or negative until August of 2022 which has led to choose a more conservative number of 2.5%, supposing a slightly decrease in the upcoming months.

## 4.4. ELECTRICITY CONTRACT DETERMINATION

Annually, the University of UPV engages in a competitive auction process with various enterprises for its electricity contract. During this process, the university submits its projected annual electricity consumption, against which electricity providers propose their tariff rates. The contract ultimately selected is the one offering the lowest cost per €/kWh.

The UPV's electricity contract falls under the 6.1 TD Spanish tariff, which is segmented into different pricing periods, contingent upon the month, day, or hour of consumption. The electricity contract comprises two distinct terms: the fixed term, associated with the contracted power, and the variable term, linked to monthly energy consumption.

| - | P1 | P2 | P3 | P4 | P5 | P6 |
|---|---|---|---|---|---|---|
| **Contracted Power Pci (kW)** | 11,830 | 11,830 | 11,830 | 11,830 | 11,830 | 12,121 |
| **Power fee Tpi (€/kW)** | 30.536 | 25.895 | 14.909 | 12.094 | 3.939 | 2.109 |

*Table 4. Contracted power and power fees of the 2023 UPV's electricity contract.*

The fixed term is calculated by multiplying the contracted power by the power rate, yielding an annual cost for this component.

Conversely, the variable term is contingent upon the rates proposed by electricity companies and the prices determined through daily auctions within the Spanish electric system. This component varies based on market conditions and consumption patterns.

To obtain the electricity prices, the following equations are used:

$$TQi = \frac{Ai + Bi \cdot OMIP}{100} \tag{1}$$

The term "Ai" represents the fixed cost components during the specified period, which include payments for capacity, payments to the system operator, payments to the market operator, the tariff access fee mandated by the law IET/107/204, adjustment services, and the retailer's margin. These costs are denominated in cents per euro per kilowatt-hour (cts€/kWh). On the other hand, "Bi" is a regulated factor that is applied to OMIP (Portuguese Market Index for Wholesale Electricity) prices, it accounts for the coefficient of losses in the network and the municipal rate, Table 5 contains these Ai and Bi factor for each period.

| **Tariff 6.1TD** | **Offered coefficients** | | | | | | |
|---|---|---|---|---|---|---|---|
| | - | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** |
| **Coefficients for the OMIP** | **Ai (c€/kWh)** | 4.93 | 4.19 | 3.18 | 2.59 | 1.95 | 2.17 |
| | **Bi** | 1.14 | 1.13 | 1.15 | 1.18 | 1.10 | 1.08 |

*Table 5. Electricity contract Ai and Bi coefficients.*

The term OMIP is the mean current/future electricity in the wholesale market. It has been employed the 2023 monthly OMIP prices, between January and September, as shown in Figure 23. The mean value is 91.49 €/MWh used in the simulations for the economic analysis.

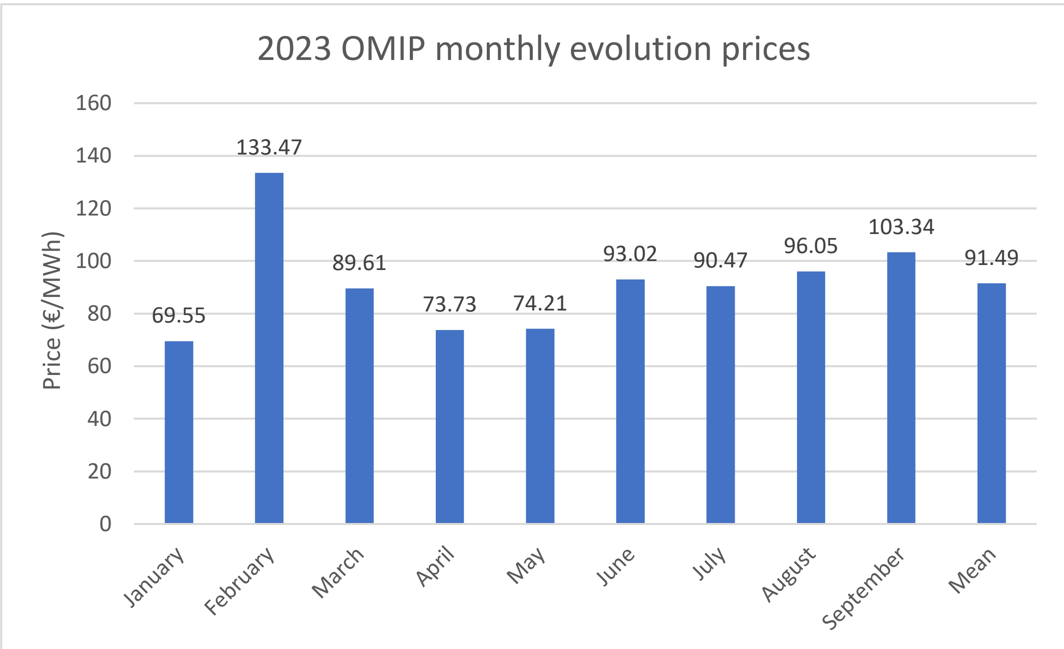



*Figure 23. OMIP Price evolution during 2023* [34].

The power costs come from multiplying the contracted power in each period times the fee for each period. This is an annual value so; it is divided by 12 for the monthly value. Both the energy and power cost are calculated without the taxes fees which in Spain are affected by the Electric

Tax of 5.1% and IVA (Impuesto de Valor Añadido) of 21%. The las two equations applied eventually are:

$$TQi = \frac{Ai + Bi \cdot OMIP}{100} \cdot 1.051127 \cdot 1.21 \tag{2}$$

$$Pi\ 6.1 = \frac{Pci \cdot Tpi}{12} \cdot 1{,}051127 \cdot 1.21 \tag{3}$$

In Table 6 are represented the monthly power term and the energy term prices for each period, calculated from the University electricity contract and the mean OMIP of 91.5 €/MWh price following the equations (2) and (3).

| **Period** | **Electricity bid price (with taxes), OMIP 91.43 €/MWh** | |
|---|---|---|
| | **Power term (€/(kW·month))** | **Energy term (€/kWh)** |
| **P1** | 3.236056 | 0.195028 |
| **P2** | 2.744213 | 0.184434 |
| **P3** | 1.580009 | 0.174603 |
| **P4** | 1.281719 | 0.169652 |
| **P5** | 0.417403 | 0.152724 |
| **P6** | 0.223470 | 0.153451 |

*Table 6. Final power cost per month and energy prices per kWh with OMIP 91.5€/MWh.*

However, as the future trend for the electricity market is supposed to decrease the prices, which would be detrimental for the viability of the project, more simulations with different prices are included. In the first case the OMIP value would be reduced to the mean value supposed for the next 10 years, that is 55.8 €/MWh [35]. In Table 7 it is shown the comparison between the prices with OMIP 91.5 €/MWh and 55.8 €/MWh.

| **Period** | **OMIP 91.5 €/MWh** | **OMIP 55.8 €/MWh** |
|---|---|---|
| | **Energy term (€/kWh)** | **Energy term (€/kWh)** |
| **P1** | 0.195028 | 0.139967 |
| **P2** | 0.184434 | 0.130575 |

| | | |
|---|---|---|
| **P3** | 0.174603 | 0.117031 |
| **P4** | 0.169652 | 0.109293 |
| **P5** | 0.152724 | 0.100095 |
| **P6** | 0.153451 | 0.105661 |

*Table 7. Electricity rates comparison between OMIP 91.5€/MWh and OMIP 55.83 €/MWh.*

For the second case the evolution is applied, as Figure 24 shows, there is the trend of the OMIP sell price for the next 25 years as well as the evolution of every electricity period, following similar variations as the OMIP value. [35] provides the future data for the following 9 years until 2032, but as can be seen in the Figure 24, the prices trend to stabilize reaching those years, so the 2032 price of 42.95 €/MWh has been assumed for the following years until 2047. Figure 24 also shows the price trend for the 6 electricity periods that show similar curves as the OMIP represent, because the periods prices are multiplied by the OMIP factor.

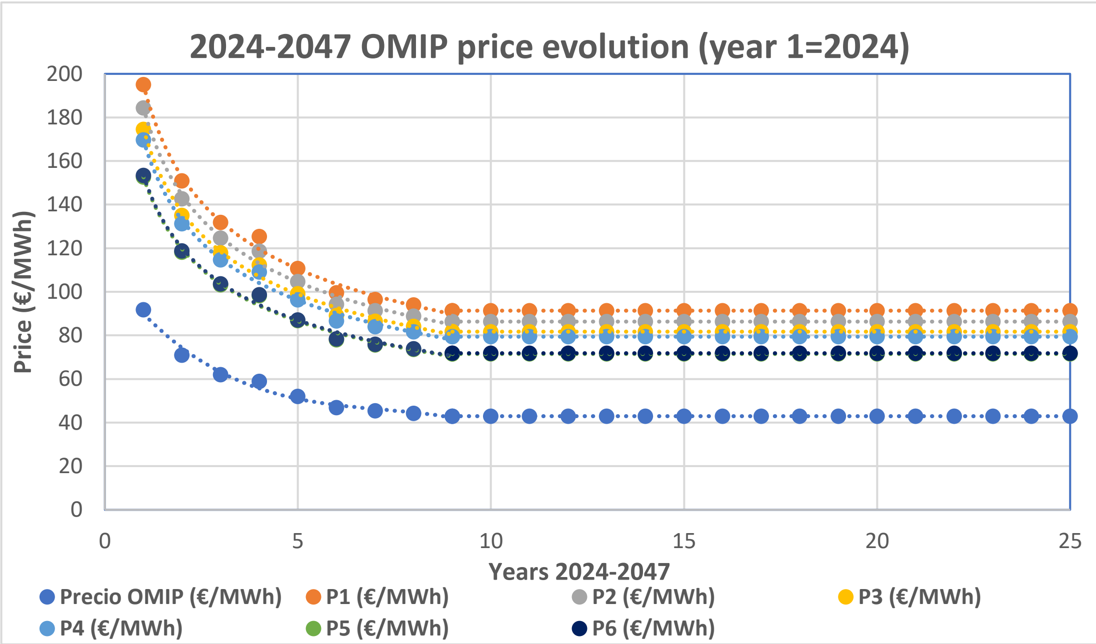



*Figure 24. OMIP, P1, P2, P3, P4, P5 and P6 price evolution from 2024 to 2047* [35].

In the Table 52 of the annexes there is the detailed distribution of the yearly prices for the OMIP, P1, P2, P3, P4, P5 and P6 until 2047.

### 4.5. SIMULATION INPUTS AND SCENARIOS

In this section are explained both base scenarios designed for the simulations, depending on the electricity contract and future prices and the power to be installed.

#### 4.5.1.CASE 1

The case 1 scenario, could be named as the base scenario, is simulated considering the full photovoltaic of the UPV, including façades and rooftops, just excluding the North façade. The process of extracting the available surface was explained in the methodology and in the following chapter is explained how is calculated from, the surface, the power to install in every building and in the University. As we can see in Table 10 of the next chapter, in total there will be installed a peak power of 15,003 kW, of those 41.93% come from the rooftops modules and the 58.07% come from the façades.

The economic analysis has been performed with three different electricity prices, using the current UPV electricity contract as a base, it has been changed the OMIP sell price as has been explained before:

- Current UPV's electricity contract with OMIP 91.5 €/MWh.
- Current UPV's electricity contract with OMIP 55.8 €/MWh.
- Current UPV's electricity contract with OMIP following future trend depreciation[35]

#### 4.5.2.CASE 2

The case 2 scenario is based on the simulation of the system extracting the West array, the least efficient system, which means a reduction of 2,678 kW, to make a total of 12,326 kW in the plant. In this case the peak power in the façades is 6,034 kW almost similar to the capacity installed in rooftops. The objective of this case is to observe how the change would affect to the energy generation and at the same time combine it with its economic analysis. The current electricity contract with with OMIP following future trend depreciation[35] has been selected for the simulation, not being necessary to perform it with the same 3 variants as Case 1, since same conclusions would be obtained.

| | Rooftops | East | South | Façades | Total |
|---|---|---|---|---|---|
| **Total surface ($m^2$)** | 29,921 | 12,151 | 16,294 | 28,455 | 58,366 |
| **Number of panels** | 10,496 | 4,288 | 5,760 | 10,048 | 20,544 |
| **Power (kW)** | 6,297 | 2,578 | 3,456 | 6,034 | 12,331 |
| **Power/Total power (%)** | 51.07 | 20.91 | 28.03 | 48.93 | 100 |

*Table 8. System power table summary without West array.*

# CHAPTER 5. DESIGN SUPPORTING CALCULATIONS

## 5.1. UPV'S PHOTOVOLTAIC POTENCIAL

### 5.1.1. ROOFTOPS

In case of the rooftops, as in the methodology was mentioned, the surface and the power distribution among the buildings have been obtained from [1]. The total available space on the rooftops amounts to 29,921 m$^2$. Furthermore, the dimensions of the PV panels selected for the current project align with those considered in [1], allowing for a successful extraction of both the surface area and power specifications for the photovoltaic rooftop system, amounting in total a possible 6.3 MW peak power to install. In the annexes there is a table specifying rooftops power to install in every building.

### 5.1.2. FACADES

Following the methodology, the available surface for every building is expressed in the following Table 9, discretizing the surface for each orientation:

| Building | East (m$^2$) | South (m$^2$) | West (m$^2$) |
|---|---|---|---|
| **1C** | 70 | 337 | 0 |
| **1E** | 357 | 386 | 296 |
| **1F** | 104 | 450 | 123 |
| **1H** | 0 | 0 | 90 |
| **1G** | 178 | 105 | 0 |
| **2A** | 0 | 173 | 402 |
| **2F** | 0 | 287 | 515 |
| **3A** | 574 | 98 | 565 |
| **3B** | 0 | 131 | 0 |
| **3C** | 83 | 258 | 0 |
| **3F** | 67 | 86 | 0 |
| **3H** | 0 | 105 | 0 |
| **3M** | 1,918 | 715 | 2,191 |
| **3G** | 0 | 0 | 94 |
| **3I** | 0 | 55 | 44 |
| **3J** | 0 | 0 | 43 |
| **3K** | 0 | 0 | 34 |
| **3P** | 138 | 903 | 341 |
| **4A** | 0 | 95 | 0 |
| **4D** | 151 | 593 | 291 |
| **4G** | 178 | 316 | 0 |
| **4L** | 107 | 320 | 474 |
| **4N** | 185 | 0 | 165 |

| | | | |
|---|---|---|---|
| **4P** | 185 | 0 | 208 |
| **4Q** | 0 | 134 | 165 |
| **5C** | 0 | 127 | 165 |
| **5E** | 156 | 514 | 0 |
| **5F** | 175 | 108 | 0 |
| **5G** | 0 | 98 | 0 |
| **5H** | 216 | 0 | 0 |
| **5I** | 138 | 0 | 0 |
| **5J** | 189 | 0 | 0 |
| **5K** | 159 | 136 | 143 |
| **5L** | 0 | 143 | 104 |
| **5N** | 241 | 558 | 125 |
| **6B** | 0 | 318 | 0 |
| **6C** | 0 | 294 | 169 |
| **6F** | 189 | 169 | 119 |
| **6G** | 0 | 1,046 | 447 |
| **7A** | 275 | 123 | 508 |
| **7B** | 91 | 738 | 59 |
| **7C** | 706 | 110 | 640 |
| **7D** | 280 | 346 | 0 |
| **7E** | 91 | 582 | 60 |
| **7F** | 354 | 492 | 0 |
| **7G** | 306 | 377 | 384 |
| **7I** | 578 | 1,738 | 324 |
| **8D,C,A** | 404 | z199 | 340 |
| **8G,E,B** | 2,449 | 1,118 | 2,418 |
| **8F** | 351 | 344 | 216 |
| **8P** | 248 | 728 | 194 |
| **9C** | 260 | 341 | 191 |
| **Total** | **12,151** | **16,294** | **12,647** |

*Table 9. Available façade surface for each building and orientation.*

As it was mentioned in the methodology, the surface shown in this Table 9 have been already discretized for the PV panels selected considering its dimensions, so for calculating the capacity of each building the equation above. The ratio of kW/m$^2$ of the panels used is 0.212 kW/m$^2$ of facade surface.

$$P_{peak} = \frac{Surface\ facade(m^2)}{Surface\ panel\left(\frac{m^2}{kW}\right)} \quad (4)$$

In the annexes there is a detailed distribution of each building power in case of the facades, however as a summary the following table contains the principal results of the UPV's photovoltaic potential.

As we can see in Table 10, in total there will be installed a peak power of 15,003 kW, of those 41.93% come from the rooftops modules and the 58.07% come from the façades. The distribution among facades corresponds to a higher capacity on the South facades with 3,456 kW almost 1 MW more than the East and West façades presenting both similar capacities amounting to 2,578 kW and 2,678 kW, respectively.

| | Rooftops | East | South | West | Façades | Total |
|---|---|---|---|---|---|---|
| **Total surface ($m^2$)** | 29,921 | 12,151 | 16,294 | 12,647 | 41,092 | 71,013 |
| **Number of panels** | 10,496 | 4,288 | 5,760 | 4,464 | 14,519 | 25,008 |
| **Power (kW)** | 6,297 | 2,578 | 3,456 | 2,678 | 8,712 | 15,003 |
| **Power/Total power (%)** | 41.93 | 17.18 | 23.04 | 17.85 | 58.07 | 100 |

*Table 10. System power table summary.*

### 5.2. NUMBER OF PANELS PER MPPT INPUT OF INVERTER

To calculate the number of panels in series that can be connected to the inverter, it is necessary to calculate the minimum and maximum temperatures to which they will be subjected, because they affect the generated and no-load voltage of the panels. The minimum temperature ($T_{min}$) and the maximum temperature ($T_{max}$) are calculated by the equations (5) and (6), where the values considered are; $\mathrm{T}_{amb,max}$=45 °C, as a conservative number even though the maximum temperature value in the weather file is 38.3 °C; $\mathrm{T}_{amb,min}$=-5 °C being conservative as the weather data provides 2.1 °C as the minimum temperature; $I_{max}$ is the maximum surface irradiance which value has been approximated from 973 W/$m^2$,on the weather file to 1,000 W/$m^2$; $I_{min}$is the minimum surface irradiance supposed 100 W/$m^2$; $T_{noc}$ is the nominal operating cell temperature that shown in Figure 25 corresponds to 42 ±3 °C

| TEMPERATURE RATINGS | |
|---|---|
| NOCT (Nominal Operating Cell Temperature) | 43°C (±2°C) |
| Temperature Coefficient of PMAX | - 0.34%/°C |
| Temperature Coefficient of Voc | - 0.25%/°C |
| Temperature Coefficient of Isc | 0.04%/°C |

| MAXIMUMRATINGS | |
|---|---|
| Operational Temperature | -40~+85°C |
| Maximum System Voltage | 1500V DC (IEC) |
| | 1500V DC (UL) |
| Max Series Fuse Rating | 30A |

*Figure 25. Temperature characteristics of the panel.*

$$T_{max}(°\mathrm{C}) = \mathrm{T}_{amb,max} + I \cdot \frac{(T_{noc} - 20)°C}{800\ W/m^2} \tag{5}$$

$$T_{max}(°C) = 45\ °C + 1000\ W/m^2 \cdot \frac{(45-20)°C}{800\ W/m^2}$$

$$T_{max}(°C) = 76.25\ °C$$

$$T_{min}(°C) = T_{amb,min} + I_{min} \cdot \frac{(T_{noc}-20)°C}{800\ W/m^2} \tag{6}$$

$$T_{min}(°C) = -5\ °C + 100\ W/m^2 \cdot \frac{(41-20)°C}{800\ W/m^2}$$

$$T_{min}(°C) = -2.38\ °C$$

As the Figure 25 represents, the operational temperature of the panels is between -40 °C and 85 °C. In this case both minimum and maximum temperatures are between these range.

Once calculated the extreme working temperatures of the modules, the working voltage panels in extreme temperatures is obtained for calculate, later on, the number of panels allowed per string. The maximum open circuit tension voltage of the panels is calculated trough the equation (7). Where $V_{oc}$ is the open circuit tension of the panel, amounting to 41.5 V and $\alpha_{OC}$ is the temperature coefficient with a value, shown in Figure 25 of 0.25 %/°C.

$$V_{oc,max}(V) = V_{oc} \cdot \left[1 + \alpha_{OC} \cdot \frac{(T_{min}-25)°C}{100\%}\right]$$

$$V_{oc,max}(V) = 41.5\ V \cdot \left[1 - 0.25\ \%/°C \cdot \frac{(-2.38-25)°C}{100\%}\right] \tag{7}$$

$$V_{oc,max}(V) = 44.34\ V$$

For the minimum open circuit voltage, a similar equation is used in (8). Two changes are expressed in (7), $T_{min}$ is now replaced by $T_{max}$ and $V_{oc}$ is replaced by $V_{MPP}$ which is the nominal working voltage with a radiation of 1000 W/m$^2$. Through equation (8) the value of $V_{OCMIN}$ is calculated reaching a value of 29.99 V.

$$V_{oc,min}(V) = V_{mpp} \cdot \left[1 + \alpha_{oc} \cdot \frac{(T_{max}-25)°C}{100\%}\right]$$

$$V_{oc,min}(V) = 34.4\ V \cdot \left[1 - 0.25\ \%/°C \cdot \frac{(76.25-25)°C}{100\%}\right] \tag{8}$$

$$V_{oc,min}(V) = 29.99\ V$$

The maximum number of panels per MPPT string ($N_{MPPT,max}$) is different for each inverter as present different maximum input voltage per MPPT. Equations (9) and (10) calculate the values of $N_{MPPT,max}$ and $N_{MPPT,min}$ in function of the $V_{oc,max}$ and $V_{oc.min}$ that are characteristics of each model of inverter.

$$N_{MPPT,max} \leq \frac{V_{MPPT,max}}{V_{oc,max}} \tag{9}$$

$$N_{MPPT,min} \geq \frac{V_{MPPT,min}}{V_{oc.min}} \tag{10}$$

The modules distribution per string and per inverter is expressed in the annexes. It has been selected the highest possible number of panels per string to minimize the MPPT used and therefore reducing the number of cables used and the costs. Table 11 contains these values.

### 5.3. NUMBER OF STRINGS IN PARALLEL

Another condition imposed by the inverter is the maximum number of strings in parallel, which depends on the maximum current allowed by the inverter in DC. According to this criterion, it is necessary to check that the current supplied by the modules does not exceed the maximum that the inverter can admit, and in the modules the maximum current occurs in short circuit. As the temperature of the cells increases, the current increases, and using the temperature coefficient of $I_{sc}$ the maximum short-circuit current is calculated:

$$\begin{gathered} I_{sc,max}(A) = I_{sc} \cdot \left[1 + \alpha_{sc} \cdot \frac{(T_{amb,max} - 25)°C}{100\%}\right] \\ I_{sc,max}(A) = 18.52\ A \cdot \left[1 + 0.04\ \%/°C \cdot \frac{(45 - 25)°C}{100\%}\right] \\ I_{sc,max}(A) = 18.67\ A \end{gathered} \tag{11}$$

This value is used to obtain the maximum number of parallel strings using the following equation, represented in Table 11.

$$N_{string,max} \leq \frac{I_{inv,max}}{I_{sc,max}}$$

| Inverter | V MPPT max (V) | V MPPT min (V) | Nº MPPT max | Nº MPPT min | Max Current per MPPT | Nº string max |
|---|---|---|---|---|---|---|
| **SUN2000-300KTL-H0** | 1500 | 500 | 33 | 17 | 65 | 3 |
| **SUN2000-250KTL-H0** | 1500 | 500 | 33 | 17 | 65 | 3 |
| **SUN2000-215KTL-H3** | 1500 | 500 | 33 | 17 | 30 | 1 |
| **SUN2000-185KTL -H1** | 1500 | 500 | 33 | 17 | 26 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **SUN2000-115KTL-M2** | 1000 | 200 | 22 | 7 | 30 | 1 |
| **SUN2000-100KTL-M2** | 1000 | 200 | 22 | 7 | 30 | 1 |
| **SUN2000-90KTL-M1** | 1500 | 600 | 33 | 20 | 22 | 1 |
| **SUN2000-75KTL-M1** | 1000 | 200 | 22 | 7 | 30 | 1 |
| **SUN2000-60KTL-M1** | 1000 | 200 | 22 | 7 | 22 | 1 |
| **SUN2000-50KTL-M1** | 1000 | 200 | 22 | 7 | 22 | 1 |
| **SUN2000-40KTL-M3** | 1000 | 200 | 22 | 7 | 27 | 1 |
| **SUN2000-30KTL-M3** | 1000 | 200 | 22 | 7 | 27 | 1 |
| **SUN2000-20KTL-M3** | 1000 | 200 | 22 | 7 | 30 | 1 |
| **SUN2000-15KTL-M2** | 950 | 160 | 21 | 6 | 22 | 1 |
| **SUN2000-10KTL-M2** | 950 | 160 | 21 | 6 | 22 | 1 |

*Table 11. Number of panels admitted per MPPT in serial connection and strings admitted in parallel per MPPT.*

## 5.4. BUILDINGS MPPT DISTRIBUTION

Taking in account the MPPT inputs of every inverter selected for each building and the panels allowed within the calculations for every MMPT input, here is the list of the panel's distribution per MMPT in every building:

SECTOR 1

- **Building 1B**:
  - SUN2000-300KTL-H0: 18 strings of 32 panels rooftop.
  - SUN2000-115KTL-M2: 9 strings of 22 panels Rooftop, 1 string of 18 panels Rooftop.
- **Building 1C**:
  - SUN2000-75KTL-M1: 1 string of 12 panels east, 1 string de 13 panels east, 5 string de 20 panels south, 1 string de 20 panels south, 1 string de 15 panels rooftop.
- **Building 1E**:
  - SUN2000-250KTL-H0: 3 string of 32 panels East , 1 string of 30 panels East, 4 string of 27 panels South, 1 string of 28 panels South, 3 string of 26 panels West, 1 string of 27 panels West, 3 string of 30 panels Rooftop, 3 string of 29 panels Rooftop
- **Building 1F**:
  - SUN2000-75KTL-M1: 7 string of 20 panels South, 1 string of 19 panels South

  - SUN2000-75KTL-M1: 1 string de 18 panels East, 1 string de 19 panels East, 1 string de 21 panels West, 1 string de 22 panels West, 3 string of 17 panels Rooftop, 1 string of 18 panels Rooftop
- **Building 1G**:
  - SUN2000-75KTL-M1: 3 string de 21 panels East, 5 string of 17 panels Rooftop
  - SUN2000-75KTL-M1: 7 string of 17 panels Rooftop, 1 string of 16 panels Rooftop
- **Building 1H**:
  - SUN2000-50KTL-M1: 2 string de 16 panels west, 4 string de 18 panels rooftop.

SECTOR 2

- **Building 2A**:
  - SUN2000-75KTL-M1: 2 string of 20 panels South, 1 string of 21 panels South, 6 string de 20 panels West, 1 string de 22 panels West
  - SUN2000-75KTL-M1: 8 string of 19 panels Rooftop
- **Building 2B**:
  - SUN2000-75KTL-M1: 7 string de 15 panels rooftop, 2 string de 14 panels rooftop.
- **Building 2C**:
  - SUN2000-75KTL-M1: 7 string de 20 panels rooftop.
- **Building 2D**:
  - SUN2000-60KTL-M1: 5 string de 21 panels rooftop, 1 string de 19 panels rooftop.
- **Building 2E**:
  - SUN2000-60KTL-M1: 5 string de 18 panels rooftop, 1 string de 21 panels rooftop.
- **Building 2F**:
  - SUN2000-250KTL-H0: 3 string of 25 panels South, 1 string of 26 panels South, 13 string of 25 panels Rooftop, 1 string of 20 panels Rooftop
  - SUN2000-90KTL-M1: 5 string de 30 panels West, 1 string de 32 panels West
- **Building 2G**:
  - SUN2000-15KTL-M2: 1 string de 15 panels rooftop, 1 string de 16 panels rooftop.

SECTOR 3

- **Building 3A**:
  - SUN2000-215KTL-H3: 3 string de 25 panels east, 1 string de 28 panels east, 1 string de 17 panels south, 1 string de 18 panels south, 8 string de 25 panels west, 1 string de 18 panels rooftop, 1 string de 19 panels rooftop.
- **Building 3B**:
  - SUN2000-75KTL-M1: 2 string de 15 panels south, 1 string de 16 panels south, 5 string de 15 panels rooftop, 1 string de 19 panels rooftop.
- **Building 3C**:
  - SUN2000-100KTL-M2: 1 string de 15 panels East, 1 string de 14 panels East, 4 string of 22 panels South, 4 string of 22 panels Rooftop
- **Building 3D**:
  - SUN2000-15KTL-M2: 2 string de 12 panels rooftop.

- **Building 3F**:
  - SUN2000-75KTL-M1: 2 string de 12 panels east, 2 string de 15 panels south, 5 string de 15 panels rooftop, 1 string de 18 panels rooftop.
- **Building 3G**:
  - SUN2000-50KTL-M1: 1 string de 16 panels west, 1 string de 17 panels west, 3 string de 16 panels rooftop, 1 string de 17 panels rooftop.
- **Building 3H**:
  - SUN2000-60KTL-M1: 1 string de 18 panels south, 1 string de 19 panels south, 4 string de 15 panels rooftop, 1 string de 17 panels rooftop.
- **Building 3I**:
  - SUN2000-50KTL-M1: 1 string de 16 panels west, 4 string de 15 panels rooftop, 1 string de 14 panels rooftop.
- **Building 3J**:
  - SUN2000-40KTL-M3: 1 string de 15 panels west, 3 string de 21 panels rooftop
- **Building 3K**:
  - SUN2000-40KTL-M3: 1 string de 12 panels west, 2 string de 22 panels rooftop, 1 string de 21 panels rooftop.
- **Building 3M**:
  - SUN2000-300KTL-H0: 17 string de 33 panels east, 1 string de 32 panels south
  - SUN2000-300KTL-H0: 3 string de 30 panels south, 15 string de 33 panels west
  - SUN2000-185KTL -H1: 9 string de 33 panels West
- **Building 3P**:
  - SUN2000-300KTL-H0: 8 string of 32 panels Rooftop, 1 string of 30 panels Rooftop, 9 string of 33 panels South
  - SUN2000-100KTL-M2: 2 string de 22 panels East, 2 string of 17 panels South, 1 string of 16 panels South, 5 string de 22 panels West
- **Building 3Q**:
  - SUN2000-40KTL-M3: 3 string de 20 panels rooftop, 1 string de 21 panels rooftop.

SECTOR 4

- **Building 4A**:
  - SUN2000-60KTL-M1: 2 string of 17 panels South, 3 string de 21 panels Rooftop, 1 string de 22 panels Rooftop
- **Building 4D**:
  - SUN2000-185KTL -H1: 9 string de 33 panels Rooftop
  - SUN2000-75KTL-M1: 10 string of 21 panels South
  - SUN2000-75KTL-M1: 2 string de 18 panels East, 1 string de 17 panels East, 4 string de 21 panels West, 1 string de 19 panels West
- **Building 4E**:
  - SUN2000-40KTL-M3: 4 string de 19 panels rooftop.
- **Building 4F**:
  - SUN2000-75KTL-M1: 7 string de 19 panels rooftop.
- **Building 4G**:
  - SUN2000-100KTL-M2: 3 string de 21 panels East, 5 string of 19 panels South, 1 string of 17 panels South

    - SUN2000-100KTL-M2: 9 string de 19 panels Rooftop, 1 string de 12 panels Rooftop
- **Building 4H**:
    - SUN2000-40KTL-M3: 3 string de 19 panels roof, 1 string de 18 panels south.
- **Building 4I**:
    - SUN2000-15KTL-M2: 1 string de 13 panels rooftop, 1 string de 14 panels rooftop.
- **Building 4J**:
    - SUN2000-60KTL-M1: 5 string de 22 panels Rooftop, 1 string de 17 panels Rooftop
- **Building 4K**:
    - SUN2000-20KTL-M3: 1 string de 17 panels rooftop, 1 string de 18 panels rooftop.
- **Building 4L**:
    - SUN2000-100KTL-M2: 2 string de 19 panels East, 7 string de 21 panels West, 1 string de 20 panels West
    - SUN2000-100KTL-M2: 5 string of 19 panels South, 1 string of 18 panels South, 3 string de 18 panels Rooftop, 1 string de 17 panels Rooftop
- **Building 4M**:
    - SUN2000-20KTL-M3: 1 string de 18 panels roof, 1 string de 19 panels rooftop.
- **Building 4N**:
    - SUN2000-50KTL-M1: 4 string de 20 panels Rooftop, 1 string de 18 panels Rooftop
    - SUN2000-50KTL-M1: 2 string de 22 panels East, 1 string de 21 panels East, 2 string de 19 panels West, 1 string de 20 panels West
- **Building 4P**:
    - SUN2000-115KTL-M2: 9 string de 21 panels Rooftop, 1 string de 19 panels Rooftop
    - SUN2000-50KTL-M1: 2 string de 22 panels East, 1 string de 21 panels East, 3 string de 22 panels West
- **Building 4Q**:
    - SUN2000-50KTL-M1: 2 string de 16 panels south, 1 string de 15 panels south, 2 string de 20 panels west, 1 string de 18 panels west.

SECTOR 5

- **Building 5B**:
    - SUN2000-20KTL-M3: 2 string de 20 panels rooftop.
- **Building 5C**:
    - SUN2000-75KTL-M1: 3 string de 15 panels south, 2 string de 20 panels west, 1 string de 18 panels west, 2 string 20 panels rooftop, 1 string de 21 panels rooftop.
- **Building 5E**:
    - SUN2000-100KTL-M2: 2 string de 22 panels East, 8 string de 20 panels Rooftop
    - SUN2000-100KTL-M2: 9 string of 22 panels South, 1 string de 20 panels Rooftop
- **Building 5F**:

- SUN2000-75KTL-M1: 2 string de 21 panels east, 1 string de 20 panels east, 2 string de 19 panels south, 3 string de 20 panels rooftop, 1 string de 21 panels rooftop.

- **Building 5G**:
  - SUN2000-100KTL-M2: 1 string de 18 panels south, 1 string de 17 panels south, 7 string de 18 panels rooftop, 1 string de 20 panels rooftop.
- **Building 5H**:
  - SUN2000-75KTL-M1: 4 string de 19 panels east, 1 string de 18 panels east, 4 string de 20 panels rooftop, 1 string de 18 panels rooftop.
- **Building 5I**:
  - SUN2000-40KTL-M3: 1 string de 17 panels east, 2 string de 16 panels east, 2 string de 17 panels rooftop.
- **Building 5J**:
  - SUN2000-75KTL-M1: 3 string de 17 panels East, 1 string de 16 panels East, 4 string de 19 panels Rooftop, 1 string de 18 panels Rooftop
- **Building 5K**:
  - SUN2000-50KTL-M1: 1 string de 18 panels East, 3 string de 21 panels Rooftop, 2 string de 22 panels Rooftop.
  - SUN2000-50KTL-M1: 2 string de 19 panels East, 2 string of 22 panels South, 2 string de 22 panels West
- **Building 5L**:
  - SUN2000-75KTL-M1: 3 string de 17 panels south, 1 string de 18 panels west, 1 string de 19 panels west, 3 string de 16 panels rooftop.
- **Building 5M**:
  - SUN2000-30KTL-M3: 2 string de 18 panels rooftop, 1 string de 19 panels rooftop.
- **Building 5N**:
  - SUN2000-115KTL-M2: 8 string of 22 panels South, 1 string of 21 panels South, 1 string de 22 panels Rooftop.
  - SUN2000-115KTL-M2: 5 string of 19 panels South, 4 string de 21 panels East, 1 string de 22 panels East, 1 string de 22 panels West
- **Building 5O**:
  - SUN2000-90KTL-M1: 6 string de 33 panels Rooftop
  - SUN2000-90KTL-M1: 4 string de 32 panels Rooftop, 1 string de 31 panels Rooftop
- **Building 5Q**:
  - SUN2000-10KTL-M2: 1 string de 20 panels rooftop.

SECTOR 6

- **Building 6A**:
  - SUN2000-250KTL-H0: 16 string de 31 panels Rooftop, 1 string de 28 panels Rooftop.
- **Building 6B**:
  - SUN2000-50KTL-M1: 5 string of 19 panels South, 1 string of 17 panels South.
- **Building 6C**:

- SUN2000-100KTL-M2: 4 string of 21 panels South, 1 string of 20 panels South, 2 string de 22 panels West, 2 string de 17 panels Rooftop, 1 string de 16 panels Rooftop

- **Building 6D**:
  - SUN2000-10KTL-M2: 2 string de 11 panels rooftop.
- **Building 6E**:
  - SUN2000-20KTL-M3: 2 string de 21 panels rooftop.
  - SUN2000-115KTL-M2: 10 string de 22 panels Rooftop.
- **Building 6F**:
  - SUN2000-115KTL-M2: 3 string de 22 panels East, 3 string of 20 panels South, 3 string de 20 panels Rooftop, 1 string de 22 panels Rooftop.
- **Building 6G**:
  - SUN2000-250KTL-H0: 12 string of 31 panels South, 1 string of 33 panels South, 3 string of 32 panels Rooftop, 1 string of 33 panels Rooftop.
  - SUN2000-75KTL-M1: 8 string de 17 panels West, 1 string de 22 panels West

SECTOR 7

- **Building 7A**:
  - SUN2000-185KTL -H1: 2 string de 32 panels East, 1 string de 33 panels East, 2 string of 21 panels South, 4 string de 33 panels West
- **Building 7B**:
  - SUN2000-250KTL-H0: 1 string de 32 panels East, 7 string of 33 panels South, 1 string of 30 panels South, 1 string de 21 panels West, 7 string de 30 panels Rooftop, 1 string de 33 panels Rooftop
- **Building 7C**:
  - SUN2000-250KTL-H0: 8 string de 32 panels east, 1 string de 29 panels east, 1 string de 24 panels south, 1 string de 25 panels south, 5 string de 32 panels west, 2 string de 33 panels west.
- **Building 7D**:
  - SUN2000-100KTL-M2: 5 string de 21 panels East, 5 string of 22 panels South
- **Building 7E**:
  - SUN2000-185KTL -H1: 6 string of 33 panels South, 4 string de 31 panels Rooftop
  - SUN2000-30KTL-M3: 2 string de 16 panels East, 1 string de 21 panels East
- **Building 7F**:
  - SUN2000-75KTL-M1: 6 string de 18 panels East, 1 string de 17 panels East
  - SUN2000-75KTL-M1: 8 string of 19 panels South, 1 string of 21 panels South
- **Building 7G**:
  - SUN2000-75KTL-M1: 4 string de 22 panels East 1 string de 20 panels East, 4 string of 18 panels South, 1 string de 22 panels Rooftop.
  - SUN2000-75KTL-M1: 2 string of 22 panels South, 1 string of 20 panels South, 6 string de 20 panels West, 1 string de 16 panels West
- **Building 7H**:
  - SUN2000-90KTL-M1: 5 string de 31 panels rooftop, 1 string de 30 panels rooftop.

- **Building 7I**:
  - SUN2000-215KTL-H3: 6 string de 29 panels east, 1 string de 30 panels east, 19 string de 31 panels south, 1 string de 27 panels south, 3 string de 28 panels west, 1 string de 30 panels west, 4 string de 28 panels rooftop, 1 string de 24 panels rooftop.
- **Building 7J**:
  - SUN2000-30KTL-M3: 2 string de 16 panels rooftop, 1 string de 17 panels rooftop.
- **Building 7L**:
  - SUN2000-30KTL-M3: 2 string de 22 panels rooftop, 1 string de 21 panels rooftop.

SECTOR 8

- **Building 8A,C,D**:
  - SUN2000-75KTL-M1: 6 string de 20 panels East, 1 string de 22 panels East, 3 string of 22 panels South.
  - SUN2000-75KTL-M1: 6 string de 20 panels West, 2 string de 13 panels Rooftop
- **Building 8F**:
  - SUN2000-250KTL-H0: 18 string de 33 panels Rooftop
  - SUN2000-250KTL-H0: 4 string de 31 panels East, 2 string of 31 panels South, 2 string of 30 panels South, 2 string de 25 panels West, 1 string de 26 panels West, 5 string de 30 panels Rooftop
- **Building 8B,E,G**:
  - SUN2000-250KTL-H0: 18 string de 31 panels East
  - SUN2000-250KTL-H0: 11 string de 31 panels East, 1 string de 33 panels East, 6 string of 31 panels South
  - SUN2000-250KTL-H0: 8 string of 31 panels South, 1 string of 32 panels South, 9 string de 33 panels West
  - SUN2000-250KTL-H0: 14 string de 33 panels West, 1 string de 29 panels West
- **Building 8H**:
  - SUN2000-185KTL -H1: 8 string de 29 panels roof, 1 string de 30 panels rooftop.
- **Building 8K**:
  - SUN2000-100KTL-M2: 8 string de 22 panels Rooftop
- **Building 8N**:
  - SUN2000-20KTL-M3: 2 string de 21 panels rooftop.
- **Building 8P**:
  - SUN2000-185KTL -H1: 8 string of 33 panels South, 1 string of 29 panels South.
  - SUN2000-75KTL-M1: 4 string de 22 panels East, 1 string de 22 panels West, 5 string de 21 panels Rooftop

SECTOR 9

- **Building 9A**:
  - SUN2000-185KTL -H1: 8 string de 29 panels Rooftop, 1 string de 33 panels Rooftop.

- **Building 9B**:
  - SUN2000-185KTL -H1: 8 string de 32 panels Rooftop.
- **Building 9C**:
  - SUN2000-115KTL-M2: 5 string of 22 panels South, 5 string de 22 panels Rooftop.
  - SUN2000-75KTL-M1: 4 string de 18 panels East, 1 string de 20 panels East
- **Building 9D**:
  - SUN2000-75KTL-M1: 6 string de 20 panels roof 1 string de 18 panels rooftop.
- **Building 9F**:
  - SUN2000-10KTL-M2: 1 string de 17 panels rooftop.
- **Building 9G**:
  - SUN2000-10KTL-M2: 1 string de 14 panels rooftop.
- **Building 9H**:
  - SUN2000-10KTL-M2: 1 string de 17 panels rooftop.
- **Building 9I**:
  - SUN2000-10KTL-M2: 1 string de 17 panels rooftop.
- **Building 9J**:
  - SUN2000-10KTL-M2: 1 string de 21 panels rooftop.

### 5.5. ROOFTOPS PANEL'S STRUCTURE

The rooftops structure above the one the modules are placed accomplish a triple purpose:

- It facilitates the modules mechanic consistency and a proper anchoring system.
- Serve as system of orientation and inclination for the panels.
- Distribute the loads equally among the rooftop structure.

Since both roofs will have two different configurations, 1 or 2 rows of modules, two different structure models will be required.

In the case where the supporting structure has a single row, the selected model is Triangular structure Veleta closed TV2010A, for horizontal layout. In the case where the structure supports two rows of modules, the selected model is the super triangle structure Mulhacen. Both structures will be anchored to the roof to give more stability and height to the installation, thus preventing water from reaching the modules in case of flooding. Further in the project in the section of the rooftops mounting structures, are shown the images of both structures.

Following this section, it is shown the required calculations to verify the structural strength of the installation, considering both loads, the weight combining the modules and its mounting structure, and the wind loads.

The estimated load that the UPV's rooftops buildings can support is between 300-400 kg/m$^2$. To check the loads are not larger than the maximum load the rooftops can support, the first thing calculated is the load of the photovoltaic elements:

$$W_{roof,mod} = n^{\circ}\ of\ modules/rooftop\ \cdot W_{mod}$$
$$W_{roof,struc} = meters\ of\ structure/rooftop \cdot W_{struc}\ (per\ meter) \tag{12}$$

$$Load_{elem,rooftop} = \frac{W_{tot,elem}}{Surface\ under\ PV\ installation}$$

To these loads must be added the ones produced by the wind, which will be different in every building because although, they are located very close to each other and present the same direction, have the different height. To estimate this load, the procedure of the basic document of the Documento Básico SE-AE Seguridad Estructural Acciones en la edificación [36], for wind actions on the structure of a photovoltaic installation, will be followed.

The characteristics of the system are:

- Ubication in zone A as the wind map and urban zone expresses.
- Rooftop height: Depends on the building.
- Module dimensions: 2172×1303 mm.
- Module weight: 30.9 kg
- Flat rooftops
- Slope angle of the structures: 37°.

The action of the wind, in general a force perpendicular to the surface of each exposed point, or static pressure ($q_e$), where; $q_b$ is the dynamic pressure of the wind; $c_e$ is the exposition coefficient; $c_p$ is the wind coefficient or external pressure. Can be expressed as:

$$q_e = q_b \cdot c_e \cdot c_p \tag{13}$$

The dynamic pressure of the wind is calculated by the following expression, where $\delta$ is the air density supposed as 1.25 kg/m$^3$: and $v_b^2$ is the basic local value of the wind speed for every location. In Valencia ubicated in the A zone, according to CTE DB SE-AE [36] it takes a value of 26 m/s. Replacing these values in the equation, $q_b$ gets a value of 0.42 kN/m$^2$.

$$q_b = 0.5 \cdot \delta \cdot v_b^2 \tag{14}$$

The value of the exposure coefficient depends on the environment (therefore more local effect than that of the dynamic wind pressure) and can be obtained with the expression:

$$c_e = F \cdot (F + 7k) \tag{15}$$

F being in turn the degree of roughness of the environment, which can be calculated by:

$$F = k \cdot \ln\left(\frac{max(z, Z)}{L}\right) \tag{16}$$

Z being the height of the site, in our case varies depending on the building and k, L and Z being the characteristic parameters of each type of environment, according to the following Figure 26.

**Tabla D.2 Coeficientes para tipo de entorno**

| | Grado de aspereza del entorno | Parámetro | | |
|---|---|---|---|---|
| | | **k** | **L** (m) | **Z** (m) |
| **I** | Borde del mar o de un lago, con una superficie de agua en la dirección del viento de al menos 5 km de longitud | 0,15 | 0,003 | 1,0 |
| **II** | Terreno rural llano sin obstáculos ni arbolado de importancia | 0,17 | 0,01 | 1,0 |
| **III** | Zona rural accidentada o llana con algunos obstáculos aislados, como árboles o construcciones pequeñas | 0,19 | 0,05 | 2,0 |
| **IV** | Zona urbana en general, industrial o forestal | 0,22 | 0,3 | 5,0 |
| **V** | Centro de negocios de grandes ciudades, con profusión de edificios en altura | 0,24 | 1,0 | 10,0 |

*Figure 26. Coefficients according to the type of surroundings.*

Considering the UPV is inside the zone IV, k, L and Z acquire values of 0.22, 0.3 m. and 5 m. respectively.

The wind or external pressure coefficient depends on the relative wind direction, the area of influence, the shape of the building, the position of the element considered and its area of influence, taking into account that in Valencia the predominant wind direction is to the West, the angle with respect to the building is 71°. With this data, the degree of inclination of the modules, it is obtained that the value of cp is -1.5 from [36].

| Building | Height (m) | Z (m) | F | Ce | $q_e$ (kg/m²) | Weight load (kg/m²) | Total load (kg/m²) |
|---|---|---|---|---|---|---|---|
| **1B** | 4 | 5 | 0.62 | 1.34 | 86.36 | 10.44 | 96.80 |
| **1C** | 18 | 18 | 0.90 | 2.20 | 142.08 | 10.35 | 152.42 |
| **1E** | 15 | 15 | 0.86 | 2.07 | 133.52 | 12.63 | 146.15 |
| **1F** | 15 | 15 | 0.86 | 2.07 | 133.52 | 11.45 | 144.97 |
| **1G** | 15 | 15 | 0.86 | 2.07 | 133.52 | 11.10 | 144.62 |
| **1H** | 15 | 15 | 0.86 | 2.07 | 133.52 | 10.39 | 143.91 |
| **2A** | 14 | 14 | 0.85 | 2.02 | 130.34 | 12.81 | 143.15 |
| **2B** | 14 | 14 | 0.85 | 2.02 | 130.34 | 11.73 | 142.06 |
| **2C** | 14 | 14 | 0.85 | 2.02 | 130.34 | 12.43 | 142.77 |
| **2D** | 14 | 14 | 0.85 | 2.02 | 130.34 | 11.02 | 141.36 |
| **2E** | 14 | 14 | 0.85 | 2.02 | 130.34 | 12.13 | 142.46 |
| **2F** | 14 | 14 | 0.85 | 2.02 | 130.34 | 8.98 | 139.32 |
| **2G** | 14 | 14 | 0.85 | 2.02 | 130.34 | 6.48 | 136.82 |
| **3A** | 14 | 14 | 0.85 | 2.02 | 130.34 | 10.10 | 140.44 |
| **3B** | 14 | 14 | 0.85 | 2.02 | 130.34 | 10.70 | 141.04 |
| **3C** | 14 | 14 | 0.85 | 2.02 | 130.34 | 10.54 | 140.88 |
| **3D** | 14 | 14 | 0.85 | 2.02 | 130.34 | 8.83 | 139.17 |
| **3F** | 14 | 14 | 0.85 | 2.02 | 130.34 | 11.04 | 141.38 |
| **3G** | 14 | 14 | 0.85 | 2.02 | 130.34 | 10.14 | 140.48 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **3H** | 14 | 14 | 0.85 | 2.02 | 130.34 | 9.80 | 140.14 |
| **3I** | 14 | 14 | 0.85 | 2.02 | 130.34 | 11.18 | 141.52 |
| **3J** | 14 | 14 | 0.85 | 2.02 | 130.34 | 8.04 | 138.38 |
| **3K** | 14 | 14 | 0.85 | 2.02 | 130.34 | 9.12 | 139.46 |
| **3P** | 15 | 15 | 0.86 | 2.07 | 133.52 | 12.43 | 145.95 |
| **3Q** | 6 | 6 | 0.66 | 1.45 | 93.66 | 12.81 | 106.47 |
| **4A** | 13 | 13 | 0.83 | 1.96 | 126.95 | 9.35 | 136.30 |
| **4D** | 18 | 18 | 0.90 | 2.20 | 142.08 | 11.19 | 153.27 |
| **4E** | 13 | 13 | 0.83 | 1.96 | 126.95 | 10.76 | 137.71 |
| **4F** | 13 | 13 | 0.83 | 1.96 | 126.95 | 12.33 | 139.28 |
| **4G** | 15 | 15 | 0.86 | 2.07 | 133.52 | 11.50 | 145.02 |
| **4H** | 13 | 13 | 0.83 | 1.96 | 126.95 | 8.32 | 135.27 |
| **4I** | 13 | 13 | 0.83 | 1.96 | 126.95 | 6.43 | 133.38 |
| **4J** | 13 | 13 | 0.83 | 1.96 | 126.95 | 13.09 | 140.04 |
| **4K** | 16 | 16 | 0.87 | 2.11 | 136.53 | 12.11 | 148.64 |
| **4L** | 16 | 16 | 0.87 | 2.11 | 136.53 | 9.50 | 146.02 |
| **4M** | 13 | 13 | 0.83 | 1.96 | 126.95 | 7.04 | 133.99 |
| **4N** | 17 | 17 | 0.89 | 2.16 | 139.37 | 12.17 | 151.54 |
| **4P** | 20 | 20 | 0.92 | 2.28 | 147.12 | 12.41 | 159.53 |
| **5B** | 3 | 5 | 0.62 | 1.34 | 86.36 | 10.98 | 97.33 |
| **5C** | 12 | 12 | 0.81 | 1.91 | 123.33 | 8.94 | 132.27 |
| **5E** | 16 | 16 | 0.87 | 2.11 | 136.53 | 9.63 | 146.16 |
| **5F** | 12 | 12 | 0.81 | 1.91 | 123.33 | 9.21 | 132.54 |
| **5G** | 9 | 9 | 0.75 | 1.71 | 110.65 | 12.75 | 123.40 |
| **5H** | 12 | 12 | 0.81 | 1.91 | 123.33 | 9.35 | 132.68 |
| **5I** | 9 | 9 | 0.75 | 1.71 | 110.65 | 12.31 | 122.96 |
| **5J** | 12 | 12 | 0.81 | 1.91 | 123.33 | 9.24 | 132.57 |
| **5K** | 9 | 9 | 0.75 | 1.71 | 110.65 | 12.66 | 123.32 |
| **5L** | 9 | 9 | 0.75 | 1.71 | 110.65 | 10.21 | 120.86 |
| **5M** | 12 | 12 | 0.81 | 1.91 | 123.33 | 10.22 | 133.55 |
| **5N** | 16 | 16 | 0.87 | 2.11 | 136.53 | 12.03 | 148.55 |
| **5O** | 9 | 9 | 0.75 | 1.71 | 110.65 | 11.88 | 122.53 |
| **5Q** | 6 | 6 | 0.66 | 1.45 | 93.66 | 8.59 | 102.25 |
| **6A** | 12 | 12 | 0.81 | 1.91 | 123.33 | 11.21 | 134.55 |
| **6C** | 20 | 20 | 0.92 | 2.28 | 147.12 | 10.71 | 157.83 |
| **6D** | 20 | 20 | 0.92 | 2.28 | 147.12 | 10.55 | 157.67 |
| **6E** | 6 | 6 | 0.66 | 1.45 | 93.66 | 12.82 | 106.48 |
| **6F** | 6 | 6 | 0.66 | 1.45 | 93.66 | 12.54 | 106.21 |
| **6G** | 20 | 20 | 0.92 | 2.28 | 147.12 | 9.67 | 156.79 |
| **7A** | 25 | 25 | 0.97 | 2.45 | 158.02 | 11.98 | 170.01 |
| **7B** | 23 | 23 | 0.95 | 2.38 | 153.91 | 10.66 | 164.58 |
| **7C** | 8 | 8 | 0.72 | 1.63 | 105.61 | 9.26 | 114.87 |
| **7D** | 25 | 25 | 0.97 | 2.45 | 158.02 | 10.62 | 168.65 |
| **7E** | 23 | 23 | 0.95 | 2.38 | 153.91 | 11.17 | 165.08 |
| **7F** | 25 | 25 | 0.97 | 2.45 | 158.02 | 3.55 | 161.58 |
| **7G** | 25 | 25 | 0.97 | 2.45 | 158.02 | 9.08 | 167.11 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **7H** | 4 | 5 | 0.62 | 1.34 | 86.36 | 8.95 | 95.30 |
| **7I** | 23 | 23 | 0.95 | 2.38 | 153.91 | 10.69 | 164.60 |
| **7J** | 23 | 23 | 0.95 | 2.38 | 153.91 | 8.11 | 162.02 |
| **7K** | 4 | 5 | 0.62 | 1.34 | 86.36 | 8.50 | 94.86 |
| **7L** | 10 | 10 | 0.77 | 1.78 | 115.24 | 11.31 | 126.55 |
| **8D,C,A** | 15 | 15 | 0.86 | 2.07 | 133.52 | 8.70 | 142.22 |
| **8G,E,B** | 20 | 20 | 0.92 | 2.28 | 147.12 | 10.80 | 157.92 |
| **8H** | 6 | 6 | 0.66 | 1.45 | 93.66 | 11.56 | 105.22 |
| **8K** | 6 | 6 | 0.66 | 1.45 | 93.66 | 12.23 | 105.90 |
| **8N** | 4 | 5 | 0.62 | 1.34 | 86.36 | 8.49 | 94.85 |
| **8P** | 14 | 14 | 0.85 | 2.02 | 130.34 | 10.86 | 141.19 |
| **9A** | 8 | 8 | 0.72 | 1.63 | 105.61 | 12.14 | 117.75 |
| **9B** | 6 | 6 | 0.66 | 1.45 | 93.66 | 14.34 | 108.01 |
| **9C** | 13 | 13 | 0.83 | 1.96 | 126.95 | 11.34 | 138.29 |
| **9D** | 6 | 6 | 0.66 | 1.45 | 93.66 | 12.91 | 106.57 |
| **9F** | 6 | 6 | 0.66 | 1.45 | 93.66 | 11.96 | 105.62 |
| **9G** | 6 | 6 | 0.66 | 1.45 | 93.66 | 8.66 | 102.32 |
| **9H** | 5 | 5 | 0.62 | 1.34 | 86.36 | 11.90 | 98.26 |
| **9I** | 5 | 5 | 0.62 | 1.34 | 86.36 | 12.29 | 98.64 |
| **9J** | 5 | 5 | 0.62 | 1.34 | 86.36 | 14.12 | 100.48 |

*Table 12. Wind load calculations and building's rooftops loads.*

As can be seen in Table 12, where is expressed the total load supported by the rooftops produced by the panels installations, divided by the elements loads, including the panels and structure weight and the wind loads, every building supports a load not larger than 200 kg/m$^2$ which is considerably lower than the limit establish by the rooftops, allowing the plant.

For the structure calculation, in intention of being conservative, it has been supposed to half of the structure simple and the other half double. Although, a detailed study of every building distribution should be done, the structure load produce little variations in the total load that changes in the structure distribution would be low significant.

### 5.6. DC CABLE SECTION ACCORDING TO VOLTAGE DROP CRITERIA

This direct current section corresponds to the connection from the string output of the solar panels to the MPPT input of the Inverter with unipolar cables. The method for determining the ideal conductor size is to solve the power flow that is required with safety and minimum energy losses in this section. The minimum cross section of the DC wiring ($S_{DCCABMIN}$) can be determined by applying equation (17). Where: $l_{DC}$ is the length of the cable for this case, a conservative number of 100 m is assumed; $I_{SC}$ is the short circuit current of the panel equal to 18.52 A; The resistivity of copper at 20 °C is $\rho_{CU20°C}$ and $\Delta V_{DC}$ is the recommended DC cable voltage drop. As the ITC-BT-40 norm expresses that the maximum voltage drop in the installation must not be greater than 1.5%, for the DC side the voltage drop is fixed in 0.25%. Since the maximum string voltage at the inverter input $V_{MAXINPUTMPPT}$ will be different depending on the inverter the voltage drop will vary for each building in annexes is represented every calculation. Equation (18) considers the resistivity of the cable at maximum operating temperature 40 °C, α is the temperature coefficient for copper resistivity of 0.0039 1/°C.

$$S_{DCCABMIN} \geq \frac{2 \cdot l_{DC} \cdot \rho_{CU}(T_{AMB,MAX}) \cdot I_{SC}}{\Delta V_{DC}} \tag{17}$$

$$\rho_{CU}\left(T_{AMB,MAX}\right) = \rho_{CU20°C} \cdot \left(1 + \alpha \cdot \left(T_{AMB,MAX} - 20°C\right)\right) \tag{18}$$

$$\rho_{CU20°C} = \frac{1}{58}\Omega \cdot \frac{mm^2}{m}$$

$$\alpha = 0.00393\frac{1}{°C}$$

$$\rho_{CU}\left(T_{AMB,MAX}\right) = \frac{1}{58}\Omega \cdot \frac{mm^2}{m} \cdot \left(1 + 0.00393\frac{1}{°C} \cdot (45°C - 20°C)\right)$$

$$\rho_{CU}\left(T_{AMB,MAX}\right) = 0.0189\ \Omega \cdot \frac{mm^2}{m}$$

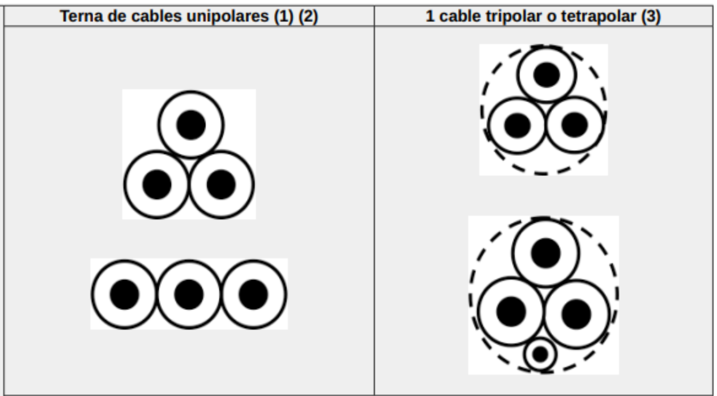
$$S_{DC,CAB,MIN} \geq \frac{2 \cdot 100\ m \cdot 0.0189\ \Omega \cdot \frac{mm^2}{m} \cdot 18.52\ A}{\Delta V_{DC}}$$

From equation (18) it is obtained that for a cable length of 100 m for the selected type of panels, a cable with a minimum cross-section greater than or equal to 29.53 $mm^2$ must be used for the SUN2000-10KTL-M2 inverter to 18.7 for the SUN2000-300KTL-H0. Therefore, 35 $mm^2$ wiring is used and meets the Voltage drop for these conditions, and for the cases if the length of the cable needs to be higher than 100 meters (in buildings of high-power installations), the cable of 35 $mm^2$ would still match the specifications. The reason of selecting this length of the cable is because, analyze for every building the exact length is very time-demanding and by making it by Google Earth could not be perfectly matched with the real specifications, so the conservative value of 100 meters was decided from the 8C installation.

| Inverter Model | VMPPTMAX (V) | 0.25% Voltage drop (V) | Cable section ($mm^2$) |
|---|---|---|---|
| **SUN2000-300KTL-H0** | 1,500 | 3.75 | 18.70 |
| **SUN2000-250KTL-H0** | 1,500 | 3.75 | 18.70 |
| **SUN2000-215KTL-H3** | 1,500 | 3.75 | 18.70 |
| **SUN2000-185KTL-H0** | 1,500 | 3.75 | 18.70 |
| **SUN2000-115KTL-M2** | 1,000 | 2.50 | 28.05 |
| **SUN2000-100KTL-M2** | 1,000 | 2.50 | 28.05 |
| **SUN2000-90KTL-M1** | 1,500 | 3.75 | 18.70 |
| **SUN2000-75KTL-M1** | 1,000 | 2.50 | 28.05 |
| **SUN2000-60KTL-M1** | 1,000 | 2.50 | 28.05 |
| **SUN2000-50KTL-M1** | 1,000 | 2.50 | 28.05 |
| **SUN2000-40KTL-M3** | 1,000 | 2.50 | 28.05 |
| **SUN2000-30KTL-M3** | 1,000 | 2.50 | 28.05 |
| **SUN2000-20KTL-M3** | 1,000 | 2.50 | 28.05 |
| **SUN2000-15KTL-M2** | 950 | 2.38 | 29.53 |
| **SUN2000-10KTL-M2** | 950 | 2.38 | 29.53 |

*Table 13. Minimum DC cable section for each inverter.*

The following Figure 27 shows a table of the cable section in terms of admissible current, for single-pole cables of 35 $mm^2$ section with cross-linked polyethylene (XLPE) insulation, the maximum admissible current is 190 A.



| Sección nominal mm² | Terna de cables unipolares (1) (2) | | | 1 cable tripolar o tetrapolar (3) | | |
|---|---|---|---|---|---|---|
| | Tipo de aislamiento | | | | | |
| | XLPE | EPR | PVC | XLPE | EPR | PVC |
| 6 | 72 | 70 | 63 | 66 | 64 | 56 |
| 10 | 96 | 94 | 85 | 88 | 85 | 75 |
| 16 | 125 | 120 | 110 | 115 | 110 | 97 |
| 25 | 160 | 155 | 140 | 150 | 140 | 125 |
| 35 | 190 | 185 | 170 | 180 | 175 | 150 |
| 50 | 230 | 225 | 200 | 215 | 205 | 180 |
| 70 | 280 | 270 | 245 | 260 | 250 | 220 |
| 95 | 335 | 325 | 290 | 310 | 305 | 265 |
| 120 | 380 | 375 | 335 | 355 | 350 | 305 |
| 150 | 425 | 415 | 370 | 400 | 390 | 340 |
| 185 | 480 | 470 | 420 | 450 | 440 | 385 |
| 240 | 550 | 540 | 485 | 520 | 505 | 445 |
| 300 | 620 | 610 | 550 | 590 | 565 | 505 |
| 400 | 705 | 690 | 615 | 665 | 645 | 570 |
| 500 | 790 | 775 | 685 | – | – | – |
| 630 | 885 | 870 | 770 | – | – | – |

*Figure 27. Maximum allowable current, in amperes, for cables with copper conductors*[37].

## 5.7. DC CABLE SECTION ACCORDING TO THERMAL CRITERIA

This criterion corresponds to the sizing of the cable considering the maximum operating temperature of the cabling without suffering any type of degradation or damage. Equation (19) takes into account the minimum cable sizing current criterion ($I_{MINDCCABLE}$), this must be greater than 125% of the generated current, in this case, the maximum current that will circulate through the panels will be its short circuit current value $I_{SC}(T_{MAX})$ taking into account the temperature coefficient. That is, this current parameter $I_{SC}$ can change to $T_{MAX}$, $T_{MAX}$ is calculated with equation (4). Equation (20) represents the $I_{SC}(T_{MAX})$ considering the temperature correction coefficient of the short-circuit current.

$$I_{MINDCCABLE} = 1.25 \cdot I_{SC}(T_{MAX})$$

$$I_{SC}(T_{MAX}) = I_{SC} \cdot \left[1 + \alpha_{SC} \cdot \frac{T_{MAX}(°C) - 25°C}{100\%}\right] \qquad (19)$$

$$T_{MAX} = 76.25°C$$

$$\alpha_{SC} = 0.05\%/°C$$

$$I_{SC}(T_{MAX}) = 18.52 \cdot \left[1 + 0.04\%/°C \cdot \frac{76.25°C - 25°C}{100\%}\right] \qquad (20)$$

$$I_{SC}(T_{MAX}) = 18.90\ A$$

$$I_{MINDCCABLE} = 23.62\ A$$

The compliance condition is represented by the expression (21) where $F_{Corr}$ is the correction factor obtained from ITC-BT 07. The DC wiring is intended to be installed in PVC pipes with a maximum of 16 single-pole cables per pipe. Therefore, $F_{Corr}$ will depend on; a) reduction factor for grouping the number of cables per conduit $F_{rGroup}$. In this case, according to ITC-BT 07, single-pole cables of 35 mm$^2$ without separation and in contact, the $F_{rGroup}$ is equal to 0.56; b) the reduction factor due to cable depth $F_{rDepth}$, assuming a depth of 0.9 the $F_{rDepth} = 0.98$; the reduction factor due to ground temperature $F_{rTemp}$ assuming $T_{AMBMAX}$ of 45 °C with service temperatures of 90 °C the $F_{rTemp}$ is 0.83. The maximum admissible current for the selected 35 mm$^2$ cable ($I_{DCCABLE}$) is 190 A.

$$I_{DCCABLE} \cdot F_{Corr} \geq I_{MINDCCABLE}$$

$$F_{Corr} = F_{rGroup} \cdot F_{rDepth} \cdot F_{rTemp}$$

$$F_{Corr} = 0.43 \cdot 0.98 \cdot 0.83 = 0.483 \qquad (21)$$

$$190\ A \cdot 0.56 \geq I_{MINDCCABLE}$$

$$66.445\ A \geq 23.62\ A$$

Therefore, with a 35 mm$^2$ cable section for every inverter, the thermal criterion is met, as well as the maximum voltage drop criterion of 0.25%.

## 5.8. AC CABLE SECTION ACCORDING TO VOLTAGE DROP CRITERIA

The cable section corresponding to alternating current refers to the connection between the inverter and the main switchboard. By means of the voltage drop criterion, the voltage drop will be limited to a maximum of 1.25% of the line-to-line voltage of the VLL network according to IDAE installation specifications. For the buildings where there are 2 or more inverters, this voltage drop is divided at the same time, in two sections, the first, from the inverter to the photovoltaic AC modular box with 0.625% of voltage drop, and the following from the modular box to the general low voltage box where the electricity of the building system is transferred.

### 5.8.1. BUILDINGS WITH ONE INVERTER

The minimum AC cable section ($S_{ACCABMIN}$) is calculated with equation (22), where the AC cabling distance ($l_{AC}$) has a maximum length of 60 m (being conservatives), the line-to-line voltage ($V_{LL}$) is 400 V being $\Delta V_{LL}$= 5 V and the maximum line current ($I_{LLMAX}$) of the three-phase system is obtained by equation (23). Cos(ϕ) is the power factor taken as 0.9. The inverter output power ($P_{OINV}$) would change depending on the inverter capacity, so the AC cable section would change for each subarray. In this case the same reasoning has been used for the length of the wirings, but as the inverter and the electric board are supposed to be close, as distance of 60 meters has been decided.

$$S_{ACCABMIN} \geq \frac{2 \cdot l_{AC} \cdot \rho_{CU}(T_{AMBMAX}) \cdot I_{LLMAX}}{\Delta V_{LL}} \quad (22)$$

$$I_{LLMAX} = \frac{P_{OINV}}{\sqrt{3} \cdot V_{LL} \cdot \cos(\varphi)} \quad (23)$$

| Inverter Model | Output power (kW) | $I_{LLMAX}$ (A) | Minimum cable section (mm²) |
|---|---|---|---|
| **SUN2000-300KTL-H0** | 300 | 481.13 | 182.21 |
| **SUN2000-250KTL-H0** | 250 | 400.94 | 151.84 |
| **SUN2000-215KTL-H3** | 215 | 344.81 | 130.58 |
| **SUN2000-185KTL-H0** | 185 | 296.69 | 112.36 |
| **SUN2000-115KTL-M2** | 115 | 184.43 | 69.85 |
| **SUN2000-100KTL-M2** | 100 | 160.38 | 60.74 |
| **SUN2000-90KTL-M1** | 90 | 144.34 | 54.66 |
| **SUN2000-75KTL-M1** | 75 | 120.28 | 45.55 |
| **SUN2000-60KTL-M1** | 60 | 96.23 | 36.44 |
| **SUN2000-50KTL-M1** | 50 | 80.19 | 30.37 |
| **SUN2000-40KTL-M3** | 40 | 64.15 | 24.29 |
| **SUN2000-30KTL-M3** | 30 | 48.11 | 18.22 |
| **SUN2000-20KTL-M3** | 20 | 32.08 | 12.15 |
| **SUN2000-15KTL-M2** | 15 | 24.06 | 9.11 |
| **SUN2000-10KTL-M2** | 10 | 16.04 | 6.07 |

*Table 14. Inverters current output and minimum cable section for the AC union.*

Comparing the data obtained in Table 14 with the Figure 27, from the Inverter SUN2000-300KTL-H0 to SUN2000-50KTL-M1 none fulfill with the current limitations of the wirings for the exact minimum cable section calculated, needing the implementation of bigger sections. However, the inverters from SUN2000-40KTL-M3 to SUN2000-10KTL-M2 would fulfill the requirements as the minimum section in the IDEA is 6 mm$^2$ supporting until 72 A, less than the $I_{LLMAX}$ (A) of these inverters.

### 5.8.2.BUILDINGS WITH MORE THAN ONE INVERTER

In this case, the AC wiring are divided into two sections the first, from the inverter to the photovoltaic AC modular box and the following from the modular box to the general low voltage box, dividing also the 1.25% voltage drop available for this side into, 1% for the after the inverter as it is a cable of 60 meters and 0.25% for the wires for the common general box that has been supposed to be 15 meters as maximum, therefore in the following table are the results that show the same cable section for the two parts and in the table is also included the final wiring section for these buildings taking considering also the thermal criteria shown in the next section.

| Inverter Model | $I_{LLMAX}$ (A) | Minimum cable section (mm$^2$) 60 meters | Minimum cable section (mm$^2$) 15 meters | Cable Section (mm$^2$) |
|---|---|---|---|---|
| **SUN2000-300KTL-H0** | 481.13 | 273.31 | 273.31 | 300 |
| **SUN2000-250KTL-H0** | 400.94 | 227.76 | 227.76 | 240 |
| **SUN2000-185KTL-H0** | 296.69 | 168.54 | 168.54 | 185 |
| **SUN2000-115KTL-M2** | 184.43 | 104.77 | 104.77 | 120 |
| **SUN2000-100KTL-M2** | 160.38 | 91.10 | 91.10 | 95 |
| **SUN2000-90KTL-M1** | 144.34 | 81.99 | 81.99 | 95 |
| **SUN2000-75KTL-M1** | 120.28 | 68.33 | 68.33 | 70 |
| **SUN2000-50KTL-M1** | 80.19 | 45.55 | 45.55 | 50 |
| **SUN2000-30KTL-M3** | 48.11 | 27.33 | 27.33 | 35 |

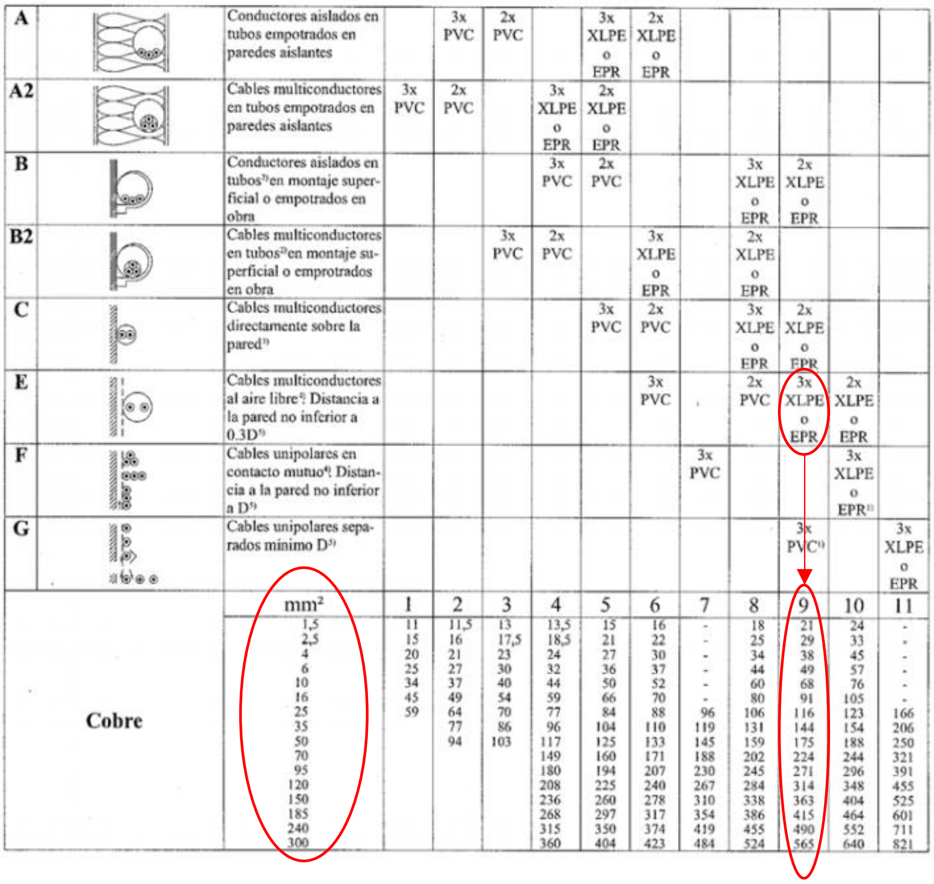
*Table 15. Wires section of the AC side for buildings with more than one inverter.*

### 5.9.AC CABLE SECTION ACCORDING TO THERMAL CRITERIA

This criterion corresponds to the sizing of the cable considering the maximum operating temperature of the cabling. Equation (24) considers the minimum cable sizing current criterion ($I_{MINACCABLE}$), which must be greater than 125% of the maximum line current. The compliance condition is represented by expression (25) where $F_{CTemp}$ is the temperature correction factor obtained from ITC-BT 07 and for 45°C ambient temperature and 90°C service temperature the $F_{CTemp}$ is equal to 0.95. From ITC-BT-19, $I_{ACCABLE}$ can also be obtained by means of the wiring section table as a function of admissible current in Figure 28. In Table 19 is expressed the $I_{MINACCABLE}$ and $I_{ACCABLE}$ for each inverter as well as the final cable sections for each inverter considering both criteria.

$$I_{MINACCABLE} = 1.25 \cdot I_{LLMAX} \quad (24)$$

$$I_{ACCABLE} \geq \frac{I_{MINACCABLE}}{F_{CTemp}} \quad (25)$$



| | Descripción | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Conductores aislados en tubos empotrados en paredes aislantes | | 3x PVC | 2x PVC | | 3x XLPE o EPR | 2x XLPE o EPR | | | | | |
| A2 | Cables multiconductores en tubos empotrados en paredes aislantes | 3x PVC | 2x PVC | | 3x XLPE o EPR | 2x XLPE o EPR | | | | | | |
| B | Conductores aislados en tubos[2] en montaje superficial o empotrados en obra | | | | 3x PVC | 2x PVC | | | 3x XLPE o EPR | 2x XLPE o EPR | | |
| B2 | Cables multiconductores en tubos[2] en montaje superficial o emprotrados en obra | | | 3x PVC | 2x PVC | | 3x XLPE o EPR | | 2x XLPE o EPR | | | |
| C | Cables multiconductores directamente sobre la pared[3] | | | | | 3x PVC | 2x PVC | | 3x XLPE o EPR | 2x XLPE o EPR | | |
| E | Cables multiconductores al aire libre[4] Distancia a la pared no inferior a 0.3D[5] | | | | | | 3x PVC | | 2x PVC | 3x XLPE o EPR | 2x XLPE o EPR | |
| F | Cables unipolares en contacto mutuo[4] Distancia a la pared no inferior a D[5] | | | | | | | 3x PVC | | | 3x XLPE o EPR[1] | |
| G | Cables unipolares separados mínimo D[5] | | | | | | | | | 3x PVC[1] | | 3x XLPE o EPR |
| Cobre | mm² | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | 1,5 | 11 | 11,5 | 13 | 13,5 | 15 | 16 | - | 18 | 21 | 24 | - |
| | 2,5 | 15 | 16 | 17,5 | 18,5 | 21 | 22 | - | 25 | 29 | 33 | - |
| | 4 | 20 | 21 | 23 | 24 | 27 | 30 | - | 34 | 38 | 45 | - |
| | 6 | 25 | 27 | 30 | 32 | 36 | 37 | - | 44 | 49 | 57 | - |
| | 10 | 34 | 37 | 40 | 44 | 50 | 52 | - | 60 | 68 | 76 | - |
| | 16 | 45 | 49 | 54 | 59 | 66 | 70 | - | 80 | 91 | 105 | - |
| | 25 | 59 | 64 | 70 | 77 | 84 | 88 | 96 | 106 | 116 | 123 | 166 |
| | 35 | | 77 | 86 | 96 | 104 | 110 | 119 | 131 | 144 | 154 | 206 |
| | 50 | | 94 | 103 | 117 | 125 | 133 | 145 | 159 | 175 | 188 | 250 |
| | 70 | | | | 149 | 160 | 171 | 188 | 202 | 224 | 244 | 321 |
| | 95 | | | | 180 | 194 | 207 | 230 | 245 | 271 | 296 | 391 |
| | 120 | | | | 208 | 225 | 240 | 267 | 284 | 314 | 348 | 455 |
| | 150 | | | | 236 | 260 | 278 | 310 | 338 | 363 | 404 | 525 |
| | 185 | | | | 268 | 297 | 317 | 354 | 386 | 415 | 464 | 601 |
| | 240 | | | | 315 | 350 | 374 | 419 | 455 | 490 | 552 | 711 |
| | 300 | | | | 360 | 404 | 423 | 484 | 524 | 565 | 640 | 821 |

*Figure 28. Wiring section according to admissible current* [37].

| Inverter Model | 1.25 x $I_{LLMAX}$ (A) | $I_{MIN,AC,CABLE}$ (A) | $I_{AC,CABLE}$ (A) | Cable Section (mm²) |
|---|---|---|---|---|
| SUN2000-300KTL-H0 | 601.41 | 633.06 | 640 | 400 |
| SUN2000-250KTL-H0 | 501.17 | 527.55 | 565 | 300 |
| SUN2000-215KTL-H3 | 431.01 | 453.69 | 490 | 240 |
| SUN2000-185KTL-H0 | 370.87 | 390.39 | 415 | 185 |
| SUN2000-115KTL-M2 | 230.54 | 242.67 | 271 | 95 |
| SUN2000-100KTL-M2 | 200.47 | 211.02 | 224 | 70 |
| SUN2000-90KTL-M1 | 180.42 | 189.92 | 224 | 70 |
| SUN2000-75KTL-M1 | 150.35 | 158.26 | 175 | 50 |

| | | | | |
|---|---|---|---|---|
| **SUN2000-60KTL-M1** | **120.28** | **126.61** | **144** | **50** |
| **SUN2000-50KTL-M1** | **100.23** | **105.51** | **116** | **35** |
| **SUN2000-40KTL-M3** | **80.19** | **84.41** | **91** | **25** |
| **SUN2000-30KTL-M3** | **60.14** | **63.31** | **68** | **25** |
| **SUN2000-20KTL-M3** | **40.09** | **42.20** | **49** | **16** |
| **SUN2000-15KTL-M2** | **30.07** | **31.65** | **38** | **10** |
| **SUN2000-10KTL-M2** | **20.05** | **21.10** | **29** | **10** |

*Table 16. AC wiring sections based on the thermal criteria.*

## 5.10. OVERLOAD PROTECTIONS

An overload refers to the case when the current circulates with a magnitude greater than the maximum supposed for the line and in extreme cases the current can be higher the maximum tolerated by the cable. One of the causes can be a short-circuit appearance. To protect the system, a circuit breaker is used to interrupt the flow of electric current in the event of an overload or short circuit. It is estimated that the rated current of the circuit breaker is greater than the operating current of the system and less than the maximum current admissible by the cable or conductor. The first condition to be fulfilled by the MCB is shown in equation (26).

$$I_z \geq I_n \geq I_b \tag{26}$$

Where:

- $I_b$: Designed current for the circuit
- $I_n$: Current assigned to the protection circuit
- $I_z$: Capacity current allowed by the cable

The above inequality refers to the fact that the protection must allow the necessary current to pass for the installation to operate under normal conditions, but it must not allow currents that could damage the cable to reach it.

The second condition to satisfy is:

$$I_2 \leq 1.45 \cdot I_z \tag{27}$$

The value taken by $I_2$ is equal to $I_f$ in case the protection is a fuse. The value of $I_f$ is a function of $I_z$, as shown below:

| $I_{OVPROT}$ (A) | Standard time (h) | $I_f$ (A) |
|---|---|---|
| $I_{OVPROT} < 4$ | 1 | $2.1 \cdot I_{OVPROT}$ |
| $4 \leq I_{OVPROT} < 16$ | 1 | $1.9 \cdot I_{OVPROT}$ |
| $16 \leq I_{OVPROT} < 63$ | 1 | $1.6 \cdot I_{OVPROT}$ |
| $63 \leq I_{OVPROT} < 160$ | 2 | $1.6 \cdot I_{OVPROT}$ |
| $160 \leq I_{OVPROT} < 400$ | 3 | $1.6 \cdot I_{OVPROT}$ |

| | | |
|---|---|---|
| **400≤ $I_{OVPROT}$** | 4 | 1.6 · $I_{OVPROT}$ |

*Table 17. $I_f$ values for a fuse* [38]

For protections based on circuit breakers, $I_2$ will be equal to $1.45 \cdot I_n$ according to UNE 20460 [38].

This inequality expresses that electrical cables are able to withstand transient overloads without deterioration of up to 145% of the maximum admissible current and these only have to act (melt) when during the stipulated time.

### 5.10.1.DC PROTECTIONS

The overcurrent protection on the DC side will be installed with a circuit breaker. The criteria followed for the sizing of the fuses are the ones explained in equations 15 and 16:

| Inverter Model | Current admissible cable (A) $I_z$ | Current protection (A) $I_n$ | Current dimensioned circuit (A) $I_b$ | $I_f$ (A) (1.6· $I_b$) | 1.45·$I_z$ (A) |
|---|---|---|---|---|---|
| **SUN2000-300KTL-H0** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-250KTL-H0** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-215KTL-H3** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-185KTL-H0** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-115KTL-M2** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-100KTL-M2** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-90KTL-M1** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-75KTL-M1** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-60KTL-M1** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-50KTL-M1** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-40KTL-M3** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-30KTL-M3** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-20KTL-M3** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-15KTL-M2** | 96 | 40 | 30 | 64 | 139.2 |
| **SUN2000-10KTL-M2** | 96 | 40 | 30 | 64 | 139.2 |

*Table 18. DC protections dimensioning.*

As for the DC side the protections to apply are fuses, $I_f$ is calculated by multiplying 1.6 to $I_b$. As can be seen in the Table 18 both conditions explained before are achieved with fuses of 40 A of limit current.

### 5.10.2.AC PROTECTIONS

For each inverter the following protections will be installed:

- **Magnetothermal circuit breaker:** to protect the installation against short circuits and overloads. and overloads. The criteria followed for the sizing of the circuit breakers are equations 24 and 25.

| Inverter Model | Current admissible cable (A) $I_z$ | Current protection (A) $I_n$ | Current dimensioned circuit (A) $I_b$ | $I_f$ (A) (1.45· $I_b$) | 1.45·$I_z$ (A) |
|---|---|---|---|---|---|
| **SUN2000-300KTL-H0** | 640 | 500 | 481 | 797.5 | 928 |
| **SUN2000-250KTL-H0** | 565 | 500 | 401 | 725.0 | 819.25 |
| **SUN2000-215KTL-H3** | 490 | 400 | 345 | 652.5 | 710.5 |
| **SUN2000-185KTL-H0** | 415 | 320 | 297 | 507.5 | 601.75 |
| **SUN2000-115KTL-M2** | 271 | 250 | 184 | 290.0 | 392.95 |
| **SUN2000-100KTL-M2** | 224 | 200 | 160 | 290.0 | 324.8 |
| **SUN2000-90KTL-M1** | 224 | 160 | 144 | 290.0 | 324.8 |
| **SUN2000-75KTL-M1** | 175 | 125 | 120 | 217.5 | 253.75 |
| **SUN2000-60KTL-M1** | 144 | 125 | 96 | 181.3 | 208.8 |
| **SUN2000-50KTL-M1** | 116 | 100 | 80 | 145.0 | 168.2 |
| **SUN2000-40KTL-M3** | 91 | 80 | 64 | 108.8 | 131.95 |
| **SUN2000-30KTL-M3** | 68 | 63 | 48 | 87.0 | 98.6 |
| **SUN2000-20KTL-M3** | 49 | 40 | 32 | 58.0 | 71.05 |
| **SUN2000-15KTL-M2** | 38 | 25 | 24 | 43.5 | 55.1 |
| **SUN2000-10KTL-M2** | 29 | 25 | 16 | 36.3 | 42.05 |

*Table 19. AC protections dimensioning.*

- **Differential circuit breaker:** for the detection of shunts and protection of people against indirect contacts. As it is recommended that this circuit breaker had a current capacity higher than 1.45·$I_n$ (A).

| Inverter Model | Differential current (A) |
|---|---|
| **SUN2000-300KTL-H0** | 725 |
| **SUN2000-250KTL-H0** | 725 |
| **SUN2000-215KTL-H3** | 580 |
| **SUN2000-185KTL-H0** | 464 |
| **SUN2000-115KTL-M2** | 363 |
| **SUN2000-100KTL-M2** | 290 |
| **SUN2000-90KTL-M1** | 232 |
| **SUN2000-75KTL-M1** | 181 |
| **SUN2000-60KTL-M1** | 181 |
| **SUN2000-50KTL-M1** | 145 |
| **SUN2000-40KTL-M3** | 116 |
| **SUN2000-30KTL-M3** | 91 |
| **SUN2000-20KTL-M3** | 58 |
| **SUN2000-15KTL-M2** | 36 |
| **SUN2000-10KTL-M2** | 36 |

*Table 20. Differential circuit breaker current dimensioning.*

- **Surge protection device.** The device selected will be the same as for the DC side.
- Next to the inverter protections there will be a **general circuit breaker,** using the same magnetothermal switches as for the inverters, located on the main busbar that will

allow the cut-off of the whole installation and a disconnecting switch. The criteria followed for the sizing of the circuit breaker are the equations 24 and 25:

In this case as there are buildings dimensioned with two or more inverters, those buildings after the differential switch, the wirings are directed into another AC protection box near the main building's busbar, where the wires coming from each inverter combine in one only cable, adding every current of all wires in one. After this union, the installation will follow with the surge protection device and finally the general circuit braker.

## 5.11. GROUND RESISTANCES

In photovoltaic installations, two ground connections must be galvanically isolated by the inverter. One ground connection is located on the power grid, and the other on the DC side of the panel structure. The latter does not protect against a possible earth fault as occurs in low voltage installations. Grounding is defined as the direct electrical connection, without any protection or fuses, of a part of the electrical circuit or of a conductive part not belonging to it through an earth connection with a group of electrodes buried in the ground. The purpose of the installation is to ensure that no potential differences appear in the installation as a whole, and at the same time to allow the passage of fault and discharge currents to ground. The earth connected on the mains side is calculated according to the specifications of ITC 19/18 and 24.

The electrode is dimensioned with a resistance value higher than the one presented by the ground resistance. The resistance of an electrode depends on its dimensions, its shape and the resistivity of the ground on which it is established. The resistivity of the soil varies according to the type of soil and the depth at which it is tested. In this project a geological study of the soil on which the photovoltaic plant is located has not been carried out. It has been considered that the soil is limestone type, which has an average soil resistivity of 300 Ω-m.

The contact voltage cannot be higher than 50 V for our study analysis, the value of the ground resistance to achieve this comes from using the Ohm's Law:

$$R = \frac{Voltage\ (50\ V)}{Differential\ switch\ sensitivity\ (300\ mA)} = 166.7\ \Omega$$

| Electrode | Ground resistance (Ω) |
|---|---|
| **Plate electrode** | $R = 0.8 \cdot \frac{r}{P}$ |
| **Vertical electrode** | $R = \frac{r}{L}$ |
| **Horizontal trench** | $R = 2 \cdot \frac{r}{L}$ |

*Table 21. Ground resistance in function of the electrode type.*[37]

As for the plant both the horizontal and vertical electrode are supposed to be used, because in this project there is not a detailed study of the University's ground, not knowing the presence of water and its depth, wells, and other elements under the buildings that will stablish the type of electrode to use. From Table 21 it has been calculated that for the vertical electrode a depth of 1.8 meters is necessary and for the horizontal electrode 3.6 meters. In cases where there is enough depth in the underground, for a more trusting protection can be selected the horizontal device or both in combination, and the vertical device exclusively in cases of for tighter depths.

### 5.12. PROTECTION CONDUCTORS

The section of the protective conductors will be equal to the one fixed before, depending on the section of the phase or polar conductors of the installation. The section of the protective conductors is calculated according to the following table, or it will be obtained by calculation according to the indicated in the UNE 20.460 -5-54 Standard, section 543.1.1. It has been established 6 $mm^2$ as the base section of the protection conductors for the inverters with lower wiring sections.

| Cross-section of the phase conductors of the installation ($mm^2$) | Minimum cross-section of the protection conductors ($mm^2$) |
|---|---|
| $\boldsymbol{S \leq 16}$ | $Sp = S$ |
| $\boldsymbol{16 > S \leq 35}$ | $Sp = 16$ |
| $\boldsymbol{S > 35}$ | $Sp = S/2$ |

*Table 22. minimum cable section for ground conductors depending on the phase conductors section.* [37]

* Section must be 4 $mm^2$ at least if the conductors of protection are not part of the energy channeling and does not have mechanic protection.

### 5.13. EQUIPOTENTIAL BONDING CONDUCTORS

The equipotential bonding conductors must have a cross-section equal to or greater than that of the protective conductors as specified in ITC BT-18.

### 5.14. GROUND CONECTIONS

The grounding of the entire photovoltaic installation will be connected to the existing grounding of the buildings. This connector will join the structure and the frame of the modules and other metallic elements.

Table 23 shows every calculation required for the AC side, including cable sections, cable maximum current, cable short-circuit current, inverter short-circuit disconnection time response and ground connectors section. In the annexes there are all the calculations of every expression of the minimum specifications for cables, connectors and protections of the AC area.

| Inverter Model | Cable Section ($mm^2$) | Ground connectors section ($mm^2$) | Equipotential bonding conductors ($mm^2$) | Ground connections section ($mm^2$) |
|---|---|---|---|---|
| **SUN2000-300KTL-H0** | 400 | 200 | 100 | 200 |

| | | | | |
|---|---|---|---|---|
| **SUN2000-250KTL-H0** | 300 | 150 | 75 | 150 |
| **SUN2000-215KTL-H3** | 240 | 120 | 60 | 120 |
| **SUN2000-185KTL-H0** | 185 | 93 | 46 | 93 |
| **SUN2000-115KTL-M2** | 95 | 48 | 24 | 48 |
| **SUN2000-100KTL-M2** | 70 | 35 | 17 | 35 |
| **SUN2000-90KTL-M1** | 70 | 35 | 17 | 35 |
| **SUN2000-75KTL-M1** | 50 | 25 | 12 | 25 |
| **SUN2000-60KTL-M1** | 35 | 18 | 9 | 18 |
| **SUN2000-50KTL-M1** | 25 | 16 | 8 | 16 |
| **SUN2000-40KTL-M3** | 16 | 8 | 4 | 8 |
| **SUN2000-30KTL-M3** | 10 | 5 | 2 | 5 |
| **SUN2000-20KTL-M3** | 6 | 4 | 2 | 4 |
| **SUN2000-15KTL-M2** | 4 | 4 | 2 | 4 |
| **SUN2000-10KTL-M2** | 3 | 4 | 2 | 4 |

*Table 23. Summary of the AC side calculations: cable sections, cable maximum current, cable short-circuit current, inverter short-circuit disconnection time response and ground connectors section.*

# CHAPTER 6. DEVICES SELECTION

## 6.1. PV MODULE

The market boasts a vast array of brands and varieties of photovoltaic (PV) panels. It is imperative to exercise judicious selection when choosing a panel to maximize output power while minimizing surface area utilization, considering factors such as module cost, annual efficiency degradation, and module dimensions compatible with the available façade space. The module designated for the project is the Trina Solar TSM-600DE20. The Trina Solar brand stands out as one of the preeminent, technologically advanced, and dependable entities within the market. In Table 24 are shown the four modules considered for this project and its specifications:

| **Brand** | **Trina Solar** | **Risen Energy** | **HT-SAAE** | **CSI Solar** |
|---|---|---|---|---|
| **Model** | TSM-600DE20 | RSM120-8-600M | HT78-18X | HiKu7 Mono PERC |
| **Power** | 600 W | 600 W | 600 W | 600 W |
| **Dimensions** | 2.172 x 1.303 x 0.033 m | 2.172 x 1.303 x 0.035 m | 2.47 x 1.133 x 0.035 m | 2.172 x 1.303 x 0.035 m |
| **Solar Cells** | Monocrystalline | Monocrystalline | Monocrystalline | Monocrystalline |
| **Weight** | 30.9 kg | 31.5 kg | 31 kg | 31 kg |
| **First year degradation** | 2% | 2% | 2.5% | 2% |
| **Annual energy degradation** | 0.55% | 0.55% | 0.6% | 0.55% |
| **Voltage at maximum power (Vmpp)** | 34.4 (V) | 34.7 (V) | 44.8 (V) | 34.9 (V) |

| | | | | |
|---|---|---|---|---|
| **Current at maximum power (Impp)** | 17.44 (A) | 17.3 (A) | 13.3 (V) | 17.2 (A) |
| **Efficiency** | 21.2 % | 21.2% | 21.4% | 21.2% |
| **Price** | 115.68 € | 136.95 € | 130.25 € | 117.82€ |
| **Price/Watt** | 0.192 €/watt | 0.227 €/watt | 0.217 €/watt | 0.201 €/watt |
| **Product Workmanship Warranty (Years)** | 12 | 12 | 12 | 12 |
| **Power Warranty (Years)** | 25 | 25 | 25 | 25 |

*Table 24. Modules characteristics.*

Table 24 provides comprehensive data sourced from panel data sheets, with pricing information obtained from both online sources and local providers. It is important to note that, except for the HT-SAAE panel, all modules demonstrate similar characteristics with minimal differences in dimensions, efficiency, degradation rates, and other relevant parameters. To maintain consistency, a reference power of 600W was used to align the panels with those featured in [1].

The primary criterion for panel selection was the cost per kilowatt-peak (€/kWp). Ultimately, the Trina Solar TSM-600DE20 module was chosen due to its competitive price, specifically the lowest cost at 0.192 €/watt. On the other hand, the HT-SAAE HT78-18X panel was not considered for this project due to its dimensions not aligning with those utilized in [1]. The warranty and years of correct functionality was a landmark decider, as all four panels presents the same years of warranty of 12 years for the Product Workmanship and 25 for the Power, it is possible to precise the module selection by the kW/€ criteria, continuing with the Trina Solar TSM-600DE20.

### 6.2. INVERTER

The selection and installation of inverters underwent a rigorous analysis, with a specific inverter chosen for each building based on the peak power of the respective subarrays. In the market, various inverter families are available, offering a wide range of power capacities. However, the Huawei SUN2000 series was chosen due to its expansive capacity range, spanning from small inverters of a few kilowatts to high-capacity inverters of up to 300 kW. Additionally, these inverters are equipped with a substantial number of inputs and MPPT (Maximum Power Point Tracking) trackers, fitting with the 4 different panels orientations the buildings present.

Starting from the SUN2000-30KTL-M3 model up to the SUN2000-300KTL-H0 model, each of them provides a minimum of 8 inputs and at least 4 MPP Trackers. This allows for the efficient connection of every subarray in a building to a single inverter, reducing overall costs by requiring fewer inverters. In buildings where a 20 kW or lower capacity inverter is employed, the number of MPPT Trackers may be less than four. However, this does not pose an issue as such installations typically consist solely of rooftop PV panels, making a high number of inputs unnecessary. In Table 25 is the list of the inverters selected with its capacity (kW) and price (€).

In the annexes there is also the detailed distribution of every building's installed power in both, the façades and rooftop systems and with the proper inverter to install in each of them depending on the power presented. In annexes there are also the specifications of the inverters taken from their catalogues data.

| Inverter | Capacity (kW) | Price (€) | €/kW |
|---|---|---|---|
| **SUN2000-300KTL-H0** | 300 | 10,900 | 36.33 |
| **SUN2000-250KTL-H1** | 250 | 8,455 | 33.82 |
| **SUN2000-215KTL-H0** | 215 | 8,140 | 37.86 |
| **SUN2000-185KTL -H1** | 185 | 6,369 | 36.39 |
| **SUN2000-115KTL-M0** | 115 | 6,215 | 54.04 |
| **SUN2000-100KTL-M1** | 100 | 5,638 | 56.38 |
| **SUN2000-90KTL-H0** | 90 | 5,068 | 56.31 |
| **SUN2000-75KTL-M1** | 75 | 4,626 | 61.67 |
| **SUN2000-60KTL-M0** | 60 | 4,009 | 66.82 |
| **SUN2000-50KTL-M0** | 50 | 3,160 | 63.20 |
| **SUN2000-40KTL-M3** | 40 | 3,285 | 82.13 |
| **SUN2000-30KTL-M3** | 30 | 2,860 | 95.33 |
| **SUN2000-20KTL-M5** | 20 | 2,419 | 120.95 |
| **SUN2000-15KTL-M2** | 15 | 2,039 | 135.93 |
| **SUN2000-10KTL-M2** | 10 | 1,935 | 193.50 |

*Table 25. List of inverters used and its capacity.*

### 6.3. ROOFTOPS MOUNTING STRUCTURE

The panel's structure present three vital functions; it support the modules mechanic consistency and a proper anchoring system; facilitates the orientation and optimal slope angle to produce energy; distributes the panels load equally among the rooftops surfaces. In this case, almost every building of the Campus present flat rooftop which facilitates the installation in optimal angle and orientation.

The system used are, the triangular support structure (Figure 29), for cases where only one row is installed and the double inclined support for structures of 2 rows of panels one above the other (Figure 30). Both structures are manly made of aluminum due to its low weight, high resistance to corrosion and the esthetic image, and will be anchored to the roof to give more stability and height to the installation, thus preventing water from reaching the modules in case of flooding.

The structures contain these elements:

- Guide: Are the sloped structure where the panels are placed.
- Triangular structure: Determine the angle the panels will have. It can be regulated.

- Guide union: Element for joining two guide sections.
- Hardware store: For unions between elements. Need to be of stainless steel.
- Clamp: Fix the panels on the guides.
- Iron cramp: Used for fixing panels in the guides, specially at the ends.

The structures selected for this application are:

- The triangular vertical structure “Veleta”[39] for the one row configurations.
- The double triangular vertical structure “Mulhacén”[40] for the double row configurations.

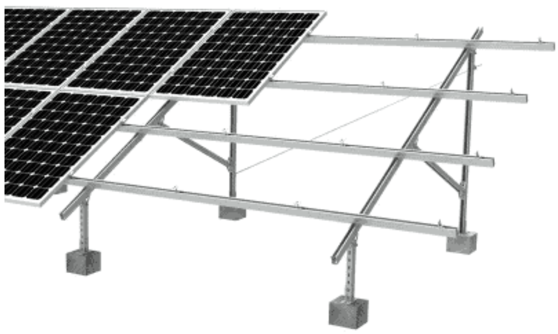


*Figure 30. Double inclined support structure.*

*Figure 29. Triangular support structure.*

## 6.4. MOUNTING STRUCTURE OF FAÇADES

The paper [17] presents a structural design, primarily thought for BIPV technologies but with the possibility to be extrapolated to BAPV façade modules.

In Figure 31 it is shown the scheme of the mounting structure.

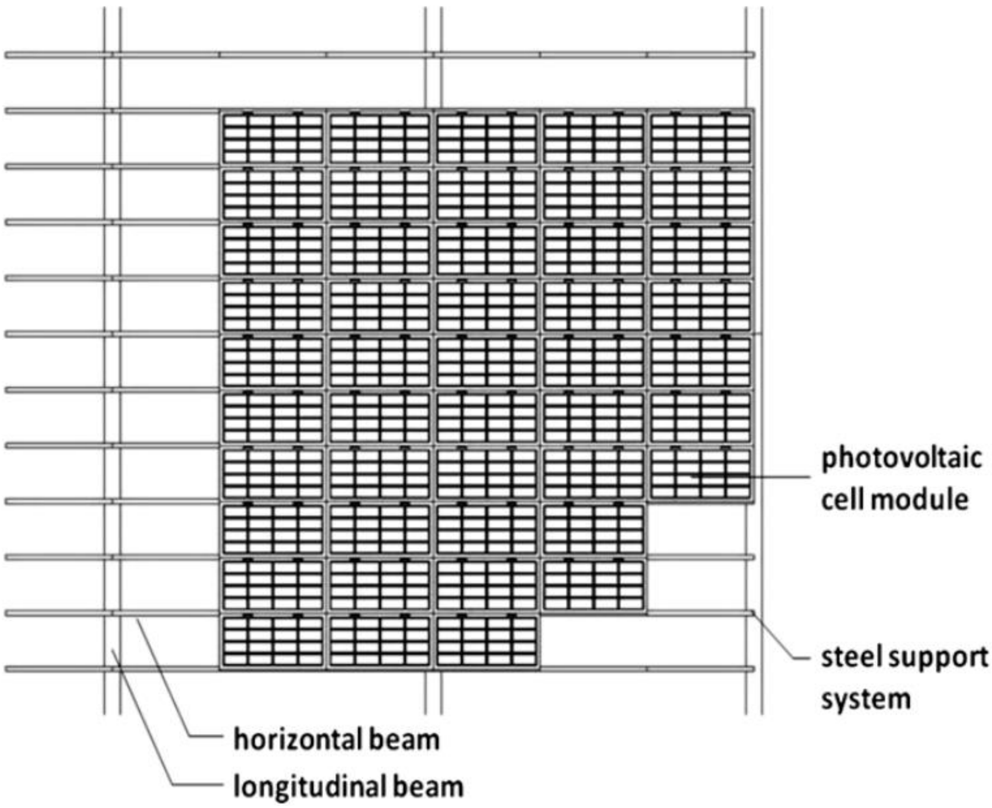



*Figure 31. Façade mounting design.* [17]

The Figure 32 represents another scheme of the mounting structure, where the panels are connected to the electric network by two upper-spring connections models and two under-fixed connection models. The upper spring connection model is comprised of two springs and a sliding block in which the “anode-cathode” contact points of the electric circuit are at the end.

The steel support system includes horizontal and vertical beams. The vertical beam has the shape of an I-beam. The two sides of the I-beam are the ones supporting the structure, the outer side holding the electrical circuit box and the indoor side connecting directly with the

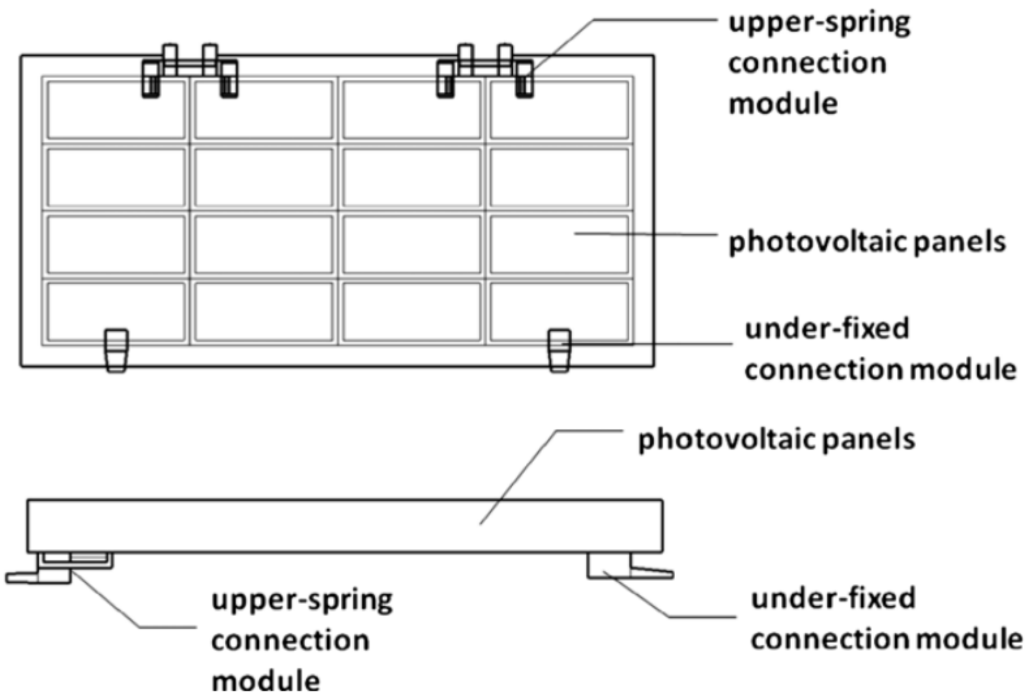



*Figure 32. Mounting structure scheme.* [17]

buildings. The horizontal beam is a C-beam where the cell modules are mounted plugging their upper spring models and under-fixed models into the connectors of the C-beam. Both the C-beam and I-beam have space for placing electrical components, where inside the C-beam, the connectors of photovoltaics modules and the electrical circuit box hide and alongside the I-beam both have electrical circuit boxes for placement of cables. The rest of images describing the mounting structure are in the annexes.

### 6.5. ELECTRIC INSTALLATION COMPONENTS

There are different zones in the installation in relation to the wiring used: the DC wiring from the modules to the inverters and the AC wiring from the inverters to the system connection point, which in every case will be at the general low-voltage switchboard of each building.

ITC-BT-40 [37] recommends that the voltage drop should be less than 1.5% between the generator and the point of interconnection to the Public Distribution Network and that the connection cables should be sized for a current of 125% of the maximum current of the generator and the voltage drop between the generator and the point of interconnection to the Public Distribution Network.

#### 6.5.1 DC CONNECTORS

As the calculations showed, 6 mm$^2$ of section wirings support the working conditions of every combination of panels to their input on each inverter. This wiring consists of two conductors, the positive and negative poles. The connection between the photovoltaic modules and the inverters is made with H1Z2Z2-K copper conductors, which are specific for photovoltaic installations and can be used in both outdoor and indoor installations. Therefore, the DC connections have been designed with this type of wirings presenting the following characteristics (Figure 33):

| | |
|---|---|
| **Connector** | Tinned cooper, flexible, 5 s/IEC 60228 class |
| **Insulation** | Polyolefin-based crosslinked compound |
| **Nominal voltage (V)** | 0.6/1 kV |
| **Temperature range (°C)** | -40°C to 70°C, max Tª 90°C |
| **Allowed current outdoors (A)** | 70 |
| **Allowed current on a surface (A)** | 67 |
| **Section (mm$^2$)** | 10 |

*Table 26. DC wiring connectors characteristics.*

*Figure 33. H1Z2Z2-K copper conductor*[41].

### 6.5.2 AC CONNECTORS

The AC wiring, contrary to the DC connectors, are dimensioned for the output power of each inverter resulting in way range of cable sections needed to match the specifications. The selected cable is the X-VOLT RHZ1 (S) Cu/OL/2OL with the following specifications:

| | |
|---|---|
| **Connector** | Cooper, class 2/IEC 60228 |
| **Insulation** | Cross-linked polyethylene (XLPE) |
| **Nominal voltage (V)** | 0.6/1 kV |
| **Temperature range (°C)** | -30 °C to 90 °C |
| **Section (mm$^2$)** | 2.5/4/6/10/16/25/35/50/70/95/120/185/240/300/400 |
| **Allowed current outdoors (A)** | 33/45/58/80/107/135/169/207/268/328/383/444/510/607/703/823 |

| | |
|---|---|
| **Allowed current on a surface (A)** | 28/37/48/66/88/117/144/175/222/269/312/358/408/481/553/661 |

*Table 27. AC wiring connectors characteristics.*

In case of overload or malfunction of the system, in order to protect the installation and people is necessary to introduce protections in both the DC and AC sides. All installations that transform any type of energy into electricity must comply with the stipulations of the ITC BT-40 [37].

### 6.5.3 DC PROTECTIONS

The selected fuse for the protection of the system in the DC side, facing overload presents a current limit of 30 A, since the one the fuse will break not letting the current pass through. As it is the same wires for every building, the same fuse will be used. The model is ZR-VCC (14X85) DE 30A GPV (Figure 34).


*Figure 34. Fuse ZR-VCC (14X85) of 30A.*

A Type 2 Discharge Protective System (DPS), characterized by its utilization of varistors or Zener diodes, wherein the impedance exhibits a gradual reduction with escalating voltage, has been selected to safeguard against direct current (DC) overvoltage within the context of the photovoltaic installation. The device selected is DC 1000V 40KA from the series MD BF3-40 (Figure 35).


*Figure 35. Type 2 DPS, MD BF3-40 DC 1000V 40KA.* [42]

### 6.5.4 AC PROTECTIONS

Four types of protections are installed on the AC side, because of the higher currents on the system:

- Magnetothermal switch for the protection facing short-circuits and overloads shown in Table 19 (Figure 377).
- Differential switch for the derivations detection and protection to people facing direct contacts, in Table 28.
- Discharge protective system, selected the model DEHNguard SE H 1000 FM (Figure 36) of 40 kA.
- In the main busbar that will allow the cutting of the entire installation, an automatic switch, using the same magnetothermal switches designed for the short-circuits.

| Inverter Model | Magnetothermal switch breaker | Differential switch breaker |
|---|---|---|
| **SUN2000-300KTL-H0** | CVS500F TM500D | MCCB DPX3 1600 800A 300mAh |
| **SUN2000-250KTL-H0** | CVS500F TM500D | MCCB DPX3 1600 800A 300mAh |
| **SUN2000-215KTL-H3** | CVS400F TM400D | DPX3 630MT 4P 630A 300mAh |
| **SUN2000-185KTL-H0** | CVS320B TM320D | DPX3 630MT 4P 500A 300mAh |
| **SUN2000-115KTL-M2** | CVS250B TM250D | DPX3 630MT 4P 400A 300mAh |
| **SUN2000-100KTL-M2** | CVS200B TM200D | DPX3 630MT 4P 320A 300mAh |
| **SUN2000-90KTL-M1** | CVS160B TM160D | DPX3 630MT 4P 250A 300mAh |
| **SUN2000-75KTL-M1** | CVS125B TM125D | DPX3 250 4P 200A 300mAh |
| **SUN2000-60KTL-M1** | CVS125B TM125D | DPX3 250 4P 200A 300mAh |
| **SUN2000-50KTL-M1** | CVS100B TM100D | DPX3 250 4P 160A 300mAh |
| **SUN2000-40KTL-M3** | CVS80B TM80D | DPX3 160 4P 125A 300mAh |
| **SUN2000-30KTL-M3** | CVS63B TM63D | DPX3 250 4P 100A 300mAh |
| **SUN2000-20KTL-M3** | CVS40B TM40D | DPX3 160 4P 63A 300mAh |
| **SUN2000-15KTL-M2** | CVS25B TM25D | DPX3 250 4P 40A 300mAh |
| **SUN2000-10KTL-M2** | CVS25B TM25D | DPX3 250 4P 40A 300mAh |

*Table 28. Magnetothermal and differential switches modules for each inverter.*

*Figure 36. DPS, DEHNguard SE H 1000 FM*[59]

*Figure 37. Magnetothermal switch* [43]

### 6.5.5 GROUND CONNECTIONS

Grounding is an essential element because it protects both people and equipment from electrical hazards. Its main functions are to limit the voltage of the metallic masses with respect to ground, to ensure the performance of the protections and to eliminate the risk due to a failure in the electrical materials used. The following elements have been selected for the grounding section.

For both the protection connectors and equipotential connectors the model of wires used are the same as for the AC wiring, the X-VOLT RHZ1 (S) Cu/OL/2OL, the elements used for the ground system are:

| | |
|---|---|
| **Protection connectors ($mm^2$)** | 4/5/8/16/18/25/35/48/60/93/120/150/200 |
| **Equipotential connectors ($mm^2$)** | 2/2.5/4/8/9/22/17/24/30/46/60/75/100 |
| **Grounding connectors ($mm^2$)** | 4/5/8/16/18/25/35/48/60/93/120/150/200 |
| **Electrodes** | Grounding spike, copper coated |

*Table 29. Elements specifications of the grounding connections.*

# CHAPTER 7. SIMULATION RESULTS

## 7.1. SYSTEM ELECTRICITY GENERATION

As illustrated in Figure 38, a summary of Table 30 is provided here for visual clarity. In this representation, the energy bill load is depicted in blue, the energy acquired from the grid in orange, the energy generated from the PV system and utilized to meet the University's demand in grey, the surplus energy sold to the retailer in yellow, and the total energy production in green. The energy output from the system exhibits notable variations among different months, primarily due to the rooftop system, which experiences the most significant fluctuations throughout the year.

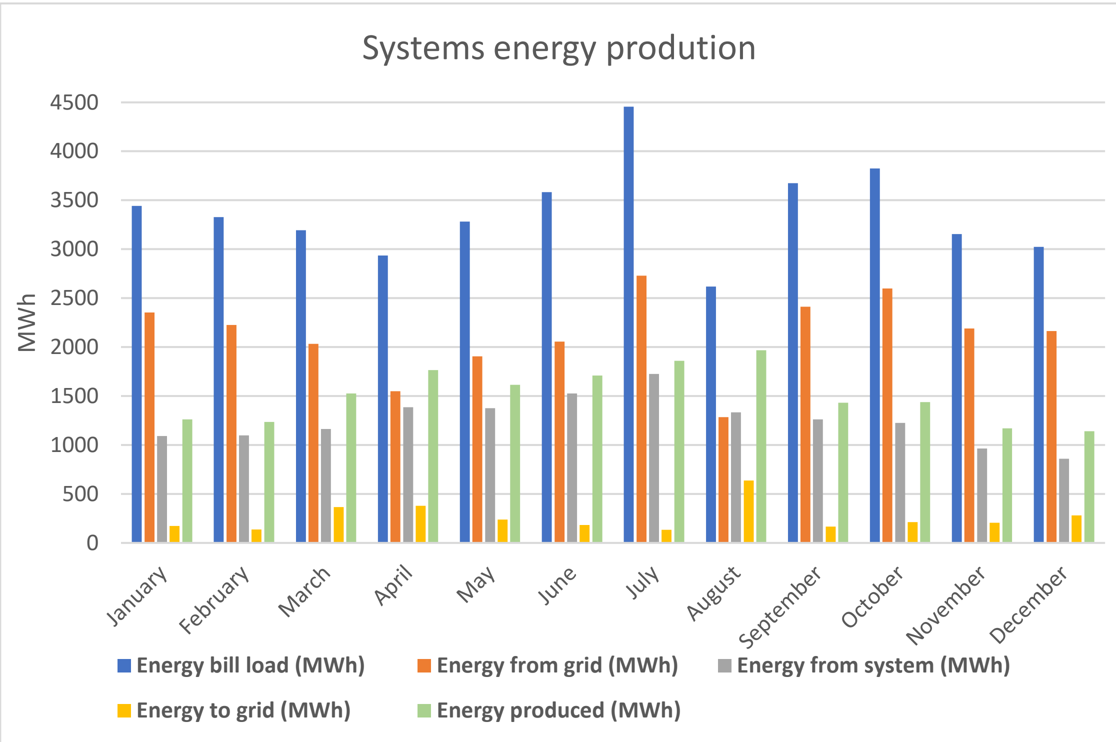



*Figure 38. Monthly energy load, from grid, to grid and production.*

The electricity production significantly impacts the energy consumption within UPV. The months with higher production, such as April (1,765.59 MWh) and July (1,860.35 MWh), also coincide with the periods of increased energy utilization within the University, especially in April, May, and June, with coverage rates of 47.23%, 41.94%, and 42.64%, respectively, shown in both Table 30 and Table 31. August represents the month with the highest energy production, totaling 1968.89 MWh. However, during this month, as previously mentioned in Section 2, the University remains closed, with only some buildings operational, resulting in a reduced energy demand, which is also reflected in the energy utilization from the PV system.

| Month | Energy bill load (MWh) | Energy from grid (MWh) | Energy from system (MWh) | Energy to grid (MWh) | Total Energy production (MWh) |
|---|---|---|---|---|---|
| **January** | 3,444 | 2,354 | 1,090 | 172 | 1,262 |
| **February** | 3,326 | 2,228 | 1,099 | 136 | 1,234 |
| **March** | 3,194 | 2,032 | 1,162 | 365 | 1,528 |
| **April** | 2,936 | 1,550 | 1,387 | 379 | 1,766 |
| **May** | 3,281 | 1,905 | 1,376 | 239 | 1,615 |
| **June** | 3,583 | 2,055 | 1,528 | 182 | 1,710 |
| **July** | 4,455 | 2,729 | 1,726 | 135 | 1,860 |
| **August** | 2,617 | 1,284 | 1,333 | 636 | 1,969 |
| **September** | 3,676 | 2,412 | 1,263 | 167 | 1,430 |
| **October** | 3,824 | 2,599 | 1,225 | 213 | 1,438 |
| **November** | 3,154 | 2,189 | 965 | 206 | 1,172 |
| **December** | 3,022 | 2,163 | 860 | 281 | 1,141 |
| **Annual** | 40,514 | 25,500 | 15,014 | 3,112 | 18,126 |

*Table 30. Load, Production and energy distribution from the system (first year).*

Energy obtained from the grid is a consequence of the energy production and the energy demand. Throughout the year, the University consistently consumes more electricity from the grid than it acquires from the PV installation. Moreover, during months with lower energy generation, such as January, February, September, October, November, and December, the percentage of energy obtained from the grid is close to 70%.

The scenario for surplus energy sold back to the retailer deviates from the aforementioned trends. Here, the timing of electricity generation and demand plays a more significant role. Summer months, when energy generation is high, do not result in a surplus energy surplus as seen in the winter months. Instead, winter months see a higher percentage of energy sold back to the grid, with selling percentages of 14.82%, 17.62% for October, November respectively, compared to the 10.67% and 7.23% seen in June and July, percentages in reference to the monthly energy production, represented in Table 31. This difference is explained by the increased demand for cooling during hot months. The months with the highest surplus energy are August, due to the institution's inactivity, as well as April, May and December, with percentages of 32.31%, 23.91%, 21.45% and 24.65 of the total generation. In the case of April and May, this phenomenon occurs because production increases during the central hours of the day while demand remains low, as there is no need for refrigeration or heating systems.

| Month | E.from Grid/Load (%) | E.from System/Load (%) | E.to Grid/E. Generation (%) |
|---|---|---|---|
| **January** | 68.34% | 31.66% | 13.63% |
| **February** | 66.98% | 33.02% | 11.00% |
| **March** | 63.62% | 36.38% | 23.91% |
| **April** | 52.77% | 47.23% | 21.45% |
| **May** | 58.06% | 41.94% | 14.82% |
| **June** | 57.36% | 42.64% | 10.67% |
| **July** | 61.26% | 38.74% | 7.23% |
| **August** | 49.08% | 50.92% | 32.31% |
| **September** | 65.63% | 34.37% | 11.70% |
| **October** | 67.96% | 32.04% | 14.82% |
| **November** | 69.40% | 30.60% | 17.62% |
| **December** | 71.55% | 28.45% | 24.65% |
| **Annual** | 62.94% | 37.06% | 17.17% |

*Table 31. Energy from Grid, Energy from System and Energy to grid in percentages.*

In summary, out of the annual energy consumption of 40,513 MWh, 62.94%% (25,499.98 MWh) is sourced from the grid, while 37.06% (15,013.64 MWh) is provided by the PV system. Additionally, 17.17% (3,112.49 MWh) of the total energy demand is sold back to the grid. These relatively low figures can be attributed to two primary factors. Firstly, the lower percentage is influenced by nighttime electricity consumption when the panels are not actively generating power. When excluding nighttime energy consumption from the analysis, the proportion of energy derived from the PV system corresponds to 42.12% of the total demand. Secondly, despite the façade system having 27.67% more installed capacity than the rooftop system, it produces 7,610 MWh, which is 39.2% less than the 10,593 MWh generated by the rooftops with 6,297 kW of capacity.

**Energy production per system**

The simulations reveal that, per array, the rooftop installation proves to be the most efficient and productive, generating 10,320 MWh annually, accounting for 56.93% of the total energy generation (Table 32 and Figure 39). In contrast, the results for the façade system are less optimistic. Despite having 27.67% more installed capacity, the annual production is only 43.07%, resulting in 7,806 MWh of generated energy. The façade system's production is distributed as follows: 3,748 MWh for the South array, 2,302 MWh for the East array, and 1,756 MWh for the West array.

Table 32 presents the monthly production from rooftops and façades in comparison to the total production. It is noticeable that, while the absolute production varies throughout the year, with the highest total production occurring in August at 1,969 MWh and the lowest in December at

1,141 MWh, the proportional contribution remains relatively stable across the months. The fluctuations are within 5.18% for rooftops and 6.85% for façades, with the most significant variations observed in December.

| Month | Energy production Rooftops (MWh) | Energy production South (MWh) | Energy production East (MWh) | Energy production West (MWh) |
|---|---|---|---|---|
| **January** | 688 | 357 | 148 | 70 |
| **February** | 677 | 314 | 148 | 96 |
| **March** | 872 | 329 | 195 | 132 |
| **April** | 1,022 | 328 | 231 | 185 |
| **May** | 943 | 263 | 207 | 202 |
| **June** | 1,005 | 247 | 224 | 234 |
| **July** | 1,103 | 271 | 251 | 235 |
| **August** | 1,146 | 344 | 261 | 218 |
| **September** | 812 | 295 | 186 | 137 |
| **October** | 798 | 350 | 177 | 114 |
| **November** | 638 | 319 | 140 | 73 |
| **December** | 616 | 331 | 133 | 61 |
| **Annual** | 10,320 | 3,748 | 2,302 | 1,756 |

*Table 32. Monthly electricity generation per array.*

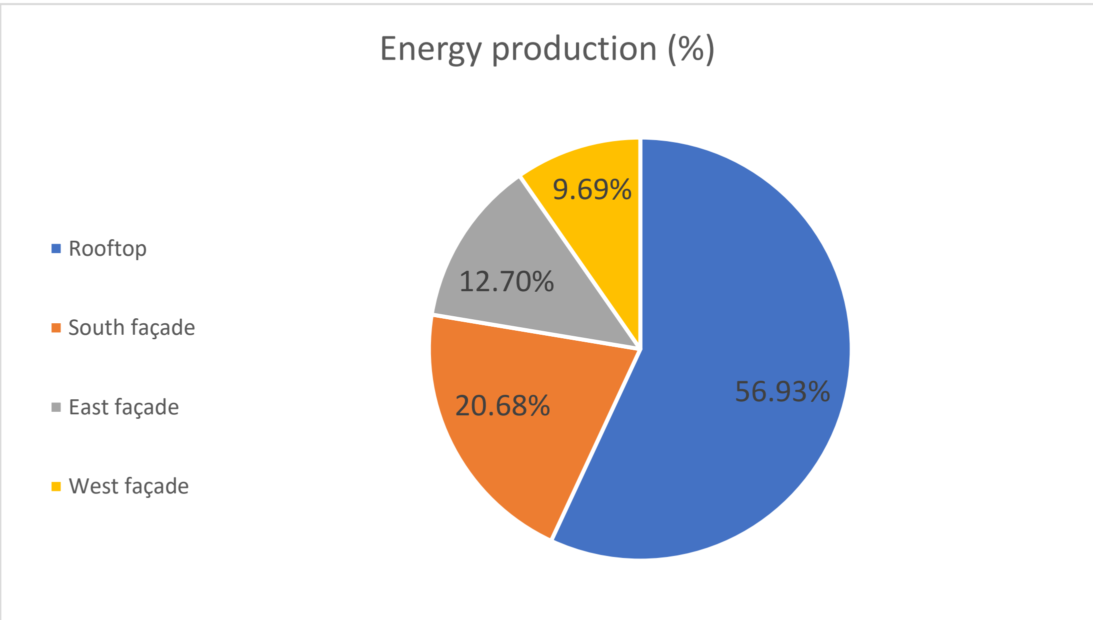



*Figure 39. Energy generation percentage distribution.*

| Month | Rooftops production (MWh) | Façades production (MWh) | Total production (MWh) | % Rooftops production/ Total | % Façades production/ Total |
|---|---|---|---|---|---|
| **January** | 688 | 575 | 1,262 | 54.48% | 45.52% |
| **February** | 677 | 558 | 1,234 | 54.83% | 45.17% |
| **March** | 872 | 656 | 1,528 | 57.06% | 42.94% |
| **April** | 1,022 | 744 | 1,766 | 57.89% | 42.11% |
| **May** | 943 | 672 | 1,615 | 58.38% | 41.62% |
| **June** | 1,005 | 705 | 1,710 | 58.79% | 41.21% |
| **July** | 1,103 | 758 | 1,860 | 59.27% | 40.73% |
| **August** | 1,146 | 823 | 1,969 | 58.21% | 41.79% |
| **September** | 812 | 618 | 1,430 | 56.77% | 43.23% |
| **October** | 798 | 640 | 1,438 | 55.49% | 44.51% |
| **November** | 638 | 533 | 1,172 | 54.48% | 45.52% |
| **December** | 616 | 525 | 1,141 | 53.98% | 46.02% |
| **Annual** | 10,320 | 7,806 | 18,126 | 56.93% | 43.07% |

*Table 33. Monthly production per Array and percentage.*

The results presented earlier are in absolute figures, but a more insightful perspective can be gained by examining Table 33, where the production is normalized by the installed power for each array. Firstly, a consistent trend is observed where the rooftop array proves to be the most efficient, with an annual average of 1,638 kWh produced per kW installed. This varies from 182 kWh/kW in August to 98 kWh/kW in December, influenced by the sun's position.

| Month | Energy production Rooftops (kWh/kW) | Energy production South (kWh/kW) | Energy production East (kWh/kW) | Energy production West (kWh/kW) |
|---|---|---|---|---|
| **January** | 109 | 103 | 57 | 26 |
| **February** | 107 | 91 | 58 | 36 |
| **March** | 138 | 95 | 76 | 49 |
| **April** | 162 | 95 | 90 | 69 |
| **May** | 150 | 76 | 80 | 75 |
| **June** | 160 | 71 | 87 | 87 |
| **July** | 175 | 79 | 98 | 88 |
| **August** | 182 | 100 | 101 | 81 |
| **September** | 129 | 85 | 72 | 51 |
| **October** | 127 | 101 | 69 | 42 |
| **November** | 101 | 92 | 55 | 27 |
| **December** | 98 | 96 | 52 | 23 |
| **Annual** | 1,638 | 1,085 | 894 | 655 |

*Table 34. Monthly energy production per kW installed and per array.*

Secondly, the South façade system's production increases during the winter months when it takes advantage of the low sun positions, resulting in lower efficiencies during the summer months when the sun's rays are less perpendicular to the modules. This is evident in January, with a production of 103 kWh/kW, which is only 5.29% lower than the rooftop array's generation for the same period, or in June with 71 kWh/kW of energy production when the difference ascends to a 44.38% lower.

Thirdly, the East façade array exhibits higher production numbers during the summer months, reaching 101 kWh/kW in August and 52 kWh/kW in December as the least favorable month during the winter period.

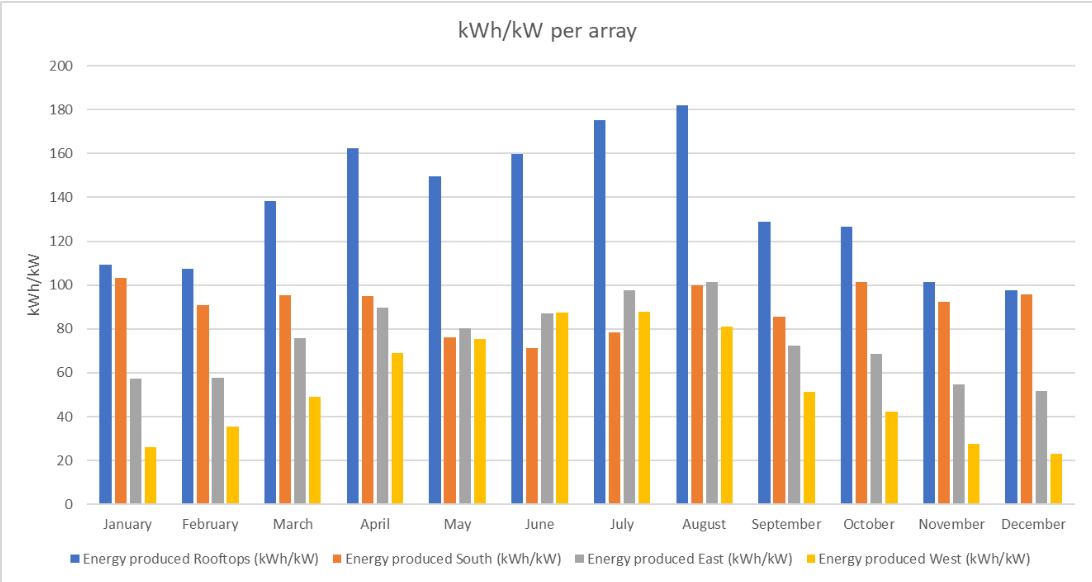



*Figure 40. Monthly kWh production divided by kW installed per array*

Lastly, a similar trend is observed in the West array, although its production numbers are lower in every month. This pattern for the East and West arrays is explained by the sun's position and duration. During the summer months, even though the sun is at a higher position, the days are longer, particularly noted in the early and late hours of the day when the East and West orientations receive more sunlight. In Figure 40 is represented every array's production per kW of power installed.

### 7.2. PHOTOVOLTAIC MODULES DEGRADATION

As was expressed in the panel selection section, the modules present an annual electricity production degradation, starting with 2% for the first year and in the following years a reduction of 0.55% annually, as the fabricant details. This means that after 26 years in the lifetime of the plant the electricity generation would be reduced a 16.45% in comparison to the first year, as can be seen in Figure 41 where the production for the last year amounts to 15,368 MWh.

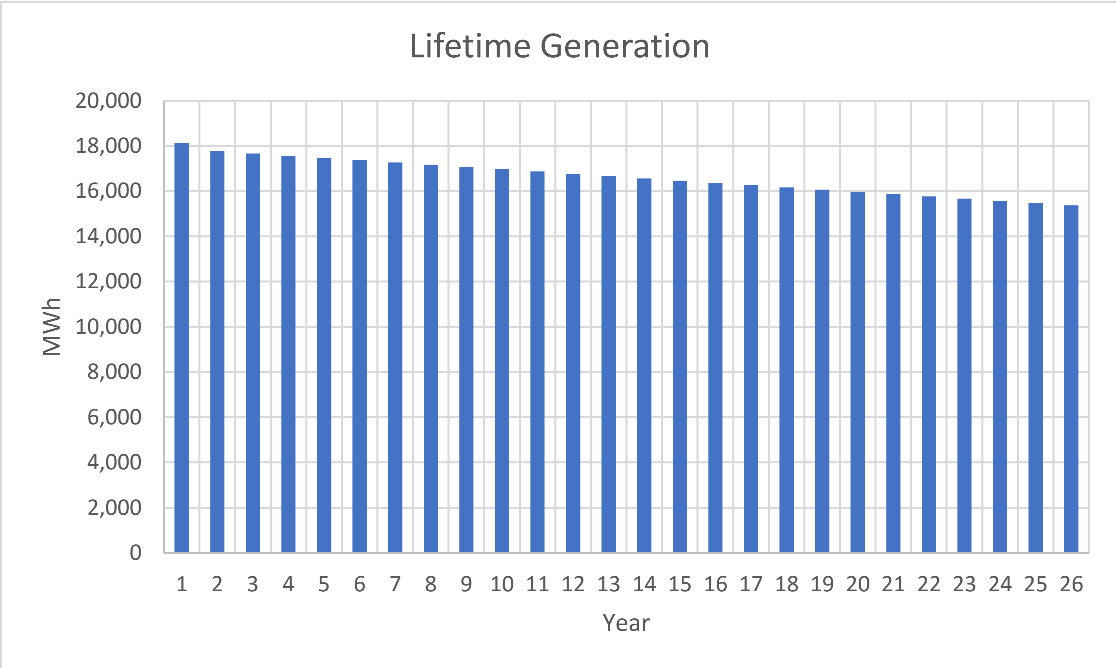



*Figure 41. Lifetime generation of the plant.*

## 7.3. DAILY PROFILES

In Figure 42, it is presented the average daily, electricity generation profiles for each one of the four subarrays, including the total system generation, and the electricity load. The data pertains to the month of January. The orange profile illustrates the aggregate electricity generated, encompassing all four subarrays of the system. Notably, during midday hours, particularly around 13:00, the production exceeds 6,000 kW, almost covering the current electricity load. As anticipated, the rooftop panels exhibit the highest electricity generation, benefiting from their optimal tilt angle. The peak power generation surpasses 4,000 kW, occurring during midday and aligning with the system profile.

Interestingly, the vertical arrays display distinct profiles worth noting. The South array emerges as the highest producer due to its orientation and the favorable incident angle of the winter sun rays. The peak power generation exceeds 2,000 kW, also manifesting during midday hours, albeit slightly delayed due to a 20-degree positive rotation of the University buildings.

On the other hand, the East façade array attains its peak generation earlier than the other arrays, around 11:00, owing to its azimuth orientation of 110 degrees, generating approximately 1,200 kW.

The East and West arrays ideally should yield comparable electricity and exhibit similar profiles, albeit phased throughout the day. However, due to the 20-degree rotation of both the South and East façades, the West surfaces align closer to the North orientation, resulting in an azimuth of 290 degrees. This shift leads to a reduction in production for the West array as less sun hours its receiving.

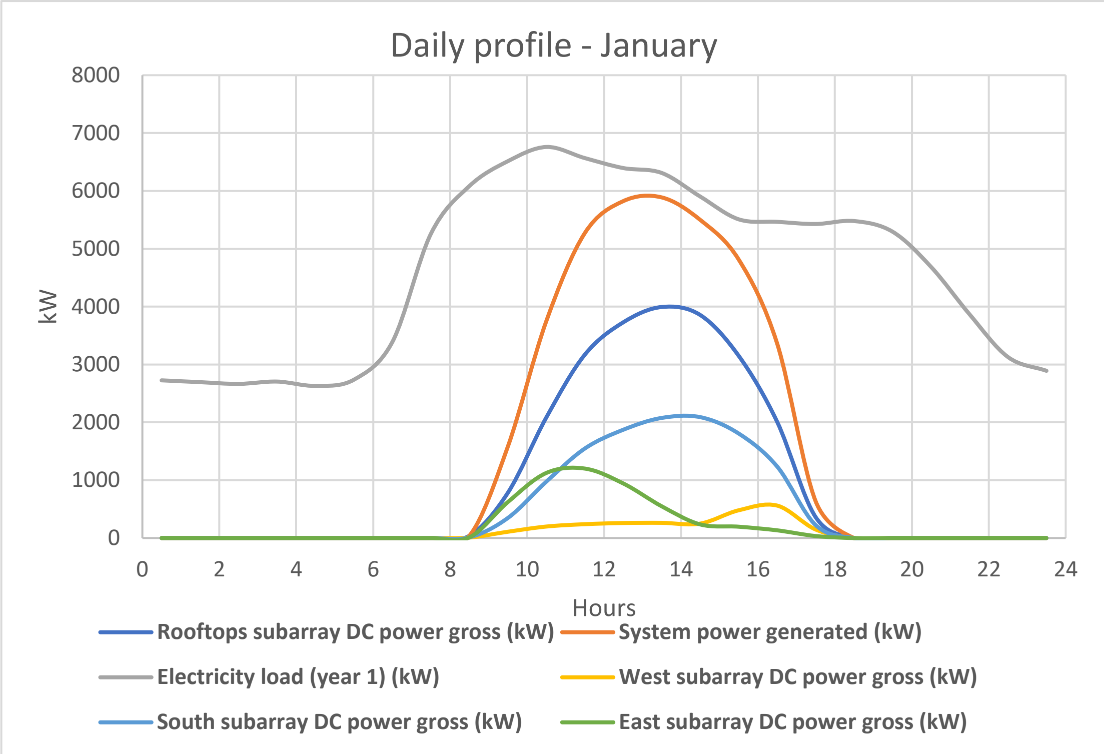



*Figure 42. Daily energy profiles of the system generation and demand in a reference day of January.*

In comprison to January there this next figure:

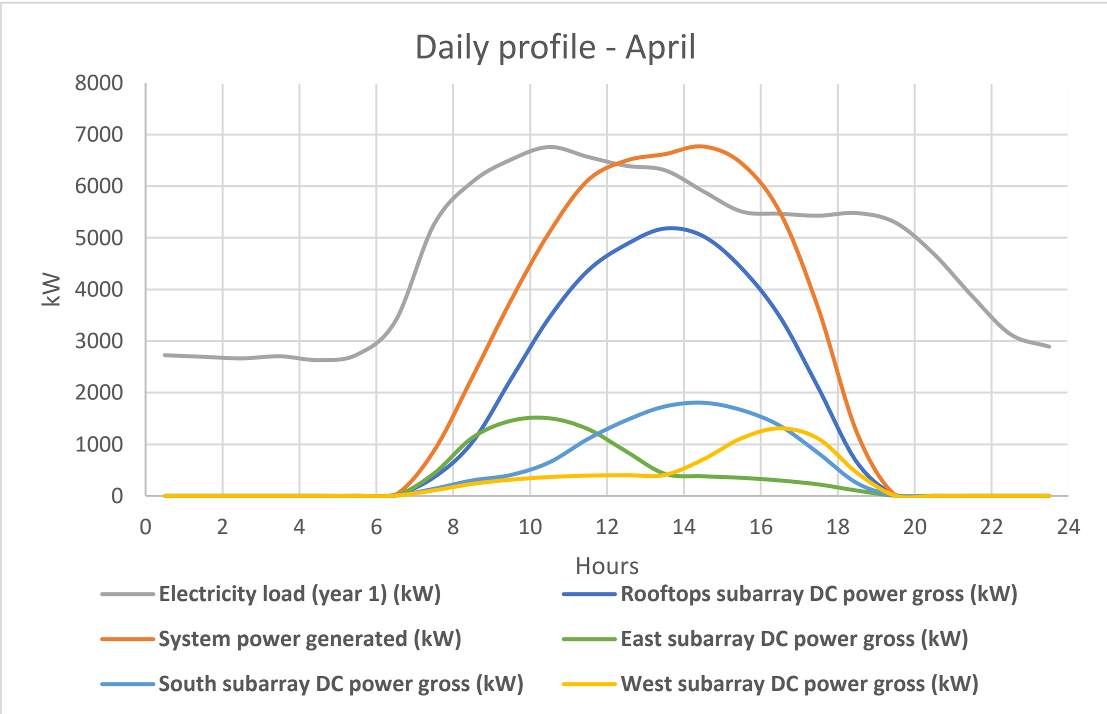



*Figure 43. Daily energy profiles of the system generation and demand in a reference day of April.*

The electricity generation profile for the month of April in Figure 43 exhibits distinct characteristics owing to the changing incidence angle of the sun rays as summer approaches. As the sun rays become more perpendicular to the horizontal axis, certain peculiarities are evident. The rooftop array experiences a notable increase of approximately 1000 kW in peak production compared to January. Conversely, the South façade array sees a reduction in peak production by almost 200 kW relative to January due to the reduced direct radiation from the sun on the vertical axis.

In the case of the East façade array, the profile resembles that of January, yet with an increased peak production attributed to longer hours of sunlight per day. The effect of extended sun hours is particularly pronounced in the West façade, resulting in an almost 1000 kW increase in peak production compared to the January profile.

Overall, the system's generated power surpasses the demand during mid-day hours, allowing for not only complete coverage of the demand but also the potential to sell excess energy production back to the retailer.

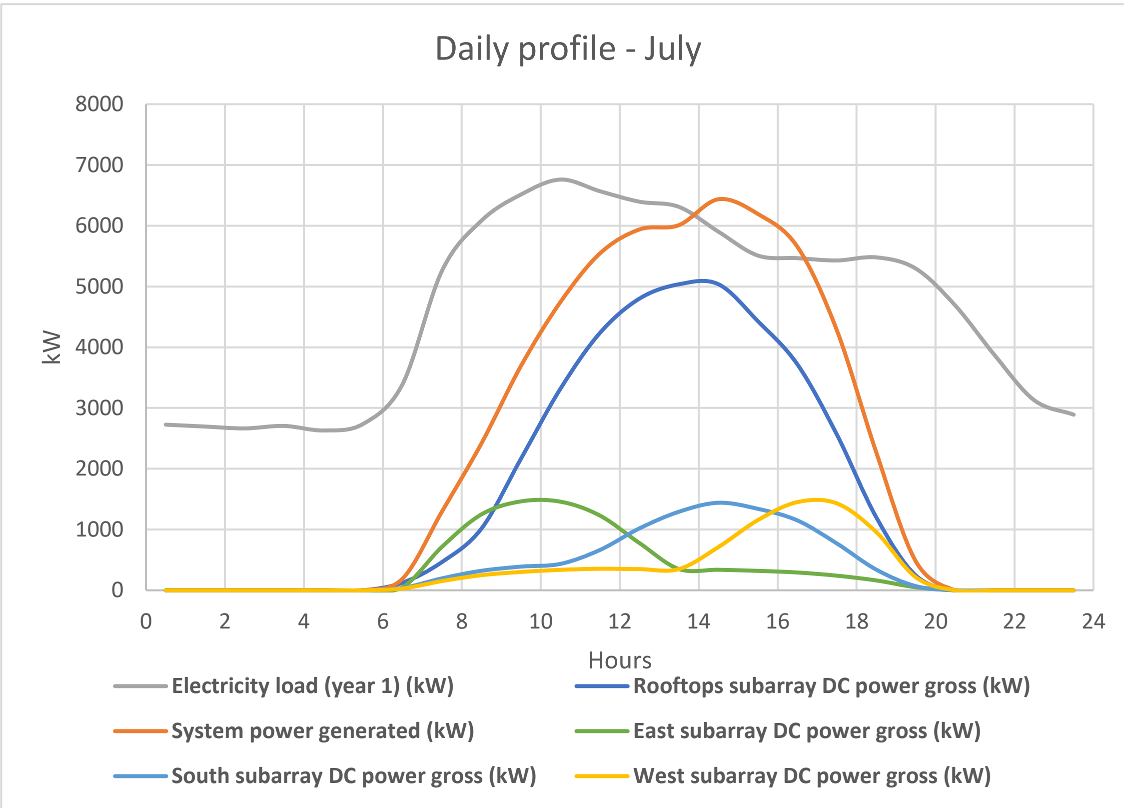



*Figure 44. Daily energy profiles of the system generation and demand in a reference day of July.*

The electricity generation profile for the month of July in Figure 44, continues the trends observed in April. The rooftop array maintains a similar pattern, as do the East and West arrays, with a slight increase in peak generation, particularly noticeable in the West system. However, the most prominent peculiarity is the decrease in generation from the South façade. This reduction is attributed to the high perpendicularity of the sun rays' incidence, impacting the efficiency of the South façade array.

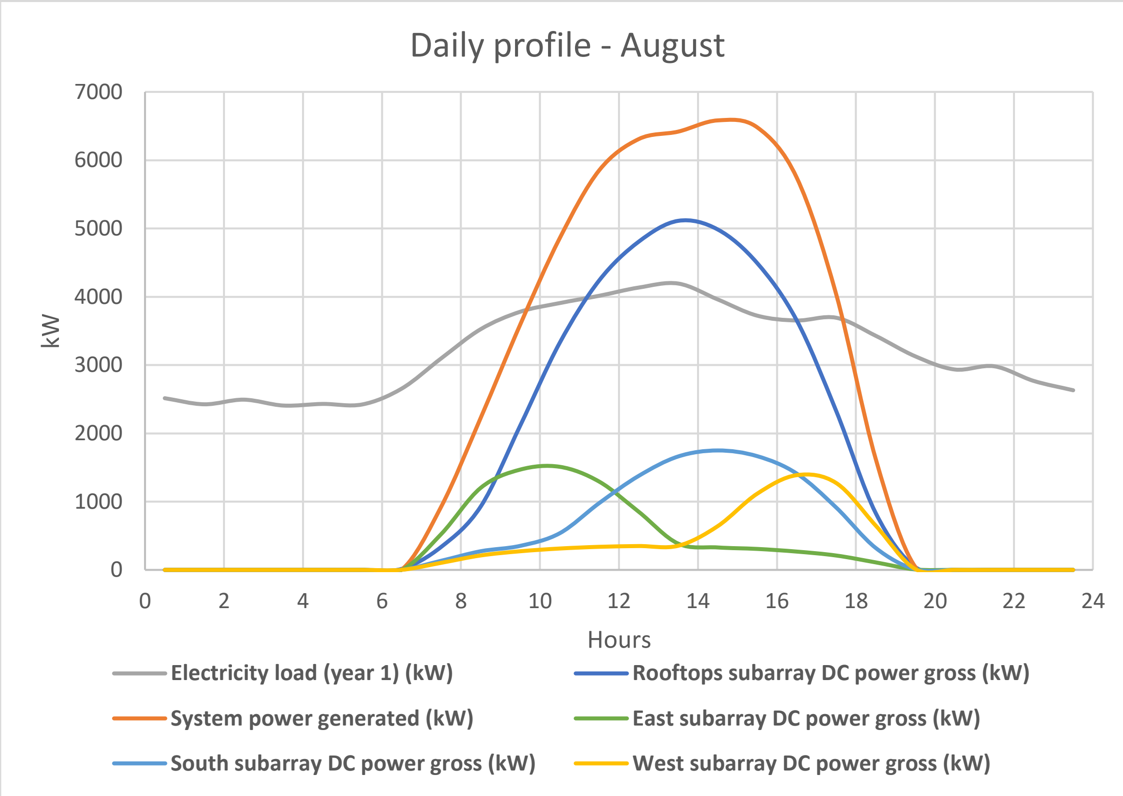



*Figure 45. Daily energy profiles of the system generation and demand in a reference day of August.*

The case of August is the most special at the University, during this month it is mixed the highest annual production while the lowest electricity consumption, Figure 45. In August the University is closed, only some departments, laboratories and researching buildings are still working, affecting directly to the demand, meaning that from, approximately since 9:00 AM to 17:00 PM the PV plant fully cover the energy consumption and furthermore, during the mid-day hours the production excess amounts to 2.300 kW, permitting the sold of this energy. This month presents a similar production as July in every system, however there is an increase in the South facade production due to the decrease in the angle of the rays inclination.

The electricity generation profile for October in Figure 46, closely resembles that of April, with a mirrored trend due to the changing angle of sun rays as they become less perpendicular, and the day receives fewer sunlight hours. The main differences lie in a generally lower peak production, resulting from the sun being in a different position during these months. Consequently, there is a higher non-correlation observed between the East and West profiles. Given the predictable nature of these trends and the anticipation of similar profiles or variations in other months, a detailed analysis of each additional month is deemed redundant and unlikely to yield more relevant information.

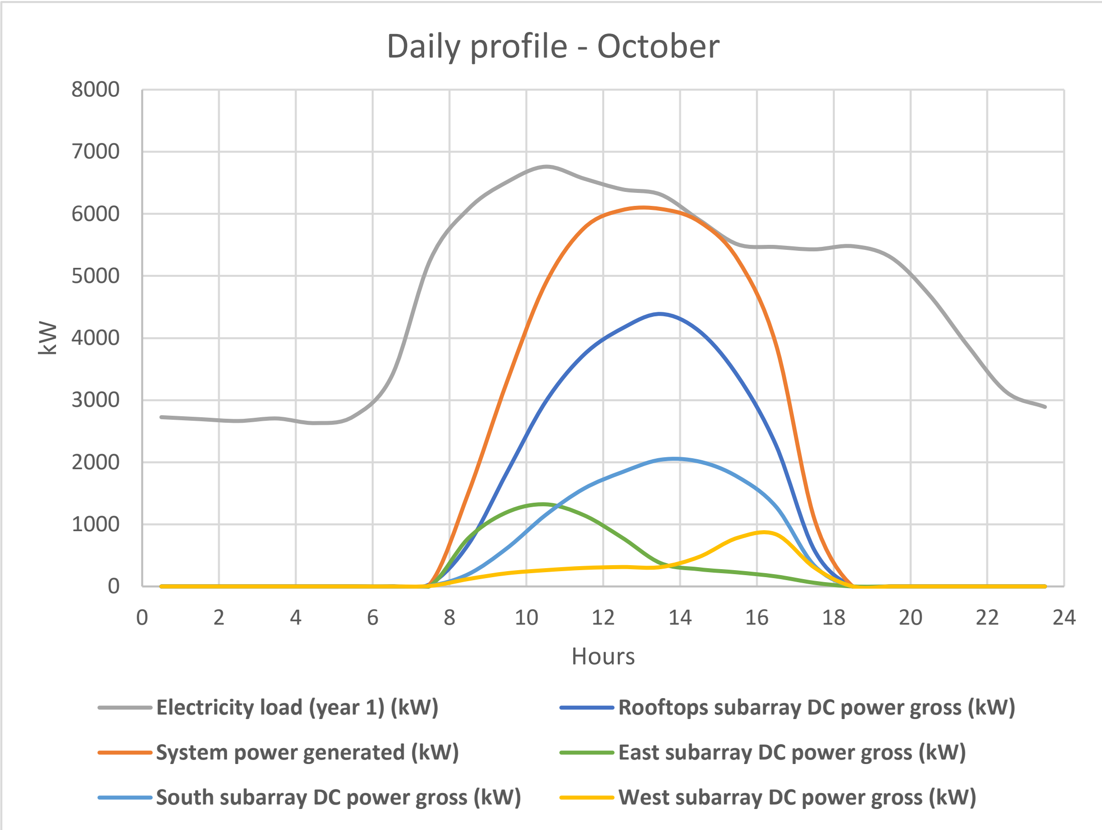



*Figure 46. Daily energy profiles of the system generation and demand in a reference day of October.*

A special case happens in June, this is the only month that the production in the West array is higher than the East array, however this difference is almost insignificant of 10 kWh with 224 kWh and 234 kWh of generation for the East and West systems respectively (Table 34). Examining the Irradiation profiles, a typical day, as the 12$^{th}$ of June can be seen in the Figure 47. Here is appreciated that both the East and West arrays present a similar trend, receiving 700 Watts of radiation per square meter of panels installed, only a slightly higher peak irradiation is appreciated for the East side. The justification for increase of production comes, apart from the higher peak power installed on the West array, from the weather, which, for this month presents a higher number of cloudy periods during the first hours of the day, in opposite of the bright periods during the latter hours. In annexes is represented  a chart with the mean Irradiation for June, observing that in average the West array receive more radiation than the East array.

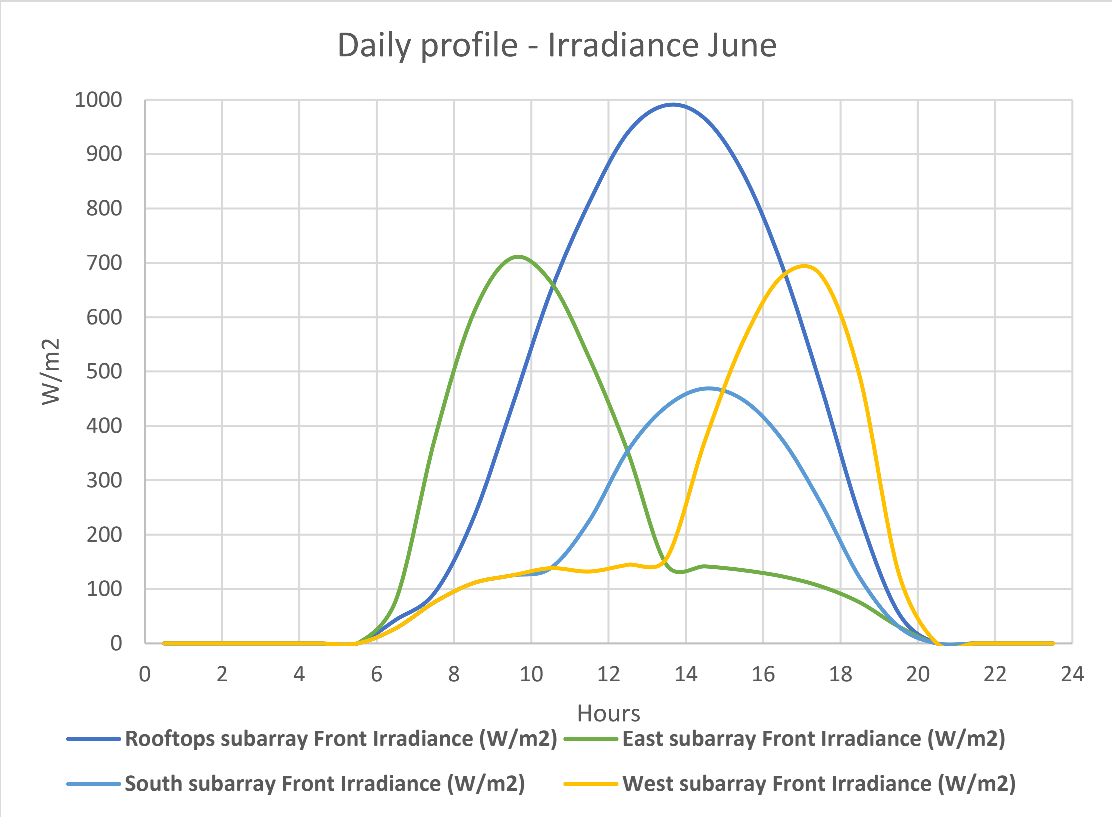



*Figure 47. Irradiation per array profiles on the 12th of July.*

### 7.4. CO2 EMISSIONS REDUCTION

The energy production by PV panels is considered as a green, renewable and sustainable energy [44]. During the process of electricity generation, no greenhouse gasses are generated so the energy from the grid replaced by the generated in the plan, that in some part does not come from renewable sources emitting $CO_2$, would not be generated leading to a reduction in emissions.

The Spanish energy mix is represented in Figure 48, where the red line represents the monthly tons of $CO_2$ equivalents per MWh of electricity production. The mean from November of 2022 to October of 2023 amounts to 0.13 $tCO_2$ eq./MWh, factor used for the following calculations. The first year of the installation the 18,128 MWh generated, suppose a reduction of 2,356.63 $tCO_2$ eq. and after 25 years of usage the total emissions avoided amounts to 56,198.20 $tCO_2$ eq. In the annexes there is data with every year's emissions avoided.

The University's most recent emissions report is from 2019 [3], the total emissions counting electricity, transporting, gas consumption, waste, etc. amounted to 11,219 $tCO_2$ eq. leading the plant to reduce the UPV's CO2 equivalent emitted in 21.01%. Furthermore, this data can be related to the neighborhood of "La Carrasca" of whom the UPV is part from and is responsible of two thirds of its electricity demand, the annual neighborhood electricity demand is 60,761 MWh [45]. In total "La Carrasca" emissions amount to 62,513.9 $tCO_2$ eq. per year [45] including gas consumption, electricity, transportation, and all every kind of emission, the PV plant would reduce the emissions in 3.77% in the neighborhood, a small number considering most of them come from other sources apart from electricity consumption [45].

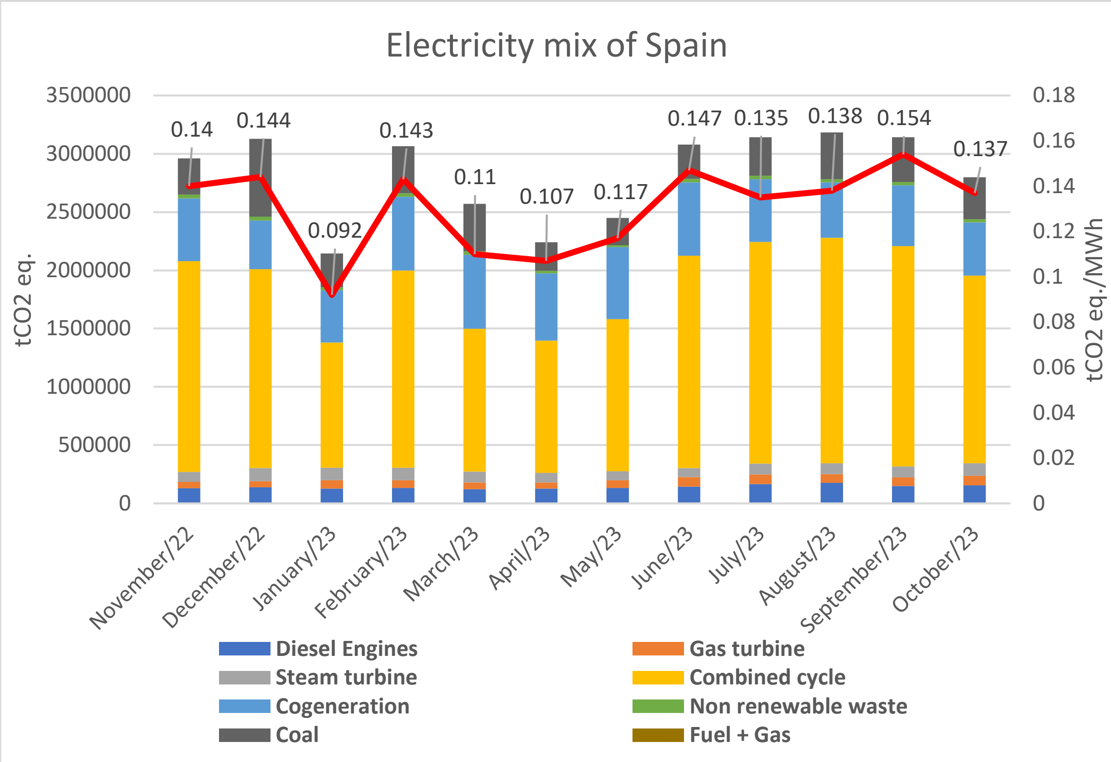



*Figure 48. Spanish electricity mix from Nov/22 to Oct/23* [46].

# CHAPTER 8. ECONOMIC FEASIBILITY ANALYSIS

The current electricity contract, as explained before, was negotiated in moments where the fees and the trend were excessively expensive leading to optimistic economic analyses that in the reality do not match with the real values. It has been simulated 3 scenarios, changing the electricity contract to adjust, with the most accuracy possible, to the future trend.

## 8.1. SCENARIO CURRENT CONTRACT

The economic values for this scenario are gathered in the following table:

| Component (€) | Investment (€) | Replacement (€) | O&M (€) | Total (€) |
|---|---|---|---|---|
| **PV system** | 15,220,487.00 € | - € | 9,088,150.00 € | 24,308,637.00 € |
| **Grid purchases** | - € | - € | 176,153,127.68 € | 176,153,127.68 € |
| **Surplus sales** | - € | - € | -8,075,521.96 € | -8,075,521.96 € |
| **Plant** | 15,220,487.00 € | - € | 177,165,755.72 € | **192,386,242.72 €** |

*Table 35. Lifetime plant costs OMIP 91.5 €/MWh*

| LCOE Levelized cost of energy (€/kWh) | 4.37 € |
|---|---|
| **Electricity bill without system (Total) €** | 267,986,472.51 € |
| **Electricity bill with system (Total) (€)** | 168,077,605.72 € |
| **Net savings with system (Total) (€)** | 99,908,866.79 € |
| **Net present value (€)** | 21,565,208.00 € |
| **Simple payback period (years)** | 4.2 |
| **Discounted payback period (years)** | 5.1 |
| **Return of investment (%)** | 17.4% |

*Table 36. Economic indicators OMIP 91.5€/MWh*

Following the simulation, SAM yields economic outcomes for the system, indicating a notably favorable discounted payback period of 5.1 years, particularly noteworthy considering the substantial installed power capacity. Nevertheless, it is imperative to underscore that the elevated electricity tariffs stipulated in the contractual agreement significantly amplify the procurement expenditures for energy, thereby resulting in higher total expenditure on electricity bills. This augmentation is primarily attributable to the elevated electricity rates. In total there is a reduction of 99,908,866.79 € after 25 years in the electricity bill using the photovoltaic system which at the end suppose a Return of investment (ROI%) of 17.4%.

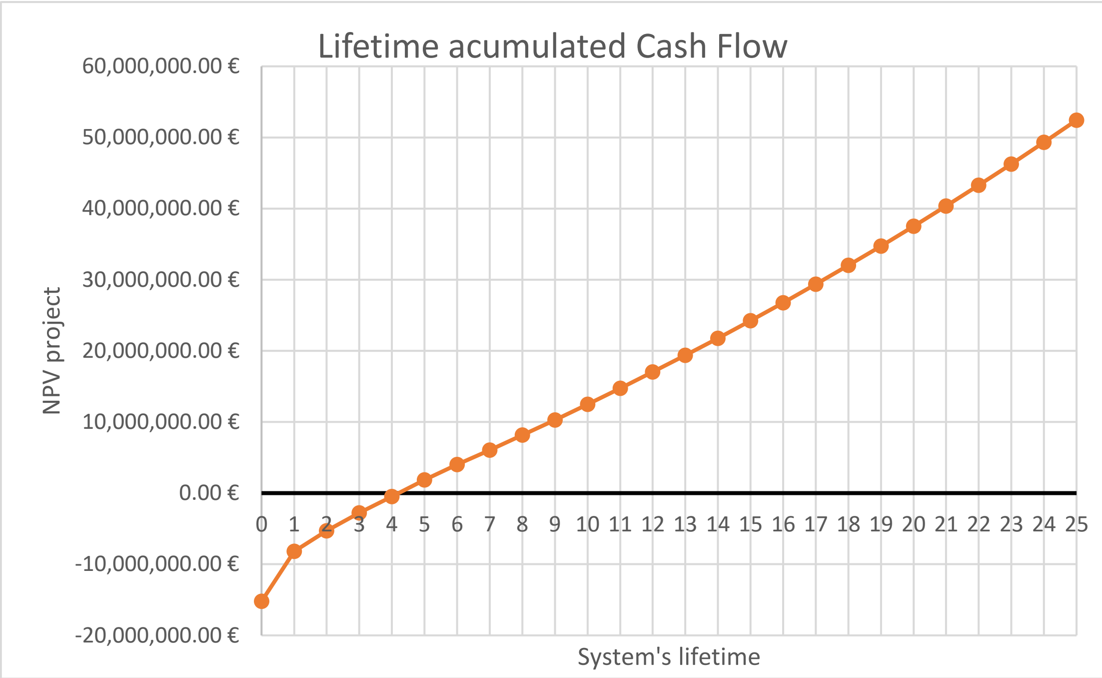



*Figure 49. Net present value evolution OMIP 91.5 €/MWh.*

In Figure 49 is represented the NPV (Net Present Value) of the project through the 25 years of the economic analysis. As it is the simple payback, it does not include the financial parameters of Inflation and discount rates, moreover the final value after 25 years differs from the one in the Table 36 because of the omission.

## 8.2. SCENARIO CURRENT CONTRACT WITH OMIP 55.8 €/MWH

| Component (€) | Investment (€) | Replacement (€) | O&M (€) | Total (€) |
|---|---|---|---|---|
| **PV system** | 15,220,487.00 € | - € | 9,088,150.00 € | 24,308,637.00 € |
| **Grid purchases** | - € | - € | 125,500,537.65 € | 125,500,537.65 € |
| **Surplus sales** | - € | - € | -4,928,090.72 € | -4,928,090.72 € |
| **Plant** | 15,220,487.00 € | - € | 129,660,596.93 € | **144,881,083.93 €** |

*Table 37. Lifetime plant costs OMIP 55.8 €/MWh.*

| LCOE Levelized cost of energy (€/kWh) | 4.73 € |
|---|---|
| **Electricity bill without system (Total) €** | 189,187,177.01 € |
| **Electricity bill with system (Total) (€)** | 120,572,446.93 € |
| **Net savings with system (Total) (€)** | 68,614,730.08 € |
| **Net present value (€)** | 10,221,426.00 € |
| **Simple payback period (years)** | 6.2 |
| **Discounted payback period (years)** | 8.6 |
| **Return of investment (%)** | 10.55% |

*Table 38. Economic indicators OMIP 55.8 €/MWh.*

In this case the simple payback shows a period of 6.2 years to make the system profitable which is a reasonable value, considering the number of years the plant is going to produce electricity, at least 25, profits would be obtained for more than 18 years. Moreover, the electricity prices instability, due to external factors, could not follow the trend showed in [35], as happened in 2021-2022, thus in opposite, an increase in the purchase price would be beneficial to the installation of the system, decreasing the payback time.

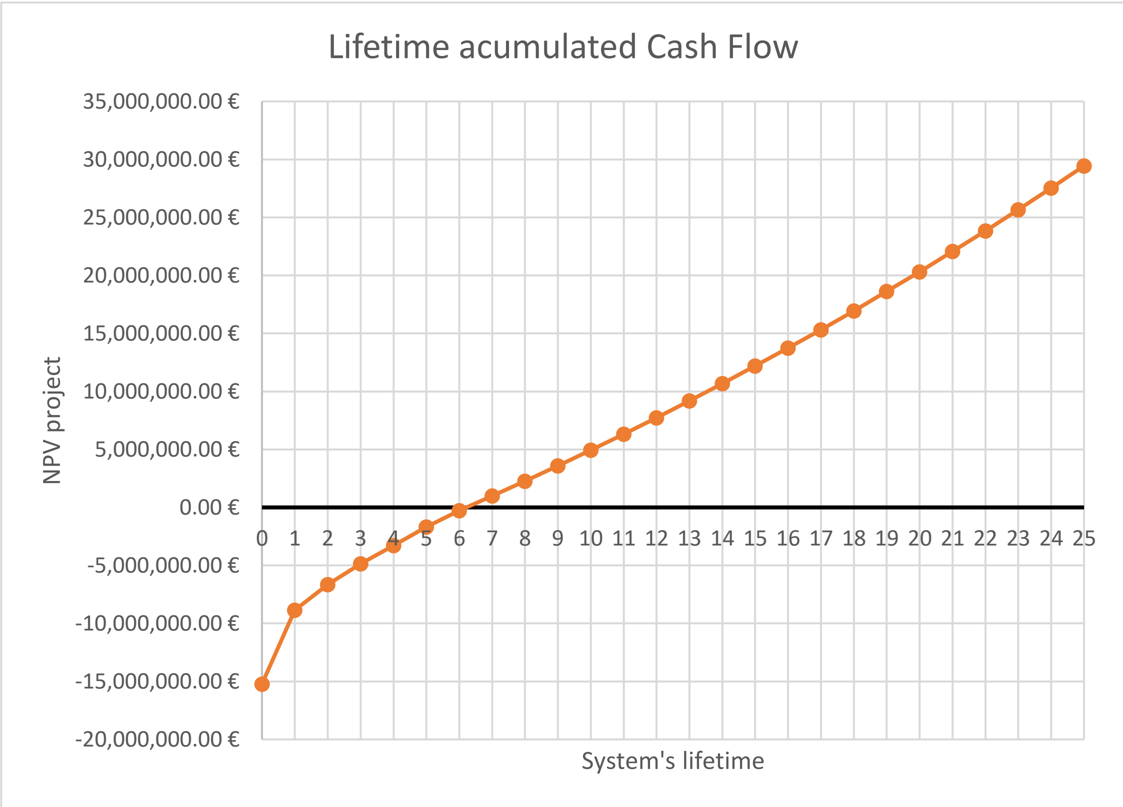



*Figure 50. Net present value evolution OMIP 55.8 €/MWh.*

Figure 50 shows the same characteristics as the one with OMIP 91.5 €/MWh, in does not include the financial parameters in the evolution. Finally, this system presents an acceptable ROI of 10.55%.

### 8.3. SCENARIO OMIP TREND 25 YEARS

In this case the initial electricity prices are the ones from the current UPV' contract , however as the years go through it has been supposed a trend, for the following 25 years, for the OMIP price [35] which multiplies the bill factors producing a reduction of the electricity fees.

In the case the lifetime cost of the plant are:

| Component (€) | Investment (€) | Replacement (€) | O&M (€) | Total (€) |
|---|---|---|---|---|
| **PV system** | 15,220,487.00 € | - € | 9,088,150.00 € | 24,308,637.00 € |

| | | | | |
|---|---|---|---|---|
| **Grid purchases** | - € | - € | 62,376,764.73 € | 62,376,764.73 € |
| **Surplus sales** | - € | - € | -3,020,893.02 € | -3,020,893.02 € |
| **Plant** | 15,220,487.00 € | - € | 68,444,021.71 € | **83,664,508.71 €** |

*Table 39. Lifetime plant costs following OMIP trend* [35].

| **LCOE Levelized cost of energy (€/kWh)** | **4.73 €** |
|---|---|
| **Electricity bill without system (Total) €** | 95,454,539.56 € |
| **Electricity bill with system (Total) (€)** | 59,355,871.71 € |
| **Net savings with system (Total) (€)** | 36,098,667.85 € |
| **Net present value (€)** | 619,289 € |
| **Simple payback period (years)** | 7.4 |
| **Discounted payback period (years)** | 16.2 |
| **Return of investment (%)** | 3.48% |

*Table 40. Economic indicators following OMIP trend* [35].

This scenario shows the payback period with 7.4 years. The reduction of the electricity prices plays the principal role in this large period. Moreover, presents the lowest cost savings from using the system with 36,068,667.85 € after 25 years, corresponding to a net present value of the system of 619,289 € and reflected in the lowest ROI% with 3.48%.

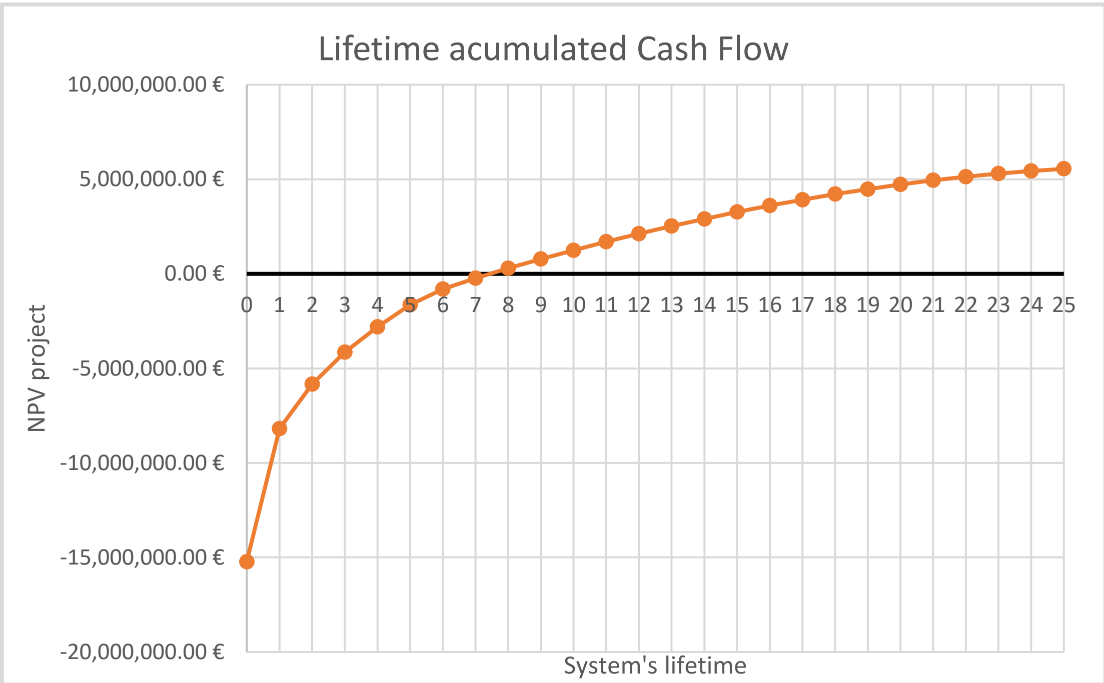



*Figure 51. Net present value evolution following OMIP trend* [35].

## 8.4. SCENARIO OMIP TREND EXCLUDING WEST FAÇADES

West façades, as it has been explained, are the ones with the lowest energy production per surface installed among the four subarrays, a simulation with its exclusion would be interesting to propose a new possibility of the system installation that although affects the energy production, presents better economic conditions.

| Annual production | Full system | System without West FAC |
|---|---|---|
| **Energy bill load (MWh)** | 40,514 | 40,514 |
| **Energy from grid (MWh)** | 25,500 | 26,616 |
| **Energy from system (MWh)** | 15,014 | 13,897 |
| **Energy to grid (MWh)** | 3,112 | 2,477 |
| **Energy production (MWh)** | 18,126 | 16,375 |
| **Percentage grid (%)** | 62.94% | 65.70% |
| **Percentage system (%)** | 37.06% | 34.30% |
| **Percentage to grid (%)** | 17.17% | 15.13% |

*Table 41. Energetic comparison between system with and W/O the West array.*

The energy comparison between the two simulations reveals an identical energy analysis. As depicted in Table 41, the 4 Arrays system generates a higher annual energy output, totaling 18,126 MWh, compared to the 16,375 MWh generated without the West panels. This disparity affects the energy drawn from the grid, the energy sourced from the PV system, and the energy sold to the retailer. It is worth noting that these variances constitute a relatively small portion of the total energy generation, resulting in a modest 2.76% fluctuation in grid/PV system energy utilization. Additionally, the surplus energy generation is reduced by 635 MWh, corresponding to a 2.04% decrease relative to the total generated.

| | Case 1 | Case 2 |
|---|---|---|
| **LCOE Levelized cost of energy (€/kWh)** | 4.73 € | 4.30 € |
| **Electricity bill without system (Total) €** | 95,454,539.56 € | 95,454,539.56 € |
| **Electricity bill with system (Total) (€)** | 59,355,871.71 € | 62,489,278.14 € |
| **Net savings with system (Total) (€)** | 36,098,667.85 € | 32,965,261.42 € |
| **Net present value (€)** | 619,289 € | 1,906,478.00 € |
| **Simple payback period (years)** | 7.4 | 5.8 |
| **Discounted payback period (years)** | 16.2 | 10.2 |
| **Return of investment (%)** | 3.48% | 6.02% |
| **Investment (€)** | 15,220,487.00 € | 12,511,684 € |
| **Plant costs (€)** | 83,664,508.71 € | 82,469,752.14 € |

*Table 42. Economic comparison between the system with and without West array.*

Conversely, the economic analysis reveals similar conclusions in both cases, as presented in the full system. The total investment associated with solar panels, inverters, and the entire system amounts to 12,511,684 €, which is 2,810,832 € less than the cost of installing the West modules. The billing payments are affected by the capacity loss, resulting from the decrease in energy generation. Consequently, the electricity purchased from the retailer increases by €3,133,406.43 when compared to the full system. However, it is noteworthy that the Net Present Value (NPV) remains similar for both simulations, approximately €2,000,000. The most significant disparities are observed in the discounted payback period and Return on Investment (ROI%), which are pivotal indicators for project viability. These metrics both exhibit positive changes, with the payback period decreasing from 7.4 years to 5.8 years, and the ROI% increasing from 3.48% to 6.02%, thus enhancing the economic feasibility of the project.

This analysis leads to a conclusion that in order to increase the economic feasibility while at the same time, the electricity generation is reduced by only a 2.76 % annually the system without the West array is more beneficial.

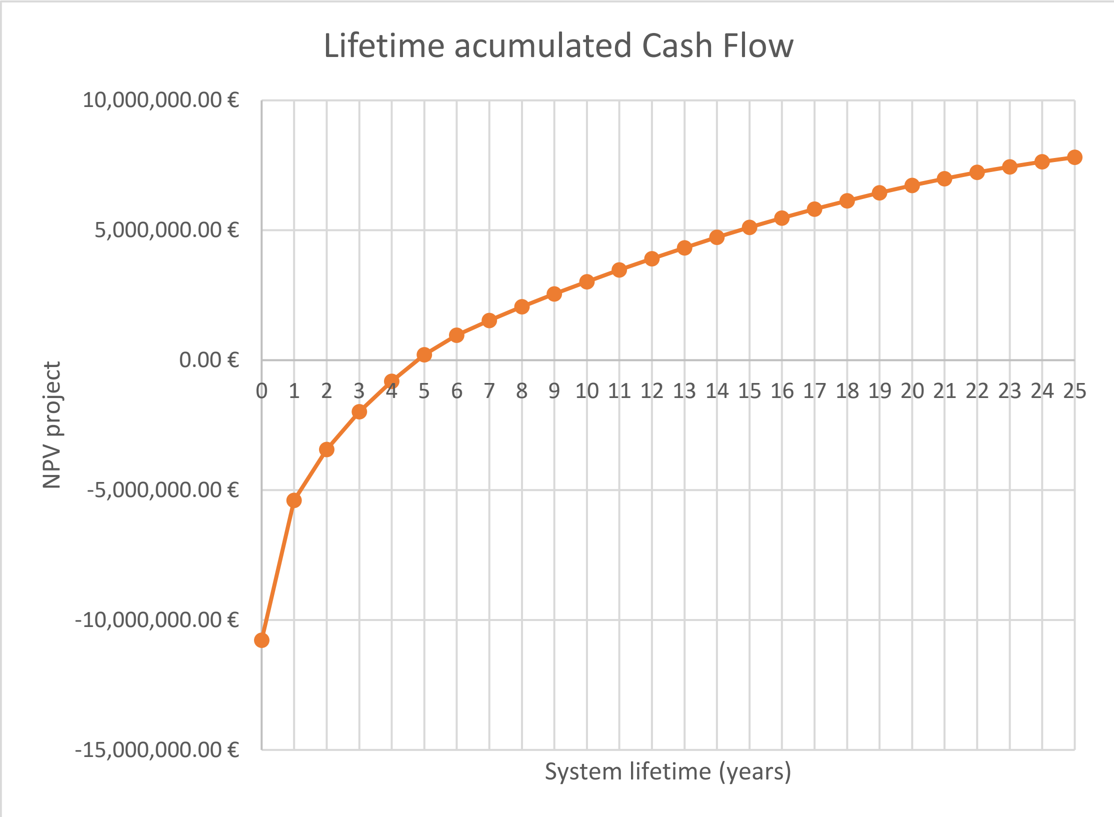



*Figure 43. Net present value evolution without West array following OMIP trend* [35].

# CHAPTER 9. CONCLUSIONS

In response to the increasing demand for renewable, local, and self-sufficient energy sources, the deployment of photovoltaic plants emerges as one of the most economically viable contemporary approaches to meet the growing need for sustainable energy solutions. The present study focuses on a comprehensive investigation of a photovoltaic system implementation in the Vera Campus of the Universitat Politècnica de València. The project evaluates available surface in rooftops and the East, South, and West façades of campus buildings for this purpose. To assess economic feasibility and system profitability, three simulations were conducted in the System Advisor Model (SAM), adjusting electricity rates according to different possible scenarios in the following years.

The proposed system covers 37.06% of the UPV's electricity demand, concentrated during midday hours when photovoltaic (PV) production is at its peak. In the first year of the project the total PV electricity production is 18,126 MWh/year. Main part of this electricity (82.8%) is self-consumed and about 17.2% (3,112 MWh/year) is surplus energy sold to the grid.

The energy production of the plant is distributed among four panel systems. The rooftop system, comprising 6.297 MW and constituting 41.93% of the total power, yields the highest electricity output, amounting to 10,320 kWh annually. This corresponds to 56.93% of the total generation and establishes itself as the most profitable system in terms of energy production per installed power. In the second case, the South facade panels contribute 20.68% to the annual electricity production, generating 3,748 kWh with 3.456 MW installed, representing 23.04% of the total. This system emerges as the second most efficient. The third profitable system, considering production per installed power, is the East orientation. The panels with a capacity of 2.578 MW, accounting for 17.18% of the total, produce 2,302 kWh, representing 12.7% of the overall production. Lastly, the West orientation, facing fewer sun hours, involves 2.678 MW, more than the East panels, contributing 17.85% to the total, and producing 1,756 kWh annually, amounting to 9.69% of the plant's production.

Despite lower efficiencies, the facade panels offer an alternative method to enhance self-sufficiency and a higher percentage of electricity consumption coming from renewable sources. Counting only rooftops the renewable electricity percentage amounts to 26.23% of the electricity demand, while adding the three facade systems the percentage rises to 46.07, utilizing only surfaces of the University buildings without the need to acquire external land. Additionally, the facade modules, facing three different orientations, capitalize on sunlight throughout most of the day, balancing the production curve. This results in the utilization of electricity generated by the photovoltaic panels earlier and later in the day compared to rooftop production. Furthermore, during winter months, when the sun's rays hit at a more horizontal inclination, the efficiency of the South facade system notably increases, reaching 103 kWh/kW (installed) and 96 kWh/kW in January and December. This nearly matches the rooftop production during these months, which reaches its lowest point with 109 kWh/kW and 98 kWh/kW, respectively. However, the East and West systems are not affected by this benefit due to the shorter duration of sun hours.

Three electricity tariff scenarios have been evaluated:

- Scenario 1 assumes a consistent electricity contract without variation over the years, coupled with an OMIP value of 91.5€/MWh.
- Scenario 2 employs the tariffs from the current UPV electricity contract, assuming a constant OMIP value of 55.8€/MWh annually.
- Scenario 3 assumes the current UPV electricity contract with an OMIP of 91.5€/MWh, as the first scenario, but including an annually depreciation until the OMIP reaches a value of 42.95€/MWh for 2032 and constant for the following years.

According to economic feasibility indicators of each scenario, the Simple Payback Period exhibits an exceptionally optimistic value of 4.2 years for the first scenario, contrasting with more realistic values of 6.2 and 7.4 years for scenarios 2 and 3, respectively due to the unusual high tariffs in the current electricity contract. Secondly, the Return on Investment (ROI) follows the trend observed in the Simple Payback, with an unrealistically high value of 17.40% for scenario 1. In contrast, scenarios 2 and 3 present more reasonable values, with ROI figures of 10.55% and 3.48%, respectively. Despite scenario 3 presents the lowest economic profitability, it is considered the most reliable, utilizing price data from a trustworthy source and serving as the primary reference for the project's economic feasibility indicators, following a decreasing trend in the electricity rates for the following years, and in case the prices rise due to inflation, this would mean in a reduction of the payback period, favorizing the installation. Other scenarios were explored to account for the inherent instability and unpredictability of the electricity market, with a recognition that such volatility may impact purchasing prices, potentially enhancing profitability. Even though of  tariffs depreciation, in cases of market stability, the project exhibits favorable indicators following the conservative trend.

In alignment with the overarching goal of achieving self-sufficiency and sustainability, the implementation of a photovoltaic installation contributes significantly to the reduction of greenhouse gas emissions. The annual reduction in CO2 equivalent emissions attributable to the PV plant is 3,163.07 tons, encompassing both energies utilized for UPV's demand and surplus energy sold to the grid. This reduction, when contrasted with the University's annual emissions of 12,922 tons of $CO_2$ equivalent [3], represents a noteworthy 24.35% enhancement in sustainability. Furthermore, when contextualized within the broader emissions context of the "La Carrasca" neighborhood, of which UPV is a part and responsible for two-thirds of the electricity consumption, the total reduction in greenhouse gas emissions for the neighborhood would be 4.85%.

A supplementary simulation was conducted, excluding the panels situated on the West façades due to their lower efficiency. From an energy analysis standpoint, this adjustment resulted in an energy production of 16,375 MWh, marking a 10.7% decrease compared to the full system that included the West façades. This production is further categorized into 13,897 MWh utilized for UPV's demand and 2,477 MWh of surplus energy sold to the grid, translating to reductions of 8.03% and 25.64%, respectively, in comparison to the entire system. On the economic front, under the assumption of identical electricity prices as indicated in scenario 3 (refer to Table 33), the revised configuration yielded a simple payback period of 5.8 years, a Levelized Cost of Electricity (LCOE) of 4.30 €, and a Return on Investment (ROI) of 4.02%. These values are notably positive and advantageous when juxtaposed with those obtained in scenario 3.

In conclusion, the project yields positive outcomes, both in terms of energy independence, fostering sustainable consumption, and economically, with the most conservative scenario demonstrating a reasonable payback period and Return on Investment (ROI), manifesting benefits within a span of no more than 7.5 years post-installation. The final simulation underscores the importance of a phased implementation, starting with the rooftops as the most efficient and feasible system and, progressively, extending to the less feasible systems in façades. This phased approach ensures optimal conditions, both in terms of energy efficiency and economic feasibility, even in the event that the entire plant is not fully installed.

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# ANNEX I PROJECT BUDGET

The budget has been divided into 6 sections differentiating the function of the element and moreover, the cost of the labor as well as the cost of the realization of the viability and security studies prior the beginning of its operating. It has been obtained the exact price of every element and multiplied by the number of them installed, estimating the cable meters, protections and other security elements.

The inverters distribution among the buildings is represented later in the annexes, the Table 44 shows every inverter presented in the plant and its prices.

| Inverter | Capacity (kW) | Price (€) | €/kW |
|---|---|---|---|
| **SUN2000-300KTL-H0** | 300 | 8611.00 | 28.70 |
| **SUN2000-250KTL-H1** | 250 | 6679.62 | 26.72 |
| **SUN2000-215KTL-H0** | 215 | 6430.60 | 29.91 |
| **SUN2000-185KTL -H1** | 185 | 5,360.15 | 27.20 |
| **SUN2000-115KTL-M0** | 115 | 4,909.85 | 42.69 |
| **SUN2000-100KTL-M1** | 100 | 4,454.02 | 44.54 |
| **SUN2000-90KTL-H0** | 90 | 4,003.72 | 44.49 |
| **SUN2000-75KTL-M1** | 75 | 3,654.54 | 48.73 |
| **SUN2000-60KTL-M0** | 60 | 3,257.17 | 52.79 |
| **SUN2000-50KTL-M0** | 50 | 2,496.40 | 49.93 |
| **SUN2000-40KTL-M3** | 40 | 2,595.15 | 64.88 |
| **SUN2000-30KTL-M3** | 30 | 2,259.40 | 75.31 |
| **SUN2000-20KTL-M5** | 20 | 1,911.01 | 95.55 |
| **SUN2000-15KTL-M2** | 15 | 1,610.81 | 107.39 |
| **SUN2000-10KTL-M2** | 10 | 1,528.65 | 152.87 |

*Table 44. List of inverters selected for the installation and its prices.*

The modules selected are the Trina Solar TSM-DE20 600 W, with a price of 0.192€/Wp supposing 115.2 € per panel.

The following budget contains the complete installation, and the remainder elements are included.

All prices do not include the Spanish taxes, IVA (Impuesto de valor añadido) of 21% added to the final price in the budget summary. The system's costs per Watt installed are 0.72 €/W without IVA and 1.015 €/W including IVA.

## BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| **SECTION 01 - SOLARFIELD** | | | | |
| **CAPFV595** | **- PV PANEL 600WP MONOCRYST VERTEX TSM-DE20 600**<br>Trina Solar monocrystalline 120-cell photovoltaic panel model VERTEX TSM-DE20 585-605. Panel peak power: 595W. Maximum power voltage: 34.4V. Open circuit voltage Voc: 41,5V. Maximum power current: 17.44A. Short circuit current Isc: 18.52A. Module efficiency Module efficiency: 21,4% Panel dimensions: 2172·1303·35mm. Weight: 30.9Kg | 25,008.00 | 114.00 | 2,850,038.00 |
| **TRIANGSTRUCT** | **- TRIANGULAR SUPPORT STRUCTURE TV2010A**<br>Aluminum structure for supporting photovoltaic panels on roofs and pitched roofs in sheet metal, in horizontal or vertical arrangement, with availability of any gradual inclination, anchoring to concrete and metal straps, large double profile, with capacity for 2 modules. | 2,491.00 | 249.15 | 620,601.73 |
| **DOUBLESTRUCT** | **- DOUBLE INCLINED SUPPORT STRUCTURE**<br>Aluminum structure for supporting photovoltaic panels on roofs and terrains, in horizontal or vertical arrangement, with availability of any gradual inclination, anchoring to concrete, large double profile, with capacity for 4 modules. | 1,418.00 | 487.20 | 690,792.70 |
| **FACADSTRUCT** | **- FACADE PHOTOVOLTAICS SUPPORT STRUCTURE**<br>Aluminum structure for supporting photovoltaic panels on facades, in horizontal or vertical arrangement, with availability for 90º, anchoring to concrete, with capacity for 4 modules. | 4,256.00 | 312.53 | 1,330,127.68 |
| **CONNECSTRUCT** | **- Fasteners, ballast and fasteners**<br>Fasteners, ballast and fasteners for the connection between aluminum structures. | 9,307.00 | 5.10 | 47,464.14 |
| | **TOTAL SECTION 01 - SOLAR GAIN ..........** | | | **5,538,986.25** |

## BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| **SECTION 02 - INVERTERs** | | | | |
| **INV10KW** | **- INVERTER HUAWEI 10kW-400V**<br>Inverter HUAWEI SUN2000-10 KTL-M2 of 99% of efficiency, for 2 MPPT, y 4 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1,080 V.<br>- Max. current per MPPT: 22 A.<br>- Nominal input voltage: 160-950 V.<br>OUTPUT<br>- Active power: 10 kW.<br>- Nominal output voltage: 220/400V. | 7.00 | 1,528.65 | 10,700.55 |
| **INV15KW** | **- INVERTER HUAWEI 15kW-400V**<br>Inverter HUAWEI SUN2000-15 KTL-M2 of 99% of efficiency, for 2 MPPT, y 4 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.080 V.<br>- Max. current per MPPT: 22 A.<br>- Nominal input voltage: 160-950 V.<br>OUTPUT<br>- Active power: 15 kW.<br>- Nominal output voltage: 220/400V. | 3.00 | 1,610.81 | 4,832.43 |
| **INV20KW** | **- INVERTER HUAWEI 20kW-400V**<br>Inverter HUAWEI SUN2000-20 KTL-M5 of 99% of efficiency, for 2 MPPT, y 4 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 20 kW.<br>- Nominal output voltage: 220/400V. | 5.00 | 1,911.01 | 9,555.05 |
| **INV30KW** | **- INVERTER HUAWEI 30kW-400V**<br>Inverter HUAWEI SUN2000-30 KTL-M3 of 99% of efficiency, for 4 MPPT, y 8 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 27 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 30 kW.<br>- Nominal output voltage: 220/400V. | 4.00 | 2,259.40 | 9,037.60 |
| **INV40KW** | **- INVERTER HUAWEI 40kW-400V**<br>Inverter HUAWEI SUN2000-40 KTL-M3 of 99% of efficiency, for 4 MPPT, y 8 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 40 kW.<br>- Nominal output voltage: 220/400V. | 6.00 | 2,259.40 | 9,037.60 |

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| INV50KW | **- INVERTER HUAWEI 50kW-400V**<br>Inverter HUAWEI SUN2000-50 KTL-M0 of 99% of efficiency, for 6 MPPT, y 12 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 22 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 50 kW.<br>- Nominal output voltage: 220/400V. | 10.00 | 2,496.40 | 24,964.00 |
| INV60KW | **- INVERTER HUAWEI 60kW-400V**<br>Inverter HUAWEI SUN2000-60 KTL-M0 of 99% of efficiency, for 6 MPPT, y 12 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 22 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 60 kW.<br>- Nominal output voltage: 220/400V. | 5.00 | 3,257.17 | 16,285.85 |
| INV75KW | **- INVERTER HUAWEI 75kW-400V**<br>Inverter HUAWEI SUN2000-75 KTL-M1 of 99% of efficiency, for 10 MPPT, y 20 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 75 kW.<br>- Nominal output voltage: 220/400V. | 29.00 | 3,654.54 | 105,981.66 |
| INV90KW | **- INVERTER HUAWEI 90kW-400V**<br>Inverter HUAWEI SUN2000-90 KTL-H0 of 99% of efficiency, for 6 MPPT, y 12 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.500 V.<br>- Max. current per MPPT: 22 A.<br>- Nominal input voltage: 600-1.500 V.<br>OUTPUT<br>- Active power: 90 kW.<br>- Nominal output voltage: 220/400V. | 4.00 | 4,003.72 | 16,014.88 |
| INV100KW | **- INVERTER HUAWEI 100kW-400V**<br>Inverter HUAWEI SUN2000-100 KTL-M1 of 99% of efficiency, for 10 MPPT, y 20 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 100 kW.<br>- Nominal output voltage: 220/400V. | 12.00 | 4,454.02 | 53,448.24 |
| INV115KW | **- INVERTER HUAWEI 115kW-400V**<br>Inverter HUAWEI SUN2000-115 KTL-M0 of 99% of efficiency, for 10 MPPT, y 20 inputs, with the | | | |

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| | following characteristics:<br>INPUT<br>- Max. input Voltage: 1.100 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 200-1.000 V.<br>OUTPUT<br>- Active power: 115 kW.<br>- Nominal output voltage: 220/400V. | | | |
| | | 7.00 | 4,909.85 | 34,368.95 |
| INV185KW | **- INVERTER HUAWEI 185kW-400V**<br>Inverter HUAWEI SUN2000-185 KTL-H1 of 99% of efficiency, for 9 MPPT, y 18 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.500 V.<br>- Max. current per MPPT: 26 A.<br>- Nominal input voltage: 500-1.500 V.<br>OUTPUT<br>- Active power: 185 kW.<br>- Nominal output voltage: 220/400V. | | | |
| | | 9.00 | 5,360.15 | 48,241.35 |
| INV215KW | **- INVERTER HUAWEI 215kW-400V**<br>Inverter HUAWEI SUN2000-215 KTL-H0 of 99% of efficiency, for 9 MPPT, y 18 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.500 V.<br>- Max. current per MPPT: 30 A.<br>- Nominal input voltage: 500-1.500 V.<br>OUTPUT<br>- Active power: 215 kW.<br>- Nominal output voltage: 220/400V. | | | |
| | | 2.00 | 6,430.60 | 12,861.20 |
| INV250KW | **- INVERTER HUAWEI 250kW-400V**<br>Inverter HUAWEI SUN2000-250 KTL-H1 of 99% of efficiency, for 6 MPPT, y 28 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.500 V.<br>- Max. current per MPPT: 65 A.<br>- Nominal input voltage: 500-1.500 V.<br>OUTPUT<br>- Active power: 250 kW.<br>- Nominal output voltage: 220/400V. | | | |
| | | 12.00 | 6,679.45 | 80,153.40 |
| INV300KW | **- INVERTER HUAWEI 300kW-400V**<br>Inverter HUAWEI SUN2000-300 KTL-H0 of 99% of efficiency, for 6 MPPT, y 28 inputs, with the following characteristics:<br>INPUT<br>- Max. input Voltage: 1.500 V.<br>- Max. current per MPPT: 65 A.<br>- Nominal input voltage: 500-1.500 V.<br>OUTPUT<br>- Active power: 300 kW.<br>- Nominal output voltage: 220/400V. | | | |
| | | 4.00 | 8,611.00 | 34,444.00 |
| SMARTLOGGER | **- SMARTLOGGER SL3000A INVERTER COM.INVERTER ACCESSORY**<br>Accessory for communication and control of three-phase inverter, in app (DATTALOGER), type HUAWEI Smartlogger SL3000A of 1000 A, with anti-switching function, for connection with program through Ethernet network, installed, connected, programmed and working. | | | |

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| | | 119.00 | 570.38 | 67,875.22 |
| ENERGMETER | - THREE-PHASE ENERGY METER<br>Three-phase energy meter, type HUAWEI DTSU666-H, for three-phase inverter SUN2000-75KTL, with anti-spill function and for system monitoring, including measuring traps, installed, connected, programmed and in operation | | | |
| | | 119.00 | 247.27 | 29,425.13 |
| | **TOTAL SECTION 02 - INVERTER** | | | **499,099.88** |

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| **SECTION 03 – ELECTRIC INSTALLATION** | | | | |
| **BLACKWIRE4** | **- SOLAR CABLE 1x10mm² H1Z2Z2-K BLACK**<br>1x10 mm² line based on insulated copper conductors type H1Z2Z2-K 0.6/1 KV, 1,000 V. insulation level. insulation level; special for photovoltaic solar installations, according to UNE EN 50618 standard, with black sheath for connection(+), installed50618, with black cover for connection(+), installed on a tray, channel or tube. | 147,600 | 1.42 | 209,887.20 |
| **REDWIRE4** | **- SOLAR CABLE 1x10mm² H1Z2Z2-K RED**<br>1x10 mm² line based on insulated copper conductors type H1Z2Z2-K 0.6/1 KV, 1,000 V. insulation level. insulation level; special for photovoltaic solar installations, according to UNE EN 50618 standard, with red sheath for connection(+), installed50618, with red cover for connection(+), installed on a tray, channel or tube. | 147,600 | 1.42 | 209,887.20 |
| **RHZ1CAB6** | **- CABLE 1x6 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x6 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 420.00 | 1.17 | 491.06 |
| **RHZ1CAB10** | **- CABLE 1x10 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x10 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 180.00 | 1.63 | 292.93 |
| **RHZ1CAB16** | **- CABLE 1x16 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x16 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 420.0 | 2.31 | 694.41 |
| **RHZ1CAB25** | **- CABLE 1x25 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x25 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 480.00 | 3.33 | 2,000.28 |
| **RHZ1CAB35** | **- CABLE 1x35 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x35 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 300.00 | 4.48 | 2,687.58 |
| **RHZ1CAB50** | **- CABLE 1x50 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x50 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 1240.00 | 6.19 | 12,618.83 |

## BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| RHZ1CAB70 | **- CABLE 1x70 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x70 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 480.0 | 8.46 | 8,122.46 |
| RHZ1CAB95 | **- CABLE 1x95 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x95 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 360.0 | 11.31 | 4,751.38 |
| RHZ1CAB185 | **- CABLE 1x185 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x185 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 960.0 | 21.57 | 11,646.18 |
| RHZ1CAB240 | **- CABLE 1x240 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x240 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 720.0 | 27.83 | 3,339.80 |
| RHZ1CAB300 | **- CABLE 1x300 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x300 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 120.0 | 34.67 | 24,958.94 |
| RHZ1CAB400 | **- CABLE 1x400 mm2 X-VOLT RHZ1 (S)**<br>Line of 1x400 mm² based on insulated copper conductors type X-VOLT RHZ1 (S)- halogen free 0.6/1 KV of 1,000 V. insulation level; especially for electrical circuits in public places and other installations where there is a high risk of fire, installed on a tray, channel or tube. | 360.0 | 46.06 | 11,053.68 |
| CORRUGTUB | **- PVC corrugated tube 40/33 mm**<br>UV Resistant empty tube for photovoltaic installation of solar PV installations, 25m, 40mm diameter, 40/33, corrugated tube with tensile wire 1997. | 6217.60 | 1.49 | 9,192.79 |
| M4CONNEC | **- Male connector MC4**<br>Male MC4 connector for quick, safe, watertight and hermetic connection of photovoltaic modules. For 4-6mm² solar cable. | 24,179.15 | 1.44 | 34,764.78 |
| F4CONNEC | **- Female connector MC4**<br>Female MC4 connector for quick, safe, watertight and hermetic connection of photovoltaic modules. For 4-6mm² solar cable. | 24,179.15 | 1.44 | 34,764.78 |

**TOTAL SECTION 03 – ELECTRIC INSTALLATION ............ 581,154.30**

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| **SECTION 04 – PROTECTIONS AND EARTH WIRE** | | | | |
| **BMODDC** | **- Modular box DC**<br>Modular box with opaque door for surface placement, built in plastic material, IP40 and IK09, with capacity up to 150 modules, for housing protection of 6 Strings of photovoltaic modules. | 119.00 | 249.48 | 29,688.36 |
| **FUSEDC** | **- Fuse ZR- VCC (14X85) 30A GPV**<br>Unipolar fuse for DC up to 1,000 V. DC rated current 30 A. model Fuse ZR- VCC (14X85) 30A GPV from DF Electric or similar, measurements fuse cartridge size (14x85). | 1476.00 | 13.67 | 20,172.49 |
| **SURP2DC** | **- Surge protection device type 2**<br>Three-pole surge protection device type 2, nominal discharge current 40 kA, maximum discharge current 40 kA, protection level < 1 kV. DC 1000V 40KA MD BF3-40 model. | 738.0 | 53.86 | 39,750.30 |
| **BMODAC** | **- Modular box AC**<br>Electrical panel with IP64 protection degree, supplied for the installation of 2 125A magneto-thermal switches, 2,200 A differential switches and 315 A automatic switch. | 119.00 | 569.99 | 67,828.22 |
| **MT25A40KAC** | **- Magnetothermal switch CVS25B TM25D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS25B TM25D or similar. | 20.00 | 244.03 | 4,880.62 |
| **MT25A40KAC** | **- Magnetothermal switch CVS40B TM40D**<br>Magnetothermal switch of 40 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS40B TM40D or similar. | 10.00 | 391.63 | 3,916.27 |
| **MT25A40KAC** | **- Magnetothermal switch CVS63B TM63D**<br>Magnetothermal switch of 63 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS63B TM63D or similar. | 8.00 | 617.93 | 4,943.44 |
| **MT25A40KAC** | **- Magnetothermal switch CVS80B TM80D**<br>Magnetothermal switch of 80 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS80B TM80D or similar. | 12.00 | 785.20 | 9,422.46 |
| **MT25A40KAC** | **- Magnetothermal switch CVS100B TM100D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS100B TM100D or similar. | 20.00 | 787.71 | 15,754.18 |
| **MT25A40KAC** | **- Magnetothermal switch CVS125B TM125D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS125B TM125D or similar. | 68.00 | 1,227.98 | 83,502.37 |
| **MT25A40KAC** | **- Magnetothermal switch CVS160B TM160D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS160B TM160D or similar. | 8.00 | 1,290.97 | 10,327.76 |
| **MT25A40KAC** | **- Magnetothermal switch CVS200B TM200D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, | | | |

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| | curve C, SCHNEIDER model CVS200B TM200D or similar. | | | |
| | | 24.00 | 1,965.94 | 47,182.53 |
| MT25A40KAC | **- Magnetothermal switch CVS250B TM250D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS250B TM250D or similar. | | | |
| | | 14.00 | 2,697.32 | 37,762.49 |
| MT25A40KAC | **- Magnetothermal switch CVS320B TM320D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS320B TM320D or similar. | | | |
| | | 18.00 | 3,146.67 | 56,640.11 |
| MT25A40KAC | **- Magnetothermal switch CVS400F TM400D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS400F TM400D or similar. | | | |
| | | 4.00 | 4,560.51 | 18,242.05 |
| MT25A40KAC | **- Magnetothermal switch CVS500F TM500D**<br>Magnetothermal switch of 25 A, 4P, operating voltage 230/400 V AC, breaking capacity 40 KA, curve C, SCHNEIDER model CVS500F TM500D or similar. | | | |
| | | 32.00 | 4,917.77 | 157,368.76 |
| DIF40A300MA | **- Differential switch 4P/40A/IV/300 mA**<br>Modular differential switch 40 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 40A 50kA or similar | | | |
| | | 10.00 | 2,030.73 | 20,307.35 |
| DIF40A300MA | **- Differential switch 4P/63A/IV/300 mA**<br>Modular differential switch 63 A, 4P, with low sensitivity of 300 mA, model DPX3 160 4P 63A 50kA or similar | | | |
| | | 5.00 | 2,497.79 | 12,488.95 |
| DIF40A300MA | **- Differential switch 4P/100A/IV/300 mA**<br>Modular differential switch 100 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 100A 70kA or similar | | | |
| | | 4.00 | 2,790.03 | 11,160.11 |
| DIF40A300MA | **- Differential switch 4P/125A/IV/300 mA**<br>Modular differential switch 125 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 125A 50kA or similar | | | |
| | | 6.00 | 2,944.31 | 17,665.84 |
| DIF40A300MA | **- Differential switch 4P/160A/IV/300 mA**<br>Modular differential switch 160 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 160A 50kA or similar | | | |
| | | 10.00 | 3,675.72 | 36,757.20 |
| DIF40A300MA | **- Differential switch 4P/200A/IV/300 mA**<br>Modular differential switch 200 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 200A 25kA or similar | | | |
| | | 34.00 | 3,843.60 | 130,682.50 |
| DIF40A300MA | **- Differential switch 4P/250A/IV/300 mA**<br>Modular differential switch 250 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 250A 36kA or similar | | | |
| | | 4.00 | 4,090.57 | 16,362.29 |

# BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| DIF40A300MA | **- Differential switch 4P/320A/IV/300 mA**<br>Modular differential switch 320 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 320A 36kA or similar | | | |
| | | 12.00 | 3,903.55 | 46,842.58 |
| DIF40A300MA | **- Differential switch 4P/400A/IV/300 mA**<br>Modular differential switch 400 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 400A 36kA or similar | | | |
| | | 7.00 | 4,181.63 | 29,271.40 |
| DIF40A300MA | **- Differential switch 4P/500A/IV/300 mA**<br>Modular differential switch 500 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 500A 36kA or similar | | | |
| | | 9.00 | 4,975.89 | 44,783.05 |
| DIF40A300MA | **- Differential switch 4P/630A/IV/300 mA**<br>Modular differential switch 630 A, 4P, with low sensitivity of 300 mA, model DPX3 630MT 4P 630A 36kA or similar | | | |
| | | 2.00 | 5,351.30 | 10,702.60 |
| DIF40A300MA | **- Differential switch 4P/800A/IV/300 mA**<br>Modular differential switch 800 A, 4P, with low sensitivity of 300 mA, model DPX3 250 4P 800A 36kA or similar | | | |
| | | 16.00 | 10,176.54 | 162,824.69 |
| SURP2AC | **- Surge protection device type 2**<br>Three-pole surge protection device type 2, nominal discharge current 20 kA (8/20), maximum discharge current 40 kA, protection level < 1 kV. DEHNguard SE H 1000 FM model from the DEHN brand or similar. | | | |
| | | 119.00 | 199.33 | 23,720.60 |
| EARTHW | **- Earth wire**<br>Photovoltaic installation earth wire, with a 1.8 meter copper spike, mass protection conductors to the variable section conductor, equipotential bonding conductors and connection to the earthing of the building. | | | |
| | | 119.00 | 2,431.01 | 289,290.39 |

**TOTAL SECTION 04 - PROTECTIONS AND EARTH WIRE.................................................................... 1,460,241.93**

# BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| **SECTION 05 - INSTALLATION OF THE SYSTEM** | | | | |
| LABOR | - Labor | 1,00 | 1,264,391.86 | 1,264,391.86 |
| TESTCOMMON | - Testing, commissioning and monitoring | 1,00 | 27,372.63 | 27,372.63 |
| | **TOTAL SECTION 05 - INSTALLATION OF THE SYSTEM** | | | **1,291,764.49** |
| **SECTION 06 - OVERHEAD AND ENGINEERING** | | | | |
| ENGPROJECT | - Technical engineering project | 1,00 | 1,041,263.88 | 1,041,263.88 |
| BHSS | - Basic Health and Safety Study | 1,00 | 257,761.65 | 257,761.65 |
| QCONTROL | - Quality Control | 1,00 | 97,949.30 | 97,949.30 |
| WASMAN | - Ud. Waste Management | 1,00 | 103,104.48 | 103,104.48 |
| | **TOTAL SECTION 06 - OVERHEAD AND ENGINEERING** | | | **1,500,079.31** |
| | **TOTAL** | | | **10,871,326.16** |

## BUDGET AND MEASUREMENTS

| CODE | SUMMARY | QUANTITY | PRICE | AMOUNT |
|---|---|---|---|---|
| | **SUMMARY OF BUDGET** | | | |
| SEC01 | - SECTION 01 - SOLAR GAIN | 1,00 | 5,538,986.25 | 47.30% |
| SEC02 | - SECTION 02 - INVERTER | 1,00 | 554,849.00 | 5.11% |
| SEC03 | - SECTION 03 – ELECTRIC INSTALLATION | 1,00 | 773,651.19 | 7.13% |
| SEC04 | - SECTION 04 - PROTECTIONS AND EARTH WIRE | 1,00 | 1,600,663.24 | 14.88% |
| SEC05 | - SECTION 05 - INSTALLATION OF THE SYSTEM | 1,00 | 1,291,764.49 | 11.9% |
| SEC06 | - SECTION 06 - OVERHEAD AND ENGINEERING | 1,00 | 1,500,079.31 | 13.82% |
| | **TOTAL MATERIAL AND LABOUR** | | | **11,259,993.48** |
| GENCOST | - GENERAL COSTS | 1,00 | 1,463,799.15 | 13.00% |
| INDUSBEN | - INDUSTRIAL BENEFIT | 1,00 | 675,599.61 | 6.00% |
| | **TOTAL – GENERAL COST + INDUSTRIAL BENEFIT** | | | **2,139,398.76** |
| 21%IVA | - 21% IVA | 1,00 | 2,364,598.63 | 21.00% |
| | **TOTAL BUDGET** | | | **15,763,990.87** |

The general budget amounts to FIFTEEN MILLION ONE HUNDRED NINETY-SEVEN THOUSAND SEVEN HUNDRED AND TWUELVE EUROS AND NINETY-EIGHT CENT

## BUDGET HUMAN RESOURCES

This document shows the cost of carrying out this project, broken down into unit costs per human resources and per broken down in unit costs by human resources and by material resources.

| Position | Cost |
|---|---|
| **Tutor** | 40€/h |
| **Co-tutor** | 40€/h |
| **Engineer** | 25€/h |

*Table 45. Costs of human resources*

For the calculation of these human resources expenses, the following has been taken into account:

- The technical engineer has worked 4 hours a day, which corresponds to 20 hours a week, during 24 weeks in total 500 hours.
- Meetings with the project tutors in the company have been held on a regular basis according to the progress made.

| Element | Prize | Weekly cost | Cost |
|---|---|---|---|
| **Computer for reports, design and simulations** | 900€ | 4.7€/week | 117.5 € |
| **Microsoft Office licenses** | 539€ | 22.5 €/week | 539 € |
| **AutoCAD license** | 291€(Monthly) | 72.75 €/week | 873 € |

*Table 46. Costs of personal elements and software.*

The case for the computer if its supposed to have a lifetime of 4 years, the use of 24 weeks corresponds to a 12.25%.

| Element | Price | Total |
|---|---|---|
| **Table** | 120 € | 120€ |
| **Lightning and electricity** | 0,1723 €/kWh | 9.35 € |
| **Heating and cooling** | 0.0438 €/kWh | 5.78€ |

*Table 47. Cost related to the office time.*

- It is supposed a mean of 110.6 kWh/m2 annually, so for 6 months corresponds to 55.3 kWh
- For heating and cooling it is supposed a demand of 132 kWh for the period.

Dividing the period of the project in different phases:

| Phase | Hours |
|---|---|
| **State of the art and research** | 80 h |
| **Study of the photovoltaic potential** | 130 h |
| **Simulate the system** | 40 h |
| **Design of the systems** | 120 h |
| **Energy, economic and environmental analyses** | 50 h |
| **Elaboration of the report and planes** | 80 h |

*Table 48. Working hours distribution.*

Counting the reunion with the tutors, supposing it to 1 hour per 2 weeks it is obtained the complete budget:

| Phase 1 | 2,000 € |
|---|---|
| **Phase 2** | 3,250 € |
| **Phase 3** | 1,000 € |
| **Phase 4** | 3,000 € |
| **Phase 5** | 1,250 € |
| **Phase 6** | 2,000 € |
| **Own material costs** | 1,529.5 € |
| **Office costs** | 135.13 € |
| **Tutor, Co-tutor costs** | 520 € |
| **Total costs** | 14,684.63 |
| **Taxes (IVA 21%)** | 3,083.77 |
| **Final cost** | **17,768.40 €** |

*Table 49. Summary cost table.*

## ANNEX II RELATIONSHIP OF WORK WITH THE SUSTAINABLE DEVELOPMENT GOALS OF THE AGENDA

It is imperative that your project be intricately associated with the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda. This comprehensive framework encompasses not only emissions reduction but also addresses social and economic dimensions. Through alignment with the SDGs, your initiative plays a pivotal role in advancing global objectives, showcasing social responsibility, and garnering resources and collaborations that augment its impact, sustainability, and support at both local and international scales. The relationship between the development of this project and the corresponding mitigation measures is delineated in Table 50, illustrating the project's alignment with the SDGs.

| Sustainable development Goal | HIGH | MEDIUM | LOW | NOT MATCHING |
|---|---|---|---|---|
| SDGs 1. End of poverty | | | | X |
| SDGs 2. Zero hunger | | | | X |
| SDGs 3. Health and wellness | | | | X |
| SDGs 4. Quality education | | | | X |
| SDGs 5. Gender equality | | | | X |
| SDGs 6. Clearwater and sanity | | | | X |
| SDGs 7. Affordable and non-polluting energy | X | | | |
| SDGs 8. Decent work and economic growth. | | | X | |
| SDGs 9. Industry, innovation, and infrastructure. | | X | | |
| SDGs 10. Reduction of inequalities. | | | | X |
| SDGs 11. Sustainable cities and communities. | X | | | |
| SDGs 12. Responsible production and consumption. | X | | | |
| SDGs 13. Climate action | X | | | |
| SDGs 14. Submarine life | | | | X |
| SDGs 15. Life of terrestrial ecosystems. | | | | X |
| SDGs 16. Peace, justice, and solid institutions. | | | | X |
| SDGs 17. Alliances to achieve objectives. | X | | | |

*Table 50. Sustainable goal of the agenda related to the project.*

The most important relationships of the project and their relationships with the SDGS are briefly described below.

**SDG 7: Affordable and non-polluting energy**

The emphasis on reducing emissions in your project contributes to the promotion of clean and non-polluting energy sources, aligning to ensure access to affordable, reliable, sustainable, and modern energy for all.

**SDG 11: Sustainable cities and communities**

The introduction of new sources of green energy production by photovoltaic panels, favors the generation and consumption of the energy locally transforming cities into more sustainable and more self-sufficient.

**SDG 12: Responsible production and consumption**

The production and consumption of the energy in the same place produces less energy transformations and transportation. Also, the system can be designed to be aligned with the peak consumption of the University, matching the production for these moments.

**SDG 13: Climate action**

The reduction of emissions targeted by your project directly addresses the challenge of climate change, aligning to take urgent action to combat climate change and its impacts.

**SDG 17: Partnerships for the goals**

Your project aligns to form partnerships to achieve objectives, as it involves collaboration and coordination among various stakeholders to implement sustainable urban development strategies.

# ANNEX III FACADE MOUNTING STRUCTURE

This annex shows the rest of the elements of the facades mounting structures [17]

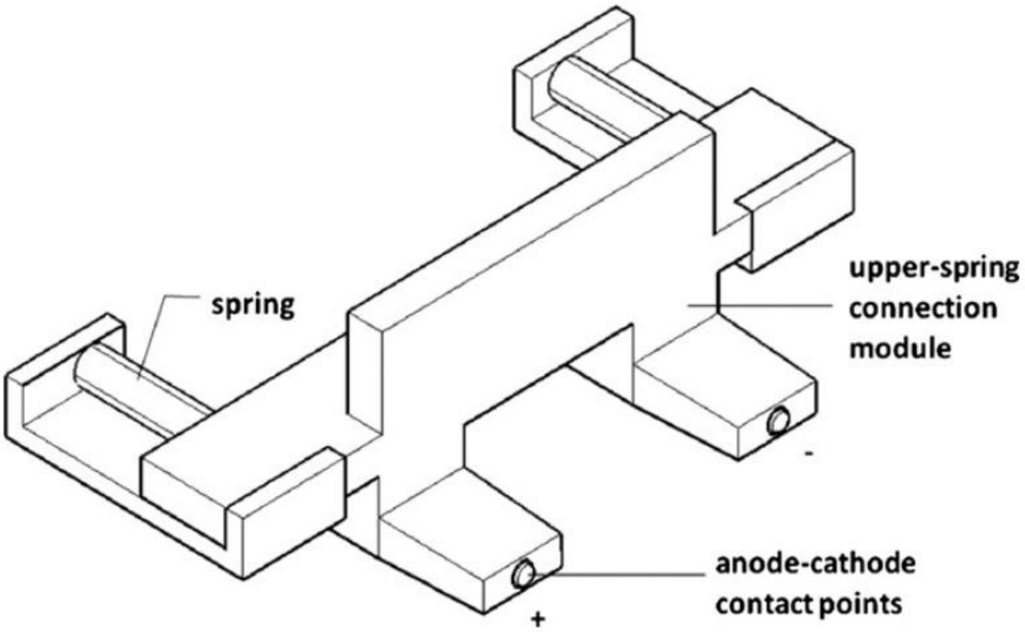



*Figure 52. Upper-spring connection module.*

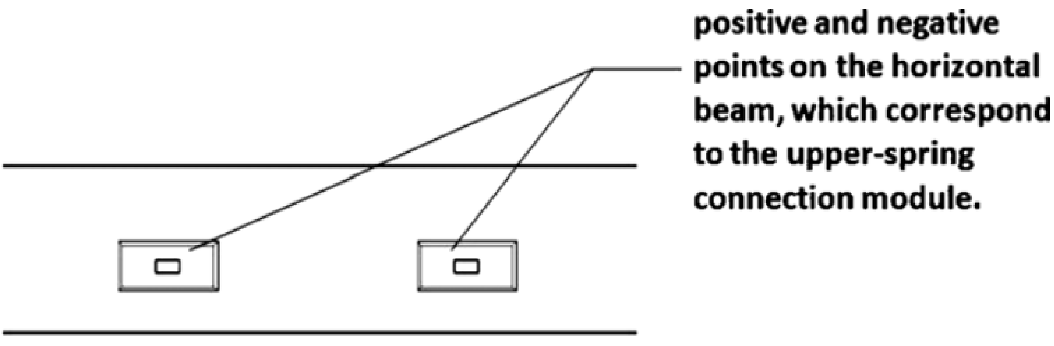



*Figure 53. "Anode-Cathode" contact points of the electric circuit at the horizontal beam*

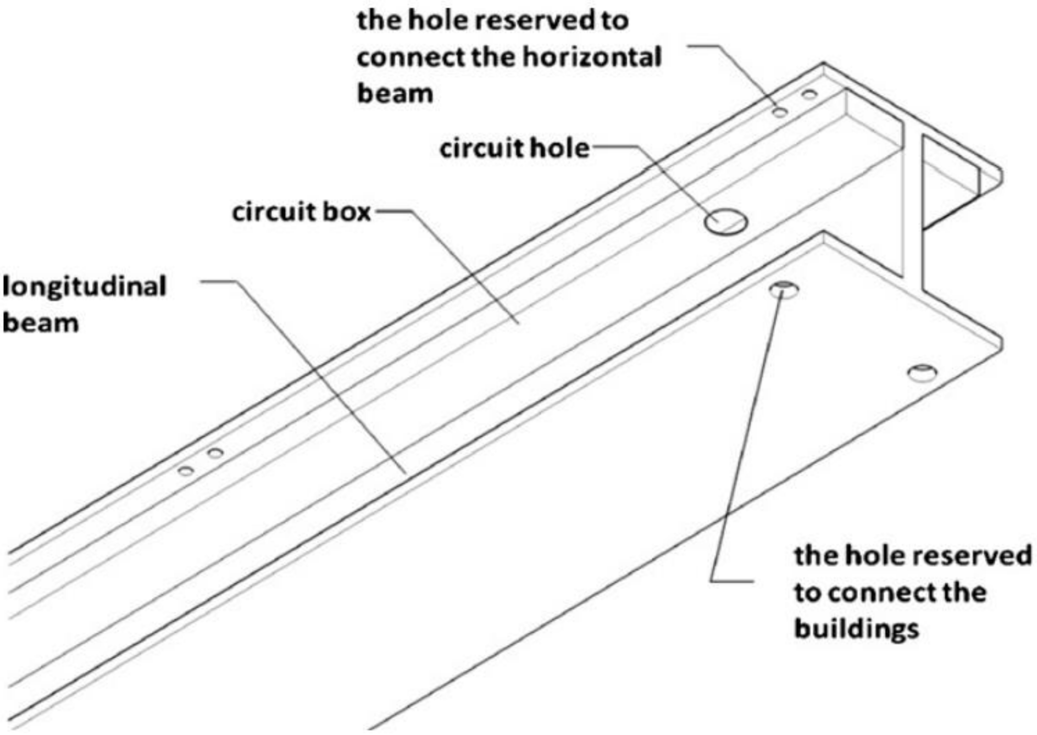



*Figure 54. Vertical, I-beam, in detail.*

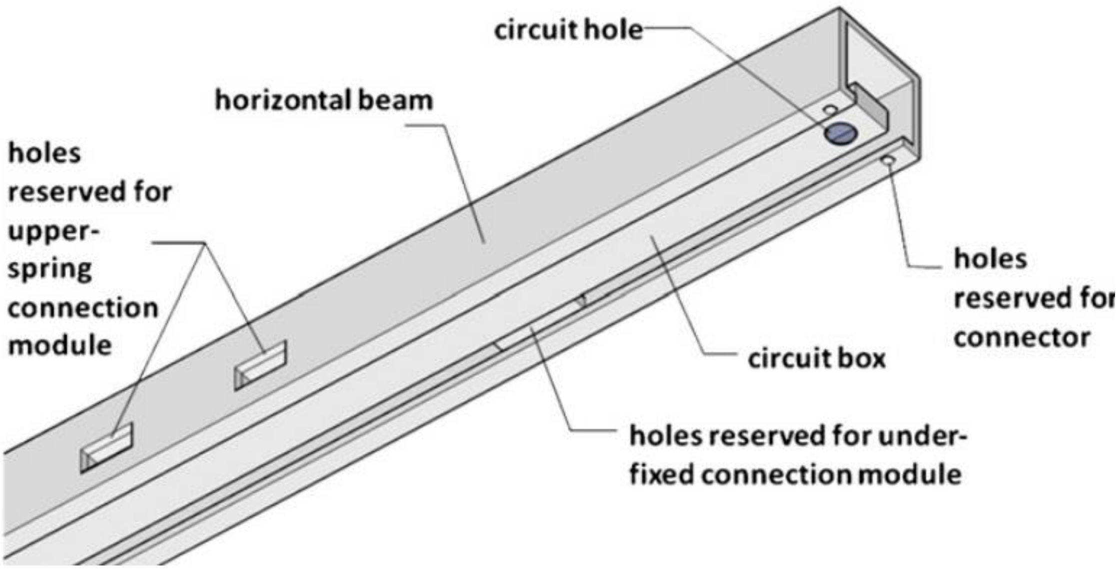



*Figure 55. Horizontal, U-beam in detail.*

*Figure 56. Representation of a façade modules system.*

# ANNEX IV PHOTOVOLTAIC PANEL DATASHEET

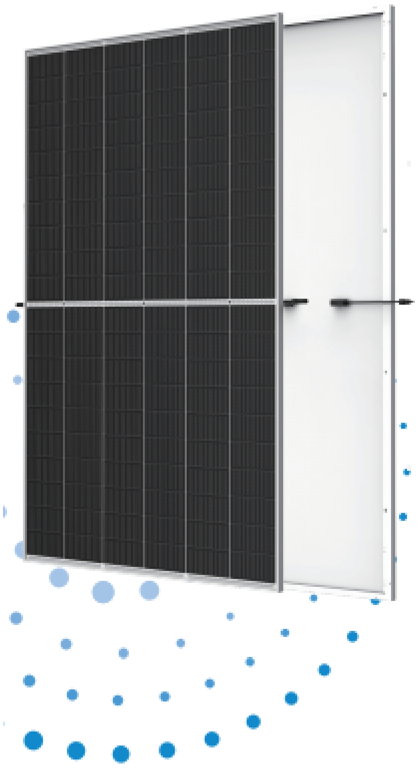
## Vertex

**BACKSHEET MONOCRYSTALLINE MODULE**

PRODUCT: TSM-DE20

PRODUCT RANGE: 590-610W

| 610W | 0~+5W | 21.6% |
|---|---|---|
| MAXIMUM POWER OUTPUT | POSITIVE POWER TOLERANCE | MAXIMUM EFFICIENCY |



### High customer value

- Lower LCOE (Levelized Cost Of Energy), reduced BOS (Balance of System) cost, shorter payback time
- Lowest guaranteed first year and annual degradation;
- Designed for compatibility with existing mainstream system components

### High power up to 610W

- Up to 21.6% module efficiency with high density interconnect technology
- Multi-busbar technology for better light trapping effect, lower series resistance and improved current collection

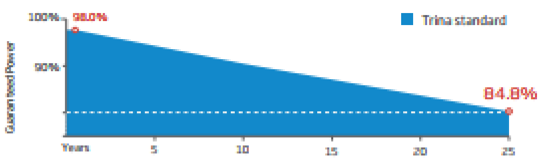
### High reliability

- Minimized micro-cracks with innovative non-destructive cutting technology
- Ensured PID resistance through cell process and module material control
- Resistant to harsh environments such as salt, ammonia, sand
- Mechanical performance up to 5400 Pa positive load and 2400 Pa negative load

### High energy yield

- Excellent IAM (Incident Angle Modifier) and low irradiation performance, validated by 3rd party certifications
- The unique design provides optimized energy production under inter-row shading conditions
- Lower temperature coefficient (-0.34%) and operating temperature

**Trina Solar's Backsheet Performance Warranty**




**Comprehensive Products and System Certificates**

IEC61215/IEC61730/IEC61701/IEC62716/UL61730
ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO14064: Greenhouse Gases Emissions Verification
ISO45001: Occupational Health and Safety Management System

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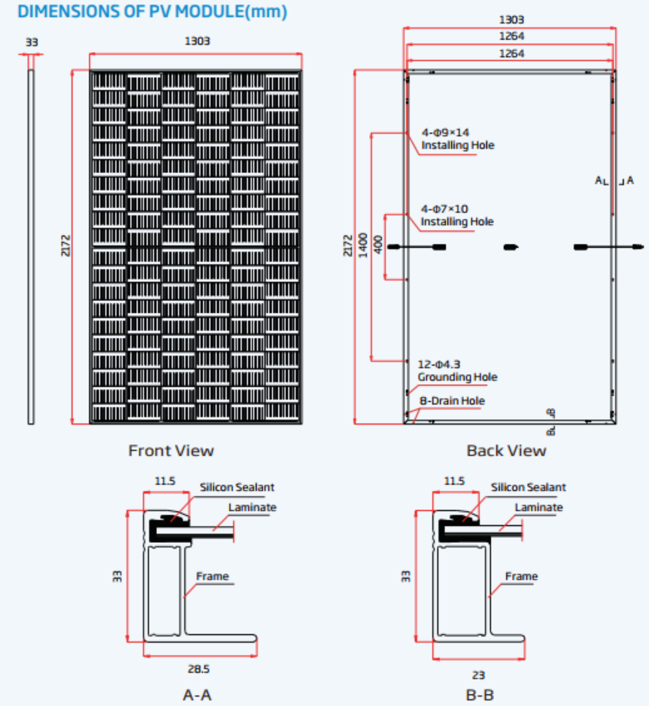
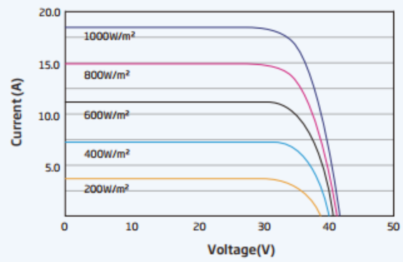
**Vertex** BACKSHEET MONOCRYSTALLINE MODULE

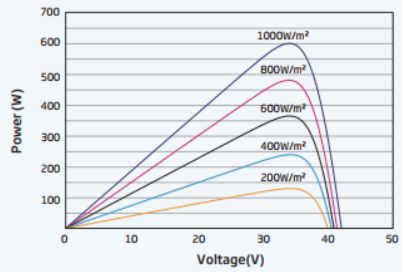
## DIMENSIONS OF PV MODULE(mm)




## I-V CURVES OF PV MODULE(600 W)




## P-V CURVES OF PV MODULE(600W)




### ELECTRICAL DATA (STC)

| | | | | | |
|---|---|---|---|---|---|
| Peak Power Watts-PMAX (Wp)* | 590 | 595 | 600 | 605 | 610 |
| Power Tolerance-PMAX (W) | | | 0 ~ +5 | | |
| Maximum Power Voltage-VMPP (V) | 34.0 | 34.2 | 34.4 | 34.6 | 34.8 |
| Maximum Power Current-IMPP (A) | 17.35 | 17.40 | 17.44 | 17.49 | 17.53 |
| Open Circuit Voltage-Voc (V) | 41.1 | 41.3 | 41.5 | 41.7 | 41.9 |
| Short Circuit Current-Isc (A) | 18.42 | 18.47 | 18.52 | 18.57 | 18.62 |
| Module Efficiency η m (%) | 20.8 | 21.0 | 21.2 | 21.4 | 21.6 |

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

### ELECTRICAL DATA (NOCT)

| | | | | | |
|---|---|---|---|---|---|
| Maximum Power-PMAX (Wp) | 447 | 451 | 454 | 458 | 461 |
| Maximum Power Voltage-VMPP (V) | 31.7 | 31.9 | 32.0 | 32.2 | 32.4 |
| Maximum Power Current-IMPP (A) | 14.09 | 14.13 | 14.18 | 14.22 | 14.25 |
| Open Circuit Voltage-Voc (V) | 38.7 | 38.9 | 39.1 | 39.3 | 39.5 |
| Short Circuit Current-Isc (A) | 14.85 | 14.88 | 14.92 | 14.96 | 15.00 |

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

### MECHANICAL DATA

| | |
|---|---|
| Solar Cells | Monocrystalline |
| No. of cells | 120 cells |
| Module Dimensions | 2172×1303×33 mm (85.51×51.30×1.30 inches) |
| Weight | 30.6 kg (67.5 lb) |
| Glass | 3.2 mm (0.13 inches), High Transmission, AR Coated Heat Strengthened Glass |
| Encapsulant material | EVA/POE |
| Backsheet | White |
| Frame | 33mm(1.30 inches) Anodized Aluminium Alloy |
| J-Box | IP 68 rated |
| Cables | Photovoltaic Technology Cable 4.0mm² (0.006 inches²),<br>Portrait: 350/280 mm(13.78/11.02 inches)<br>Length can be customized |
| Connector | MC4 EVO2 / TS4* |

*Please refer to regional datasheet for specified connector.

### TEMPERATURE RATINGS

| | |
|---|---|
| NOCT (Nominal Operating Cell Temperature) | 43°C (±2°C) |
| Temperature Coefficient of PMAX | - 0.34%/°C |
| Temperature Coefficient of Voc | - 0.25%/°C |
| Temperature Coefficient of Isc | 0.04%/°C |

### MAXIMUMRATINGS

| | |
|---|---|
| Operational Temperature | -40~+85°C |
| Maximum System Voltage | 1500V DC (IEC)<br>1500V DC (UL) |
| Max Series Fuse Rating | 30A |

### WARRANTY

12 year Product Workmanship Warranty

25 year Power Warranty

2% first year degradation

0.55% Annual Power Attenuation

(Please refer to product warranty for details)

### PACKAGING CONFIGUREATION

Modules per box: 33 pieces

Modules per 40' container: 594 pieces

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



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# ANNEX V JUNE MEAN IRRADIATION

This annex shows the mean Sun irradiation per every system orientation. In this case as an anomaly, the West peak irradiation is higher than the East orientation, this happens because in the weather information, during the month June the mornings present more clouds than later in the day affecting the mean values. However, even though the peak irradiation is higher, the curve of the East orientation is wider corresponding that more hours of sun are hitting those panels.

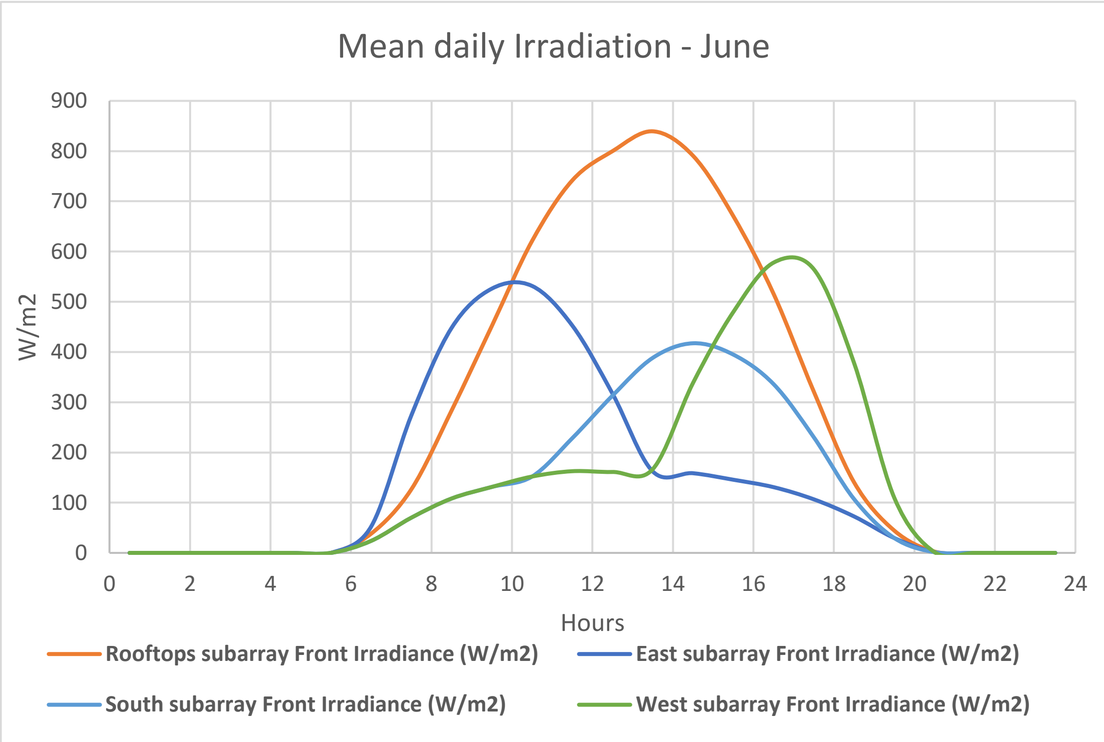



*Figure 57. June mean irradiation profiles per subsystem.*

# ANNEX VI LIFETIME REDUCTION OF $CO_2$ EMISSIONS

This table shows the reduction on emissions the system produces, representing a total after 25 years of 56,198.20 tCO2/eq.

| Year | Emissions Reduction ($tCO_2$/eq.) |
|---|---|
| 1 | 2,356.63 |
| 2 | 2,309.44 |
| 3 | 2,296.46 |
| 4 | 2,283.49 |
| 5 | 2,270.50 |
| 6 | 2,257.53 |
| 7 | 2,244.55 |
| 8 | 2,231.57 |
| 9 | 2,218.59 |
| 10 | 2,205.61 |
| 11 | 2,192.63 |
| 12 | 2,179.65 |
| 13 | 2,166.66 |
| 14 | 2,153.68 |
| 15 | 2,140.70 |
| 16 | 2,127.71 |
| 17 | 2,114.72 |
| 18 | 2,101.74 |
| 19 | 2,088.75 |
| 20 | 2,075.76 |
| 21 | 2,062.78 |
| 22 | 2,049.79 |
| 23 | 2,036.80 |
| 24 | 2,023.81 |
| 25 | 2,010.83 |
| 26 | 1,997.84 |
| **Total** | 56,198.20 |

*Table 51. $CO_2$ emissions reduction every year of the system's lifetime.*

# ANNEX VII OMIP PRICE TREND UNTIL YEAR 2047

| Year | Installation lifetime | OMIP price (€/MWh) | P1 (€/MWh) | P2 (€/MWh) | P3 (€/MWh) | P4 (€/MWh) | P5 (€/MWh) | P6 (€/MWh) | Cumulative yearly price diminution (%) |
|---|---|---|---|---|---|---|---|---|---|
| **2024** | 1 | 91.75 | 195.03 | 184.43 | 174.60 | 169.65 | 152.72 | 153.45 | 0.00% |
| **2025** | 2 | 71.00 | 150.92 | 142.72 | 135.12 | 131.28 | 118.18 | 118.75 | 22.62% |
| **2026** | 3 | 62.00 | 131.79 | 124.63 | 117.99 | 114.64 | 103.20 | 103.69 | 32.43% |
| **2027** | 4 | 59.00 | 125.41 | 118.60 | 112.28 | 109.10 | 98.21 | 98.68 | 35.69% |
| **2028** | 5 | 52.11 | 110.77 | 104.75 | 99.17 | 96.36 | 86.74 | 87.15 | 43.20% |
| **2029** | 6 | 46.88 | 99.65 | 94.24 | 89.21 | 86.68 | 78.04 | 78.41 | 48.90% |
| **2030** | 7 | 45.43 | 96.57 | 91.32 | 86.45 | 84.00 | 75.62 | 75.98 | 50.49% |
| **2031** | 8 | 44.21 | 93.97 | 88.87 | 84.13 | 81.75 | 73.59 | 73.94 | 51.81% |
| **2032** | 9 | 42.97 | 91.34 | 86.38 | 81.77 | 79.45 | 71.53 | 71.87 | 53.17% |
| **2033** | 10 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2033** | 11 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2034** | 12 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2035** | 13 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2036** | 14 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2037** | 15 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2038** | 16 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2039** | 17 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2040** | 18 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2041** | 19 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2042** | 20 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2043** | 21 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2044** | 22 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2045** | 23 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2046** | 24 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |
| **2047** | 25 | 42.95 | 91.30 | 86.34 | 81.74 | 79.42 | 71.49 | 71.83 | 53.19% |

*Table 52. OMIP, P1, P2, P3, P4, P5 and P6 until 2047.*

# ANNEX VIII CABLE, CONNECTORS AND PROTETIONS SUMMARY TABLE CALCULATION

| Inverter Model | Output Power (kW) | $I_{LLMAX}$ (A) | Minimum cable section (mm$^2$) | 1.25 x $I_{LLMAX}$ (A) | $I_{MINACCABLE}$ (A) | $I_{ACCABLE}$ (A) | Selected Cable Section (mm$^2$) | Resistance Cable (OHM) | $I_{SCLL}$ (A) | $I_{SCLN}$ (A) | Time response (s) | Ground connectors section (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SUN2000-300KTL-H0 | 300.00 | 481.13 | 30.37 | 601.41 | 633.06 | 640.00 | 400.00 | 0.01 | 63,373.55 | 36,439.79 | 0.82 | 200.00 |
| SUN2000-250KTL-H0 | 250.00 | 400.94 | 25.31 | 501.17 | 527.55 | 565.00 | 300.00 | 0.01 | 63,373.55 | 36,439.79 | 0.82 | 150.00 |
| SUN2000-215KTL-H3 | 215.00 | 344.81 | 21.76 | 431.01 | 453.69 | 490.00 | 240.00 | 0.01 | 50,698.84 | 29,151.83 | 0.82 | 120.00 |
| SUN2000-185KTL-H0 | 185.00 | 296.69 | 18.73 | 370.87 | 390.39 | 415.00 | 185.00 | 0.01 | 39,080.36 | 22,471.20 | 0.82 | 92.50 |
| SUN2000-115KTL-M2 | 115.00 | 184.43 | 11.64 | 230.54 | 242.67 | 271.00 | 95.00 | 0.02 | 20,068.29 | 11,539.27 | 0.82 | 47.50 |
| SUN2000-100KTL-M2 | 100.00 | 160.38 | 10.12 | 200.47 | 211.02 | 224.00 | 70.00 | 0.02 | 14,787.16 | 8,502.62 | 0.82 | 35.00 |
| SUN2000-90KTL-M1 | 90.00 | 144.34 | 9.11 | 180.42 | 189.92 | 224.00 | 70.00 | 0.02 | 14,787.16 | 8,502.62 | 0.82 | 35.00 |
| SUN2000-75KTL-M1 | 75.00 | 120.28 | 7.59 | 150.35 | 158.26 | 175.00 | 50.00 | 0.03 | 10,562.26 | 6,073.30 | 0.82 | 25.00 |
| SUN2000-60KTL-M1 | 60.00 | 96.23 | 6.07 | 120.28 | 126.61 | 144.00 | 35.00 | 0.04 | 7,393.58 | 4,251.31 | 0.82 | 17.50 |
| SUN2000-50KTL-M1 | 50.00 | 80.19 | 5.06 | 100.23 | 105.51 | 116.00 | 25.00 | 0.06 | 5,281.13 | 3,036.65 | 0.82 | 16.00 |
| SUN2000-40KTL-M3 | 40.00 | 64.15 | 4.05 | 80.19 | 84.41 | 91.00 | 16.00 | 0.09 | 3,379.92 | 1,943.46 | 0.82 | 8.00 |
| SUN2000-30KTL-M3 | 30.00 | 48.11 | 3.04 | 60.14 | 63.31 | 68.00 | 10.00 | 0.15 | 2,112.45 | 1,214.66 | 0.82 | 5.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SUN2000-20KTL-M3** | 20.00 | 32.08 | 2.02 | 40.09 | 42.20 | 49.00 | 6.00 | 0.25 | 1,267.47 | 728.80 | 0.82 | 4.00 |
| **SUN2000-15KTL-M2** | 15.00 | 24.06 | 1.52 | 30.07 | 31.65 | 38.00 | 4.00 | 0.38 | 844.98 | 485.86 | 0.82 | 4.00 |
| **SUN2000-10KTL-M2** | 10.00 | 16.04 | 1.01 | 20.05 | 21.10 | 29.00 | 2.50 | 0.61 | 528.11 | 303.66 | 0.82 | 4.00 |

*Table 53. Cables, connectors and protections summary table*

# ANNEX IX LIFETIME ELECTRICITY BILLS WITH PV SYSTEM

| System lifetime (years) | January(€) | February(€) | March(€) | April(€) | May(€) | June(€) | July(€) | August(€) | September(€) | October(€) | November(€) | December(€) | Total Year (€) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| 2 | 442,308.29 € | 424,409.37 € | 345,037.48 € | 221,407.03 € | 292,870.63 € | 342,732.46 € | 514,906.15 € | 140,893.77 € | 425,640.84 € | 414,587.60 € | 384,395.87 € | 396,391.25 € | 4,345,580.74 € |
| 3 | 459,785.46 € | 441,391.41 € | 359,675.08 € | 232,472.93 € | 306,308.26 € | 358,642.54 € | 537,311.98 € | 149,141.77 € | 443,613.76 € | 431,514.08 € | 399,727.92 € | 411,836.61 € | 4,531,421.80 € |
| 4 | 475,154.72 € | 456,193.16 € | 371,980.75 € | 240,899.16 € | 317,072.84 € | 371,287.47 € | 555,836.32 € | 154,881.10 € | 458,756.95 € | 446,078.07 € | 413,124.20 € | 425,538.56 € | 4,686,803.30 € |
| 5 | 491,037.58 € | 471,493.80 € | 384,706.22 € | 249,630.10 € | 328,217.00 € | 384,373.23 € | 574,993.31 € | 160,833.99 € | 474,413.04 € | 461,133.89 € | 426,972.28 € | 439,695.72 € | 4,847,500.16 € |
| 6 | 507,449.87 € | 487,305.08 € | 397,863.47 € | 258,673.73 € | 339,753.30 € | 397,914.08 € | 594,805.16 € | 167,012.40 € | 490,599.28 € | 476,695.10 € | 441,287.55 € | 454,326.72 € | 5,013,685.74 € |
| 7 | 524,412.02 € | 503,654.84 € | 411,470.74 € | 268,043.86 € | 351,695.15 € | 411,925.46 € | 615,295.20 € | 173,427.83 € | 507,333.52 € | 492,783.37 € | 456,085.05 € | 469,443.46 € | 5,185,570.50 € |
| 8 | 541,943.20 € | 520,554.38 € | 425,550.44 € | 277,748.53 € | 364,054.85 € | 426,423.55 € | 636,486.46 € | 180,080.82 € | 524,634.19 € | 509,413.20 € | 471,380.94 € | 485,061.85 € | 5,363,332.41 € |
| 9 | 560,070.20 € | 538,027.26 € | 440,111.98 € | 287,798.81 € | 376,847.36 € | 441,427.67 € | 658,401.97 € | 186,979.95 € | 542,520.33 € | 526,601.90 € | 487,195.19 € | 501,199.74 € | 5,547,182.36 € |
| 10 | 578,806.61 € | 556,084.28 € | 455,182.55 € | 298,205.64 € | 390,086.18 € | 456,957.90 € | 681,070.20 € | 194,136.20 € | 561,011.64 € | 544,367.47 € | 503,541.02 € | 517,873.27 € | 5,737,322.96 € |
| 11 | 598,182.53 € | 574,747.03 € | 470,770.58 € | 308,984.65 € | 403,790.61 € | 473,029.81 € | 704,515.04 € | 201,561.27 € | 580,128.44 € | 562,733.53 € | 520,437.37 € | 535,103.79 € | 5,933,984.65 € |
| 12 | 618,214.11 € | 594,036.35 € | 486,890.81 € | 320,149.02 € | 417,979.73 € | 489,662.65 € | 728,759.51 € | 209,261.73 € | 599,894.22 € | 581,716.38 € | 537,900.82 € | 552,905.35 € | 6,137,370.68 € |
| 13 | 638,916.69 € | 613,970.21 € | 503,563.30 € | 331,717.37 € | 432,662.82 € | 506,872.75 € | 753,830.67 € | 217,247.68 € | 620,328.96 € | 601,335.75 € | 555,947.73 € | 571,301.04 € | 6,347,694.97 € |
| 14 | 660,314.05 € | 634,573.75 € | 520,807.68 € | 343,709.94 € | 447,864.76 € | 524,679.78 € | 779,756.50 € | 225,528.47 € | 641,454.89 € | 621,615.50 € | 574,600.55 € | 590,311.52 € | 6,565,217.39 € |
| 15 | 682,430.58 € | 655,865.65 € | 538,646.09 € | 356,140.57 € | 463,595.61 € | 543,104.75 € | 806,565.91 € | 234,122.79 € | 663,296.27 € | 642,583.14 € | 593,875.92 € | 609,958.58 € | 6,790,185.86 € |
| 16 | 705,295.93 € | 677,873.14 € | 557,095.79 € | 369,025.19 € | 479,879.46 € | 562,169.87 € | 834,288.79 € | 243,042.36 € | 685,875.86 € | 664,258.00 € | 613,794.53 € | 630,256.78 € | 7,022,855.70 € |
| 17 | 728,943.02 € | 700,617.17 € | 576,176.64 € | 382,376.38 € | 496,732.36 € | 581,895.63 € | 862,956.03 € | 252,293.21 € | 709,218.44 € | 686,656.62 € | 634,377.80 € | 651,231.86 € | 7,263,475.16 € |
| 18 | 753,381.83 € | 724,132.12 € | 595,912.59 € | 396,206.54 € | 514,173.28 € | 602,308.16 € | 892,600.77 € | 261,889.01 € | 733,349.78 € | 709,810.13 € | 655,659.91 € | 672,910.43 € | 7,512,334.55 € |
| 19 | 778,641.60 € | 748,448.20 € | 616,327.85 € | 410,539.68 € | 532,228.33 € | 623,427.93 € | 923,257.24 € | 271,843.22 € | 758,297.93 € | 733,744.44 € | 677,663.28 € | 695,307.60 € | 7,769,727.30 € |
| 20 | 804,750.58 € | 773,581.29 € | 637,443.87 € | 425,389.04 € | 550,920.52 € | 645,280.73 € | 954,957.33 € | 282,165.82 € | 784,088.64 € | 758,483.12 € | 700,403.58 € | 718,449.01 € | 8,035,913.53 € |
| 21 | 831,730.50 € | 799,569.12 € | 659,279.39 € | 440,785.89 € | 570,262.61 € | 667,892.43 € | 987,736.32 € | 292,870.76 € | 810,751.27 € | 784,055.98 € | 723,906.98 € | 742,358.38 € | 8,311,199.63 € |
| 22 | 859,618.63 € | 826,429.73 € | 681,877.41 € | 456,741.67 € | 590,279.05 € | 691,287.18 € | 1,021,631.41 € | 303,972.56 € | 838,315.38 € | 810,490.61 € | 748,199.56 € | 767,062.07 € | 8,595,905.26 € |
| 23 | 888,452.17 € | 854,204.86 € | 705,268.98 € | 473,281.83 € | 610,997.97 € | 715,496.74 € | 1,056,688.24 € | 315,481.70 € | 866,809.92 € | 837,813.00 € | 773,303.04 € | 792,586.32 € | 8,890,384.77 € |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **24** | 918,251.45 € | 882,911.77 € | 729,475.20 € | 490,428.21 € | 632,442.35 € | 740,544.53 € | 1,092,937.62 € | 327,417.87 € | 896,270.61 € | 866,051.02 € | 799,246.23 € | 818,957.27 € | 9,194,934.13 € |
| **25** | 949,054.18 € | 912,584.19 € | 754,516.73 € | 508,189.88 € | 654,636.99 € | 766,458.37 € | 1,130,420.30 € | 339,794.31 € | 926,725.67 € | 895,235.21 € | 826,059.01 € | 846,210.46 € | 9,509,885.30 € |
| **26** | 980,891.00 € | 943,249.32 € | 780,426.07 € | 526,594.23 € | 677,606.23 € | 793,270.60 € | 1,169,189.60 € | 352,628.35 € | 958,208.27 € | 925,397.10 € | 853,771.73 € | 874,368.47 € | 9,835,600.97 € |

*Table 54. System lifetime electricity bills, with current UPV's electricity contract with OMIP 91.5 €/MWh*

| System lifetime (years) | January(€) | February(€) | March(€) | April(€) | May(€) | June(€) | July(€) | August(€) | September(€) | October(€) | November(€) | December(€) | Total Year(€) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| 2 | 327,597.18 € | 315,057.51 € | 253,697.09 € | 154,334.58 € | 200,829.76 € | 239,591.68 € | 379,178.07 € | 102,756.08 € | 297,319.75 € | 284,313.60 € | 278,033.49 € | 295,828.32 € | 3,128,537.11 € |
| 3 | 340,302.47 € | 327,430.02 € | 264,137.67 € | 161,773.03 € | 209,848.26 € | 250,503.41 € | 395,443.55 € | 108,359.57 € | 309,650.53 € | 295,735.41 € | 288,914.33 € | 307,094.15 € | 3,259,192.40 € |
| 4 | 351,586.67 € | 338,320.61 € | 273,065.88 € | 167,548.52 € | 217,152.92 € | 259,258.66 € | 408,982.38 € | 112,407.83 € | 320,135.52 € | 305,642.93 € | 298,517.57 € | 317,216.02 € | 3,369,835.51 € |
| 5 | 363,245.34 € | 349,575.92 € | 282,295.62 € | 173,530.44 € | 224,713.26 € | 268,316.96 € | 422,980.68 € | 116,603.55 € | 330,973.05 € | 315,882.78 € | 308,442.56 € | 327,671.35 € | 3,484,231.51 € |
| 6 | 375,289.83 € | 361,204.07 € | 291,835.21 € | 179,724.01 € | 232,537.81 € | 277,687.92 € | 437,454.58 € | 120,955.60 € | 342,174.90 € | 326,464.03 € | 318,700.30 € | 338,473.98 € | 3,602,502.24 € |
| 7 | 387,735.21 € | 373,226.09 € | 301,697.85 € | 186,138.53 € | 240,635.26 € | 287,382.08 € | 452,420.99 € | 125,472.17 € | 353,753.24 € | 337,401.28 € | 329,301.47 € | 349,632.26 € | 3,724,796.43 € |
| 8 | 400,595.41 € | 385,649.72 € | 311,900.06 € | 192,779.38 € | 249,013.79 € | 297,410.46 € | 467,896.56 € | 130,152.56 € | 365,720.66 € | 348,704.23 € | 340,257.48 € | 361,157.74 € | 3,851,238.05 € |
| 9 | 413,890.44 € | 398,492.50 € | 322,447.88 € | 199,653.88 € | 257,683.42 € | 307,786.38 € | 483,897.85 € | 135,002.59 € | 378,090.14 € | 360,384.49 € | 351,582.80 € | 373,063.46 € | 3,981,975.83 € |
| 10 | 427,629.68 € | 411,761.57 € | 333,361.55 € | 206,769.38 € | 266,653.12 € | 318,523.58 € | 500,445.76 € | 140,029.73 € | 390,875.13 € | 372,454.11 € | 363,286.40 € | 385,361.09 € | 4,117,151.10 € |
| 11 | 441,835.78 € | 425,472.76 € | 344,646.61 € | 214,136.50 € | 275,936.87 € | 329,632.64 € | 517,557.42 € | 145,242.07 € | 404,089.48 € | 384,929.04 € | 375,381.79 € | 398,066.40 € | 4,256,927.36 € |
| 12 | 456,520.04 € | 439,641.22 € | 356,313.10 € | 221,764.01 € | 285,547.04 € | 341,126.73 € | 535,249.15 € | 150,643.91 € | 417,749.35 € | 397,820.15 € | 387,880.51 € | 411,189.40 € | 4,401,444.61 € |
| 13 | 471,693.01 € | 454,279.75 € | 368,375.53 € | 229,664.53 € | 295,489.26 € | 353,016.83 € | 553,540.45 € | 156,242.18 € | 431,868.26 € | 411,140.63 € | 400,793.89 € | 424,746.93 € | 4,550,851.25 € |
| 14 | 487,372.02 € | 469,406.87 € | 380,847.71 € | 237,852.03 € | 305,780.46 € | 365,316.35 € | 572,451.52 € | 162,043.25 € | 446,461.37 € | 424,906.57 € | 414,138.08 € | 438,754.16 € | 4,705,330.39 € |
| 15 | 503,574.84 € | 485,035.82 € | 393,745.45 € | 246,336.09 € | 316,427.04 € | 378,039.64 € | 592,003.20 € | 168,059.67 € | 461,545.34 € | 439,136.44 € | 427,924.49 € | 453,227.08 € | 4,865,055.10 € |
| 16 | 520,323.60 € | 501,186.67 € | 407,080.81 € | 255,126.87 € | 327,445.28 € | 391,201.98 € | 612,217.03 € | 174,299.85 € | 477,135.54 € | 453,843.08 € | 442,167.71 € | 468,175.72 € | 5,030,204.14 € |
| 17 | 537,642.52 € | 517,874.41 € | 420,868.16 € | 264,232.67 € | 338,846.16 € | 404,817.15 € | 633,115.28 € | 180,767.68 € | 493,248.84 € | 469,036.54 € | 456,882.87 € | 483,619.09 € | 5,200,951.37 € |
| 18 | 555,537.62 € | 535,124.75 € | 435,124.60 € | 273,661.95 € | 350,642.04 € | 418,903.12 € | 654,721.94 € | 187,472.40 € | 509,902.81 € | 484,738.85 € | 472,095.26 € | 499,576.85 € | 5,377,502.19 € |
| 19 | 574,030.27 € | 552,959.99 € | 449,867.60 € | 283,430.79 € | 362,850.80 € | 433,473.68 € | 677,061.77 € | 194,423.09 € | 527,116.75 € | 500,967.23 € | 487,820.65 € | 516,059.29 € | 5,560,061.91 € |
| 20 | 593,140.99 € | 571,390.75 € | 465,112.20 € | 293,548.24 € | 375,487.95 € | 448,546.59 € | 700,157.58 € | 201,626.29 € | 544,908.00 € | 517,737.44 € | 504,069.31 € | 533,085.14 € | 5,748,810.48 € |
| 21 | 612,884.98 € | 590,445.25 € | 480,871.40 € | 304,035.81 € | 388,561.31 € | 464,139.55 € | 724,034.75 € | 209,091.76 € | 563,296.66 € | 535,069.45 € | 520,859.88 € | 550,671.53 € | 5,943,962.33 € |
| 22 | 633,289.89 € | 610,135.68 € | 497,177.44 € | 314,900.53 € | 402,087.34 € | 480,268.80 € | 748,720.17 € | 216,829.20 € | 582,302.91 € | 552,981.75 € | 538,210.80 € | 568,837.60 € | 6,145,742.11 € |
| 23 | 654,383.22 € | 630,493.31 € | 514,052.64 € | 326,159.77 € | 416,084.95 € | 496,956.28 € | 774,247.40 € | 224,845.48 € | 601,946.29 € | 571,491.67 € | 556,137.00 € | 587,602.40 € | 6,354,400.41 € |
| 24 | 676,178.74 € | 651,529.58 € | 531,511.30 € | 337,827.82 € | 430,569.95 € | 514,217.59 € | 800,637.89 € | 233,154.10 € | 622,251.35 € | 590,617.86 € | 574,658.94 € | 606,984.76 € | 6,570,139.88 € |
| 25 | 698,704.15 € | 673,269.11 € | 549,567.61 € | 349,910.59 € | 445,559.67 € | 532,071.60 € | 827,921.04 € | 241,763.84 € | 643,237.07 € | 610,380.73 € | 593,797.88 € | 627,011.08 € | 6,793,194.37 € |
| 26 | 721,981.43 € | 695,731.21 € | 568,245.29 € | 362,426.47 € | 461,068.93 € | 550,540.63 € | 856,136.29 € | 250,686.36 € | 664,926.00 € | 630,801.39 € | 613,575.38 € | 647,697.14 € | 7,023,816.52 € |

*Table 55. System lifetime electricity bills, with current UPV's electricity contract with OMIP 55.8 €/MWh*

| System lifetime (years) | January(€) | February(€) | March(€) | April(€) | May(€) | June(€) | July(€) | August(€) | September(€) | October(€) | November(€) | December(€) | Total Year(€) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € | - € |
| **2** | 342,258.15 € | 328,407.97 € | 266,990.01 € | 171,324.76 € | 226,623.29 € | 265,206.38 € | 398,434.38 € | 109,023.60 € | 329,360.88 € | 320,807.88 € | 297,445.53 € | 306,727.55 € | 3,362,610.38 € |
| **3** | 301,306.41 € | 289,252.43 € | 235,702.12 € | 152,344.06 € | 200,729.80 € | 235,025.48 € | 352,111.05 € | 97,735.52 € | 290,708.78 € | 282,779.62 € | 261,949.53 € | 269,884.59 € | 2,969,529.39 € |
| **4** | 287,416.69 € | 275,947.02 € | 225,007.71 € | 145,717.67 € | 191,794.42 € | 224,588.35 € | 336,220.24 € | 93,686.15 € | 277,497.83 € | 269,828.49 € | 249,895.01 € | 257,404.34 € | 2,835,003.92 € |
| **5** | 254,425.54 € | 244,299.15 € | 199,331.15 € | 129,343.00 € | 170,061.91 € | 199,158.62 € | 297,926.25 € | 83,334.30 € | 245,811.72 € | 238,931.28 € | 221,230.83 € | 227,823.34 € | 2,511,677.09 € |
| **6** | 229,409.23 € | 220,302.13 € | 179,867.14 € | 116,941.88 € | 153,596.54 € | 179,890.01 € | 268,901.04 € | 75,503.39 € | 221,791.38 € | 215,505.54 € | 199,498.40 € | 205,393.19 € | 2,266,599.87 € |
| **7** | 222,772.53 € | 213,954.78 € | 174,794.57 € | 113,866.21 € | 149,401.64 € | 174,987.74 € | 261,380.10 € | 73,672.90 € | 215,517.51 € | 209,336.54 € | 193,746.93 € | 199,421.64 € | 2,202,853.09 € |
| **8** | 217,323.14 € | 208,746.07 € | 170,648.80 € | 111,379.17 € | 145,988.63 € | 170,998.93 € | 255,235.67 € | 72,213.71 € | 210,382.11 € | 204,278.38 € | 189,027.17 € | 194,513.31 € | 2,150,735.09 € |
| **9** | 211,670.88 € | 203,340.05 € | 166,334.31 € | 108,769.63 € | 142,424.31 € | 166,831.56 € | 248,834.03 € | 70,666.52 € | 205,038.15 € | 199,021.99 € | 184,128.77 € | 189,421.59 € | 2,096,481.79 € |
| **10** | 212,063.45 € | 203,738.43 € | 166,770.01 € | 109,256.73 € | 142,919.97 € | 167,420.46 € | 249,530.84 € | 71,127.72 € | 205,543.72 € | 199,445.62 € | 184,487.61 € | 189,738.67 € | 2,102,043.23 € |
| **11** | 212,552.04 € | 204,224.71 € | 167,278.79 € | 109,791.43 € | 143,478.81 € | 168,081.56 € | 250,335.15 € | 71,620.71 € | 206,136.89 € | 199,955.96 € | 184,926.88 € | 190,138.29 € | 2,108,521.22 € |
| **12** | 213,044.19 € | 204,712.23 € | 167,788.56 € | 110,327.29 € | 144,040.96 € | 168,743.77 € | 251,139.49 € | 72,114.16 € | 206,730.93 € | 200,466.62 € | 185,367.24 € | 190,537.98 € | 2,115,013.42 € |
| **13** | 213,537.53 € | 205,199.97 € | 168,299.98 € | 110,865.96 € | 144,603.75 € | 169,406.05 € | 251,943.87 € | 72,608.11 € | 207,325.18 € | 200,977.30 € | 185,807.80 € | 190,939.16 € | 2,121,514.66 € |
| **14** | 214,032.51 € | 205,689.11 € | 168,813.27 € | 111,409.26 € | 145,169.74 € | 170,068.36 € | 252,748.28 € | 73,102.22 € | 207,919.55 € | 201,488.86 € | 186,249.55 € | 191,342.07 € | 2,128,032.78 € |
| **15** | 214,529.44 € | 206,178.46 € | 169,329.23 € | 111,956.64 € | 145,736.29 € | 170,730.85 € | 253,552.72 € | 73,599.03 € | 208,514.36 € | 202,002.96 € | 186,691.32 € | 191,747.08 € | 2,134,568.38 € |
| **16** | 215,029.97 € | 206,669.34 € | 169,846.85 € | 112,508.06 € | 146,305.21 € | 171,393.83 € | 254,357.20 € | 74,098.53 € | 209,109.20 € | 202,518.37 € | 187,133.11 € | 192,152.11 € | 2,141,121.78 € |
| **17** | 215,536.30 € | 207,160.82 € | 170,365.83 € | 113,062.32 € | 146,875.48 € | 172,056.84 € | 255,161.71 € | 74,598.90 € | 209,704.07 € | 203,032.92 € | 187,574.94 € | 192,558.40 € | 2,147,688.53 € |
| **18** | 216,043.49 € | 207,655.70 € | 170,886.84 € | 113,618.15 € | 147,446.87 € | 172,720.86 € | 255,966.60 € | 75,100.59 € | 210,299.01 € | 203,548.66 € | 188,020.28 € | 192,967.12 € | 2,154,274.17 € |
| **19** | 216,552.33 € | 208,155.08 € | 171,410.36 € | 114,177.47 € | 148,020.97 € | 173,385.00 € | 256,772.19 € | 75,603.82 € | 210,894.44 € | 204,065.73 € | 188,468.69 € | 193,375.85 € | 2,160,881.93 € |
| **20** | 217,062.99 € | 208,655.79 € | 171,935.84 € | 114,738.92 € | 148,598.16 € | 174,049.66 € | 257,577.81 € | 76,107.75 € | 211,489.90 € | 204,583.40 € | 188,917.78 € | 193,785.12 € | 2,167,503.12 € |
| **21** | 217,573.66 € | 209,160.52 € | 172,461.91 € | 115,305.86 € | 149,175.87 € | 174,715.01 € | 258,383.46 € | 76,612.51 € | 212,085.67 € | 205,102.41 € | 189,367.94 € | 194,194.67 € | 2,174,139.49 € |
| **22** | 218,086.47 € | 209,666.40 € | 172,993.27 € | 115,876.01 € | 149,754.64 € | 175,380.54 € | 259,189.34 € | 77,118.27 € | 212,681.80 € | 205,622.62 € | 189,819.29 € | 194,604.74 € | 2,180,793.39 € |
| **23** | 218,603.03 € | 210,176.50 € | 173,530.93 € | 116,450.66 € | 150,335.62 € | 176,047.47 € | 259,997.39 € | 77,624.05 € | 213,277.97 € | 206,143.29 € | 190,270.66 € | 195,015.30 € | 2,187,472.87 € |
| **24** | 219,120.47 € | 210,687.43 € | 174,073.18 € | 117,029.88 € | 150,918.43 € | 176,714.63 € | 260,805.48 € | 78,131.06 € | 213,875.23 € | 206,663.99 € | 190,722.50 € | 195,426.10 € | 2,194,168.38 € |
| **25** | 219,640.06 € | 211,199.79 € | 174,618.16 € | 117,610.62 € | 151,502.95 € | 177,381.82 € | 261,613.70 € | 78,638.76 € | 214,472.56 € | 207,184.71 € | 191,175.23 € | 195,838.89 € | 2,200,877.25 € |
| **26** | 220,161.06 € | 211,712.38 € | 175,166.69 € | 118,194.11 € | 152,088.77 € | 178,049.65 € | 262,424.69 € | 79,147.46 € | 215,069.92 € | 207,705.45 € | 191,629.13 € | 196,252.07 € | 2,207,601.38 € |

*Table 56. System lifetime electricity bills, with current UPV's electricity contract following OMIP trend*[35]

# ANNEX X SYSTEM’S ENERGY PRODUCTION WITHOUTH WEST FAÇADES

| Month | Energy bill load (MWh) | Energy from grid (MWh) | Energy from system (MWh) | Energy to grid (MWh) | Energy production (MWh) | Percentage grid (%) | Percentage system (%) | Percentage to grid (%) |
|---|---|---|---|---|---|---|---|---|
| **January** | 3,444 | 2,399 | 1,045 | 148 | 1,193 | 69.65% | 30.35% | 12.40% |
| **February** | 3,326 | 2,296 | 1,030 | 109 | 1,139 | 69.04% | 30.96% | 9.58% |
| **March** | 3,194 | 2,097 | 1,097 | 299 | 1,396 | 65.65% | 34.35% | 21.40% |
| **April** | 2,936 | 1,640 | 1,297 | 284 | 1,581 | 55.83% | 44.17% | 17.96% |
| **May** | 3,281 | 2,041 | 1,240 | 174 | 1,414 | 62.22% | 37.78% | 12.32% |
| **June** | 3,583 | 2,236 | 1,347 | 129 | 1,477 | 62.40% | 37.60% | 8.76% |
| **July** | 4,455 | 2,924 | 1,531 | 95 | 1,626 | 65.63% | 34.37% | 5.82% |
| **August** | 2,617 | 1,352 | 1,265 | 486 | 1,752 | 51.65% | 48.35% | 27.77% |
| **September** | 3,676 | 2,519 | 1,157 | 137 | 1,294 | 68.52% | 31.48% | 10.56% |
| **October** | 3,824 | 2,679 | 1,145 | 180 | 1,325 | 70.06% | 29.94% | 13.60% |
| **November** | 3,154 | 2,237 | 917 | 181 | 1,098 | 70.92% | 29.08% | 16.51% |
| **December** | 3,022 | 2,197 | 825 | 255 | 1,080 | 72.69% | 27.31% | 23.58% |
| **Annual** | 40,514 | 26,616 | 13,897 | 2,477 | 16,375 | 65.70% | 34.30% | 15.13% |

*Table 57. System’s production and energy distribution without the West array.*

# ANNEX XI INVERTERS DATASHEETS

| | SUN2000-75KTL-M1 | SUN2000-60KTL-M0 | SUN2000-50KTL-M0 | SUN2000-40KTL-M3 | SUN2000-30KTL-M3 | SUN2000-20KTL-M5 | SUN2000-15KTL-M2 | SUN2000-10KTL-M2 |
|---|---|---|---|---|---|---|---|---|
| **Efficiency** | | | | | | | | |
| **Max. Efficiency** | 0.988 | 0.989 | 0.987 | 0.9875 | 0.9875 | 0.984 | 0.9865 | 0.985 |
| **European Efficiency** | 0.984 | 0.987 | 0.985 | 0.985 | 0.9845 | 0.981 | 0.983 | 0.98 |
| **Input** | | | | | | | | |
| **Max. Input Voltage** | 1,100 V | 1,100 V | 1,100 V | 1,100 V | 1,100 V | 1,100 V | 1,080 V | 1,080 V |
| **Number of MPP Trackers** | 10 | 6 | 6 | 4 | 4 | 2 | 2 | 2 |
| **Max. Current per MPPT** | 30 A | 22 A | 22 A | 27 A | 27 A | 30 A | 22 A | 22 A |
| **Max. Short Circuit Current per MPPT** | 40 A | 30 A | 30 A | 40 A | 40 A | 40 A | 30 A | 30 A |
| **Max. PV Inputs per MPPT** | 20 | 12 | 12 | 8 | 8 | 4 | 4 | 4 |
| **Start Voltage** | 200 V | 200 V | 200 V | 200 V | 200 V | 200 V | 200 V | 200 V |
| **MPPT Operating Voltage Range** | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 160 V ~ 950 V | 160 V ~ 950 V |
| **Nominal Input Voltage** | 720 V | 720 V | 600 V | 720 V | 720 V | 600 V | 600 V | 600 V |
| **Output** | | | | | | | | |
| **Nominal AC Active Power** | 75 kW | 60 kW | 50 kW | 40 kW | 30 kW | 20 kW | 15 kW | 10 kW |
| **Max. AC Apparent Power** | 75 kVA | 66 kVA | 55 kVA | 44 kVA | 33 kVA | 22 kVA | 16.5 kVA | 11 kVA |
| **Max. AC Active Power (cosφ=1)** | 75 kW | 66 kW | 55 kW | 44 kW | 33 kW | 22 kW | 16.5 kW | 11 kW |
| **Nominal Output Voltage** | 480 V, 3 W + (N)b + PE | 480 V, 3 W + (N)b + PE | 415 V, 3 W + (N)b + PE | (480 V AC), 3W+PE | (480 V AC), 3W+PE | 230 V/400 V, 3W/N+PE | 230 V/400 V, 3W/N+PE | 230 V/400 V, 3W/N+PE |
| **Rated AC Grid Frequency** | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz |
| **Nominal Output Current** | 90.25 A | 72.2 A | 69.6 A | 48.1 A | 36.1 A | 28.9 A | 21.7 A | 14.5 A |
| **Max. Output Current** | 90.25 A | 79.4 A | 76.6 A | 53.2 A | 39.9 A | 31.9 A | 25.2 A | 17 A |
| **Adjustable Power Factor Range** | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD |
| **Total Harmonic Distortion** | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% |
| **Protection** | | | | | | | | |
| **Smart String-Level Disconnector(SSLD)** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Anti-islanding Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **AC Overcurrent Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **DC Reverse-polarity Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **PV-array String Fault Monitoring** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **DC Surge Arrester** | Type II | Type II | Type II | Type II | Type II | Type II | Type II | Type II |
| **AC Surge Arrester** | Type II | Type II | Type II | Type II | Type II | Type II | Type II | Type II |
| **DC Insulation Resistance Detection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **AC Grounding Fault Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Residual Current Monitoring Unit** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Communication** | | | | | | | | |
| **Display** | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP | LED Indicator s, WLAN + APP |
| **USB** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **MBUS** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **RS485** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **General** | | | | | | | | |
| **Dimensions (W x H x D)** | 1,035 x 700 x 365 mm | 1,075 x 555 x 300 mm | 1,075 x 555 x 300 mm | 640 x 535 x 270 mm | 640 x 535 x 270 mm | 460 x 546 x 228 mm | 525 x 470 x 262 mm | 525 x 470 x 262 mm |
| **Weight (with mounting plate)** | ≤90 kg | ≤74 kg | ≤74 kg | ≤43 kg | ≤43 kg | ≤21 kg | ≤25 kg | ≤25 kg |
| **Operating Temperature Range** | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ | -25 ℃ ~ 60 ℃ |
| **Cooling Method** | Smart Air Cooling | Natural Convecti on | Natural Convecti on | Natural Convecti on | Natural Convecti on | Smart Air Cooling | Smart Air Cooling | Smart Air Cooling |
| **Max. Operating Altitude without Derating** | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m |
| **Relative Humidity** | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% |
| **AC Connector** | Crimping module + OT/DT terminal | Cable gland + OT terminal | Cable gland + OT terminal | Cable gland + OT terminal | Cable gland + OT terminal | Cable gland + OT terminal | Cable gland + OT terminal | Cable gland + OT terminal |
| **Protection Degree** | IP 66 | IP 65 | IP 65 | IP 66 | IP 66 | IP 66 | IP 65 | IP 65 |

*Table 58. Catalogue data of inverters from 75 kW to 10 kW.*

| | SUN200 0-300KT L-H0 | SUN200 0-250KT L-H1 | SUN2000-215KTL -H0 | SUN2000-185KTL -H1 | SUN2000-115KTL-M0 | SUN2000 -100KTL-M1 | SUN2000-90KTL-H0 |
|---|---|---|---|---|---|---|---|
| **Efficiency** | | | | | | | |
| **Max. Efficiency** | 0.99 | 0.99 | 0.99 | 0.99 | 0.986 | 0.986 | 0.986 |
| **European Efficiency** | 0.988 | 0.988 | 0.988 | 0.986 | 0.984 | 0.984 | 0.988 |
| **Input** | | | | | | | |
| **Max. Input Voltage** | 1,500 V | 1,500 V | 1,500 V | 1,500 V | 1,100 V | 1,100 V | 1,500 V |
| **Number of MPP Trackers** | 6 | 6 | 9 | 9 | 10 | 10 | 6 |
| **Max. Current per MPPT** | 65 A | 65 A | 30 A | 26 A | 30 A | 30 A | 22 A |
| **Max. Short Circuit Current per MPPT** | 115 A | 115 A | 50 A | 40 A | 40 A | 40 A | 33 A |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Max. PV Inputs per MPPT** | 28 | 28 | 18 | 18 | 20 | 20 | 12 |
| **Start Voltage** | 550 V | 550 V | 550 V | 550 V | 200 V | 200 V | 600 V |
| **MPPT Operating Voltage Range** | 500 V ~ 1,500 V | 500 V ~ 1,500 V | 500 V ~ 1,500 V | 500 V ~ 1,500 V | 200 V ~ 1,000 V | 200 V ~ 1,000 V | 600 V ~ 1,500 V |
| **Nominal Input Voltage** | 1,080 V | 1,080 V | 1,080 V | 1,080 V | 720 V | 720 V | 1080 V |
| **Output** | | | | | | | |
| **Nominal AC Active Power** | 300 kW | 250 kW | 200 kW | 175 kW | 115 kW | 100 kW | 90 kW |
| **Max. AC Apparent Power** | 330 kVA | 275 kVA | 215 kVA | 185 kVA | 125 kVA | 110 kVA | 100 kVA |
| **Max. AC Active Power (cosφ=1)** | 330 kW | 275 kW | 215 kW | 185 kW | 125 kW | 110 kW | 100 kW |
| **Nominal Output Voltage** | 800 V, 3W + PE | 800 V, 3W + PE | 800 V, 3W + PE | 800 V, 3W + PE | 480 V, 3W + PE | 480 V, 3 W + (N)b + PE | 800 V, 3W + PE |
| **Rated AC Grid Frequency** | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz | 50 Hz / 60 Hz |
| **Nominal Output Current** | 216.6 A | 180.5 A | 144.4 A | 126.3 A | 126.3 A | 120.3 A | 65 A |
| **Max. Output Current** | 238.2 A | 198.5 A | 155.2 A | 134.9 A | 134.9 A | 133.7 A | 72.9 A |
| **Adjustable Power Factor Range** | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD | 0.8 LG ... 0.8 LD |
| **Total Harmonic Distortion** | ＜ 1% | ＜ 1% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% | ＜ 3% |
| **Protection** | | | | | | | |
| **Smart String-Level Disconnector(SSLD)** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Anti-islanding Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **AC Overcurrent Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **DC Reverse-polarity Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **PV-array String Fault Monitoring** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **DC Surge Arrester** | Type II | Type II | Type II | Type II | Type II | Type II | Type II |
| **AC Surge Arrester** | Type II | Type II | Type II | Type II | Type II | Type II | Type II |
| **DC Insulation Resistance Detection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **AC Grounding Fault Protection** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Residual Current Monitoring Unit** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Communication** | | | | | | | |
| **Display** | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP | LED Indicators, WLAN + APP |
| **USB** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **MBUS** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **RS485** | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **General** | | | | | | | |
| **Dimensions (W x H x D)** | 1,048 x 732 x 395 mm | 1,048 x 732 x 395 mm | 1,035 x 700 x 365 mm | 1,035 x 700 x 365 mm | 1,035 x 700 x 365 mm | 1,035 x 700 x 365 mm | 1,075 x 605 x 310 mm |
| **Weight (with mounting plate)** | ≤112 kg | ≤112 kg | ≤86 kg | ≤85 kg | ≤85 kg | ≤90 kg | ≤76 kg |
| **Operating Temperature Range** | -30 ℃～60 ℃ | -25 ℃～60 ℃ | -25 ℃～60 ℃ | -25 ℃～60 ℃ | -25 ℃～60 ℃ | -25 ℃～60 ℃ | -25 ℃～60 ℃ |

| **Cooling Method** | Smart Air Cooling | Smart Air Cooling | Smart Air Cooling | Natural Convection | Natural Convection | Smart Air Cooling | Natural Convectio n |
|---|---|---|---|---|---|---|---|
| **Max. Operating Altitude without Derating** | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m | 4,000 m |
| **Relative Humidity** | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% | 0 ~ 100% |
| **AC Connector** | Waterproo f Connector + OT/DT Terminal | Waterproo f Connector + OT/DT Terminal | Waterproo f Connector + OT/DT Terminal | Waterproo f Connector + OT/DT Terminal | Waterproo f Connector + OT/DT Terminal | Crimping module + OT/DT terminal | Cable gland + OT/DT terminal |
| **Protection Degree** | IP 66 | IP 66 | IP 66 | IP 65 | IP 65 | IP 66 | IP 65 |

*Table 59. Catalogue data of inverters from 300 kW to 90 kW.*

# ANNEX XII BUILDINGS PEAK POWER INSTALLED AND SPECIFIC INVERTER

| Building | Power Façades (kW) | Power Rooftop (kW) | Total power (kW) | Inverter | Capacity (kW) | Units | Inverter capacity (kW) |
|---|---|---|---|---|---|---|---|
| **1B** | 0 | 486 | **486** | SUN2000-300KTL-H0 | 300 | 1 | **415** |
| | | | | SUN2000-115KTL-M2 | 115 | 1 | |
| **1C** | 86 | 9 | **96** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **1E** | 220 | 72 | **292** | SUN2000-250KTL-H0 | 250 | 1 | **250** |
| **1F** | 144 | 42 | **185** | SUN2000-75KTL-M1 | 75 | 2 | **150** |
| **1G** | 38 | 133 | **170** | SUN2000-75KTL-M1 | 75 | 2 | **150** |
| **1H** | 19 | 43 | **63** | SUN2000-50KTL-M1 | 50 | 1 | **50** |
| **2A** | 122 | 92 | **214** | SUN2000-75KTL-M1 | 75 | 2 | **150** |
| **2B** | 0 | 80 | **80** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **2C** | 0 | 84 | **84** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **2D** | 0 | 75 | **75** | SUN2000-60KTL-M1 | 60 | 1 | **60** |
| **2E** | 0 | 67 | **67** | SUN2000-60KTL-M1 | 60 | 1 | **60** |
| **2F** | 170 | 207 | **377** | SUN2000-250KTL-H0 | 250 | 1 | **340** |
| | | | | SUN2000-90KTL-M1 | 90 | 1 | |
| **2G** | 0 | 19 | **19** | SUN2000-15KTL-M2 | 15 | 1 | **15** |
| **3A** | 262 | 28 | **291** | SUN2000-215KTL-H3 | 215 | 1 | **215** |
| **3B** | 28 | 57 | **85** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **3C** | 72 | 54 | **126** | SUN2000-100KTL-M2 | 100 | 1 | **100** |
| **3D** | 0 | 15 | **15** | SUN2000-15KTL-M2 | 15 | 1 | **15** |
| **3F** | 32 | 56 | **89** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **3G** | 20 | 39 | **59** | SUN2000-50KTL-M1 | 50 | 1 | **50** |
| **3H** | 22 | 46 | **69** | SUN2000-60KTL-M1 | 60 | 1 | **60** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **3I** | 9 | 45 | **54** | SUN2000-50KTL-M1 | 50 | 1 | **50** |
| **3J** | 9 | 38 | **47** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **3K** | 7 | 39 | **47** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **3M** | 875 | 0 | **875** | SUN2000-300KTL-H0 | 300 | 1 | **785** |
| | | | | SUN2000-300KTL-H0 | 300 | 1 | |
| | | | | SUN2000-185KTL -H1 | 185 | 1 | |
| **3P** | 310 | 172 | **482** | SUN2000-300KTL-H0 | 300 | 1 | **400** |
| | | | | SUN2000-100KTL-M2 | 100 | 1 | |
| **3Q** | 0 | 49 | **49** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **4A** | 20 | 51 | **71** | SUN2000-60KTL-M1 | 60 | 1 | **60** |
| **4D** | 219 | 178 | **398** | SUN2000-185KTL -H1 | 185 | 1 | **335** |
| | | | | SUN2000-75KTL-M1 | 75 | 2 | |
| **4E** | 0 | 46 | **46** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **4F** | 0 | 81 | **81** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **4G** | 105 | 117 | **221** | SUN2000-100KTL-M2 | 100 | 2 | **200** |
| **4H** | 0 | 47 | **47** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **4I** | 0 | 16 | **16** | SUN2000-15KTL-M2 | 15 | 1 | **15** |
| **4J** | 0 | 77 | **77** | SUN2000-60KTL-M1 | 60 | 1 | **60** |
| **4K** | 0 | 22 | **22** | SUN2000-20KTL-M3 | 20 | 1 | **20** |
| **4L** | 191 | 43 | **234** | SUN2000-100KTL-M2 | 100 | 2 | **200** |
| **4M** | 0 | 23 | **23** | SUN2000-20KTL-M3 | 20 | 1 | **20** |
| **4N** | 74 | 59 | **133** | SUN2000-50KTL-M1 | 50 | 2 | **100** |
| **4P** | 83 | 125 | **208** | SUN2000-115KTL-M2 | 115 | 1 | **165** |
| | | | | SUN2000-50KTL-M1 | 50 | 1 | |
| **4Q** | 63 | 0 | **63** | SUN2000-50KTL-M1 | 50 | 1 | **50** |
| **5B** | 0 | 24 | **24** | SUN2000-20KTL-M3 | 20 | 1 | **20** |
| **5C** | 62 | 37 | **99** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **5E** | 153 | 108 | **261** | SUN2000-100KTL-M2 | 100 | 2 | **200** |
| **5F** | 60 | 49 | **109** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **5G** | 21 | 88 | **108** | SUN2000-100KTL-M2 | 100 | 1 | **100** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **5H** | 56 | 59 | **115** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **5I** | 29 | 20 | **50** | SUN2000-40KTL-M3 | 40 | 1 | **40** |
| **5J** | 40 | 57 | **97** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **5K** | 93 | 64 | **157** | SUN2000-50KTL-M1 | 50 | 2 | **100** |
| **5L** | 52 | 29 | **82** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **5M** | 0 | 30 | **30** | SUN2000-30KTL-M3 | 30 | 1 | **30** |
| **5N** | 209 | 69 | **278** | SUN2000-115KTL-M2 | 115 | 2 | **230** |
| **5O** | 0 | 215 | **215** | SUN2000-90KTL-M1 | 90 | 2 | **180** |
| **5Q** | 0 | 12 | **12** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **6A** | 0 | 315 | **315** | SUN2000-250KTL-H0 | 250 | 1 | **250** |
| **6B** | 67 | 0 | **67** | SUN2000-50KTL-M1 | 50 | 1 | **50** |
| **6C** | 98 | 30 | **128** | SUN2000-100KTL-M2 | 100 | 1 | **100** |
| **6D** | 0 | 14 | **14** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **6E** | 0 | 26 | **26** | SUN2000-20KTL-M3 | 20 | 1 | **20** |
| **6F** | 101 | 182 | **283** | SUN2000-115KTL-M2 | 115 | 2 | **230** |
| **6G** | 338 | 78 | **416** | SUN2000-250KTL-H0 | 250 | 1 | **350** |
| | | | | SUN2000-75KTL-M1 | 75 | 1 | |
| **7A** | 192 | 4 | **196** | SUN2000-185KTL -H1 | 185 | 1 | **185** |
| **7B** | 188 | 146 | **334** | SUN2000-250KTL-H0 | 250 | 1 | **250** |
| **7C** | 330 | 27 | **357** | SUN2000-250KTL-H0 | 250 | 1 | **250** |
| **7D** | 136 | 7 | **143** | SUN2000-100KTL-M2 | 100 | 1 | **100** |
| **7E** | 155 | 75 | **230** | SUN2000-185KTL -H1 | 185 | 1 | **215** |
| | | | | SUN2000-30KTL-M3 | 30 | 1 | |
| **7F** | 179 | 1 | **181** | SUN2000-75KTL-M1 | 75 | 2 | **150** |
| **7G** | 226 | 14 | **240** | SUN2000-75KTL-M1 | 75 | 2 | **150** |
| **7H** | 0 | 111 | **111** | SUN2000-90KTL-M1 | 90 | 1 | **90** |
| **7I** | 560 | 83 | **643** | SUN2000-215KTL-H3 | 215 | 2 | **430** |
| **7J** | 0 | 30 | **30** | SUN2000-30KTL-M3 | 30 | 1 | **30** |
| **7L** | 0 | 39 | **39** | SUN2000-30KTL-M3 | 30 | 1 | **30** |
| **8D,C,A** | 200 | 16 | **216** | SUN2000-75KTL-M1 | 75 | 2 | **150** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **8G,E,B** | 1332 | 0 | **1747** | SUN2000-250KTL-H0 | 250 | 4 | **1000** |
| **8F** | 193 | 414.16 | **607.29** | SUN2000-250KTL-H0 | 250 | 2 | **500** |
| **8H** | 0 | 158 | **158** | SUN2000-185KTL -H1 | 185 | 1 | **185** |
| **8K** | 0 | 106 | **106** | SUN2000-100KTL-M2 | 100 | 1 | **100** |
| **8N** | 0 | 25 | **25** | SUN2000-20KTL-M3 | 20 | 1 | **20** |
| **8P** | 269 | 64 | **333** | SUN2000-185KTL -H1 | 185 | 1 | **260** |
| | | | | SUN2000-75KTL-M1 | 75 | 1 | |
| **9A** | 0 | 159 | **159** | SUN2000-185KTL -H1 | 185 | 1 | **185** |
| **9B** | 0 | 175 | **175** | SUN2000-185KTL -H1 | 185 | 1 | **185** |
| **9C** | 168 | 70 | **238** | SUN2000-115KTL-M2 | 115 | 1 | **190** |
| | | | | SUN2000-75KTL-M1 | 75 | 1 | |
| **9D** | 0 | 83 | **83** | SUN2000-75KTL-M1 | 75 | 1 | **75** |
| **9F** | 0 | 11 | **11** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **9G** | 0 | 9 | **9** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **9H** | 0 | 10 | **10** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **9I** | 0 | 10 | **10** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **9J** | 0 | 13 | **13** | SUN2000-10KTL-M2 | 10 | 1 | **10** |
| **Total** | 8,712 | 6,300 | **15,012** | | | | **12,265** |

*Table 60. Every building's rooftop and façade installed power and inverter selected.*

The DC to AC ratio Power installed/Inverters capacity, is 1.23.

# ANNEX XIII SAM SIMULATION INPUTS

This annex is destined to explain and show the inputs specified in SAM for the run of simulations. Every data and input is referenced, as well as it is an explanation of why the value, or the option is selected.

## I. MODULE SELECTION

The program has different ways to enter the characteristics of the selected photovoltaic module, but the selected one is:

*CEC Performance Model with Module Database:* This model calculates the solar-to-electricity conversion efficiency of modules from data stored in a module parameter library for thousands of commercially available modules.

## II. INVERTER SELECTION

The program has different ways to enter the characteristics of the selected inverter, but the selected one is:

*Inverter Datasheet:* allows you to specify the inverter parameters using the values from the manufacturer's datasheet and calculates the coefficients from the parameters you provide.

For the SAM simulations as the program only allows to select one model of inverter for the hole system, the inverter used for the simulations is the Huawei SUN2000-40KTL-M3 and it has been introduced the enough number of them to reach the system's inverters capacity.

## III. SAM SYSTEM DESIGN

SAM allows to design a photovoltaic project with maximum 4 different panel configuration. In this project the first subarray correspond to the rooftop panels and the missing three subarrays with each azimuth orientation: East, South, West. The North orientation has been suppressed due to the lack of efficiency and the low energy production in comparison with the other ones.

The first array, the rooftops system, contains panels oriented 200º direction South-West with a tilt angle of 37º. The facade systems are facing 110º, 200º and 290º directions with a tilt angle of 90º. Every system is considered fixed as it has not been included technology in any axis to increase the efficiency facing the Sun

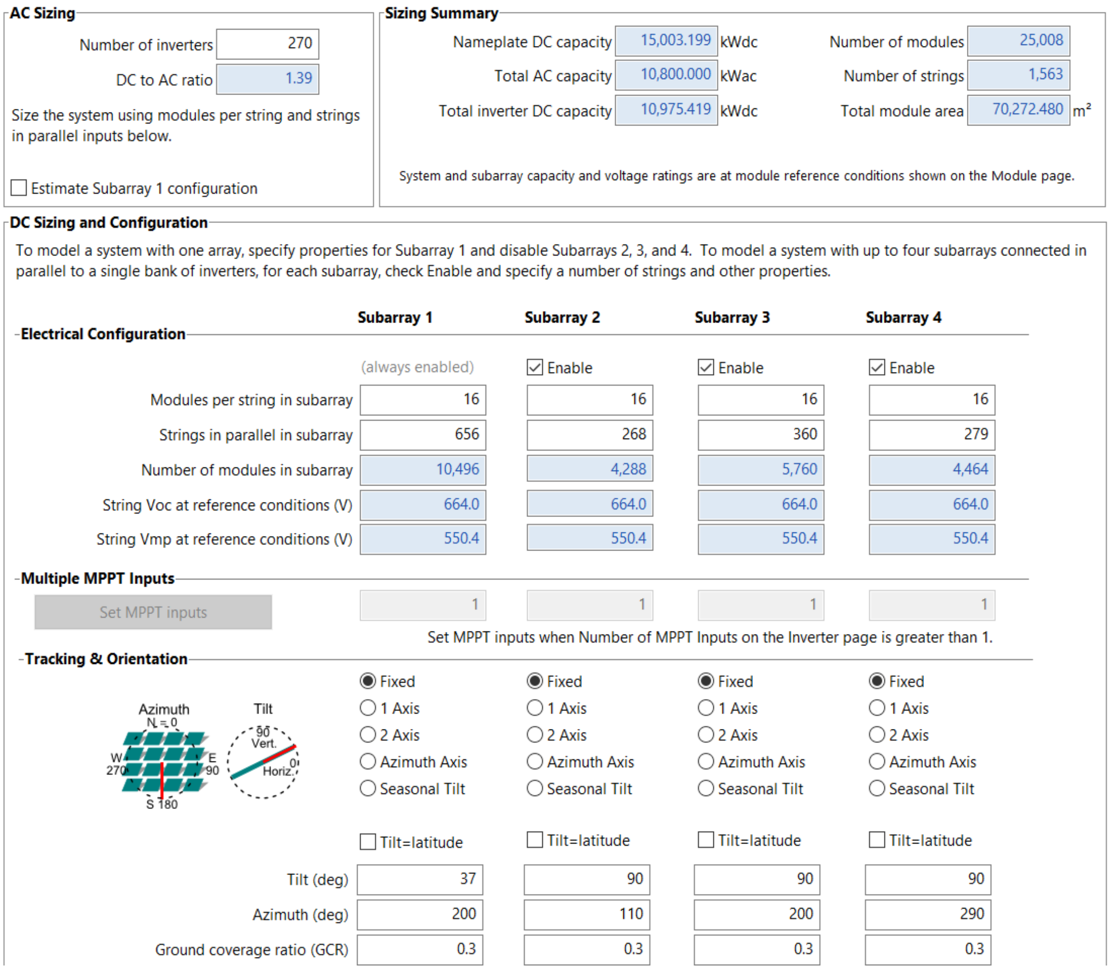



*Figure 58. SAM interface, system design.*

In total counting rooftops and façades there are 25,008 panels and a power capacity of 15,033.199 kW.

In Figure 58, there are the parameters of the system introduced in SAM.

## IV. INVERTERS CAPACITY

It has been made an exhaustive analysis of the inverters selected for each University building, which consist of calculating the power installed in each building in both, façades and rooftop and thus, adjust a proper inverter in function of the capacity and its distribution among the arrays. The total capacity of all inverters amounts to 10,800 kW which means a factor between the panels power installed divided by the total inverter's capacity of 1.37 DC to AC ratio. This corresponds to a high value in comparison to the regular tilted PV plants, however due to the fact that half of the power installed becomes from façade panels and its production depending on the orientation is flattened around the day, in most buildings the full power installed do not produce energy at the same time allowing to introduce lower capacity inverters to reduce the investment costs without losing efficiency.

## V. LOSSES

In the photovoltaic systems there are a wide number of components such as, modules, DC/AC wires, transformers, etc., that due to mismatch, transmission, break, environmental factors, among others, produce losses in the electricity generation. Losses that is imperative to localize, quantify and reduce in systems to leverage the maximum energy production. Figure 59 shows a scheme of the losses distribution on a regular PV plant which shows that around a 25% of the energy production is not used due to losses. In other study [47], was found that total system losses in a 190 kW plant including solar radiation, temperature, module quality, array mismatch, ohmic wiring, and inverter amounted to 31.7%. For this reason, it is important to stablish detailed research for each one of this losses section trying to approximate it as much as possible to real-life performance.

### ▪ SHADING LOSSES

In this case, as for the study of the available surfaces the shadowing was already taken into account, therefore the areas affected by shades were extracted in both the rooftops and the façades, this type of losses are negligible apart from the ones generated by the bad weather conditions such as clouds however those are considered in the weather data file.

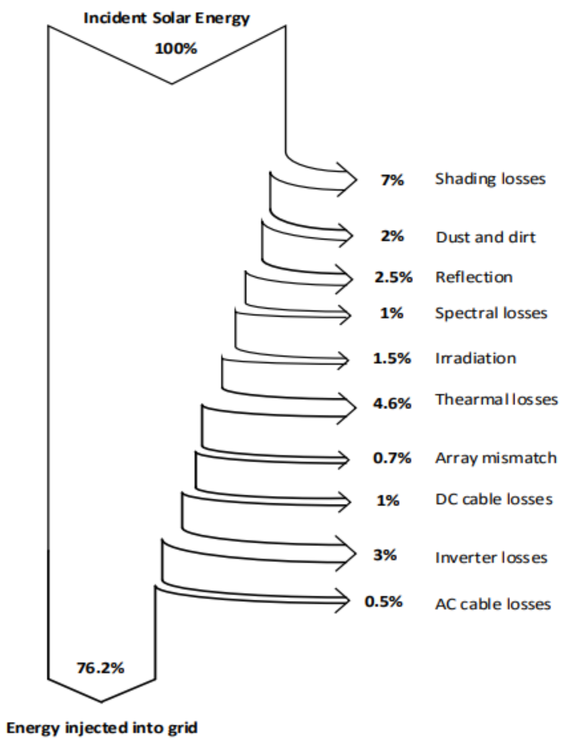



*Figure 59. Scheme of a PV system's losses distribution* [48]

### ▪ AC AND DC LOSSES

Inside the mismatch losses there is differentiated, the temporary and permanent losses. Temporary partial shade loss, falling birds, temperature and weather variations affect on the radiation absorption by photovoltaic components. Permanent losses are related to defects in the photovoltaic modules, such as soiling defects, corrosion, lightning, delaminating, cracking of the coating and coloration [49]. According to the data provided by the SAM software of default losses for central inverters systems of 2% and the estimation of the same type of losses in [47] amounting to 2.2% both for mismatch losses a value of 2% has decided for the simulation.

For the wiring losses as [48] expresses and the SAM software by default applies for central inverters a value of 2% has been supposed. The same default values have been applied in the losses scenario as the ones provided by SAM, changing both the DC wiring losses to 1% and the AC wiring losses to 1.5% following the numbers selected in Chapter 5:

**DC losses**

- Module mismatch: 2%
- Diodes and connections: 0.5%
- DC wiring: 1%
- Tracking error: 0%
- Nameplate: 0%

**AC losses**

- AC wiring: 1.5%

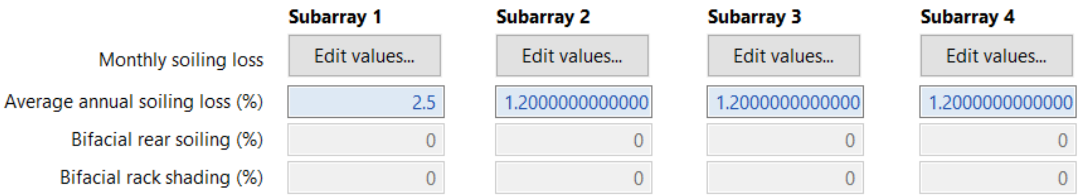
No transformer losses are applied for the simulation as no need for distribution or substation transformers are implemented.

## VI. SOILING LOSSES

It is known that among all the losses that PV systems present, a big part come from the soiling loss. Soiling losses are referred to the energy production lost due to accumulation of dust on the panels surface, thus reducing the solar irradiance received by the modules [50]. Dust represent a name for solid particles with a diameter less than 500 µm. These particles can be deposited on the surface of the PV panels by being transported in the air or by falling from the atmosphere being mixed with water rain. Usually the word dust includes also, mineral dust, pollutants, sea salt, bird droppings, etc. which inevitably occurs due to their outdoors operating conditions [50]. The amount of dust particles deposited on the panels changes and highly varies with the location and weather of the place and the form of installing the panels. Locations near deserts or places with a big amount of dust particles will highly increase their soiling losses if no solutions are applied. This effect can be seen in [51] and [52] both studies made in Qatar, the soiling loss (%/day) is 0.52 and 0.42 respectively, while in studies made in locations similar to Valencia, for example, [53] in Tudela, Spain, [54] Puglia, Italy or [55] Athens, Greece, this the soiling loss factor represent a 0.2, 0.12 and 0.17 respectively.

Slope angle also represent a key factor in the soiling losses. As the slope angle decreases the panels are more exposed to dust and have more facility to retain these particles when natural cleaning, such as rain and strong winds, happen. This is studied in [56], where for a study made in Madrid, panels with a slope angle of 35° experimented a reduction in the annual output power of 1.1% while panels with a slope angle of 8° experimented a reduction of 2.4% in the annual output power. This conclusion is expected to increase slope angle, resulting in low soiling losses for vertical BAPV and bigger effect in cleaning with natural processes, meaning at the end, in less maintenance and artificial cleaning in the systems.

The soiling losses applied to SAM, it has been chosen conservative values, 2.5% annual to rooftops panels and 1.2% annual for façades panels, applied in SAM in Figure 60.



| | Subarray 1 | Subarray 2 | Subarray 3 | Subarray 4 |
|---|---|---|---|---|
| Monthly soiling loss | Edit values... | Edit values... | Edit values... | Edit values... |
| Average annual soiling loss (%) | 2.5 | 1.2000000000000 | 1.2000000000000 | 1.2000000000000 |
| Bifacial rear soiling (%) | 0 | 0 | 0 | 0 |
| Bifacial rack shading (%) | 0 | 0 | 0 | 0 |

*Figure 60. SAM soiling losses.*

## VII. SYSTEM COSTS

As SAM does not include a detailed option for budgets, the reals cost of the system are presented in the Budget annexes, is SAM it has been introduced some values to reach the same costs as calculated.

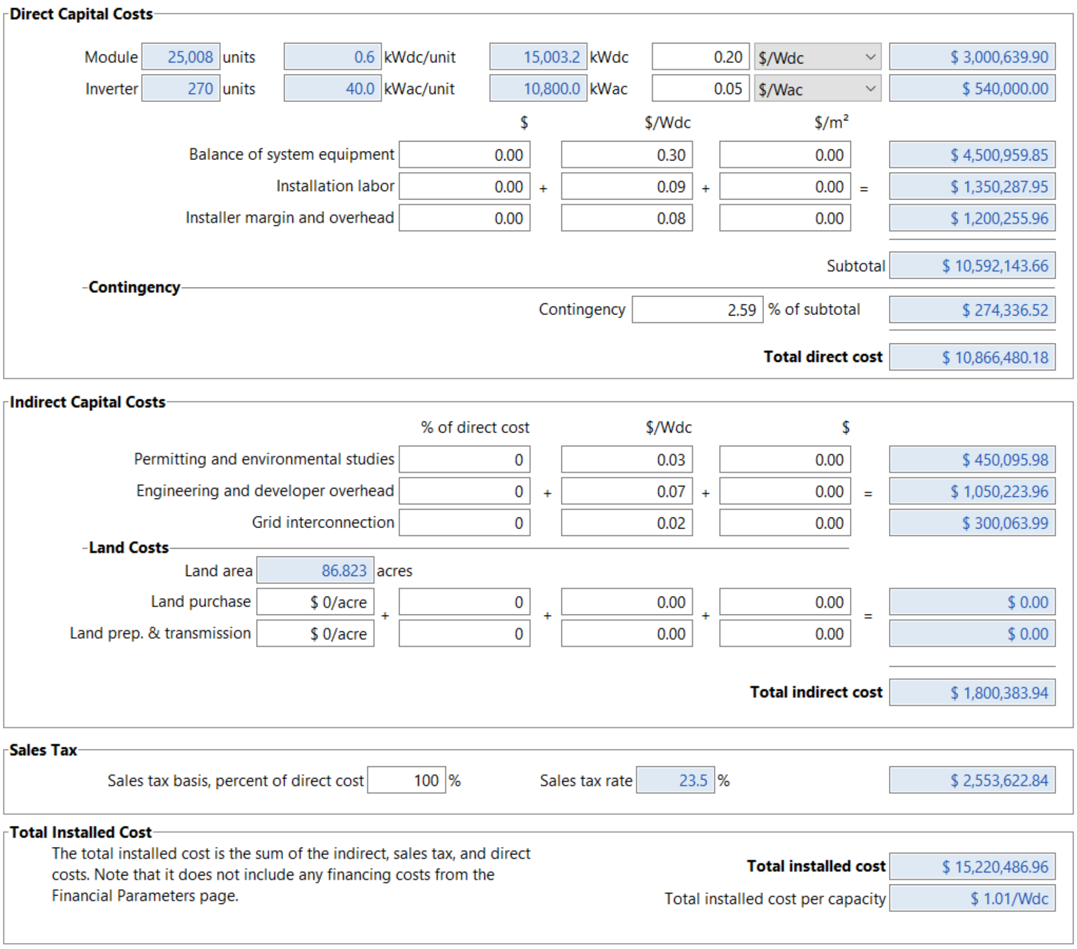



*Figure 61. SAM inputs for the installation costs.*

The operation and maintenance costs refer to the costs the system needs through the years to continue with a correct operation including module cleaning, vegetation and/or pest management, system inspection and monitoring, hardware components replacement or insurance, among others. As it is detailed in Ignis [57], 2021 the value introduced in SAM and the regular costs for Spain in photovoltaic fields is 1.5% yearly cost from the total investment. That means a total of 33.9 (€/kW·yr).

## VIII. ELECTRICITY RATES

The program allows to select between 5 different types of electricity bills. It has been selected "Net billing" that is the most similar to the University contract that is defined by 6 price periods, P1 being the more expensive and P6 the cheapest, and allowing to sell back to the retailer the excess of electricity generation.

| Period | Tier | Max. Usage | Max. Usage Units | Buy ($/kWh) | Sell ($/kWh) |
|---|---|---|---|---|---|
| 1 | 1 | 1e+38 | kWh | 0.195028 | 0.0914944 |
| 2 | 1 | 1e+38 | kWh | 0.184434 | 0.0914944 |
| 3 | 1 | 1e+38 | kWh | 0.174603 | 0.0914944 |
| 4 | 1 | 1e+38 | kWh | 0.169652 | 0.0914944 |
| 5 | 1 | 1e+38 | kWh | 0.152724 | 0.0914944 |
| 6 | 1 | 1e+38 | kWh | 0.153451 | 0.0914944 |

*Figure 62. Electricity rates specified in SAM.*

The period map can be seen in the Figure 62. The year is separated in seasons depending on the month the energy is consumed. The seasons for Spain are categorized as follows [58]:

- **High season**: January, February, July, and December
- **Mid-high season**: March and November
- **Mid-season**: June, August, and September
- **Low season**: April, May, and October

The period 6 correspond to weekends, holidays, and the hours from 24:00 to 08:00 hours in the weekdays.

**Weekday**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| Feb | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| Mar | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 |
| Apr | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 |
| May | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 |
| Jun | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| Jul | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |
| Aug | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| Sep | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 |
| Oct | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 5 |
| Nov | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 |
| Dec | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 |

*Figure 63. Distribution of electricity periods during weekdays.*

Given that this installation exceeds 100 kW of installed power for production, in accordance with "Real Decreto 244/2019," the Photovoltaic Power Plant (UPV) would not fall under the simplified compensation mechanism. Instead, it would need to participate in the daily electricity market for surplus energy, wherein the UPV would function as a generator within the electrical grid. The selling price of the energy has been determined as the same OMIP price used for the electricity contract in each scenario, for the first scenario an OMIP price of 91.5€/MWh, in the second 55.8€/MWh and for the last scenario the starting price is the same as the first one, 91.5€/MWh but it follows the same trend as the OMIP price showed in [35], until reaching 42.95€/MWh in 2032.

**Weekend**

| | 12am | 1am | 2am | 3am | 4am | 5am | 6am | 7am | 8am | 9am | 10am | 11am | 12pm | 1pm | 2pm | 3pm | 4pm | 5pm | 6pm | 7pm | 8pm | 9pm | 10pm | 11pm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Feb | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Mar | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Apr | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| May | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Jun | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Jul | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Aug | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Sep | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Oct | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Nov | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Dec | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |

*Figure 64. Distribution of electricity periods during weekends.*

# ANNEX XIV SCENARIO OMIP TREND 25 YEARS SIMULATION REPORT

## System Advisor Model Report

| | | |
|---|---|---|
| Detailed Photovoltaic | 15.0 DC MW Nameplate | 39.5, -0.47 |
| Commercial | $1.01/W Installed Cost | UTC +1 |

### Performance Model

| **Modules** | |
|---|---|
| Trina Solar TSM-600DE20 | |
| Cell material | Mono-c-Si |
| Module area | 2.81 m² |
| Module capacity | 599.94 DC Watts |
| Quantity | 25,008 |
| Total capacity | 15 DC MW |
| Total area | 70,272 m² |

| **Inverters** | |
|---|---|
| <null> | |
| Unit capacity | 40 AC kW |
| Input voltage | 530 - 850 VDC DC V |
| Quantity | 270 |
| Total capacity | 10.8 AC MW |
| DC to AC Capacity Ratio | 1.39 |
| AC losses (%) | 0.00 |

| **Four subarrays:** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| Strings | 656 | 268 | 360 | 279 |
| Modules per string | 16 | 16 | 16 | 16 |
| String Voc (DC V) | 664.00 | 664.00 | 664.00 | 664.00 |
| Tilt (deg from horizontal) | 37.00 | 90.00 | 90.00 | 90.00 |
| Azimuth (deg E of N) | 180 | 110 | 200 | 290 |
| Tracking | no | no | no | no |
| Backtracking | - | - | - | - |
| Self shading | no | no | no | no |
| Rotation limit (deg) | - | - | - | - |
| Shading | no | no | no | no |
| Snow | no | no | no | no |
| Soiling | yes | yes | yes | yes |
| DC losses (%) | 4.44 | 4.44 | 4.44 | 4.44 |

| **Performance Adjustments** | |
|---|---|
| Availability/Curtailment | none |
| Degradation | none |
| Hourly or custom losses | none |

| **Annual Results (in Year 1)** | | | | |
|---|---|---|---|---|
| GHI kWh/m²/day | 4.47 | 4.47 | 4.47 | 4.47 |
| POA kWh/m²/day | 125.00 | 67.00 | 81.00 | 49.00 |
| Net to inverter | 18,667,000 DC kWh | | | |
| Net to grid | 18,127,000 AC kWh | | | |
| Capacity factor | 13.8 | | | |
| Performance ratio | 0.87 | | | |

### Financial Model

| **Project Costs** | |
|---|---|
| Total installed cost | $15,220,486 |
| Salvage value | $0 |

| **Analysis Parameters** | |
|---|---|
| Project life | 25 years |
| Inflation rate | 3.07% |
| Real discount rate | 2.5% |

| **Project Debt Parameters** | |
|---|---|
| Debt fraction | 0% |
| Amount | $0 |
| Term | 25 years |
| Rate | 4% |

| **Tax and Insurance Rates** | |
|---|---|
| Federal income tax | 21 %/year |
| State income tax | 7 %/year |
| Sales tax (% of indirect cost basis) | 23.5% |
| Insurance (% of installed cost) | 0 %/year |
| Property tax (% of assessed val.) | 0 %/year |

| **Incentives** | |
|---|---|
| Federal ITC | 30% |

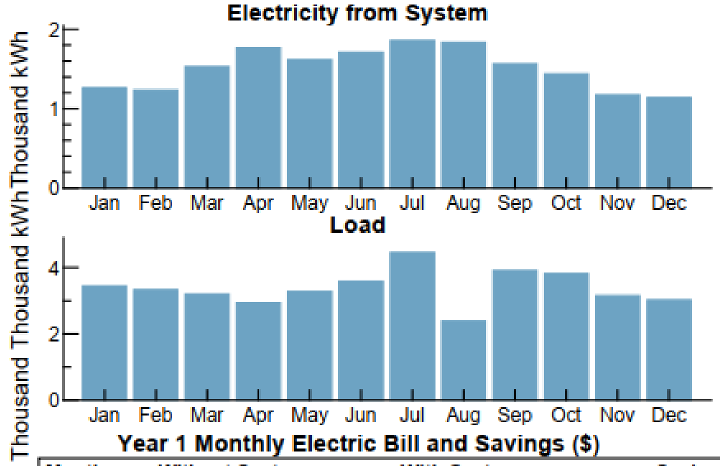
**Electricity Usage and Rate Summary**

Annual peak demand 13,327.5 kW
Annual total usage 40,513,620 kWh
Generic Commercial
Hourly (subhourly) excess credited in current month
Annual rate escalation: -47.574%/year (average)
Tiered TOU energy rates: 6 periods, 1 tier

| **Results** | |
|---|---|
| Nominal LCOE | 6.5 cents/kWh |
| Net present value | $619,200 |
| Payback period | 7.4 years |

| | | |
|---|---|---|
| Detailed Photovoltaic | 15.0 DC MW Nameplate | 39.5, -0.47 |
| Commercial | $1.01/W Installed Cost | UTC +1 |

**Year 1 Monthly Generation and Load Summary**




**Year 1 Monthly Electric Bill and Savings ($)**

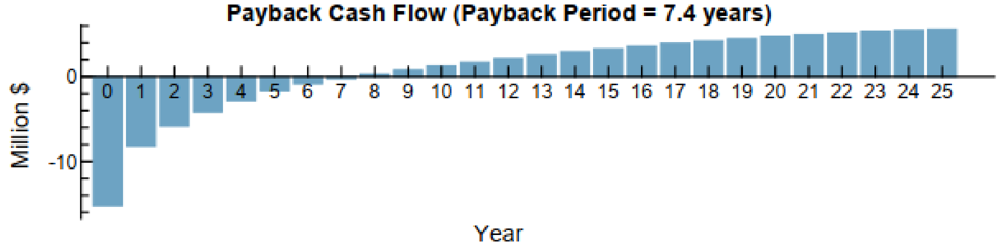
| Month | Without System | With System | Savings |
|---|---|---|---|
| Jan | 664,069 | 442,308 | 221,761 |
| Feb | 648,792 | 424,409 | 224,383 |
| Mar | 585,626 | 345,037 | 240,589 |
| Apr | 481,984 | 221,407 | 260,577 |
| May | 537,823 | 292,870 | 244,952 |
| Jun | 623,253 | 342,732 | 280,520 |
| Jul | 857,637 | 514,906 | 342,731 |
| Aug | 408,680 | 140,893 | 267,787 |
| Sep | 679,236 | 425,640 | 253,595 |
| Oct | 631,500 | 414,587 | 216,912 |
| Nov | 578,989 | 384,395 | 194,593 |
| Dec | 585,398 | 396,391 | 189,007 |
| Annual | 7,282,992 | 4,345,580 | 2,937,411 |

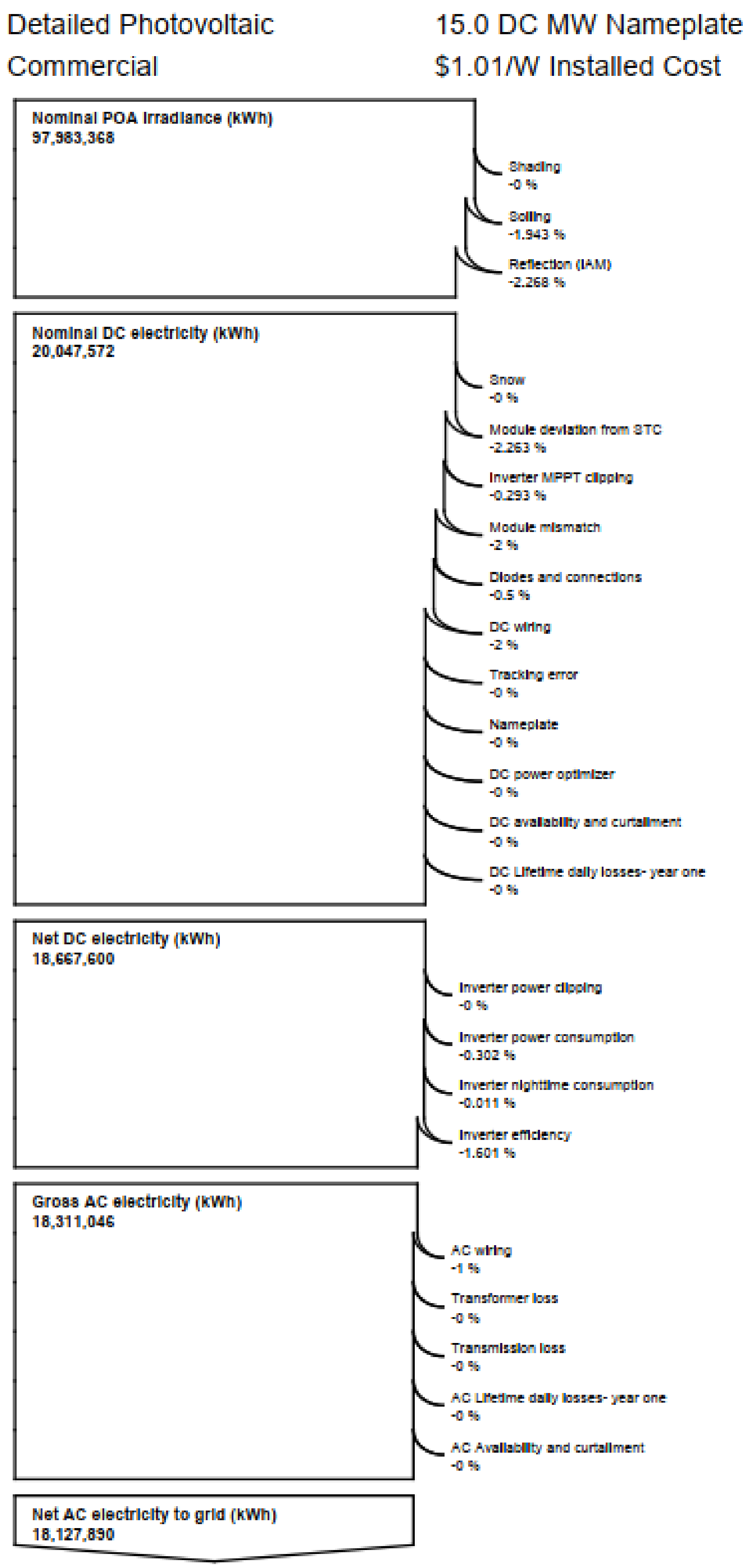
**NPV Approximation using Annuities**

| Annuities, Capital Recovery Factor (CRF) = 0.0756 | | |
|---|---|---|
| Investment | $-1,150,900 | Sum: |
| Expenses | $-687,500 | $46,800 |
| Savings | $732,500 | NPV = Sum / CRF: |
| Energy value | $1,152,800 | $619,000 |

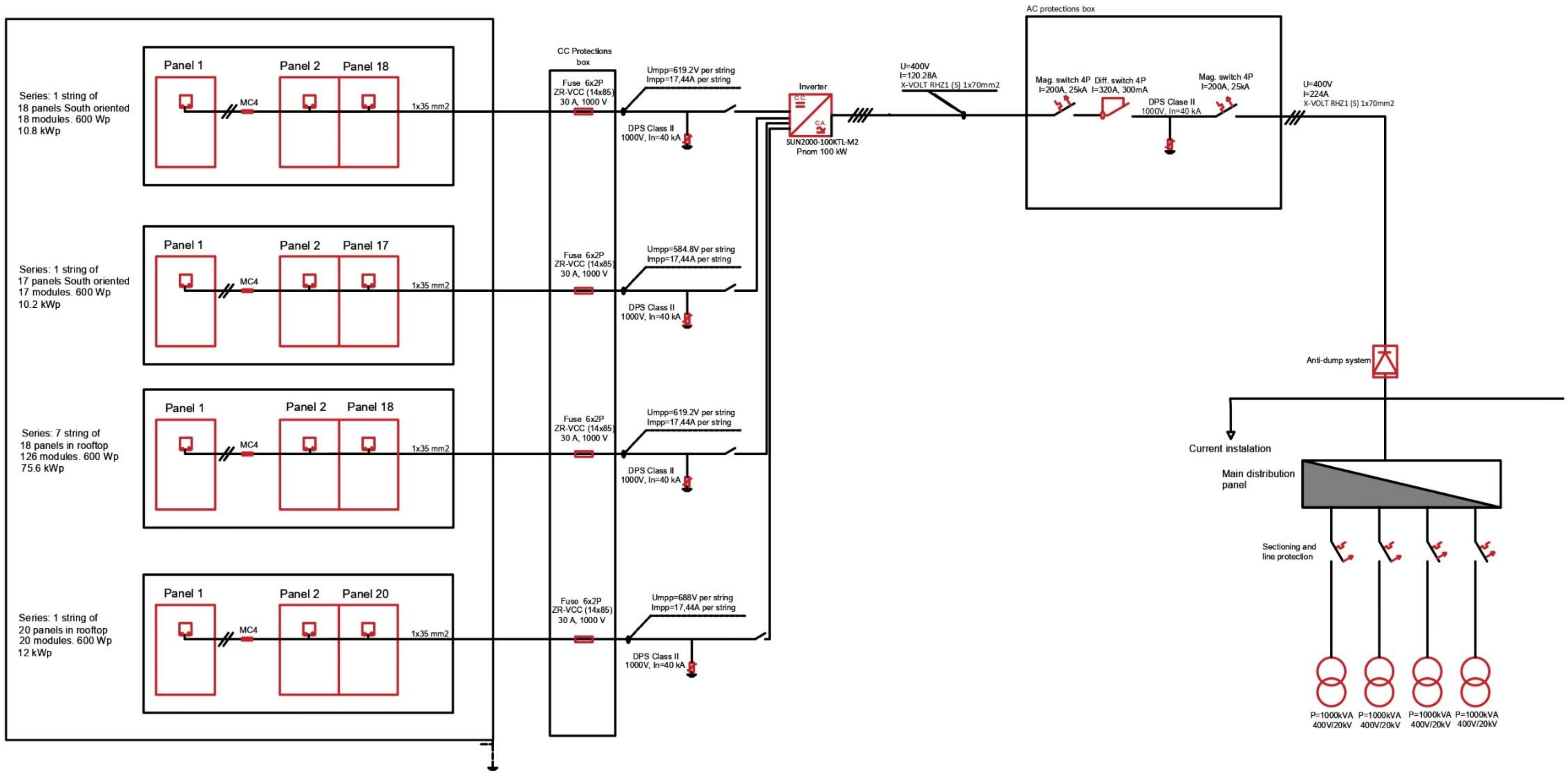
Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 5.6467%

**Payback Cash Flow (Payback Period = 7.4 years)**




Detailed Photovoltaic
Commercial
15.0 DC MW Nameplate
$1.01/W Installed Cost
Nominal POA irradiance (kWh)
97,983,368
Shading
-0 %
Soiling
-1.943 %
Reflection (IAM)
-2.268 %
Nominal DC electricity (kWh)
20,047,572
Snow
-0 %
Module deviation from STC
-2.263 %
Inverter MPPT clipping
-0.293 %
Module mismatch
-2 %
Diodes and connections
-0.5 %
DC wiring
-2 %
Tracking error
-0 %
Nameplate
-0 %
DC power optimizer
-0 %
DC availability and curtailment
-0 %
DC Lifetime daily losses- year one
-0 %
Net DC electricity (kWh)
18,667,600
Inverter power clipping
-0 %
Inverter power consumption
-0.302 %
Inverter nighttime consumption
-0.011 %
Inverter efficiency
-1.601 %
Gross AC electricity (kWh)
18,311,046
AC wiring
-1 %
Transformer loss
-0 %
Transmission loss
-0 %
AC Lifetime daily losses- year one
-0 %
AC Availability and curtailment
-0 %
Net AC electricity to grid (kWh)
18,127,890

# ANNEX XV PLANES




TFM

MASTER'S DEGREE IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

PROYECT

STUDY OF THE POTENTIAL FOR THE IMPLEMENTATION OF PHOTOVOLTAIC SYSTEMS ON FACADES AND ROOFS AT THE UNIVERSITAT POLITÈCNICA DE VALENCIA

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

PLANE: ELECTRIC SCHEME OF BUILDING 5G

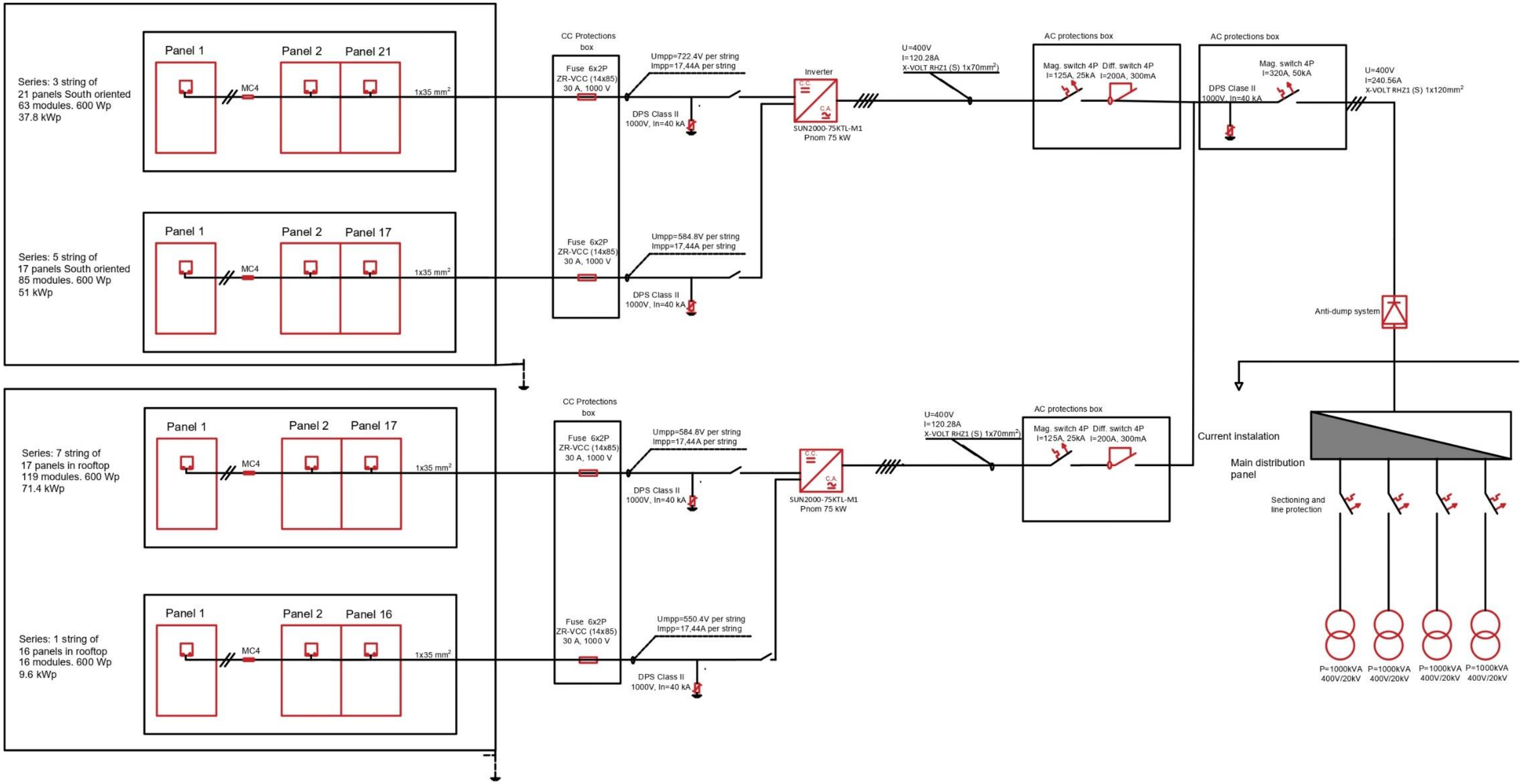
Nº PLANE: 1

SCALE:

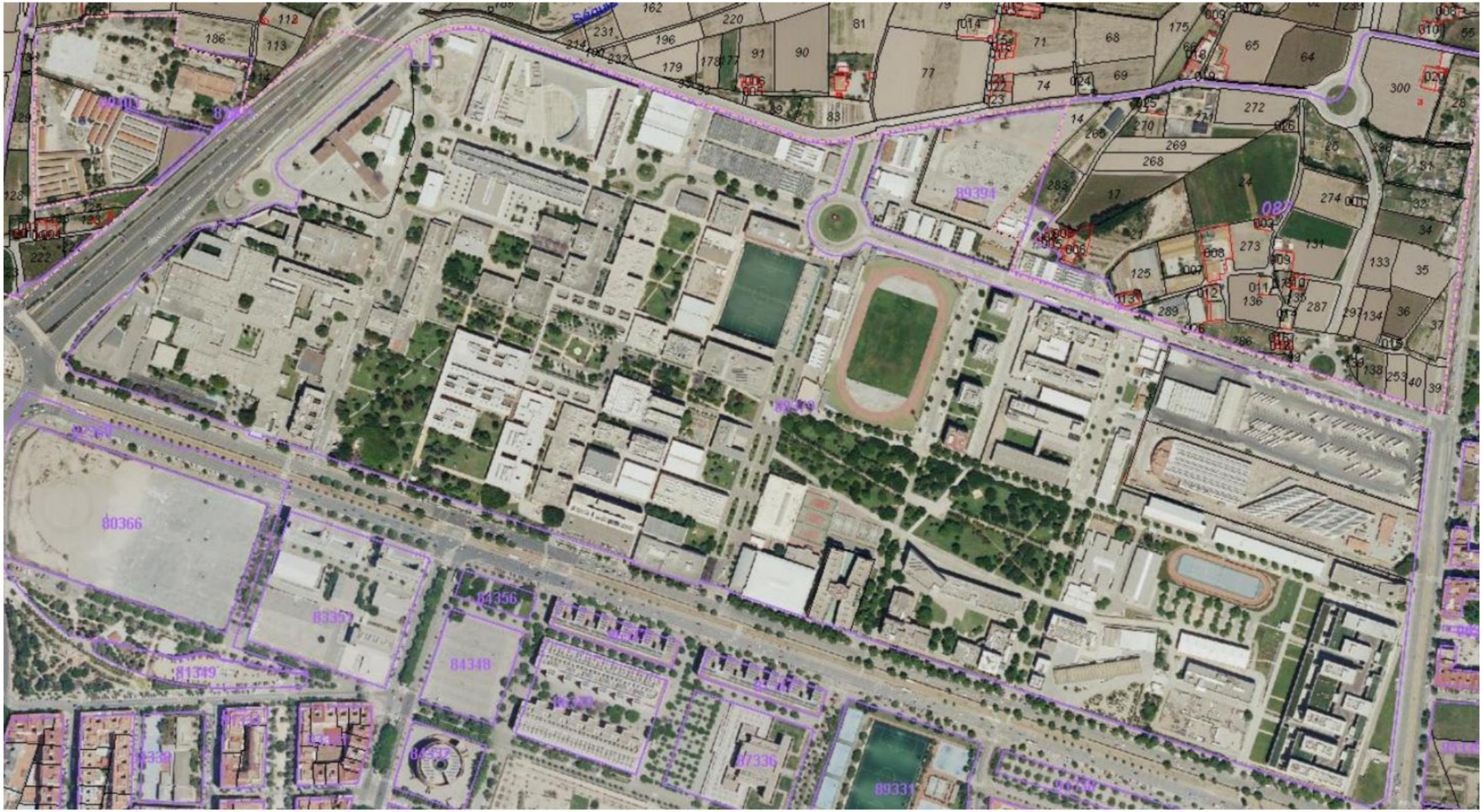
REVISION: 0

AUTHOR: MANUEL BAILAC MUR

DATE: 15/01/2024




| TFM | PROYECT | | |
|---|---|---|---|
| MASTER'S DEGREE IN ENERGY TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT | STUDY OF THE POTENTIAL FOR THE IMPLEMENTATION OF PHOTOVOLTAIC SYSTEMS ON FACADES AND ROOFS AT THE UNIVERSITAT POLITÈCNICA DE VALENCIA | | |
| UNIVERSITAT POLITÈCNICA DE VALÈNCIA | PLANE: ELECTRIC SCHEME PV BUILDING IG | | Nº PLANE: 2 |
| | AUTHOR: MANUEL BAILAC MUR | DATE: 15/01/2024 | ESCALA: / REVISION: 0 |




| TFM | PROYECT |
|---|---|
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| | | | | |
|---|---|---|---|---|
| UNIVERSITAT POLITÈCNICA DE VALÈNCIA | PLANE: UPV'S SATELITE PLANE | | Nº PLANE: | 3 |
| | AUTHOR: MANUEL BAILAC MUR | DATE: 15/01/2024 | ESCALA: | REVISION: 0 |